Technical Guidance Document: Compliance Assurance Monitoring

Revised Draft

For U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Measurement Center

MRI Project No. 4701-05

August 1998

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PREFACE

This document was prepared by Midwest Research Institute (MRI) for the Office of Air Quality Planning and Standards (OAQPS), U. S. Environmental Protection Agency (EPA), under Contract No. 68-D2-0165, Work Assignment No. 4-06 and Contract No. W6-0048, Work Assignment No. 2-05. Mr. Dan Bivins is the work assignment manager.

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1.0 OVERVIEW

1.1 PURPOSE OF CAM

Compliance assurance monitoring (CAM) is intended to provide a reasonable assurance of compliance with applicable requirements under the Clean Air Act (CAA) for large emission units that rely on pollution control device equipment to achieve compliance. Monitoring is conducted to determine that control measures, once installed or otherwise employed, are properly operated and maintained so that they continue to achieve a level of control that complies with applicable requirements. The CAM approach establishes monitoring for the purpose of: (1) documenting continued operation of the control measures within ranges of specified indicators of performance (such as emissions, control device parameters, and process parameters) that are designed to provide a reasonable assurance of compliance with applicable requirements; (2) indicating any excursions from these ranges; and (3) responding to the data so that the cause or causes of the excursions are corrected.

1.2 CAM PROCESS

This section provides an overview of the process of implementing CAM. The overall process can be represented by four major steps: (1) CAM applicability determination, (2) CAM submittal, (3) review and approval of CAM submittal, and (4) CAM implementation. The following paragraphs describe each of these four major steps of the CAM process in more detail. Figure 1-1 presents a flow diagram for this process. The important steps and decision blocks in these figures are labeled with a number enclosed in brackets (e.g., **[23]**) that is cross-referenced to the description of the CAM process that follows.

1.2.1 Applicability Determination

The first major step in the CAM process is the determination of the applicability of CAM **[1]** to each pollutant-specific emissions unit (hereafter referred to as "emissions unit," or simply "unit"). Section 64.2 of the CAM rule specifies the criteria for making this determination, and Table 1-1 summarizes the applicability requirements for Part 64. If the unit satisfies all of the applicability requirements listed in Table 1-1, the unit is subject to CAM. Otherwise, Part 64 does not apply to the emissions unit. Essentially, for a unit to be subject to Part 64, the unit must: be located at a major source for which a Part 70 or 71 permit is required; be subject to an emission limitation or standard; use a control device to achieve compliance; have potential precontrol emissions of at least 100 percent of the major source amount; and must not otherwise be exempt from CAM. If the unit does not meet all of these requirements, the unit is not subject to CAM **[2]**. It should be emphasized that the applicability determination is made on a pollutant-by-pollutant basis for each emissions unit.

The term "emission limit or standard" is defined in § 64.1 to mean any applicable requirement that constitutes an emission limitation, emission standard, standard of performance, or means of emission limitation as defined under the Act. Part 64 states that the term "applicable requirement," shall have the same meaning as provided under Part 70. Therefore, Part 64 establishes that only those emission limitations or standards that are applicable requirements as defined in Part 70 and included as Federally enforceable permit conditions in a Part 70 permit are subject to the requirements of Part 64. Additional language in the Part 64 definition of "emission limitation or standard" clarifies that, for the purposes of Part 64, the definition of "emission limitation or standard" does not include general operation requirements that an owner or operator may be required to meet, such as requirements to obtain a permit, to operate and maintain sources in accordance with good air pollution control practices, to develop and maintain a malfunction abatement plan, or to conduct monitoring, submit reports or keep records. The complete definition of a major source is provided in Figure 1-2.

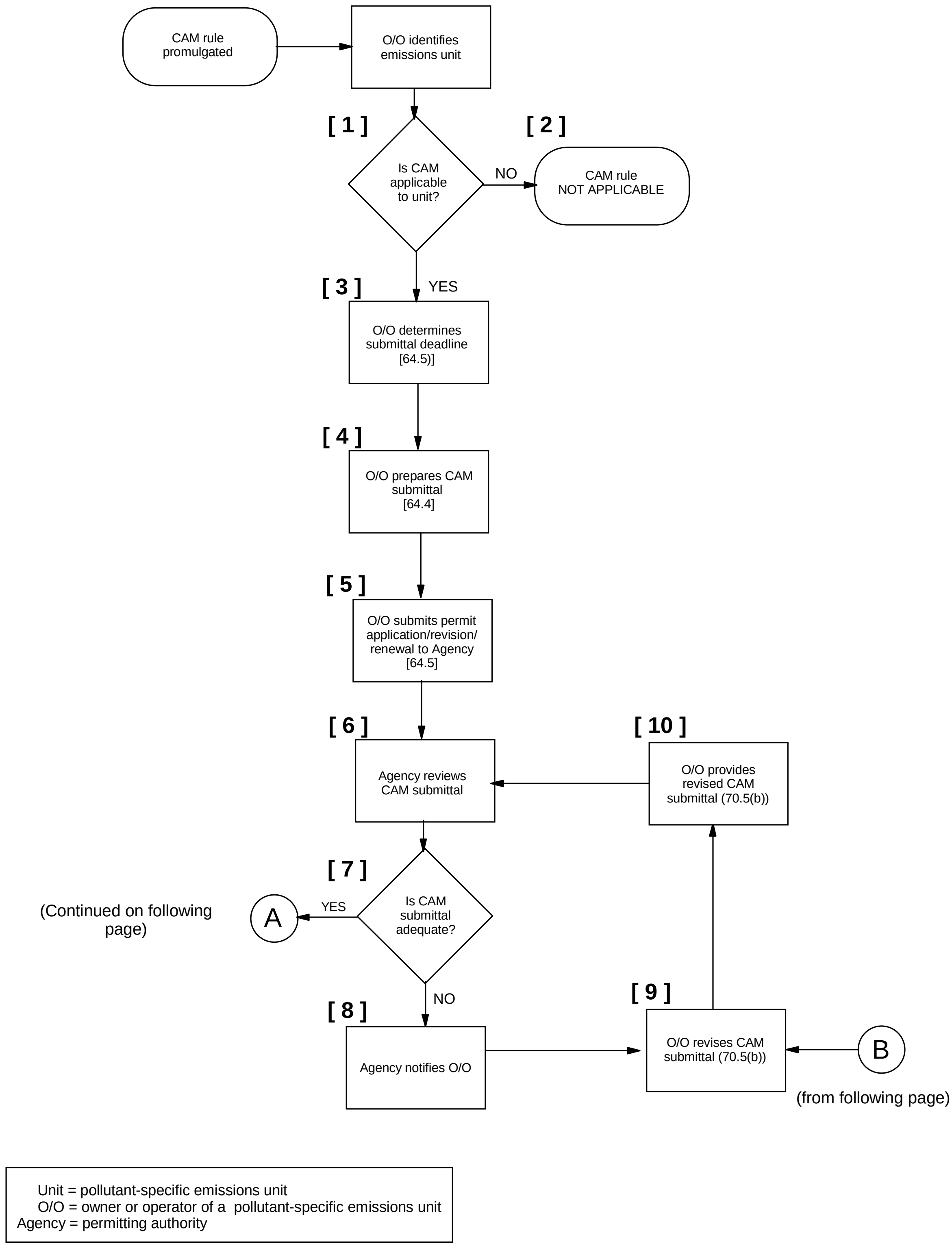

Figure 1-1. Flow diagram for CAM process.

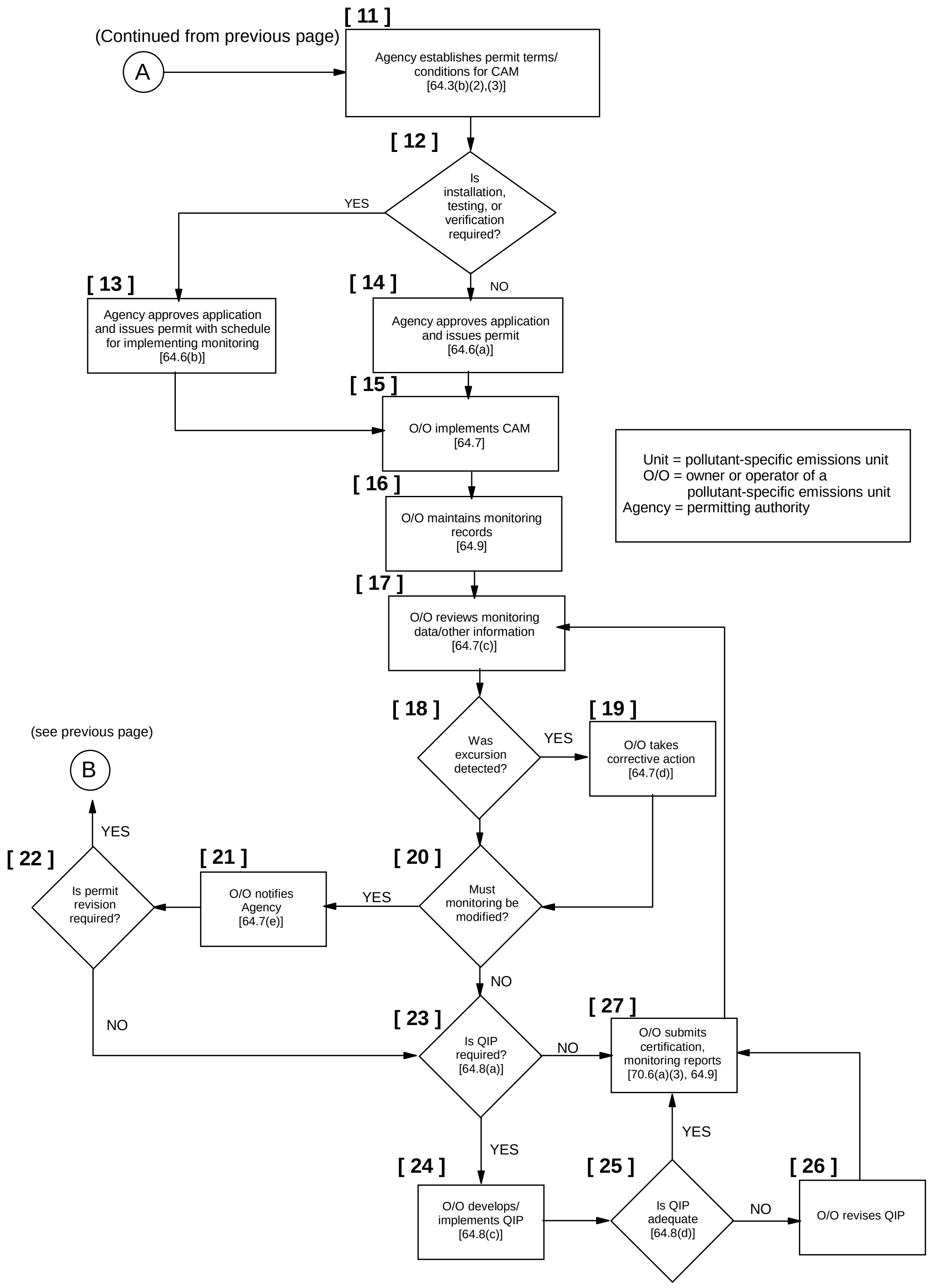

Figure 1-1. (continued)

TABLE 1-1. APPLICABILITY REQUIREMENTS FOR CAM

Part 64 reference	Requirement
§ 64.2(a)	Unit is located at major source that is required to obtain Part 70 or 71 permit
§ 64.2(a)(1)	Unit is subject to emission limitation or standard for the applicable pollutant
§ 64.2(a)(2)	Unit uses a control device to achieve compliance (See § 64.1 for definition of control device.)
§ 64.2(a)(3)	Potential precontrol emissions of applicable pollutant from unit are at least 100 percent of major source amount
§ 64.2(a)(b)	Unit is not otherwise exempt (See Table 1-2 for list of specific exemptions.)

Major source means any stationary source (or any group of stationary sources that are located on one or more contiguous or adjacent properties, and are under common control of the same person (or persons under common control) belonging to a single major industrial grouping and that are described in paragraph (1), (2), or (3) of this definition. For the purposes of defining "major source," a stationary source or group of stationary sources shall be considered part of a single industrial grouping if all of the pollutant emitting activities at such source or group of sources on contiguous or adjacent properties belong to the same Major Group (i.e., all have the same two-digit code) as described in the Standard Industrial Classification Manual, 1987.

(1) A major source under Section 112 of the Act, which is defined as:

(I) For pollutants other than radionuclides, any stationary source or group of stationary sources located within a contiguous area and under common control that emits or has the potential to emit, in the aggregate, 10 tons per year (tons/yr) or more of any hazardous air pollutant which has been listed pursuant to Section 112(b) of the Act, 25 tons/yr or more of any combination of such hazardous air pollutants, or such lesser quantity as the Administrator may establish by rule. Notwithstanding the preceding sentence, emissions from any oil or gas exploration or production well (with its associated equipment) and emissions from any pipeline compressor or pump station shall not be aggregated with emissions from other similar units, whether or not such units are in a contiguous area or under common control, to determine whether such units or stations are major sources; or

(ii) For radionuclides, "major source" shall have the meaning specified by the Administrator by rule.

(2) A major stationary source of air pollutants, as defined in Section 302 of the Act, that directly emits or has the potential to emit, 100 tons/yr or more of any air pollutant (including any major source of fugitive emissions of any such pollutant, as determined by rule by the Administrator). The fugitive emissions of a stationary source shall not be considered in determining whether it is a major stationary source for the purposes of Section 302(j) of the Act, unless the source belongs to one of the following categories of stationary source:

(I) Coal cleaning plants (with thermal dryers);
(ii) Kraft pulp mills;
(iii) Portland cement plants;
(iv) Primary zinc smelters;
(v) Iron and steel mills;
(vi) Primary aluminum ore reduction plants;
(vii) Primary copper smelters;
(viii) Municipal incinerators capable of charging more than 250 tons of refuse per day;
(ix) Hydrofluoric, sulfuric, or nitric acid plants;
(x) Petroleum refineries;
(xi) Lime plants;
(xii) Phosphate rock processing plants;

Figure 1-2. Definition of major source.

(xiii) Coke oven batteries
(xiv) Sulfur recovery plants;
(xv) Carbon black plants (furnace process);
(xvi) Primary lead smelters;
(xvii) Fuel conversion plants;
(xviii) Sintering plants;
(xix) Secondary metal production plants;
(xx) Chemical process plants;
(xxi) Fossil-fuel boilers (or combination thereof) totaling more than 250 million British thermal units per hour heat input;
(xxii) Petroleum storage and transfer units with a total storage capacity exceeding 3,000,000 barrels;
(xxiii) Taconite ore processing plants;
(xxiv) Glass fiber processing plants;
(xxv) Charcoal production plants;
(xxvi) Fossil-fuel-fired steam electric plants of more than 250 million British thermal units per hour heat input; or
(xxvii) All other stationary source categories regulated by a standard promulgated under Section 111 of 112 of the Act, but only with respect to those air pollutants that have been regulated for that category;

(3) A major stationary source as defined in Part D of title I of the Act, including:

(I) For ozone nonattainment areas, sources with the potential to emit 100 tons/yr or more of volatile organic compounds or oxides of nitrogen in areas classified as “marginal” or “moderate,” 50 tons/yr or more in areas classified as “serious,” 25 tons/yr or more in areas classified as “severe,” and 10 tons/yr or more in areas classified as “extreme”; except that the references in this paragraph to 100, 50, 25 and 10 tons/yr of nitrogen oxides shall not apply with respect to any source for which the Administrator has made a finding, under Section 182(f) (1) or (2) of the Act, that requirements under Section 182(f) of the Act do not apply;

(ii) For ozone transport regions established pursuant to Section 184 of the Act, sources with the potential to emit 50 tons/yr or more of volatile organic compounds;

(iii) For carbon monoxide nonattainment areas:

(A) That are classified as “serious,” and

(B) in which stationary sources contribute significantly to carbon monoxide levels as determined under rules issued by the Administrator, sources with the potential to emit 50 tons/yr or more of carbon monoxide; and

(iv) For particulate matter (PM-10) nonattainment areas classified as “serious,” sources with the potential to emit 70 tons/yr or more of PM-10.

Figure 1-2. (continued)

Section 64.1 defines the term "control device" as it pertains to the CAM rule. The following sections discuss procedures for estimating potential precontrol device emissions and exemptions to CAM, respectively.

1.2.1.1 Estimating Potential Precontrol Device Emissions

In order to determine the applicability of Part 64, owners and operators of emissions units that may be subject to the CAM rule must estimate potential precontrol device emission rates for the regulated pollutant (§ 64.2). The two basic approaches to performing this estimate are based on: (1) the controlled potential to emit and the control device efficiency for the subject emissions unit; or (2) uncontrolled emission test data from measurements taken prior to the control device inlet or uncontrolled emission factors. Guidance on estimating potential to emit is provided in the *White Paper for Streamlined Development of Part 70 Permit Applications* (White Paper No. 1), published by EPA in July 1995. White Paper No. 1 specifies the types of information that can be used to estimate potential to emit. These types of information, which also are recommended as the basis for estimating potential precontrol device emissions, include the following:

1. Emission test data;
2. Emission factors published in EPA documents and data bases such as *Compilation of Air Pollutant Emission Factors* (AP-42), the locating and estimating (L&E) documents, and the factor information and retrieval (FIRE) data base;
3. Emission factors from other publications, such as the *Air Pollution Engineering Manual* and vendor literature;
4. Emission factors developed by State and local regulatory agencies; and
5. Reasonable engineering estimates, such as mass balances.

As stated previously, the first approach to estimating potential precontrol device emissions uses the potential to emit and the control device control efficiency for the subject control device. The information sources listed above provide control device efficiencies explicitly and/or information that can be used to estimate control device efficiency. For example, for many types of emissions units, AP-42 provides both controlled and uncontrolled emission factors, from which control efficiencies can be calculated. The second approach to estimating potential precontrol device emissions requires test data on uncontrolled emissions or the emission factor for uncontrolled emissions and the annual production rates used to calculate the potential to emit for the subject emissions unit.

In general, the use of available information is adequate for estimating potential emissions. Although emissions test data would be useful for estimating potential precontrol device emissions, conducting emissions tests for the sole purpose of making an applicability determination is not expected. Figure 1-3 provides examples of how precontrol device emissions can be estimated. Figure 1-4 lists some technical references that may be useful for estimating emissions for the purpose of determining CAM applicability.

1.2.1.2 Exemptions to Part 64

Section 64.2(b) lists several specific exemptions to the CAM rule. These exemptions are summarized in Table 1-2. First, certain emission limitations or standards are exempted, including: new source performance standards (NSPS) or national emission standards for hazardous air pollutants (NESHAP) proposed after November 15, 1990, stratospheric ozone requirements, Acid Rain Program requirements, requirements that apply solely under an emissions trading program that allows emission credit trading or selling, requirements that cap total emissions in accordance with § 70.4(b)(12), and limits or standards for which the Part 70 or 71 permit specifies a continuous compliance determination method that does not use an assumed control factor.

Table 1-3 includes NSPS and NESHAP proposed after November 15, 1990. This table does not include rules that were amended after Nov. 15, 1990. It includes only those NSPS and NESHAP with an original proposal date after Nov. 15, 1990. Whether emission standards amended after Nov. 15, 1990 are exempt from CAM would depend on the nature of the amendment and whether the amended rule includes monitoring requirements that satisfy CAM. Currently, only one such rule has been identified. An amendment to subpart L of Part 61 (National Emission Standard for Benzene Emissions from Coke By-Product Recovery Plants) was published in the *Federal Register* on September 19, 1991, that added provisions for the use of carbon adsorbers and vapor incinerators as alternative means of complying with the standards for process vessels, storage tanks, and tar-intercepting sumps. The added provisions include testing, monitoring, recordkeeping, and reporting requirements for the alternative controls. Therefore, emissions units subject to the amended part of this rule are exempt from the CAM rule.

The term "continuous compliance determination method" is defined in § 64.1 of the rule. A continuous compliance determination method is a method which (1) is used to determine compliance with an emission limitation or standard on a continuous basis, consistent with the averaging period established for the emission limitation or standard, and (2) either provides data in units of the standard or is correlated directly with the compliance limit. Table 1-4 lists examples of continuous compliance determination methods and identifies some specific regulations that incorporate these continuous compliance determination methods. Note that for a monitoring method to be a continuous compliance method it must incorporate items (1) and (2) identified above (and specified in the Part 64 definition of continuous compliance determination); the examples cited in Table 1-4 incorporate these two items. If a unit is subject to both exempt and nonexempt emission limitations or standards, Part 64 still applies to the unit.

Second, § 64.2(b)(2) exempts backup utility power emissions units that are owned by a municipality and for which the owner or operator provides documentation in the Part 70 or 71 permit application that: the unit is exempt from all Part 75 monitoring requirements; the unit is operated solely to provide electricity during peak demand or emergency periods; and the average annual emissions for the three previous years is less than 50 percent of the major source amount and emissions are expected to remain below the 50 percent level.

EXAMPLE I:	**Potential Precontrol Device Emissions Based on Potential to Emit and Estimated Control Efficiency**
Emissions unit:	Container glass melting furnace
Control device:	Venturi scrubber
Pollutant:	SO_2
Potential to emit:	10.6 tons/yr (based on title V applicability determination for subject emissions unit)
Control efficiency:	94 % (based on AP-42, Table 11.15-1)
Potential precontrol device emissions	$10.6 \times 100/(100\text{-}94) = 177$ tons/yr
EXAMPLE II:	**Potential Precontrol Device Emissions Based on Uncontrolled Emission Factor From AP-42**
Emissions unit:	Hot mix asphalt dryer, drum mix process
Control device:	Fabric filter
Pollutant:	PM-10
Basis for potential to emit:	
Production rate:	210 tons/hr
Operating capacity:	8,760 hr/yr
Uncontrolled emission factor:	4.3 lb/ton (AP-42, Table 11.1-5)
Potential precontrol device emissions:	$210 \times 8{,}760 \times 4.3 = 7{,}910{,}000$ lb = 3,960 tons/yr

Figure 1-3. Examples of potential precontrol device emission estimates.

For potential to emit:

1. *White Paper for Streamlined Development of Part 70 Permit Applications*, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 10, 1995.

For emission factors and control efficiencies:

1. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, AP-42, Fifth Edition*, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1995.
2. Buonicore, A. and W. Davis (ed.), *Air Pollution Engineering Manual*, Air and Waste Management Association, Van Nostrand Reinhold, New York, NY, 1992.
3. *APTI Course 413, Control of Particulate Emissions, Student Manual*, EPA 450/2-80-086, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1981.
4. *APTI Course 415, Control of Gaseous Emissions, Student Manual*, EPA 450/2-81-005, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1981.
5. *APTI Course SI: 431, Air Pollution Control Systems for Selected Industries, Self-Instructional Guidebook*, EPA 450/2-82-006, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

Figure 1-4. Useful references for estimating potential precontrol device emissions.

TABLE 1-2. SUMMARY OF CAM RULE EXEMPTIONS

Part 64 reference	
	EXEMPTED EMISSION LIMITATIONS OR STANDARDS[a]
§ 64.2(b)(1)(I)	Post-11/15/90 NSPS or NESHAP (see Table 1-3)
§ 64.2(b)(1)(ii)	Stratospheric ozone protection requirements
§ 64.2(b)(1)(iii)	Acid Rain Program requirements
§ 64.2(b)(1)(iv)	Emission limitations, standards, or other requirements that apply solely under an approved emission trading program
§ 64.2(b)(1)(v)	Emissions cap that meets requirements of § 70.4 (b) (12)
§ 64.2(b)(1)(vi)	Emission limitations or standards for which a Part 70 or 71 permit specifies a continuous compliance determination method that does not use an assumed control factor (see Table 1-4 for examples.)
	EXEMPTED EMISSIONS UNITS
§ 64.2 (c) (2)	Backup utility power units that: • are owned by a municipality; • are exempt from all monitoring requirements in Part 75; • are operated solely for providing electricity during peak periods or emergency situations; and • for which actual emissions for the previous 3 years are less than 50 percent of the major source cutoff and are expected to remain so.

[a]Note: If nonexempt emission limitations or standards apply to the emissions unit, the unit is not exempt.

TABLE 1-3. PART 60 AND 63 RULES PROPOSED AFTER NOVEMBER 15, 1990

Source category	Subpart	Affected facility
New Source Performance Standards--40 CFR 60		
Municipal Solid Waste Landfills	Cc	Existing landfills
Municipal Waste Combustor Emissions	Cb, Eb	Medical waste combustors
Medical Waste Incinerators	Ec, Ce	Medical waste incinerators
Phosphate Fertilizer Industry	X	Granular triple superphosphate production
Municipal Solid Waste Landfills	WWW	New, modified MSW Landfills
SOCMI Wastewater	YYY	New, modified, and reconstructed facilities
National Emission Standards for Hazardous Air Pollutants–40 CFR 63		
HON	F,G,H,I, J, K	Process vents storage vessels, transfer racks, wastewater streams, and equipment leaks used to produce one or more of 396 SOCMI chemicals
Coke Oven Batteries and Source Categories	L	Coke Oven Batteries
Dry Cleaning	M	Dry Cleaning Machines (at major and area sources)
Chromium Electroplating	N	Electroplating or Anodizing Tank
Ethylene Oxide	O	Ethylene Oxide Sterilizers and Fumigators
Sterilizers Industrial Process Cooling Towers	Q	Industrial Process Cooling Towers using Chromium
Gasoline Distribution	R	Total Bulk Terminal and Breakout Station
Pulp and Paper	S	Pulp and Paper and Paperboard
Halogenated Solvent Cleaning	A,T	Halogenated Solvent Cleaning Machines at Major and Area Sources
Polymers and Resins Group I	U	Existing and new facilities that manufacture elastomers
Epoxy Resins Production and Non-nylon Polyamides Production	W	Existing and new facilities that manufacture polymers and resins
Secondary Lead Smelters	X	New and existing sec. lead smelters
Marine Tank Vessel Loading and Unloading Operations	Y	New and existing marine tank vessel loading and unloading operations
Phosphoric Acid Manufacturing and Phosphate Fertilizers Production	AA	New and existing major sources in phosphoric acid manufacturing and phosphate fertilizer production plants
Petroleum Refineries	CC	Petroleum Refinery Processes
Offsite Waste Recovery Operations	DD	Offsite Waste and Recovery Operations

TABLE 1-3. (CONTINUED)

Source category	Subpart	Affected facility
Magnetic Tape Manufacturing Operations	EE	Magnetic Tape Products
Aerospace Manufacturing and Rework	GG	New and existing commercial, civil, and military aerospace OEM and rework facilities that are major sources of HAPS
Shipbuilding and Ship Repair	II	Surface coating operations from new or existing shipbuilding or ship repair facilities
Wood Furniture	JJ	Existing and new wood furniture mfg. operations
Printing and Publishing	KK	Existing and new sources
Primary Aluminum Reduction Plants	LL	New or existing potline paste production operation, and anode bake furnace
Steel Pickling	CCC	New and existing facilities that pickle steel using acid
Mineral Wool	DDD	New or existing sources in mineral wool production plants
Flexible Polyurethane Foam Production	lll	New and existing major sources of HAP; applies to manufacture of molded, slabstock, and rebond foam
Pharmaceuticals	GGG	HAPS from new and existing facilities that manufacture pharmaceuticals
Polymers and Resins IV	JJJ	Existing and new facilities that manufacture one or more Group IV polymers and resins
Pesticide Active Ingredient Production	MMM	New and existing facilities that manufacture Pesticide Active Ingredients (PAI)
Wool Fiberlgass	NNN	New and existing sources in wool fiberglass
Polyether Polyols Production	PPP	Existing and new facilities that manufacture Polyether polyols located at major source plant sites.

Note: This table does not include rules that were amended after Nov. 15, 1990. It includes only those NESHAP and NSPS with an original proposal date after Nov. 15, 1990. Whether emission limitations or standards amended after Nov. 15, 1990 are exempt from CAM would depend on the nature of the amendment and whether the amended rule includes monitoring requirements that satisfy CAM. See Chapter 3 for a discussion of presumptively acceptable CAM.

TABLE 1-4. EXAMPLES OF CONTINUOUS COMPLIANCE DETERMINATION METHODS

Monitoring method	Specific example
Continuous emission monitoring systems (CEMS) which are used to determine compliance with an emission limitation or standard on a continuous basis, consistent with the averaging period established for the emission limitation or standard and provide data in units of the standard	NO_x and SO_2 CEMS specified in Part 60 subpart Da, Standards of Performance for Electric Utility Steam Generating Units for which Construction is Commenced after September 18, 1978 NO_x and SO_2 CEMS specified in Part 60, subpart Db, Standards of Performance for Industrial-Commercial-Institutional Steam Generating Units NO_x CEMS specified in Part 60, subpart Dc, Standards of Performance for Small-Industrial-Commercial-Institutional Steam Generating Units NO_x and SO_2, and CO CEMS specified in Part 60, subpart Ea, Standards of Performance for Municipal Waste Combustors SO_2 CEMS for Fluid Catalytic Cracking Units Regenerators specified in Part 60, subpart J, Standards of Performance for Petroleum Refineries.

1.2.2 CAM Submittals

The next major step is the preparation and submittal of the required information for CAM. However, before preparing the submittals, owners or operators of affected units should determine the submittal date for units that are subject to CAM **[3]**. Deadlines for CAM submittals are addressed in § 64.5. In specifying submittal deadlines, the CAM rule distinguishes between large emissions units and other units. Large units are those with the (postcontrol) potential to emit the applicable pollutant at least 100 percent of the major source amount. Beginning April 20, 1998, owners or operators of large units that are subject to Part 64 must submit the required information as part of the application of a Part 70 or 71 permit if, by that date, the application has not been filed or has not yet been determined to be complete. In addition, beginning that same date, if the owner or operator of a large unit is required to submit a significant permit revision for that unit, the CAM submittal for that unit must be submitted as part of the permit revision application. For all other large units and for all other affected emission units, CAM submittals are to be included with the renewal of the Part 70 or 71 permit for the unit. Section 64.5(b) further specifies that a permit reopening is not required to submit the information required by Part 64. However, if the permit is reopened for cause by EPA or the permitting authority, the applicable agency may require the submittal of information for CAM as part of the permit reopening process.

Section 64.4 (a) requires owners or operators of affected units to prepare **[4]** and submit **[5]** several items that define the monitoring procedures that will be used to comply with the rule. Table 1-5 summarizes these required submittal items. Chapter 2 of this document describes the contents of CAM monitoring approach submittals and provides additional details on CAM submittal requirements; several example submittals are provided in Appendix A.

1.2.3 Review and Approval of CAM Submittal

As part of the process of issuing or denying Part 70 or 71 permit applications, the permitting authority reviews the CAM submittal (§ 64.6) **[6]**. To process the CAM submittal, the permitting authority follows the procedures specified in § 70.5 for Part 70 permit applications. First, the CAM submittal is reviewed for completeness and adequacy **[7]**. If additional information is needed or corrections are required, the permitting authority notifies the owner or operator **[8]**. Section 70.5(b) requires the owner or operator of the unit to revise or supplement the CAM submittal **[9]** and "promptly" provide the additional or revised information to the permitting authority **[10]**. Once the CAM submittal is determined to be acceptable, the permitting authority establishes permit terms or conditions for the affected emissions unit **[11]**. Table 1-6 summarizes the requirements that must, at a minimum, be specified in the permit.

If the monitoring proposed for the affected emissions unit requires installation, testing, or final verification of operational status **[12]**, the permitting authority may issue a permit with a schedule for completing the installation and testing, establishing applicable indicator ranges, or completing other required activities **[13]**.

1.2.4 CAM Implementation

Following approval and incorporation of the CAM requirements in the Part 70 or 71 permit **[13, 14]**, owners and operators of affected units must implement the monitoring **[15]** upon issuance of the permit, unless the permit specifies a later date (§ 64.7(a)). In such cases, monitoring must be implemented by the specified date. With the exception of periods when the monitoring system is under repair, maintenance, or QA/QC procedures, the monitoring must be conducted continuously or intermittently, as specified in the permit, during all periods when the emissions unit is in operation. In addition, § 64.7(b) requires owners and operators of units subject to CAM to maintain spare parts for routine repairs of monitoring instruments and equipment. Spare parts may be maintained by local vendors if there is no significant impact on immediate availability.

TABLE 1-5. SUMMARY OF SUBMITTAL REQUIREMENTS FOR CAM

Part 64 reference	Requirement[a]
§ 64.4(a)	Information on indicators, indicator ranges or process by which indicators are to be established, and performance criteria
§ 64.4(b)	Justification for the proposed elements of the monitoring
§ 64.4(c)	Control device operating data recorded during performance test, supplemented by engineering assessments or manufacturer's recommendations to justify the proposed indicator range
§ 64.4(d)	Test plan and schedule for obtaining data, if performance test data are not available
§ 64.4(e)	Implementation plan, if monitoring requires installation, testing, or other activities prior to implementation

[a] Sections 64.4 (f) and (g) do not specify additional items to be submitted, but allow owners and operators of affected units to provide one submittal for multiple units that are served by a single control device, and one submittal for an emission unit that is served by multiple control devices.

TABLE 1-6. SUMMARY OF REQUIRED PERMIT CONDITIONS OR TERMS

Part 64 reference	Requirement
§ 64.6(c)(1)	The approved monitoring approach, including the indicators to be monitored, the method of measuring the indicators, and the performance criteria specified in § 64.3 of the CAM rule
§ 64.6(c)(2)	The means of defining exceedances or excursions, the level which constitutes an exceedance or excursion or the means by which that level will be defined, the averaging period that associated with exceedances or excursions, and the procedures for notifying the permitting authority of the establishment or reestablishment of any exceedance or excursion level
§ 64.6(c)(3)	The obligation to conduct monitoring and satisfy the requirements of the §§ 64.7 through 64.9
§ 64.6(c)(4)	If appropriate, the minimum data availability requirement for valid data collection for each averaging period and, if appropriate, the minimum data availability requirement for the averaging periods in a reporting period

Section 64.9 specifies the reporting and recordkeeping requirements for CAM **[16]**. Monitoring reports must be submitted and records must be maintained in accordance with § 70.6(a)(3)(iii). As an alternative to paper records, § 64.9(b)(2) allows owners and operators of affected units to maintain records on alternate media, such as microfilm, computer files, magnetic tape disks, or microfiche provided that the records are readily accessible and the use of

such alternative media does not conflict with other recordkeeping requirements. Table 1-7 summarizes the reporting and recordkeeping requirements for CAM.

As CAM is implemented, owners and operators of affected emissions units periodically should review the monitoring data **[17]** to determine the need for additional measures to assure compliance with the applicable emission standards or limits. If an excursion or exceedance is detected **[18]**, the owner or operator must take the corrective actions **[19]** necessary to return the emissions unit and control system to normal operation and minimize the likelihood that similar excursions or exceedances recur. If the owner or operator determines that deviations occurred that the monitoring did not indicate as an excursion or exceedance, or the results of a subsequent compliance test indicate that the indicator ranges must be modified **[20]**, § 64.7(e) requires the owner or operator of the emissions unit to notify the permitting authority promptly **[21]**. If a permit revision is required **[22]**, the owner or operator of the unit must identify proposed revisions to the CAM submittal **[9]** and submit the proposed revisions to the permitting authority **[10]** for review and approval prior to implementing the plan.

After reviewing the report of excursions or exceedances, subsequent corrective actions taken, monitoring data, and other relevant information, the permitting authority or Administrator may require **[23]** the source to develop and implement a QIP **[24]**. In some cases, the Part 70 or 71 permit also may specify the threshold for requiring a source to implement a QIP. Quality improvement plans are discussed in Section 3.4 of this document.

If required by the permitting authority, owners or operators of affected units may be required to maintain written QIP's on file for inspection and review. When a QIP is required, owners or operators must develop and implement the QIP as quickly as possible and must notify the permitting authority if more than 180 days will be required for completing the improvements specified. If it is determined that the QIP was inadequate **[25]**, the permitting authority also may require the source to modify the QIP **[26]**.

TABLE 1-7. SUMMARY OF REPORTING AND RECORDKEEPING REQUIREMENTS FOR CAM

Part 64 reference	Requirement
MONITORING REPORT REQUIREMENTS	
§ 64.9(a)(2)(I)	Summary of the number, duration, and cause of excursions or exceedances and the corrective actions taken
§ 64.9(a)(2)(ii)	Summary of the number, duration, and cause of monitoring equipment downtime incidents, other than routine downtime for calibration checks
§ 64.9(a)(2)(iii)	Description of the actions taken to implement a QIP, and, upon completion of the QIP, documentation that the plan was completed and reduced the likelihood of similar excursions or exceedances
COMPLIANCE CERTIFICATIONS	
§ 70.69(a)(3)(iii)(A)	Identification of each term or condition of the permit that is the basis of the certification
§ 70.69(a)(3)(iii)(B)	Identification of the methods or other means used by the owner or operator for determining the compliance status with each term and condition during the certification period, and whether such methods or other means provide continuous or intermittent data
§ 70.69(a)(3)(iii)(C)	Status of compliance with the terms and conditions of the permit for the period covered by the certification and identification of each deviation and, as possible exceptions to compliance, any periods during which compliance was required and an excursion or exceedance occurred
§ 70.69(a)(3)(iii)(D)	Any other information required by the permitting authority
RECORDKEEPING REQUIREMENTS	
§ 64.9(b)	Records of monitoring data, monitor performance data, corrective actions taken, written QIP's, actions taken to implement a QIP, and other supporting information

In addition to the reporting requirements specified in § 64.9, § 70.6(a)(3)(iii) requires owners or operators of affected emissions units to submit monitoring reports with the required compliance certifications to the permitting authority at least semiannually **[27]**. Table 1-7 lists the types of information that must be included in the monitoring reports and compliance certifications.

2.0 MONITORING APPROACH SUBMITTALS

Part 64 requires all owners or operators of affected facilities to submit information about the monitoring approach to be used to comply with the rule. The information to be submitted is compiled in what is referred to in this guidance document as a monitoring approach submittal, or CAM submittal.

A monitoring approach submittal is required for each pollutant-specific emissions unit (PSEU). If a single control device is common to more than one PSEU, the facility owner or operator may provide a monitoring approach submittal for the control device that identifies the PSEU’s affected and any process or associated capture device conditions that must be maintained or monitored to comply with the CAM general criteria. Similarly, if a single PSEU is controlled by more than one control device that are similar in design and operation, the owner or operator may provide a monitoring approach submittal that applies to all the control devices. The CAM submittal must identify the affected control devices and any process or associated capture device conditions that must be maintained or monitored to comply with the general monitoring criteria.

This chapter provides guidance on preparing monitoring approach submittals. Section 2.1 presents the objectives of a CAM submittal. Section 2.2 presents and discusses the submittal requirements. Section 2.3 discusses the process of selecting a monitoring approach and appropriate indicator range(s) for the parameters that are to be monitored. Section 2.4 discusses QIP's.

Example monitoring approach submittals are provided in Appendix A.

2.1 MONITORING APPROACH SUBMITTAL OBJECTIVES

The objectives of a monitoring approach submittal are to identify the monitoring approach that will be used, the indicator range(s) to be maintained, and the rationale for selecting the monitoring approach and indicator range(s).

Part 64 identifies specific information that must be submitted to the permitting authority. As mentioned above, the compilation of this information is called a CAM submittal. The submittal requirements are identified and discussed in the following section. If the CAM submittal includes all of the necessary elements, it should provide sufficient information to allow the permitting authority to determine if the owner or operator of the affected emissions unit is monitoring in a manner that complies with Part 64. The CAM submittal will provide a succinct summary of the monitoring requirements necessary for compliance with Part 64 for both facility personnel and the permitting agency. Providing detailed Standard Operating Procedures (SOP's) or a detailed Quality Assurance/Quality Control (QA/QC) manual is not the intended objective of a CAM submittal. The justification for the CAM submittal must include documentation that describes the rationale for how the requirements of Part 64 are satisfied.

The information included in the CAM submittal is extensive and covers all aspects of the monitoring approach and how it complies with Part 64. Once the permitting authority approves a facility's proposed monitoring, the facility's operating permit must establish permit terms or conditions that specify the required monitoring. The information included in the permit, however, need not be as all inclusive as the information contained in the CAM submittal presented to the permitting authority for approval. Only certain types of information contained in the CAM submittal must be incorporated directly into the facility's operating permit. These minimum requirements are discussed further in Section 2.2.

2.2 ELEMENTS OF A MONITORING APPROACH SUBMITTAL

Suggested outlines for CAM submittals that incorporate the elements required by the rule are presented in Figures 2-1a and 2-1b. Figure 2-1a pertains to facilities using a monitoring approach that does not involve the use of continuous emission monitoring systems (CEMS), continuous opacity monitoring systems (COMS), or predictive emission monitoring systems (PEMS) and Figure 2-1b pertains to facilities using CEMS, COMS, or PEMS as the monitoring approach. For clarification purposes the information is presented in two separate outlines. However, a facility using a combination of methods should compile all the necessary information pertaining to each monitoring method into one CAM submittal. In the figures, the required elements are presented in bold type. Each element is addressed in the following sections. An example CAM submittal format that may be used to provide the necessary information is presented in Figure 2-2.

As mentioned above in Section 2.1, only some of the information included in the CAM submittal need be incorporated directly into the facility’s operating permit. Section 64.6(c) of the rule states that, at a minimum, the facility’s operating permit must specify: (1) the approved monitoring approach, including the indicator(s) to be monitored, the means or device to measure the indicator(s), and the monitoring approach performance specifications; (2) the indicator range(s), including appropriate averaging periods; (3) a general statement of the owner or operator’s obligation to conduct the monitoring and to satisfy the requirements for quality improvement plans and reporting and recordkeeping requirements; and (4) if appropriate, minimum data availability requirements for valid data collection for each averaging period and for each reporting period. Items 1 and 2 above are required to be addressed in the CAM submittal. Based on the outline presented in Figure 2-1a and the example format presented in Figure 2-2, the information contained in item II--Monitoring Approach would cover items 1 and 2 of the minimum operating permit requirements listed above. As shown in Figure 2-2, this information is compiled in a table. This table, along with a general statement of obligation and minimum data availability requirements, would be a convenient format for incorporation into a facility’s operating permit. For completed example CAM submittals using this format refer to Appendix A.

Monitoring Approach Submittal[a]

I. Background

A. Emissions unit identification
B. Applicable regulation, emission limits, and monitoring requirements
C. Control technology description

II. Monitoring Approach

A. General Criteria

1. **Performance indicator(s)**
2. **Indicator range(s) or designated condition(s)**

B. Performance Criteria

1. **Data representativeness**
2. **Verification of operational status (new or modified equipment)**
3. **QA/QC practices**
4. **Monitoring frequency and data collection procedures**

Justification[a]

I. Monitoring approach and indicator

II. Indicator range(s)

A. Compliance test data and indicator data supporting range, or
B. Compliance test plan and schedule, or
C. Rationale and documentation for indicating that ranges can be established without the need for compliance test data

---

[a]Items in bold are specific elements required by the rule [§ 64.4].

Figure 2-1a. Outline for monitoring approach submittal and justification.

Monitoring Approach Submittal[a]

I. Background

A. Emissions unit identification
B. Applicable regulation, emission limits, and monitoring requirements
C. Control technology description

II. Monitoring Approach

A. General Criteria

1. Performance indicator(s)
2. Indicator range(s) for COMS used to assure compliance with a PM standard

B. Performance Criteria

1. Exceedance reporting required by regulation
2. Exceedance period to be used for CAM

Justification[a]

I. Monitoring approach and indicator

II. Indicator range(s) for CEMS and PEMS: reference the most recent certification test for the monitor

III. Indicator range(s) for COMS used to assure compliance with a PM standard

A. Compliance test data and indicator data supporting range, or
B. Compliance test plan and schedule, or
C. Rationale and documentation for indicating that ranges can be established without the need for compliance test data

[a] Items in bold are specific elements required by the rule [§ 64.3].

Figure 2-1b. Outline for monitoring approach submittal and justification for CEMS, COMS, and PEMS.

MONITORING APPROACH SUBMITTAL

I. Background

A. Emissions Unit

Description: ______________________________
(Type of emission point)

Identification: ______________________________
(Emission point number)

Facility: ______________________________
(Location)

B. Applicable Regulation, Emission Limits, and Monitoring Requirements

Regulation No.:

Pollutant: ______________________ ______________________
(Emission limit)

Pollutant: ______________________ ______________________
(Emission limit)

Monitoring Requirements:

C. Control Technology
(Describe control technology)

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table 1.

JUSTIFICATION

(Present justification for selection of monitoring approach and indicator range(s).)

Figure 2-2. Monitoring approach submittal example format.

TABLE 1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2
I. Indicator		
Measurement Approach		
II. Indicator Range QIP Threshold (optional)		
III. Performance Criteria A. Data Representativeness		
B. Verification of Operational Status		
C. QA/QC Practices and Criteria		
D. Monitoring Frequency		
Data Collection Procedures		
Averaging Period		

Figure 2-2. (continued)

2.2.1 Background

This section of the CAM submittal provides background information on the pollutant-specific emissions unit to which the submittal applies. The pollutant-specific emissions unit is identified and briefly described. The applicable emission limitation or standard(s) and pollutant(s) also are identified. If applicable, any existing monitoring requirements that apply to the pollutant-specific emissions unit also are described. Finally, the emissions control technology for the unit is identified and briefly described.

2.2.2 Monitoring Approach

This section of a CAM submittal presents a description of the monitoring approach to be used. Section 64.3 of the rule specifies design criteria that the monitoring approach must address to satisfy Part 64. These criteria are categorized as general criteria, performance criteria, and special criteria where CEMS, COMS or PEMS are to be used; and are summarized in Table 2-1. The description of the monitoring approach must address how each of the applicable design criteria are satisfied. Thus, the description should include the following:

1. General criteria: performance indicator(s) and indicator range(s);
2. Performance criteria: data representativeness, verification of operational status, QA/QC procedures, and monitoring frequency and data collection procedures; and
3. Special criteria (if applicable for use of CEMS, COMS, or PEMS): performance indicator(s), indicator range(s), performance criteria, and reporting of exceedances.

Each of these elements to be included in the CAM submittal are described in the following sections.

2.2.2.1 General Criteria: Performance Indicator(s) and Indicator Range(s)

The monitoring approach must be designed to provide data for one or more indicators of performance of the control device, any associated capture system, and/or any processes significant to achieving compliance. Such indicators can include a measured or predicted emissions level, such as total hydrocarbon concentration, nitrogen oxides (NO_x) concentration, opacity, or visible emissions; a pollution control device operating parameter, such as temperature or pressure drop; a process operating parameter, such as temperature or flow; a recordkeeping item, such as pounds of volatile organic compound per gallon of coating; a work practice activity, such as records of solvent usage for cleaning activities; recorded findings of inspection and maintenance activities, such as an internal fabric filter baghouse inspection; or a combination of these types of indicators.

TABLE 2-1. MONITORING DESIGN CRITERIA

Part 64 reference	Description
GENERAL CRITERIA	
§ 64.3 (a) (1)	Must be designed to obtain data for one or more indicators of performance of the control device, any associated capture system, and processes necessary to assure compliance.
§ 64.3 (a) (2)	Must be based on establishing appropriate indicator ranges or designated conditions such that operation within the ranges provides a reasonable assurance of ongoing compliance with the applicable requirement over the anticipated range of operations. Reasonable assurance of compliance will be assessed by maintaining performance within the indicator range(s) or designated conditions that reflect proper operation and maintenance of the control device (and associated capture system).
§ 64.3 (a) (3)	Ranges may be based on a minimum or maximum value; based on different values for different operating conditions; expressed as a function of process variables; expressed as maintaining the applicable indicator in a particular operational status; and established as interdependent between more than one indicator.
PERFORMANCE CRITERIA	
§ 64.3 (b) (1)	<u>Data Representativeness</u>: Detector location and installation specifications to provide for obtaining representative data.
§ 64.3 (b) (2)	<u>Verification of Operational Status</u>: Verification procedures, including installation, calibration, and operation in accordance with manufacturer's recommendations, to confirm the operational status of the monitoring prior to the commencement of required monitoring.
§ 64.3 (b) (3)	<u>QA/QC Procedures</u>: QA/QC practices to ensure continuing validity of data.
§ 64.3 (b) (4)	<u>Frequency of Monitoring</u>: Monitoring frequency, data collection, and averaging period consistent with the characteristics and typical variability of the emissions unit and commensurate with the time period over which an exceedance or excursion is likely to occur. Emissions units with postcontrol PTE $\geq$100 percent of the amount classifying the source as a major source must collect four or more values per hour to be averaged. Other emissions units must collect data at least once per 24 hour period.
EVALUATION FACTORS	
§ 64.3 (c)	Site-specific factors should be considered in designing monitoring to meet § 64.3(a) and (b). These factors include: applicability of existing monitoring procedures; ability of monitoring to account for process and control device operational variability; reliability and latitude built into control technology; and level of actual emissions compared to compliance limitation.
SPECIAL CRITERIA FOR USE OF CEMS, PEMS, OR COMS	
§ 64.3 (d) (1)	CEMS, PEMS, or COMS that are required by other authorities under the Clean Air Act, State, or local law must be used to satisfy the CAM rule.
§ 64.3 (d) (2)	CEMS, PEMS, or COMS that satisfy any of the following monitoring requirements are deemed to satisfy the general design and performance criteria: § 51.214 and Appendix P of 40 CFR 51; § 60.13 and Appendix B of 40 CFR 60; § 63.8 and applicable performance specifications of the applicable subpart of 40 CFR 63; 40 CFR 75; subpart H and Appendix IX of 40 CFR 266; or comparable requirements established by the permitting authority.
§ 64.3 (d) (3)	Must allow for reporting of exceedances (or excursions) consistent with any underlying requirement or with § 64.3(b)(4), and provide an indicator range consistent with § 64.3(a) for a COMS used to assure compliance with a PM standard.

The general criteria also require that the monitoring approach be based on establishing appropriate ranges for control performance indicators that provide a reasonable assurance of compliance with the applicable requirement within the anticipated range of operations. A reasonable assurance of compliance can be achieved when control device performance is maintained within the indicator ranges that reflect proper operation and maintenance of the control device. Except for CEMS, COMS, and PEMS that provide data in units of the applicable emissions standard, the CAM submittal must specify the range to be maintained for each monitored indicator. The indicator range may be a true range, comprised of upper and lower limits; (e.g., 3.5 to 5.0 in. w.c. for differential pressure); a single maximum or minimum value not to be exceeded (e.g., not less than 1650°F for a thermal incinerator temperature); different values for different operating conditions (e.g., different ranges for high vs. low process load); expressed as a function of process variables (e.g., maintaining condenser temperatures "x" degrees below the condensation temperature of the applicable compounds being processed); expressed as maintaining the applicable indicator in a particular operational status (e.g., maintaining the position of a damper controlling gas flow to the atmosphere through a bypass duct); or established as interdependent between more than one indicator.

Additional information on selection of operating ranges is presented in Section 2.3.

2.2.2.2 <u>Performance Criteria</u>

Monitoring approaches used to comply with Part 64 are subject to minimum performance criteria specified in § 64.3. Under § 64.6(c) of the rule, these minimum performance criteria are to be included in the facility's operating permit. The minimum criteria assure that the data generated by the monitoring approach provide valid and sufficient information on the actual conditions being monitored. Detailed information that is not necessary to assure the data are representative need not be included in the facility's operating permit. Unnecessary detail in the permit may restrict a facility from making minor changes to the monitoring approach without undergoing procedures for a permit revision. For example, details related to the types of monitoring devices and recording systems (e.g., specifying a "Type K" thermocouple) may be left out as long as the minimum accuracy of the monitoring device is specified (e.g., thermocouple with a minimum accuracy of ±4°F or ±0.75 percent, whichever is greater). This approach allows the owner or operator to change the type of thermocouple without triggering the need for a permit revision while providing minimum sensor specifications that assure representative data are obtained.

The performance criteria that are to be addressed by the monitoring approach are as follows:

1. Data Representativeness. The monitoring approach must include specifications that provide for obtaining data that are representative of the emissions or parameters being monitored. Typically these specifications should include, as a minimum, a brief description of: (1) detector location, (2) installation requirements (if applicable), and (3) minimum acceptable accuracy. For example, the specifications for a thermocouple used to measure thermal incinerator combustion chamber temperature could be as follows:

a. Detector location–exit of thermal incinerator combustion chamber;

b. Installation requirements–housed in a ceramic protection tube, shielded from flame;

c. Minimum acceptable accuracy–thermocouple sensor with a minimum accuracy of ±4°F or ±0.75 percent, whichever is greater, and a data recording system with a minimum resolution of 20°F.

2. Verification of Operational Status. For new or modified monitoring equipment, the monitoring approach must describe the verification procedures that will be used to confirm the operational status of the monitoring prior to the date by which the owner or operator must conduct monitoring for compliance with § 64.7. Verification procedures include procedures for installation, calibration, and operation of the monitoring equipment, and should be conducted in accordance with the monitoring equipment manufacturer's recommendations.

3. QA/QC Practices. The monitoring approach must identify the minimum QA/QC activities that will be used to assure the continuing validity of the data for the purpose of indicating potential adverse changes in control performance. Quality control activities are those routine activities included as a part of normal internal procedures such as periodic calibration checks (e.g., zero check of manometer), visual inspections by operating staff, routine maintenance activities (e.g., replacement of filters on COMS purge air system, weekly blowback purge of manometer lines), or training/certification of staff. Quality assurance activities are those activities that are performed on a less frequent basis, typically by someone other than the person(s) responsible for the normal routine operations. An example of a QA activity is quarterly or annual calibration verification/adjustments performed by an instrument technician.

In developing minimum QA/QC activities for monitoring equipment and instruments the owner or operator should take into account the calibration and maintenance requirements or recommendations specified by the instrument manufacturer or supplier. When establishing QA/QC activities, the desired precision and accuracy of the data should be considered; e.g., if greater inaccuracy can be tolerated for the application (i.e, ±20°F rather than ±2°F), less frequent calibrations and/or less stringent acceptance criteria may be necessary.

The CAM submittal should include a list of the primary QA/QC activities; their frequency; and, where appropriate, the acceptable limits. A tabular summary with brief explanations, as necessary, generally is sufficient. A separate, detailed Quality Assurance Plan is not required as a part of the CAM submittal. For example, for a thermocouple, the QA/QC activities could be specified as follows:

a. Visual inspection of thermocouple sensor and well (semiannually); and

b. Measurement of system accuracy using a thermocouple simulator (calibrated millivolt source) at the sensor terminal location (semiannually); specified accuracy limit of ±40°F at 1800°F.

4. Frequency of Monitoring. The monitoring approach must address specifications for monitoring frequency, data collection procedures, and if applicable, averaging periods for discrete data points to be used in determining whether an excursion or exceedance has occurred. The monitoring and data collection frequency (including associated averaging periods) must be designed to obtain data at such intervals that are, as a minimum, consistent with the time period over which an excursion is likely to occur based on the characteristics and typical variability of the emissions unit (including the control device and associated capture system).

Part 64 includes minimum acceptable frequency requirements for PSEU's with the potential to emit the applicable regulated pollutant, calculated including the effect of control devices (i.e., postcontrol), in an amount equal to or greater than 100 percent of the major source threshold level. For each parameter monitored, emissions units within this category must collect at least four data points equally spaced over each hour. The permitting authority may approve less frequent monitoring, if appropriate, based on information presented by the owner or operator concerning the data collection mechanisms available for a particular parameter for the particular PSEU. Approval of less frequent monitoring is appropriate where frequent monitoring is not feasible because of the available data collection mechanisms for the parameter (e.g., integrated raw material or fuel analysis data, noninstrumental measurement of feed rate or visible emissions, use of a portable analyzer or an alarm sensor). For other PSEU's (postcontrol potential to emit less than 100 percent of the major source threshold), monitoring may be less frequent but must include some data collection at least once per 24-hour period (e.g., a daily inspection of a carbon adsorber system in conjunction with a weekly or monthly check of emissions with a portable analyzer.)

The monitoring approach must specify the monitoring frequency (how often measurements will be taken and recorded), the data collection procedures (e.g., manual readings and data logging or use of a data acquisition system), and the data averaging period (if applicable) for each parameter. Examples of monitoring frequency include: (1) incinerator temperature at 1-minute intervals, (2) NO_x and oxygen (O_2) concentration at 15-minute intervals, (3) differential pressure at 1-hr intervals, and (4) opacity observations for 15 contiguous minutes per day. Where the measurement frequency and the recording frequency differ, both should be specified. Also, if the proposed parameter indicator will be an average value, the CAM submittal must clearly specify the averaging period that will be used to determine that the indicator range is maintained. For example: "The NO_x analyzer will measure the concentration at 10-second intervals, and the average value for each 15-minute period will be recorded. The 15-minute values for each clock-hour will be averaged to provide a 1-hour NO_x concentration to assess compliance with the indicator range." For monitoring an operating parameter: "The thermocouple will measure thermal incinerator combustion chamber temperature at 1-minute intervals, and the average value for each 1-hour period will be recorded. The 1-hour values will be averaged over each 3-hour period to provide a 3-hour temperature to assess compliance with the indicator range."

Data acquisition procedures should indicate the equipment or method and the frequency at which indicator values are to be recorded. Examples of data acquisition procedures include: (1) 24-hour circular chart--incinerator temperature at 1-minute intervals, (2) electronic data file via data acquisition system--incinerator temperature at 1-minute intervals, (3) electronic data file via data acquisition system--15-minute average NO_x and O_2 CEMS measurements, (4) written entry on log sheet--hourly differential pressure, and (5) completion of Reference Method 9 visible emission data form--daily opacity observations.

2.2.2.3 Special Criteria for the use of CEMS, COMS, or PEMS

Part 64 specifies that where CEMS, COMS, or PEMS are already required, the monitoring approach must incorporate such systems. Therefore, source owners and operators whose emissions units have had CEMS, COMS, and/or PEMS imposed by underlying regulations, emissions trading programs, judicial settlements, or through other circumstances must use those systems when developing a monitoring approach. The use of these systems in accordance with general monitoring requirements and performance specifications will be sufficient for the system to satisfy the Part 64 general and performance criteria discussed above in Sections 2.2.2.1 and 2.2.2.2.

An exception to this general rule is a COMS used to assure compliance with a particulate matter standard. Indicator range(s) need not be specified for CEMS and PEMS that provide data in units of the applicable emissions standard because the level of the standard is the level at which an excess emission occurs. However, when a COMS is used to monitor opacity as an indicator of compliance with a particulate matter standard, the indicator (opacity) is not in terms of the standard (gr/dscf, for example) and an indicator range for opacity must be specified in the CAM submittal. Consequently, for a source that has both an applicable particulate matter (PM) standard and a requirement to continuously monitor opacity, if the source chooses opacity as the indicator (or one of multiple indicators) for PM, it is conceivable (and probable) that the specified indicator range for PM would be established at a different (lower) level and a different averaging time than the opacity emission limit which establishes the excess emission level for opacity. It should be emphasized that even in cases where a COMS is required for opacity, the COMS need not be specified as part of CAM for particulate matter. Other appropriate indicators may be selected to satisfy CAM. The above discussion applies only in cases where a facility chooses to use a COMS to monitor opacity as an indicator of compliance with a particulate matter standard.

In addition to addressing performance criteria and indicator range(s) (when applicable), the owner or operator must present information with the CAM submittal on how the CEMS, COMS, or PEMS system is designed to allow for reporting of exceedances (or excursions if applicable to a COMS used to assure compliance with a particulate matter standard).

2.2.3 Justification for Selected Monitoring Approach and Indicator Range(s)

The essence of Part 64 is the requirement that the owner or operator monitor the indicator(s) of control technology performance necessary to ensure the detection of potential adverse changes in control performance that affect emissions. The selection of the monitoring approach is the responsibility of the owner/operator. However, as part of the information provided with the CAM submittal, the owner/operator must submit justification that describes how the proposed monitoring satisfies the minimum requirements of Part 64. Essentially, this means the owner/operator must present justification for the selection of the monitoring approach (the performance indicator) and the indicator ranges. The documentation for each of these items is discussed in the following sections.

2.2.3.1 Justification for Selected Monitoring Approach and Indicator(s)

The justification should briefly describe how the proposed monitoring approach satisfies the requirements of Part 64, that is, how the selected monitoring approach and performance indicator ranges are adequate to:

1. Demonstrate that the control device and processes significant to achieving compliance are operated and maintained in accordance with good air pollution practices that will minimize emissions at least to levels required by all applicable requirements; and

2. Provide reasonable assurance of compliance with emission limitations for the anticipated range of operations.

To support the justification the owner/operator may rely on:

1. Facility or corporate experience with monitoring control device or process operation performance;

2. Generally available sources of information (e.g., air pollution engineering manuals, EPA and permitting authority publications on monitoring, operation, and maintenance of pollution control devices); or

3. Regulatory precedents, such as the following:

a. Presumptively acceptable or required monitoring approaches established by the permitting authority to achieve compliance with the CAM rule for the particular pollutant-specific emissions unit;

b. Continuous emission, opacity, or predictive emission monitoring systems that satisfy applicable monitoring requirements and performance specifications as specified in the rule [64.3(d)];

c. Alternative monitoring methods allowed or approved pursuant to Part 75;

d. Monitoring included for standards exempt from CAM; and

e. Monitoring requirements established in other regulations for the same or similar type sources (e.g., a monitoring requirement in an NSPS).

Factors to consider in selecting the monitoring approach and indicator(s) of performance are discussed in Section 2.3.

2.2.3.2 Justification for Selected Indicator Range(s)

For CEMS and PEMS, the indicator range presumptively is the level of the standard. As a result, the justification provided with the CAM submittal may simply reference the most recent certification test for the monitor. Note that if a COMS is used as the monitoring approach for a particulate matter standard, justification should be provided for selection of the indicator (i.e., opacity) range and averaging time.

Parameter data collected during performance testing and other relevant information, such as engineering assessments, manufacturers' design criteria, and historical monitoring data are used to establish indicator ranges for other monitoring approaches. The selection of appropriate indicator ranges is further discussed in Section 2.3.2.

The justification for the selected indicator range(s) should include a summary (tabular or graphical format) of the data supporting the selected ranges, supplemented by engineering assessments or control device manufacturer's recommendations, if necessary. References for the appropriate compliance test report(s) also should be provided. If site-specific compliance data are not available, the documentation must include a test plan and schedule for obtaining such data. The test plan should identify the:

1. Pollutants to be measured and the compliance test methods to be used;
2. Number and duration of test runs to be conducted;
3. Proposed process operating conditions during the tests (e.g., percent of full load);

4. Proposed control device operating conditions and indicator ranges (e.g., venturi pressure drop, condenser temperature);

5. Process and control device parameters to be monitored during the test and reported; and

6. Whether indicator data will be collected over an extended time period and the process/control device data to be collected concurrently.

As an alternative to providing a compliance test plan, the owner/operator may propose other information as the basis for the indicator ranges proposed. However, in such cases, the documentation provided must demonstrate to the permitting authority's satisfaction that compliance testing is unnecessary to establish indicator ranges at levels that satisfy Part 64 criteria.

Other information that the owner/operator may consider in selecting operator ranges, in lieu of compliance test data, in order of preference includes:

1. Site-specific data from tests other than compliance tests;

2. Data from tests performed on similar units at the facility or similar facilities;

3. Empirical information concerning the assessment of control technology performance (e.g., empirical performance information from a scrubber control technology handbook);

4. Regulatory precedents involving appropriate monitoring of similar emissions units (e.g., NSPS requirement for same control technology at a similar source); and

5. Theoretical considerations based on generally accepted engineering practices (i.e., engineering judgement).

If the owner/operator bases the indicator ranges on any of the other types of available information listed above rather than on site-specific compliance test data, the documentation must include a concise explanation of the rationale for relying on information other than site-specific compliance data. The rationale must demonstrate that compliance testing is not necessary for the owner/operator to establish operating ranges so that excursions from the operating ranges can be addressed prior to potential emission exceedances. Factors to consider in the rationale for using information other than compliance test data include the ability to establish the appropriate operating ranges based upon engineering principles, and conservative assumptions with respect to the emissions variability and the margin of compliance associated with the emissions unit and control device.

2.3 SELECTION OF MONITORING APPROACH AND SELECTION OF INDICATOR RANGE

This section discusses the selection process for determining a monitoring approach that is acceptable for Part 64 and addresses selection of appropriate ranges for the indicators to be monitored.

2.3.1 Selection of Monitoring Approach

This section describes a selection process developed to assist facilities with selecting a monitoring approach. The basic concepts and principles used to design the State of Virginia CAM selection process were relied upon in designing this selection process.[1] The selection process itself is not a requirement of Part 64, rather it is a suggested strategy for identifying appropriate monitoring approaches. The purpose of the selection process is ultimately to arrive at the most cost-effective monitoring approach that is consistent with facility operations and provides sufficient data to indicate proper operation and maintenance of the control device such that there is a reasonable assurance of compliance with emission limitations or standards. The underlying concept of the selection process is to begin with the current monitoring practice used at a specific emissions unit within a facility, review this practice, and modify the practice when necessary to comply with the criteria established by Part 64. The selection process can be broken down into several steps as illustrated in Figure 2-3 and discussed in the following paragraphs. Figure 2-4, the Monitoring Approach Selection Process Worksheet, can be used to assist the facility with information gathering and decision making throughout the step-by-step selection process.

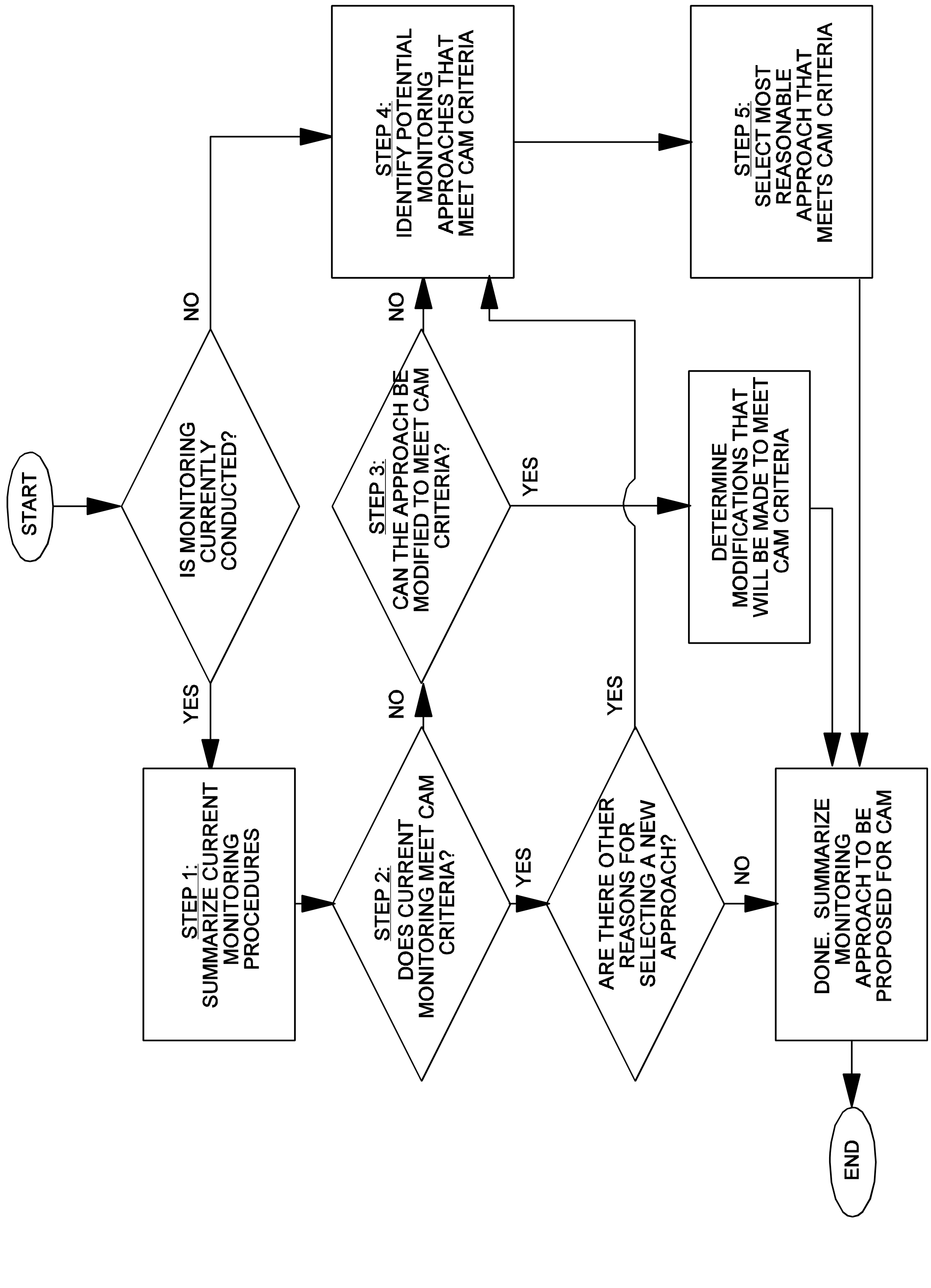

Figure 2-3. Monitoring approach selection process.

General Information

Facility Name: ____________________
Facility Location: ____________________
Date: ____________________
Emissions Unit: ____________________
Regulated Pollutant: ____________________

Applicable Requirements
Regulation and emission limit: ____________________
Monitoring requirement: ____________________

Step 1. Summarize Current Monitoring Procedures

Control Device: ____________________
Monitoring Method: ____________________
Indicator(s) tracked: ______ ______ ______
Frequency of measurements: ______ ______ ______
Rationale for indicators (check one or provide other rationale):
Required by rule ______ ______ ______
Direct measure of emissions ______ ______ ______
Indicator of emissions ______ ______ ______
Indicator of proper APCD performance, operation, and maintenance ______ ______ ______
Indicator of APCD inspection and maintenance ______ ______ ______
Recordkeeping procedures: ____________________
Reporting procedures: ____________________

Step 2. Evaluate Current Monitoring Procedures

Does design and performance of current procedures meet CAM criteria listed below? (CAM criteria are summarized in Table 2-1)

(Y/N)
Based on indicators and established indicator ranges ____
Data representativeness ____
Verification of operational status ____
QA/QC procedures ____
Frequency of monitoring ____
Special criteria for use of CEMS, PEMS, COMS ____

If yes (to all applicable), current monitoring procedures can be proposed as CAM. Complete "Proposed CAM Monitoring Approach" box (above right).
If no for any applicable criteria above, go to step 3.

Proposed CAM Monitoring Approach

Control Device: ____________________
Monitoring Method: ____________________
Indicator(s) tracked: ______ ______ ______
Frequency of measurements: ______ ______ ______
Rationale for indicators (check one or provide other rationale):
Required by rule ______ ______ ______
Direct measure of emissions ______ ______ ______
Indicator of emissions ______ ______ ______
Indicator of proper APCD performance, operation, and maintenance ______ ______ ______
Indicator of APCD inspection and maintenance ______ ______ ______
Recordkeeping procedures: ____________________
Reporting procedures: ____________________

Step 3. Evaluate Possible Modifications to Meet CAM Criteria

Can the current monitoring procedures be modified to meet CAM criteria? ____ (Y/N)
If no, go to step 4 (on page 2 of this form)
If yes, identify the modifications:
____
____

Does modified approach meet CAM criteria listed below: (Y/N)
Based on indicators and established indicator ranges ____
Data representativeness ____
Verification of operational status ____
QA/QC procedures ____
Frequency of monitoring ____
Special criteria for use of CEMS, PEMS, COMS ____

Describe the revised monitoring approach to be proposed for CAM in box above.

Figure 2-4. Monitoring approach selection process worksheet.

Step 4. Identify Potential Monitoring Approaches that Meet CAM Criteria (Example for thermal incinerator)

	Option 1	Option 2	Option 3
Monitoring approach:			
Indicator(s)	Combustion chamber T		
Frequency	Daily		
CAM criteria:			
Based on indicator(s) and range(s)	✓		
Data representativeness	✓		
Verification of operational status	✓		
QA/QC procedures	✓		
Frequency of Monitoring	✓		
Special criteria for use of CEMS, PEMS, COMS	✓		

Step 5. Evaluate Options Identified in Step 4 and Select Most Reasonable[a] (Example for thermal incinerator)

	Option 1	Pros (Rate 1 to 3)	Option 2	Pros (Rate 1 to 3)	Option 3
Pros (Rate 1 to 3)					
1. Combustion T already measured at the facility	3	1.		1.	
2. Frequency consistent with other measurements taken at facility	2	2.		2.	
3. Low costs	3	3.		3.	
4. Equipment needs are minimal	3	4.		4.	

	Option 1	Cons (Rate -1 to -3)	Option 2	Cons (Rate -1 to -3)	Option 3
Cons (Rate -1 to -3)					
1. The confidence level is low, once daily not good indicator of operation	-3	1.		1.	
2.		2.		2.	
3.		3.		3.	
4.		4.		4.	

[a]For identifying pros and cons consider:

Is the approach consistent with process monitoring procedures or other APCD procedures on-site?
Monitoring frequency: Is it adequate to detect changes in control device performance for which corrective action is appropriate. Is it consistent with other measurements taken at the facility?
Level of confidence: Is it acceptable?
Equipment needs: Are they reasonable? Is the type of equipment currently being used elsewhere within the plant? Are plant personnel familiar with the use of the necessary equipment? Considering these needs, is the approach still feasible?
Costs: Considering production and O&M benefits, are the costs reasonable?

Figure 2-4. (continued)

Step 1: Summarize the current monitoring procedures

If monitoring is currently conducted, the first step in the selection process is to summarize the current monitoring procedures. This summary should include information on the affected emissions unit, the control device used on that unit, the monitoring methods that are currently used (e.g., manual monitoring, emission calculation procedures, operating parameter monitoring, PEMS, CEMS), the indicators that are tracked, the reasons for selecting the indicators currently monitored, the frequency of measurements, and any reporting and recordkeeping procedures.

If no monitoring procedures are currently in place, the owner or operator of the facility may follow the process of identifying potential monitoring approaches and selecting the most appropriate as outlined in Steps 4 and 5 of the selection process.

Step 2: Evaluate the current monitoring procedures

For those facilities with monitoring procedures in place, the next step is to determine if the design and performance of the current monitoring procedures satisfy the criteria established by Part 64. Monitoring design criteria required by Part 64 are discussed in detail in Section 2.2.2 and summarized in Table 2-1 of that section. If the current monitoring procedures meet these minimum Part 64 criteria, those procedures may be proposed as the monitoring approach. However, in some cases even though the current procedures satisfy Part 64, the facility owner or operator may have other reasons for proposing a new monitoring approach. For example, a facility owner or operator who currently monitors combustion temperature to ensure proper operation of a thermal incinerator and has addressed all the Part 64 criteria listed in Table 2-1 satisfies Part 64. This facility owner or operator may choose to propose the current monitoring procedures (e.g., use of strip chart recorder) or may choose to select a different approach (e.g., electronic data recording with hourly averaging) for other reasons.

On the other hand, if the current monitoring procedures fail to address all of the Part 64 criteria (e.g., if QA/QC procedures are not addressed, or if the monitoring frequency and averaging time are not sufficient to detect a change in control device performance), those procedures do not satisfy Part 64. The owner or operator would then be required to determine if modifications can be made to meet Part 64 criteria (Step 3) or if an alternative monitoring approach is preferable (step 4).

The rule specifies that if a facility is currently using a CEMS, COMS, or PEMS to comply with an applicable requirement, this system must also be used to satisfy Part 64. Special criteria for the use of CEMS, COMS, and PEMS to satisfy Part 64 are discussed in Section 2.2.2.

Step 3. Determine if current monitoring procedures can be modified to meet Part 64 criteria

If the current monitoring procedures do not meet Part 64 minimum criteria, but the procedures can be modified to do so, the owner or operator has two options. The owner or operator can either modify the current monitoring approach to meet the minimum Part 64 criteria or implement an alternative approach that satisfies all Part 64 requirements (as outlined in step 4).

If a facility chooses to modify the current approach, the owner or operator determines the modifications that will be made to satisfy Part 64 and incorporates these modifications along with the current monitoring practices into the revised monitoring approach. For example, a calciner using a wet scrubber to comply with a PM limit has current monitoring procedures that consist of monitoring pressure drop and liquid flow rate. To satisfy Part 64, this facility would need to expand the current monitoring practices to address performance criteria such as data representativeness and QA/QC procedures associated with the monitoring approach.

If the current monitoring system cannot be modified to meet Part 64 criteria, the owner or operator must consider alternative approaches, as outlined in step 4. For example, a facility with a thermal incinerator may currently monitor whether the burner is operating (flame “on” indicator). This indicator is not considered to be an adequate indicator of control device performance and cannot be modified to meet Part 64. The facility owner or operator would need to monitor other parameters that are better indicators of control device performance, such as combustion chamber temperature with an appropriate monitoring frequency and averaging time. Similarly, a medical waste incinerator using a baghouse to control particulate emissions may currently monitor charge weight, hourly charge rate, and secondary combustion chamber temperature. To meet Part 64 requirements, the facility would need to monitor additional parameters that are indicators of control device performance, such as baghouse pressure drop and visible emissions.

Step 4. Identify potential indicators and/or combinations of indicators to meet Part 64 criteria

If a facility is not currently monitoring emissions or control device performance or if the current monitoring approach does not meet the Part 64 criteria and cannot be modified to meet the criteria, the owner or operator of the facility must select an alternative monitoring approach to comply with Part 64. Appendix B presents illustrations of some of the alternative monitoring approaches applicable to different combinations of control devices, pollutants, and sources. Appendix B does not provide an all inclusive list of monitoring techniques and is intended only as a guide to assist owners/operators with identifying alternative monitoring approaches. Other sources of information include monitoring requirements for same or similar sources specified in Federal, State, and/or local regulations, State guidance, in-house expertise, and manufacturers’ recommendations. In addition, Chapter 5 provides an annotated bibliography of monitoring reference materials.

Using these or other appropriate sources of information as guidance, the owner/operator of the facility identifies potential monitoring approaches. The approaches may include monitoring measured or predicted emissions (such as THC, opacity, or visible emissions); process and/or control device operating parameters that affect control device performance (such as production rate or thermal incinerator operating temperature); recorded findings of inspection and maintenance activities related to maintaining the performance of the control device; or a combination of these types of indicators.

Step 5: Select most reasonable approach that meets Part 64 criteria

Of the approaches identified, the owner/operator can select the most reasonable for the situation. Factors to be considered in making this determination are described below. Considering these factors and others that may be appropriate to each specific emissions unit, the owner or operator selects and proposes a monitoring approach.

As illustrated in the Monitoring Approach Selection Process Worksheet (Figure 2-2), to facilitate the selection process the facility could use a pro/con approach. The factors that are considered in making a determination can be classified as either a pro or con and assigned a rating. Factors that are considered a pro can be assigned a rating of 1 (a weak pro) to 3 (a strong pro). Similarly, factors that are considered a con can be assigned a rating of -1 (a weak con) to -3 (a strong con). The sum of the ratings for each option is a rough measure of reasonableness of the approach; the higher the value, the more reasonable the option. For all the options considered, this sum can be compared to help select the most reasonable option.

Frequency of monitoring. Monitoring frequency (including data collection and data averaging periods) should be designed to obtain data at intervals that are consistent with the time period over which a change in control device performance is likely to be observed. Data measurement frequency should be sufficient to allow calculation over averaging periods that are short enough to observe significant changes in control device performance, and to allow early detection of problems so that timely corrective action is possible. At the same time, averaging periods should not be so short that minor perturbations as a result of normal variations in a parameter are flagged as exceedances. Also, for manual measurements, the facility should consider the frequency of other measurements taken at the plant and try to minimize the number of times the operator must take readings, while still meeting the minimum frequency requirements.

Level of confidence. Level of confidence is a subjective measure of how appropriate the selected monitoring approach is with respect to ensuring that the control device is operating properly, and, as a result, there is a reasonable assurance that the emissions unit is in compliance with the applicable emission limit. For example, there are numerous options available for monitoring indicators of performance for a facility that uses a thermal incinerator for volatile organic compound (VOC) control. The indicators that could be monitored include visible emissions, burner flame on indicator, combustion chamber temperature, carbon monoxide (CO) emissions measured with a CEMS, and VOC emissions measured with a CEMS. As shown in Table 2-2, a level of confidence, although subjective, can be associated with each monitoring approach. If the level of confidence in an approach is low, the owner or operator may consider monitoring other parameters that may be better indicators of control device performance, increasing the frequency of measurements (if applicable), or selecting more than one indicator to be monitored.

Equipment needs. In selecting a monitoring approach, equipment needs also should be considered. In addition to investigating the costs of such equipment, the logistics of locating, installing, and maintaining the equipment, the familiarity of plant personnel with the use of the equipment, and the use of the equipment on other processes at the facility should also be considered. For example, a facility that uses a wet scrubber on a hot exhaust stream may propose to monitor water flow to the scrubber as an indicator of control device performance. Because a water flow meter provides a direct measure of the parameter, it is preferred. However, in some cases, measuring outlet temperature as an indicator of water flow to the scrubber may be adequate and may be easier to maintain. If the facility owner or operator is currently measuring temperatures for other processes at the plant, using a thermocouple to monitor temperature is more straight-forward than introducing a new piece of equipment that plant personnel may not be familiar with. Also, water flow meters are more susceptible to malfunctions and require more frequent inspections to ensure they are operating properly. However, if the facility owner or operator is currently using water flow meters, there is likely a program in place for regular inspection and maintenance of the equipment and the addition of one more flow meter would not be inconsistent with plant operations.

Costs. The purpose of the selection process is to arrive at a cost-effective monitoring option that meets Part 64 criteria. In evaluating the costs associated with the proposed monitoring approach, it is recommended that, in addition to determining the capital and operating costs associated with monitoring, the cost benefit of operating and maintaining the control equipment in good working condition be considered as well. The monitoring costs can then be compared to possible benefits associated with employing better monitoring practices or using diagnostic systems to monitor the operating condition of the control equipment.

TABLE 2-2. LEVEL OF CONFIDENCE

Control device: Thermal incinerator for VOC control

Indicator	Level of confidence
Daily VE for “haze”	Low
Auxiliary burner flame on	Low
Comb. chamber T, daily	Low
Comb. chamber T, once/shift	Low to moderate
Comb. chamber T, hourly	Moderate to high
Comb. chamber T, continuous (averaged hourly)	High
Comb. chamber T, continuous (averaged hourly); and CO CEMS	Very high
Comb. chamber T, continuous (averaged hourly); and VOC CEMS	Very high

1. Production benefits--Improved monitoring may be cost-effective. In many cases, improved monitoring provides better process knowledge, which results in increased product yield. For example, carbon adsorbers can be used to control solvent emissions and recover solvent for reuse in a specific process. Using analyzers to measure inlet and outlet solvent concentrations as a monitoring approach would benefit the solvent recovery process. To maintain high recovery, solvent recovery efficiency can be calculated continuously and corrective action can be taken when the efficiency falls below a certain level. The savings gained by improved solvent recovery may offset the cost of monitoring.

2. Operation and maintenance (O&M) benefits--Operating and maintaining the control device in top condition may result in long-term cost savings. This can be achieved through the implementation of regular inspections of equipment to ensure that it is operated and maintained properly. Diagnostic systems (e.g., bag leak detectors) provide the ability to monitor equipment condition in real time and to spot trends that predict problems or failures. This capability may reduce O&M costs and production losses by making timely maintenance possible and by avoiding costly production losses, unnecessary maintenance, and equipment failures.

2.3.2 <u>Selection of Indicator Range</u>

The Part 64 monitoring approach is designed to provide the owner or operator of an affected emissions unit with information about the performance of control measures. Indicator ranges are critical to the validity of this approach. The owner or operator establishes appropriate ranges for selected control device performance indicators such that operating within the established ranges will provide a reasonable assurance of compliance with applicable requirements. Monitoring the indicators allows the owner or operator to identify problems with the operation and/or maintenance of the control device. An excursion or exceedance of an indicator range signals a potential problem with the operation or maintenance of the control equipment and alerts the owner or operator of the need to determine whether corrective action is necessary to restore operations to normal conditions.

Parameter data collected during performance testing are key in establishing indicator ranges that represent good operating conditions. However, other relevant information, such as engineering assessments, manufacturers' design criteria, and historical monitoring data, also may be used. For example, engineering specifications for a venturi scrubber installed to control particulate matter from an affected emissions unit may include design operational ranges for liquid flow rate and pressure drop across the venturi. For this example, it is assumed that the scrubber design conditions are intended to achieve the desired emission reductions for uncontrolled emission rates that correspond to 120 percent of the affected unit's process design rate. The results of a performance test during which the scrubber is operated within these design conditions and the process is operated at conditions representative of high load (near 100 percent design rate) would be used to confirm that operating within the scrubber design conditions achieves the emission reduction desired and provides a reasonable assurance of compliance across the anticipated range of process conditions for ongoing operation.

In many cases, historical monitoring data, in addition to parameter data collected during compliances tests, are useful or even necessary for establishing indicator ranges. Typically, compliance tests are of short duration; three 1-hr test runs, for example. Use of only 3 hours of parameter data may not be sufficient to fully characterize parameter values during normal operation. Specifically, these data may be insufficient to identify normal short-term fluctuations in the indicator parameters. Furthermore, if the owner/operator desires to use statistics in establishing the indicator range, a larger body of data would be necessary. Historical monitoring data should be collected during periods of normal operation when the emissions unit and associated control device are properly operated and maintained. These data are referred to as the baseline data. The baseline data for establishing an indicator range should be collected over a sufficient period of normal operation such that normal perturbations and ranges can be identified. Providing a summary of 1 to 3 months of parameter data in addition to the parameter data obtained simultaneously with the compliance test methods is recommended, whether these data are used to establish the indicator range or not. If these data are not used to establish the indicator range, they will serve to verify that the range can be maintained over an extended time period.

The baseline data, results from performance tests, and other information are evaluated to establish appropriate indicator ranges. Several factors impact the choice of data evaluation procedures and analytical methods used to select appropriate indicator ranges. These factors include: (1) type of data collected (data that are conducive to numeric manipulation such as averaging vs. data that are not; e.g., continuous temperature or pressure drop measurements vs. equipment inspections); (2) frequency of measurements (continuously measured data vs. intermittently measured data; e.g., temperature measured at 1-minute intervals vs. temperature measured daily); (3) quantity of data that are available for analysis (e.g., temperature measurements recorded at 1-minute intervals during the compliance test [three, 3-hour runs] vs. 3 months of historical temperature measurements recorded at 1-minute intervals); and (4) variability among the data (e.g., small variability vs. significant variability). Considering these factors, and others that may be appropriate, the facility owner or operator determines an appropriate data evaluation procedure and establishes an indicator range.

The selected range must meet the following criteria: (1) the range should be selected such that parameter data from the most recent performance test, if available, fall within the range; (2) the range should be indicative of the normal operating range under good operation and maintenance practices; (3) the range should be sensitive enough such that changes in control device performance can be identified, yet not so sensitive that minor variations which are a part of normal operation are continually signaled as potential problems; and (4) the range and averaging period/data reduction technique should account for routine operating functions at the facility (e.g., flushing of WESP once per hour causes kV to drop below the normal operating range for up to 6 minutes per flush).

In addition to establishing indicator range(s), affected facilities may choose to propose threshold levels that trigger the requirement for a QIP. Part 64 provides that a QIP may be required if it is determined that the source owner or operator has failed to meet the obligation of properly operating and maintaining the source. For the purpose of determining when a QIP is needed, Part 64 provides that a threshold level may be set in the facility's permit, but does not require it. Where such a trigger is established, a level of 5 percent of the operating time is suggested as a potentially appropriate threshold.

Although establishing a threshold level is not required by Part 64, in many cases it may benefit the facility to propose a threshold level rather than to leave it to the permitting authority to make a determination of whether the facility is meeting the obligation to properly operate and/or maintain the source. The facility could evaluate historical data to determine how often the selected indicator range was exceeded during periods of normal operation. These data could be used to establish an appropriate threshold level that triggers the need for a QIP. For example, if historical monitoring data for a facility indicate that the indicator range was exceeded ten times in a 6-month period, the threshold could be established at no more than 10 excursions outside the indicator range during a 6-month reporting period. This threshold level is based on the number of excursions identified in a reporting period. As suggested by Part 64, threshold levels also could be established based on the duration of excursions as a percentage of operating time.

The selection of indicator ranges and threshold levels are inherently related. Source owners may select a broad indicator range thereby avoiding excursions. The selection of a broad range would result in a lower number of excursions encountered during the monitoring period over which data were collected. As a result, the threshold level selected based on the historical monitoring data would allow few excursions during a reporting period. On the other hand, if a tighter indicator range is selected, the number of excursions encountered during the monitoring period would be higher and a more lenient threshold level could be established (the threshold level would allow more excursions from the indicator range). An indicator range should be selected that is representative of normal operating conditions and that would allow the owner or operator to identify potential problems with control device and/or process operation in a timely manner. Consequently, it may benefit a facility to establish a tighter range that is more representative of normal operation such that changes in control device performance can be observed. At the same time, the facility could establish a threshold level that allows for excursions that are considered part of normal operation.

This section is divided into three subsections. Section 2.3.2.1 presents several factors that affect the choice of data evaluation procedures for selecting the indicator range; Section 2.3.2.2 presents various general data analysis approaches that could be used in determining an indicator range; and Section 2.3.2.3 presents a flow chart of a general decision process that might be useful to a facility when selecting indicator ranges. This section also presents two examples of the selection of indicator ranges. For each example, the procedures for evaluating the data, determining an appropriate data analysis approach, and selecting the specific indicator range are outlined.

2.3.2.1 Data Evaluation Factors to be Considered in Selecting an Indicator Range

2.3.2.1.1 Type of data. Most measurements are conducive to averaging and other data manipulations. As a result, the indicator range may be calculated as a numeric limit. Some methods for determining this numeric limit are discussed in Section 2.3.2.3; they include plotting the data and making a qualitative determination of an acceptable range, calculating an “x”th percentile, and using other simple statistical methods to determine an acceptable range.

Approaches to establishing an indicator range include: (1) a range never to be exceeded, (2) a range not to be exceeded over a certain averaging period, (3) a range not to be exceeded for periods greater than "x" amount of time, or (4) a range not to be exceeded for periods greater than "x" percent of the operating time.

Some measurements are not conducive to data manipulations that result in a numeric value. For example, the results of equipment inspections are either acceptable or are unacceptable. Similarly, in some cases a "visible" or "no visible" measurement of emissions is used. For these types of data, a "pass/fail" approach is most appropriate for determining when an exceedance has occurred. If the facility is not operating within the selected indicator range (e.g., if visible emissions are found during the routine VE test or if bag leaks are detected during the routine equipment inspection), the facility would be required to take corrective action to restore the emissions unit and control device to normal operating conditions.

2.3.2.1.2 Frequency of measurements. As discussed in Section 3.3.1, the frequency of indicator measurements (including data collection and averaging periods) should be adequate to identify changes in the performance of control equipment in a timely manner. The averaging period used in evaluating the data will directly impact the selection of an indicator range. In selecting an averaging period, the owner or operator should consider variability among the data that are a part of normal process and/or control device operation. An averaging period should be selected that is long enough to allow this normal variability among the data without identifying them as exceedances. At the same time, if the selected averaging period is too long, deviations from normal operation may not be identified in a timely manner to allow the owner or operator to take corrective action. The frequency of measurements should be sufficient to allow calculation over the selected averaging period and to account for variability among the data. For example, if a 3-hour average is selected, measurements can be taken at 1-hour, 15-minute, or 1-minute intervals and averaged over a 3-hour period. If the data are fairly consistent, three 1-hour measurements may be sufficient. However, if there is significant variability among the data, 1-minute or 15-minute measurement intervals may be more appropriate.

2.3.2.1.3 Amount of data. The amount of data available for manipulation has a significant impact on the methods used to analyze the data. Statistical analyses have little or no meaning when the data set is limited to a few data points. If the available data are not sufficient for statistical methods, the data could be plotted and a qualitative determination of an acceptable range can be made based on these plots. However, if the facility owner or operator has a reasonable amount of data, statistical analyses can be conducted to determine an appropriate indicator range. Some methods for analyzing data are presented in Section 2.4.2.2.

2.3.2.1.4 Variability among data. Variability among the data can range from little or no variability (very consistent data) to significant variability. The effect of variability among the data on selecting an appropriate averaging period and measurement frequency are discussed above in Section 2.3.2.1.2. The amount of variability among the data should also be considered in selecting an appropriate indicator action level or range. For data that are fairly consistent with little or no variability, selecting a narrow indicator range or an indicator level that is fairly close to the data may be appropriate. On the other hand, if there is significant variability among the data, a broader indicator range or an indicator level with a substantial "buffer" may be selected. For example, consider a vent condenser where outlet coolant temperature is monitored once every 2 hours. Over a 1 month period, the range of values observed is between 5° and 8°C, with all but two of the data points between 6° and 8°C. One option for selecting the indicator range would be to establish a value at the maximum value plus a "buffer" such that significant changes in operation are evident. The maximum value observed is 8°C. Because there is very little variability among the data, only a small "buffer" is necessary. The facility could set the maximum level at 9. If, for this same example, the range of values observed was larger and the data points were more evenly scattered within this range, a larger "buffer" could be used to account for the increased variability.

2.3.2.2 Approaches for Determining Indicator Range

Numerous approaches are available for analyzing the data and selecting an indicator range. Some of the more common approaches are identified in this section. These approaches are intended only as examples and are not all inclusive. Other approaches also are acceptable.

1. Plotting the data and making a qualitative determination of an acceptable range:
   a. mean value observed
   b. mean value ± a "buffer" (e.g., "x"% of the mean, a set value (±50°F))
   c. max/min value observed
   d. max/min value ± a "buffer" (e.g., "x"% of the max/min, a set value (±50°F))
2. Calculating the "x"th percentile:

A range is selected based upon a given percent of the observed data; e.g., the range encompassing the 10th to 90th percentiles of the observed data.

3. Conducting other simple statistical methods for cases where sufficient data are available for analysis:
   a. mean value ± standard deviation (or multiple standard deviations)
   b. confidence intervals (mean value $\pm t_{1-\alpha} \frac{s}{\sqrt{n}}$)

where:

$t_{1-\alpha}$ is the t-statistic and α is the decimal representation of the confidence level (e.g., for a 90 percent confidence level, $t_{0.1}$).

4. Specifying the process for determining the indicator range, instead of specifying an actual numerical range (e.g., basing the range on the most recent source test, as below):

a. mean value observed during the most recent performance test demonstrating compliance with the applicable emission limit
b. mean value observed during the most recent performance test demonstrating compliance with the applicable emission limit ± a "buffer" (e.g. for a thermal incinerator, "corrective action is triggered by a temperature more than 50°F below the average temperature during the most recent performance test demonstrating compliance with the emission limitation for VOC")
c. max/min value observed during the most recent performance test demonstrating compliance with the applicable emission limit
d. max/min value observed during the most recent performance test demonstrating compliance with the applicable emission limit ± a "buffer"

2.3.2.3 Selection Process Flow Chart and Examples

Figure 2-5 presents a flow chart of a typical decision process for selecting an indicator range. The first step is to determine whether the measurements are conducive to data manipulations. If not, a pass/fail approach, as discussed in Section 2.3.2.1.1, may be used. If the data can be manipulated numerically, the facility owner or operator should consider whether existing regulations establish data reduction techniques that could be used to evaluate the data. The facility owner or operator would also determine if the existing regulation establishes indicator ranges, if these ranges comply with Part 64 criteria, and if these ranges meet the facility's needs for establishing performance. In many cases, a regulation may establish or suggest data reduction techniques yet not include a range for the selected indicator. A facility owner or operator in this situation could use the suggested data reduction techniques to evaluate the data and determine a range. If the regulation includes an established indicator range, the facility owner or operator should determine if the required range meets Part 64 criteria. If so, this range may be proposed. In cases where the regulation does not establish either data reduction procedures or a range or in cases where the range established by the regulation does not meet Part 64 criteria, the facility owner or operator should consider the data analysis options discussed in Section 2.3.2.2 or other approaches believed to be appropriate, and select a range.

The following paragraphs present examples of approaches used to evaluate data and select appropriate indicator ranges. The examples address some of the factors that impact the selection of data reduction and data analysis procedures: data type, measurement frequency, amount of available data, and variability among the data. For each example, the procedures for evaluating the data, determining an appropriate data analysis approach, and selecting the specific indicator range are outlined. The examples are intended only to address the selection of an appropriate indicator range for individual operating parameters that are indicators of control device performance. These examples are not complete in terms of satisfying Part 64 requirements and are not intended to imply that single parameter monitoring meets Part 64 requirements. In many cases, monitoring a single parameter may not be sufficient to ensure proper operation of the control device.

Example 1: Baghouse pressure drop (limited data)

This example presents an approach used to evaluate available data and select an appropriate indicator range for a single parameter. The parameter data to be evaluated in this example are pressure drop measurements across the pulse-jet baghouse, an indicator of proper performance of the bag-cleaning cycle. For a more complete monitoring approach, other indicators of baghouse performance that could be monitored include periodic visible emissions observations and periodic inspections.

The bag cleaning cycle is designed to keep the differential pressure across the fabric filter between 3 and 4 inches of water column (in. w.c.). When the differential pressure reaches 4 in. w.c., one row is pulsed. If, after 15 seconds, the differential pressure is still above 3 in. w.c., a second row is pulsed. During the most recent performance test, the pressure drop was recorded at 15-minute intervals. Over 6 days, a total of 78 pressure drop readings were taken. Table 2-3 summarizes the daily minimum, maximum, and average readings. Figure 2-6 graphically presents the daily readings. Although the individual data can be averaged, either on an hourly or daily basis, because the pressure drop is expected to vary over a range during the normal operation of the baghouse and cleaning cycle, it makes more sense to track the pressure drop and assure it remains within the normal operating range rather than calculate an average value. Several options could be used for selecting the actual range including:

1. The minimum and maximum values observed;
2. The “x”th percentile of the observed values; or
3. The minimum and maximum values observed plus a set value.

The observed data set is limited; it includes only 6 days of operation. Consequently, the third option was selected--the observed range of values plus a set value as a “buffer.” The observed range comprised of the minimum and maximum values observed is 2.3 to 4.2 in. w.c. A set value of 0.5 in. w.c. was added to this range to yield a range of 1.8 to 4.7 in. w.c., and this range was rounded to the nearest 0.5 in. to yield the recommended indicator range of 2.0 to 4.5 in. w.c.

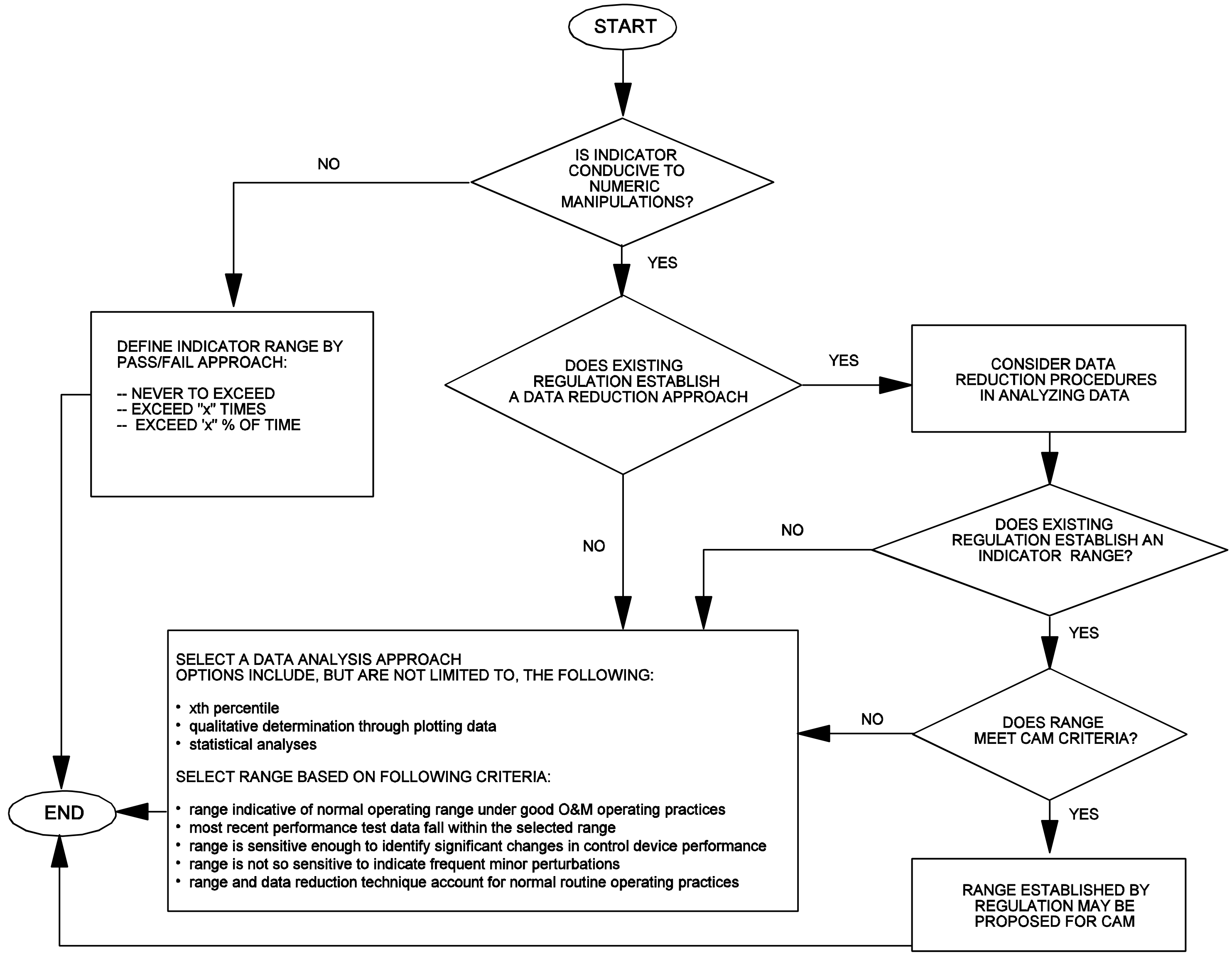

Figure 2-5. Indicator range selection process flow chart.

TABLE 2-3. BAGHOUSE PRESSURE DROP READINGS

Date	Test No.	Time	No. of readings	Daily minimum value, in. w.c.	Daily maximum value, in. w.c.	Daily average value, in w.c.
11/18	1	0918-1840	14	2.6	3.9	3.4
11/19	2	1550-2158	13	2.8	4.1	3.5
11/20	3	1230-2250	14	2.6	4.1	3.5
11/21	4	1230-1750	12	2.3	4.1	3.3
11/22	5	1045-1845	15	3.0	4.2	3.5
11/23	6	0930-1350	10	3.0	3.9	3.4
	Average			2.7	4.1	3.4

Number of values:	78
Range of all values:	2.3 -4.2
5th percentile:	2.7
10th percentile:	2.8
90th percentile:	3.9
95th percentile	4.1

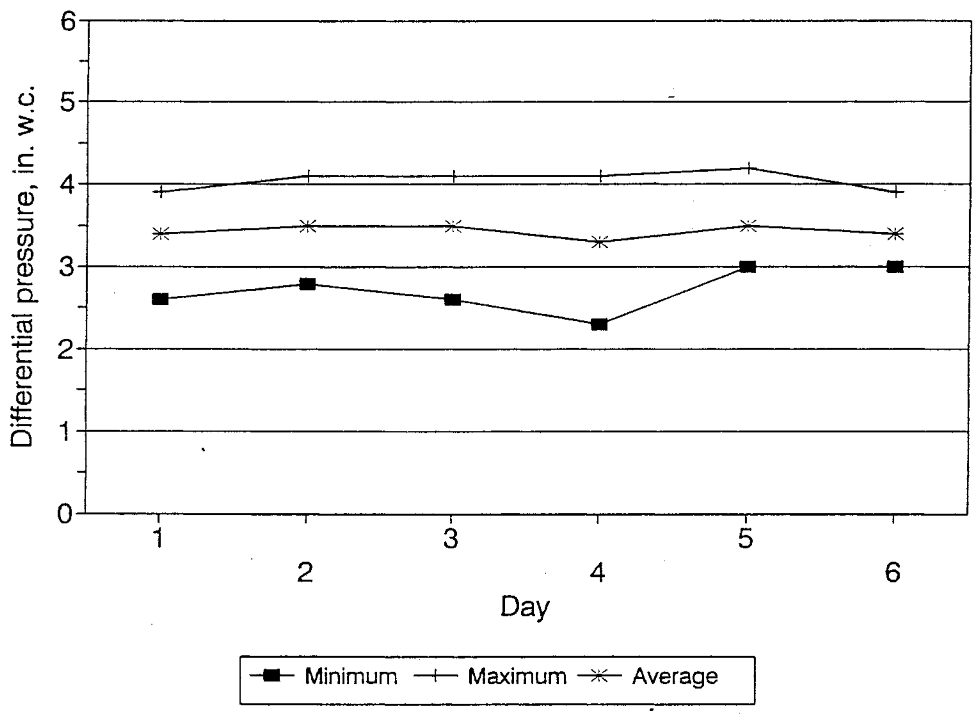

Figure 2-6. Baghouse differential pressure by day.

Simply using the minimum and maximum values observed was not done because of the very limited size of the data set. A larger data set for establishing indicator ranges is desirable. The use of the range comprised of the 5th to 95th percentile (2.7 to 4.1 in. w.c.) was examined, but this approach does not make sense. Ten percent of the observed data during the performance test when the baghouse was properly operating would fall outside the established range.

Example 2: Vent Condenser coolant temperature (extended operating data)

This example presents an approach used to evaluate available data and select appropriate indicator ranges for two parameters. The parameter data to be evaluated in this example are inlet and outlet coolant temperature measurements, which are indicators of condenser performance. Other indicators of condenser performance that could be monitored include outlet VOC concentration and outlet gas temperature.

The vent condenser uses brine solution as the cooling medium. Temperature limits specified in the operating permit allow a maximum inlet coolant temperature of 46°F (8°C) and a maximum outlet coolant temperature of 49°F (9°C). These maximum inlet and outlet coolant temperatures were estimated based on the outlet vent gas stream temperature that must be achieved to condense the pollutants. The outlet gas stream temperature was calculated using vapor pressure versus temperature data. Four months of historical monitoring data for the vent condenser are available. These data include monitoring of the inlet and outlet coolant temperature once every 2 hours. The facility permit requires monitoring once per day. A cursory review of the 4 months of data indicate that the temperature is very constant. Consequently, only 1 month's data were plotted and reviewed in detail. Figures 2-7 and 2-8 graphically present time series plots of the 2-hour readings for the brine supply and brine return temperatures, respectively.

Several options could be used for selecting the indicator range, including:

1. The maximum values observed for the temperatures;
2. The “x”th percentile of the observed values;
3. The values observed plus a set amount; or
4. A calculated design limit.

The indicator ranges were selected based on calculated design limits evaluated in conjunction with maximum values observed during the month. For the brine return temperature, the maximum observed value was 8ºC; the calculated value to achieve compliance is 9ºC. Consequently, the indicator range selected is ≤9ºC. For the brine inlet temperature, the calculated value to achieve compliance is 8ºC. The range of values observed was between 5° and 9.5ºC, with the majority of the values between 6° and 8ºC. During the month, only 3 values of the 326 recorded values exceeded 8ºC. Consequently, the indicator range selected is ≤8ºC, which is consistent with the calculated value to achieve compliance. A qualitative review of the data for the remaining 3 months that were not plotted indicates similar results would be obtained.

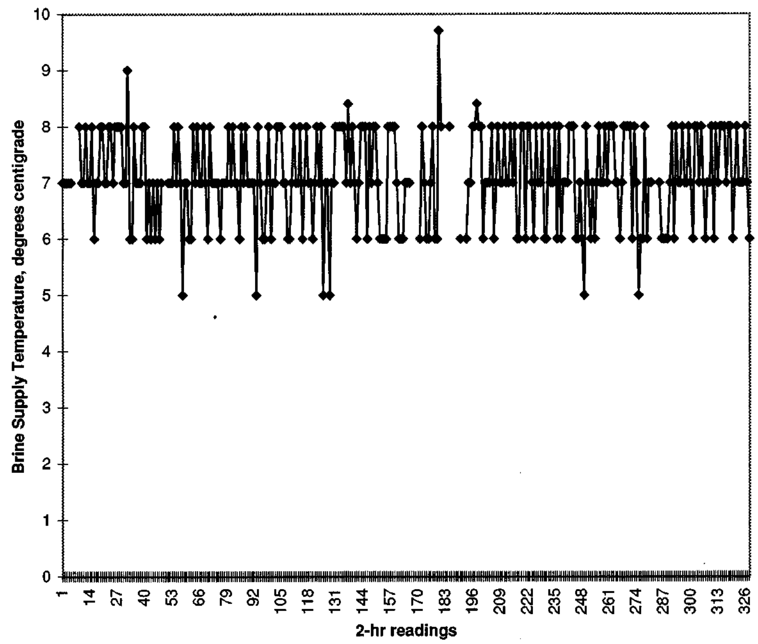

Figure 2-7. Recorded brine supply temperature for May.

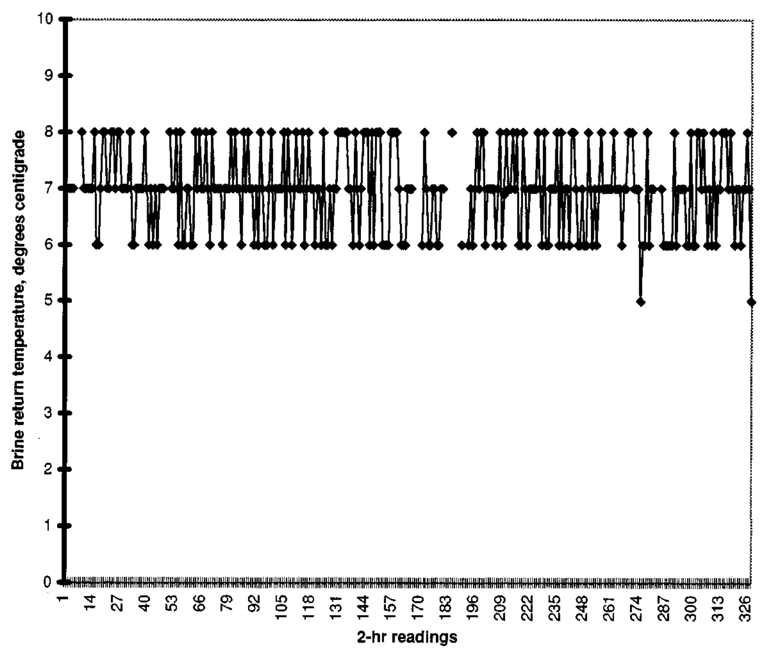

Figure 2-8. Recorded brine return temperature values for May.

2.4 QUALITY IMPROVEMENT PLANS (QIP's)

A QIP is a written plan that outlines the procedures that will be used to evaluate problems that affect the performance of control equipment. The permitting authority or the Administrator may require a source to develop and implement a QIP after a determination that the source has failed to use acceptable procedures in responding to an excursion or exceedance. Also, the rule provides, but does not require, that the Part 70 or 71 permit may specify an appropriate threshold level for requiring the implementation of a QIP. Where a threshold level is used, the rule recommends the level at which the total duration of excursions or exceedances at the affected emissions unit is greater than 5 percent of the unit's total operating time. The threshold level may be set at a higher or lower percent or may rely entirely on other criteria that indicate whether the emissions unit and control device are being operated and maintained properly. Once required, the written QIP must be maintained by the owner or operator, and must be available for inspection upon request.

The QIP is developed in two basic components. First, an initial QIP would include evaluation procedures to determine the cause of control device performance problems. Based on these findings, the QIP is then modified to include procedures to improve the quality of control performance. This second component would include the procedures that will be implemented to reduce the probability of a recurrence of the problem, and the schedule for making such improvements. Depending on the nature of the problem, the modified QIP could include procedures for conducting one or more of the following, as appropriate:

1. Improved preventative maintenance practices;
2. Process operation changes;
3. Appropriate improvements to control methods; and/or
4. Other steps appropriate to correct problems affecting control performance.

In conjunction with these procedures, the QIP also may include more frequent or improved monitoring procedures.

An example QIP has been developed as guidance. The example is for a baghouse used on a dry malt milling operation at a brewery. The example QIP includes a section titled "Background Information," which is not required by the rule but is included to provide additional information about the emissions unit, the control device, the monitoring procedures, and the excursions or exceedances that have triggered the need for a QIP. Sections II and III of the example QIP represent the two components of QIP's described above and required by the rule.

Example Quality Improvement Plan

I. Background Information

The affected emissions unit is the material handling system for the malt mills and ground malt storage hoppers at XYZ Brewery. The process stream exhaust is controlled by a pulse-jet baghouse operated under negative pressure. The baghouse is a single compartment unit containing 11 rows with 11 bags per row (121 bags total). The bag cleaning system is designed to keep the differential pressure across the fabric filter between 3 and 4 in. w. c. The facility currently monitors differential pressure on a daily basis and conducts daily visible emissions (VE) tests to satisfy CAM requirements.

The facility's Title V permit for this emissions unit specifies a threshold level for requiring the implementation of a QIP. This threshold is defined as the level at which the total duration of excursions (from the indicator ranges specified in the permit) is greater than 5 percent of the emission unit's total operating time during that reporting period. During this reporting period, the emissions unit/control device exceeded the 5 percent duration allowed for excursions from the indicator ranges. For 5 of the 90 operating days during the reporting period the baghouse pressure drop was above the high end of the 2.0 to 4.5 in. w.c. indicator range that was established by the facility for monitoring pursuant to the CAM rule.

II. Initial Investigation Procedures

The initial investigation will be conducted within ___ days of the last excursion that triggered the need for a QIP. The initial investigation will include:

1. Inspection of the baghouse discharge hopper/rotary valve system for blockage;
2. Inspection of the fan operation;
3. External inspection of the baghouse for signs of corrosion/air leakage;
4. Verification of pulse-jet cleaning system operation;
5. Hourly differential pressure readings until readings are within the established indicator range; and
6. Hourly VE inspections until the VE readings are withing the established indicator range.

Based on the results of this initial investigation, the QIP will be modified to include procedures for enhancing the current monitoring approach to avoid similar problems in the future. These procedures will be described in Section III.

III. Modifications to Enhance Current CAM Practices

Based on the results of the initial investigation it was found that ineffective cleaning of the filter bags resulted in excessively high pressure drop. The following preventative maintenance practices will be implemented to prevent similar problems with the cleaning system in the future:

1. Check all cleaning system components daily;
2. Monitor discharge hopper daily to ensure dust is removed as needed;
3. Check compressed-air lines weekly;
4. Check bag cleaning sequence weekly; and
5. Check high-wear parts on cleaning system annually and replace as necessary.

These practices will be implemented on _____ (insert date).

2.5 REFERENCES

1. Virginia State Advisory Board on Air Pollution, Sub-Committee Report on Compliance Assurance Monitoring (CAM), October 16, 1995.

3.0 CAM ILLUSTRATIONS

This chapter introduces illustrations of the types of monitoring that generally satisfy the requirements of the CAM rule. Sections 3.1 and 3.2 describe the purpose and format of the illustrations, Section 3.3 presents general information about the illustrations and their use. Section 3.4 discusses presumptively acceptable CAM. The illustrations of CAM are presented in Appendix B.

3.1 PURPOSE OF ILLUSTRATIONS

The purpose of the illustrations is to give examples of the types of monitoring (i.e., indicators or combinations of indicators) that may be used in conjunction with specific types of emission control methods to provide a reasonable assurance of compliance with emission limitations. Each illustration corresponds to a specific combination of pollutant, control method, and monitoring approach.

The combinations of pollutant and control device type have been designated as "categories" for organizational purposes. Table 3-1 provides a list of potential categories of CAM illustrations. The control devices listed are based on controls identified in the Aerometric Information Retrieval System (AIRS) data base; selected control devices and their AIRS identification codes are given in Table 3-2. For each illustration category or designation, the list includes examples of emissions units to which the illustration may apply. The table also indicates which illustrations have been drafted to date. This list of illustrations is not meant to be all-inclusive. Emission units with control technologies other than those listed in Table 3-1 may be subject to CAM, and monitoring approaches other than those addressed in these **nonprescriptive** illustrations may be acceptable for satisfying the requirements of Part 64. Facilities are encouraged to consider not only the monitoring approaches included in the CAM illustrations presented but other options that provide a reasonable assurance of compliance.

The CAM illustrations presented in Appendix B are not meant to be examples of monitoring approach submittals; CAM submittals are addressed in Chapter 2 and Appendix A of this document. A CAM submittal provides all the monitoring information that is required [§ 64.4] to be submitted to the permitting authority for a PSEU.

TABLE 3-1. POTENTIAL CAM ILLUSTRATIONS

Control	Pollutant	Emissions units	Category
Fabric filter	PM	Furnace, kiln, dryer, incinerator, material processing & handling, industrial process vents	1 (a,b,c,d,e) *
ESP	PM	Furnace, kiln, dryer, incinerator, material processing & handling	2 *
Wet ESP	PM	Insulation mfg.	3
Wet scrubber	PM	Furnace, kiln, dryer, incinerator, material processing & handling	4 (a)*
Wet scrubber	SO_2	Combustor	5*
Spray drying	SO_2	Combustors, furnaces, boilers	6 *
Wet scrubber	TRS	Smelt dissolving tank, furnace	7
Wet scrubber	Fluorides	Phosphate fertilizer manufacturing, primary aluminum processing	8
Absorber	VOC	Polymer mfg., distillation units, air oxidation units, misc. reactors	9
Afterburner	PM	Saturator, blowing still	10
Thermal incinerator	CO	FCCU catalyst regeneration, petroleum refining	11 (a,b) *
Oxidation control	SO_2	Sulfur recovery, sweetening units	12
Reduction and incineration	SO_2	Sulfur recovery, sweetening units	13
Combustion	TRS	Furnaces, combustors	14
Incinerator	TRS	Smelt dissolving tank, kraft pulp wall processes	15
Thermal incinerator	VOC	Coating, spraying, printing, polymer mfg., distillation units, wastewater treatment units, equipment leaks, air oxidation units, misc. SOCMI units	16(a,b,c)*
Catalytic combustor	PM	Wood heater	17
Catalytic oxidizer	VOC	Coating, spraying, printing, polymer mfg., distillation units, wastewater treatment units, equipment leaks, air oxidation units, misc. SOCMI units	18*
Flare	CO, VOC	EAF, coke oven batteries, misc. SOCMI units	19
Condenser	VOC	Coating, polymer mfg., distillation units, equipment leaks air oxidation units, misc. reactors, pharmaceuticals	21*
Gravel bed filter	PM	Kiln, cooler, dryer	22
Carbon adsorber	VOC	Coating, spraying, printing, polymer mfg., distillation units, wastewater treatment units, dry cleaning, degreasing, pharmaceuticals, leaks	23*
Cyclone	PM	Combustors, mineral processing, furnaces, kilns	24 (a,b)*
Gravity collector	PM	Combustors, mineral processing, furnaces, kilns	25 *
Flue gas desulfurization	SO_2	Boiler	26
Acid plant neutralization	SO_2	Furnace	27
Dual absorption system	SO_2	Sulfuric acid production	28
Dry sorbent injection	SO_2	Combustor	29
Water injection	NO_x	Turbines	30
Ext. column absorption	NO_x	Nitric acid production	31
Selective cat. reduction	NO_x	Nitric acid production	32(a,b)

*Indicates illustrations already drafted.

TABLE 3-2. SELECTED AIRS IDENTIFICATION CODES FOR CONTROL DEVICES

AIRS Code		Description of control method
001 002 003	Wet scrubber:	High efficiency Medium efficiency Low efficiency
004 005 006	Gravity collector:	High efficiency Medium efficiency Low efficiency
007 008 009	Centrifugal collector:	High efficiency Medium efficiency Low efficiency
010 011 012	Electrostatic Precipitator (ESP):	High efficiency Medium efficiency Low efficiency
013	Gas scrubber, general	
014 015	Mist eliminator:	High Velocity Low Velocity
016 017 018	Fabric filter:	High Temperature Medium Temperature Low Temperature
019 020	Catalytic:	Afterburner Heat Exchanger
021 022	Direct flame:	Afterburner Heat Exchanger
023	Flaring	
026	Flue gas recirculation	
028 032	Injection:	Steam or Water Ammonia
034 035 036 037 038	Scrubbing:	Wellman-Lord/Sodium Sulfate Magnesium Oxide Dual Alkali Citrate Process Ammonia
039	Catalytic oxidation-flue gas desulfurization	
040	Alkalized alumina vapor space tank	
041 042	Limestone injection:	Dry Wet
043 044	Sulfuric acid plant:	Contact Process Double Contact Process
045	Sulfur plant	
047	Vapor recovery system	
048	Activated carbon adsorption	
049	Liquid filtration system	

TABLE 3-2. (continued)

AIRS Code		Description of control method
050 051	Gas absorber column:	Packed Tray Type
052	Spray tower	
053 055	Scrubber:	Venturi Impingement plate
056 057	Dynamic separator:	Dry Wet
058 059 063 064	Filter - Mat or panel Metal fabric filter screen Filter:	 Gravel bed Annular ring
065	Catalytic reduction	
066	Molecular sieve	
067 068 069 070	Scrubbing:	Wet lime slurry Alkaline fly ash Sodium carbonate Sodium-alkali
071	Fluid bed dry scrubber	
072 073 074	Condenser:	Tube and shell Refrigerated Barometric
075 076 077	Cyclone: Single Multi without fly ash reinjection Multi with fly ash reinjection	
079	Dry electrostatic granular filter	
080	Chemical oxidation	
081	Chemical reduction	
082	Ozonation	
083	Chemical neutralization	
084	Activated clay adsorption	
085	Wet cyclonic separator	
086	Water curtain	
087	Nitrogen blanket	
098	Moving bed dry scrubber	
101	High Efficiency Particulate Air (HEPA) Filter	
107	Selective Noncatalytic Reduction (SNCR) for NO_x	

3.2 FORMAT OF ILLUSTRATIONS

Figure 3-1 presents the general format for CAM illustrations and provides a brief description of the elements that comprise an illustration.

1. APPLICABILITY

1.1 Control Technology
Type of control device (e.g., wet scrubber) or method to monitor (e.g., work practices). [The numbers listed in this section are the AIRS control device identification codes.]

1.2 Pollutants
Primary: The pollutant specified in the applicable requirement for the emissions unit (e.g., VOC).
Other: Other pollutants that may be controlled incidentally by the control device or method (e.g., organic HAP's)

1.3 Process/Emissions Unit
Some examples of types of emission units subject to the applicable requirement (e.g., boiler).

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored
The indicators of control method performance that are to be monitored to satisfy CAM. In many cases, only one indicator (e.g., pressure drop) may be monitored to assure compliance with the applicable requirement. In other cases, two or more indicators may be monitored.

2.2 Rationale for Monitoring Approach
Short justification for the adequacy of the monitoring approach for assuring compliance with the applicable requirement (e.g., scrubber efficiency increases with pressure drop).

2.3 Monitoring Location
Suggested locations for monitoring the indicator of control technology performance (e.g., across venturi throat).

2.4 Analytical Devices Required
Examples of the instruments, devices, or other relevant equipment that could be used to perform the type of monitoring addressed in the illustration (e.g., differential pressure gauges). Information on various types of parameter measurement equipment are presented in Chapter 4, Monitoring Equipment Technical Reference.

2.5 Data Acquisition and Measurement System Operation
For each parameter that is to be monitored, the frequency of monitoring, applicable units of measurement, and options for recording the monitoring data.

2.6 Data Requirements
Types and amounts of data and other information needed to establish the indicator ranges.

2.7 Specific QA/QC Procedures
Calibration, maintenance and operation of instrumentation that would be required to assure proper QA/QC for the given monitoring.

2.8 References
Numbered references to the bibliography provided at the end of the CAM illustrations section, listing those that were used for the illustration and would be useful for generating a CAM plan.

3. Comments

Additional explanation or comments on the illustration.

Figure 3-1. CAM illustration format.

3.3 ILLUSTRATIONS

The CAM illustrations completed to date are presented in Appendix B. Additional illustrations will be added to the Appendix as they become available. The illustrations are organized by control method, according to the order presented in Table 3-1.

Section 3.3.1 presents general comments that pertain to the illustrations.

3.3.1 General Information

3.3.1.1 Multiple Monitoring Approaches

For some categories of control device/pollutant combinations, multiple CAM illustrations have been presented; that is, multiple monitoring approaches have been identified. The monitoring approach for a PSEU should be evaluated on a case-by-case basis. Depending upon the PSEU, any of the multiple approaches presented (or other approaches not presented) might be appropriate. In other cases, because of the specific design and operating conditions of the PSEU, not all of the approaches presented would be applicable to, or sufficient for, the specific unit. For example, for a thermal incinerator used for VOC control on a process where capture efficiency is not a factor, an illustration that presents monitoring of the temperature of the combustion chamber as the only parameter monitored might be appropriate. On the other hand, if the capture efficiency of the VOC fume is a factor in the control system performance, a monitoring approach that also incorporates an indicator for monitoring capture efficiency (such as flow) would be appropriate.

Also, approaches presented separately in different illustrations can be combined to establish a complete monitoring approach. For example, for the fabric filter/PM category, periodic (daily) visible emission monitoring is presented as a separate illustration of a monitoring approach. This monitoring can be combined with other illustrations presented for baghouses, such as the continuous monitoring of baghouse pressure drop, (or other approaches not presented) to provide the overall monitoring approach selected for a PSEU for inclusion in a CAM submittal.

3.3.1.2 Frequency of Data Recording

For large pollutant specific emission units (i.e., PSEU's with the potential to emit, calculated including the effect of control devices, the applicable regulated air pollutant in an amount equal to or greater than 100 percent of the amount, in tons per year, required for a source to be classified as a major source), CAM requires the owner or operator to collect four or more data values equally spaced over each hour and average the values, as applicable, over the applicable averaging period, for each parameter monitored [§ 64.3(b)(4)(ii)].

Some of the illustrations presented in Appendix B may indicate a reduced data collection frequency. These monitoring approaches may not be acceptable for large units unless approved by the permitting authority or used in conjunction with the monitoring of other parameters for which the data collection frequency is at least four times per hour. However, the permitting authority may approve a reduced data collection frequency, if appropriate, based on information presented by the owner or operator concerning the data collection mechanisms available for a particular parameter for a particular pollutant-specific emissions unit (e.g., integrated raw material or fuel analysis data, noninstrumental measurement of waste feed rate or visible emissions, use of a portable analyzer or alarm sensor).

3.4 PRESUMPTIVELY ACCEPTABLE CAM

Monitoring identified by the Administrator as presumptively acceptable monitoring satisfies the requirements of the CAM Rule's Monitoring Design Criteria [§ 64.3]. These requirements include both general criteria [§ 64.3(a)] and performance criteria [§ 64.3(b)].

The general criteria set guidelines for:

(a) Designing an appropriate monitoring system; and

(b) Setting the appropriate parameter range(s).

The performance criteria require:

(a) Data representativeness;

(b) A method to confirm the operational status of the monitoring equipment (for new or modified monitoring equipment only);

(c) Quality assurance and quality control procedures; and

(d) Specifications for the monitoring frequency and data collection procedure.

The owner or operator may propose presumptively acceptable monitoring without additional permit content or justification, except that for new or modified monitoring systems the owner/operator must submit information on the method to be used to confirm operational status of the monitoring equipment.

The monitoring requirements for all NSPS and NESHAP in 40 CFR 60 and 40 CFR 61 were reviewed with respect to meeting each of the Part 64 criteria listed above, with the exception of the criterion for verifying operational status for new systems. Because this requirement applies only to new systems, it is not appropriate to include this criterion in the evaluation of presumptively acceptable monitoring. Instead the expectation is that an owner/operator proposing monitoring that involves a new system does need to provide information on the approach to be used for confirming operational status of a new system even for presumptively acceptable monitoring.

Table 3-3 lists the rules that incorporate presumptively acceptable monitoring. The monitoring approaches presented in the table are presumptively acceptable for the same type of emissions units for which the monitoring in the cited rules apply, with the caveat that all the elements of the monitoring approach presented in the rule are incorporated into the monitoring proposed by the source owner to satisfy CAM (e.g., setting of parameter ranges, frequency of measurement and data collection, averaging times, and quality assurance/control procedures and frequency).

Many of the rules that were reviewed have monitoring requirements that satisfy some or most of the criteria. An important criterion that is absent in all of the Part 60 and 61 rules is the establishment of monitoring requirements for capture efficiency, for rules in which capture efficiency is a factor in determining compliance with the regulation. Because establishing parameters for monitoring capture efficiency, if applicable, is an important criterion of CAM (see § 64.3), these regulations were not considered to be presumptively acceptable. Typically, the criterion that was not met for many of the other rules was the criterion for quality assurance and quality control procedures. Rules that simply stated: "calibrate according to manufacturer's recommendations" were not considered to satisfy the Part 64 QA/QC procedures requirement. As a minimum, the frequency of QA/QC procedures or calibrations should be specified.

Rules that are missing only one or two CAM performance criteria (e.g., acceptable calibration drift or calibration frequency) but are acceptable with respect to all other criteria have been identified as "Conditionally Presumptively Acceptable Rules" and are listed in Table 3-4. This means that information to address the criterion not included in the rule must be included with the CAM submittal. For new or modified monitoring equipment, verification procedures to confirm the operational status of the monitoring also must be included in the CAM submittal.

Rules that require flares to meet 40 CFR 60.18 (general control device requirements) have been determined to be presumptively acceptable for CAM. These rules do not specifically meet all of the Part 64 criteria (specifically, neither the rules nor Part 60.18 establish QA/QC practices or a frequency of calibration). Nonetheless, because the required monitoring is limited to the continuous monitoring of the presence of a pilot flame (yes/no) and because Part 60.18 stipulates design criteria for flares, the lack of specific QA/QC practices is not considered a deficiency for this control device/monitoring combination. If the sensor fails, the lack of a pilot flame will be indicated and corrective action will be required.

The use of CEMS that provide results in units of the standard for the pollutant of interest and meet the criteria presented in § 64.3.(d)(2) is presumptively acceptable CAM; specific regulations utilizing CEMS have not been listed in the table as a matter of convenience. Note, however, that rules using continuous VOC monitors have been included because (a) in many cases, the emission limit is not expressed as a concentration limit (the CEMS does not provide data in units of the standard), so consideration must be given to whether CAM monitoring design criteria (e.g., establishing an indicator range and averaging time) are addressed; and (b) some rules require parameter monitoring <u>or</u> continuous VOC emissions monitoring.

TABLE 3-3. PRESUMPTIVELY ACCEPTABLE MONITORING[a]

Subpart	Source category	Emissions unit	Control device	Pollutant	Required monitoring
NSPS (40 CFR 60)					
VV	Equipment leaks of VOC in the SOCMI	Equipment leaks captured by closed vent system	Flare	VOC	Continuous presence of pilot flame
DDD	VOC emissions from polymer industry	Process vents	Flare	VOC	Continuous presence of pilot flame
GGG	Equipment leaks of VOC in petroleum refineries	Equipment leaks captured by closed vent system	Flare	VOC	Continuous presence of pilot flame
III	SOCMI air oxidation unit processes with VOC emissions	Reactors and recovery systems	Flare	VOC	Continuous presence of pilot flame
KKK	Equipment leaks of VOC from onshore natural gas processing	Equipment leaks captured by closed vent system	Flare	VOC	Continuous presence of pilot flame
NNN	VOC emissions from SOCMI distillation operations	Distillation units	Flare	VOC	Continuous presence of pilot flame, and indicator of diversion of gas flow from flare
QQQ	VOC emissions from petroleum refinery wastewater systems	Wastewater systems	Flare	VOC	Continuous presence of pilot flame
RRR	VOC emissions from SOCMI reactor processes	Reactor processes	Flare	VOC	Continuous presence of pilot flame, and indicator of diversion of gas flow from flare
NESHAP (40 CFR 61)					
F	Vinyl chloride	Ethylene dichloride, vinyl chloride, and polyvinyl chloride plants	Flare on relief valve	VOC	Continuous presence of pilot flame
J	Equipment leaks of benzene	Equipment leaks captured by closed vent system	Flare	Benzene	Continuous presence of pilot flame
V	Equipment leaks	Equipment leaks captured by closed vent system	Flare	VHAP	Continuous presence of pilot flame
Y	Benzene from benzene storage vessels	Benzene storage vessels with closed vent system	Flare	Benzene	Continuous presence of pilot flame
BB	Benzene emissions from benzene transfer operations	Tank truck, rail, and marine vessel loading racks	Flare	Benzene	Continuous presence of pilot flame
FF	Benzene waste operations	Chemical manufacturing plants, coke by-product plants, and petroleum refineries	Flare	Benzene	Continuous presence of pilot flame

[a]Monitoring is presumptively acceptable only if it complies with all monitoring provisions stipulated in the subpart.

TABLE 3-4. CONDITIONALLY PRESUMPTIVELY ACCEPTABLE RULES

Subpart	Source category	Emissions unit	Pollutant	Control	Required monitoring	Additional conditions to be met (must be specified in CAM submittal)
NSPS (40 CFR 60)						
DDD	VOC emissions from polymer industry	Polymer manufacturing processes	VOC	Thermal incinerator	Temperature (continuous)	Specify device calibration frequency
				Catalytic incinerator	Temperature differential across catalyst bed (continuous)	Specify device calibration frequency
				Boiler/ process heater[a]	Temperature (continuous)	Specify device calibration frequency
				Carbon adsorber	Outlet organics concentration (continuous)	If monitor does not meet PS 8 or PS 9, specify device calibration frequency and accuracy
				Absorber	• Outlet organics concentration (continuous), or • Temperature (continuous), and • Liquid specific gravity (continuous)	If outlet organics concentration monitored, If monitor does not meet PS 8 or PS 9, specify device calibration frequency and accuracy If temperature and specific gravity monitored, Specify device calibration frequency
				Condenser	• Outlet organics concentration (continuous), or • Temperature (continuous)	If outlet organics concentration monitored, If monitor does not meet PS 8 or PS 9, specify device calibration frequency and accuracy If temperature monitored, Specify device calibration frequency
				All	Bypass: Flow indicator downstream of each valve that would allow bypass (15 min.) and/or check bypass valves/car seals monthly.	None

TABLE 3-4. (continued)

Subpart	Source category	Emissions unit	Pollutant	Control	Required monitoring	Additional conditions to be met (must be specified in CAM submittal)
III	SOCMI air oxidation unit processes VOC emissions	Reactors and recovery systems	VOC	Thermal incinerator	• Temperature continuous) • Bypass: hourly indication of flow	Specify device calibration frequency
				Catalytic incinerator	• Temperature differential across catalyst bed (continuous) • Bypass: hourly indication of flow	Specify device calibration frequency
				Boiler/ process heater[a]	• Temperature (continuous) • Bypass: hourly indication of flow	Specify device calibration frequency
				Carbon adsorber	Outlet organics concentration (continuous)	If monitor does not meet PS 8 or PS 9, specify device calibration frequency and accuracy
				Absorber	• Outlet organics concentration (continuous), or • Temperature (continuous), and • Liquid specific gravity (continuous)	If outlet organics concentration monitored, If monitor does not meet PS 8 or PS 9, specify device calibration frequency and accuracy If temperature and specific gravity monitored, Specify device calibration frequency
				Condenser	• Outlet organics concentration (continuous), or • Temperature (continuous)	If outlet organics concentration monitored, If monitor does not meet PS 8 or PS 9, specify device calibration frequency and accuracy If temperature monitored, Specify device calibration frequency

TABLE 3-4. (continued)

Subpart	Source category	Emissions unit	Pollutant	Control	Required monitoring	Additional conditions to be met (must be specified in CAM submittal)
LLL	On-shore natural gas processing: SO_2 emissions	Sweetening units	SO_2	Incinerator with oxidation or reduction system	• Outlet temperature (continuous • SO_2 concentration	Specify data collection procedures
NNN	VOC emissions for SOCMI distillation operations	Distillation units	VOC	Thermal incinerator	• Temperature (continuous) • Bypass: hourly indication of flow	Specify device calibration frequency
				Catalytic incinerator	• Temperature differential across catalyst bed (continuous) • Bypass: hourly indication of flow	Specify device calibration frequency
				Boiler/ process heater[a]	• Temperature (continuous) • Bypass: hourly indication of flow	Specify device calibration frequency
				Carbon adsorber	Outlet organics concentration (continuous)	If monitor does not meet PS 8 or PS 9, specify device calibration frequency and accuracy
				Absorber	• Outlet organics concentration (continuous), or • Temperature (continuous), and • Liquid specific gravity (continuous)	<u>If outlet organics concentration monitored</u>, If monitor does not meet PS 8 or PS 9, specify device calibration frequency and accuracy <u>If temperature and specific gravity monitored</u>, Specify device calibration frequency
				Condenser	• Outlet organics concentration (continuous), or • Temperature (continuous)	<u>If outlet organics concentration monitored</u>, CEMS must meet PS 8 requirements <u>If temperature monitored</u>, Specify device calibration frequency

TABLE 3-4. (continued)

Subpart	Source category	Emissions unit	Pollutant	Control	Required monitoring	Additional conditions to be met (must be specified in CAM submittal)
PPP	Wool Fiberglass Insulation Manufacturing Plants	Rotary spin wool fiberglass manufacturing lines	PM	WESP	• Primary and secondary current and voltage (4h), • Inlet water flow rate (4h), and • Total solids content of inlet water (daily)	• Increase monitoring frequency for large units • Data representativeness criteria (i.e., measurement location) • Data averaging period, if applicable
QQQ	VOC emissions from petroleum refinery wastewater systems	Oil-water separator tanks for >16 L/sec, drain systems	VOC	Thermal incinerator	Temperature (continuous)	Specify device calibration frequency
				Catalytic incinerator	Temperature differential across catalyst bed (continuous)	Specify device calibration frequency
				Carbon adsorber	Outlet organics concentration (continuous)	If monitor does not meet PS 8 or PS 9, specify device calibration frequency and accuracy
				All	Bypass: Flow indicator on vent stream to control device to ensure vapors are being routed to device.	None
RRR	VOC emissions from SOCMI reactor processes	Reactors	VOC	Thermal incinerator	• Temperature (continuous) • Bypass: hourly indication of flow	Specify device calibration frequency
				Catalytic incinerator	• Temperature across catalyst bed (continuous) • Bypass: hourly indication of flow	Specify device calibration frequency
				Boiler/process heater[a]	• Temperature (continuous) • Bypass: hourly indication of flow	Specify device calibration frequency
				Carbon adsorber	• Outlet organics concentration (continuous)	If monitor does not meet PS 8, specify device calibration frequency and accuracy
				Adsorber	• Outlet organics concentration (continuous), or • Temperature (continuous), and • Liquid specific gravity (continuous)	If outlet organics concentration monitored, If monitor does not meet PS 8, specify device calibration frequency and accuracy If temperature and specific gravity monitored, Specify device calibration frequency
				Condenser	• Outlet organics concentration (continuous), or • Temperature (continuous), and • Liquid specific gravity (continuous)	If outlet organics concentration monitored, If monitor does not meet PS 8, specify device calibration frequency and accuracy If temperature and specific gravity monitored, Specify device calibration frequency
NESHAP (40 CFR 61)						

TABLE 3-4. (continued)

Subpart	Source category	Emissions unit	Pollutant	Control	Required monitoring	Additional conditions to be met (must be specified in CAM submittal)
L	Benzene from coke by-product recovery plants	Process vessels, storage tanks, tar intercepting sumps	Benzene	Thermal incinerator	• Temperature (continuous) • Bypass: Inlet gas flow indicator (hourly) or outlet gas flow indicator (15 min.) or monthly check of locked bypass valves (e.g., car seal)	Specify device calibration frequency
				Catalytic incinerator	• Temperature differential across catalyst bed (continuous) • Bypass: Inlet gas flow indicator (hourly) or outlet gas flow indicator (15 min.) or monthly check of locked bypass valves (e.g., car seal)	Specify device calibration frequency
				Regenerative carbon adsorber	Benzene or organics concentration (continuous)	If monitor does not meet PS 8 or PS 9, specify device calibration frequency and accuracy
BB	Benzene emissions from benzene transfer operations	Tank truck, rail, and marine vessel loading racks	Benzene	Thermal incinerator	Temperature (continuous)	Specify device calibration frequency
				Catalytic incinerator	Temperature differential across catalyst bed (continuous)	Specify device calibration frequency
				Boiler/ process heater[a]	Temperature (continuous)	Specify device calibration frequency
				Carbon adsorber	Outlet organics concentration (continuous)	If monitor does not meet PS 8 or PS 9, specify device calibration frequency and accuracy
				All	Bypass: Flow indicator downstream of each valve that would allow bypass (15 min.) and/or check bypass valves/car seals monthly.	None

TABLE 3-4. (continued)

Subpart	Source category	Emissions unit	Pollutant	Control	Required monitoring	Additional conditions to be met (must be specified in CAM submittal)
FF	Benzene waste operations	Chemical manufacturing plants, coke by-product plants, & petroleum refineries	Benzene	Thermal incinerator	Temperature (continuous)	Specify device calibration frequency
				Catalytic incinerator	Temperature differential across catalyst bed (continuous)	Specify device calibration frequency
				Boiler/ process heater[a]	Temperature (continuous)	Specify device calibration frequency
				Carbon adsorber	Outlet organics or benzene concentration (continuous)	If monitor does not meet PS 8 or PS 9, specify device calibration frequency and accuracy
				Condenser	• Outlet organics or benzene concentration (continuous), or • Outlet temperature (continuous) and • Coolant exit temperature (continuous)	<u>If outlet organics concentration monitored</u>, If monitor does not meet PS 8 or PS 9, specify device calibration frequency and accuracy <u>If temperatures monitored</u>, Specify device calibration frequency Specify device accuracy
				All	Bypass: Flow indicator every 15 min. or locked bypass valves (e.g., car seal).	None

[a]Note that temperature monitoring is only required for boilers or process heaters with a design heat capacity of <150 million Btu/hr (44 MW).

4.0 TECHNICAL REFERENCE FOR MONITORING EQUIPMENT AND INSTRUMENTS

4.1 INTRODUCTION

The objective of this section is to provide reference materials for various types of sensors commonly used to measure process and/or air pollution control equipment operating parameters. The owner or operator of a facility may use this chapter as guidance in developing a QA/QC program. This section is in no way intended to specify prescriptive QA/QC procedures that must be used. Instead, the focus of this section is on (1) identifying the types of sensors commonly used to monitor a given parameter, and (2) identifying basic calibration techniques that may be used in the development of an integrated QA/QC program for assuring continued accurate performance over time.

This section describes the various types of sensors, the measurement principle(s), other system components used with the sensor to perform measurements, and basic calibration techniques for the following measurement systems:

4.2 Temperature
4.3 Pressure
4.4 Flow rate
4.5 pH and conductivity
4.6 Electrical [Reserved]
4.7 Level indicators [Reserved]
4.8 Motion and rotation [Reserved]

For each type of measurement system, the following information is presented:

- Description of sensor, measurement principle, and measurement system components;
- Expected accuracy and precision ranges;
- Calibration techniques;
- QA/QC procedures; and
- Additional resources and references.

For each sensor system, descriptions of some of the different types of systems used are presented, including the operating principles and identification of individual components requiring QA/QC procedures. Operating and maintenance procedures and common problems, as well as calibration techniques and procedures and expected accuracy and precision ranges, are included. Much of this information is drawn from manufacturers' data. References are provided at the end of each subsection.

In describing the characteristics and operation of many of the devices covered by this chapter, some general terms are used. Because these terms are used throughout the chapter, the definitions of the more important terms are provided below.

Accuracy: The closeness of an indicator or reading of a measurement device to the actual value of the quantity being measured; usually expressed as ± percent of the full scale output or reading.

Drift: The change in output or set point value over long periods of time due to such factors as temperature, voltage, and time.

Hysteresis: The difference in output after a full cycle in which the input value approaches the reference point (conditions) with increasing, then decreasing values or vice versa; it is measured by decreasing the input to one extreme (minimum or maximum value), then to the other extreme, then returning the input to the reference (starting) value.

Linearity: How closely the output of a sensor approximates a straight line when the applied input is linear.

Noise: An unwanted electrical interference on signal wires.

Nonlinearity: The difference between the actual deflection curve of a unit and a straight line drawn between the upper and lower range terminal values of the deflection, expressed as a percentage of full range deflection.

Precision: The degree of agreement between a number of independent observations of the same physical quantity obtained under the same conditions.

Repeatability: The ability of a sensor to reproduce output readings when the same input value is applied to it consecutively under the same conditions.

Resolution: The smallest detectable increment of measurement.

Sensitivity: The minimum change in input signal to which an instrument can respond.

Stability: The ability of an instrument to provide consistent output over an extended period during which a constant input is applied.

Zero balance: The ability of the transducer to output a value of zero at the electronic null point.

Calibration is the process of adjusting an instrument, or compiling a deviation chart for a probe, so that its readings can be correlated to the actual value being measured. Generally, inaccuracies within a monitoring system are cumulative; therefore, the entire system should be calibrated when possible. Many monitoring applications may rely more on repeatability than on accuracy. In such cases, documentation takes on added significance when detecting system drift.

While manual methods may be sufficient for CAM in some instances (e.g., visible emissions monitoring), electronic measurement of parameters such as temperature, pressure and flow provides the opportunity to incorporate that monitoring into other systems, such as process control. Although not discussed here, centralized control strategies, hierarchical plant-wide networks of programmable logic controllers (PLC's), single loop controllers, and PC's are now in use for monitoring process parameters. Many proprietary distributed control systems have been successfully implemented. Future control systems will include peer-to-peer networks of interconnected field devices that improve the reliability of sensor-actuator systems. Fuzzy logic-based software can be used to improve control systems efficiency. Incorporation of improved system controls can make industrial processes run more smoothly, thus making emissions control and monitoring easier.

4.2 TEMPERATURE MEASUREMENT SYSTEMS

4.2.1 Introduction

Temperature measurement can be accomplished using several types of sensing mechanisms. Temperature measurement systems generally consist of a sensor, a transmitter, an external power supply (for some types of systems), and the wiring that connects these components. The temperature measurement sensors most commonly used in engineering applications are thermocouples, resistance temperature detectors (RTD's), and infrared (IR) thermometers; these devices are described in detail in the following paragraphs. Integrated circuit (IC) temperature transducers and thermistors also are commonly used but have more limitations than thermocouples, RTD's, and IR thermometers. Table 4.2-1 lists some of the advantages and disadvantages of these types of temperature measuring devices.

TABLE 4.2-1 TEMPERATURE MONITORING SYSTEM CHARACTERISTICS[1-3]

Thermocouple	RTD	IR thermometer	IC sensor	Thermistor
Advantages				
• Self-powered • Simple • Rugged • Inexpensive • Many applications • Wide temperature range • Fast response	• More stable at moderate temperatures • High levels of accuracy • Relatively linear output signal	• Fast response • Non-contact • $T < 3000^\circ C$ • Less sensitive to vibration • Less sensitive to interference	• Relatively linear • High output • Inexpensive	• High output • Fast • Two-wire ohms measurement
Disadvantages				
• Nonlinear output signal • Low voltage • Reference required • Accuracy is function of two separate measurements • Least sensitive • Sensor cannot be recalibrated • Least stable	• Expensive • Self-heating • Lower temperature range	• Expensive • Must be protected • Affected by emissivity of target	• $T < 200^\circ C$ • Slower response • Self-heating	• Nonlinear • Limited temperature range • Fragile • Current source required • Self-heating

Other types of temperature sensors include bimetallic devices, fluid expansion devices, and change-of-state devices. Bimetallic temperature sensors relate temperature to the difference in thermal expansion between two bonded strips of different metals. Fluid expansion devices, such as the common thermometer, measure temperature as a function of the thermal expansion of mercury or organic liquid, such as alcohol. Change-of-state temperature sensors change appearance when a specific temperature is reached. One major drawback of these types of sensors is that they do not readily lend themselves to automatically recording temperatures on a continuous or periodic basis.

The following paragraphs describe temperature measurement systems that are based on three types of temperature sensors: Section 4.2.2 describes thermocouples, Section 4.2.3 describes RTD's, and IR thermometers are described in Section 4.2.4. For each type of system, the system components, operation, accuracy, calibration, and QA/QC procedures are discussed. References are listed in Section 4.2.5.

4.2.2 Thermocouples[1,2]

Due to their simplicity, reliability, and relatively low cost, thermocouples are widely used. They are self-powered, eliminating the need for a separate power supply to the sensor. Thermocouples are fairly durable when they are appropriately chosen for a given application. Thermocouples also can be used in high-temperature applications, such as incinerators.

4.2.2.1 Measurement Principle and Description of Sensor

A thermocouple is a type of temperature transducer that operates on the principle that dissimilar conductive materials generate current when joined (the Seebeck effect). Such a device is made by joining two wires made of different metals (or alloys) together at one end, generating a voltage e_{AB} when heated, as shown schematically in Figure 4.2-1.

The generated voltage is proportional to the difference between the temperatures of the measured point and an experimentally determined reference point (block temperature) and is also dependent on the materials used. A basic temperature monitoring system using a thermocouple is made up of the thermocouple, connectors, extension wires, isothermal block (also called temperature blocks, terminal blocks, or zone boxes), and a voltmeter or transmitter, as shown schematically in Figure 4.2-2.

This schematic is for a type J iron (Fe)-constantin (Cu-Ni) thermocouple. As the thermocouple junction point (J_1) is heated or cooled, the resulting voltage can be measured using a potentiometer or digital voltmeter (DVM), which is calibrated to read in degrees of temperature. In practice, a programmed indicator or a combination indicator/controller is used to

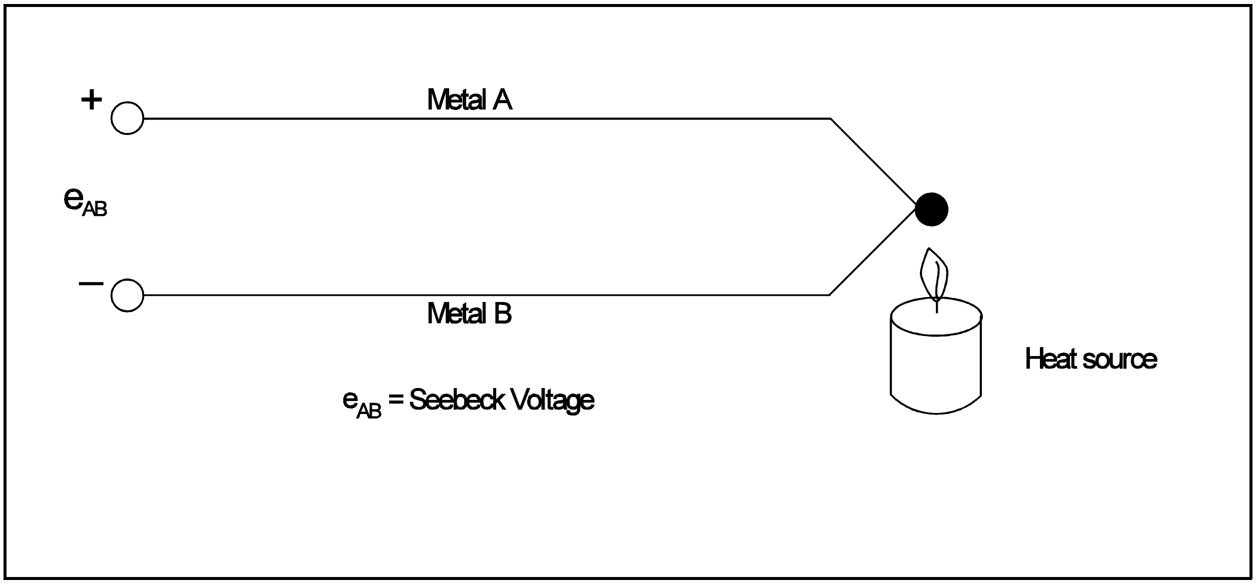

Figure 4.2-1. The Seebeck effect.[1]

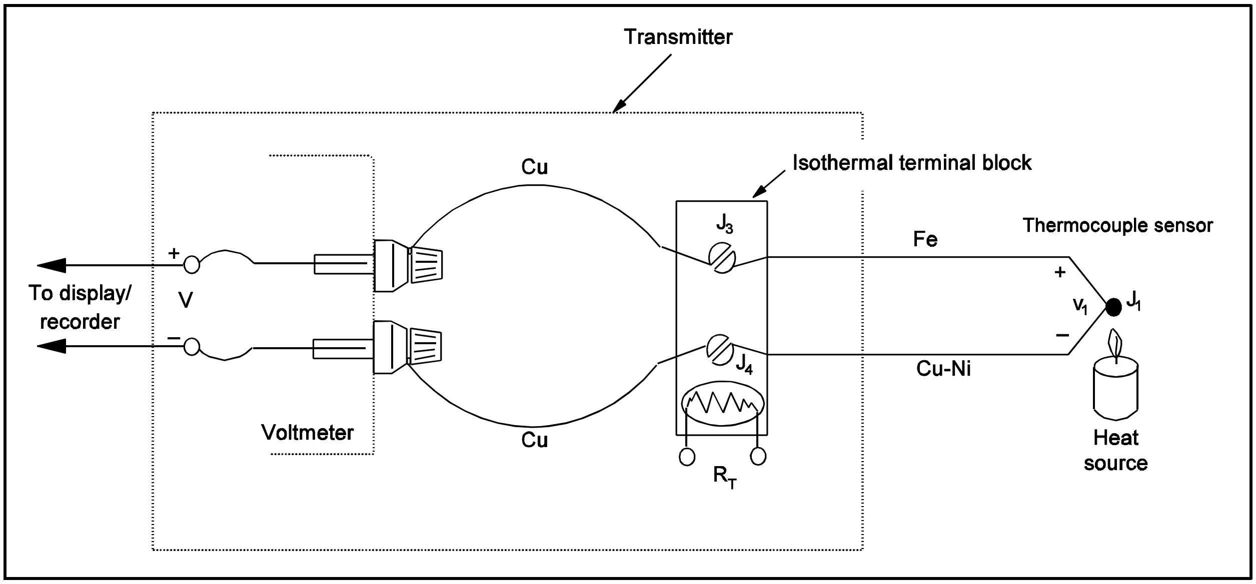

Figure 4.2-2. Temperature measurement using a thermocouple.[1]

convert the signal from voltage to temperature using the appropriate equation for the particular thermocouple materials and compensation for voltage generated at terminal connection points (J_3 and J_4). The temperature of the isothermal terminal block or zone box is measured using a proportional resistance device (R_T) such as an IC detector. That temperature is used as the reference temperature, T_{ref}, for determining the temperature being monitored at the thermocouple junction, J_1.

The voltmeter, terminal block, and associated circuitry generally are incorporated into the system transmitter. The terminal block may be located in the transmitter adjacent to the process being monitored or it may be located remotely with the controller or recorder. In the latter case, one terminal block can be used for several thermocouples simultaneously.

Figure 4.2-3 depicts a typical thermocouple assembly. In the figure, the thermocouple sensor is located inside the sheath. At the transition, the thermocouple wire from the sensor is welded or brazed to the extension lead wire, which generally is made of a more flexible material. The head consists of a small junction box, which is connected to the conduit through which the thermocouple wire passes to the controller and recorder.

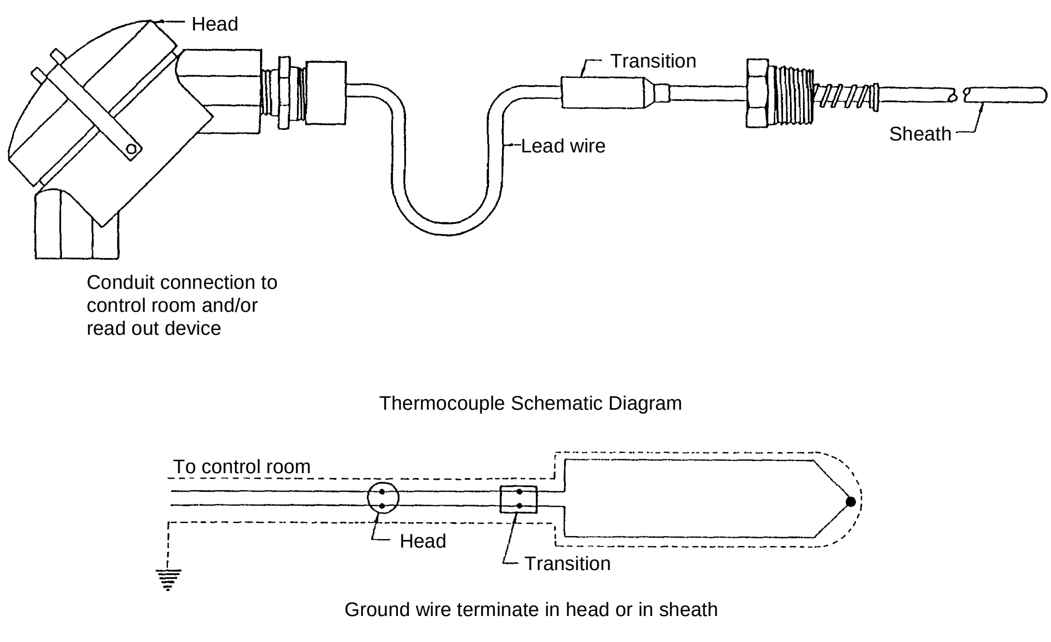

Figure 4.2-3. Thermocouple assembly.[2]

A sheath is a closed-end metal tube that protects the sensor from moisture and corrosive-process environments. The sheath also provides mechanical protection and flexibility of the assembly, isolates the thermocouple electronically, and improves the quality and reliability of the thermocouple. The sheathed thermocouple is constructed as a single unit. A commonly used type of sheathed thermocouple is the mineral-insulated metal sheathed (MIMS) thermocouple. In this device, the thermocouple wires are surrounded with a mineral-based insulating material (typically, magnesium oxide) within the sheath to provide further protection. Thermowells also are used to protect thermocouple sensors. Thermowells are tubes into which the thermocouple is inserted. Thermowells generally are bolted onto the wall of the process vessel, pipe, or duct. In some applications, the annular space between the inside wall of the thermowell and the ethermocouple inserted into the thermowell is filled with a heat transfer fluid to shorten the response time of the sensor. Other options for protecting thermocouple sensors include vinyl tips for use in environments subject to moisture and moderate temperatures, and ceramic fiber insulation.

Thermocouples have been classified by the Instrument Society of America and the American National Standards Institute (ANSI), and are available for temperatures ranging from -200° to 1700°C (-330° to 3100°F). These standard tolerance thermocouples range in tolerance from ±0.5 percent to ±2 percent of true temperature. Table 4.2-2 presents commonly available thermocouple types and operating ranges.

Thermocouples must be selected to meet the conditions of the application. Thermocouple and extension wires (used to transmit the voltage from the thermocouple to the monitoring point) are generally specified and ordered by their ANSI letter designations for wire types. Positive and negative legs are identified by the letter suffixes P and N, respectively. General size and type recommendations are based on length of service, temperature, type of atmosphere (gas or liquid constituents), and desired response times. Smaller wire gauges provide faster response but do not last as long under adverse conditions. Conversely, larger gauges provide longer service life but with longer response times. Thermowells and sheaths are recommended by thermocouple manufacturers for the extension of thermocouple life. Instruments used to convert thermocouple voltage to temperature scales are coded using the same letter designations. Failure to use matching thermocouples and instruments will result in erroneous readings.

Type J thermocouples use iron for the positive leg and copper-nickel (constantin) alloys for the negative leg. They may be used unprotected where there is an oxygen-deficient atmosphere, but a thermowell is recommended for cleanliness and generally longer life. Because the iron (positive leg) wire oxidizes rapidly at temperatures over 1000°F, manufacturers recommend using larger gauge wires to extend the life of the thermocouple when temperatures approach the maximum operating temperature.

Type K thermocouples use chromium-nickel alloys for the positive leg and copper alloys for the negative leg. They are reliable and relatively accurate over a wide temperature range. It is a good practice to protect Type K thermocouples with a suitable ceramic tube, especially in reducing atmospheres. In oxidizing atmospheres, such as electric arc furnaces, tube protection

TABLE 4.2-2. THERMOCOUPLE DESIGNATIONS, RANGES, AND TOLERANCES[4]

Thermocouple type	Temperature Range °Celsius	Temperature Range °Fahrenheit	Standard tolerance[a]
B	800 to 1700	1500 to 3100	±0.5%
C[b]	430 to 2300	800 to 4200	±1%
D[b]	0 to 2300	32 to 4200	±4.4°C (±8°F)
E	0 to 900	32 to 1650	±1.7°C or ±0.5%
G[b]	0 to 2300	32 to 4200	±4.4°C (±8°F)
J (common)	0 to 750	32 to 1400	±2.2°C or ±0.75%
K (common)	0 to 1250	32 to 2300	±2.2°C or ±0.75%
M[b]	-50 to 1400	-60 to 2600	±0.75%
N	0 to 1250	32 to 2300	±2.2°C or ±0.75%
P[b]	0 to 1400	32 to 2550	±0.10 mV
R (common) or S	0 to 1450	32 to 2650	±1.5°C or ±0.25%
T	0 to 350	32 to 660	±1.0°C or ±0.75%
Cryogenic Ranges			
E	-200 to 0	-330 to 32	±1.7°C or ±1%
K	-200 to 0	-330 to 32	±2.2°C or ±2%
T	-200 to 0	-330 to 32	±1.0°C or ±2%

[a]Where tolerances are given in degrees and as a percentage, the larger value applies. Where tolerances are given in percent, the percentage applies to the temperature measured in degrees Celsius. For example, the standard tolerance of Type J over the temperature range 277° to 750°C is ±0.75 percent. If the temperature being measured is 538°C, the tolerance is ±0.75 percent of 538, or ±4.0°C. To determine the tolerance in degrees Fahrenheit, multiply the tolerance in degrees Celsius by 1.8.

[b]Non-ANSI coded materials.

may not be necessary as long as other conditions are suitable; however, manufacturers still recommend protection for cleanliness and prevention of mechanical damage. Type K thermocouples generally outlast Type J, because the iron wire in a Type J thermocouple oxidizes rapidly at higher temperatures.

Type N thermocouples use nickel alloys for both the positive and negative legs to achieve operation at higher temperatures, especially where sulfur compounds are present. They provide better resistance to oxidation, leading to longer service life overall.

Type T thermocouples use copper for the positive leg and copper-nickel alloys for the negative leg. They can be used in either oxidizing or reducing atmospheres, but, again, manufacturers recommend the use of thermowells. These are good stable thermocouples for lower temperatures.

Types S, R, and B thermocouples use noble metals for the leg wires and are able to perform at higher temperatures than the common Types J and K. They are, however, easily contaminated, and reducing atmospheres are particularly detrimental to their accuracy. Manufacturers of such thermocouples recommend gas-tight ceramic tubes, secondary porcelain protective tubes, and a silicon carbide or metal outer protective tube depending on service locations.

4.2.2.2 System Components and Operation

Thermocouples are often placed in thermowells built into process equipment to allow convenient maintenance and to protect the thermocouples. Optional equipment includes external reference devices, data acquisition systems using scanners to switch between thermocouples, and a computer to calculate and display the measured temperatures. Electronic data logging systems can be used to store temperature data, and digital systems are often integrated with production process control. Manufacturers of thermocouple systems use some standardization in terminology and connectors, making it easier to make sure that all system parts are compatible.

4.2.2.3 Accuracy

In general, thermocouples are capable of temperature measurement within 1 to 2 percent of the temperature in degrees Celsius (see Table 4.2-2). Overall system accuracy depends on the type of calibrations performed and on the type of signal processing used.

4.2.2.4 Calibration Techniques[3,5-7]

Thermocouple systems can lose their calibration and should be inspected regularly to determine the need for replacement of thermocouples, connectors, extension wires, zone boxes, or voltmeters. Loss of calibration indicates that something besides the temperature at the measured point is affecting the current generated in the system and is causing an erroneous temperature reading. Electrical interferences may be present, requiring the use of twisted extension wires and shielded contacts. Oxidation also may occur at the thermocouple junction, changing the composition of the junction and therefore the voltage generated. Erosion of the thermocouple by entrained particles can have the same effect. When possible, final calibration should be performed under actual electromagnetic, radio frequency, and ambient temperature conditions.

4.2.2.4.1 Sensor. Although thermocouple systems can lose their calibrated accuracy, thermocouples themselves cannot be adjusted. Once they fail they must be replaced. Thermocouple sensors can be obtained with certificates of calibration at multiple points and then monitored using simple checks for evidence of drift. Comparative measurement of known temperatures (e.g., ice point, boiling point, etc.) with an American Society for Testing and Materials (ASTM) certified mercury thermometer, or even a voltage/current generator, should be enough to show that the sensor has not deteriorated significantly. Testing of thermocouples can be accomplished by measuring known temperatures and using a calibrated voltmeter to compare performance to the manufacturers' specifications. Thermocouple resistance can be checked using an ohmmeter, giving an indication of thermocouple condition. Abrupt changes in thermocouple resistance translate into voltage changes, signaling some type of problem or failure, such as an open wire, short circuit, changes due to vibration fatigue, or overheating. Voltmeters used to check thermocouple resistance must be capable of offset compensation; that is, compensation for the voltage the thermocouple generates.

4.2.2.4.2 System. Ideally, calibration should be performed on the system as a whole by measuring known temperatures at the thermocouple junction and adjusting the voltmeter accordingly. System calibration devices typically use either physical or electronically-simulated comparison methods. Figure 4.2-4 shows the setup for calibrating a thermocouple system.

First, the instrument should be electronically calibrated according to the procedures (e.g., zero and span adjustment) in the manufacturer's owners manual. Then, the thermocouple probes are placed in a device which creates a known reference temperature, traceable to National Institute for Standards and Technology (NIST) standards. Simulated temperatures using standardized voltage sources (such as "electronic ice points") can also be used. Decalibration errors (differences in electrochemical characteristics from original manufacturer design specifications) may be induced by physical or chemical changes in the thermocouple, making the task of system calibration more difficult. Decalibration errors can be caused by the absorption of atmospheric particles by the thermocouple (thus changing its chemical makeup), by radiation, or if the metal's structure is changed by heat annealing or cold-working strain. Finally, the results of the calibration efforts must be tabulated, showing the deviations between the thermocouple

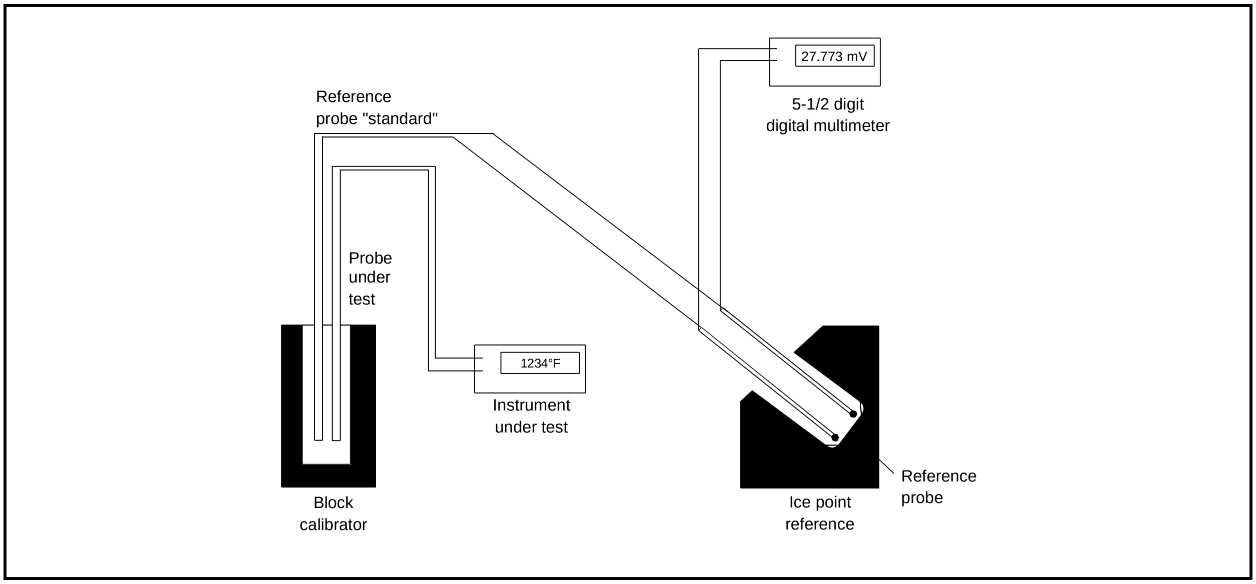

Figure 4.2-4. Setup for calibrating temperature measurement systems.[1]

system readings and known temperatures used in calibrating the system. The table can then be used to track changes in system performance and correct readings to actual temperatures. If the temperatures measured are within the tolerance (expected "accuracy") range, calibration is complete.

The ASTM provides standard test methods, which can be helpful in calibration. The appropriate thermometer can be determined using ASTM Method E 1. The ASTM Method E 220 specifies the standard method of calibrating thermocouples by comparison techniques, and the following paragraphs summarize the calibration procedures specified in that standard. The ASTM Method E 563 describes the procedure for preparing freezing point reference baths. The ASTM Method E 452 gives the standard test method for calibration of refractory metal thermocouples using an optical pyrometer. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE) provides standard methods for temperature measurement for the ANSI under ANSI/ASHRAE Standard 41.1. This guide is especially relevant for gas handling systems such as air pollution control equipment.

The ASTM E 220, "Standard Method for Calibration of Thermocouples by Comparison Techniques" covers the calibration of thermocouples using comparison to another, more accurate, thermometer. The reference thermometer could be another thermocouple, a liquid-in-glass thermometer, or an RTD. The most important consideration is that both the thermocouple to be calibrated and the reference thermometer are held at approximately the same temperature. Air is a poor conducting medium for this kind of comparison; liquid immersion or uniformly heated metal blocks, tube furnaces, or sand baths are more appropriate. Platinum resistance thermometers are the most accurate reference thermometers in stirred liquid baths from temperatures of approximately -180° to 630°C (-300° to 1170°F). Liquid-in-glass thermometers generally may be used for temperatures ranging from -180° to 400°C (-300° to 750°F), although special thermometers may be used at even higher temperatures. Types R and S thermocouples (24-gauge) can be used for very high temperatures 630° to 1190°C (1170° to 2190°F).

The general procedure specified in ASTM Method E 220 is to measure the electromotive force of the thermocouple being calibrated at selected calibration points; the temperature of each point is measured with a standard thermocouple or other thermometer standard. The number and choice of test points will depend upon the type of thermocouple, the temperature range to be covered, and the accuracy required. Thermocouples should generally be calibrated at least at three points or every 100°C (200°F). For example, if the range of measurement is 0° to 870°C (32° to 1600°F), the system should be calibrated at 300°, 600°, and 870°C (572°, 1110°, and 1600°F); if the range of measurement is 135° to 245°C (300° to 500°F), the thermocouple should be calibrated at 135°, 180°, and 245°C (300°, 400°, and 500°F). If another thermocouple is used as the reference, very precise comparisons can be made using potentiometers with reflecting devices on them. The reflected spots can be focused on a common scale, which will amplify very small differences. This procedure is especially useful because it can be used to test the monitoring system as a whole.

A useful diagnostic procedure in the event of an unexpected temperature reading is the "block test." Block tests check for proper operation of the voltmeter and isothermal block itself. To perform a block test, the thermocouple in question is temporarily short-circuited directly at the block. The system should read a temperature very close to that of the block (i.e., room temperature). If that is not the case, it is likely that either the thermocouple itself must be replaced or there is a faulty connector or extension wire in the system prior to the isothermal block. Once the system has been repaired, it can be recalibrated. In systems using redundant thermocouples, the difference in temperature readings can be monitored, indicating thermocouple drift or failure. In particularly harsh applications, scheduled thermocouple replacement may be the most expedient method for maintaining thermocouple accuracy.

A simpler method of checking thermocouple sensor performance is to install a pair of thermocouples in close proximity. The temperature readings on both thermocouples are checked simultaneously. As soon as the temperatures diverge, indicating a failure of one or both of the thermocouples, both are replaced. Another simple method for checking sensor accuracy is to insert another thermocouple with lower tolerances adjacent to the thermocouple in question and compare the temperature readings of the two thermocouples. The practices described in this paragraph do not preclude the need to calibrate the transmitter periodically. Figures 4.2-5 and 4.2-6 illustrate the equipment and connections needed to calibrate a thermocouple transmitter by means of a thermocouple simulator and an ice bath, respectively.

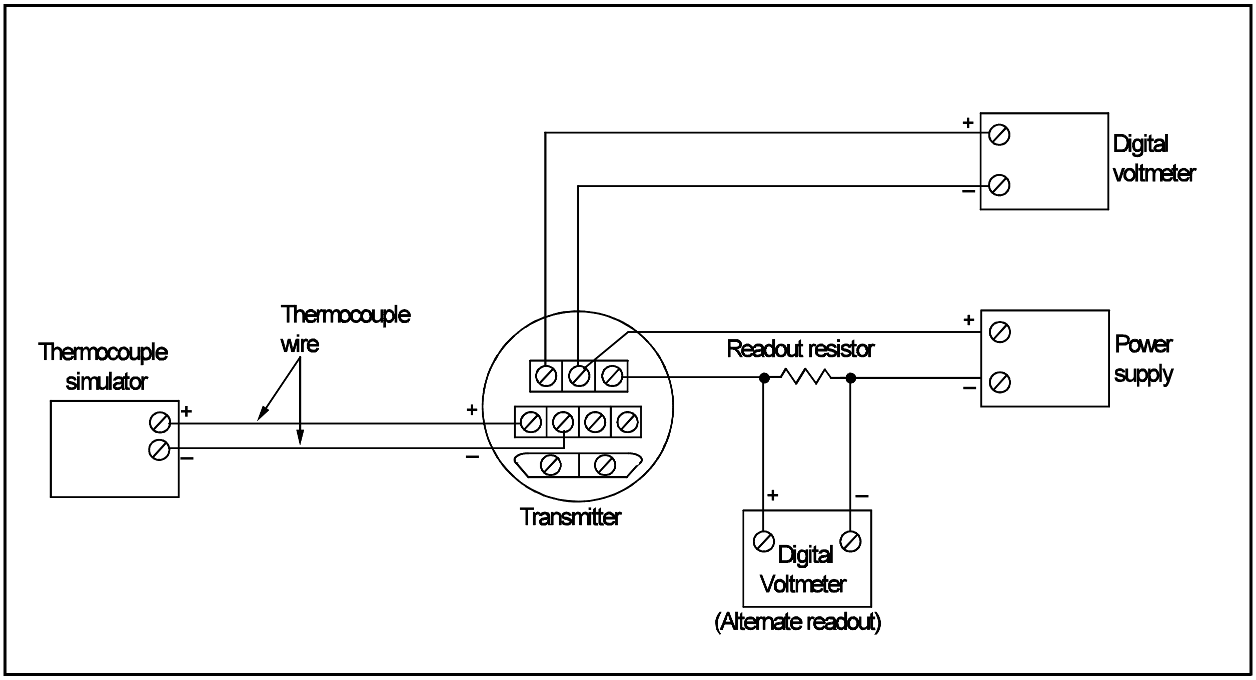

Figure 4.2-5. Setup for calibrating a thermocouple transmitter using a thermocouple simulator.[8]

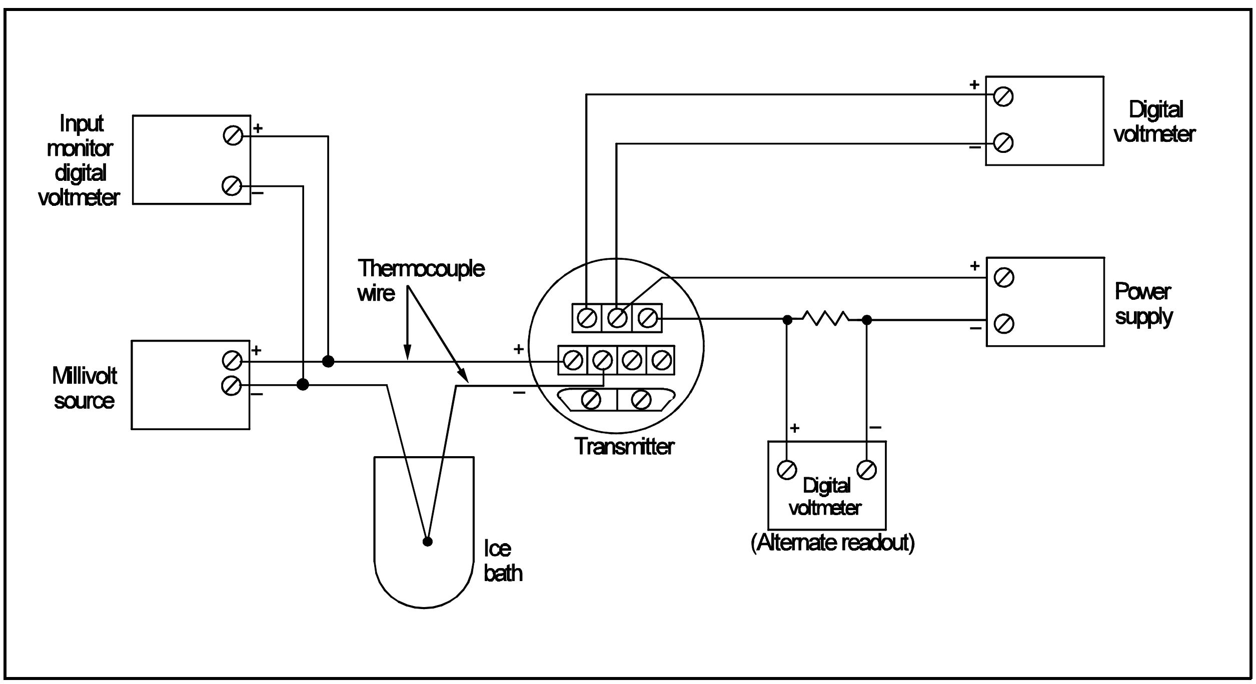

Figure 4.2-6. Setup for calibrating a thermocouple transmitter using an ice bath.[8]

4.2.2.5 **Recommended QA/QC Procedures**.[1,3-5,7,9-10]

Proper use and maintenance of thermocouple systems begin with good system design based on the strengths and weaknesses of various thermocouple types. Because these sensors contain sensitive electronics, general good practice includes use of shielded cases and twisted-pair wire, use of proper sheathing, avoidance of steep temperature gradients, use of large-gauge extension wire, and use of guarded integrating voltmeters or ohmmeters, which electronically filter out unwanted signals. The signal conditioner should be located as close as possible to the sensor, and twisted copper-wire pairs should be used to transmit the signal to the control station. To minimize electromagnetic field interference, sensor system wires should not be located parallel to power supply cables. The primary causes of loss of calibration in thermocouples include the following:

1. Electric "noise" from nearby motors, electric furnaces, or other such electrically noisy equipment;

2. Radio frequency interference from the use of hand-held radios near the instrument; and

3. "Ground loops" that result when condensation and corrosion ground the thermocouple and create a ground loop circuit with another ground connection in the sensing circuit.

Most problems with thermocouples are aggravated by use of the thermocouple to measure temperatures that approach or exceed their upper temperature limits. Careful recording of events that could affect measurements should be kept in a logbook. Any adjustments or calibrations should also be recorded. The logbook should contain the names of individuals performing maintenance and calibrations as well as defined procedures. In systems monitoring many locations, such a log is especially useful for fault diagnosis.

Thermocouples sometimes experience catastrophic failures, which may be preceded by extreme oscillations or erratic readings. In such cases, all connections associated with the thermocouple should be checked for loose screws, oxidation, and galvanic corrosion. In many cases, drift may be a more serious problem because it can go unnoticed for long periods of time. The most common causes of loss of calibration are excessive heat, work hardening, and contamination. Work hardening generally is due to excessive bending or vibration and can be prevented with properly designed thermowells, insertion lengths, and materials. Contamination is caused by chemicals and moisture, which sometimes attack wiring by penetrating sheaths, and can result in short-circuiting. A simple test to check for this problem is to disconnect the sensor at its closest connection and check for electrical continuity between the wires and the sheath using a multimeter. If the meter indicates continuity, the sensor should be replaced. Because the electromotive force (EMF) produced by thermocouples is so small, electrical noise can severely affect thermocouple performance. For that reason, it also is very important that transmitters be isolated. Thermocouples used in the vicinity of electrostatic precipitators must be shielded to avoid electrical interference. If the potential electrical interference is high, an RTD or other type of sensor may be preferred to thermocouples. With respect to thermocouple and protection tube selection, the following should be noted:

1. Type J thermocouples particularly should not be used in applications in which they might be exposed to moisture because the iron in the thermocouple will rust and deteriorate quickly;

2. Type K thermocouples should not be used in the presence of sulfur, which causes the element to corrode; because cutting oils often contain sulfur, protection tubes should be degreased before being used; stainless steel sheaths should be used to protect Type K thermocouples in stacks where SO_2 emissions are significant;

3. Platinum thermocouple elements (Types R, S, or B) should not be used with metal protection tubes unless the tubes have a ceramic lining because the metal will contaminate the platinum;

4. Ceramic, silicon carbide, and composite (metal ceramic, Cerite-II, Cerite-III) protection tubes are subject to thermal shock and should be preheated prior to inserting in high temperature process environments; and

5. Molybdenum- or tantalum-sheathed thermocouples will fail rapidly if placed in oxidizing atmospheres.

During one study of thermocouple performance, 24 combinations of thermocouple and sheath material types were tested at temperatures up to 1200°C (2200°F). The results indicated that above 600°C (1110°F) thermocouples are affected by complex chemical interactions between their components; even though wires and sheaths were physically separated, exchange of constituents occurred. The study concluded that thermocouples maintain calibration better if sheath material is similar in composition to thermocouple alloys. By using similar alloys longer performance can be expected for sensors subjected to temperatures above 600°C (1110°F), and the use of similar alloys is essential for temperatures above 1000°C (1830°F).

4.2.2.5.1 <u>Frequency of calibration</u>.[7,11-12] Calibration of thermocouple systems should follow a consistent procedure in order to allow comparisons of performance change over time. The recommended frequency of calibration depends largely on site-specific conditions. The starting point for determining calibration intervals, according to independent calibration laboratories, is a search for applicable military specifications. These specifications are issued by the procurement arm of the Department of Defense (DOD). Military Standards (MIL-STD) define requirements for manufacturers of equipment purchased by the military. Applicable standards include MIL-STD-1839A, which lists detailed calibration and measurement requirements, including frequency, imposed on equipment suppliers by the DOD. As a result, calibration intervals should be available for each component of military-acceptable (specified by a Military Specification (MIL-SPEC) number) monitoring systems. Typically, the desired calibration intervals, as well as accuracy requirements, are part of the MIL-SPEC. Manufacturers of commercial items generally supply this information as a Calibration and Measurements Requirements Summary (CMRS) included in the owner's manual.

If there is no applicable MIL-SPEC calibration interval and no information can be obtained from the manufacturer for a particular sensor system, 1 year should be the initial default calibration interval if there are no moving parts, as is the case for thermocouples; for sensors with moving parts, the initial calibration period should be 6 months. More frequent system calibration cycles may be indicated when thermocouples near the upper range of their temperature capabilities are used or following prolonged excursions above the recommended maximum temperature or other events causing suspect temperature readings. One reference recommends an initial calibration period of 3 months for Type K thermocouples.

These default calibration intervals should not be relied on indefinitely; they are the starting points for a method to determine the maximum calibration period for a particular installation. At the end of the manufacturer's or otherwise determined initial calibration period, the system should be calibrated and the data obtained should be charted. If the system is near or beyond the limit of acceptable accuracy (80 percent of acceptable error), and there were no process excursions or conditions suspected of causing the decalibration, it can be concluded that the calibration interval is too long. In such a case, the system should be recalibrated to the center of the acceptable band, and the calibration interval should be shortened. At the end of the second calibration period, calibration should be checked to determine if the system is drifting. If the system is near or beyond the limit of acceptable accuracy, similar steps should be taken, and the calibration period should be further shortened. This process should be continued until the system is determined to be within the acceptable limit of accuracy at the end of the calibration interval. If, at the end of the initial calibration period, the system is determined to be within acceptable tolerance, recalibration is not necessary, but the results should be recorded and the same calibration interval should be maintained for another calibration period. At the end of the second calibration period, calibration should be checked to determine if the system is drifting. If the system measures outside the acceptable band, it can be concluded that it took between one and two periods to lose calibration, and the calibration interval was acceptable. In any case, it is important to maintain a log of calibration checks and the results and actions taken. Calibration data should be reviewed annually in order to spot significant deviations from defined procedures or tolerances.

4.2.2.5.2 Quality control. A written procedure should be prepared for all instrument calibrations. These procedures should include:

1. The recommended interval for zero and span checks of each component of the temperature system. Readings before and after adjustment should be recorded.

2. A requirement that each thermocouple and related system components are calibrated in accordance with manufacturers' recommended procedures. Calibrations should be performed at intervals determined according to the procedures described in Section 4.2.2.5.1. Readings before and after adjustment should be recorded; if no adjustments are necessary, that should also be recorded.

3. Designation of person(s) to perform the calibrations. All records should include identification of the instrument component calibrated, the date of calibration, and the initials of the person who performed the calibration.

4.2.2.5.3 Quality assurance. The calibration logs should be reviewed to confirm that calibrations were completed and performed properly. The person performing this review and the review frequency also should be specified. The written calibration procedures should be reviewed and updated in the event of any system modifications or instrumentation changes.

4.2.3 Resistance Temperature Detectors[1-4,13]

Resistance temperature detectors are attractive alternatives to thermocouples when high accuracy, stability, and linearity (i.e., how closely the calibration curve resembles a straight line) of output are desired. The superior linearity of relative resistance response to temperature allows simpler signal processing devices to be used with RTD's than with thermocouples. Resistance Temperature Detector's can withstand temperatures up to approximately 800°C (~1500°F).

4.2.3.1 Measurement Principle and Description of Sensor

Resistance temperature detectors work on the principle that the resistivity of metals is dependent upon temperature; as temperature increases, resistance increases. Table 4.2-3 lists the resistivities of various metals used for RTD's. Platinum is usually used, because it is stable at higher temperatures and provides a near-linear temperature-to-resistance response.

Since it is a nonreactive precious metal, platinum is also corrosion resistant. Platinum wire is generally wound around a glass or ceramic core, then encased for protection. Platinum or other metals may also be made into a slurry with glass, screened or otherwise deposited on a ceramic substrate, and laser-etched. This device can then be sealed or coated to protect the element. This type of RTD is known as a thin-film RTD, and is less expensive than wire-constructed RTD's. Both types of RTD's are specified by their ice point resistance (R_0 at 0°C) and their temperature coefficient of resistance (the fractional change in element resistance for

TABLE 4.2-3. RESISTIVITY OF RTD ELEMENTS[6]

Metal	Resistivity, microhm-cm	Relative resistance[a] (R_t/R_o) at °C			
		0	100	500	900
Silver	1.50	1.00	1.408	3.150	5.091
Copper	1.56	1.00	1.431	3.210	5.334
Platinum	9.83	1.00	1.353	2.844	4.109
Nickel	6.38	1.00	1.663	5.398	7.156

[a]Ratio of resistance at temperature t (R_t) to resistance at 0°C (R_o).

each degree Celsius, in ohms per ohm per degree Celsius, [Ω/Ω/°C]), or "alpha value (α)" in order to insure system compatibility. The alpha value is calculated as follows:

$$\alpha = (R_{100} — R_0) / (100 \times R_0)$$

Many common RTD elements manufactured in the U.S. and Europe have a base resistance of 100Ω or 200Ω at 0°C and α = 0.00385 Ω/Ω/°C. Elements with other alpha values, such as 0.003916 Ω/Ω/°C, are also common in American and Japanese scientific apparatus.

4.2.3.2 System Components and Operation

Resistance temperature detector systems consist of the detector itself, extension wires, dc power supply, a Wheatstone Bridge, and an ohmmeter or voltmeter. In practice, a "transmitter," which can be installed near the detector, is often used to integrate the detector output, it produces a linearized 4 to 20 mA signal, which is converted to temperature units and displayed by the indicator/controller. Figure 4.2-7 depicts schematically a typical RTD system, and Figure 4.2-8 illustrates a typical RTD assembly. The components of the assembly are essentially the same as those described in Section 4.2.2 for thermocouple assemblies.

Detector elements are often placed in thermowells, which allow temperature monitoring of closed systems and convenient sensor maintenance. Measurement errors are caused by damage to the detector or self-heating. Damage to detectors is common because they are somewhat more fragile than thermocouples. Self-heating is due to the Joule heating caused by the measurement current sent through the RTD by the ohmmeter. The typical amount of error caused by self-heating ranges from ½°C to 1°C per milliwatt (°C/mW) (in free air). This error is reduced if the medium being measured is flowing (this effect can be used to construct flow meters based on thin film RTD's) or the RTD is immersed in a thermally conductive medium. The time it takes for an RTD to return a certain percentage response to a step change in temperature depends on the thermal conductivity and flow rate of the medium being monitored

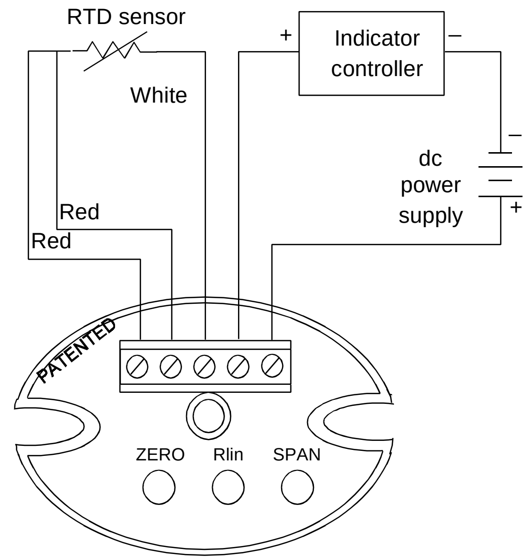

Figure 4.2-7. Resistance temperature detector (RTD) system schematic.[13]

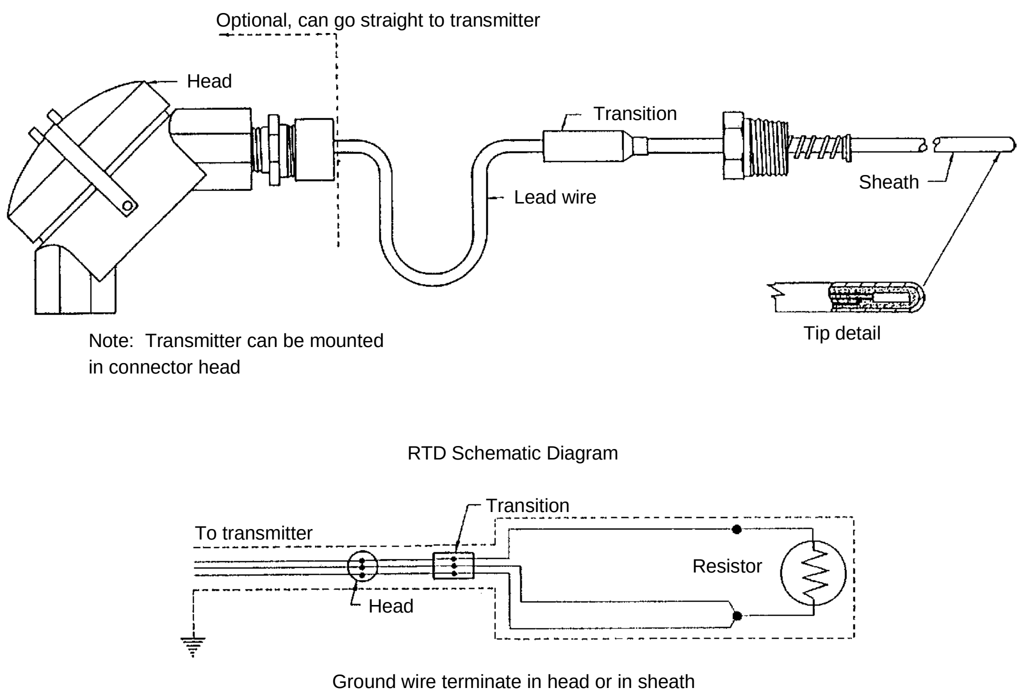

Figure 4.2-8. Resistance temperature detector (RTD) assembly.[2]

(if any) and can be termed the "time constant" of the RTD. Time constants are experimentally determined and provide a basis for comparison of response time between different commercially available RTD elements.

4.2.3.3 Accuracy

Platinum resistance RTD elements are capable of their best accuracy near ambient temperatures. Maximum allowable deviations of ±0.12Ω (±0.3°C [±0.5°F]) at the freezing point of water are reported by one manufacturer. The term "accuracy" as applied to RTD's often is defined as the difference in the base resistance of the element from its design specification at one temperature point; typically 0°C. Deviations rise to ±0.56Ω (±1.3°C [±2.3°F]) at -200°C (-330°F), which is near the lowest temperatures recommended for RTD use. Deviations rise to ±1.34Ω (±4.6°C [±8.3°F]) at the maximum recommended temperature of 850°C (1560°F). Self-heating errors in flowing air (v = 1m/s) should be less than approximately +0.1°C/mW for glass elements and up to +0.4°C/mW in flowing air for ceramic elements. Overall, systems should be calibrated such that deviation less than ±1 percent of the actual temperature is observed, which is similar to the accuracy expected of thermocouples.

4.2.3.4 Calibration Techniques[3,5-6]

Resistance temperature detector systems can lose their calibration and should be inspected regularly to determine the need for replacement of RTD elements, probes, connectors, extension wires, thermowells, power supplies, transmitters, and indicators. Loss of calibration indicates that something besides the temperature at the point being measured is affecting the current difference measured by the system and is causing an erroneous temperature reading. Electrical interferences may be present, requiring the use of twisted extension wires and shielded contacts. Vibration or exceedance of the upper temperature specification can affect the structure of the metal in the sensor, causing decalibration.

4.2.3.4.1 Sensor. Although RTD systems can lose their calibrated accuracy, RTD elements usually cannot be adjusted (unless the resistivity or the amount of metal in the element can be changed). Once RTD's fail, they must be replaced. Testing of RTD's can be accomplished by measuring known temperatures and using a calibrated voltmeter to compare performance to manufacturers' specifications. Element resistance can be checked using an ohmmeter, giving an indication of its condition. Abrupt changes in resistance translate into changes in current, signaling some type of problem or failure, such as an open wire, a short circuit, changes due to vibration fatigue, or overheating. Sensor element resistance can be checked by comparing the readings to manufacturers' specifications or to known values, as presented in Table 4.2-3.

4.2.3.4.2 System. Ideally, the system should be calibrated using known standard temperatures. Intermediate checks should be made electronically and compared to manufacturers' data and calibrations. System calibration devices typically use either physical or electronically simulated comparison methods. Figure 4.2-4 depicts the general setup for calibrating a temperature measurement system, and Figure 4.2-8 illustrates the setup used to calibrate an RTD transmitter using a resistance decade box, which is a device that allows one to simulate resistances with high precision. When installing RTD's, the system should be calibrated and allowed to stabilize at the highest likely service temperature. When possible, final calibration should be performed under actual electromagnetic, radio frequency, and ambient temperature conditions.

Individual parts of the system should be visually inspected for damage and electrically checked and compared to specifications. Then the RTD elements or probes are placed in a device that creates a known reference temperature. A resistance decade box also can be used to simulate signals equivalent to calibration temperatures. Finally, the results of the calibration efforts must be tabulated, showing the deviations between the system readings and known temperatures used in calibrating the system. The table can then be used to track changes in system performance and correct readings to actual temperatures. If the temperatures measured are within the tolerance (expected "accuracy") ranges, calibration is complete.

The ASTM provides standard test methods, which can be helpful in calibration. The appropriate thermometer can be determined using ASTM Method E 1, and ASTM Method E 644 specifies standard methods for verifying the calibration of RTD's. As stated in Section 4.2.2, ASHRAE provides standard methods for temperature measurement for ANSI under ANSI/ASHRAE Standard 41.1.

As explained in Section 4.2.2.4.2 for thermocouples, an alternate method of checking the operation of RTD's sensors is to install them in pairs; when the temperature readings on the two RTD's diverge, both can be replaced.

4.2.3.5 Recommended QA/QC Procedures[3,9,13-16]

Resistance temperature detectors sometimes experience catastrophic failures, which may be preceded by extreme oscillations or erratic readings. In such cases, all connections associated with the RTD should be checked for loose screws, oxidation, and galvanic corrosion. Although drift is less common in RTD's than in thermocouples, it still may occur and cause serious problems because it can go unnoticed for long periods of time. The most common causes of loss of calibration are excessive heat, work hardening, and contamination. Work hardening generally is due to excessive bending or vibration and can be prevented with properly designed thermowells, insertion lengths, and materials. Resistance temperature detector elements are particularly sensitive to vibrations. Contamination is caused by chemicals and moisture, which sometimes attack wiring by penetrating sheaths, and can result in short-circuiting. A simple test to check for this problem is to disconnect the sensor at its closest connection and check for electrical continuity between the wires and the sheath using a multimeter. If the meter indicates continuity, the sensor should be replaced.

During one study, 47 RTD's were tested to determine the effects of aging at temperatures in the range of 0° to 300°C (32° to 572°F). The test conditions included thermal aging for 18 months, vibration aging for 2 months, high-temperature testing for 2 days at 400°C (750°F), and thermal cycling for a 2-week period. The results indicated that most RTD's maintained their calibration within ±0.2°C (±0.4°F) for at least 2 years over the temperature range of 0° to 300°C (32° to 572°F).

4.2.3.5.1 Frequency of calibration. Calibration of RTD systems should follow a consistent procedure, in order to allow comparisons of performance change over time. The recommended frequency of calibration depends largely on site-specific conditions. The procedures described in Section 4.2.2.5.1 for thermocouple systems can generally be used to determine the calibration frequency for RTD systems.

More frequent zero reset and span checks should be performed if deemed necessary by experience with a particular installation. More frequent calibration cycles may also be advantageous if RTD's are used near the upper range of their specifications or after prolonged excursions above the recommended maximum temperature.

4.2.3.5.2 Quality control. A written procedure should be prepared for all instrument calibrations. These procedures should include:

1. The recommended interval for zero and span checks of each component of the temperature system. Readings before and after adjustment should be recorded.

2. A requirement that each RTD sensor and related system components are calibrated in accordance with manufacturers' recommended procedures. Calibrations should be performed at intervals determined according to the procedures described in Section 4.2.2.5.1. Readings before and after adjustment should be recorded; where no adjustments are necessary, that should also be recorded.

3. Designation of person(s) to perform the calibrations. All records should include identification of the instrument component calibrated, the date of calibration, and the initials of the person who performed the calibration.

4.2.3.5.3 Quality assurance. The calibration logs should be reviewed to confirm that calibrations were completed and performed properly. The person performing this review and also the review frequency should be specified. The written calibration procedures should be reviewed and updated in the event of any system modifications or instrumentation changes.

4.2.4 Infrared Thermometry[6,17-21]

Infrared thermometers are more expensive than thermocouples or RTD's, but IR temperature measurement has applications in areas where high electrical interference or extremely high temperatures exist. Because the IR sensor is remote from the measurement point, vibration problems can also be eliminated. In addition, IR instruments can provide rapid response to temperature changes.

4.2.4.1 Measurement Principle and Description of Sensor

All objects with a temperature greater than absolute zero emit IR radiation. Infrared radiation is part of the electromagnetic spectrum that extends from wavelengths of approximately 0.75 micrometers (μm), which is just beyond the wavelength of visible light, to more than 1,000 μm. However, for practical purposes, the IR spectrum generally is considered to range from wavelengths of 0.75 to 30 μm. As the temperature of an object increases, the amplitude of the emitted IR radiation increases, and the wavelength associated with the peak energy shifts toward the shorter wavelengths. Below wavelengths of 0.75 μm, the radiation emitted by an object enters the visible range, and the object begins to glow red.

An IR thermometer measures the IR emitted by an object and converts the measurement to the corresponding temperature. The measurement principle is based on the theoretical radiation wavelength that would be emitted by an ideal radiator, which is referred to as a blackbody. However, real objects (graybodies) emit only a portion of the IR that would be emitted by a blackbody at the same temperature. This characteristic is called the emissivity of an object and is defined as the ratio of the thermal radiation emitted by a graybody to that of a blackbody at the same temperature. In addition to temperature, the emissivity of an object is a function of the object's surface temperature, surface treatment, and the orientation of the object to the IR thermometer. To determine the temperature of an object, an IR thermometer must compensate for the emissivity of the object. Because IR thermometers measure the radiation emitted by an object, they can be used for remote sensing without contacting the object directly.

4.2.4.2 System Components and Operation

Infrared temperature monitoring systems, (often referred to as pyrometers), consist of an optical assembly, signal conditioner, recorder (or display), and a power supply. The optical assembly includes an aperture, lenses, and optical filters. The lenses and filters collect the incoming IR radiation, emitted by the source, and focus it on the detector. The detector converts the incoming IR radiation to an electrical signal. The most common detectors are made of mercury/cadmium/telluride or indium/antimony. Silicon, lead sulfide, indium/arsenide, and lead selenate detectors also are used as well as nonphotosensitive detectors made of thermopiles. (Thermopiles are arrays of thermocouples arranged to provide a higher output signal than a single thermocouple.) Lead sulfide detectors are the most sensitive, indium-based detectors fall in the mid-range of sensitivity, and thermopile detectors are the least sensitive.

In the signal conditioner, the electric signal from the detector is amplified, thermally compensated and stabilized, linearized, and converted to a digital signal, which then appears on the display or is recorded. A typical system is shown schematically in Figure 4.2-9. This basic configuration must be adapted for monitoring different objects or substances within different temperature ranges and under different conditions.

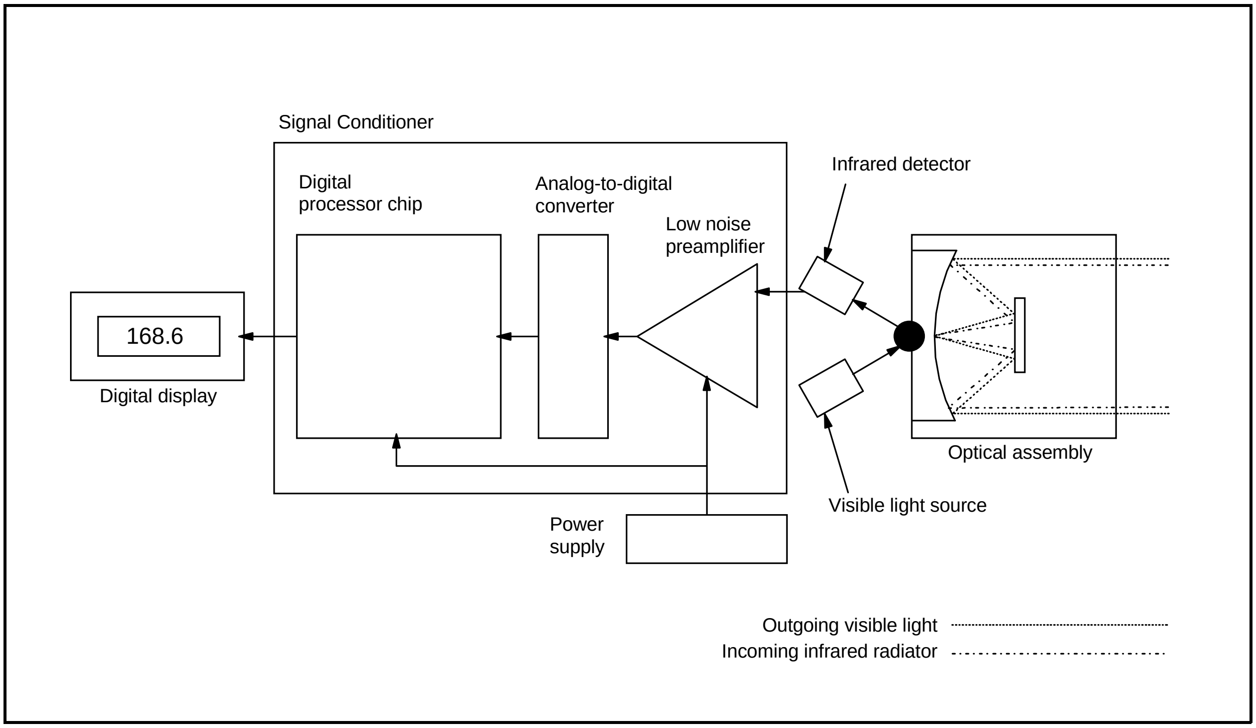

Figure 4.2-9. Infrared temperature measurement system.[18]

A recent development in IR temperature sensing is the IR "thermocouples." These devices have proprietary IR detection systems, which can be used with thermocouple controllers. These also are noncontact devices. When the sensor is aimed at the target object, it converts the radiation to an electrical signal, which is scaled to the thermocouple characteristics.

Infrared pyrometers generally have faster response times than other types of temperature measurement devices (on the order of 100 milliseconds to 1 second). Commercial IR thermometers generally measure temperatures up to approximately 815°C (1500°F). However, high-performance IR thermometers are available that measure temperatures in excess of 2760°C (5000°F) with response times of 0.5 to 1.5 seconds. Infrared thermometers are able to monitor the temperature of vibrating equipment that would fatigue thermocouple wiring or damage RTD's, and are able to measure higher temperatures than can be measured by thermocouples or RTD's. Infrared thermometry is also useful in areas where high electrical interference precludes use of thermocouples or RTD's. However, infrared thermometers are somewhat sensitive, and must be protected from dirt, dust, flames, and vapors. Infrared energy can be channeled through fiber optics, sight tubes, or reflected from front-surfaced mirrors in order to avoid subjecting the detector to damaging environments. Water-cooled shells, flame shutters, and explosion-proof housings also are available for ensuring that the IR system is protected. By using such precautions, IR thermometry can be used where corrosion precludes the use of other temperature measurement devices or where accessibility is difficult. Signal processor considerations include choices of analog or digital and control and alarm functions.

4.2.4.3 Accuracy

Analog IR thermometer systems generally are capable of measurement to within ±1 percent to ±4 percent of the true temperature at distances of 5 to 7 m (15 to 20 ft). Digital systems can include electronic compensation for emissivity and linearity, which can allow calibration to within ±0.1°C at specific temperatures.

4.2.4.4 Calibration Techniques

Calibration of IR temperature monitoring devices is similar in principle to calibration of simpler systems. Targets of known temperature are measured, and the instrumentation is adjusted to give the same readings. Since the emissivity of the target directly affects the amount of IR energy received by the sensor, the emissivity of the target must either be known or determined.

4.2.4.4.1 Sensor. Infrared sensors can provide thermocouple, current, or millivolt outputs. Calibration is performed to adjust the output to correlate with the correct temperature. Digital systems often include internal reference temperature devices, which allow them to self-calibrate at predetermined intervals. The results of the calibration cycle are then sent to the PC or microcomputer that controls the system.

4.2.4.4.2 System. Blackbody calibration sources are available that use a temperature-controlled device to present a calibration target of known temperature and emissivity. A black-body is defined as a theoretical object that absorbs all energy incident upon it and emits the maximum amount of energy for a given temperature. Blackbody devices should be accurate within 1 to 2 percent of the actual temperature over the range of the instrument to be calibrated.

Another method to calibrate an IR thermometer or pyrometer is to use published standard emissivity values for various materials. The emissivity is set to match the published value for the target material, and the IR system is then calibrated at known temperatures. Calibration of IR systems to measure the same target (such as the outlet duct of an incinerator) repeatedly can be done by heating a sample of the material to be monitored (duct material) in an oven to the desired range using an accurate temperature measuring device and measuring its temperature with the IR pyrometer. The output of the IR pyrometer can then be adjusted to display the correct temperature. For relatively lower temperatures found in most air pollution control equipment, a piece of masking tape can be stuck to the target and the temperature of the masking tape measured with the IR pyrometer, using an emissivity setting of 0.95. The temperature of the target is then measured, and the emissivity compensator is adjusted until the display shows the correct temperature. When the target can be coated, flat black paint or other nonmetallic coating can be applied to adjust the emissivity to approach 1.0 (the greatest possible emission ratio). The known temperature is then measured as before with the emissivity adjustment set to 1.0, and the temperature reading is reset to the correct value.

4.2.4.5 Recommended QA/QC Procedures

Calibration of IR systems should follow a consistent procedure in order to allow comparisons of changes in performance over time. Calibration data should be reviewed annually in order to spot significant deviations from defined procedures or tolerances. Because the IR thermometer must correct for the emissivity of the source, the emissivity setting on the dial must be routinely checked and adjusted as needed. Losses in the transmission of IR radiation can be caused by objects and particles in the line of sight between the source and the IR detector, resulting in a lower than actual temperature reading. Therefore, it is important that the instrument lens and any windows in the line of sight are kept clean and maintained as transparent as possible. The line of sight also should be routinely checked for other objects that may interfere with the radiation path. Background radiation can be transmitted to the IR thermometer if the target source is a good reflector or transmitter, resulting in a temperature reading that is biased high. To overcome such potential problems, the instrument should be placed so that it is out of the geometric path of background reflections or transmissions. Alternately, a cool opaque shielding material can be placed between the background source and the target source.

4.2.4.5.1 Frequency of calibration. The recommended frequency of calibration depends largely on site-specific conditions. The procedures described in Section 4.2.2.5.1 for thermocouple systems can generally be used to determine the calibration frequency for IR thermometers systems. Zero reset and span checks can be performed more often; actual schedules may depend on operator experience. More frequent system calibration cycles may be dictated under certain conditions or should be initiated following events causing suspect temperature readings.

4.2.4.5.2 Quality control. A written procedure should be prepared for all instrument calibrations. These procedures could include:

1. The recommended interval for zero and span checks of each component of the temperature system. Readings before and after adjustment should be recorded.

2. A requirement that each IR thermometer and related system components are calibrated in accordance with manufacturers' recommended procedures. Calibrations should be performed at intervals determined according to the procedures described in Section 4.2.2.5.1. Readings before and after adjustment should be recorded; where no adjustments are necessary, that should also be recorded.

3. Designation of person(s) to perform the calibrations. All records should include identification of the instrument component calibrated, the date of calibration, and also the initials of the person who performed the calibration.

4.2.4.5.3 Quality assurance. The calibration logs should be reviewed to confirm that calibrations were completed and performed properly. The person performing the review and the review frequency should be specified. The written calibration procedures should be reviewed and updated in the event of any system modifications or instrumentation changes.

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4.3 PRESSURE MEASUREMENT SYSTEMS[1-7]

Pressure measuring devices can be classified as those that require no outside source of power other than the applied pressure that is to be measured and those that require external, electrical power to operate. For the purposes of this document, these two groups are referred to as mechanical devices and electrical devices, respectively.

Mechanical pressure measurement devices measure pressure by balancing the force exerted on a unit area against the hydrostatic force applied by a liquid or against the deflection of an elastic element. A device that uses a hydrostatic force to measure pressure is referred to as a manometer. Devices that measure pressure as a function of the deflection of an elastic element can be classified according to the type of element as Bourdon, bellows, or diaphragm devices. Mechanical dial pressure gauges generally incorporate one of these three types of elastic elements as the pressure sensor.

Pressure measurement devices that rely on electrical energy to operate commonly are referred to as pressure transducers. Transducers can be defined as devices that receive energy from one system and transmit the energy, usually in another form, to another system. In this sense, the elastic element in a mechanical pressure gauge is a type of transducer because it transfers the applied pressure through mechanical linkage to a pointer to indicate pressure. However, the term pressure transducer is used in this document to pertain only to those devices that utilize electrical energy. Several types of pressure transducers are available. Some of the most commonly used pressure sensing elements used in pressure transducers include strain gauges, linear variable differential transformers (LVDT's), and capacitance transducers. Other commonly used pressure transducer types include force balance, potentiometric, variable reluctance, piezoelectric, and piezoresistive transducers. Tables 4.3-1 and 4.3-2 present comparisons of mechanical and electrical pressure measurement devices, respectively.

After a brief discussion of pressure terminology in the following paragraph, some of the commonly used pressure measurement devices are described. Mechanical devices are described first; manometers are addressed in Section 4.3.1, and mechanical dial pressure gauges are described in Section 4.3.2. The discussion of pressure gauges includes descriptions of Bourdon, bellows, and diaphragm elements. Pressure transducers are described in Section 4.3.3.

Gauge pressure is the difference between the pressure of a fluid and the surrounding ambient pressure. The zero point for gauge pressure is ambient pressure. Absolute-pressure gauges use an atmospheric pressure equal to zero as the zero point; subsequently, absolute pressure is a sum of the ambient pressure and the system pressure. Negative pressure gauges measure pressure below atmospheric pressure. Negative pressure is also called vacuum pressure. Compound pressure gauges are able to measure pressure both above (+) and below (-) ambient

TABLE 4.3-1. COMPARISON OF MECHANICAL PRESSURE SENSING ELEMENTS[6]

Characteristics	Bourdon	Diaphragm	Bellows
Pressure range, kPa (psi)	83 to 690,000 (12 to 100,000)	35 to 103 (5 to 15)	3.4 to 207 (0.5 to 30)
Temperature range, °C (°F)	-40 to 190 (-40 to +375)	-40 to 190 (-40 to +375)	-40 to 190 (-40 to +375)
Advantages	Low cost; field replaceable; variety of materials for media and range	Variety of materials for media and range; field replaceable; large force	Compact, accurate, field replaceable
Disadvantages	Slow response; large sensor volume sensitive to shock and vibration	Limited capacity; position sensitive in low ranges	Limited material; may be position sensitive

pressure. Differential pressure gauges measure the pressure difference between two points. Differential pressure has no reference to ambient pressure or to zero; the ambient pressure will have the same effect on both points.

4.3.1 Manometers[1,2,8]

Simple manometers, also known as piezometers, consist of a vertical open-ended tube in which the liquid in a pipe or pressure vessel is allowed to rise. The pressure in the pipe is proportional to the height to which the liquid rises in the piezometer. U-tube manometers can be used to measure the pressure of both liquids and gases by balancing the force exerted on the mouth of the U-tube against a liquid of known weight, generally water or mercury. For increased accuracy when measuring low-gas-pressure heads, manometers filled with two different fluids are sometimes used. Figure 4.3-1 illustrates a U-tube manometer. In the figure, the pressure at point A in the pipe can be determined by the following relationship:

$$P_A = \gamma_m \Delta h - \gamma_p L$$

where:

P_A = the pressure at point A;

γ_m = the specific weight of the manometer fluid;

Δh = the rise in elevation of the manometer above point B (which is located at the interface between the process fluid and the manometer fluid);

γ_p = the specific weight of the process fluid; and

L = the difference in elevation between point A and point B.

TABLE 4.3-2. COMPARISON OF ELECTRICAL PRESSURE MEASUREMENT DEVICES[7]

Sensor	Excitation signal	Output level	Accuracy, %	Pressure range, kPa (psi)	Temp. range, °C (°F)	Shock and vibration sensitivity	Stability, % per year	Life or calibration shift with use
Unbounded strain gauge	ac-dc Regulated 10 V ac-dc	Low	0.25	3.4 to 69,000 (0.5 to 10,000)	-195 to 315 (-320 to 600)	Good	0.5	<0.5% cal. shift after 10^6 cycles
Bonded-foil strain gauge	10 V ac-dc	Low	0.25	35 to 69,000 (0.5 to 10,000)	-54 to 121 (-65 to 250)	Very good	0.5	>10^6 cycles
Thin-film strain gauge	10 V ac-dc	Low	0.25	103 to 69,000 (15 to 10,000)	-195 to 315 (-320 to 600)	Very good	0.25	>10^6 cycles with <0.25% cal. shift
LVDT	ac Special	High	0.05	207 to 69,000 (30 to 10,000)	-18 to 74 (0 to 165)	Poor	0.25	>10^6 cycles life
Capacitance	ac-dc Special	High	0.05 to 0.5	0.07 to 69,000 (0.01 to 10,000)	-18 to 815 (0 to 1,500)	Poor to good	0.05 to 1.0	>10^7 cycles with <0.05% cal. shift
Force-balance	ac Line Power	High	0.05	6.9 to 35,000 (1 to 5,000)	4.4 to 74 (40 to 165)	Poor	0.05	>10^7 cycles with <0.05% cal. shift
Potentiometer	ac-dc Regulated	High	1	35 to 69,000 (5 to 10,000)	-54 to 149 (-65 to 300)	Poor	0.5	<10^6 cycles life
Variable reluctance	ac Special	High	0.5	3.0 to 69,000 (0.4 to 10,000)	-195 to 315 (-320 to 600)	Very good	0.5	>10^4 cycles life
Piezoelectric	dc Amp and self-generating ac	Medium	1	0.7 to 69,000 (0.1 to 10,000)	-268 to 204 (-450 to 400)	Excellent	1	Unmeasurable use effects
Piezoresistive	10 V to 28 V dc	Medium	0.25	0.7 to 35,000 (15 to 5,000)	-54 to 121 (-65 to 250)	Very good	0.25	<0.25% cal. shift after 10^6 cycles

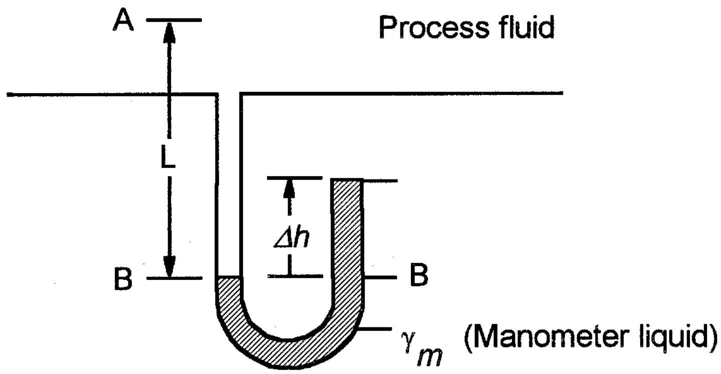

Figure 4.3-1. U-tube manometer.[1]

Differential manometers are used to measure the difference in pressure between two points. Figure 4.3-2 depicts a differential manometer. In the figure, the difference in pressure can be determined as:

$$\Delta P = \gamma_m \Delta h$$

where:

ΔP = the difference in pressure, and

γ_m and Δh = as defined previously.

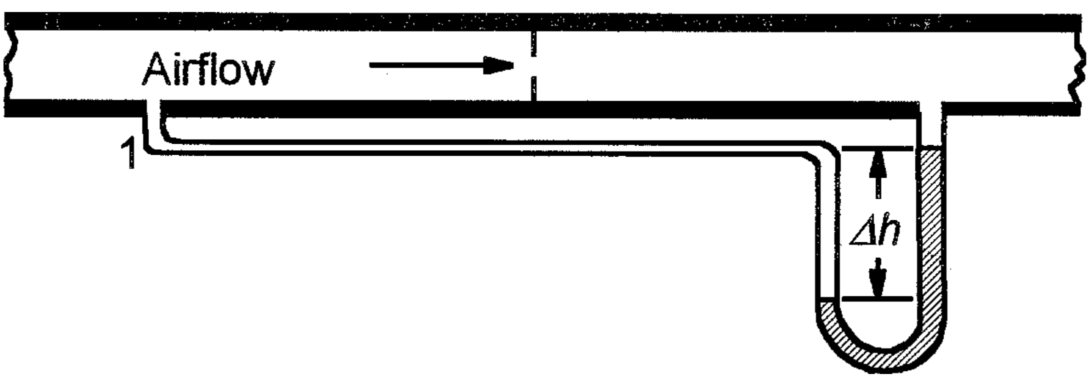

Figure 4.3-2. Differential manometer.[1]

Manometers can be used to make accurate measurements of pressure at specific points and pressure drop across two points, such as the inlet and outlet of an air pollution control device. However, measuring pressure by manometers tends to be labor-intensive and is not practical in many applications. Furthermore, manometer measurements do not lend themselves readily to automated recording. For these reasons, they generally are not used where frequent or continuous pressure measurement is required. Manometers often are used in conjunction with pitot tubes to measure the difference between impact and static pressure in a gas stream for velocity determinations or to measure pressure drop. For gas velocity measurement, the two most common pitot tube types are the standard and the S-type. The standard pitot tube consists of a small (impact) tube within a larger tube that is positioned so the open end of the smaller tube faces the gas stream. Static pressure is measured by holes located radially around the large tube. The S-type pitot tube consists of separate impact and static pressure tubes, the ends of which are oriented 180 degrees relative to each other. The pitot is positioned so that the impact pressure tube faces the gas stream. Differential measurement using pitot tubes also is commonly made in combination with a Magnehelic™ gauge, which is described in the following section.

Properly designed manometers, which incorporate accurate scales and are constructed to minimize the effect of capillarity, do not require calibration. As a result they are often used as standards for calibrating other types of pressure measuring devices. Conventional U-tube manometers are used as pressure standards in the range of 0.025 to 690 kilopascals (kPa) (0.0036 to 100 pounds per square inch [psi]) with a calibration uncertainty of 0.02 to 0.2 percent. Specially designed manometers, known as micromanometers, are used as pressure standards to measure pressure differences in the range of 5.0×10^{-5} to 5.0 kPa (7.0×10^{-6} to 0.72 psi).

4.3.2 Mechanical Dial Pressure Gauges[2-5,8]

Mechanical dial pressure gauges are used in a wide variety of applications and offer an economical solution for noncontinuous or manually recorded pressure measurement. As explained previously, mechanical dial pressure gauges incorporate a mechanical sensing element. In addition to the type of sensor, pressure gauges are classified according to function, case type, general type of use, and accuracy. Classifications by function include standard gauge for measuring gauge pressure; vacuum gauge for negative pressure; compound gauge for both positive and negative pressure; duplex gauge for measuring two separate pressure sources; differential pressure gauge for measuring the difference in pressure between two points; retard gauge, in which a portion of the gauge scale, usually the upper portion, is compressed to allow a larger range of full scale; and suppressed scale gauge, in which pressure is indicated only between two values, a lower limit and an upper limit.

Classification of pressure gauges by case type is based on size, which ranges from 3.8 to 40.6 cm (1.5 to 16 in.); method of mounting; location of connection; and case construction. The pressure gauge classifications by use include commercial, industrial, process, and test gauges. Classification by accuracy is described in Section 4.3.2.3. The classifications of mechanical dial pressure gauges by element type include Bourdon, bellows, and diaphragm. These types of sensing elements are described in detail in Section 4.3.2.2.

The ANSI has published standards for mechanical dial pressure gauges, titled *Gauges - Pressure Indicating Dial Type - Elastic Element* under ANSI B 40.1 and ANSI B 40.1M-1979. Table 4.3-3 lists commonly available pressure gauges and their typical measurement ranges.

TABLE 4.3-3. PRESSURE GAUGES COMMONLY AVAILABLE[3]

Element	Application	Minimum range (commonly supplied)	Maximum range (commonly supplied)
Bourdon	Pressure	0-12 psi	0-60,000 psi
	Vacuum	0-30 in. Hg vac	0-30 in. Hg vac
	Compound	30 in. Hg-0-15 psi	30 in. Hg vac-0-300 psi
Bellows	Pressure	0-1 in. Hg	0-100 psi
	Vacuum	0-1 in. Hg vac	0-30 in. Hg vac
	Compound	Any total span of more than 1 in. Hg	Any total span of less than 100 psi
Metallic diaphragm	Pressure	0-10 in. H_2O	0-10 psi
	Vacuum	0-10 in. H_2O	0-30 in. Hg vac
	Compound	Any total span of more than 10 in. H_2O	30 in. Hg vac-0-10 psi

4.3.2.1 <u>Measurement Principle and Description of Sensor</u>

Mechanical dial pressure gauges use an elastic chamber to detect the pressure. As the pressure changes, the elastic chamber moves. This movement is converted into proportional motion and transferred to the pointer. The pointer's position gives a reading of the pressure measurement using a calibrated scale located immediately behind the pointer.

4.3.2.2 <u>System Components and Operation</u>

The components of a mechanical dial pressure gauge consist of one or two sensing elements; a linkage that transfers the movement of the sensor to a geared sector and pinion; a needle connected to the pinion; a scale to indicate the pressure; a stem, which is connected to the pressure vessel or conduit; and a case. Figure 4.3-3 depicts these basic components.

Most mechanical dial pressure gauges use either a bourdon tube, bellows, or diaphragm to measure pressure. The following paragraphs describe each of these types of sensing elements.

4.3.2.2.1 <u>Bourdon elements</u>. Bourdon tubes are produced in four basic designs. The most commonly used type of Bourdon element consists of a narrow tube with elliptical cross section that is bent into a circular arc, as shown in Figure 4.3-3. This design is referred to as the C-shaped Bourdon. Other Bourdon designs include spiral, helix, or twisted tubes. The fitting end of the tube (shown at the bottom in the figure) is open to the process fluid; the free end of the tube is sealed and connected by linkage to the gauge pointer or needle. When pressure is applied to the gauge, the tube tends to straighten, thereby actuating the pointer to read the corresponding pressure on the scale.

Bourdons are springs reacting to the force of pressure. The tubing material type, wall thickness, and length vary greatly to allow for a broad range of applications and accuracy.

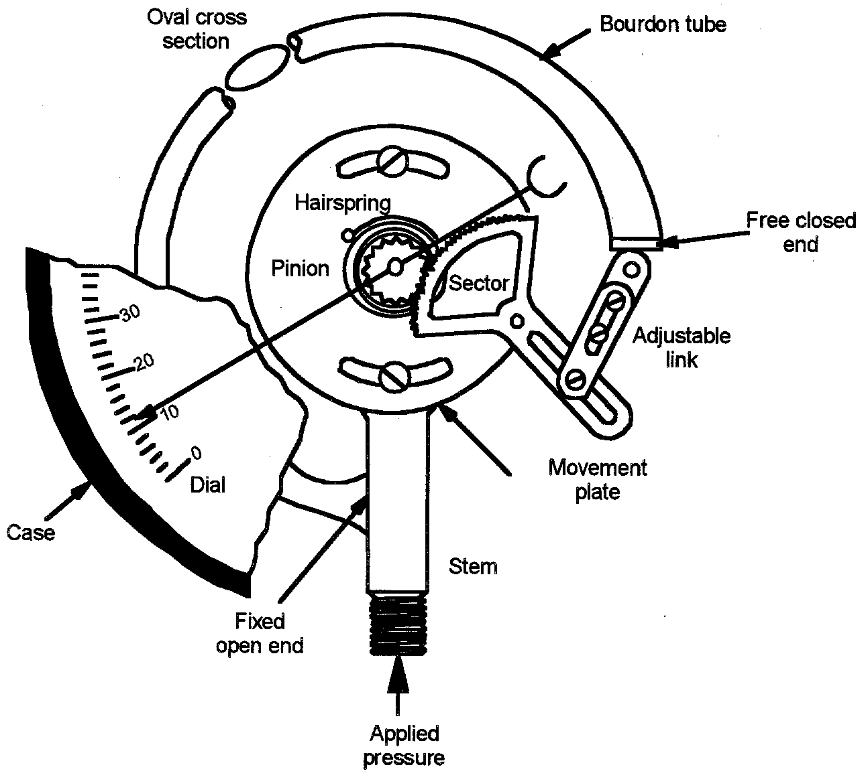

Figure 4.3-3. Bourdon-tube pressure gauge.[4]

Bourdon-tube gauges are reliable if not subjected to excessive pulsations in pressure or external shock. To dampen the effect of pulsations, some gauges are designed with fluid-filled cases.

4.3.2.2.2 <u>Bellows elements</u>. In a bellows-type pressure gauge, the applied pressure pushes against a miniature thin-walled bellows, forcing the bellows to move as shown in Figure 4.3-4. The bellows movement is transferred to a pointer. Brass is the material most often used for bellows elements. A coil spring added to the bellows reduces fatigue and stress. Bellows most commonly are used for low-pressure measurements.

4.3.2.2.3 <u>Diaphragm elements</u>. For mechanical dial gauges, diaphragms typically are made from thin metallic material joined to form small capsules. Figure 4.3-5 illustrates a diaphragm-type pressure gauge. Diaphragm elements work well in low-pressure applications and for absolute-pressure gauges.

A Magnehelic™ gauge is a special type of diaphragm-based pressure gauge commonly used with pitot tubes for gas velocity measurements. Magnehelic™ gauges also are commonly used to measure differential pressure across air pollution control devices. The Magnehelic™ uses a proprietary magnetic linkage to translate the deflection of the diaphragm to the movement on the pointer.

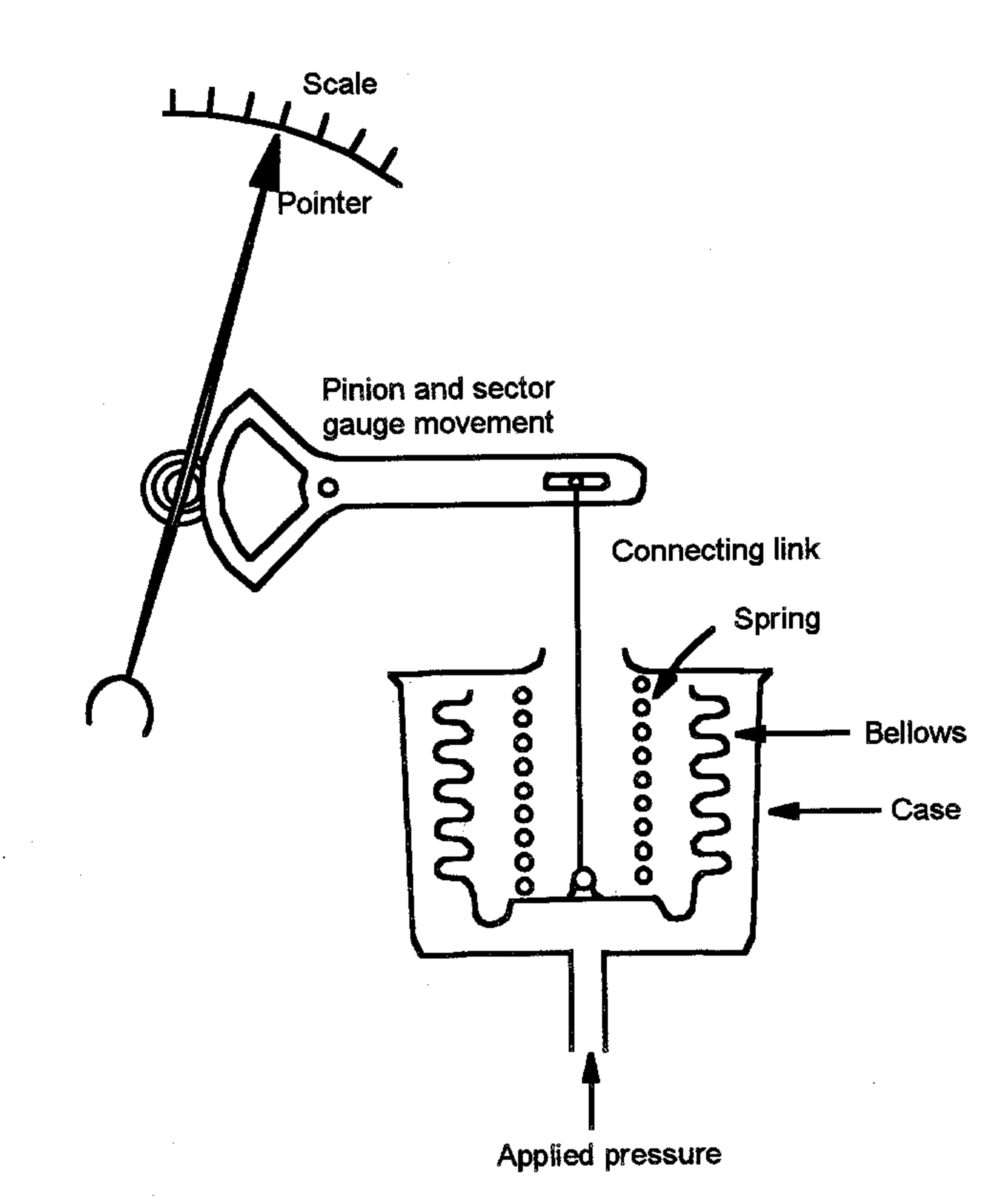

Figure 4.3-4. Bellows-type pressure gauge.[4]

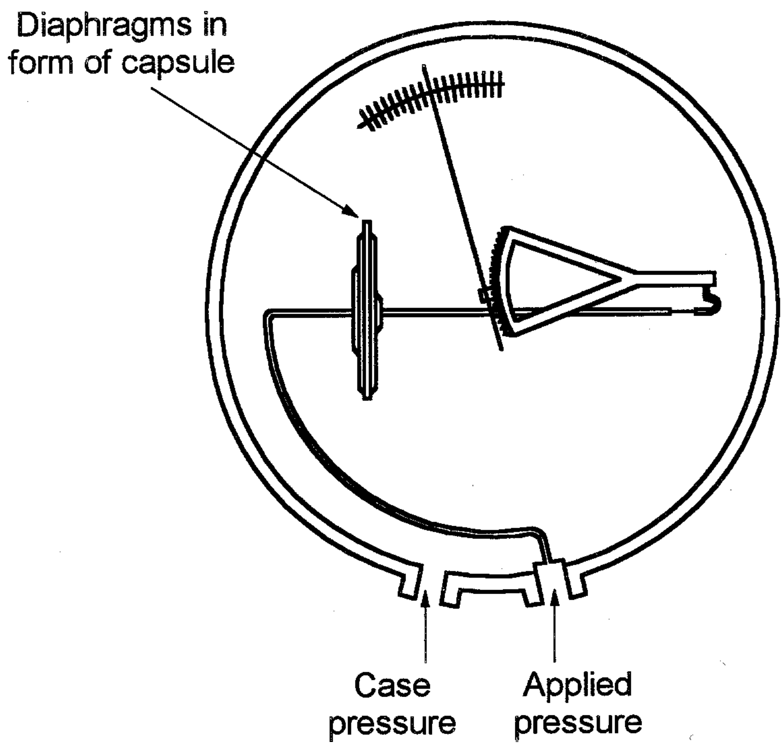

Figure 4.3-5. Diaphragm-type pressure gauge.[4]

4.3.2.3 Accuracy[3,9]

The accuracy of the pressure gauge is generally represented as a percentage of the gauge's range. A pressure gauge with the range of 0 to 250 psi with an accuracy of 1 percent would have a maximum error of 2.5 psi.

A wide range of accuracies are available for pressure gauges. The ANSI classifies the accuracies into seven grades as shown in Table 4.3-4. Increasing accuracy of the pressure gauge also increases the cost of the gauge. Grade B gauges are manufactured in the largest quantities and considered as the commercial class; common uses include water pumps, paint sprayers, and air compressors. Grade 2A gauges are used in petroleum, chemical, and industrial processes and are commonly referred to as process gauges. Grade A and 2A gauges often are used to measure the pressure drop across air pollution control devices. Grade 3A and 4A gauges, which are referred to as test gauges, have lighter moving parts and smaller bearings than do gauges of other grades, resulting in reduced friction and increased sensitivity to small pressure changes.
Grade 4A gauges also incorporate temperature-compensating linkages to minimize calibration shifts due to dimensional changes of the gauge components.

TABLE 4.3-4. PRESSURE GAUGE CLASSIFICATIONS[3]

Grade	Permissible error ±% of span		
	First 25%	Middle 50%	Last 25%
4A	0.1	0.1	0.1
3A	0.25	0.25	0.25
2A	0.5	0.5	0.5
A	2.0	1.0	2.0
B	3.0	2.0	3.0
C	4.0	3.0	4.0
D	5.0	5.0	5.0

4.3.2.4 Calibration Techniques[3-4]

The required accuracy, the type of gauge, and the operating conditions help to determine the frequency of calibration required. Operating conditions such as vibration, pulsating pressure, and corrosion affect the useful life of the pressure gauge. Lower-grade gauges, such as Grade B, are usually inexpensive enough that it is more economical to replace the gauge than to repair and recalibrate it.

Calibrating a pressure gauge involves applying a controlled pressure source to the pressure gauge and comparing it to a pressure standard of known accuracy. Controlled pressure sources include air pressure, vacuums, and hydraulic pressure. Pressure standards include precision mercury-column manometers, precision test gauges, and deadweight testers, which use standard weights mounted on a piston to apply specific pressure values to the pressure gauge. Deadweight testers generally are used for higher pressures (4.1 to 103 MPa [600 to 15,000 psi]).

For the actual calibration, the pressure standard is placed in-line with the gauge to be calibrated. A tee is placed as close as possible to the gauge to be calibrated. After the system has been proven to be leak tight, the controlled pressure is applied. The pressure gauge and the pressure standard are compared at incremental pressures for the entire range of the pressure gauge. From this comparison, the error of the pressure gauge can be determined. Figures 4.3-6 and 4.3-7 illustrate the setups for calibrating pressure gauges using precision manometers and deadweight testers, respectively.

Calibration can be checked using a tee in the pressure line to perform a zero check by nulling to the atmosphere and an operating pressure check by connecting the gauge to a calibrated reference meter or manometer.

4.3.2.5 Recommended QA/QC Procedures[3-4,10]

Those parts of the pressure monitoring system requiring special attention include the bellows, bourdon tubes, springs, and other interior components, all of which are subject to damage and corrosion. Before installation, it is important to check that the pressure gauge is to be used for its intended purpose. The conditions most detrimental to pressure gauges are pulsating pressure, vibration, and internal and external corrosion. Steps also should be taken to ensure that pressure gauges are not subjected to excessive pressure or temperature extremes. According to one manufacturer of air pollution control devices, gauges for measuring pressure drop across a control device generally should be calibrated or replaced quarterly.

4.3.2.5.1 Quality control. Inspection and calibrations of the pressure gauge should be made and recorded at periodic intervals. As stated in Section 4.3.2.4, the frequency of these events depends on the operating conditions, required accuracy, and the type of gauge.

The gauge manufacturer can best recommend at what interval these inspection and calibrations should occur with regard to specific operating conditions for the gauge. Calibration measurements should be recorded both before and after any adjustments are made to the pressure gauge. Calibration records should identify the instrument calibrated, date of calibration, person that performed the calibration, and the measurements observed.

Inspections should visually check that the pressure gauge appears to be operating normally. An inspection log will provide a record to ensure that inspections take place at recommended intervals and can help identify potential problems with pressure gauges. Quick checks include possible leaks, no dial reading, and excessive vibration.

4.3.2.5.2 Quality assurance. Quality assurance should include review of recorded pressure measurements, calibration records, and inspection log. The QA should be performed by a person not involved with regular measurements or calibrations of the pressure gauge.

4.3.3 Pressure Transducer[3-5,7]

As explained in the introduction to Section 4.3, the term pressure transducer in this document refers to devices that convert pressure to electrical signals, which then are displayed and/or recorded as pressure measurements. Thus, pressure transducers include the sensor, power supply, output signal conditioner, and the associated electronic circuitry. Pressure transducers can be made using many different types of pressure elements and sensing systems. Among the types of pressure transducers in use are strain gauges, LVDT's, capacitance, force balance, potentiometric, variable reluctance, piezoelectric, and piezoresistive transducers.

Different types of pressure-monitoring systems are available, including those using millivolt output, amplified voltage output, and current loop output transducers. Millivolt systems use small sensors remote from the signal-conditioning device. Amplified voltage systems

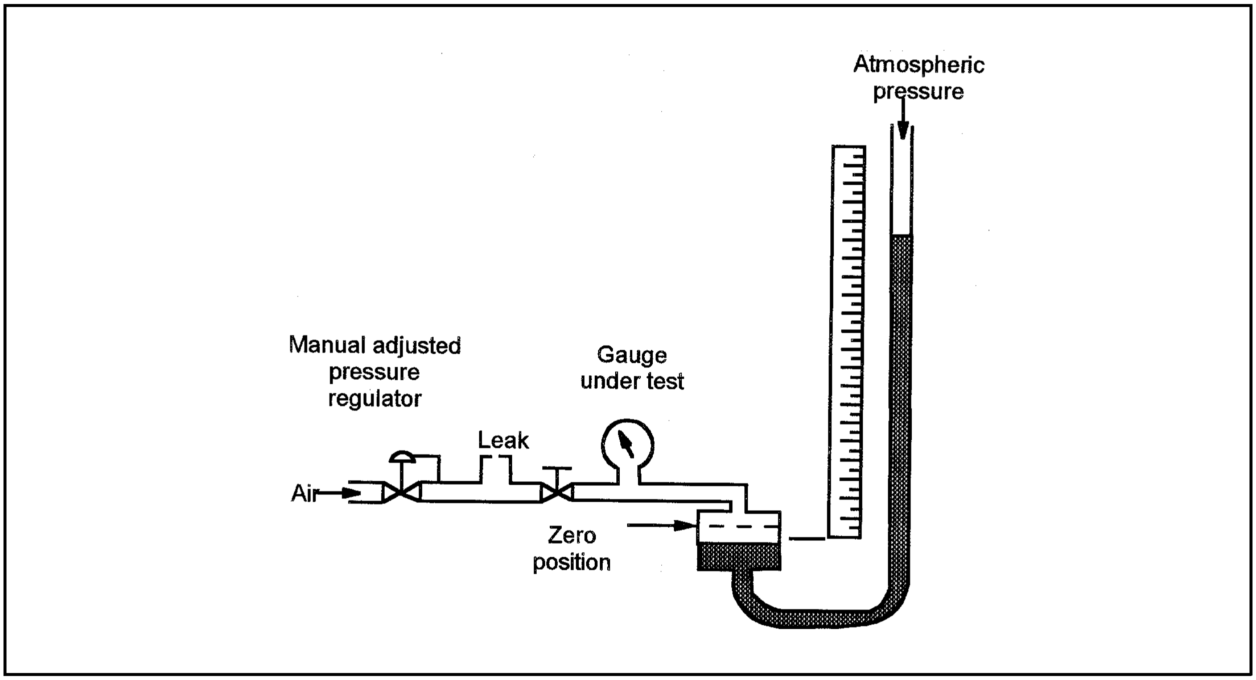

Figure 4.3-6. Setup for calibrating a pressure gauge using mercury column manometer.[2]

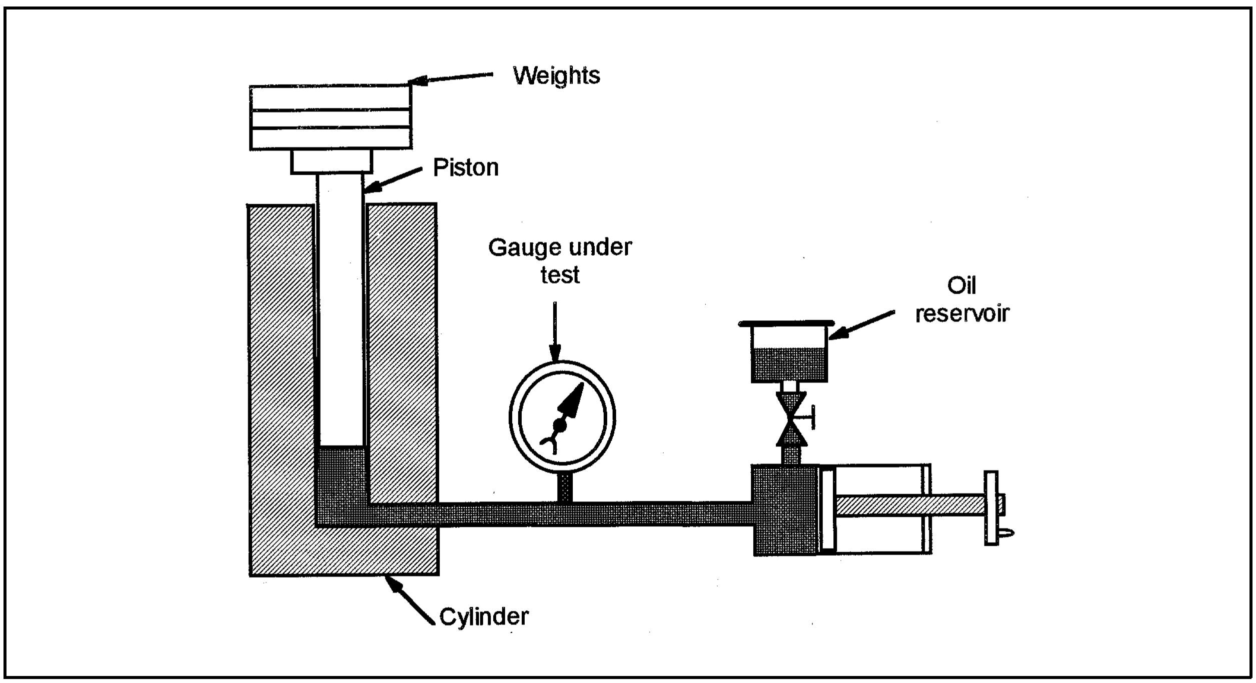

Figure 4.3-7. Setup for calibrating a pressure gauge using a deadweight tester.[2]

employ sensor-contained amplifiers in order to overcome electromagnetic interferences. Current loop systems have built-in transmitters, allowing long runs of direct-wire connection between the sensor and the signal processor. Selection of pressure-sensing elements depends on the pressure range to be monitored, temperature, and the advantages and disadvantages of specific devices.

4.3.3.1 Measurement Principle and Description of Sensor

4.3.3.1.1 Strain gauge transducers.[3-5,8,11] Strain gauge transducers operate on the principal that the electrical resistance in a metal (usually in the form of a fine wire or foil) changes when it is elastically deformed due to an applied stress. The change in resistance results in an electrical output signal, which varies proportionally to compressive or tensile strain (compression or expansion of the diaphragm). Strain gauge transducers use several sensor designs, the most common of which are the bonded foil, unbonded metallic filament, thin film, and the diffused semiconductor strain gauges. Diffused semiconductor strain gauges are also referred to as piezoresistive pressure transducers and are described in Section 4.3.1.4. The other types of strain gauge transducers are described in the following paragraphs.

In a bonded strain gauge transducer, four strain gauges are bonded to the diaphragm in a Wheatstone bridge configuration, as shown in Figure 4.3-8. When the diaphragm is subjected to pressure, two opposing strain gauges (e.g., R1 and R3 in the figure) are put into tension, and the other two gauges (i.e., R2 and R4 in the figure) undergo compression and there will be a potential difference in voltage across terminals B and D. The Wheatstone bridge arrangement has the advantage that it compensates for strain induced by changes in temperature because the ratio of R1 to R4 remains the same as the ratio of R2 to R3. Figure 4.3-9 depicts a bonded strain gauge pressure transducer.

In an unbonded strain gauge transducer, one or more filaments of resistance wire are stretched between supporting insulators. The supports are either attached directly to an elastic element or are attached by means of an insulating coupling. When the sensing element is displaced, the filament length changes, causing a change in resistance. Thin-film strain gauge transducers use a metallic or semiconductor film for the resistance elements.

4.3.3.1.2 Capacitance transducers.[3,5,12] Capacitance transducers consist of two parallel conducting plates placed a short distance apart and operate on the principle that the capacitance between plates varies with their separation distance. As the diaphragm, which acts as one of the conducting plates, deflects under the applied pressure, the distance to the other conducting plate decreases, resulting in a change in the charge between plates. Figure 4.3-10 depicts a capacitance transducer.

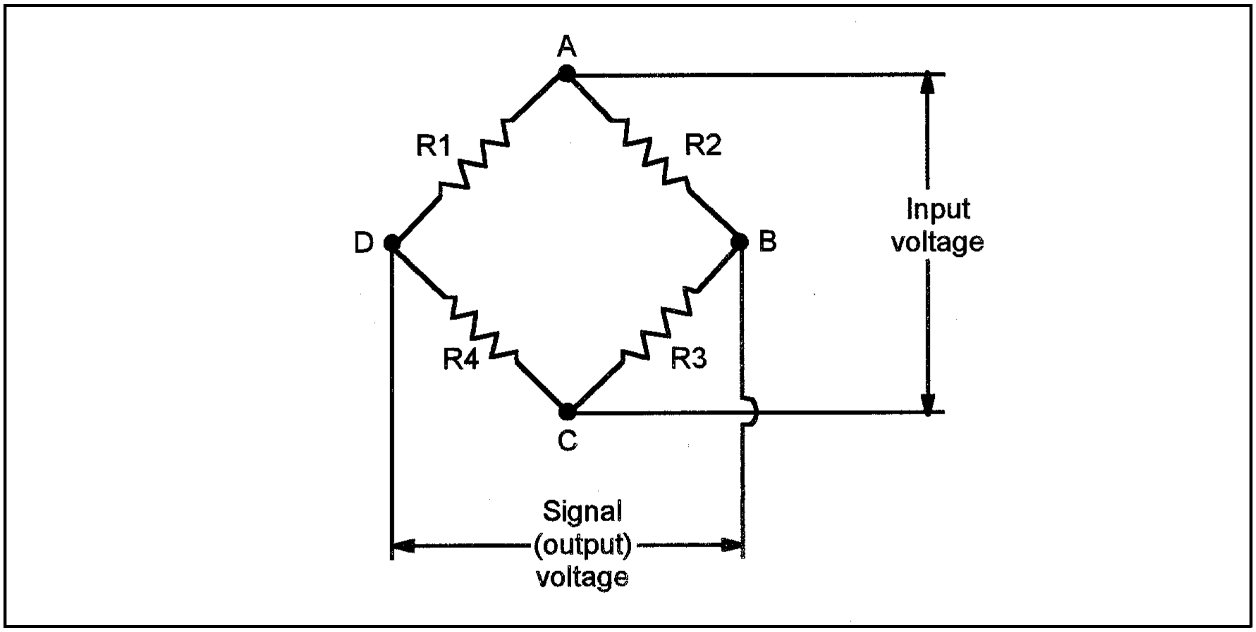

Figure 4.3-8. Wheatstone bridge.[3]

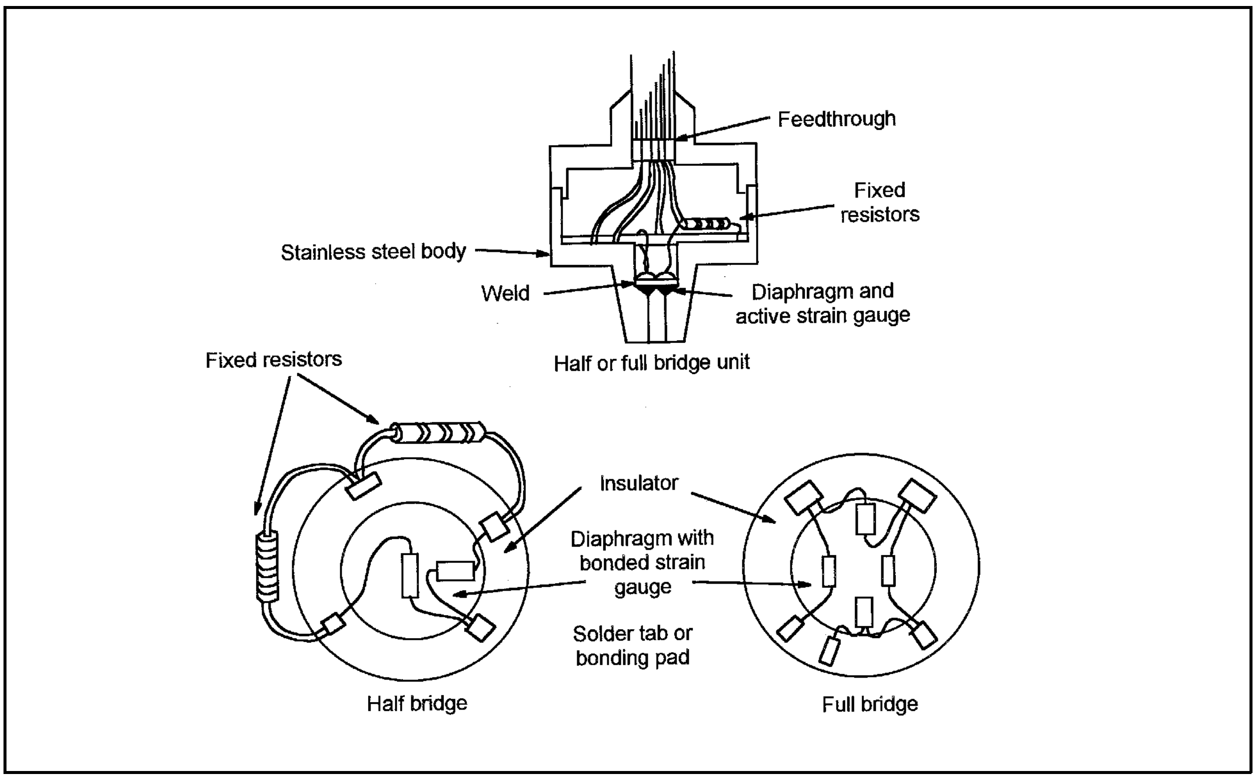

Figure 4.3-9. Strain gauge pressure transducer.[5]

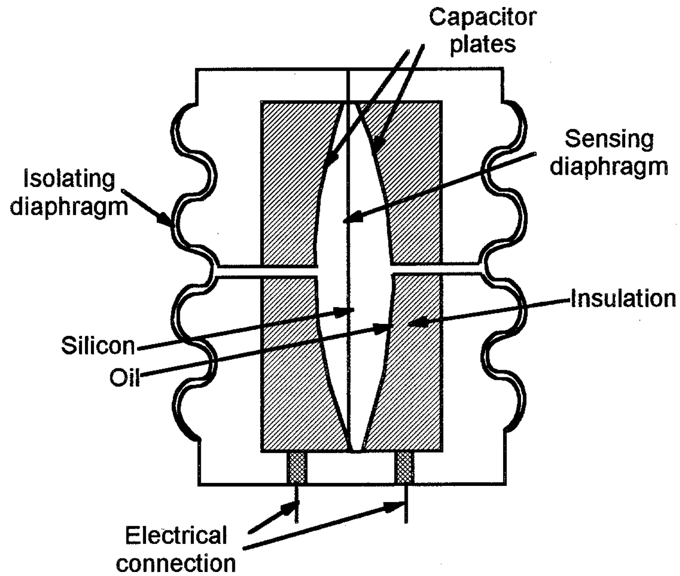

Figure 4.3-10. Capacitance pressure transducer.[5]

Diaphragms in capacitance transducers can be fabricated of stainless steel, ceramics, or other chemically nonreactive materials. Capacitance elements generally produce a stronger electrical signal than strain gauge elements generate, and less signal amplification is required with capacitance transducers. However, because capacitance transducer diaphragms undergo less movement than strain gauge diaphragms, small dimensional changes due to temperature are more critical for this type of transducer.

4.3.3.1.3 LVDT's.[3-5] Linear variable differential transformers convert small motions to electrical signals when a magnetic core moves between a primary and two secondary wire coils. A constant ac voltage is applied to the primary coil. The secondary coils are in opposition so that the signal induced in one is 180 degrees out of phase with the signal in the other secondary coil. When the metallic core is moved from the zero position, the voltage in the secondary coils becomes unbalanced and an electronic signal is induced in the leads. Figure 4.3-11 depicts an LVDT pressure transducer.

4.3.3.1.4 Other types of pressure transducers. The following paragraphs briefly describe some of the other commonly used types of pressure transducers.

Force Balance. In a force balance transducer, a mechanical pressure sensor moves one end of a balance beam, which generates an inductive or reluctive signal that is amplified and converted to pressure units.

Potentiometric. A potentiometric pressure transducer uses a mechanical pressure element such as a bellows to drive the wiper arm of a potentiometer and an ammeter to measure the

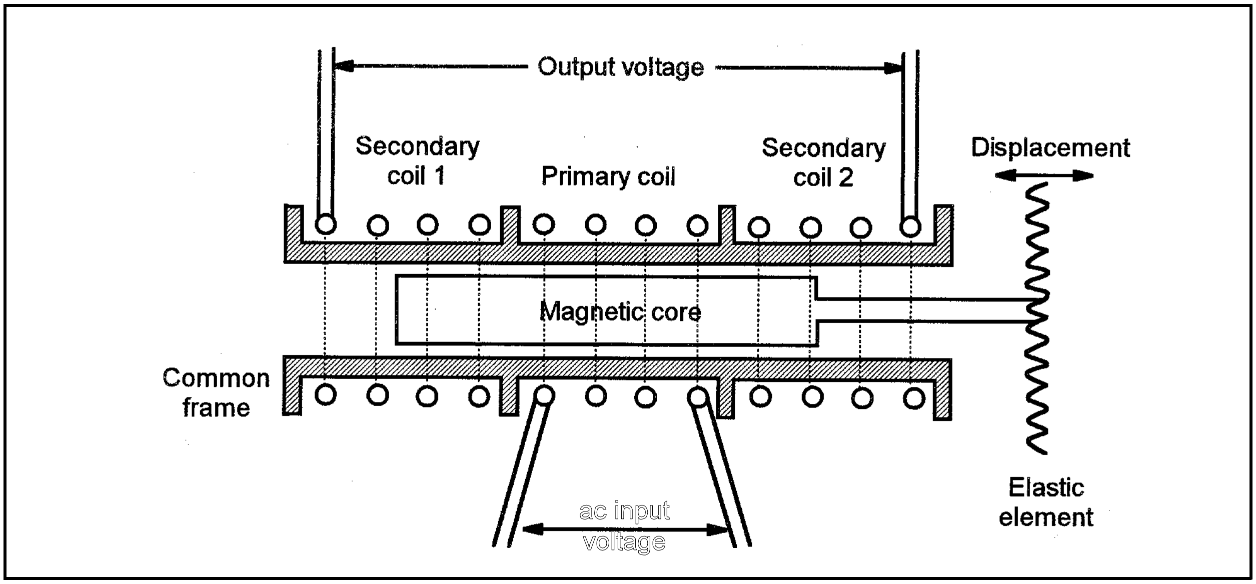

Figure 4.3-11. Linear variable differential transformer (LVDT).[4]

change in circuit current resistance resulting from the change in pressure on the bellows. The amount of change is then correlated to the change in pressure, and the ammeter may be calibrated in units of pressure.

Variable Reluctance. In a variable reluctance transducer, two coils with equivalent impedances are wired in series with a magnetically permeable stainless steel diaphragm mounted between them. When pressure is applied, the diaphragm deflects, and the magnetic flux density in one coil changes. The induction in the coil changes and the resulting output signal is proportional to the applied pressure.

Piezoelectric. The principle behind the piezoelectric transducer is that certain crystals, such as quartz or polycrystalline ceramics, generate an electric charge when strained. In a piezoelectric transducer, thin crystal wafers are stacked in series (positive side to negative side). One side of the stacked wafers is in contact with a diaphragm, and an electrical connection is made on the other side of the crystal stack. As pressure is applied, the crystal wafers are compressed, and a charge proportional to the pressure is generated.

Piezoresistive. Piezoresistive transducers are a variation of the bonded strain gauge transducer. In a piezoresistive transducer, strain-sensitive resistors are implanted or diffused into silicon wafers and connected in a Wheatstone bridge configuration. A diaphragm is then created by etching or grinding the silicon wafer. As pressure is applied, the resistors are strained, causing an imbalance across the Wheatstone bridge proportional to the applied pressure.

4.3.3.2 System Components and Operation

Pressure transducer monitoring systems consist of pressure transducers, a power supply, and a signal processor with an output device such as a meter, controller, or recorder.

4.3.3.3 Accuracy

Initial accuracy of general purpose pressure transducers ranges from approximately 0.05 percent to 1.5 percent of true pressure. Good sensor system calibration and compensation results in an error of less than 2 percent of scale. Strain gauge pressure transducers respond quickly and have virtually infinite resolution. Linear variable differential transformers exhibit good linearity with extremely high resolution.

4.3.3.4 Calibration Techniques

Pressure transducer systems must be calibrated for sensitivity, zero balance, nonlinearity, hysteresis, and thermal pressure coefficient. Sensitivity calibration is done by adjusting bridge resistance by adding fixed resistors or adjusting potentiometers to produce output calibrated to a known pressure source. Zero balance is also calibrated using potentiometers or fixed resistors to adjust the bridge resistance. Zero balance is affected by temperature, so it should be adjusted at operating temperature of the equipment or by using a calibrated temperature chamber. Nonlinearity and hysteresis can be compensated for using equations programmed into a microprocessor-controlled signal-conditioning device or transmitter. Thermal effects on sensitivity may be difficult to compensate for and require the use of a calibrated pressure source and temperature chamber.

A simple calibration check can be performed using a tee in the pressure line to perform a zero check by nulling to the atmosphere and an operating pressure check by connecting the gauge to a calibrated reference meter or manometer.

4.3.3.4.1 Sensor. Pressure transducers can usually be returned to the manufacturer for recalibration and scaling. Calibrating a pressure sensor involves applying a controlled pressure source to the pressure sensor and comparing it to a pressure standard of known accuracy. Controlled pressure sources include air pressure, vacuums, and hydraulic pressure. Pressure standards include deadweight testers, precision test gauges, and manometers.

4.3.3.4.2 System. Pressure transducer systems can be calibrated in the field using a series of pressure manifolds. A tee is placed as close as possible to the gauge to be calibrated. After the system has been demonstrated to be leak tight, the controlled pressure is applied. The pressure gauge and the pressure standard are compared at incremental pressures for the entire range of the pressure gauge. From this comparison, the error of the pressure sensor can be determined, allowing adjustments to be made.

Specifications and tests of potentiometric pressure transducers are standardized by the ANSI and the Instrument Society of America (ISA) in standard ISA-S37.6. This guide specifies calibration procedures, gives examples of recordkeeping sheets, and contains bibliographic references. The ISA-S37.3 standard gives similar specifications and tests for strain gauge pressure transducers. The ISA-S37.6 standard is intended to be a guide for technical personnel at user facilities as well as a guide for manufacturers. It provides standard practices for specifying, calibrating, and testing performance characteristics of potentiometric pressure transducers. This group includes absolute pressure transducers, differential pressure transducers, and gauge pressure transducers. Many types of measurement errors and other terminology are defined.

The basic equipment required for acceptance tests and calibrations consists of a pressure source, an “excitation” (voltage) source, and an output voltmeter. The combined errors or uncertainties of the measuring system made up of these three components should be less than 20 percent of the acceptable error of the system being tested and should be traceable to NIST standards. A pressure medium similar to the one intended to be measured by the monitoring system should be used. The pressure source should be capable of producing 125 percent of the full scale of the transducer. These pressure sources are typically air or oil piston devices, which are measured using a precision dial gauge or mercury manometer. Voltage sources can be batteries or electronically regulated power supplies with current-limiting devices. The output-indicating device or voltmeter/ratiometer may be analog or digital.

Calibration and testing is to be performed at ordinary room conditions. The procedure is summarized as follows:

1. Visually inspect for defects and other mechanical problems.

2. Use a precision ohmmeter to measure transduction element resistance; verify the number of potentiometric elements or taps, and check electrical connections.

3. Use a megohmmeter to measure the insulation resistance between all the element terminals or leads connected in parallel and the case (ground pin) at 50 V unless another voltage is specified.

4. Verify the dielectric withstand voltage, using a sinusoidal ac voltage test with all the transduction element terminals paralleled and tested to case and ground pin.

5. Connect the transducer to the pressure source, the power supply, and indicating instrument (readout). After allowing adequate warmup, leak check the setup. Once leak check is passed, recheck the electrical connections for correctness and impedance. Run two or more complete calibration cycles, generating at least 11 data points (pressures). Record the readout at each pressure in both the ascending and descending directions (increasing and decreasing pressures). From these readings, determine the endpoints, full scale output, linearity, hysteresis (or combine linearity and hysteresis), friction error, and repeatability.

6. For differential pressure transducers, perform a three-point (e.g., 10, 50, and 90 percent) calibration cycle at both the minimum and maximum specified reference pressures, to establish reference pressure error.

4.3.3.5 Recommended QA/QC Procedures[4-5,7,11-12]

Those parts of the pressure monitoring system requiring special attention include the diaphragms of the pressure transducers, which are subject to damage and corrosion, and the electronic calibration of the signal processor, which can drift over time.

Subjecting pressure transducers to pressures beyond their design limits is a common problem. Manufacturers typically specify a normal operating pressure range and a proof pressure; exceeding the proof pressure generally results in a permanent calibration shift. Exposing pressure transducers to temperatures above or below the specified operating ranges also can degrade the stability of the instrument or result in permanent calibration shifts. Excess vibration is another cause of transducer stability degradation.

Sensors and transmitters, as well as data acquisition systems, are all adversely affected by harsh environments. The more sensitive the sensor, the more susceptible to corrosion, heat decalibration, and other problems. Picking the correct sensor requires some determination of its operating environment. Sensors that will be exposed to moisture, the outdoors, a hazardous (explosive) environment, temperature extremes, shock, or vibration must be manufactured to withstand those conditions; or they will not give reliable service. If the sensor system will be exposed to strong electrical interference that can be characterized, sensor manufacturers can incorporate electromagnetic interference filters in the design. It is always recommended to use twisted-wire pairs for transmission of sensor outputs because of all the interference generated by walkie-talkies, motor brushes, static discharges, and general electrical activity in the vicinity of the instrument. Most of the time, shielding is not required for pressure transmitter wire because the signal is strong enough to prevail. Wire size is not that critical; 18 gauge is generally adequate unless the wires are very long. Because electrical excitation is required by all electronic pressure transducer elements, the quality and strength of electrical power supplied can impact performance.

Corrosion-resistant coatings and putties can be used to protect transducer diaphragms. High-precision voltage and current-calibrating devices are used to check and recalibrate signal processors according to manufacturers' specifications.

4.3.3.5.1 Frequency of calibration.[13-14] Calibration of pressure transducer systems should follow a consistent procedure in order to allow comparisons of performance change over time. The recommended frequency of calibration depends largely on site-specific conditions. The starting point for determining calibration intervals, according to independent calibration laboratories, is a search for applicable military specifications. These specifications are issued by the procurement arm of the Department of Defense. Military Standards define requirements for manufacturers of equipment the military purchases. Applicable standards include MIL-STD-1839A, which lists detailed calibration and measurement requirements, including frequency, imposed on equipment suppliers by the Department of Defense. As a result, calibration intervals should be available for each component of military-acceptable (specified by a MIL-SPEC number) monitoring systems. Typically, the desired calibration intervals, as well as accuracy requirements, are part of the MIL-SPEC. Manufacturers of commercial items generally supply this information as a CMRS included in the owner's manual.

If there is no applicable MIL-SPEC calibration interval and no information can be obtained from the manufacturer for a particular sensor system, 6 months is the initial default calibration interval if there are moving parts, as is the case for pressure transducers. More frequent system calibration cycles may be indicated when using transducers outside the recommended operating pressure and temperature ranges.

These default calibration intervals should not be relied on indefinitely; they are the starting points for a method to determine the maximum calibration period for a particular installation. At the end of the manufacturer's or otherwise determined initial calibration period, the system should be calibrated, and the data obtained should be charted. If the system is near or beyond the limit of acceptable accuracy (80 percent of acceptable error) and there were no process excursions or conditions suspected of causing the decalibration, it can be concluded that the calibration interval is too long. In such a case, the system should be recalibrated to the center of the acceptable band, and the calibration interval should be shortened. At the end of the second calibration period, calibration should be checked to determine if the system is drifting. If the system is near or beyond the limit of acceptable accuracy, similar steps should be taken, and the calibration period should be further shortened. This process should be continued until the system is determined to be within the acceptable limit of accuracy at the end of the calibration interval. If, at the end of the initial calibration period, the system is determined to be within acceptable tolerance, recalibration is not necessary, but the results should be recorded, and the same calibration interval should be maintained for another calibration period. At the end of the second calibration period, calibration should be checked to determine if the system is drifting. If the system measures outside the acceptable band, it can be concluded that it took between one and two periods to lose calibration, and the calibration interval was acceptable. In any case, it is important to maintain a log of calibration checks and the results and actions taken. Calibration data should be reviewed at least annually in order to spot significant deviations from defined procedures or tolerances.

4.3.3.5.2 <u>Quality control</u>. A written procedure could be prepared for all instrument calibrations. These procedures could include:

1. The recommended interval for zero and span checks of each component of the pressure measurement system. Readings before and after adjustment should be recorded.

2. A requirement that each pressure transducer and its related system components be calibrated in accordance with manufacturers' recommended procedures. Calibrations should be performed at intervals determined according to the procedures described in Section 4.3.3.5.1. Readings before and after adjustment should be recorded; if no adjustments are necessary, that also should be recorded in the log.

3. Designation of person(s) to perform the calibrations. All records should include identification of the instrument component calibrated, the date of calibration, and the initials of the person who performed the calibration.

4.3.3.5.3 <u>Quality assurance</u>. The calibration logs can be reviewed to confirm that calibrations were completed and performed properly. The person performing this review and the review frequency also should be specified. The written calibration procedures should be reviewed and updated in the event of any system modifications or instrumentation changes.

4.3.4 References for Pressure Measurement

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4.4 FLOW RATE MEASUREMENT SYSTEMS

4.4.1 Introduction

The need for quantifying fluids (i.e., liquids or gases) flowing through closed conduits (i.e., pipes) is widespread; and flow measurements have been conducted for about a hundred years. In an industrial setting, these flow measurements serve two main purposes: (1) as a means to account for fluid commodities (e.g., fluid product usage or production); and (2) as the basis for controlling processes and manufacturing operations (e.g., steam flow to a turbine and scrubber slurry flow). Additionally, in recent years, the flow rates of certain fluids have been correlated to process emission rates of air contaminants.

Considering the wide diversity in the nature of the fluids to be measured, the range of flow-measurement applications is vast. Additionally, the need to measure a wide range of flow rates has added to the expanse of measurement technology. No flow rate measurement technology is universal to all applications.

Flow rate measurement technology can be classified a variety of ways. For the purposes of this document, flow meters have been classified as either energy extractive or energy additive, either direct determination or indirect determination, and either velocity or mass rate. In general, most flow rate determining devices measure a physical principal (e.g., pressure drop across a restriction, momentum transfer to a propeller, heat transfer, or wave formation by a blunt object inserted in the fluid) and infer the fluid flow rate using a mathematical relationship. This section on flow rate measurement will present each technology for determining fluid flow (e.g., differential pressure, positive displacement, and ultrasonic), and the various techniques within a technology will be discussed. For each type of flow measurement device, the system components, operation, accuracy, calibration, and QA/QC procedures are discussed. Table 4.4-1 presents a comparison of the flow measurement devices described in this section.

4.4.2 Differential Pressure Flow Measurement Devices[1]

Differential pressure flow meters, or head meters, represent one of the most commonly used flow meter technologies. Their versatility, cost, and simplicity make them attractive for many applications. Differential pressure devices can be applied to virtually all low viscosity liquid flow measurement applications, as well as to most gas flow rate measurement applications.

Differential pressure devices utilize empirical correlations to quantify the relationship between the change in pressure and the volumetric flow through a carefully specified restriction in a pipe or duct. These devices do not measure the mass, velocity, or volume directly; instead

TABLE 4.4-1. COMPARISON OF FLOW MEASUREMENT DEVICES[1-10]

Type of flow meter	Type of measurement	Liquid, gas, or both	Applicable pipe diameter	Applicable flow rate	Straight pipe requirements[a]	Net pressure loss	Accuracy	Restrictions
Venturi tube	Volumetric	Both	5 to 120 cm (2 to 48 in.)	Limited to ~4:1 flow range	6 to 20 D up 2 to 40 D down	10 to 20% of ΔP depending on β	±0.75% flow rate w/o calibration	Eliminate swirl and pulsations
Flow nozzle	Volumetric	Both	7.6 to 60 cm (3 to 24 in.)	Limited to ~4:1 flow range	6 to 20 D up 2 to 4 D down	30 to 85% of ΔP depending on β	±1.0% flow rate w/o calibration	Eliminate swirl and pulsations
Orifice plate	Volumetric	Both	1.3 to 180 cm (½ to 72 in.)	Limited to ~4:1 flow range	6 to 20 D up 2 to 4 D down	Slightly more than flow nozzle	±0.6% flow rate w/o calibration	Eliminate swirl and pulsations
Magnetic	Velocity	Liquid (not petroleum)	0.25 to 250 cm (0.1 to 96 in.)	0.0008 to 9,500 L/min (0.002 to 2,500 gal/min)	None	None	±1% flow rate	Conductive liquid, not for gas
Nutating disk	Volumetric	Liquid	1.3 to 5 cm (½ to 2 in.)	7.5 to 600 L/min (2 to 160 gal/min)	None		±0.5% flow rate	Household water meter; low maximum flow rate
Oscillating piston	Volumetric	Liquid	1.3 to 5 cm (½ to 2 in.)	2.8 to 600 L/min (0.75 to 160 gal/min.) Maximum of 4.3 to 480 m^3/hr (150 to 17,000 ft^3/hr)	None		±0.5% flow rate	Household water meter; low maximum flow rate
Bellows gas	Volumetric	Gas		Maximum of 4.3 to 480 m^3/hr (150 to 17,000 ft^3/hr)	None			Used for commercial and domestic gas service
Lobed impeller	Volumetric	Both	3.8 to 60 cm (1½ to 24 in.)	30 to 68,000 L/min (8 to 18,000 gal/min)	None	Low	±0.2% flow rate	Best used at high flow rates
Slide-vane rotary	Volumetric	Liquid	Up to 40 cm (Up to 16 in.)		None		±0.1 to 0.2% flow rate	
Retracting-vane rotary	Volumetric	Liquid	Up to 10 cm (Up to 4 in.)		None		±0.1 to 0.2% flow rate	
Helical gear	Volumetric	Liquid	3.8 to 25 cm (1½ to 10 in.)	19 to 15,000 L/min (5 to 4,000 gal/min)	None	Low	±0.1 to 0.2% flow rate	High viscous liquids only
Turbine	Volumetric	Both	0.64 to 60 cm (¼ to 24 in.)	190,000 L/min (50,000 gal/min) 65 scmm (230,000 scfm)	10 D up 5 D down	34 to 41 kPa @ 6.1 m/sec (5 to 6 psi @ 20 ft/sec) water flow	±0.5% flow rate	Straightening vanes Do not exceed maximum flow
Vortex shedding	Velocity	Both	2.5 to 30 cm (1 to 12 in.)	0.30 to 6.1 m/sec (1 to 20 ft/sec) 11 to 19,000 L/min (3 to 5,000 gal/min)	10 to 20D up 5D down	34 to 41 kPa @ 6.1 m/sec (5 to 6 psi @ 20 ft/sec) water flow	±1% flow rate (liquid) ±2% flow rate (gas)	Straightening vanes
Vortex precession	Velocity	Gas	2.5 to 20 cm (1 to 8 in.)	0.30 to 6.1 m/sec (1 to 20 ft/sec)	10 to 20D up 5D down	5x more than shedder	±2% flow rate	Straightening vanes

TABLE 4.4-1. (continued)

Type of flow meter	Type of measure-ment	Liquid, gas, or both	Applicable pipe diameter	Applicable flow rate	Straight pipe requirements[a]	Net pressure loss	Accuracy	Restrictions
Fluidic oscillating	Velocity	Liquid	2.5 to 10 cm (1 to 4 in.)	Up to 6.1 m/sec (20 ft/sec)	6D up 2D down	34 to 41 kPa @ 6.1 m/sec 5 to 6 psi @ 20 ft/s water flow	±1.25 to 2% flow rate	Carefully determine minimum flow rate
TOF ultrasonic	Velocity	Both	>0.32 cm (>⅛ in.)	Minimum 0.03 m/sec (0.1 ft/sec)	10 to 30D up 5 to 10D down	None	±0.5 to 10% full scale	Need clean fluid
Doppler ultrasonic	Velocity	Liquid	>0.32 cm (>⅛ in.)	Minimum 0.15 m/s (0.5 ft/sec); 0.38 L/min (0.1 gal/min)	Yes	None	As low as 1% flow rate	Fluid must have sufficient particles or bubbles
Thermo-anemometer	Velocity (mass)	Gas	>5 cm (>2 in.)		8 to 10D up 3D down	Very low	+2% flow rate	Critically positioned probes Highly fluid composition dependent
Colorimetric	Velocity (mass)	Gas	>5 cm (>2 in.)		8 to 10D up 3D down	Low	±4% flow rate	
Corrolis mass	Mass flow	Both limited gas	0.16 to 15 cm (1/16 to 6 in.)	Definitive max. + min. flow rate	None	High	±0.2 to 0.4% flow rate	Pressure drop across flow meter cannot exceed max. system pressure drop
Rotameter	Velocity	Both	1.3 to 10 cm (½ to 4 in.)	Up to 750 L/min (200 gal/min for liquid); unlimited for gas	None	Low	±1 to 2% full scale	Must be mounted vertically

[a]D = pipe diameters (e.g., 6D = 6 pipe diameters).

the flow rate is inferred by comparison to flow meters that have been carefully tested under laboratory conditions.

4.4.2.1 Measurement Principal[1]

If a constriction is placed in a closed channel carrying a stream of fluid, an increase in velocity will occur, and hence an increase in kinetic energy, at the point of the constriction. From an energy balance, as given by Bernoulli's theorem, a corresponding reduction in pressure must occur. The rate of discharge from the constriction can be determined from the change in pressure, the area available for the flow at the constriction, the density of the fluid, and the coefficient of discharge. The coefficient of discharge is defined as the ratio of the actual flow to the theoretical flow.

4.4.2.2 System Components and Operation[1-5]

Three types of differential pressure flow devices are commonly used in industrial applications: (1) Herschel-type venturi tubes, (2) flow nozzles, and (3) orifice plates. Figures 4.4-1, 4.4-2, and 4.4-3 present diagrams of the venturi tube, flow nozzle, and orifice plate, respectively. These devices are described in the following paragraphs. A fourth type of differential pressure flow device, the pitot tube, typically is not used for continuous measurements of fluid flow in industrial applications. Therefore, a discussion of the pitot tube is not presented.

4.4.2.2.1 Venturi tubes. The venturi tube consists of a converging cone, venturi throat, and diffuser. The inlet section to the venturi tube consist of a converging cone that has an included angle of roughly 21 degrees (°). The converging cone is joined by a smooth curve to a short cylindrical section called the venturi throat. Another smooth curve joins the throat to the diffuser, which consists of a cone with an included angle of roughly 7° to 8°. The diffuser recovers most of the pressure normally lost by an orifice plate.

The venturi tube can be used to measure fluid flow in pipes with diameters of approximately 5 to 120 centimeters (cm) (2 to 48 inches [in.]). The venturi has the following advantages over the orifice plate:

1. Handles more flow while imposing less permanent pressure loss--approximately 60 percent greater flow capacity;
2. Can be used with fluids containing a higher percentage of entrained solids; and
3. Has greater accuracy over a wider flow rate range.

4.4.2.2.2 Flow nozzles. The flow nozzle is similar to the venturi tube in that it has a throat; the primary difference is that the flow nozzle does not include a long converging cone and

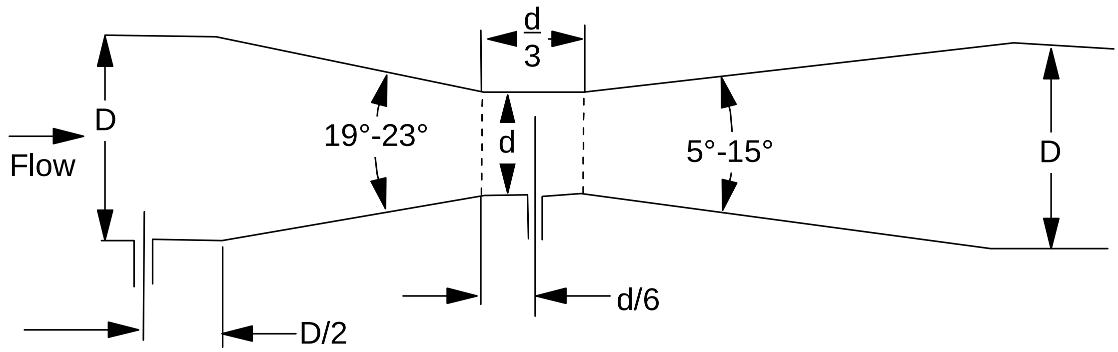

Figure 4.4-1. Venturi tube.[2]

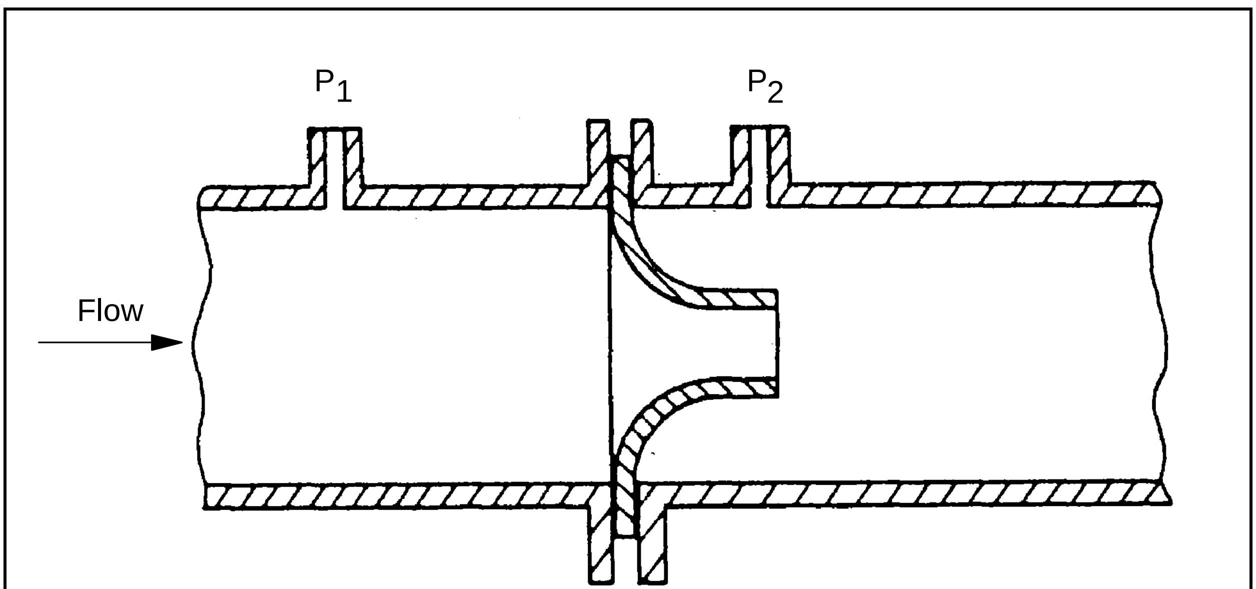

Figure 4.4-2. Flow nozzle.[1]

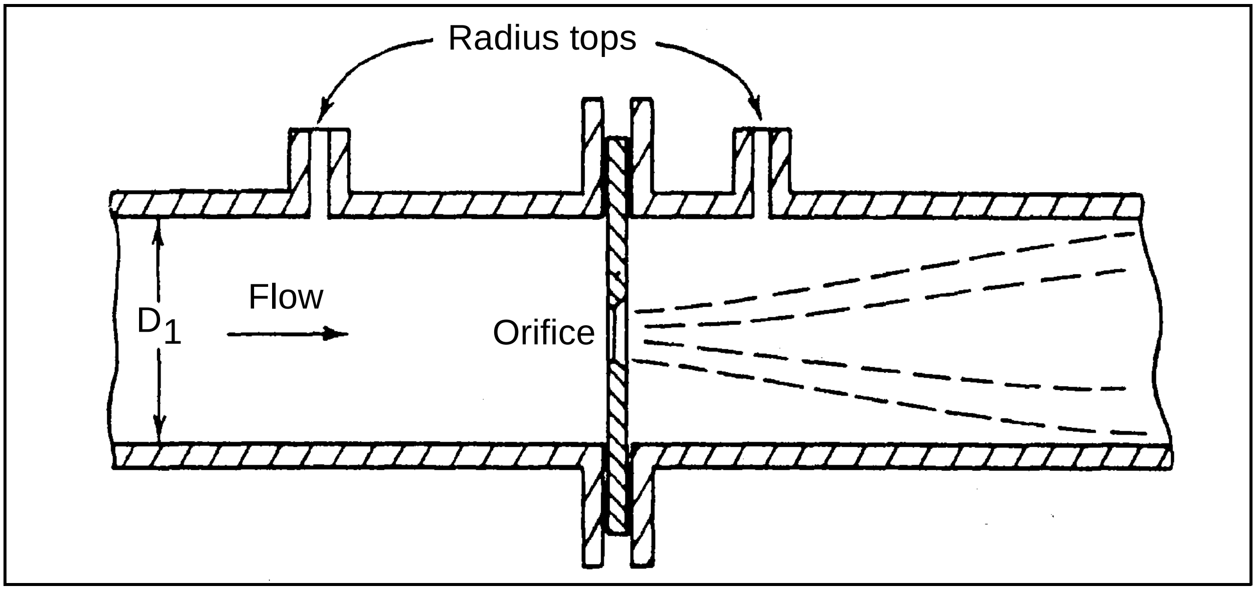

Figure 4.4-3. Orifice plate.[1]

diffuser. Flow nozzles are generally selected for high temperature, pressure, and velocity applications (e.g., measuring steam flow).

Flow nozzles, which can be used to measure fluid flow in pipes with diameters of approximately 7.6 to 61 cm (3 to 24 in.), have the following advantages:

1. Net pressure loss is less than for an orifice plate (although the net pressure loss is much greater than the loss associated with venturi tubes), and
2. Can be used in fluids containing solids that settle.

Flow nozzles have the following disadvantages:

1. More expensive than orifice plates, and
2. Limited to moderate pipe sizes.

4.4.2.2.3 Orifice plates. Orifice plates can be used to measure fluid flow in pipes with diameters of approximately 1.3 to 180 cm (0.5 to 72 in.). Orifice plates operate on the same principle as the venturi tube and the flow nozzle, but their design is quite different. An orifice plate consists of a square-edged or sharp-edged, thin opening in a metallic plate attached to a handle. The opening is of a predetermined size and shape and is machined to tight tolerances. The key dimensional information is usually stamped in the upstream side of the plate handle. The presence of the handle gives the orifice plate the appearance of a paddle. The opening in an orifice plate is either:

1. Concentric, with a circular center hole;
2. Eccentric, with an eccentric circular hole at the top (liquids) or bottom (gases) of the plate; or
3. Segmental, with a semicircular hole at the top (liquids) or bottom (gases) of the plate.

The differential pressure readings for an orifice plate are obtained from a pair of pressure taps, which are located in one of the following configurations:

1. Corner taps, which consist of static holes drilled as close as possible to the orifice plate, one in the upstream flange and one in the down-stream flange;

2. Radius taps, which consist of static holes located 1 pipe diameter upstream and 0.5 pipe diameters down-stream from the plate;

3. Pipe taps, which are static holes located 2.5 pipe diameters upstream and 8 pipe diameters downstream from the plate;

4. Flange taps, which consist of static holes located 2.5 cm (1 in.) upstream and 2.5 cm (1 in.) downstream of the plate; and

5. Vena contract, which are static holes located 0.5 to 2 pipe diameters upstream and at the minimum pressure point downstream from the plate. Corner taps and flange taps are advantageous because the pressure points can be tapped in the plate carrying the orifice. Pipe taps give the lowest differential pressure. Table 4.4-2 summarizes the advantages and disadvantages of orifice plate flow meters.

4.4.2.3 Accuracy[5-7]

Precision machining has led to increased accuracy of differential pressure flow meters. Typically, these devices meet ASME accuracy requirements without laboratory calibration. Each of the accuracy levels presented below can be increased, if needed, with laboratory calibration.

TABLE 4.4-2. ADVANTAGES AND DISADVANTAGES OF ORIFICE PLATE FLOW METERS

Advantages	Disadvantages
Low cost	High net pressure loss--30 to 85 percent of the differential reading, depending on the opening to pipe diameter ratio (β)
Available in numerous materials of construction	Tendency to clog; not useful for slurries or entrained particles
Can be used with a wide range of pipe sizes	Flow range limited to about 3:1
Characteristics are well known and predictable from years of applicable experience	Characteristics tend to change with time due to erosion and corrosion of the opening
	Accuracy is dependent upon care during installation.

Venturi tube: ±0.75 percent of flow rate

Flow nozzle: ±1.0 percent of flow rate

Orifice plate: ±0.6 percent of flow rate.

4.4.2.4 Calibration Techniques[5]

4.4.2.4.1 Sensor. Differential pressure flow meters are inferential devices, so the physical condition of the throat, nozzle, or bore should be checked to ensure that dimensions are within tolerance. The most critical of these is the bore of the orifice plate. In addition, the appropriate ASME method for calibration should be used for calibration of these devices. For example, ASME MFC-3M-1989 could be used for venturi tubes, flow nozzles, and orifice plates.

4.4.2.4.2 System. The differential pressure transmitter can be calibrated by simulating inputs to the transmitter and making the required zero and span adjustments if the calibration error is outside the acceptable performance standard. Another system calibration that can be performed involves the determination of the energy or mass balance of fluid flow to process operations. If fluid flow energy or mass agrees (balances) within the performance specifications to actual production rates or heat input, then the flow rate system can be assumed to be in calibration. Additionally, comparisons of recent energy or mass balances to past data can be made.

4.4.2.5 Recommended QA/QC Procedures

Differential pressure flow measurement devices are extremely sensitive to swirling flow or abnormal velocity distributions caused by disturbances (e.g., pipe bends) upstream or downstream of the device. The presence of swirling flow and abnormal velocity distributions can be reduced or eliminated with sufficient straight piping or installing flow straighteners. Table 4.4-2 shows the recommended upstream and downstream disturbance distances from differential pressure meter orifices or nozzles.

Table 4.4-3 indicates the recommended locations both with and without straightening vanes. The criteria for straightening vanes (a set of smaller pipes arranged in a honeycomb configuration installed inside the fluid pipe) are as follows:

$$d_v \leq D_p/4 \qquad \text{and} \qquad l_v > 8d_v$$

where:

d_v = diameter of each straightening vane pipe;
D_p = fluid pipe diameter; and
l_v = length of each straightening vane pipe.

The presence of fluid flow pulsations caused by piston pumps, reciprocating equipment, and the like will cause differential pressure readings to be high. Such pulsations in the differential pressure readings can be dampened in order to stabilize differential pressure readings for controlling process operations; however, doing so will not produce more accurate flow rate measurements. The most effective approach to minimizing the effect of fluid flow pulsations is to install a dampening chamber near the pulsating or reciprocating equipment.

TABLE 4.4-3. LOCATIONS OF ORIFICES AND NOZZLES RELATIVE TO PIPE FITTINGS[1]

Type of fitting upstream	D_2[a] / D_1	Distance, upstream fitting to orifice: Without straightening vanes	Distance, upstream fitting to orifice: With straightening vanes	Distance, vanes to orifice	Distance, nearest downstream fitting from orifice
Single 90-deg. ell, tee, or cross used as ell	0.2	6			2
	0.4	6			
	0.6	8	10		
	0.8	20	12	8	4
2 short-radius 90-deg. ells in form of "S"	0.2	7			
	0.4	8	8		
	0.6	13	10	6	
	0.8	25	15	11	4
2 long- or short-radius 90-deg. ells in perpendicular planes	0.2	15	9	5	2
	0.4	18	10	6	
	0.6	25	11	7	
	0.8	40	13	9	
Contraction or enlargement	0.2	8	Vanes have no advantage		2
	0.4	9			
	0.6	10			
	0.8	15			
Globe valve or stop check	0.2	9	9	5	2
	0.4	10	10	6	
	0.6	13	10	6	
	0.8	21	13	9	
Gate valve, wide open, or plug cocks	0.2	6	Same as globe valve		2
	0.4	6			
	0.6	8			
	0.8	14			4

[a]Distances in pipe diameters, D_1, D_2.

For best results, the proper device (i.e., venturi, nozzle, orifice) should be selected based on expected fluid temperature, pressure, density, velocity, percent of solids or entrained particles, viscosity, amount of straight pipe, and pipe size. Additionally, the proper differential pressure device and appropriate measurement range should be chosen.

The piping at least four diameters upstream and two diameters downstream of the device should have a smooth finish, free of mill scale, holes, bumps, grooves, pits, seam distortions, and the like. The pipe inside diameter should not depart from the average by more than 0.33 percent. Inside pipe distortions should be corrected by filling in, grinding, or filing.

In liquid flow applications, insulating or heat tracing the differential pressure lines will help ensure accuracy of the system measurements by preventing the liquid in the pressure lines from freezing. In some installations in which the differential pressure lines are subject to clogging, it may be necessary to install a purge system on the differential pressure lines to keep them clean. In addition, the differential pressure lines should be checked periodically for leakage.

Orifice plate bore wear can be detected by a slow reduction of indicated flow rate with time. If the measured flow rate diverges from the expected flow rate over time, the orifice plate should be removed and inspected for bore wear, encrustation, or material buildup on the square edge of the orifice plate bore. Bore wear results in a measured flow rate that is lower than actual, and material buildup results in a measured flow rate that is higher than the actual flow rate.

4.4.2.5.1 Frequency of calibration. Calibration of differential pressure flow monitoring devices should follow a consistent pattern to allow for comparison of performance changes over time. The recommended frequency of calibration depends largely on site-specific conditions and facility standard operating procedures. Moreover, specific regulations may require a specific calibration frequency (e.g., annually). In general, calibration frequency should be within the manufacturer's recommendations. The above calibration intervals should not be relied on indefinitely; they are starting points. At the end of the initial calibration period, the system should be calibrated or examined, as appropriate, and the data obtained should be charted. If the system is near or beyond the limit of accuracy (80 percent of acceptable error) and no process excursions or conditions are suspected of causing the loss of calibration, the calibration interval probably is too long. In such a case, the system should be recalibrated to the center of the acceptance band, and the calibration interval should be shortened. At the end of the second calibration period, calibration should be checked to determine if the system is drifting. If the system is near or beyond the limit of acceptable accuracy, similar steps should be taken, and the calibration period should be further shortened. This process should be repeated until the system is within the acceptable limit of accuracy at the end of the calibration interval. If, at the end of the initial calibration period, the system is determined to be within acceptable tolerance, adjustment is not necessary. The results should be recorded and the same calibration interval should be maintained for another calibration period. A log of all calibration check results should be maintained at the facility. Any corrective actions or adjustments should be recorded. Calibration data should be reviewed annually in order to spot significant deviations from defined procedures or tolerances.

4.4.2.5.2 Quality control. Written procedures should be prepared for instrument calibrations. These procedures should include:

1. The recommended interval for zero and span calibration checks of the differential pressure transducer (Readings before and after adjustment should be recorded.);
2. The reference zero and span values to be applied;
3. Step-by-step written procedures;

4. Blank field calibration forms (Records should include identification of the instrument component calibrated, the date of calibration, and initials of the person who performed the calibration.);

5. Designation of responsibility to perform the calibration (i.e., name of person(s) or position);

6. Designation of person to whom to report any failed calibration; and

7. Place to store calibration results.

4.4.2.5.3 Quality assurance. The calibration logs should be reviewed to confirm that calibrations were completed and performed properly. The person performing this review and the frequency of review should be specified. The written calibration procedures should be reviewed and updated to reflect any changes (e.g., system modifications or instrument changes).

4.4.3 Magnetic Flow Meters[2,4]

Magnetic flow meters are effective for monitoring the flow rate of fluids that present difficult handling problems, such as corrosive acids, rayon viscose, sewage, rock and acid slurries, sand and water slurries, paper pulp stock, rosin size, detergents, bleaches, dyes, emulsions, tomato pulp, milk, soda, and beer. Magnetic flow meters mainly are applicable to liquids that have a conductivity of 0.1 microsiemens per centimeter or greater. They are not applicable to petroleum products or gases.

4.4.3.1 Measurement Principal[4]

The basis of the magnetic flow meter is Faraday's Law of Electromagnetic Induction. In summary, a voltage induced in a conductor (i.e., the fluid flowing in the conduit) moving in a magnetic field is proportional to the velocity of the conductor. This relationship can be expressed mathematically as follows:

$$E = C \times B \times D \times v$$

where:

E = induced voltage;

C = constant;

B = magnetic flux density;

D = diameter of conduit; and

v = velocity of fluid.

4.4.3.2 System Components and Operation[2,4-5]

Two different types of magnetic flow meters are used in industrial applications; the difference between the two is the type of current used to generate the magnetic field. Alternating current (ac) magnetic flow meters excite the flowing fluid with an ac electromagnetic field. Direct current (dc), or pulsed, magnetic flow meters excite the flowing fluid with a pulsed dc electromagnetic field. Figure 4.4-4 presents a diagram of a magnetic flow meter. Direct current magnetic flow meters are more common than ac magnetic flow meters.

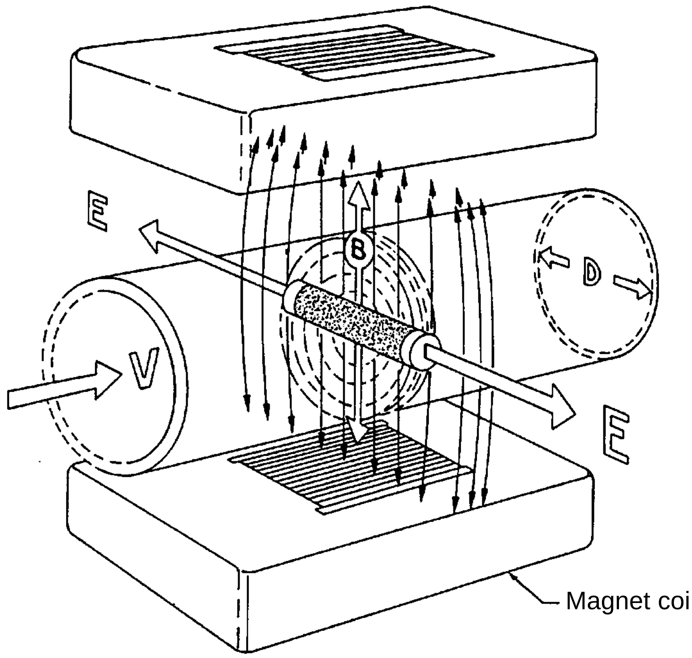

Figure 4.4-4. Magnetic flow meter.[5]

In principle, the fluid flowing through the pipe passes through the magnetic field. This action generates a voltage that is linearly proportional to the average velocity in the plane of the lectrodes. If the velocity profile changes due to swirl or helical flow patterns, the total measured velocity is unaffected as long as the velocity profile across the pipe is symmetrical. Nonsymmetrical flow profiles may cause flow rate measurement errors of several percent.

In operation, the magnetic coils create a magnetic field that passes through the flow tube and into the process fluid. When the conductive fluid flows through the flow meter, a voltage is induced between the electrodes, which are in contact with the process fluid and isolated electrically from the pipe walls by a nonconductive liner to prevent a short circuit in the electrode signal voltage. Grounding is required for magnetic flow meters to shield the relatively low voltage signal that is measured at the electrodes from the relatively high common-mode potentials that may be present in the fluid. If the pipe is conductive and comes in contact with the flow meter, the flow meter should be grounded to the pipe both upstream and downstream of the flow meter. If the pipe is constructed of a nonconductive material, such as plastic, or a conductive material that is insulated from the process fluid, such as plastic-lined steel pipe, grounding rings should be installed in contact with the liquid.

Magnetic flow meters can be used in pipes that range in diameter from 0.25 to 240 cm (0.1 to 96 in.). Magnetic flow meters are available for flow rates in the range of 0.008 liters per minute (L/min) (0.002 gallons per minute [gal/min]) to 570,000 L/min (150,000 gal/min). Since magnetic flow meters do not place an obstruction in the pipe, the devices do not cause a loss in fluid pressure. Also, straight pipe requirements do not apply to this flow monitor device. Magnetic flow meters are insensitive to density and viscosity and can measure flow in both directions. In addition, because they cause no obstructions, magnetic flow meters often are used to measure the flow rate of slurries.

4.4.3.3 Accuracy[2]

If all components of a magnetic flow metering system are calibrated as a unit, system accuracies of ±0.5 percent of flow rate are possible. However, normal accuracy specifications are ±1.0 percent of flow rate. Higher accuracy systems match the primary flow meter with a transmitter in the factory.

4.4.3.4 Calibration Techniques[5]

Calibration of the electronics can be accomplished with a magnetic flow meter calibrator or by electronic means. Magnetic flow meter calibrators are precision instruments that inject the output signal of the primary flow meter into the transmitter, which effectively checks and calibrates all of the electronic circuits. An alternate calibration method, although not as accurate, is to make adjustments based upon test signals injected into the transmitter, circuit test measurements, or thumbwheel switches according to manufacturer's specifications.

Calibration of an ac magnetic flow meter must be performed at zero flow with the flow meter full of fluid. Zero adjustments to compensate for noise that may be present in the system also must be made with the flow meter full of fluid. Pulsed dc magnetic flow meters do not require this zero compensation for noise in the system because the flow signal is extracted regardless of the zero shifts that may occur due to noise.

4.4.3.5 Recommended QA/QC Procedures[5]

Magnetic flow meters can be affected adversely by electrode coating, liner damage, and electronic failure. Alternating current magnetic flow meters are most susceptible to nonconductive electrode coating, which causes a calibration shift due to changes in the conductivity that the electrodes sense. Device manufacturers should be consulted about electrode cleaning methods that do not require removal or replacement of the flow meter. If this is a continual problem, an ultrasonic cleaner may be added or the ac flow meter could be replaced with a dc flow meter. Liner damage generally requires that the flow meter be replaced or sent back to the manufacturer for overhaul. Finally, most dc flow meters have a reference signal that checks about 90 percent of the electronic circuits. The reference signal can be used to check for a suspected malfunction.

The following recommended spare parts should be maintained: assortment of electrodes, liner, flow tube, and electronic components.

4.4.3.5.1 Frequency of calibration. Calibration of magnetic flow meters should follow a consistent pattern to allow for comparison of performance changes over time. The recommended frequency of calibration depends largely on site-specific conditions and facility standard operating procedures. Moreover, specific regulations may require a specific calibration frequency (e.g., annually). In general, calibration frequency should be within the manufacturer's recommendations. These calibration intervals should not be relied on indefinitely; they are starting points. At the end of the initial calibration period, the system should be calibrated or examined, as appropriate, and the data obtained should be charted. If the system is near or beyond the limit of accuracy (80 percent of acceptable error) and no process excursions or conditions are suspected of causing the decalibration, the calibration interval probably is too long. In such a case, the system should be recalibrated to the center of the acceptance band, and the calibration interval should be shortened. At the end of the second calibration period, calibration should be checked to determine if the system is drifting. If the system is near or beyond the limit of acceptable accuracy, similar steps should be taken, and the calibration period should be further shortened. This process should be repeated until the system is within the acceptable limit of accuracy at the end of the calibration interval. If, at the end of the initial calibration period, the system is determined to be within acceptable tolerance, adjustment is not necessary. The results should be recorded and the same calibration interval should be maintained for another calibration period. A log of all calibration check results should be maintained at the facility. Any corrective actions or adjustments should be recorded. Calibration data should be reviewed annually in order to spot significant deviations from defined procedures or tolerances.

4.4.3.5.2 Quality control. Written procedures should be prepared for instrument calibrations. These procedures should include the following:

1. The recommended interval for zero and span calibration checks of the electronics, and the recommended interval for reference (internal) signal electronics checks (Readings before and after any adjustment should be recorded.);
2. The reference zero and span values to be applied;
3. Step-by-step written procedures;

4. Blank field calibration forms (Records should include identification of the instrument component calibrated, the date of calibration, and initials of the person who performed the calibration.);

5. Designation of responsibility to perform the calibration (i.e., name of person(s) or position);

6. Designation of person to whom to report any failed calibration; and

7. Place to store calibration results.

4.4.3.5.3 <u>Quality assurance</u>. The calibration logs should be reviewed to confirm that calibrations were completed and performed properly. The person performing this review and the frequency of review should be specified. The written calibration procedures should be reviewed and updated to reflect any changes (e.g., system modifications or instrument changes).

4.4.4 <u>Positive Displacement Flow Meters</u>

Positive displacement meters generally measure velocity as a function of how the fluid being measured produces a motion or rotation to a piston or vane. Examples of positive displacement meters used for measuring gas flow include vane anemometers, turbine meters, and propeller meters. These devices consist of blades, propellers, or cups, mounted on a rotating shaft; velocity is measured as a function of rotational speed of the shaft induced by the gas flow.

4.4.4.1 <u>Measurement Principal</u>[5]

Positive displacement type flow meters repeatedly entrap a known quantity of fluid as it passes through the flow meter. The number of times the fluid is entrapped is counted, and therefore the quantity of fluid passed through the flow meter is known. Because the measurements by a positive displacement meter are independent of time (a positive displacement of the meter occurs for each quantity or volume of fluid), positive displacement flow meters measure total flow and can be classified as volume meters.

4.4.4.2 <u>System Components and Operation</u>[2,4]

Seven types of positive displacement flow meters are commonly used. Four of these can be classified as rotating positive displacement flow meters: lobed-impeller meters, slide-vane rotary flow meters, retracting vane rotary flow meters, and helical gear flow meters. The other three types of positive displacement flow meters are nutating disk meters, oscillating disk meters, and bellows gas meters. Nutating-disk meters and oscillating piston meters generally are used as household water meters and can be used to measure flow rates up to a maximum of about 760 L/min (200 gal/min). The bellows gas meter is widely used in commercial and domestic natural gas service and has a maximum flow capacity range of 68 to 7,950 L/min (18 to

2,100 gal/min). For industrial applications, rotating positive displacement flow meters are the most commonly used type of positive displacement flow meter. The following paragraphs describe these flow measurement devices in greater detail.

4.4.4.2.1 Lobed-impeller meters. Lobed-impeller meters contain two fixed position rotors that revolve inside a cylindrical housing. The measuring chamber is formed by the walls of the cylinder and the surface of one half of one rotor. When the rotor is in the vertical position, a specific volume of fluid is contained in the measuring compartment. As the impeller turns, due to a slight differential pressure between the inlet and outlet ports, the measured volume is discharged through the bottom of the meter. This action occurs four times for a full revolution, with the impeller rotating the opposite direction at a speed proportional to the volume of the fluid. Figure 4.4-5 depicts a lobed-impeller flow meter.

Lobed-impeller meters can be used to measure fluid flow in pipes with diameters of approximately 3.8 to 61 cm (1.5 to 24 in.) Measurable maximum flow rates range from 30 to 66,000 L/min (8 to 17,500 gal/min). Table 4.4-4 summarizes the advantages and disadvantages of lobed-impeller flow meters.

4.4.4.2.2 Slide-vane rotary flow meters. Slide-vane rotary flow meters contain a cylindrical rotor that revolves on ball bearings around a central shaft and stationary cam. As fluid flows against an extended blade, the resulting rotation of the rotor and action of the cam cause the blades to act as cam followers, creating measuring chambers that measure fluid throughput. Figure 4.4-6 depicts a slide-vane rotary flow meter.

Slide-vane rotary flow meters can be used to measure fluid flow in pipes with diameters of up to 41 cm (16 in.). This type of flow measurement device can be used in temperatures to 204°C (400°F) and pressures up to 3,450 kPa (500 [psi]). Slide-vane rotary flow meters are characterized by high accuracy, but have the following limitations:

1. High costs;
2. Limited flow rate range--from 5:1 to 10:1; and
3. Moving parts that are subject to wear.

4.4.4.2.3 Retracting vane rotary flow meters. In retracting vane rotary flow meters, the vanes are jointed. As fluid enters the meter, it is deflected downward against the extended blade, causing rotation of the measuring element. Retracting vane rotary flow meters can be used to measure fluid flow in pipes with diameters up to four inches, at fluid temperatures up to 204°C (400°F) and pressures up to 6,200 kPa (900 psi). As is the case for slide-vane rotary flow meters, retracting vane rotary meters are characterized by high accuracy, but have the following limitations:

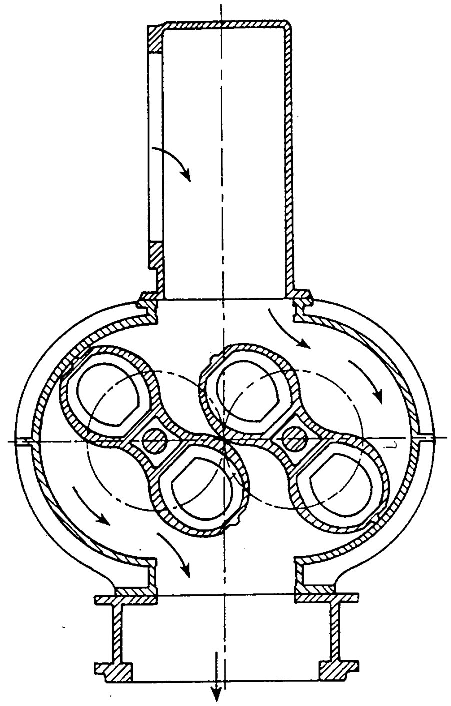

Figure 4.4-5. Lobed-impeller flow meter.[2]

TABLE 4.4-4. ADVANTAGES AND DISADVANTAGES OF LOBED-IMPELLER FLOW METERS

Advantages	Disadvantages
Can be used at relatively high temperatures (204°C [400°F]) and pressure (8,200 kPa [1,200 psi]) Low net pressure loss Available in numerous materials of construction No upstream or downstream pipe diameter requirements Applicable for gases and a wide range of light to viscous liquids Wide range of flow rates	Susceptible to damage from entrained vapors Larger sizes are bulky and heavy High cost Moving parts subject to wear Best used at high flow rates because of possible slippage at low flow rates

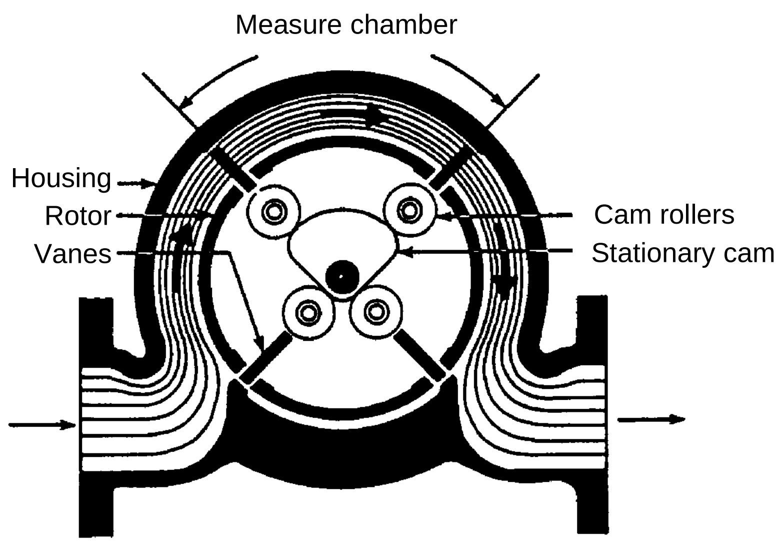

Figure 4.4-6. Slide-vane rotary flow meter.[2]

1. High costs;
2. Limited flow rate range--from 5:1 to 10:1; and
3. Moving parts that are subject to wear.

Figure 4.4-7 depicts a retracting vane rotary flow meter.

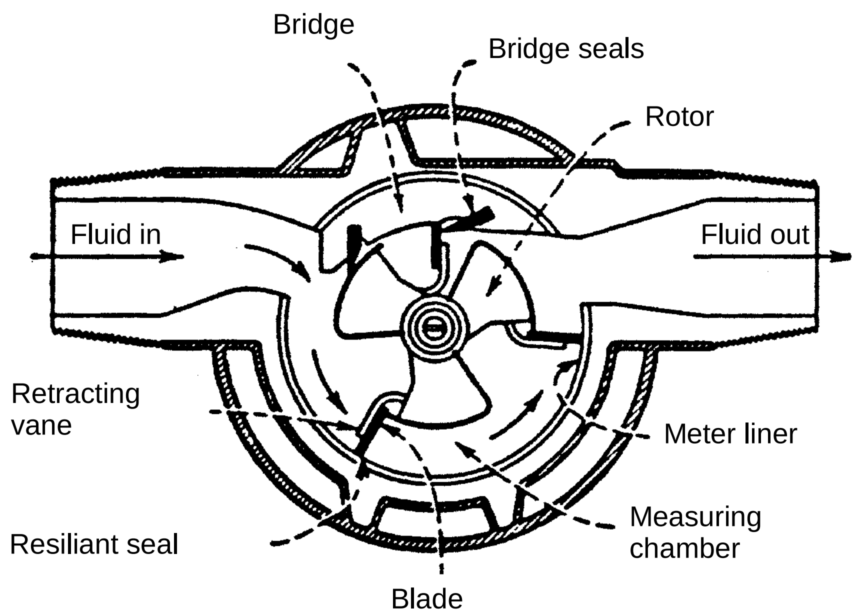

Figure 4.4-7. Retracting vane rotary flow meter.[4]

4.4.4.2.4 <u>Helical gear flow meters</u>. Helical gear meters use two radially-pitched helical gears to continually entrap liquid as it passes through the flow meter, causing the rotors to rotate in a longitudinal plane. Flow is proportional to the rotational speed of the gears. System components include the rotor, bearings, and sensing system. Magnetic or optical sensing systems monitor the speed of the gears. In a magnetic sensor, the gear teeth are sensed by a magnetic pickup and amplified. An optical sensor uses a magnetically driven, optically encoded disc. Rotation of the disc is sensed by an optical pickup that senses a pulse each time a portion of a revolution occurs. Figure 4.4-8 depicts a helical gear flow meter.

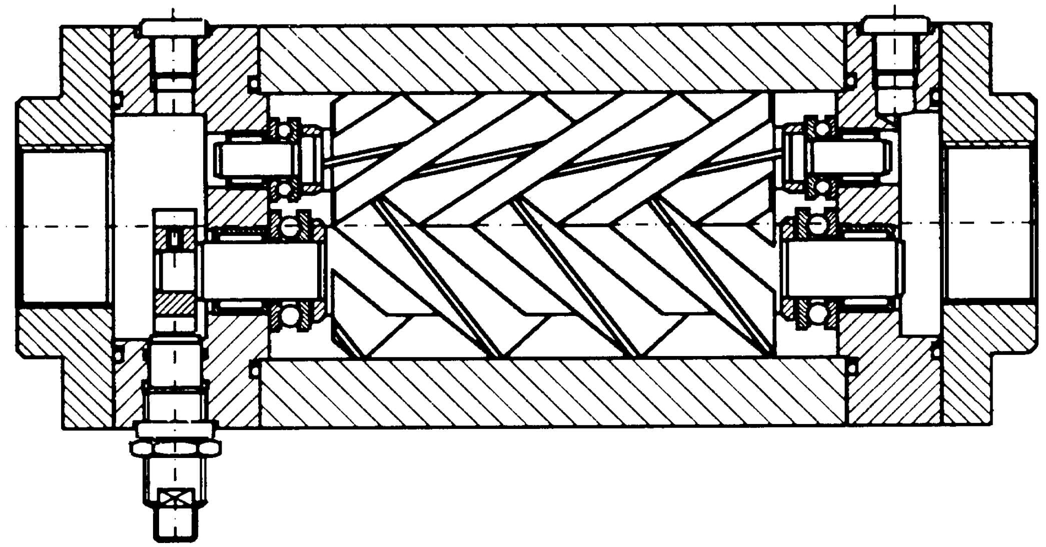

Figure 4.4-8. Helical gear flow meter.[11]

Helical gear meters can be used to measure highly viscous liquid flow in pipes with diameters of approximately 3.8 to 25 cm (1.5 to 10 in.). Measurable flow rates range from 19 to 15,100 L/min (5 to 4,000 gal/min). Table 4.4-5 summarizes the advantages and disadvantages of helical gear flow meters.

4.4.4.3 <u>Accuracy</u>[4,5]

The following accuracies apply to the four rotating positive displacement flow meters:

Lobed-impeller: ±0.2 percent of flow rate

Slide-vane rotary: ±0.2 percent of flow rate

Retracting vane rotary: ±0.2 percent of flow rate

Helical gear: ±0.2 to 0.4 percent of flow rate.

4.4.4.4 <u>Calibration Techniques</u>[5]

4.4.4.4.1 <u>Sensor</u>. The meter constant (K-factor), which establishes the relationship between the frequency output of the flow meter, the volumetric flow, and the output of the converter, is fixed by design and cannot be calibrated.

TABLE 4.4-5. ADVANTAGES AND DISADVANTAGES OF HELICAL GEAR FLOW METERS

Advantages	Disadvantages
Applicable to highly viscous liquids	Moving parts subject to wear
Low net pressure loss	Only applicable to liquids
Good accuracy	

4.4.4.4.2 System. To calibrate positive displacement flow meter systems, a frequency signal that corresponds to the output of the primary flow meter device at a known flow is injected into the converter so as to verify operation of the converter and set zero and span. Another system calibration that can be performed involves energy or mass balance calculation of fluid flow to process operations; if fluid flow energy or mass agrees (balances) within the performance specifications to actual production rates or heat input, the flow rate measurement system can be assumed to be in calibration. Additionally, comparisons of recent energy or mass balances to past data can be made.

4.4.4.5 Recommended QA/QC Procedures[5]

Positive displacement flow meters are subject to deterioration due to wear, corrosion, exposure to a dirty liquid, and abrasion. Pluggage can occur if the flow meter is exposed to a dirty liquid. Excessive slippage usually results from corrosion or abrasion. Line cleaning before commissioning a new unit is recommended. Additionally, the meter should not be exposed to steam, which is often used to clean pipes. The following recommended spare parts should be maintained: rotor, sensor, bearings, and electronic components.

4.4.4.5.1 Frequency of calibration. Calibration of the positive displacement flow meter converter should follow a consistent pattern to allow for comparison of performance changes over time. If slippage is suspected, appropriate procedures should be undertaken, and the meter should be sent back to the manufacturer for repair. The recommended frequency of calibration depends largely on site-specific conditions and facility standard operating procedures. Moreover, specific regulations may require a specific calibration frequency (e.g., annually). In general, calibration frequency should be within the manufacturer's recommendations. These calibration intervals should not be relied on indefinitely; they are starting points. At the end of the initial calibration period, the system should be calibrated or examined, as appropriate, and the data obtained should be charted. If the system is near or beyond the limit of accuracy (80 percent of acceptable error) and no process excursions or conditions are suspected of causing the decalibration, the calibration interval probably is too long. In such a case, the system should be recalibrated to the center of the acceptance band, and the calibration interval should be shortened. At the end of the second calibration period, calibration should be checked to determine if the system is drifting. If the system is near or beyond the limit of acceptable accuracy, similar steps should be taken, and the calibration period should be further shortened. This process should be repeated until the system is within the acceptable limit of accuracy at the end of the calibration interval. If, at the end of the initial calibration period, the system is determined to be within acceptable tolerance, adjustment is not necessary. The results should be recorded and the same calibration interval should be maintained for another calibration period. A log of all calibration check results should be maintained at the facility. Any corrective actions or adjustments should be recorded. Calibration data should be reviewed annually in order to spot significant deviations from defined procedures or tolerances.

4.4.4.5.2 Quality control. Written procedures should be prepared for instrument calibrations. These procedures should include:

1. The recommended interval for zero and span calibration checks of the converter (Readings before and after adjustment should be recorded.);
2. The reference zero and span values to be applied;
3. Step-by-step written procedures;
4. Blank field calibration forms (Records should include identification of the instrument component calibrated, the date of calibration, and initials of the person who performed the calibration.);
5. Designation of responsibility to perform the calibration (i.e., name of person(s) or position);
6. Designation of person to whom to report any failed calibration; and
7. Place to store calibration results.

4.4.4.5.3 Quality assurance. The calibration logs should be reviewed to confirm that calibrations were completed and performed properly. The person performing this review and the frequency of review should be specified. The written calibration procedures should be reviewed and updated to reflect any changes (e.g., system modifications or instrument changes).

4.4.5 Turbine Flow Meters

4.4.5.1 Measurement Principal

Unlike positive displacement flow meters, which physically capture a discrete volume of fluid, turbine flow meters infer the total quantity of flow from the reaction of the fluid on the turbine flow meter.

4.4.5.2 System Components and Operation[2,4-5]

A turbine flow meter consists of a rotating device (i.e., rotor) that is positioned in the flow stream in such a manner that the rotational velocity of the rotor is proportional to the fluid velocity and hence the flow through the device. The flowing fluid reaction with the turbine blades imparts a force to the blade surface and sets the rotor in motion. The steady-state speed is proportional to the fluid velocity.

The rotor speed may be transmitted through the meter housing by a mechanical shaft, with magnetic coupling to an external shaft, or through a suitable gland in the housing. In another type of turbine flow meter design, a signal is generated by means of a magnetic pickup coil, consisting of a permanent magnet with coil windings, mounted in close proximity to the rotor but external to the fluid channel.

Like some other flow rate monitoring devices, the turbine meter is sensitive to swirling and perturbed flows. Therefore, all turbine flow meters use a section of straightening vanes upstream of the rotor to ensure that the fluid entering the rotor is free from swirl. Standard requirements for turbine flow meters are 10 diameters of straight pipe upstream and 5 diameters of straight pipe downstream of the rotor with straightening vanes.

Turbine flow meters for measuring gas flow are characterized by a central hub that is larger than the hub in turbine flow meters used for liquid flow measurement. A diagram of the turbine flow meter is presented in Figure 4.4-9. Other turbine flow meter designs are the paddle wheel, propeller, and tangential turbine.

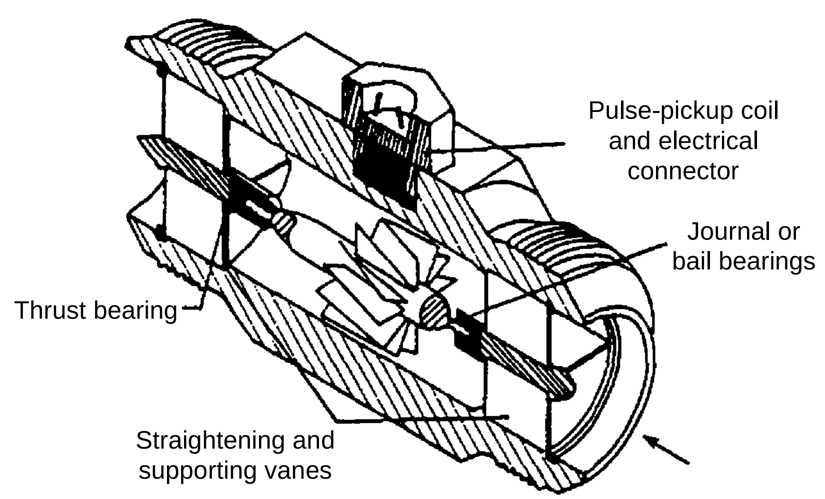

Figure 4.4-9. Turbine flow meter.[2]

Turbine flow meters can be used to measure fluid flow in pipes with diameters of approximately 0.64 to 61 cm (0.25 to 24 in.). The turbine flow meter can measure liquid flow rates from 0.23 to 189,000 L/min (0.06 to 50,000 gal/min) and gas flow rates from (100 to 230,000 standard cubic feet per minute [scfm]). Table 4.4-6 summarizes the advantages and disadvantages of turbine flow meters.

TABLE 4.4-6. ADVANTAGES AND DISADVANTAGES OF TURBINE FLOW METERS

Advantages	Disadvantages
Sensitive to fluctuations in flow and can more accurately detect changes in fluid velocity	Exhibit a larger amount of slip than do positive displacement flow meters
Rotor stoppage does not totally block the flow of fluid as would be the case for positive displacement flow meters	Contain many moving parts Require straight pipe and flow straightening vanes
Available for a wide range of flow rates	Cannot operate at flows greater than recommended; overspinning the rotor can destroy the bearings

4.4.5.3 Accuracy[5]

Although the trend in flow rate measurement has been toward flow meters than have few or no moving parts, the turbine flow meter often is used when high accuracy is desired. The accuracy of liquid-flow turbine flow meters is approximately ±0.5 percent over a 10 to 1 flow rate range. Accuracy typically is not as high in turbine flow meters used for gas flow applications.

4.4.5.4 Calibration Techniques[5]

4.4.5.4.1 Sensor. The primary flow meter device is factory calibrated.

4.4.5.4.2 System. Turbine transmitter calibration is performed by adjustment to properly interpret the frequency output of the primary device. Zero and span adjustments are made by simulating the frequency that the primary device would transmit at zero flow or maximum flow and adjusting the transmitter output as appropriate.

Another system calibration that can be performed involves energy or mass balance calculation of fluid flow to process operations. If fluid flow energy or mass agrees (balances) within the performance specifications to actual production rates or heat input, the flow rate system can be assumed to be in calibration. Additionally, comparisons of recent energy or mass balances to past data can be made.

4.4.5.5 <u>Recommended QA/QC Procedures</u>[5]

Turbine flow meters should not be subject to sudden surges of liquid flow, such as the starting of a pump or opening of a valve when the flow meter or piping is empty. Diagnosis of sensor failure, as opposed to rotor, bearing, or electronic failure, is important in order to avoid unnecessary work. Sensor failure should be suspected when flow is known to exist in the pipe but zero flow is indicated at the transmitter output. In such cases, the transmitter should be checked in the same manner as performance of a span calibration. If the transmitter functions electrically, then the fault likely lies in the rotor, the bearing, or the sensing element.

Bearing wear can be detected by applying a low flow of fluid to the turbine and checking for rotor drag. Excessive wear can cause the rotor to eventually stop rotating and fail completely. The following recommended spare parts should be maintained: rotor, sensor, bearings, and electronic components (transmitter).

4.4.5.5.1 <u>Frequency of calibration</u>. Calibration of the turbine flow meter transmitter should follow a consistent pattern to allow for comparison of performance changes over time. If slippage or bearing wear is suspected, appropriate procedures should be undertaken to correct the problem. The recommended frequency of calibration depends largely on site-specific conditions and facility standard operating procedures. Moreover, specific regulations may require a specific calibration frequency (e.g., annually). In general, calibration frequency should be within the manufacturer's recommendations. These calibration intervals should not be relied on indefinitely; they are starting points. At the end of the initial calibration period, the system should be calibrated or examined, as appropriate, and the data obtained should be charted. If the system is near or beyond the limit of accuracy (80 percent of acceptable error) and no process excursions or conditions are suspected of causing the decalibration, the calibration interval probably is too long. In such a case, the system should be recalibrated to the center of the acceptance band, and the calibration interval should be shortened. At the end of the second calibration period, calibration should be checked to determine if the system is drifting. If the system is near or beyond the limit of acceptable accuracy, similar steps should be taken, and the calibration period should be further shortened. This process should be repeated until the system is within the acceptable limit of accuracy at the end of the calibration interval. If, at the end of the initial calibration period, the system is determined to be within acceptable tolerance, adjustment is not necessary. The results should be recorded and the same calibration interval should be maintained for another calibration period. A log of all calibration check results should be maintained at the facility. Any corrective actions or adjustments should be recorded. Calibration data should be reviewed annually in order to spot significant deviations from defined procedures or tolerances.

4.4.5.5.2 Quality control. Written procedures should be prepared for instrument calibrations. These procedures should include:

1. The recommended interval for zero and span calibration checks of the transmitter (Readings before and after adjustment should be recorded.);
2. The reference zero and span values to be applied;
3. Step-by-step written procedures;
4. Blank field calibration forms (Records should include identification of the instrument component calibrated, the date of calibration, and initials of the person who performed the calibration.);
5. Designation of responsibility to perform the calibration (i.e., name of person(s) or position);
6. Designation of person to whom to report any failed calibration; and
7. Place to store calibration results.

4.4.5.5.3 Quality assurance. The calibration logs should be reviewed to confirm that calibrations were completed and performed properly. The person performing this review and the frequency of review should be specified. The written calibration procedures should be reviewed and updated to reflect any changes (e.g., system modifications or instrument changes).

4.4.6 Vortex Formation Flow Meters

4.4.6.1 Measurement Principal

Vortex formation flow meters detect vortices in the fluid flow downstream of their generation.

4.4.6.2 System Components and Operation[2,5]

Vortex formation flow meters can be classified based on design as either vortex shedding or vortex precession. In a vortex shedding device, vortex generation is induced by the means of a blunt, typically flat-faced, body placed perpendicular to the flowing fluid. As fluid passes the vortex generating element, the sharp corners cause a fixed point of fluid separation that forms a shear layer. At a specific distance downstream, the fluid in the shear layer breaks down into well-formed vortices. These vortices are formed and shed with a frequency that is linearly proportional to the fluid velocity. Sensing of the vortices is accomplished either by sensing the fluctuating pressure in the wake of the vortex generator or by sensing local velocity fluctuations around the body. Figure 4.4-10 depicts a vortex shedding flow meter.

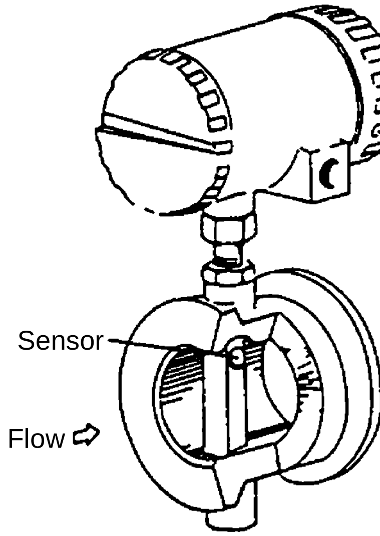

Figure 4.4-10. Vortex shedding flow meter.[2]

Vortex shedding flow meters are generally comprised of the following three basic parts: a vortex generating element, a sensor to convert vortex energy into electrical pulses, and a transmitter. The primary differences in vortex shedding flow meter designs are the shape of the generating element and the type of sensor used.

Vortex shedding flow meters are applicable to low viscosity liquids and to pressurized gases with sufficiently high densities and momentum to operate the flow meter.

In a vortex precession flow meter, the fluid entering the meter is forced into a swirl condition along the axis of flow by swirl-blade, guide vanes. The swirl is a vortex filament that is produced continuously, rather than periodically as is the case for shed vortices. At the exit of the swirl blades, the flow is contracted and expanded in a venturi-like passage, causing the vortex filament to adopt a helical path. The helical path results in a precession-like motion of the vortex filament at a fixed downstream station. A sensor placed at the downstream station relays the frequency of precession, which is linearly proportional to flow rate. Vortex precession flow meters are comprised of the following parts: swirl blades and deswirl blades, a vortex filament, a sensor, and a transmitter. The vortex precession flow meter is basically obsolete, and has yielded to the shedder device. A vortex precession flow meter is depicted in Figure 4.4-11.

Vortex formation flow meters can be used to measure fluid flow in pipes that range in diameters from 2.5 to 30 cm (1 to 12 in.) for shedding devices and from 2.5 to 20 cm (1 to 8 in.) for precession devices. The linear flow rate range for a vortex shedding flow meter is 20 to 1 for liquid and 100 to 1 for gases with the minimum flow rate of approximately 60 scfm. The applicable liquid flow rate range (for the shedding device) is 11 to 18,900 L/min (3 to 5,000 gal/min).

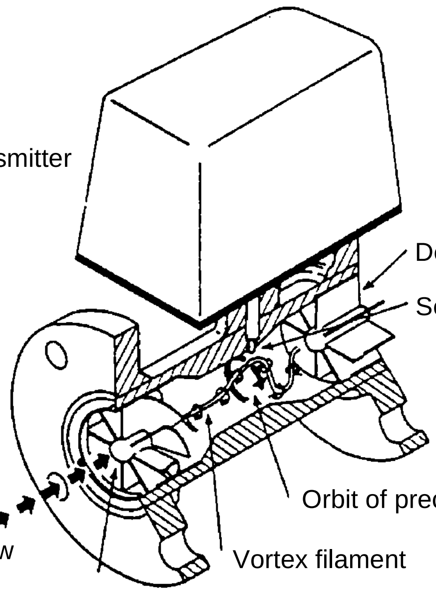

Figure 4.4-11. Vortex precession flow meter.[2]

The vortex precession flow meter is applicable only to gases with a flow rate range comparable to the vortex shedding flow meter.

Vortex formation flow meters are sensitive to swirling flow. Typical straight pipe requirements to reduce the amount of swirl in the fluid are 10 to 20 pipe diameters upstream and 5 diameters downstream. Tables 4.4-7 and 4.4-8 summarize the advantages and disadvantages of vortex shedding and vortex precession flow meters, respectively.

4.4.6.3 Accuracy[8]

The accuracy of vortex formation flow meters is approximately ±1 percent of flow rate for liquid applications and ±2 percent of flow rate for gas applications.

4.4.6.4 Calibration Techniques[5]

4.4.6.4.1 Sensor. The primary flow meter device is factory calibrated.

4.4.6.4.2 System. Calibration of the vortex formation transmitter is performed by injecting frequency signals into the transmitter and making the appropriate adjustments. This allows verification of the thumbwheel adjustments as well as fine adjustment of the zero and span analog circuit. Another possible system calibration involves energy or mass balance calculation of fluid flow to process operations. If fluid flow energy or mass agrees (balances) within the performance specifications to actual production rates or heat input, the flow rate

TABLE 4.4-7. ADVANTAGES AND DISADVANTAGES OF VORTEX SHEDDING FLOW METERS

Advantages	Disadvantages
No moving parts	Sensitive to upstream flow disturbances
Insensitive to density changes	Pulsed signal output
Linear over a wide velocity range	Limited pipe diameters
	Somewhat high net pressure loss (35 to 50 percent of the differential pressure)

TABLE 4.4-8. ADVANTAGES AND DISADVANTAGES OF VORTEX PRECESSION FLOW METERS

Advantages	Disadvantages
No moving parts	Sensitive to upstream flow disturbances
Insensitive to density changes	High net pressure loss (five times higher than for the vortex shedding device)
Continuous output	Limited pipe diameters
Linear over a wide velocity range	Limited to gas applications only

system can be assumed to be in calibration. Additionally, comparisons of recent energy or mass balances to past data can be made.

4.4.6.5 <u>Recommended QA/QC Procedures</u>[5]

Vortex shedding flow meters do not require zero adjustment. The span adjustment is typically performed with field changeable links or thumbwheel switches. When an analog output is used, both zero and span of the analog circuit should be performed. Normal shedder wear usually has no effect on the performance of the instrument. The following recommended spare parts should be maintained: sensor, shedder, and electronic components (transmitter).

4.4.6.5.1 <u>Frequency of calibration</u>. Calibration of the flow meter transmitter should follow a consistent pattern to allow for comparison of performance changes over time. The recommended frequency of calibration depends largely on site-specific conditions and facility standard operating procedures. Moreover, specific regulations may require a specific calibration frequency (e.g., annually). In general, calibration frequency should be within the manufacturer's recommendations. These calibration intervals should not be relied on indefinitely; they are starting points. At the end of the initial calibration period, the system should be calibrated or examined, as appropriate, and the data obtained should be charted. If the system is near or beyond the limit of accuracy (80 percent of acceptable error) and no process excursions or conditions are suspected of causing the decalibration, the calibration interval probably is too long. In such a case, the system should be recalibrated to the center of the acceptance band, and the calibration interval should be shortened. At the end of the second calibration period, calibration should be checked to determine if the system is drifting. If the system is near or beyond the limit of acceptable accuracy, similar steps should be taken, and the calibration period should be further shortened. This process should be repeated until the system is within the acceptable limit of accuracy at the end of the calibration interval. If, at the end of the initial calibration period, the system is determined to be within acceptable tolerance, adjustment is not necessary. The results should be recorded and the same calibration interval should be maintained for another calibration period. A log of all calibration check results should be maintained at the facility. Any corrective actions or adjustments should be recorded. Calibration data should be reviewed annually in order to spot significant deviations from defined procedures or tolerances.

4.4.6.5.2 Quality control. Written procedures should be prepared for instrument calibrations. These procedures should include:

1. The recommended interval for zero and span calibration checks of the transmitter (Readings before and after adjustment should be recorded.);
2. The reference zero and span values to be applied;
3. Step-by-step written procedures;
4. Blank field calibration forms (Records should include identification of the instrument component calibrated, the date of calibration, and initials of the person who performed the calibration.);
5. Designation of responsibility to perform the calibration (i.e., name of person(s) or position);
6. Designation of person to whom to report any failed calibration; and
7. Place to store calibration results.

4.4.6.5.3 Quality assurance. The calibration logs should be reviewed to confirm that calibrations were completed and performed properly. The person performing this review and the frequency of review should be specified. The written calibration procedures should be reviewed and updated to reflect any changes (e.g., system modifications or instrument changes).

4.4.7 Fluidic Oscillating Flow Meters

4.4.7.1 Measurement Principal[2,5]

The operation of fluidic flow meters is based on the Coanda Effect, which causes a liquid to attach itself to a surface, and fluidics, which is typified by feedback action of the liquid on itself.

4.4.7.2 System Components and Operation[2,5]

When flow is initiated, the flowing stream attaches itself to one of the two sidewalls in the flow meter (i.e., by means of the Coanda Effect). A small portion of the flow is diverted through a recycle, feedback passage to a control port. The feedback flow, acting on the main flow, diverts the main flow to the opposite side wall where the feedback action is repeated on the opposite side of the flow meter. A continuous self-induced oscillating flow results between the meter body side walls. As the main flow oscillates between the side walls, the velocity of the flow in the feedback passages cycles between zero and a maximum velocity. The feedback passages thereby contain a region of substantial flow rate change where the frequency of the oscillating fluid is detectable by a thermal sensor. The oscillating frequency is linearly proportional to the fluid velocity.

The main components of the fluidic oscillating flow meter are: the feedback passage, side wall, control port, and sensor. A diagram of the fluidic oscillating flow meter is presented in Figure 4.4-12. The figure shows both stages of flow through this type of flow meter. Fluidic oscillating flow meters can be used to measure liquid flow in pipes with a diameter range of 2.5 to 10 cm (1 to 4 in.), with a maximum velocity of 4.6 to 7.6 meter per second (m/sec) (15 to 25 feet per second [ft/sec]). The application of fluidic oscillating flow meters is limited to liquids with less than 2 percent solids such as acids, bases, water, fuel oils, and chemicals, provided the Reynolds number is greater than the minimum for flow meter operation (typically 500 to 3,000). Table 4.4-9 summarizes the advantages and disadvantages of fluidic oscillating flow meters.

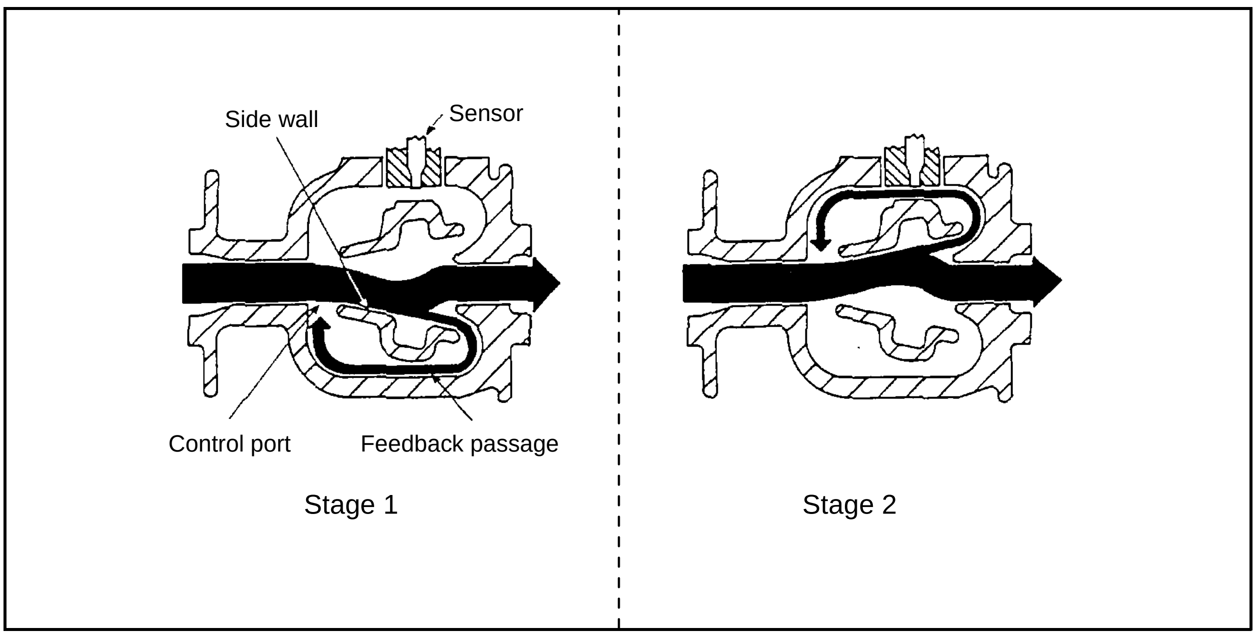

Figure 4.4-12. Fluidic oscillating flow meter.[2]

TABLE 4.4-9. ADVANTAGES AND DISADVANTAGES OF FLUIDIC OSCILLATING FLOW METERS

Advantages	Disadvantages
Lower installed cost compared to more traditional techniques	Sensitive to upstream flow disturbances (suggest following orifice installation practices)
Insensitive to density changes	Pulsed signal output
Accurate over a wide velocity range (up to 50:1)	Limited pipe diameters
Operates at velocities up to 4.6 to 7.6 m/s (15 to 25 ft/sec)	Applicable only to liquids

4.4.7.3 <u>Accuracy</u>[5]

Fluidic oscillating flow meters have accuracy statements that range from ±1.25 to 2.0 percent of flow rate.

4.4.7.4 <u>Calibration Techniques</u>[5]

4.4.7.4.1 <u>Sensor</u>. The primary flow meter device is factory calibrated.

4.4.7.4.2 <u>System</u>. Calibration of the electronics is performed by adjusting the zero with no flow through the flow meter and adjusting the span by injecting a frequency signal that simulates the maximum flow. Another system calibration that can be performed involves energy or mass balance calculation of fluid flow to process operations. If fluid flow energy or mass agrees (balances) within the performance specifications to actual production rates or heat input, the flow rate system can be assumed to be in calibration. Additionally, comparisons of recent energy or mass balances to past data can be made.

4.4.7.5 <u>Recommended QA/QC Procedures</u>[5]

If the liquid has a tendency to coat the thermal sensor, the sensor should be cleaned regularly. If sporadic operation of the flow meter occurs, the sensor is probably coated. A deflection type sensor usually does not suffer from coating effects. The recommended spare parts that should be maintained include the sensor and electronic circuit boards.

4.4.7.5.1 <u>Frequency of calibration</u>. Calibration of the flow meter transmitter should follow a consistent pattern to allow for comparison of performance changes over time. The recommended frequency of calibration depends largely on site-specific conditions and facility standard operating procedures. Moreover, specific regulations may require a specific calibration frequency (e.g., annually). In general, calibration frequency should be within the manufacturer's recommendations. These calibration intervals should not be relied on indefinitely; they are starting points. At the end of the initial calibration period, the system should be calibrated or examined, as appropriate, and the data obtained should be charted. If the system is near or beyond the limit of accuracy (80 percent of acceptable error) and no process excursions or conditions are suspected of causing the decalibration, the calibration interval probably is too long. In such a case, the system should be recalibrated to the center of the acceptance band, and the calibration interval should be shortened. At the end of the second calibration period, calibration should be checked to determine if the system is drifting. If the system is near or beyond the limit of acceptable accuracy, similar steps should be taken, and the calibration period should be further shortened. This process should be repeated until the system is within the acceptable limit of accuracy at the end of the calibration interval. If, at the end of the initial calibration period, the system is determined to be within acceptable tolerance, adjustment is not necessary. The results should be recorded and the same calibration interval should be maintained for another calibration period. A log of all calibration check results should be maintained at the facility. Any corrective actions or adjustments should be recorded. Calibration data should be reviewed annually in order to spot significant deviations from defined procedures or tolerances.

4.4.7.5.2 <u>Quality control</u>. Written procedures should be prepared for instrument calibrations. These procedures should include:

1. The recommended interval for zero and span calibration checks of the transmitter (Readings before and after adjustment should be recorded.);
2. The reference zero and span values to be applied;
3. Step-by-step written procedures;
4. Blank field calibration forms (Records should include identification of the instrument component calibrated, the date of calibration, and initials of the person who performed the calibration.);
5. Designation of responsibility to perform the calibration (i.e., name of person(s) or position);
6. Designation of person to whom to report any failed calibration; and
7. Place to store calibration results.

4.4.7.5.3 <u>Quality assurance</u>. The calibration logs should be reviewed to confirm that calibrations were completed and performed properly. The person performing this review and the frequency of review should be specified. The written calibration procedures should be reviewed and updated to reflect any changes (e.g., system modifications or instrument changes).

4.4.8 Ultrasonic Flow Meters

Ultrasonic flow meters can be applied to pipes of all sizes. Since the flow meter element is virtually the same independent of the pipe diameter, this technology has economic advantages over other flow meter technologies in large pipe applications.

4.4.8.1 Measurement Principal[2]

Electrical energy excites a piezoelectric crystal type of material to a state of mechanical resonance. As the crystal resonates, a sound wave, traveling at the speed of sound of the media, is generated. Ultrasonic flow meters determine flow rate based on the characteristics of the sound wave generated by the crystal. Piezoelectric crystals are placed either in contact with the fluid (wetted transducers) or mounted on the outside of the pipe containing the fluid (clamp-on transducers).

4.4.8.2 System Components and Operation[2,5]

Two types of ultrasonic flow meters are available: time-of-flight (TOF) and Doppler. In TOF ultrasonic flow meters, sound waves are introduced into the flowing fluid, one wave traveling with the flow and one wave traveling against the flow. The difference in transit time of the waves is proportional to the fluid flow rate, because the sound wave is accelerated when traveling with the flow and slowed when traveling against the flow. Therefore, if the sound wave velocity of the fluid (speed of sound) is known, the transit distance is known, and time difference is known, then the fluid flow rate can be determined. Time-of-flight ultrasonic flow meters can be classified as one of the following: axial transmission, multibeam (transverse or longitudinal) contra-propagating, cross beam, sing around, and reflected beam. Figure 4.4-13 depicts a TOF ultrasonic flow meter.

In wetted transducer TOF meter setups, a 45° transmission angle normally is chosen to save on needed pipe length while optimizing amplitude of the velocity vector along the sound path. Time-of-flight ultrasonic flow meters require a clean fluid so that sound pulses are not diverted (reflected) from the intended path. Any velocity profile change outside the transmission path is not felt by the sonic beam. Therefore, for greater accuracy, multiple beams may be used. To avoid swirling flow, straight runs of 10 to 30 pipe diameters upstream and 5 to 10 diameters downstream are required.

The basis of operation of Doppler ultrasonic flow meters is that, when an ultrasonic beam is projected into an inhomogeneous fluid, some acoustic energy is backscattered toward the transducer. Because the fluid is in motion relative to the fixed transducer, the scattered sound moving with the fluid is received by the transducer at a different frequency than the frequency at

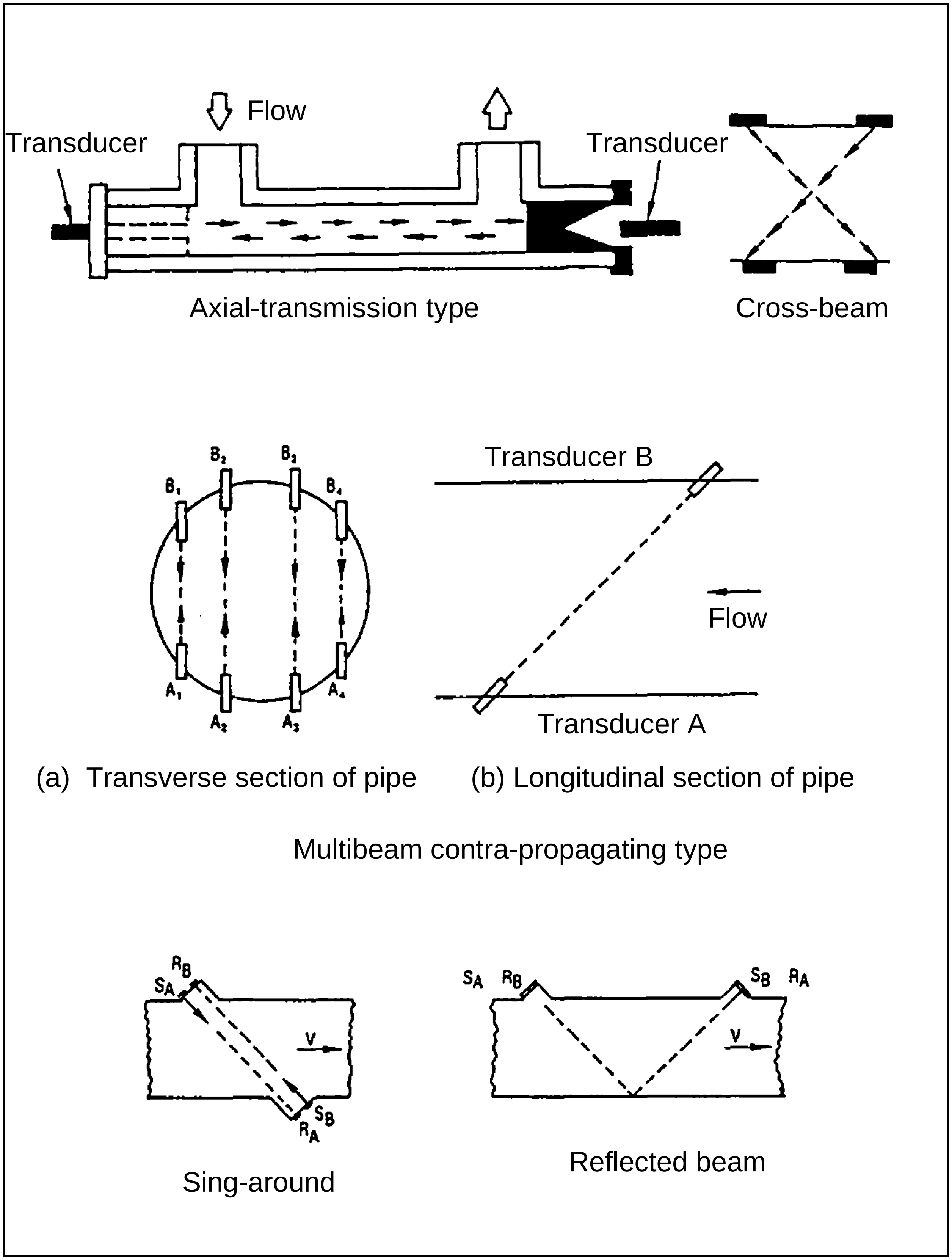

Figure 4.4-13. Time of flight ultrasonic flow meter.[2]

which it was sent. The difference between the outgoing and incoming frequencies is directly proportional to the fluid flow rate.

Most common Doppler flow meter configurations use the clamp-on arrangement, and several manufacturers offer portable clamp-on Doppler ultrasonic flow meters for field measurements. To operate well, Doppler ultrasonic flow meters require sufficient particles or bubbles in the fluid to reflect signals toward the sensor. Performance is affected by velocity profile changes because the receivers normally detect multiple frequencies, low frequencies from particles near the wall and high frequencies from particles in the center of the pipe. Signal processing techniques are used to weight each frequency to arrive at an integrated velocity. If particle concentration varies, severe errors may be incurred. Performance also is affected by particle concentration distribution.

Ultrasonic flow meters are comprised of the following basic parts: the transducer, receiver, timer, and temperature sensor. Figure 4.4-14 depicts some of the transducer arrangements used in Doppler ultrasonic flow meters. Ultrasonic flow meters can be used to measure fluid flow in pipes with a diameter greater than 0.32 cm (0.125 in.) with a minimum flow rate of approximately 0.38 L/min (0.1 gal/min). Time-of-flight ultrasonic flow meters are applicable to liquids and gases flowing at velocities greater than 0.03 m/sec (0.1 ft/sec). Doppler ultrasonic flow meters are applicable only to liquids flowing at a velocity greater than 0.15 m/sec (0.5 ft/sec). Tables 4.4-10 and 4.4-11 summarize the advantages and disadvantages of TOF and Doppler type ultrasonic flow meters, respectively.

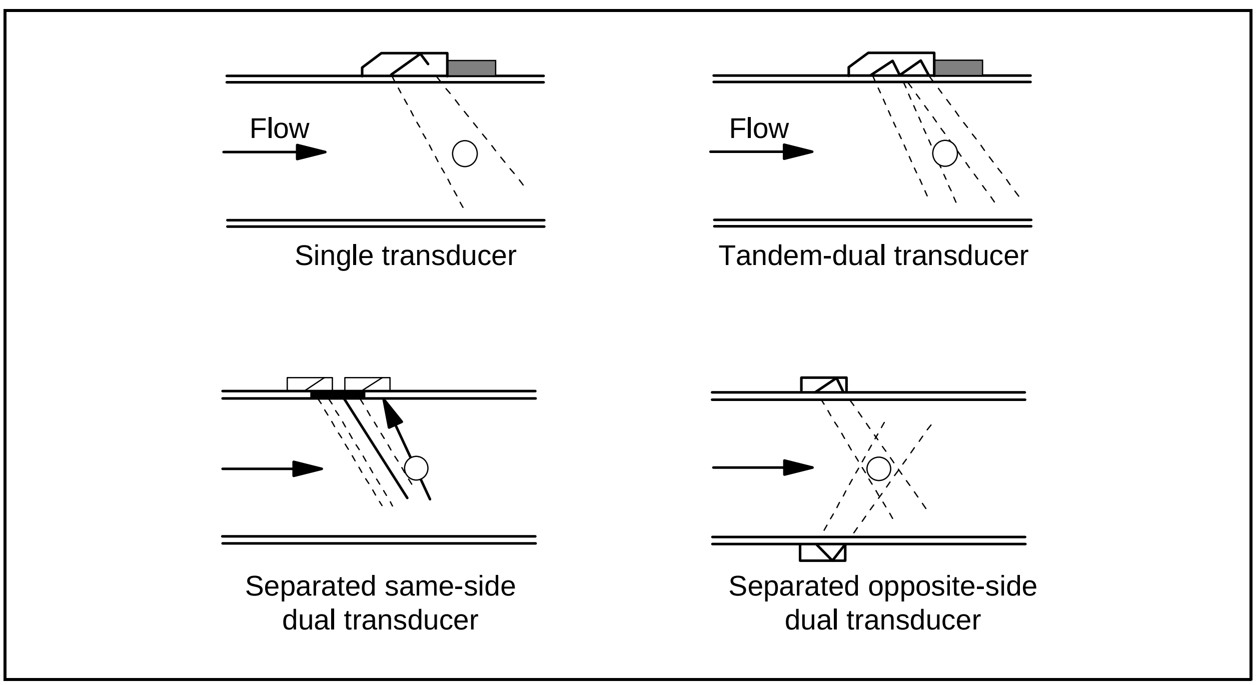

Figure 4.4-14. Doppler ultrasonic flow meter transducer arrangements.[2]

TABLE 4.4-10. ADVANTAGES AND DISADVANTAGES OF TIME-OF-FLIGHT ULTRASONIC FLOW METERS

Advantages	Disadvantages
Device does not protrude into the fluid	Sensitive to upstream flow disturbances
No moving parts	Fluid must be relatively clean
Wide range of pipe diameters	Must compensate for speed of sound changes in the fluid
Low-velocity detection limit	Need long length of straight pipe.

TABLE 4.4-11. ADVANTAGES AND DISADVANTAGES OF DOPPLER ULTRASONIC FLOW METERS

Advantages	Disadvantages
Ease of installation for clamp-on devices	Sensitive to upstream flow disturbances
Wide range of pipe diameters Low-velocity detection limit	Performance is highly variable--uncertainty of the depth of penetration, the velocity profile, or fluid composition changes can result in errors of greater than 30 percent
	Requires entrained gases or particles in the fluid Limited to liquid applications only

4.4.8.3 <u>Accuracy</u>[2,5]

Generally, wetted transducer devices are considered more accurate than clamp-on devices. Additionally, TOF ultrasonic flow meters are usually more accurate than doppler ultrasonic flow meters. The accuracy of TOF ultrasonic flow meters ranges from ±0.5 to 10 percent of full scale. The accuracy of Doppler ultrasonic flow meters can be as low as 1 percent of flow rate.

4.4.8.4 <u>Calibration Techniques</u>[5]

Calibration of ultrasonic flow meters is performed by electronically simulating the signals that would be present under flow conditions and making the necessary adjustments to the transmitter. Another possible system calibration involves energy or mass balance calculation of fluid flow to process operations. If fluid flow energy or mass agrees (balances) within the performance specifications to actual production rates or heat input, the flow rate system can be assumed to be in calibration. Additionally, comparisons of recent energy or mass balances to past data can be made.

4.4.8.5 <u>Recommended QA/QC Procedures</u>

The intensity of the ultrasonic signal should be checked periodically to ensure it is within manufacturer's specifications. The following recommended spare parts should be maintained: transducer, and mounting hardware such as gaskets or O-rings.

4.4.8.5.1 <u>Frequency of calibration</u>. Calibration of the flow meter transmitter should follow a consistent pattern to allow for comparison of performance changes over time. The recommended frequency of calibration depends largely on site-specific conditions and facility standard operating procedures. Moreover, specific regulations may require a specific calibration frequency (e.g., annually). In general, calibration frequency should be within the manufacturer’s recommendations. These calibration intervals should not be relied on indefinitely; they are starting points. At the end of the initial calibration period, the system should be calibrated or examined, as appropriate, and the data obtained should be charted. If the system is near or beyond the limit of accuracy (80 percent of acceptable error) and no process excursions or conditions are suspected of causing the decalibration, the calibration interval probably is too long. In such a case, the system should be recalibrated to the center of the acceptance band, and the calibration interval should be shortened. At the end of the second calibration period, calibration should be checked to determine if the system is drifting. If the system is near or beyond the limit of acceptable accuracy, similar steps should be taken, and the calibration period should be further shortened. This process should be repeated until the system is within the acceptable limit of accuracy at the end of the calibration interval. If, at the end of the initial calibration period, the system is determined to be within acceptable tolerance, adjustment is not necessary. The results should be recorded and the same calibration interval should be maintained for another calibration period. A log of all calibration check results should be maintained at the facility. Any corrective actions or adjustments should be recorded. Calibration data should be reviewed annually in order to spot significant deviations from defined procedures or tolerances.

4.4.8.5.2 <u>Quality control</u>. Written procedures should be prepared for instrument calibrations. These procedures should include:

1. The recommended interval for zero and span calibration checks of the transmitter (Readings before and after adjustment should be recorded.);
2. The reference zero and span values to be applied;
3. Step-by-step written procedures;
4. Blank field calibration forms (Records should include identification of the instrument component calibrated, the date of calibration, and initials of the person who performed the calibration.);
5. Designation of responsibility to perform the calibration (i.e., name of person(s) or position);

6. Designation of person to whom to report any failed calibration; and
7. Place to store calibration results.

4.4.8.5.3 Quality assurance. The calibration logs should be reviewed to confirm that calibrations were completed and performed properly. The person performing this review and the frequency of review should be specified. The written calibration procedures should be reviewed and updated to reflect any changes (e.g., system modifications or instrument changes).

4.4.9 Thermal Flow Meters

Thermal flow meters measure flow rate either by monitoring the cooling action of the flow on a heated body placed in the flow or by the transfer of heat energy between two points along the flow path. Since thermal flow meter output is dependent upon thermal (not physical) properties of the fluid, it is applicable to fluids that are not dense enough to be sensed by technologies that use mechanical devices.

4.4.9.1 Measurement Principal[2]

The general equation for determining the amount of heat given up by a heated sensor to a fluid in terms of the current supplied and the resistance can be expressed as:

$$q = 0.24I^2R$$

where:

q = amount of heat released;
I = current supplied; and
R = resistance.

In terms of fluid properties and fluid velocity:

$$q = (t_s - t_g)[C_t + (2\pi dC_v\rho V)^{1/n}]$$

where:

t_s = sensor operating temperature;
t_g = fluid temperature;
C_t = thermal conductivity of fluid;
C_v = thermal capacity (specific heat at constant volume for a gas;
ρ = density of fluid;
d = diameter of wire;
V = velocity of fluid; and
n = usually close to 2.

When considering thermal balance in a flowing system, assuming the absorption of heat by anything other than the flowing fluid (i.e., pipe wall) is negligible, the flow rate can be determined by the difference between two temperature readings as:

$$q = \rho V C_p (t_b - t_a)$$

where:

C_p = thermal capacity (specific heat at constant pressure for a gas);

t_b = temperature of fluid before the heater; and

t_a = temperature of fluid after the heater.

4.4.9.2 System Components and Operation.[2]

Two types of thermal class flow meters are available: thermal anemometers (thermo-anemometers) and calorimetric flow meters. Thermo-anemometers measure flow rate by monitoring the cooling action of the flow on a heated body placed in the flow. The thermo-element may be held at a constant temperature or variable temperatures (constant current). Rate of flow is measured by the variation in the magnitude of the current for an element with its resistance (temperature) held constant or by the variation in the element resistance for a supplied current of constant magnitude. Constant temperature circuits are used more often because they have the following advantages over constant current circuits:

1. Superior performance in both noise level and frequency response;
2. Compatibility with complex frequency characteristics of hot-film probes;
3. Increased probe life;
4. Prevention of sensor burnout due to velocity changes;
5. Linearization of constant-current system is not possible; and
6. Easy temperature compensation.

Thermo-anemometers can be either a hot-wire anemometer or a hot film anemometer. In hot-wire anemometers, the thermo-element is a fine metal wire (0.00038 cm [0.00015 in.] in diameter) made of tungsten with a thin platinum coating on the surface. The thin, metal wire element is connected as one of the arms of a balanced measuring bridge. In hot-film anemometers, the thermo-element consists of a metallic film made of alumina or quartz deposited on a vitreous or ceramic substrate (usually platinum). Hot-film anemometers come in a variety of shapes such as wires, wedges, cones, and flat surfaces. Figure 4.4-15 depicts four of these shapes.

The hot-film probe has the following advantages over the hot-wire probe:

1. More rugged;
2. Less susceptible to accumulation of foreign materials;
3. Easier to clean;
4. Better frequency response over a wider frequency range; and
5. Adapted to a variety of probe shapes.

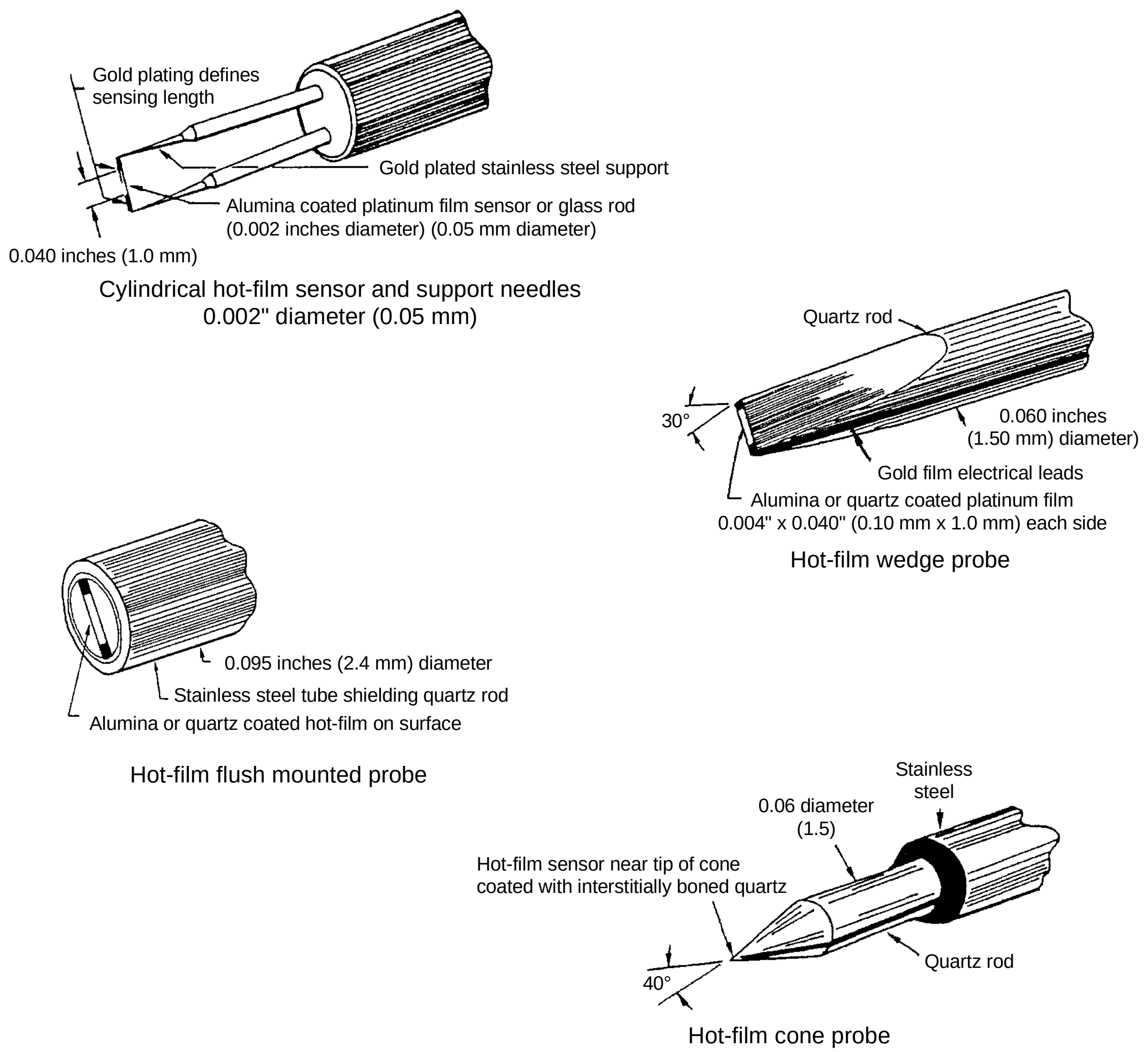

Figure 4.4-15. Thermo-anemometers in various shapes.[2]

However, in some applications, a hot-wire probe is superior. Other important characteristics of thermo-anemometers are as follows:

1. Inherently mass flow sensitive;
2. Highly dependent upon fluid composition; and
3. Probe output is nonlinear in terms of current or voltage, requiring a linearizing circuit.

Calorimetric flow meters work on the principle of heat transfer by the flow of fluid. A calorimetric flow meter consists of three elements: a temperature measurement device upstream of a heater; a heater; and a temperature measurement device downstream of a heater. The flow rate is determined by the difference in the two temperature readings. As is the case for thermo-anemometers, calorimetric flow meters are inherently sensitive to mass flow. However, unlike thermo-anemometers, calorimetric flow meters are linearly proportional to heat transfer. Figure 4.4-16 is a diagram of a calorimetric flow meter.

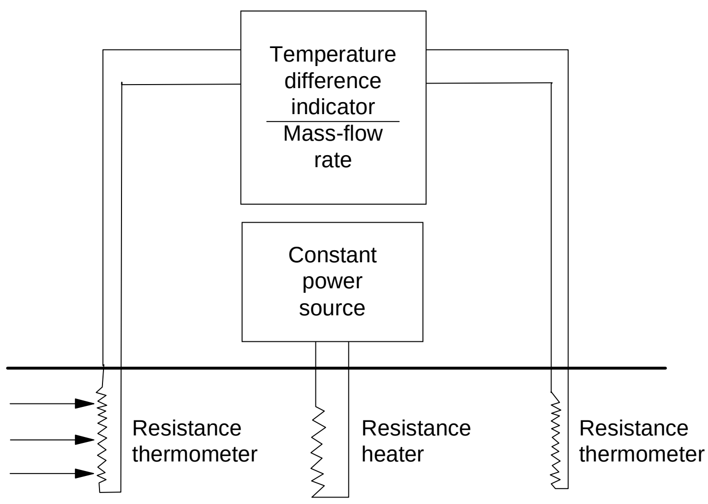

Figure 4.4-16. Calorimetric flow meter (heated grid).[2]

Calorimetric flow meters operate by one of three techniques:

1. Devices that draw constant power to the heater with simultaneous measurement of the amount of heat transferred to the flow;
2. Devices that heat the flow to a constant temperature with simultaneous measurement of the energy supplied to the heater; or
3. Devices that vary the heater temperature sinusoidally with time; in these, the flow rate is measured by the signal phase shift at the sensor compared to the input signal at the heater.

Thermal flow meters can be used to measure fluid flow in pipes with diameters of 5.1 cm (2 in.) or larger. Thermal flow meters are applicable to fluids that have known heat capacities, that is, mostly gases, with very limited liquid applications because of heat transfer problems.

Thermal flow meters are susceptible to swirling flow and require straight pipe sections of 8 to 10 diameters upstream and 3 diameters downstream of the device. Table 4.4-12 summarizes the advantages and disadvantages of thermal flow meters.

TABLE 4.4-12. ADVANTAGES AND DISADVANTAGES OF THERMAL FLOW METERS

Advantages	Disadvantages
No moving parts	Require temperature and pressure compensation
Low net pressure loss	Require temperature and pressure measurement devices
Accurate over a wide flow range (300 to 1)	Point measurements require critically positioned probes
Can be used on a variety of pipe sizes	Mostly applicable to gases
	Require straight pipe upstream of the device

4.4.9.3 <u>Accuracy</u>.[2]

Thermo-anemometer accuracy ranges from ±1.5 to 2 percent of flow rate. Calorimetric flow meter accuracy is approximately ±4 to 5 percent of flow rate.

4.4.9.4 <u>Calibration Techniques</u>.[9]

Calibration is done by the manufacturer and cannot be adjusted unless correction factors are applied to the output. Sensors are calibrated in an NIST- traceable wind tunnel in air and referenced to standard temperature and pressure. When calibrating thermal flow meters, electronic zero and span calibrations of the transmitter should be checked by injecting the appropriate signal level to the transmitter input points. Another system calibration that can be performed involves energy or mass balance calculation of fluid flow to process operations. If fluid flow energy or mass agrees (balances) within the performance specifications to actual production rates or heat input, then the flow rate system can be assumed to be in calibration. Additionally, comparisons of recent energy or mass balances to past data can be made.

4.4.9.5 <u>Recommended QA/QC Procedures</u>

Routine maintenance should include a program to keep the thermally conductive surfaces clean. Additionally, replaceable sensor tips enhance repair of failed sensors. The following recommended spare parts should be maintained: replaceable probes or entire flow meter assembly, and electronic circuit boards.

4.4.9.5.1 <u>Frequency of calibration</u>. Calibration of the flow meter transmitter should follow a consistent pattern to allow for comparison of performance changes over time. The recommended frequency of calibration depends largely on site-specific conditions and facility standard operating procedures. Moreover, specific regulations may require a specific calibration frequency (e.g., annually). In general, calibration frequency should be within the manufacturer's recommendations. These calibration intervals should not be relied on indefinitely; they are starting points. At the end of the initial calibration period, the system should be calibrated or examined, as appropriate, and the data obtained should be charted. If the system is near or beyond the limit of accuracy (80 percent of acceptable error) and no process excursions or conditions are suspected of causing the decalibration, the calibration interval probably is too long. In such a case, the system should be recalibrated to the center of the acceptance band, and the calibration interval should be shortened. At the end of the second calibration period, calibration should be checked to determine if the system is drifting. If the system is near or beyond the limit of acceptable accuracy, similar steps should be taken, and the calibration period should be further shortened. This process should be repeated until the system is within the acceptable limit of accuracy at the end of the calibration interval. If, at the end of the initial calibration period, the system is determined to be within acceptable tolerance, adjustment is not necessary. The results should be recorded and the same calibration interval should be maintained for another calibration period. A log of all calibration check results should be maintained at the facility. Any corrective actions or adjustments should be recorded. Calibration data should be reviewed annually in order to spot significant deviations from defined procedures or tolerances.

4.4.9.5.2 Quality control. Written procedures should be prepared for instrument calibrations. These procedures should include:

1. The recommended interval for zero and span calibration checks of the transmitter (Readings before and after adjustment should be recorded.);
2. The reference zero and span values to be applied;
3. Step-by-step written procedures;
4. Blank field calibration forms (Records should include identification of the instrument component calibrated, the date of calibration, and initials of the person who performed the calibration.);
5. Designation of responsibility to perform the calibration (i.e., name of person(s) or position); and
6. Designation of person to whom to report any failed calibration; and
7. Place to store calibration results.

4.4.9.5.3 Quality assurance. The calibration logs should be reviewed to confirm that calibrations were completed and performed properly. The person performing this review and the frequency of review should be specified. The written calibration procedures should be reviewed and updated to reflect any changes (e.g., system modifications or instrument changes).

4.4.10 Mass Flow Meters (Coriolis)[5]

A Coriolis mass flow meter consists of a U-shaped tube that deflects or vibrates as the fluid flows through it. The operation of this type of mass flow meter is based on the conservation of angular momentum as it applies to the Coriolis acceleration of a fluid. Coriolis acceleration is that tangential force experienced when one walks radially outward on a rotating platform. The force is only experienced when one changes position in relation to the center of rotation.

4.4.10.1 Measurement Principal[10]

As fluid enters the U-shaped tube, it is forced to take on the vertical movement of the vibrating tube. When the tube is moving upward, the fluid flowing into the meter resists being forced up by pushing down on the tube. Having been forced upward, the fluid flowing out of the meter resists having its vertical motion decreased by pushing up on the tube. The two opposing forces on the tube cause it to twist. The amount of twist is directly proportional to the mass rate of fluid flowing through the tube.

4.4.10.2 System Components and Operation[5]

A mass flow meter consists of a vibrating U-shaped tube in which the Coriolis acceleration is created and measured. In place of the rotational motion described above, the inlet and outlet of the tube are held fixed while the tube is vibrated sinusoidally about an axis formed between the inlet and outlet, typically by a magnetic device located in the bend. In most devices, magnetic sensors located on each side of the flow tube measure the respective velocities, which change as the tube twists. Newer models have two U-shaped tubes to measure fluid flow.

Coriolis mass flow meters have specific minimum and maximum operating flow rates. High-temperature sensors can operate up to 430°C (800°F). The pressure drop across the flow meter cannot exceed the maximum allowable pressure drop that the total system will accept, otherwise the fluid will not flow into the U-tube. A diagram of a Coriolis mass flow meter is presented in Figure 4.4-17.

Mass flow meters can be used to measure fluid flow in pipes with a diameter range of 0.16 to 15 cm (0.0625 to 6 in.). Coriolis mass flow meters are generally used in the following liquid applications: harsh chemicals, low to medium viscosity, foods, slurries, and blending systems. Gas applications are somewhat limited since the density of low-pressure gases is usually too low to accurately operate the flow meter. Typically, thin walled tubes are used for gas applications. However, when applicable, the mass flow meter eliminates the need for pressure and temperature compensation and the hardware necessary to implement these functions. Table 4.4-13 summarizes the advantages and disadvantages of Coriolis mass flow meters.

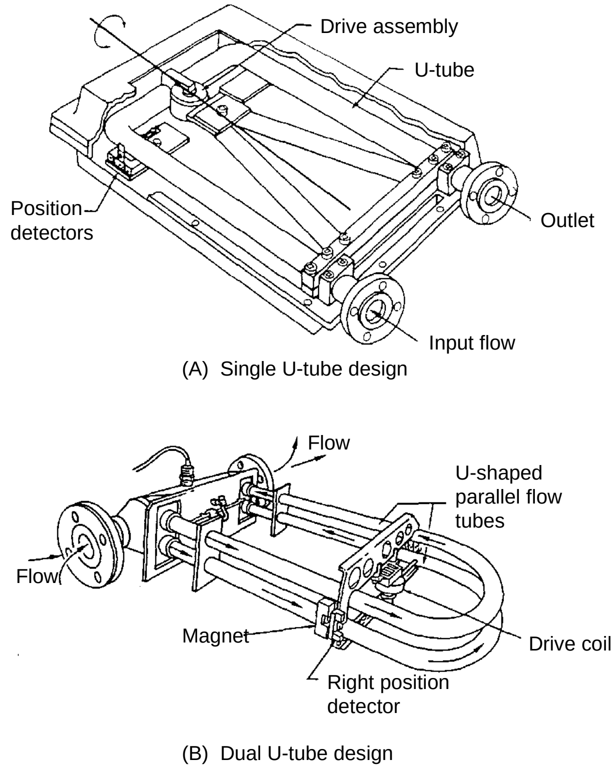

Figure 4.4-17. Coriolis mass flow meter.[5]

TABLE 4.4-13. ADVANTAGES AND DISADVANTAGES OF CORIOLIS MASS FLOW METERS

Advantages	Disadvantages
Have no Reynolds number constraints	Limited applicability to gases
Applicable to virtually any liquid	Relatively expensive
Excellent accuracy	High-net pressure loss
Not affected by swirling flow; therefore, no need for straight pipe	
No need for temperature compensation	
Provide direct mass flow measurement	

4.4.10.3 **Accuracy**[5]

Coriolis mass flow meters have an accuracy of 0.2 to 0.4 percent of flow rate (within ±28°C [±50°F] of calibrated temperature) to a mass flow rate of 0.45 kilogram per hour (kg/hr) (1 pound per hour [lb/hr]).

4.4.10.4 **Calibration Techniques**[5]

Zero and span calibration of most flow meters is performed digitally under zero flow conditions at operating temperature. Variations of more than about 28°C (50°F) from the temperature at which the zero adjustment was performed result in reduced accuracy. Another possible system calibration involves energy or mass balance calculation of fluid flow to process operations. If fluid flow energy or mass agrees (balances) within the performance specifications to actual production rates or heat input, the flow rate system can be assumed to be in calibration. Additionally, comparisons of recent energy or mass balances to past data can be made.

4.4.10.5 **Recommended QA/QC Procedures**[5]

Excessive coating of the inside of the tube can cause the tube to become restricted. This will result in a loss of accuracy if the flow is less than the minimum accurately measurable flow of the flow meter. The recommended spare parts that should be maintained include sensors and electronic circuit boards.

4.4.10.5.1 Frequency of calibration. Calibration of the flow meter transmitter should follow a consistent pattern to allow for comparison of performance changes over time. The recommended frequency of calibration depends largely on site-specific conditions and facility standard operating procedures. Moreover, specific regulations may require a specific calibration frequency (e.g., annually). In general, calibration frequency should be within the manufacturer's recommendations. These calibration intervals should not be relied on indefinitely; they are starting points. At the end of the initial calibration period, the system should be calibrated or examined, as appropriate, and the data obtained should be charted. If the system is near or beyond the limit of accuracy (80 percent of acceptable error) and no process excursions or conditions are suspected of causing the decalibration, the calibration interval probably is too long. In such a case, the system should be recalibrated to the center of the acceptance band, and the calibration interval should be shortened. At the end of the second calibration period, calibration should be checked to determine if the system is drifting. If the system is near or beyond the limit of acceptable accuracy, similar steps should be taken, and the calibration period should be further shortened. This process should be repeated until the system is within the acceptable limit of accuracy at the end of the calibration interval. If, at the end of the initial calibration period, the system is determined to be within acceptable tolerance, adjustment is not necessary. The results should be recorded and the same calibration interval should be maintained for another calibration period. A log of all calibration check results should be maintained at the facility. Any corrective actions or adjustments should be recorded. Calibration data should be reviewed annually in order to spot significant deviations from defined procedures or tolerances.

4.4.10.5.2 Quality control. Written procedures should be prepared for instrument calibrations. These procedures should include:

1. The recommended interval for zero and span calibration checks of the transmitter (Readings before and after adjustment should be recorded.);
2. The reference zero and span values to be applied;
3. Step-by-step written procedures;
4. Blank field calibration forms (Records should include identification of the instrument component calibrated, the date of calibration, and initials of the person who performed the calibration.);
5. Designation of responsibility to perform the calibration (i.e., name of person(s) or position);
6. Designation of person to whom to report any failed calibration; and
7. Place to store calibration results.

4.4.10.5.3 Quality assurance. The calibration logs should be reviewed to confirm that calibrations were completed and performed properly. The person performing this review and the frequency of review should be specified. The written calibration procedures should be reviewed and updated to reflect any changes (e.g., system modifications or instrument changes).

4.4.11 Rotameters[5]

Rotameters can be classified as a type of area flow meter. In the past, rotameters were one of the mainstays in flow meter technology because they provide economical local readouts and control of gases and nonviscous liquids. Although rotameters have been displaced to some degree by other technologies, the rotameter has maintained its place in some applications due to its design simplicity and its ability to be tailored to each application by careful selection of its components.

4.4.11.1 Measurement Principal[5]

Rotameters operate on the principle of generating a condition of dynamic balance within the flow meter, in which a float is positioned in accordance with the flow through the flow meter. The float remains in dynamic balance when the sum of the forces acting on the float are zero. Therefore, when the weight of the float less the weight of the fluid that it displaces is equal to the upward force on the float due to fluid velocity, the float is in dynamic balance.

4.4.11.2 System Components and Operation[1,4,5]

A rotameter consists of a plummet, or "float," which is free to move up or down within a slightly tapered tube, with the small end down. Fluid enters the lower end of the tube and causes the float to rise until the annular area between the float and the wall of the tube is such that the pressure drop across the constriction is just sufficient to support the float. The tapered tube, which typically is made of glass, is etched with a near linear scale on which the position of the float may be visually noted as an indication of flow. Rotameters are available with pneumatic, electric, and electronic transmitters for actuating remote recorders, integrators, and automatic flow controllers. A diagram of a rotameter is presented in Figure 4.4-18. Rotameters can be used to measure fluid flow in pipes with a diameter range of 1.3 to 10 cm (0.5 to 4 in.). Liquid flow measurement range is approximately 0.19 to 760 L/min (0.05 to 200 gal/min) for liquids with a viscosity less than about 30 centipoise. Gas flow measurement is virtually unlimited depending on float material. Rotameters require no straight runs of pipe upstream or downstream of the meter. Pressure losses are consistent over the flow range. Table 4.4-14 summarizes the advantages and disadvantages of rotameters.

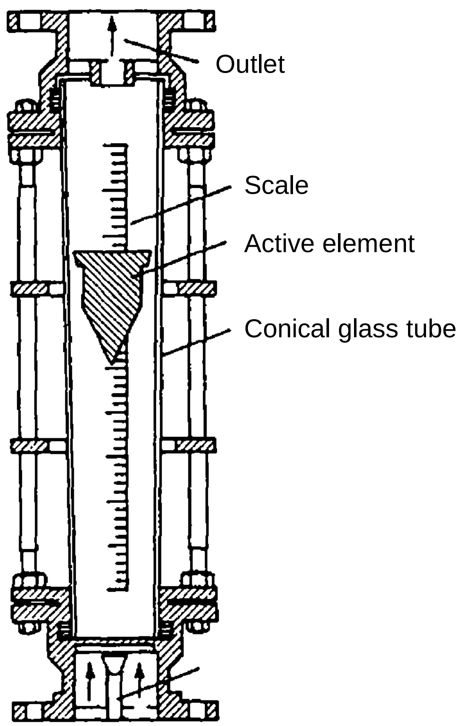

Figure 4.4-18. Rotameter.[12]

TABLE 4.4-14. ADVANTAGES AND DISADVANTAGES OF ROTAMETERS

Advantages	Disadvantages
Easily equipped with magnetic, electronic, induction, or mercury-switch transmitters	Must be mounted vertically
Viscosity-immune bobs are available	Limited to relatively small pipe sizes and capacities
Several rotameters mounted side-by-side provide convenient flow comparisons	Relatively low temperature and pressure limits
Relatively low cost	Sensitive to fluid temperature changes
Handle a wide variety of corrosive materials	
No need for straight pipe	
Extremely effective for low flows	

4.4.11.3 **Accuracy**.[5]

Rotameters have an accuracy of ±1 to 2 percent of full scale from 10 to 100 percent of the calibrated range. Some rotameters can be calibrated to ±0.5 percent of full scale.

4.4.11.4 **Calibration Techniques**.[5]

Rotameter system transmitters can be calibrated for zero and span by manipulating the float to the zero and full scale positions and making the necessary zero and span adjustments. The scale on a rotameter can be calibrated to the exact metering fluid by utilizing a bubble flow calibrator at several values along the scale. The results of the bubble calibration can be used to generate a calibration curve. Generally, rotameter calibration scales are for a specific gas (e.g., air, nitrogen, etc.) at standard temperature and pressure. Therefore, some correction to actual conditions is required for accurate measurements.

Another possible system calibration involves energy or mass balance calculation of fluid flow to process operations. If fluid flow energy or mass agrees (balances) within the performance specifications to actual production rates or heat input, the flow rate system can be assumed to be in calibration. Additionally, comparisons of recent energy or mass balances to past data can be made.

4.4.11.5 **Recommended QA/QC Procedures**[5]

Periodic cleaning of the flow tube is required to prevent a buildup on the inside of the tube. If a residue builds up on the inside of the tube, the float will stick and a reduction of accuracy will occur. The following recommended spare parts should be maintained: metering tube, floats, and electronic circuit boards.

4.4.11.5.1 Frequency of calibration. Calibration of the flow meter transmitter should follow a consistent pattern to allow for comparison of performance changes over time. The recommended frequency of calibration depends largely on site-specific conditions and facility standard operating procedures. Moreover, specific regulations may require a specific calibration frequency (e.g., annually). In general, calibration frequency should be within the manufacturer's recommendations. These calibration intervals should not be relied on indefinitely; they are starting points. At the end of the initial calibration period, the system should be calibrated or examined, as appropriate, and the data obtained should be charted. If the system is near or beyond the limit of accuracy (80 percent of acceptable error) and no process excursions or conditions are suspected of causing the decalibration, the calibration interval probably is too long. In such a case, the system should be recalibrated to the center of the acceptance band, and the calibration interval should be shortened. At the end of the second calibration period, calibration should be checked to determine if the system is drifting. If the system is near or beyond the limit of acceptable accuracy, similar steps should be taken, and the calibration period should be further shortened. This process should be repeated until the system is within the acceptable limit of accuracy at the end of the calibration interval. If, at the end of the initial calibration period, the system is determined to be within acceptable tolerance, adjustment is not necessary. The results should be recorded and the same calibration interval should be maintained for another calibration period. A log of all calibration check results should be maintained at the facility. Any corrective actions or adjustments should be recorded. Calibration data should be reviewed annually in order to spot significant deviations from defined procedures or tolerances.

4.4.11.5.2 Quality control. Written procedures should be prepared for instrument calibrations. These procedures should include:

1. The recommended interval for zero and span calibration checks of the transmitter (Readings before and after adjustment should be recorded.);
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5. Designation of responsibility to perform the calibration (i.e., name of person(s) or position);
6. Designation of person to whom to report any failed calibration; and
7. Place to store calibration results.

4.4.11.5.3 Quality assurance. The calibration logs should be reviewed to confirm that calibrations were completed and performed properly. The person performing this review and the frequency of review should be specified. The written calibration procedures should be reviewed and updated to reflect any changes (e.g., system modifications or instrument changes).

4.4.12 References for Flow Measurement

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4.5 pH AND CONDUCTIVITY MEASUREMENT SYSTEMS

4.5.1 pH Monitoring

A pH measurement system consists of three components: a pH sensing electrode, the pH meter, which is an amplifier for translating the signal, and a reference electrode. A pH sensing electrode is a small battery displaying a voltage that varies depending upon the pH of the solution in which it is immersed. The reference electrode is also a battery, but unlike the pH sensing electrode, its voltage does not vary with the pH of the solution. In a pH measurement system, the pH electrode delivers a varying voltage to the pH meter while the reference electrode delivers a constant voltage to the meter. Although a pH measurement system consists of both types of electrodes, some electrodes, known as combination electrodes, are designed to incorporate both functions.

Selecting the appropriate pH and reference electrodes for the application for which it is to be used is critical to proper pH measurement. Section 4.5.1.1 presents a discussion on selecting the proper electrodes for a particular application. Section 4.5.1.2 describes the different types of pH measurement stations, Section 4.5.1.3 presents a discussion of pH control system components, and Section 4.5.1.4 presents a discussion on electrode maintenance, and Section 1.1.5 discusses calibration procedures.

4.5.1.1 Electrode Selection[1,2]

The factors to be evaluated in selection of pH sensing and reference electrodes include where the electrodes will be used, for example, in the laboratory or in an industrial process environment, the accuracy required, the components in the sample, and the pH of the sample. The key variables in electrode selection are: (1) combination or electrode pair, (2) gel-filled or refillable, (3) reference electrode configuration, and (4) body construction.

4.5.1.1.1 Combination electrodes or electrode pair. In a combination electrode, the reference electrode surrounds the glass pH electrode. Combination electrodes are used for most laboratory and industrial applications because they are easier to use than electrode pairs. Combination electrodes can be used to monitor smaller volumes and are also more convenient in areas where access is restricted. One drawback with combination electrodes is that the pH measuring system has to be equipped with a temperature compensation system for accurate measurements. As discussed later, the output of a pH electrode is temperature sensitive. This sensitivity is magnified in a combination electrode. Combination electrodes are also not suitable for use with colloidal suspensions, samples containing iodides, samples with high solids content, viscous solutions, specific ion determinations, and high purity water. Electrode pairs should be used for these applications.

4.5.1.1.2 <u>Gel-filled or refillable electrodes</u>. Gel-filled electrodes require little or no maintenance. Most gel-filled electrodes have polymer bodies and are therefore very durable. Refillable electrodes require greater maintenance and are less durable. As the name suggests, they have to be refilled with electrolyte solution periodically. The body of refillable electrodes is typically made of glass. However, refillable electrodes are more accurate ($\pm$ 0.01 pH unit) than gel-filled electrodes ($\pm$ 0.05 pH unit) and have a longer life span (typically more than 1 year) than gel-filled electrodes (6 months to 1 year). Gel-filled electrodes are typically used in industrial environments; because of their durability and lower maintenance requirements refillable electrodes are used primarily for laboratory applications because of their accuracy.

4.5.1.1.3 <u>Reference electrode configuration</u>. The reference electrode consists of three primary parts: an internal element, electrolytic filling solution, and a permeable junction through which the filling solution flows. The internal element may be a silver wire coated with silver chloride, that is, an Ag/AgCl electrode, or a platinum wire covered with a mixture of mercuric chloride, commonly referred to as calomel (Hg_2Cl_2). Silver chloride electrodes are used for most laboratory and industrial applications. However, some samples react with the silver in the Ag/AgCl electrode. For example, strong reducing agents can reduce the silver ion to silver metal, thereby silverplating the junction. Calomel electrodes should be used for solutions containing proteins, sulfide or heavy metal ions, or strong reducing agents. However, calomel electrodes should not be used for applications in which the electrode will be exposed to temperatures above 65°C (150°F) because the electrode breaks down at higher temperatures.

Junction type is also an important factor in selecting a reference electrode. The function of the liquid junction is to allow small quantities of the filling solution from the reference electrode to leak into the sample being measured. The four most common forms of junctions are ceramic or other frit material, a fibrous material such as quartz, sleeve junctions, and double junctions.

The fritted junctions are usually white and consist of small particles pressed closely together. The filling solution moves through the open cells between the particles. The flow rate across the surface of the material is variable because the size of the cells is variable. In general, fritted junctions clog relatively easily and should not be used with samples containing small particulate that may clog the junction.

There are two basic types of fibrous material junctions, those with woven fibers and those with straight fibers. The cells of the woven fiber junctions vary in size because of the structure of the woven material. As with the fritted junctions, this leads to variability in flow rate across the junction. The flow rate is high where the fibers are loosely woven and low where the fibers are more tightly woven. Straight fiber junctions made of quartz are preferable to the woven fiber junctions. These junctions have straight fibers of quartz laid next to each other. The filling solution passes uniformly through the straight channels between the fibers. The junctions made of straight fibrous material are easier to clean and are better for dirty samples.

A sleeve junction is similar to a fritted junction in that some areas of the junction have a higher flow rate than other areas. However, the sleeve junction has a much higher flow rate than the fritted material junction and is easier to clean. Because of the high flow rate, sleeve junction electrodes are suitable for dirty viscous samples. They also provide better precision than other junction types.

Double junctions are required for applications in which the electrolytic filling solution and the sample solution should not come in contact. Contact between the filling solution and sample solution can cause precipitation of salts with low solubility, precipitation of the potassium chloride or silver chloride in the filling solutions as a result of the diffusion of water or organic solvent from the sample solution, and contamination of the sample solution by the reference filling solution. To prevent this contact an electrolyte bridge is inserted between the reference electrode and the sample solution.

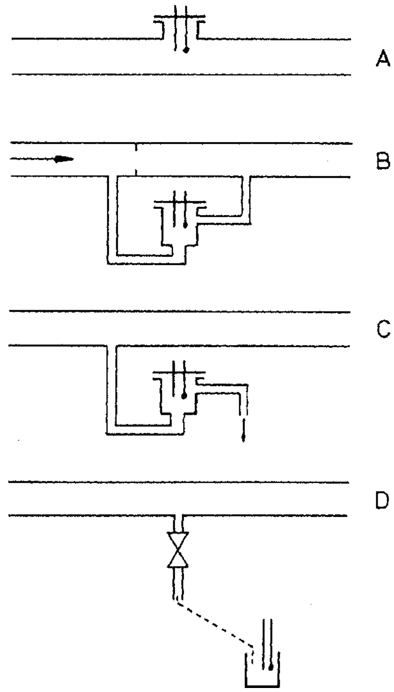
4.5.1.1.4 Body construction. Polymer body electrodes are more durable than glass body electrodes and are used more often for field or industrial applications. Electrodes with glass bodies are most often used for laboratory applications. Glass body electrodes are also the best choice for solutions containing proteins and other compounds with high surface tension, highly corrosive materials, and organics that might attack a polymer body. Samples with a very high pH, >12, require a special glass to minimize error caused by sodium ions. This special glass can be used over the entire pH scale, but it has a higher resistance than the standard glass used in most glass electrodes.

4.5.2 pH Measurement Stations[2]

There are three types of measurement stations that are typically used for inline process pH measurement: immersion electrode assemblies, built-in electrode assemblies, and flow-through electrode assemblies. Figure 4.5.1 shows a diagram of the three types of inline electrode assemblies and an offline laboratory measurement. In addition, pH measurements of a solution can be done offline by withdrawing a sample at a sample vent and taking the sample to the pH meter.

4.5.2.1 Immersion Electrode Assemblies

These electrode assemblies are used for measuring the pH of a sample in open vessels. In order to compensate for the hydrostatic pressure resulting from the immersion of the electrodes below the surface of the sample, the vessel containing the electrolyte must be raised. The reference electrode can also be installed in the electrolyte reservoir. Contact with the sample



Application of electrode assemblies. A in line, B in line with bypass, C on line, D offline.

Figure 4.5-1. Applications for electrode assemblies.

solution is made via a tube with a separator. However, a reservoir is unnecessary if the assembly is equipped with a sealed reference electrode. Immersion electrode assemblies are often mounted loose, so they can be deflected by strong currents. The electrode assemblies are moved from their holders for maintenance, which should be conducted at least every 4 weeks.

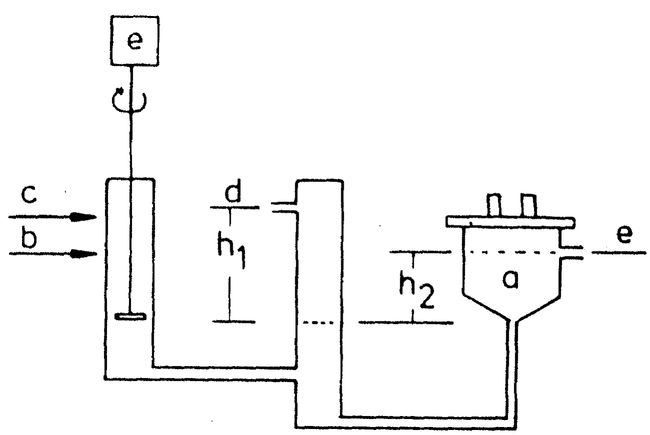
4.5.2.2 <u>Built-In Electrode Assemblies</u>

Built-in electrode assemblies are used in closed containers. These have a mounting plate similar to that used for an immersion assembly or a screw adaptor fitted with a male or female thread. Built-in electrode assemblies that are installed in the side of the vessel should have an angle of at least 15 degrees to ensure that the reference electrolyte and internal buffer will collect in the lower portions of the electrodes. The head of the built-in electrode must be made of material compatible with the material used for the piping and vessel. Enamel electrodes are often used to ensure compatibility. Because it is not possible to remove the electrode for maintenance during normal operations if the vessel is pressurized or the site is below the sample solution, an exchangeable unit should be available at all times in case removal is necessary.

4.5.2.3 Flow-Through Electrode Assemblies

Flow-through electrode assemblies are typically used for vessels with an inflow and side outflow. For most applications, flow-through units are the easiest to maintain. The electrode assemblies are mounted in pipelines, and the sample solution flows past them. The assemblies may be straight-through or angled. The sample should pass freely after the electrode so that pressure compensation is unnecessary. If a flow-through electrode assembly is used in a closed system, a bypass is needed. The electrode then can be removed for maintenance by closing the valves without having to remove the electrode housing. One potential problem with horizontal flow-through units is that impurities in sample streams with sediment or floating particles can settle out. Therefore, the units must be cleaned out regularly. Flow-through electrode assemblies can be used with piping up to 25 mm. If the diameter of the piping is larger than 25 mm, the assembly should be equipped with a bypass. In addition, pressure compensation should be used if the outflow from the unit is not free.

Flow-through units are also useful for pH measurements in nonaqueous solutions. Although most pH measurements are done in aqueous solutions, a facility may need to know whether a solvent contains excess acid or base. An extraction electrode assembly with a flow-through cell is needed for these applications. With extraction electrode assemblies, the solvent is extracted with water, which preferentially absorbs the inorganic acids and bases. The pH of the aqueous solution is then monitored. Figure 4.5.2 depicts an extraction electrode assembly.

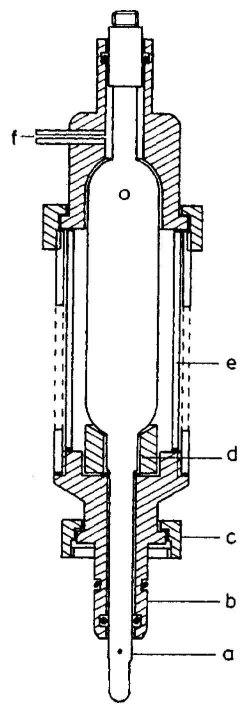


Measurement of the pH of an extract of a solvent, from Shinskey (7-13), (a) flow through cell, (b) inlet for organic solvent, (e) inlet for water, (d) outlet for organic solvent, (e) outlet for aqueous solution, h_1 static lead of organic solvent, h_2 static head of aqueous solution, R stirrer.

Figure 4.5-2. Extraction electrode assembly.

4.5.2.4 **Pressurized Chamber Electrode Assemblies**

Pressurized chamber electrode assemblies may be built-in assemblies or flow-through assemblies. They should be used when the pressure is greater than 300 kPa (3 bar). Figure 4.5.3 shows a sectional view of a pressurized chamber electrode assembly. In order to conserve space, combination electrodes are typically used with pressurized assemblies. The electrolyte reserve is stored in the enlarged stem. The assembly can be constructed in a range of lengths for built-in assemblies in pressurized vessels. It can also be used as a flow-through assembly when it is installed as a T-piece. Pressurized electrode assemblies can be used at pressures greater than 1 Mpa, but the unit must be enclosed in steel casing for these applications.



Section through a pressure chamber electrode assembly, (a) combination electrode, (b) fitting shank *d* = 19 or 25 mm, (c) sleeve, nut (d) support, (e) viewing glass, (f) pressurization connection.

Figure 4.5-3. Pressurized chamber electrode assembly.

4.5.3 **pH Control Systems**[1]

For some industrial processes, monitoring the pH is all that is required. In other processes, parameters may be adjusted if the pH is not within the expected range, but the focus of these is not on achieving a particular pH. Some industrial processes, however, based on achieving a particular pH or maintaining a specific pH. This section focuses on selecting the appropriate pH control system for different types of processes that may require pH control.

There are three basic types of pH control systems: batch processing system, continuous system with tank, and continuous system with on-line control.

4.5.3.1 Batch Processing System

This is a simple system in which the process solution is pumped into a tank until it is full, the solution is agitated and mixed, chemical is added to the solution until the desired pH is reached, and the solution flows out or is pumped out of the tank. A relay controller is used to turn the chemical addition pump on and off. Figure 4.5.4 presents an example diagram of a batch processing system.

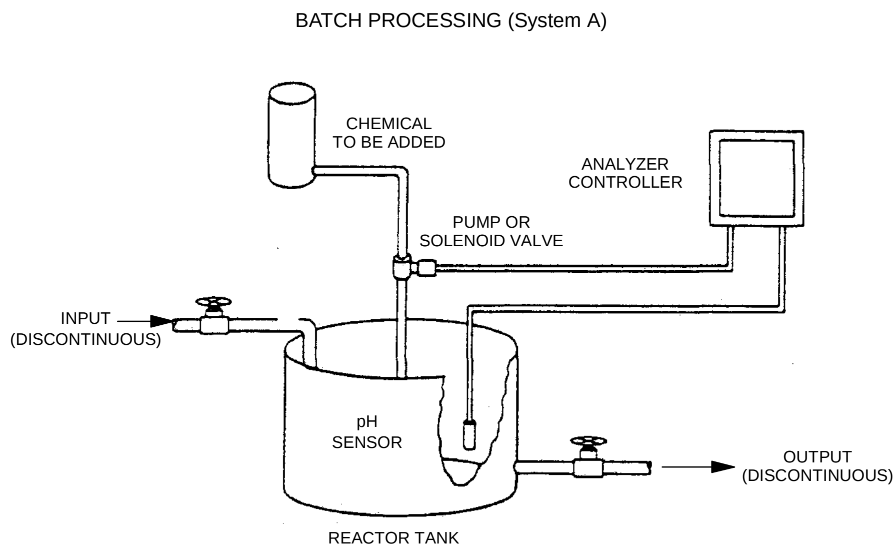


Figure 4.5-4. pH control system for batch process.

While not essential, it is desirable to have a level sensing device to monitor the amount of fluid in the tank and to signal when the tank is full or empty. The sensing device should also shut off operation of the mixer and pH controller when the solution is not at the proper level. It is important to note that the system will not reach equilibrium immediately. After the chemical addition, there will be some delay before the pH stabilizes and can be accurately measured. The actual time period before equilibrium is reached will depend upon the mixing system. The faster the mixing, the sooner the system will reach equilibrium and the pH of the system will stabilize.

4.5.3.2 Continuous System with Tank

Unlike the batch processing system, the continuous system with tank allows for continuous input. Level control and monitoring is not as important as it is with the batch system because the tank outlet can be of sufficient size to make tank overflow unlikely. A pump or an on/off valve controls chemical additions. The sizing of the control element is critical. In some cases, two control elements are needed. For example, one valve delivers the chemical used to adjust the pH at a higher rate when the pH is at a particular level and another valve delivers the chemical at a lower rate when the pH approaches the desired endpoint. Again, good mixing is critical with this type of system. The mixer should not be undersized.

4.5.3.3 Continuous System with On-Line Control

This system is used for pH control of a process sample moving through a pipe. The system consists of a pH sensor, an analyzer/controller for receiving input from the pH sensor and converting this to a signal that controls the valve or pump regulating chemical additions, and a static mixer. The static mixer provides good mixing quickly. Chemicals are injected just upstream of the mixer and the pH sensor is just downstream of the mixer. With a good mixer, the delay time, that is, the time between when the chemical is added to the sample and the pH sensor can detect the change in pH, should not be more than a few seconds.

4.5.4 Operation and Maintenance of the pH Measuring System[1,2]

Proper operation and maintenance of the pH measuring system is just as important in achieving accurate pH measurements as selecting the correct electrode and assembly. In particular, care and maintenance of the electrodes is critical. More than 80 percent of the errors encountered in pH measurements are due to electrode problems. Of these electrode problems, most are associated with the reference electrode.

4.5.4.1 Operation, Maintenance and Troubleshooting of the Reference Electrode

Reference electrodes contain a reference half-cell consisting of a sealed glass tube surrounding a piece of wire that is immersed in a mixture of crystals. For a silver chloride electrode, the wire is silver and the crystals are silver chloride. For a calomel electrode, the wire is platinum and the crystals are Hg_2Cl_2. The end of the glass tube is sealed with a wad of cotton, glass wool, or a frit. In order to provide electrical continuity, the crystals must be wet. Therefore, the glass tube and the body of the reference electrode are filled at the factory with a potassium chloride solution. Before shipment, the electrode is sealed at the filling hole and the junction.

The filling solution in the reference electrode completes the circuit with the pH electrode. Before using the reference electrode, the filling hole should be unsealed so that the filling solution can flow into the sample and complete the circuit. The filling hole should remain open as long as the reference electrode is in the sample solution. When not in use, the reference electrode should be stored at all times in an acidic solution with a low salt content. These solutions are available commercially or they can be made by adjusting a potassium chloride solution to a pH of 4.0.

Typically, the first sign that there is a problem with the reference electrode is a long stabilization time. The pH reading may vary for some time before finally reaching a stable point. The increased stabilization time may be caused by changes in temperature, reactions taking place in the sample, a sample that is not well mixed, or by absorption of CO_2 from the reference electrode. However, the most likely causes are that the reference electrode is not compatible with the sample or the reference electrode is faulty. Usually, it is possible to determine if the problem is with the electrode or if the long stabilization time is caused by other factors such as a change in temperature. If you move a hand quickly toward and then away from the electrode and the pH reading changes significantly in response to the hand movement and then reverses when the hand is retracted, it is likely the reference electrode is either partially blocked or defective. If the drift continues as before when you move your hand toward and away from the electrode, the problem is probably with the sample.

While moving a hand towards and away from the reference electrode is one method of determining if a reference electrode is faulty, there are two other methods that can better predict a problem with the reference electrode. Both of these methods involve the use of a magnetic stirrer. If stirring the sample with a magnetic stirrer causes unstable readings, then turn the stirrer off. If the reading changes significantly (0.1 to 0.2 pH units), there is a problem with the reference electrode. Another check can be done with the stirrer operating. If the pH readings fluctuate with the stirrer on and turning the stirrer down to a slower speed reduces the fluctuations, the problem is probably with the reference electrode.

If the pH readings drift continuously without ever stabilizing, the problem may be a completely blocked reference electrode or it may be an electrical problem. For example, the electrode may not properly connected to the meter, the wires within the reference or pH electrodes may be broken, the lead wire from the pH or reference electrode may be broken, or there may be an open circuit within the meter. The easiest and quickest way to determine if the problem is with the electrodes or the meter is to replace each of the electrodes. Another method is to use a wire, paper clip, or shorting plug, to short between the reference electrode input and the pH electrode input on the meter. If shorting the electrode inputs eliminates the drift, substituting the pH electrode and then the reference electrode if necessary should identify which electrode is the open circuit.

If the reference electrode dries out, there is no pH reading even though the pH electrode may be operating correctly. When the body of the electrode dries out, the fluid in the half-cell tube leaks out through the junction at the end of the tube. There is then no continuity through the crystals. To prevent the electrode from drying out, it should be stored in solution at all times.

However, a dry electrode can be restored and reused. In order to properly restore the electrode and avoid an air bubble in the tube, the electrode should be filled with filling solution, the junction plugged, and the electrode body evacuated with a laboratory aspirator. The vacuum should be maintained until no more bubbles emerge from the end of the inner glass tube. When the inner glass tube is free of air, the vacuum should be slowly released. The filling solution will then be drawn into the tube and will saturate the crystals.

In some cases, the reference electrode contains the correct amount of filling solution, but the filling hole is completely blocked. If the filling hole is blocked, the filling solution cannot flow into the sample. The electrode will not establish a consistent electrical connection with the sample, and the pH readings will vary considerably. If the filling hole is partially blocked, the solution may not flow into the sample at the proper rate. In addition, sample ions will migrate into the junction and establish new potentials. These voltages will be measured by the system and interpreted as changing pH readings.

Just as it is possible to restore a reference electrode that has dried out, it is also possible in many cases to restore a blocked or partially blocked reference electrode. There are a series of increasingly severe procedures that may be tried to restore an electrode to proper function. These procedures are presented below.

1. The first and easiest method to try to restore the electrode is simply soaking the junction in a solution of ten percent potassium chloride and 90 percent distilled or deionized water. This helps to dissolve the crystals at the end of the electrode. The reference electrode should be filled with filling solution and then soaked in the potassium chloride solution that has been slightly warmed. The electrode should soak at least 20 minutes.

2. The junction of silver chloride electrode often becomes clogged with silver chloride. Ammonium hydroxide can be used to remove the silver chloride. The first step is to remove the filling solution from the reference electrode. Next, immerse the end of the electrode (do not put ammonia inside the electrode) in the concentrated ammonia for 10 to 20 minutes. Remove the electrode, rinse the outside and inside of the electrode thoroughly with deionized or distilled water. Finally, refill the electrode with filling solution.

3. Protein can also cause a problem with the reference electrode if it penetrates the junction. The protein can be removed by soaking the electrode in 8 M urea for about 2 hours. As with the concentrated ammonia, the electrode should be rinsed well after soaking. Also, empty and rinse the filling solution and refill with fresh filling solution.

4. The reference electrode can also be cleaned with a vacuum. Connect a piece of flexible tubing to an aspirator at one end, to the reference electrode at the other end, and turn on the water. This should draw the filling solution through the junction and remove any obstruction.

5. Boiling the junction may remove obstructions that are not removed using any of the other methods. However, this method should only be used for silver chloride reference electrodes. As mentioned previously, calomel breaks down at about 65°C (150°F), so a calomel reference electrode should not be boiled. A silver chloride electrode can be immersed in boiling water for up to 30 seconds. Even with a silver chloride electrode, however, boiling the junction should be one of the last measures attempted because the glass may break.

While it is possible to restore a damaged reference electrode, proper operation and maintenance can make such measures unnecessary. The electrode should always be used in a vertical position. If the electrode is horizontal, the filling solution will leak out. Between samples, the electrode should be rinsed with distilled or deionized water. After rinsing, the end of the electrode should be blotted with lint free paper. Wiping the electrode can result in static charges that will cause variable pH readings. For accurate readings, the level of filling solution should be higher than the level of the sampling solution. In general, the electrode should be kept at least two thirds full of filling solution. With these simple measures, the reference electrode should last for several years.

Although these manual cleaning procedures work well for laboratory situations, they are not as suitable for online pH measurements. Although the electrodes used for online pH monitoring of a process can be removed and cleaned using these procedures, this requires either an interruption in the process or, a more likely scenario, an interruption in data gathering. For online pH monitoring, automatic cleaning systems are preferred.

Although the focus of manual cleaning of the electrodes is on removing contaminants and deposits from the electrode, the focus of automatic cleaning systems is frequent cleaning to prevent the deposits from ever forming. This can be done using hydraulic, chemical, or mechanical cleaning.

Because deposition of contaminants on the electrode is a greater problem with stagnant solutions, one of the simplest methods of preventing such deposits is to install the electrode in a region of high flow velocity and preferably in a turbulent zone. If flow through the area to be monitored is slow, a baffle plate can be installed to create turbulence. If the sample solution contains small particles or fibers, the electrode assembly should be installed at an angle to the flow so that the particles and fibers will not be trapped.

Chemical cleaning uses a variety of chemicals, including hydrochloric acid, detergents, and caustic soda. There are several methods that can be used for on-line chemical cleaning. The first is a bypass system with an additional feed line. Cleaning solution can be directed to the electrode by rotating a valve. This method is simple, but chemical consumption can be high. A rinsing jet or ring is more economical than a bypass system. With this system, solvent and rinsing agent are applied in the presence of the sample. The cleaning fluid is applied at regular intervals, from one to several hours, and rinsing only requires a fraction of a minute. A small pump is used to raise the pressure and force the cleaning fluid through the sample solution. A spring-loaded valve prevents the cleaning fluid from leaking out when the pH is being determined. During cleaning, the recorder is switched off so that inaccurate readings are not recorded.

Mechanical cleaning has the advantage that pH monitoring is not interrupted during cleaning. A rotating brush or a wiper is typically used, and an electric motor drives the brush or wiper. Although mechanical cleaning is effective for soft precipitates, hard crystals scratch the tube and fatty deposits are not removed but merely smeared over the electrode. Because the moving parts are immersed in the sample stream, mechanical cleaning of corrosive sample streams is not advised. The sample stream will corrode the moving parts.

4.5.4.2 Maintenance of the pH Sensing Electrode[1-3]

Before a new electrode or an older electrode that has been stored dry is used, it should be hydrated in a suitable solution. The electrode should first be soaked for at least 24 hours in a dilute solution of hydrochloric acid. After rinsing with distilled water, the electrode should then be soaked for at least 12 hours in a buffer with a pH value between 4 and 8.

With earlier glass electrodes, which were less stable than the electrodes used today, it was necessary to keep the pH electrode immersed in an aqueous solution to maintain proper function. Newer formulations are more stable and do not require immersion. However, to avoid surface contamination of the electrode, it is still a good idea to keep the pH electrode covered or immersed in a liquid. Contamination on the surface of the electrode can cause a barrier between the ions in solution and the surface of the glass. This barrier leads to inaccurate pH readings. Storing the pH electrode in liquid prevents airborne contaminants from settling on the electrode and forming this barrier. The storage solution should be somewhat acidic so that the contaminants in the pH glass are exchanged out for hydrogen ions, thereby keeping the electrode more sensitive to pH. The slightly acidic potassium chloride solution used as the filling solution for the reference electrode is a good solution for storing the pH electrode.

The pH electrode should be checked periodically to ensure that it has the required responsiveness and sensitivity. In general, an electrode is in good working order if the response is fast (<1 minute), the response during stirring is stable, and the sensitivity as determined from buffers is better than 95 percent. This last indicator of electrode performance can be tested using a series of standard buffers. The measured pH of the buffers is plotted versus the output in millivolts (mV). The resulting plot should be a straight line that approximates the theoretical slope. If the slope falls to approximately 95 percent of the theoretical slope, the electrode should be discarded or regenerated. In some cases, the electrode can be regenerated with hydrofluoric acid. However, this process shortens the life of the electrode and should only be used as a last resort.

4.5.4.3 Maintenance of the Combination Electrode[1,2]

Most combination electrodes are based on a silver chloride reference half-cell. These electrodes should not be soaked in any solution that will cause precipitation of the silver in the junction of the electrode. Solutions of low chloride concentration can cause precipitation of the silver and should not be used for electrode storage. Solutions of high chloride concentration can reduce the electrode’s sensitivity to hydrogen ion. Therefore, when storing a combination electrode overnight or for a weekend, the electrode should be stored in air with the protective cap over the end of the electrode and the filling hole covered. For longer term storage, the filling solution should be removed from the electrode and the electrode stored completely dry.

4.5.5 Calibration of the pH Meter[1,2]

Proper operation and maintenance of the pH and reference electrodes are critical components of accurate pH measurements. The other critical component is calibration of the pH meter. Meter calibration in the laboratory is a simple and straightforward process that should be done routinely. Online calibration of the electrode assemblies that are used for continuous pH monitoring can be more difficult. The basic procedures are the same for laboratory and online calibration, but to avoid having to take the pH electrodes offline for calibration, self calibration systems are required.

4.5.5.1 Laboratory Calibrations

The pH meter should be calibrated at least once every 8-hour shift. Standard buffer solutions used for calibration can be prepared in the laboratory, but they are also available commercially, usually in three pH values, 4.00, 7.00, and 10.00. The buffers should be stored in tightly sealed containers away from heat and poured just before calibration. Only fresh samples of buffer should be used for a calibration.

The calibration can be one point, two point, or multipoint, with multipoint calibrations providing the most accurate pH readings. However, two point calibrations are the most common and are sufficient for most applications. One point calibrations are often useful for quick, intermediate checks during the day.

A two point calibration uses two buffers. One of the buffers should have a pH value of 7.00 and the other should be closest to the value anticipated for the sample. For example, if the sample is acidic, the buffer with a pH value of 4.00 should be used. If the sample is basic, the buffer with a value of 10.00 should be used. Actual calibration procedures vary according to pH meter. However, the following is a summary of the basic steps for a two point calibration:

1. Set the temperature setting on the meter to the temperature of the buffers, typically room temperature or 25°C. If meter is equipped with automatic temperature compensation, make sure it is activated before calibrating.

2. Turn the pH meter to “pH” or to “ATC” if automatic temperature compensation is available.

3. Place the clean electrodes into the container of fresh pH 7.00 buffer.

4. Adjust the pH reading to 7.00 using either the “zero offset,” “standardized,” or “set” knob.

5. Rinse the electrodes with distilled or deionized water.

6. Place the electrodes in the second buffer (with a pH value of 4.00 or 10.00).

7. Adjust the pH reading to display the correct value using either the “slope,” “calibrate,” or “gain” knob.

The basic procedure is the same for a one point calibration and a multiple point calibration. For a one point calibration, use the buffer that is closest in value to the expected pH of the sample. For a multiple point calibration, calculate the calibration curve using the least squares method.

Many pH meters in use today are controlled by microprocessors. These pH meters are able to calculate the pH directly from the calibration and sample results using the appropriate equations and the stored results obtained from the calibration solution. Typically, only one calibration solution, one with a pH near that of the sample, is needed. A 7.00 buffer is not required.

4.5.5.2 <u>Temperature Compensation</u>

As discussed earlier, the output of the pH electrode will vary with temperature. The amount of variation depends upon the temperature and the pH of the solution. There are only two scenarios in which this variation does not occur. If the pH of the solution is 7.0, no matter the temperature of the solution, there is no temperature error. Likewise, there is no temperature error if the sample solution is at ambient temperature, 25°C (78°F). For all other scenarios, the temperature error can be calculated as follows:

0.03 pH error/pH unit/10°C (18°F)

The error factor calculated using this equation is added to the pH reading in some cases and subtracted from the reading in other cases. Table 4.5-1 demonstrates how to use the error factor for calculating the correct pH.

TABLE 4.5-1. USING THE ERROR FACTOR TO CALCULATE pH CORRECTED FOR TEMPERATURE

pH	Solution temperature	
	Above 25°C	Below 25°C
Above 7	Subtract error factor	Add error factor
Below 7	Add error factor	Subtract error factor

The need for temperature compensation is based on the accuracy required for a particular application and the pH and temperature of the sample solution. To determine whether or not temperature compensation is required for a particular operation, use the equation to develop the error factor for the operation and compare this value to the accuracy required. If the error factor is greater than the target accuracy value, temperature compensation should be used. For example, if the error factor is 0.1 and the target accuracy value for the operation is ±0.01, temperature compensation is required.

Temperature compensation can be done with an automatic or manual compensator. Automatic temperature compensation should be used if the temperature of the sample solution fluctuates. If the temperature of sample is fairly stable and only varies a few degrees, a manual compensator can be used. If an automatic temperature compensator is used, it should always be located with the electrodes. During calibration, the compensator should be in the buffer with the electrodes. With a manual compensator, the temperature should be adjusted to the same temperature of the sample solution or buffer.

4.5.5.3 Self Calibration Systems for Online pH Measurements

Online calibration of the electrode assemblies used for continuous pH monitoring as discussed earlier is typically more difficult than calibration in the laboratory. In order to avoid having to disassemble the electrodes and remove them to the laboratory for calibration, some electrode assemblies are equipped with a self calibration system. The type of calibration system depends upon the type of electrode assembly that is used.

There are two types of calibration systems used for immersion electrode assemblies. One option is to surround the electrode assembly with a porous plastic membrane. During routine pH measurement, the membrane is flush with the electrode. The sample penetrates the porous membrane to the electrodes. For calibration, the system is equipped with an inlet and an outlet for the buffer solution. During calibration, the buffer solution is fed through the inlet and forced through the membrane. The membrane expands and forms a pocket around the electrode for the buffer solution. Another self calibration system used with immersion electrode assemblies uses air pressure to displace the sample solution during calibration.

The self calibration system using air pressure is also used for built-in electrode assemblies. The cylinder with the electrodes has an upper and lower position. One is used for monitoring and one for calibrations. Compressed air moves the cylinder into the upper or lower position. For calibrations, the cylinder is lowered into a chamber containing buffer solution.

Self calibration systems were first used for flow-through electrode assemblies. A four-way ball valve acts as the flow-through electrode assembly with the electrode mounted in the bore. The system converts from measurement mode to calibration mode by rotating the valve 90°.

4.5.6 Conductivity Measurement[1,2,4]

The ability of a solution to conduct electricity is called conductance and its reciprocal is called resistance. As electrolytes, for example, salts, bases, and acids, are added to a solution of pure water, the conductance increases and the resistance decreases. A conductivity measurement system measures the conductance of a solution with a sensor that is immersed in the solution.

For strong acids and bases, pH values are not very meaningful indicators of the concentration. The measurement uncertainty is large because pH is a logarithmic scale. Conductivity measurements are more suitable than pH measurements for producing accurate and reproducible estimates of the concentrations of free acids and bases because the relationship between conductivity and concentration is almost linear over a range of concentrations. Because of this relationship, conductivity measurements are often used to determine the total dissolved solids content of water samples.

The standard unit for conductivity measurement in the past has been mho/centimeter (mho is the reciprocal of ohm). This conductivity value can then be converted to a total dissolved solids concentration value (in parts per million) using a standard conversion chart. The mho/cm unit is now being replaced with an interchangeable unit of measurement called the Siemen/cm. Conductivity is expressed in millionths of a Siemen, that is microSiemens/cm. Many conductivity meters provide the option of conductivity measurements in each measurement unit.

4.5.6.1 Conductivity Sensors

There are two primary types of conductivity sensors, contacting-type sensors and electrodeless-type sensors. The contacting type sensor consists of two electrodes that are insulated from each other. The electrodes may be made of 316 stainless steel, titanium-palladium alloy or graphite and are specifically sized and spaced to provide a known cell constant. The spacing of the electrodes is critical and is an important factor in selecting a conductivity sensor. A sensor with the electrodes placed closely together is used for solutions with low conductivity and a sensor with the electrodes further apart is used for solutions with high conductivity. Because all contacting-type sensors cannot be used for all solutions, it is important to have some idea of the conductivity of the solution before purchasing a sensor. There are sensors available that cover multiple ranges and can therefore be used for samples with low conductivity and high conductivity, but these sensors are typically more expensive than those designed for a specific range of conductivity. Some of the meters equipped to measure multiple conductivity ranges automatically select the most suitable range for maximum resolution.

Electrodeless-type sensors induce an alternating current in a closed loop of solution and measure the magnitude to determine the conductivity. Electrodeless-type sensors eliminate some of the problems associated with contacting-type sensors. Polarization, oily fouling, process coating or nonconducting chemical plating, all of which can affect the performance of contact-type sensors, do not affect the performance of electrodeless-type sensors unless the fouling is excessive.

The temperature of the solution can have a dramatic effect on the conductivity of the solution. The conductivity may vary as much as four percent per degree centrigrade, and the conductivity of common solutions may vary from 1 to 3 percent per degree centigrade. Therefore, no matter what type of sensor is used, the conductivity meter should be equipped with automatic temperature compensation.

4.5.6.2 Conductivity Meters

As with pH meters, there are many conductivity meters available. They range from small pocket-sized meters that can be used for a selected conductivity measuring range to micro-processor controlled meters that are set up for as many as five conductivity measuring ranges. Some meters are suitable only for laboratory measurements and others are suitable for industrial applications. Conductivity sensors, like pH measuring systems, are available in flow-through, submersion, and insertion mounting styles for continuous in-line conductivity measurements of a process stream. Flow-through sensors are threaded on the electrode end of the body and submersion sensors are threaded on the cable end. Convertible style sensors are threaded on both ends so that they can be used for flow-through or submersion applications. The conductivity sensors are equipped with an integral temperature sensor to automatically adjust conductivity values to a 25°C reference.

4.5.6.3 Meter Calibration

The calibration process for a conductivity meter is similar to that for a pH meter. As with the pH meter calibration, the standard solutions used for calibration should have a conductivity similar to that of the sample. Standard solutions covering a wide range of conductivity values are available commercially. Some meters that provide multiple units of measurement, for example, ppm, total dissolved solids, mho/cm, allow the operator to choose the measurement unit and create a specific calibration curve for that unit by measuring up to four concentration standards.

As with the buffer solutions used to calibrate pH meters, the standard solutions for calibration of the conductivity meter should be stored in closed containers and poured fresh each time the meter is calibrated. Both the standard calibration solution and the sample are easily contaminated by air. Process samples that are not analyzed inline, that is, samples that are collected from the process stream for analysis, should be analyzed immediately to avoid contamination.

4.5.7 References for pH and Conductivity Measurement

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3. Linder, Peter; Ralph Torrington, David Williams, *Analysis Using Glass Electrodes*. Open University Press, Milton Keynes, England. 1984.

4. Maguire, John (ed.), Handbook of Industrial Water Conditioning, Betz Laboratories, Trevose, PA, 1980.

4.6 ELECTRICAL

(Reserved)

4.7 LEVEL INDICATOR

(Reserved)

4.8 MOTION AND ROTATION

(Reserved)

5.0 ANNOTATED BIBLIOGRAPHY

This bibliography lists each of the documents used to develop the guidance materials presented in Chapters 2 through 4 and Appendix B of this document. The entries are listed in alphabetical order and are formatted as they are in each section reference list. Additional documents are listed that provide useful information on the subjects discussed in this document. In addition to the bibliographical information presented, keywords and phrases are provided for each of the listed documents. The complete list of keywords used is provided in Table 5.1.

TABLE 5.1 LIST OF KEYWORDS

Adsorber	Incinerator, catalytic
Afterburner, direct flame	Incinerator, thermal
Afterburner, catalytic	Level measurement
Baghouse	Monitoring frequency
Calibration methods	Monitoring parameters
Centrifugal collector	Operation and maintenance (O&M)
Conductivity measurement	pH measurement
Continuous emission monitoring system (CEMS)	Predictive emission monitoring system (PEMS)
Continuous opacity monitoring system (COMS)	Pressure gauge
Control device, other	Pressure transducer
Data acquisition system (DAS)	Pressure measurement, other devices
Electrical energy measurement	Resistance temperature detector (RTD)
Electrostatic precipitator (ESP)	State/local agency monitoring and permit guidelines
Electrostatic precipitator, wet (WESP)	Temperature measurement
Fabric filter	Temperature measurement device, other
Flare	Thermocouple
Flow measurement	Vapor recovery system
Flow meter, gas	Venturi scrubber
Flow meter, liquid	Wet scrubber, gaseous
Flow meter, mass	Wet scrubber, PM
Gravity collector	Work practice

Air Pollution Engineering Manual, Buonicore and Davis, Eds., Air and Waste Management Association, Van Nostrand Reinhold, New York, NY, 1992.
Summary: This document is a fundamental and practical source of information on air pollution control. It includes chapters on control technologies used for gaseous pollutants (i.e., absorption, adsorption, condensation, and incineration), particulates (i.e., cyclones and inertial separators, wet scrubbers, electrostatic precipitators, and fabric filters), fugitive emissions, and control of odors. For each control technology, the manual includes a description of the equipment, design and performance equations, recommended operation and maintenance procedures, and suggestions for maintaining and improving the equipment performance. The manual also includes chapters on specific industries, including combustion sources, waste incineration sources, evaporative loss sources, surface coating, graphic arts, chemical process industry, food and agriculture industry, metallurgical industry, mineral products industry, pharmaceutical industry, petroleum industry, wood processing industry, treatment and land disposal, and groundwater and soil treatment processes. These chapters include a process description, a characterization of the air emissions, and a discussion of the techniques used to control these emissions.
Keywords: Adsorber; afterburner, catalytic; afterburner, direct flame; baghouse; centrifugal collector; control ; electrostatic precipitator, wet (WESP); electrostatic precipitator (ESP); fabric filter; flare; incinerator, catalytic; incinerator, thermal; operation and maintenance (O&M); pressure measurement, other devices; temperature measurement; venturi scrubber; wet scrubber, gaseous; wet scrubber, PM.
CAM Guidance Document chapter/section: Appendix B

Allocca, J. and A. Stewart, *Transducers: Theory and Application*, Reston Publishing Company, Reston, VA, 1984.
Summary: This book contains complete and detailed information on pressure, temperature, and flow transducers. It includes chapters on background information, strain gage transducers, LVDT's, capacitive transducers, piezoelectric transducers, potentiometric transducers, RTD's, thermocouples, thermistors, photo tubes, photomultiplier tubes, photoconductive cells, photovoltaic cells, lasers, fiberoptics, environmental and biomedical transducers, position sensing transducers, transducer interfacing systems, and smoke detectors. The authors use a considerable number of comparisons of instrument types, drawings, and some mathematical information. The book was used for a comparison of electrical pressure measurement devices, for information on QA/QC procedures for pressure transducers, and for general information on pressure transducers.
Keywords: Pressure guage; pressure transducer; pressure measurement, other devices; control devices, temperature measurement; resistance temperature detector (RTD); thermocouple; temperature measurement ; electrical energy measurement; flow measurement; flow meter, gas; flow meter, liquid; flow meter, mass.
CAM Guidance Document chapter/section: 4.3

Alternative Control Technology Document - Organic Waste Process Vents, EPA-450/3-91-007, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, December, 1990.
Summary: This EPA document contains information to address VOC emissions from process vents on waste management units that are exempted from the Resource Conservation and Recovery Act (RCRA) process vent standards. The technologies regulated by the RCRA process vent standards are the most common ones used with exempted process vents, and the non-regulated units are a significant contributor to total air emissions from waste management unit process vents. The document includes technical information for State and local agencies to use in emission-reduction

planning. The information in this document will allow planners to identify process vent emission sources, identify available control options, and evaluate VOC reduction and control costs. The emission control techniques discussed include vapor recovery control techniques, such as adsorption and absorption, and combustion control devices, such as flares and thermal incinerators.
Keywords: Adsorber; flare; incinerator, catalytic; incinerator, thermal; vapor recovery system; control .
CAM Guidance Document chapter/section: Appendix B

Anderson, R.L., et al., Decalibration of Sheathed Thermocouples, *Temperature: Its Measurement and Control*, American Institute of Physics, New York, NY, 1992.
Summary: This document summarizes the results of tests conducted on 24 combinations of thermocouples and sheaths material types at temperatures up to 1200°C. Conclusions are that thermocouples maintain calibration better if sheath material is similar in composition to thermocouple alloys. Using similar sheath and thermocouple materials provides significantly longer performance for thermocouples subjected to temperatures greater than 600°C, and is essential for thermocouples subjected to temperatures greater than 1000°C.
Keywords: Temperature measurement; thermocouple.
CAM Guidance Document chapter/section: 4.2

APTI Course SI:412, Baghouse Plan Review, Student Guidebook, EPA 450/2-82-005, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, April 1982.
Summary: This document is the student manual designed to familiarize technical personnel with the steps for evaluating a fabric filter used to control particulate emissions. Used with a slide/tape program and a final exam, this is a course of study for persons responsible for reviewing plans for installations of baghouses. The document covers the following areas: fabric filtration operations and baghouse components, fabric filter material, bag cleaning, baghouse design, baghouse operation and maintenance, industrial applications, and a review exercise. This manual contains straightforward descriptions and clear, well-drawn diagrams.
Keywords: Baghouse; fabric filter.
CAM Guidance Document chapter/section: Appendix B

APTI Course 413, Control of Particulate Emissions, Student Manual, EPA 450/2-80-066, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1981.
Summary: This Student Manual is to be used in conducting APTI Course 413 “Control of Particulate Emissions” in conjunction with the Instructor’s Guide (EPA 450/2-80-066) and the Student Workbook (EPA 450/2-80-067). This manual supplements the course lecture material, presenting detailed discussions on particulate emission control equipment. The major topics include: Basic Gas Properties, Particle Dynamics, Particle Sizing, Settling Chambers, Cyclones, Electrostatic Precipitators, Fabric Filters, and Wet Collectors. This manual will assist the reader in evaluating plans for particulate emission control systems and in conducting plan reviews.
Keywords: Electrostatic precipitator, wet (WESP); fabric filter.
CAM Guidance Document chapter/section: Appendix B

ASTM Designation E 220, “Standard Method for Calibration of Thermocouples by Comparison Techniques,” American Society for Testing and Materials, Philadelphia, PA.
Summary: This document describes a protocol for calibrating thermocouples by comparing the reading from the subject thermocouple to the reading for a more accurate thermometer, which is

maintained at the same temperature. The procedure involves measuring the electromotive force of the thermocouple being calibrated at selected calibration points. The number and selection of calibration points depend on the type of thermocouple, the temperature range to which it is subjected, and the accuracy required.
Keywords: Calibration methods; temperature measurement; thermocouple.
CAM Guidance Document chapter/section: 4.2

Barron, W.R., "The Principles of Infrared Thermometry", *Sensors*, 9(12), December 1992.
Summary: This article is an in-depth discussion of infrared thermometry including design elements, single- and dual-wavelength thermometry, and reasons for the value of understanding the theory.
Keywords: Temperature measurement; temperature measurement .
CAM Guidance Document chapter/section: 4.2

Benedict, R.P., *Fundamentals of Temperature, Pressure, and Flow Measurements*, John Wiley and Sons, New York, NY, 1977
Summary: This document provides detailed information on the history, principles of operation, and calibration methods for a wide variety of temperature, pressure, and flow measurement devices.
Keywords: Calibration methods; flow measurement; flow meter, gas; flow meter, liquid; flow meter, mass; pressure guage; pressure transducer; pressure measurement, other devices; resistance temperature detector; temperature measurement; thermocouple; temperature measurement .
CAM Guidance Document chapter/section: 4.2, 4.3

Brunner, C. R., *Incineration Systems*, Government Institutes, Rockville, MD, 1982.
Summary: This book focuses on incineration system design. It includes a discussion of regulations applicable to incineration, analytical methods for systems design, and the various types of incinerators currently in use.
Keywords: Incinerator, catalytic; incinerator, thermal.
CAM Guidance Document chapter/section: Appendix B

Calvert, S., and H. M. Englund, Eds., *Handbook of Air Pollution Technology*, John Wiley and Sons, New York, NY, 1984.
Summary: This handbook includes chapters on control technologies used for gaseous pollutants (i.e., absorption, adsorption, condensation, chemical reaction, and combustion) and particulates (i.e., scrubbers, filters, electrostatic precipitators, and mechanical collectors).   For each control technology, the manual includes a description of the operating principles, applications, design, equipment, and potential problems. The handbook also includes chapters on specific industries (including typical emissions and control techniques used to control these emissions), sampling and analysis, and air pollution standards and regulations.
Keywords: Adsorber; afterburner, direct flame; afterburner, catalytic; baghouse; centrifugal collector; continuous emission monitoring system; electrostatic precipitator (ESP); electrostatic precipitator, wet (WESP); fabric filter; flare; gravity collector; incinerator, catalytic; incinerator, thermal; wet scrubber, gaseous; wet scrubber, PM.
CAM Guidance Document chapter/section: Appendix B

Combustion Emissions Technical Resource Document (CTRED), USEPA Solid Waste and Emergency Response (5305), EPA 530-R-94-014, May 1994.
Summary: To be completed.
Keywords: To be completed.

CAM Guidance Document chapter/section: Appendix B

Considine, D. M., Ed., *Van Nostrand's Scientific Encyclopedia,* 5th edition, Van Nostrand Reinhold.
Summary: This document lists the advantages and disadvantages of many of the flow meters described in this chapter. This document also lists the measurement accuracy and applicable pipe diameters of many of the flow meters described in this chapter.
Keywords: Flow measurement; flow meter, gas; flow meter, liquid; flow meter, mass.
CAM Guidance Document chapter/section: 4.4

DeCarlo, J. P., *Fundamentals of Flow Measurement,* Chapters 2, 6, 8, and 9, Instrument Society of America, Research Triangle Park, NC.
Summary: This document describes the classification of flow meters and contains information on principles of operation, orifice plates, turbine flow meters, vortex flow meters, magnetic flow meters, ultrasonic flow meters, thermal flow meters, and mass flow meters.
Keywords: Flow measurement; flow meter, gas; flow meter, liquid; flow meter, mass.
CAM Guidance Document chapter/section: 4.4

Draft Alternative Control Technology Document -- PM-10 Emissions from the Wood Products Industry: Particleboard, Oriented Strandboard, and Waferboard Manufacturing, U.S. Environmental Protection Agency, September 1992.
Summary: This document discusses particulate control techniques for dryers, boilers, hot presses, and sanders in particleboard, OSB, and waferboard manufacturing. Control of fugitive emissions from storage piles is also discussed. Control technologies examined include wet ESP's, electrified filter beds (EFB's), fabric filters, dry ESP's, wet scrubbers, and multiclones. Environmental impacts and cost analyses for the various control options for each emission point are presented.
Keywords: baghouse; centrifugal collector; electrostatic precipitator, wet (WESP); electrostatic precipitator (ESP); fabric filter; venturi scrubber; wet scrubber, PM
CAM Guidance Document chapter/section: Appendix B

Engineering Handbook for Hazardous Waste Incineration, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, OH, November, 1980.
Summary: To be completed.
Keywords: To be completed.
CAM Guidance Document chapter/section: 4.3

Everest, C.E., "Noninvasive Surface Temperature Measurement with Medical Infrared Thermometer," *Sensors*, 2(2), February, 1995.
Summary: This article contains a discussion of a small, hand-held, noncontact, infrared thermometer, which will make precision surface measurements at low temperatures.
Keywords: Temperature measurement; temperature measurement .
CAM Guidance Document chapter/section: 4.2

Galster, Helmuth, *pH Measurement*, VHC Press, New York, NY, 1991.
Summary: This book presents an overview of pH measurement stations and how to select and install the proper station for different types of streams. It also includes information on electrode selection, operation and maintenance of the pH measurement system, and calibration procedures.
Keywords: Calibration methods; operation and maintenance (O&M); pH measurement.
CAM Guidance Document chapter/section: 4.5

Generic Permit Conditions Pertaining to Monitoring, Georgia State Pollution Control Agency GDNR.
Summary: These generic permit conditions were developed by the Georgia Industrial Source Monitoring Program for use in Synthetic Minor operating permits with the aim of producing a consistent, stable, enforceable, speedy permit application and issuance process. The document outlines permit conditions to be used on all permits, when performance testing is to be required, and when performance test methods must be included in the permit. It also discusses notification reporting, and recordkeeping. Specific permit conditions pertaining to parameter monitoring and recordkeeping are listed for several control methods and source classifications. Control methods include absorbers, incinerators, enclosures, condensers, baghouses, and flares. Source categories include fuel burning equipment and stone crushing operations. The monitoring requirements given in this document are not to replace any applicable NSPS, NESHAP, or SIP monitoring requirement to which the source may be subject.
Keywords: State/local agency monitoring and permit guidelines; monitoring parameters.
CAM Guidance Document chapter/section: Appendix B

Glick, S., "Infrared Temperature Measurement Errors," *Sensors*, 5(4), April, 1988.
Summary: The discussion in this article includes temperature errors due to object emissivity, transmission loses, background interference; and some solutions.
Keyword: Temperature measurement.
CAM Guidance Document chapter/section: 4.2

Grieb, B., Temperature Measurement in Process Control, *Advances in Instrumentation and Control, Proceedings of the Annual Meeting of the Instrument Society of America, Volume 47,* Instrument Society of America, Research Triangle Park, NC, 1992.
Summary: The article provides a comprehensive overview of thermocouples and RTD's, including (in Appendix A of the paper) a comparison of the advantages and disadvantages of each. It also includes detailed illustrations of sensor components.
Keywords: Temperature measurement; thermocouple; resistance temperature detector (RTD).
CAM Guidance Document chapter/section: 4.2

Harland, P. Ed., *Pressure Gauge Handbook*, Marcel Dekker, Inc., New York, NY.
Summary: This document provides an overview of the fundamentals of pressure measurement and pressure gauges. The components, operation, maintenance, and calibration of various types of pressure gauges are described. The document also provides general information on pressure transducers.
Keywords: Pressure guage; pressure transducer; calibration methods; operation and maintenance (O&M).
CAM Guidance Document chapter/section: 4.3

Hashemian, H. M., and K. M. Peterson, Accuracy of Industrial Temperature Measurement, *Advances in Instrumentation and Control, Proceedings of the Annual Meeting of the Instrument Society of America, Volume 43,* Instrument Society of America, Research Triangle Park, NC, 1988.
Summary: The article presents a good overview of the use and applicability of thermocouples and RTD's for temperature measurement in industry; compares thermocouples and RTD's with respect to applicability, performance, and costs; and makes recommendations on calibrating at industrial installations.

Keywords: Temperature measurement; thermocouple; resistance temperature detector (RTD).
CAM Guidance Document chapter/section: 4.2

Hashemian, H. M., and K. M. Peterson, Achievable Accuracy and Stability of Industrial RTD's, *Temperature: Its Measurement and Control*, American Institute of Physics, New York, NY, 1992.
Summary: This document presents results of tests on 47 RTD's to determine the effects of aging at temperatures in the range of 0°to 300°C. Tests were conducted for thermal aging, vibration aging, high temperature application, and thermal cycling. The conclusion was that RTD's generally keep calibration to within ±0.2°C for at least 2 years over the temperature range of 0° to 300°C.
Keywords: Temperature measurement; resistance temperature detector (RTD).
CAM Guidance Document chapter/section: 4.2

Hesketh, H. E., and K. C. Schifftner, *Wet Scrubbers, A Practical Handbook*, Lewis Publishers, Inc., Chelsea, MI, 1986.
Summary: This book discusses wet scrubber types, applications, design, and maintenance and control issues. Calculations for vapor-liquid equilibrium, pressure drop, velocity, and other parameters are also discussed, and example calculations are given. The relationships of pressure drop, particle size, and particle concentration in the incoming gas stream to control efficiency are examined.
Keywords: venturi scrubber; wet scrubber, gaseous; wet scrubber, PM
CAM Guidance Document chapter/section: Appendix B

Jennings, M. S., et al., *Catalytic Incineration for Control of Volatile Organic Compound Emissions*, Noyes Publications, Park Ridge, NJ, 1985.
Summary: This book describes and evaluates the use of catalytic incinerators for the control of industrial VOC emissions. It includes a description of how catalytic incineration is applied to the control of industrial VOC emissions and assesses the overall performance, applicability, and costs as compared to alternate VOC control technologies. It also describes the results of case studies, which gathered actual performance data through a field testing program on existing operating industrial catalytic incinerators. The types of sources that typically use catalytic incinerators are also described in the book.
Keywords: Incinerator, catalytic; operation and maintenance (O&M).
CAM Guidance Document chapter/section: Appendix B

Johnson, F. L., "Detecting and Preventing RTD Drift," *Sensors*, 12(5):64-66, 78, May, 1995.
Summary: This article contains a discussion of RTD drift and procedures for preventing drift.
Keywords: Calibration methods; resistance temperature detector; temperature measurement; thermocouple.
CAM Guidance Document chapter/section: 4.2

Laird, F., "Infrared Temperature Measurement and Imaging," *Sensors*, 11(8), August, 1994 .
Summary: This article is an overview of IR temperature measurement with detailed explanations of emissivity, IR imaging systems, and applications.
Keywords: Temperature measurement; temperature measurement device.
CAM Guidance Document chapter/section: 4.2

Le, D. H. and S. Loth, "Ensuring Strain Gauge Pressure Transducer Stability," *Sensors*, 5(7), July, 1988

Summary: This article is an in-depth discussion of instability in pressure transducers, which 'can invalidate pressure accuracy by contributing an unknown error component to the measurement. Attention to design, testing, and calibration can optimize instrument stability.'
Keywords: Calibration methods, pressure transducer.
CAM Guidance Document chapter/section: 4.3

Linder, Peter, Ralph Torrington, and David Williams, *Analysis Using Glass Electrodes*, Open University Press, Milton Keynes, England, 1984.
Summary: This book presents background information on pH measurements using glass electrodes. The book includes a presentation on the pH scale and what it means, and a discussion of operation and maintenance of pH measurement systems.
Keywords: Calibration methods; operation and maintenance; pH measurement.
CAM Guidance Document chapter/section: 4.5

Lonergan, S., "Specifying Transducers for an Industrial Environment," Engineered Systems, Business News Publishing Company, August, 1994.
Summary: This article discusses stresses, including vibration, electronic noise, corrosion, and temperature fluctuations, that degrade accuracy and cause failure in pressure transducers. Solutions that lie in transducer designs, strain gage technology, and capacitive sensing are explored.
Keywords: Pressure transducer.
CAM Guidance Document chapter/section: 4.3

Maguire, John, Ed., *Handbook of Industrial Water Conditioning*, Betz Laboratories, Trevose, PA, 1980.
Summary: This reference provides background information on conductivity measurements, including how to measure the conductivity of a water stream and how conductivity measurements are used in assessing water quality and determining solids content.
Keywords: Conductivity measurement.
CAM Guidance Document chapter/section: 4.5

Model 444RL, Temperature Transmitter Owner's Manual, Rosemount, Inc., Eden Prairie, MN, Product literature.
Summary: This product manual contains a discussion of temperature transmitter design and calibration. It also includes wiring, block, parts, and circuit diagrams.
Keywords: Calibration methods; resistance temperature detector; temperature measurement; thermocouple.
CAM Guidance Document chapter/section: 4.2

North Carolina Department of Environment, Health, and Natural Resources, Division of Air Quality, *Final Testing, Monitoring, Reporting, and Recordkeeping (TMRR) Approach*.
Summary: This document consists of a series of 6 examples to assist NCDEM permit writers in writing permit conditions regarding TMRR. The examples are as follows:

- PM from boiler controlled with packed bed scrubber
- PM from boiler controlled with multiclone
- SO_2 from generic coal combustion sources
- VE from boiler with multiclone
- VOC from miscellaneous sources

Examples are short (half page each) and most are for work practices rather than parameter monitoring. No additional guidance is provided, and the only control device parameter monitoring presented is for monitoring pressure drop and liquid flow rate for packed bed scrubbers.
Keywords: Monitoring parameters; State/local agency monitoring and permit guidelines; wet-scrubber, PM; work practice.
CAM Guidance Document chapter/section: Not referenced.

Ohio EPA, Ohio EPA Engineering Guide No. 65, Ohio EPA, Division of Air Pollution Control.
Summary: This document, which is in question-and-answer format, was written to assist State permit and Title V applicants, as well as agency permit reviewers regarding the types of sources that should develop a monitoring, recordkeeping, and reporting (MRR) program to ensure continuous compliance; also provides guidance on what constitutes a reasonable and adequate program. The types of emissions units for which an MRR program should be established are described in tables by pollutant . The tables also reference the *Ohio State Air Resource System (STARS*) library of terms and conditions and list the types of limitations sources may be subject to, such as operating or production caps, that require an MRR program. The document provides guidance on how to determine if a source that is not listed in the tables must develop an MRR program. Examples also are presented.
Keywords: State/local agency monitoring and permit guidelines; monitoring frequency; monitoring parameters.
CAM Guidance Document chapter/section: Not referenced.

Ohio EPA, *The "STARS" Library of Terms and Conditions for Permits to Install, Title V Permits, and State Permits to Operate,* Version 3.0, Ohio EPA, Division of Air Pollution Control, November 1996.
Summary: "STARS" stands for State Air Resources System. This document is a compilation of common terms and conditions which are used by the Division of Air Pollution Control (DAPC) in preparing permits to install, Title V permits, and State permits to operate. The first section contains general terms and conditions which are required for Title V permits and State permits to operate. The second section contains common terms and conditions for emission units which will be used in the permits. Monitoring, recordkeeping, and reporting requirements are given for specific emission sources, as well as requirements for CEMS certification and required parameter monitoring for control devices. Compliance methods and testing requirements are also discussed, as are ambient air quality and visible particulate emission standards.
Keywords: State/local agency monitoring and permit guidelines; monitoring parameters; monitoring frequency; operation and maintenance (O&M); adsorber; baghouse; continuous emission monitoring system (CEMS); continuous opacity monitoring system (COMS); control; fabric filter; flare; incinerator, thermal; incinerator, catalytic; venturi scrubber; wet scrubber, gaseous; wet scrubber, PM.
CAM Guidance Document chapter/section: Not referenced.

Ohio EPA's Operating and Maintenance (O&M) Guidelines for Air Pollution Control Equipment, for Ohio EPA, Columbus, OH, by Environmental Quality Management, Inc., Cincinnati, OH, February 1993.
Summary: This document presents discussions of operation and maintenance (O&M) procedures for air pollution control equipment commonly used in Ohio. Proper O&M minimizes pollutant emissions, reduces equipment malfunction, ensures equipment reliability, and aids in continued compliance with air pollution regulations and Ohio's permit requirements. The document focuses on eight types of air pollution control equipment: mechanical collectors; fabric filters, including dry scrubbers; electrostatic precipitators, both wet and dry; carbon adsorbers; incinerators, thermal and catalytic;

flares; wet scrubbers; and condensers. There is a general description for each equipment type. Also wherever appropriate, there are guidelines for monitoring; inspection, operation, and maintenance procedures; example inspection forms; discussions and tables of major problems or malfunctions; and overviews of operator training and spare parts needs.
Keywords: Adsorber; baghouse; electrostatic precipitator (ESP); electrostatic precipitator, wet (WESP); fabric filter; flare; incinerator, catalytic; incinerator, thermal; vapor recovery system; venturi scrubber; wet scrubber, gaseous; wet scrubber, PM; control .
CAM Guidance Document chapter/section: Appendix B

Omega Complete Temperature Measurement Handbook and Encyclopedia, Vol. 29. Omega Engineering, Inc., Stamford, CT, 1995.
Summary: This book gives information on temperature sensing devices and their associated instrumentation manufactured by Omega Engineering, Inc. Data acquisition systems and calibration equipment are also discussed. The book also includes a technical reference section that includes information on thermistors, RTD's, monolithic temperature sensors, thermocouples, and standard wire errors.
Keywords: temperature measurement; thermocouple; resistance temperature detector (RTD); temperature measurement .
CAM Guidance Document chapter/section: 4.2

Operation and Maintenance Manual for Fabric Filters, U. S. Environmental Protection Agency, EPA/625/1-86/020, June 1986.
Summary: This manual focuses on the operation and maintenance (O&M) of typical fabric filters. The manual includes a discussion of the basic theory and design of fabric filters. It also presents the purpose, goals, and role of performance monitoring as a major element in an O&M program (including key performance indicators and their measurement) and covers instrumentation, data acquisition, and record keeping methods useful in optimizing fabric filter system performance. The use of performance monitoring in evaluating the control system performance and discovering and correcting causes of poor performance is also discussed. The manual also presents guidelines for general O&M practices and procedures for use in improving and sustaining fabric filter performance and reliability, and it provides step-by-step procedures and techniques for conducting inspections of the systems and their components.
Keywords: Baghouse; fabric filter; monitoring parameters; operation and maintenance (O&M).
CAM Guidance Document chapter/section: Appendix B

Operation and Maintenance Manual for Electrostatic Precipitators, U. S. Environmental Protection Agency, EPA/625/1-85/017, Office of Research and Development, Research Triangle Park, NC, September 1985.
Summary: This manual discusses the operation and maintenance (O&M) of typical electrostatic precipitators (ESP's). The manual includes a discussion of the basic theory and principles of electrostatic precipitation; performance monitoring as a major element in an O&M program and the use of performance monitoring in evaluating the control system performance and discovering and correcting causes of poor performance; guidelines for general O&M practices, including proper startup/shutdown procedures, normal operating practices, and schedules for inspection of equipment and for performing preventive maintenance; and common problems encountered in ESP control systems.
Keywords: Electrostatic precipitator (ESP); monitoring frequency; monitoring parameters; operation and maintenance (O&M).

CAM Guidance Document chapter/section: Appendix B

Oregon Department of Environmental Quality, Air Quality Division, *Compliance Monitoring Guidance Document–Discussion Draft*, May 11, 1994.
Summary: This document proposes guidance for Title V and Title VII compliance monitoring. A step-by-step compliance monitoring development process is described. The document includes five tables that provide guidance on appropriate compliance monitoring. These tables include lists of monitoring required by Oregon Administrative Rules, monitoring guidance for the most commonly encountered industries in Oregon, compliance monitoring guidance for PM and gaseous emissions, and recommendations for determining compliance with visible emissions limits.
Keywords: State/local agency monitoring and permit guidelines.
CAM Guidance Document chapter/section: Not referenced.

Organic Chemical Manufacturing, Volume 4: Combustion Control Devices, EPA-450/3/80/027
Summary: To be completed.
Keywords: To be completed.
CAM Guidance Document chapter/section: Appendix B

Peacock, G. R., Radiation Thermometry: Temperature Measurement Without Contact, *Advances in Instrumentation and Control, Proceedings of the Annual Meeting of the Instrument Society of America, Volume 46,* Instrument Society of America, Research Triangle Park, NC, 1991.
Summary: This document provides good overview of infrared (IR) thermometers, describes recent developments in the technology, and presents summary of advantages and disadvantages of IR thermometry.
Keywords: Temperature measurement; temperature measurement .
CAM Guidance Document chapter/section: 4.2

Perry, R. H. and C. H. Chilton, Eds., *Chemical Engineers' Handbook*, Fifth and Sixth Editions, McGraw-Hill Book Company, New York, N.Y., 1973
Summary: This document contains detailed information on venturi tubes, flow nozzles, and orifice plate flow meters. Specifically, this document describes the location of the pressure taps for an orifice plate and describes flow loss due to the pressure drop across these three types of flow meters. The document includes background information on chemical engineering arranged in 25 areas including heat-transfer equipment, gas absorption, liquid-gas systems, and process control. 135 authors contributed to this readable text. This is a good, basic reference.
Keywords: Adsorber; baghouse; centrifugal collector; conductivity measurement; control; electrical energy measurement; fabric filter; flow measurement; flow meter, gas; flow meter, liquid; flow meter, mass; gravity collector; incinerator, thermal; level measurement; operation and maintenance (O&M); pH measurement; pressure gauge; pressure measurement, other devices; pressure transducer; resistance temperature detector (RTD); temperature measurement; temperature measurement ; thermocouple; vapor recovery system; venturi scrubber; wet scrubber, gaseous; wet scrubber, PM.
CAM Guidance Document chapter/section: 4.2, 4.3, 4.4

Product literature, Badger Meter, Inc., Industrial Products Division, Milwaukee, WI.
Summary: This product literature contains application specific information (e.g., applicable pipe diameters and measurement accuracy) for orifice plates, venturi tubes, flow nozzles, ultrasonic flow meters, and turbine flow meters.
Keywords: Flow measurement; flow meter, gas; flow meter, liquid; flow meter, mass.

CAM Guidance Document chapter/section: 4.4

Product literature, Catalogue No. 60, Flow-Lin Corporation, Arlington, TX.
Summary: This product literature presents application specific design specifications and measurement accuracy of a flow nozzle flow meter.
Keywords: Flow measurement; flow meter, gas; flow meter, liquid.
CAM Guidance Document chapter/section: 4.4

Product literature, Catalogue No. 70, Flow-Lin Corporation, Arlington, TX.
Summary: This product literature presents application specific design specifications and measurement accuracy of a venturi tube flow meter.
Keywords: Flow measurement; flow meter, gas; flow meter, liquid.
CAM Guidance Document chapter/section: 4.4

Product literature, Form VT-106.1, Universal Flow Monitors, Inc., Hazel Park, MI, 1995.
Summary: This product literature presents application specific design specifications and measurement accuracy of a vortex flow meter.
Keywords: Flow measurement; flow meter, gas; flow meter, liquid.
CAM Guidance Document chapter/section: 4.4

Product information, Kurz Instruments, Inc., Monterey, CA.
Summary: This product information presents application specific design specifications, measurement accuracy, and calibration of thermal flow meters.
Keywords: Flow measurement; flow meter, gas.
CAM Guidance Document chapter/section: 4.4

Product information, McCrometer, Helmet, CA.
Summary: This product information contains the line drawing of a helical gear flowmeter used in Figure 4.4-8.
Keywords: Flow measurement; flow meter, liquid.
CAM Guidance Document chapter/section: 4.4

Product literature, Micro Motion, Boulder, CO.
Summary: This product literature presents a description of the principle of operation, specific applications for this device, measurement accuracy, and specification for a mass flow meter.
Keywords: Flow measurement; flow meter, gas; flow meter, liquid; flow meter, mass.
CAM Guidance Document chapter/section: 4.4

Protocol for Determining the Daily Volatile Organic Compound Emission Rate of Automobile and Light-Duty Truck Topcoat Operations, EPA-450/3-88-018, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, December, 1988.
Summary: This document, the EPA/Auto Protocol, is an important, useful tool that was developed jointly by EPA and the auto industry to provide EPA Regions, States, local permitting agencies, and the industry with a sound method for determining the compliance status of assembly plant painting operations. The document has been used to demonstrate compliance with RACT, NSPS, and LAER emission limits for topcoat and spray primer/surfacer coating lines. The following are significant elements of the Auto Protocol: recordkeeping requirements, procedures and example forms for the compliance determination; various directions, discussion "notes", and coating line layouts that can be

used in the compliance determination; daily VOC emission rate calculations, and other example calculations supporting the compliance determination; and bake oven control device destruction efficiency and control credit procedures. Many of these elements are applicable to other coating operations as well.
Keywords: State/local agency monitoring and permit guidelines.
CAM Guidance Document chapter/section: Appendix B

Roberson, J. A., and C. T. Crowe, *Engineering Fluid Mechanics*, Houghton Mifflin Company, Boston, MA, 1975.
Summary: This reference was used for background information on pressure sensors and for drawings of a manometer and a rotameter.
Keywords: Flow measurement; flow meter, gas; flow meter, liquid.
CAM Guidance Document chapter/section: 4.3, 4.4

Rosenberg, Robert J. , "Temperature Measurement on the job site using RTD's and Thermocouples," *ISA Transactions, Volume 33*, Instrument Society of America, Research Triangle Park, NC, 1994.
Summary: This article discusses the factors that affect calibration of RTD's and thermocouples on the job site, including electric "noise" from nearby motors and electrical equipment, radio frequency interference, and ground loops; an presents recommendations on how to minimize these decalibrating factors.
Keywords: Temperature measurement; thermocouple; resistance temperature detector (RTD).
CAM Guidance Document chapter/section: 4.2

Spitzer, D. W., *Industrial Flow Measurement*, Instrument Society of America, Research Triangle Park, NC.
Summary: Chapters 6, 7, 10-15, 18-22, and 24 of this document provide a good description of flow meter maintenance, calibration, and spare parts. Also, this document provides a good principle of operation description of most of the flow meters discussed in this chapter.
Keywords: Flow measurement; flow meter, gas; flow meter, liquid; flow meter, mass.
CAM Guidance Document chapter/section: 4.4

Staley, J., "Platinum Thin Films in RTDs and Hot Film Anemometers ," *Sensors*, 12(9):60-67, September, 1995.
Summary: This article contains a discussion of platinum thin films in RTD's and anemometers, self heating, and the ways packaging and support structures affect behavior.
Keywords: Resistance temperature detector; temperature measurement; temperature measurement ; thermocouple.
CAM Guidance Document chapter/section: 4.2

Tandeske, D., *Pressure Sensors*, Selection and Application, Marcel Dekker, Inc., New York, NY
Summary: This book features a comprehensive overview of pressure sensors. It includes background basics; classifications; descriptions; drawings; and mathematical explanations of Boyle's law, the pressure-temperature law, the combined gas law, and types of flow. There is also background information on mechanical dial pressure gauges. The book was used primarily for information and drawings of pressure transducers (in this document, pressure measurement devices that convert pressure to electrical signals). Pressure transducers described by Tandeske include strain gage sensors, LVDT's, capacitance transducers, piezoresistive transducers. He also discusses QA/QC issues and sensor specifications.

Keywords: Calibration methods; pressure gauge; pressure transducer; pressure measurement, other devices.
CAM Guidance Document chapter/section: 4.3

The Flow and Level Handbook, Omega Engineering, Inc., Stamford, CT, 1995.
Summary: This book contains a great variety of flow and level measurement equipment with specifications, a glossary, and background information.
Keywords: Calibration methods; conductivity measurement; level measurement; monitoring parameters; pressure device; control ; pH measurement; pressure guage; data acquisition system; flow measurement; flow meter, gas; flow meter, liquid; flow meter, mass; temperature measurement; thermocouple; temperature measurement .
CAM Guidance Document chapter/section: Not referenced.

The pH and Conductivity Handbook, Omega Engineering, Inc., Stamford, CT, 1995.
Summary: This handbook presents an overview of pH and conductivity measurement techniques. The handbook has sections on selecting the proper pH measurement equipment for a sample stream, proper operation and maintenance of the pH measurement system, and calibration procedures. The handbook also includes information on conductivity measurement systems and a catalog of pH and conductivity measurement systems sold by the company.
Keywords: Calibration methods; conductivity measurement; operation and maintenance (O&M); pH measurement.
CAM Guidance Document chapter/section: 4.5

Temperature Measurement and Calibration of Type K Thermocouples in High Temperature Stacks, D. Bivins, EMTIC, GD-024.
Summary: This document provides guidelines on the use and limitations of Type K thermocouples in high temperature stationary source stacks. Calibration methods are identified and recommended calibration frequencies are specified. The document also provides information on thermocouple drift.
Keywords: Calibration methods; temperature measurement; thermocouple.
CAM Guidance Document chapter/section: 4.2

Temperature Sensors Products Catalog, 1995, Pyromation Inc., Fort Wayne, IN.
Summary: This group of loose pages contains specifications and some drawings of thermocouples, RTDs, and related instruments and devices.
Keywords: Resistance temperature detector (RTD); thermocouple; temperature measurement ; temperature measurement.
CAM Guidance Document chapter/section: 4.2

U. S. Environmental Protection Agency, *Control Techniques for Particulate Emissions from Stationary Sources--Volume 1*, EPA-450/3-81-005a, September 1982.
Summary: This document presents technical information on particulate emissions and control techniques, including mechanical collectors, electrostatic precipitators, fabric filters, wet scrubbers, and incinerators. Discussions include the operating principles, control effectiveness, and maintenance requirements for these control techniques.
Keywords: Electrostatic precipitator (ESP); fabric filter; gravity collector; incinerator, catalytic; incinerator, thermal; operation and maintenance (O&M); wet scrubber, PM.
CAM Guidance Document chapter/section: Appendix B

Virginia State Advisory Board on Air Pollution, Sub-Committee Report on Compliance Assurance Monitoring (CAM), October 16, 1995.
Summary: This report largely describes a general methodology for determining the most appropriate method of monitoring an emissions unit based on the required monitoring, significance of the unit, current monitoring practices, and cost of various monitoring options. According to the methodology, the significance of an emissions unit is determined by rating the emissions unit according to four criteria and calculating the numeric average of the four ratings. The rating criteria are: type of applicable requirement, percent of potential-to-emit (PTE) for the emissions unit to the PTE for the facility as a whole, percent of PTE to major cutoff, and compliance margin. Appendix A of this document provides a fairly extensive list of monitoring options for a variety of generic emissions units and control devices.
Keywords: State/local agency monitoring and permit guidelines; monitoring parameters; adsorber; baghouse; electrostatic precipitator (ESP); fabric filter; flare; incinerator, catalytic; incinerator, thermal; wet scrubber, gaseous; wet scrubber, PM; control
CAM Guidance Document chapter/section: 2.5

Wang, T.P., A. Wells, and D. Bediones, "Accuracy and Repeatability of Temperature Measurement by RTDs," *Advances in Instrumentation and Control*, Proceedings of the Annual Meeting of the Instrument Society of America, Volume 44, Instrument Society of America, Research Triangle Park, NC, 1989
Summary: Tested 19 RTD's at moderate temperatures (200°C). Initial accuracy of all within ASTM Grade B specification; all but 3 within Grade A specs. Cycled all RTD's to 200°C. As a group, tended to stabilize after 3 calibration cycles.

- Recommended stabilizing at highest likely service temperature before putting into service.
- No significant differences in calibration as function of form (thin film or wire wound) platinum purity, 4-wire RTD's seemed to perform better than 3-wire in some cases.

Keywords: Calibration methods; resistance temperature detector (RTD), temperature measurement.
CAM Guidance Document chapter/section: 4.2

Wisconsin Air Permit Compliance Demonstration Guidance, Wisconsin Department of Natural Resources, 1994
Summary: This document is intended as a supplement to the Wisconsin Air Pollution Permit Application Instruction Booklet. It consists of 15 pages of text and copies of the Wisconsin Air Pollution Permit Application forms, which include Compliance Demonstration forms. The introduction to the document states that the permit program includes the following five components related to compliance: compliance demonstration, compliance status with applicable requirements, compliance plan, compliance certification, and a monitoring data reporting schedule. These components are related to specific application forms. The document outlines the types of monitoring that may be used to demonstrate compliance, including monitoring of control system parameters.
Keywords: State/local agency monitoring and permit guidelines.
CAM Guidance Document chapter/section: Appendix B

1994 Product Catalogue, Dwyer Instruments, Inc., Chicago, IL, 1993, Product literature.
Summary: This document contains descriptions and drawings of a variety of pressure guages, flow meters, and level switches. It was used specifically for its description of manometers.
Keywords: Flow measurement; level measurement; pressure guage; pressure measurement, other devices; control .
CAM Guidance Document chapter/section: 4.3

APPENDIX A.

EXAMPLE MONITORING APPROACH SUBMITTALS

Revision 1.0

September 2004

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ACKNOWLEDGMENT

The cooperation of the corporate environmental staff, facility personnel, and state Agency personnel that voluntarily identified facilities, provided information and data, and answered numerous questions to support development of the example monitoring approach submittals presented in this Appendix is greatly appreciated.

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PREFACE

This revision to Appendix A of the Compliance Assurance Monitoring (CAM) Technical Guidance incorporates into a single document the example CAM submittals initially published in Appendix A (August 1998) and final versions of the draft submittals published in Supplements 1 and 2 (September 2000). The original publication date for the final version of each submittal has been retained in the footer of the submittal.

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INTRODUCTION

The example compliance assurance monitoring (CAM) approach submittals presented in this Appendix are based upon "case studies" of the current monitoring approaches in use at actual facilities and historical data obtained from the monitoring system. The development process for these examples included: (1) identifying facilities which currently monitor control device parameters, had long-term monitoring data available for review, had conducted a performance/compliance test, and were willing to participate, (2) obtaining information on the monitoring approach and monitoring data from the facility, (3) reviewing and analyzing the monitoring approach and data, (4) discussing the information with plant personnel and, in some cases, conducting a site visit, and (5) preparing an example monitoring approach submittal from the information.

The basic approach used was to evaluate the monitoring conducted by the facility against CAM general (design) and performance criteria. A monitoring approach submittal based upon the facility's current monitoring, modified as necessary to comply with CAM requirements, was then drafted. If sufficient information was available to evaluate alternative approaches (e.g., different indicators, indicator ranges, or data averaging periods), alternative approaches also were investigated. Note that the resulting examples are not necessarily the only acceptable monitoring approaches for the facility or similar facilities; they are simply examples of approaches used by particular facilities. The owner or operator of a similar facility may propose a different approach that satisfies part 64 requirements. Also, the permitting authority may require additional monitoring.

One purpose of this appendix is to provide **nonprescriptive** examples of monitoring approaches that meet the CAM submittal requirements for the specific cases studied. Each example monitoring submittal contains background information (including identification of the pollutant specific emissions unit), a description of the monitoring approach, and the rationale for selecting the indicators and indicator ranges. Several of the examples also contain quality improvement plan (QIP) thresholds for particular indicators. The QIP is an optional tool for States and is not required to be included in the facility's permit or CAM submittal. These examples represent the level of detail recommended by EPA, but States may develop their own guidance as to the level of detail (more or less) required in CAM monitoring approach submittals.

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A.1a. THERMAL INCINERATOR FOR VOC CONTROL–FACILITY A

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EXAMPLE COMPLIANCE ASSURANCE MONITORING

Thermal Incinerator for VOC Control: Facility A - Example 1

I. Background

A. Emissions Unit

Description:	Coater 1, Coater 2, and Coater 3
Identification:	Stack No. XXX/ Ct. YYYYY
Stack designation:	Incinerator
APC Plant ID No.	XXXXX
Facility:	Facility A Anytown, USA

B. Applicable Regulation, Emission Limit, and Monitoring Requirements

Regulation No.:	Permit
Regulated pollutant (PSEU):	VOC
Emission limit:	95 percent reduction
Monitoring requirements in permit:	Continuously monitor chamber temperature [NOTE 1]

C. Control Technology: Thermal oxidizer

II. Monitoring Approach

The key elements of the monitoring approach, including the indicators to be monitored, indicator ranges, and performance criteria are presented in Table A.1a-1.

Note that this CAM submittal is intended as an example of monitoring the operation of the incinerator and does not address capture efficiency. Capture efficiency is a critical component of the overall control efficiency of the air pollution control system, and indicators of the performance of the capture system should be incorporated into the monitoring approach. However, sufficient information was not available from this case study to include monitoring of the capture system performance.

III. Data Availability [NOTE 2]

The minimum data availability for each semiannual reporting period, defined as the number of hours for which monitoring data are available divided by the number of hours during which the process operated (times 100) will be:

Chamber temperature: 90 percent

The data availability determination will not include periods of control device start up and shut down. For an hour to be considered a valid hour of monitoring data, a minimum of 45 minutes of data must be available.

TABLE A.1a-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2
I. Indicator	Chamber temperature	Work practice
Measurement Approach	The chamber temperature is monitored with a thermocouple.	Inspection and maintenance of the burner; observation of the burner flame.
II. Indicator Range	An excursion is defined as temperature readings less than 1500°F; excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion is defined as failure to perform annual inspection or daily flame observation.
QIP Threshold[a]	No more than six excursions below the indicator range in any semi-annual reporting period.	Not applicable
III. Performance Criteria A. Data Representativeness[b]	The sensor is located in the incinerator chamber as an integral part of the incinerator design. The minimum tolerance of the thermocouple is ±4°F or ±0.75% (of temperature measured in degrees Celius), whichever is greater. The minimum chart recorder sensitivity (minor division) is 20°F.	Not applicable
B. Verification of Operational Status	Not applicable	Not applicable
C. QA/QC Practices and Criteria[b]	Accuracy of the thermocouple will be verified by a second, or redundant, thermocouple probe inserted into the incinerator chamber with a hand held meter. This validation check will be conducted at least annually. The acceptance criterion is ±30°F.	Not applicable
D. Monitoring Frequency	Measured continuously.	Annual inspection of the burner; daily observation of the burner flame.
Data Collection Procedure	Recorded continuously on a circular chart recorder.	Record results of annual inspections and daily observations.
Averaging Period	No average is taken.	Not applicable

[a]The QIP is an optional tool for States; QIP thresholds are not required in the CAM submittal.

[b]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

Note: Capture efficiency is a critical component of the overall control efficiency of the air pollution control system, and indicators of the performance of the capture system should be incorporated into the monitoring approach. However, sufficient information was not available from this case study to include monitoring of the capture system performance.

MONITORING APPROACH JUSTIFICATION

I. Background

This is a coating facility that performs polyester film coating and paper liner coating with solvent based coatings. Three coaters are operated at the facility. Emissions from the three coaters are vented to the thermal incinerator. Emissions from mixing, coating, and drying operations are vented to this incinerator; some mixing vessels can also be vented to other oxidizers. A total of 27 sources are connected to the thermal incinerator.

II. Rationale for Selection of Performance Indicators

The incinerator chamber temperature was selected because it is indicative of the thermal incinerator operation (combustion occurring within the chamber). If the chamber temperature decreases significantly, complete combustion may not occur.

It has been shown that the control efficiency achieved by a thermal incinerator is a function of its operating temperature, or outlet temperature. By maintaining the operating temperature at or above a minimum, a level of control efficiency can be expected to be achieved. Attachment 1 presents information from the literature on incinerator control efficiency as a function of temperature.

The work practice comprised of an annual inspection and tuning of the incinerator burner was selected because an inspection verifies equipment integrity and periodic tuning will maintain proper burner operation and efficiency. In addition, a daily observation of the burner flame selected to monitor proper operation of the burner (blue flame) is appropriate.

[Sufficient information regarding bypass of the control device is not available. The damper on the bypass line, or purge line, on each coater must be closed during coating process operation to ensure that the vent stream is routed to the thermal incinerator.]

III. Rationale for Selection of Indicator Ranges

The selected indicator range for the incinerator chamber temperature is “greater than 1500°F at all times.” When an excursion occurs corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. Furthermore, if the duration of a temperature excursion exceeds 10 minutes, the coating line operation will be curtailed. All excursions will be documented and reported. The selected QIP threshold level is six excursions per semiannual reporting period [see NOTE 3]. This level is less than 0.05 percent of the process operating time (based on 2,800 operating hours). If the QIP threshold is exceeded in a semiannual reporting period, a QIP will be developed and implemented. This QIP threshold is supported by 6-months of monitoring data following the performance test.

The air pollution control permit issued by the State agency specifies that the incinerator must be designed to operate with a minimum operating temperature of 1500°F measured at the center of the incinerator chamber. Attachment 1 indicates that a thermal incinerator is expected to achieve 95 percent or greater destruction efficiency (DRE) at this temperature. The permit requirement is 95 percent DRE. The incinerator employs a temperature controller that maintains the desired chamber temperature by using a natural gas-fired auxiliary burner; the temperature controller is set to maintain a temperature of at least 1500°F.

Review of historical monitoring data for a 6-month period (July-December 1993) indicates that 1500°F can be maintained on a routine basis with some excursions. The historical monitoring data for temperature indicate that normal loading to the incinerator will result in chamber temperatures of 1500°F and higher loadings to the device will result in periods of higher operating temperatures for short durations, such as during the performance test. The historical monitoring data indicate that the indicator range was exceeded seven times in the 6-month period; two of the excursions were momentary.

The performance test confirms acceptable performance of the incinerator; the incinerator achieved the required DRE of 95 percent. During the performance test, the incinerator was operating with a temperature of at least 1500°F (in the range of 1540° to 1800°F). During the performance tests the incinerator temperature was generally nearer 1700°F than 1500°F. The higher temperatures during the performance test occurred because the facility was operated near the maximum production rate with higher VOC loadings to challenge the incinerator with maximum VOC loading. The higher operating temperatures during the performance test are not the result of a change in operation of the incinerator (i.e., changing the burner set point temperature).

The performance test of the thermal incinerator was conducted in October 1993 using EPA Reference Method 25. Three test runs (1 hour each) were conducted with 11 out of 27 sources operating and venting to the incinerator; this number of operating sources is considered normal. During the performance test, the chamber temperature was measured continuously and recorded on a circular chart (Attachment 2).

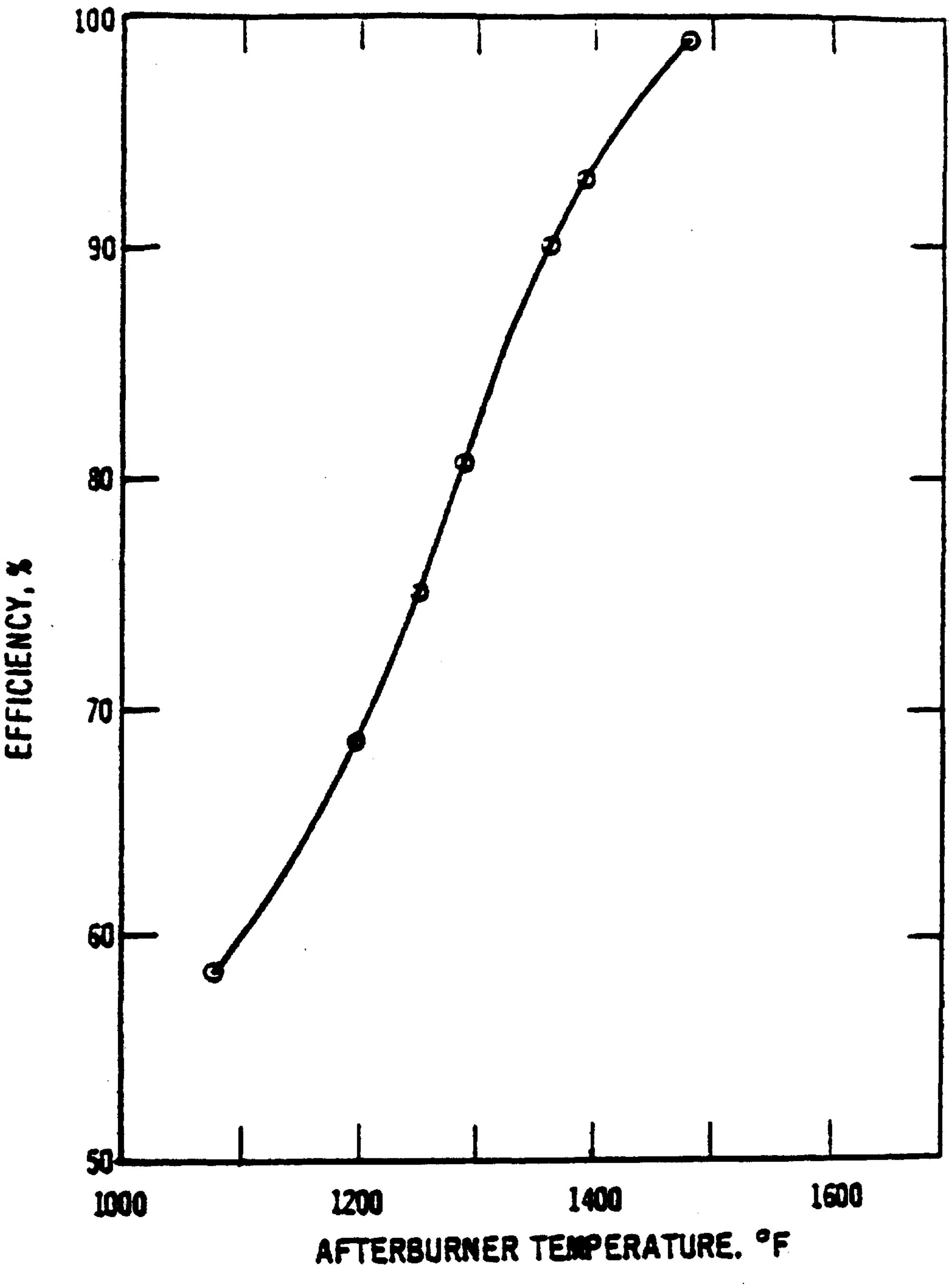
The total hydrocarbon (THC) emission limit is 154 pounds per hour (lb/hr); this limit was met. The facility's operating permit requires 95 percent reduction from the thermal incinerator. During the performance test, the thermal incinerator achieved a destruction efficiency of greater than 95 percent for all three runs (95.4, 95.5, and 97.8); average DRE for the three test runs is 96.2 percent).

The production rate during the performance test was representative of highest VOC loading to the incinerator. During the performance test, the VOC input calculated from coating usage and content was XXX lb/hr [facility requested coating usage not be presented]. By comparison, for the 6 month period for which monitoring data were reviewed, the average VOC loading to the system when all three coaters were operating (calculated as the sum of the average VOC input rate, lb/hr, of each coater) was 80 percent of the amount during the performance test.

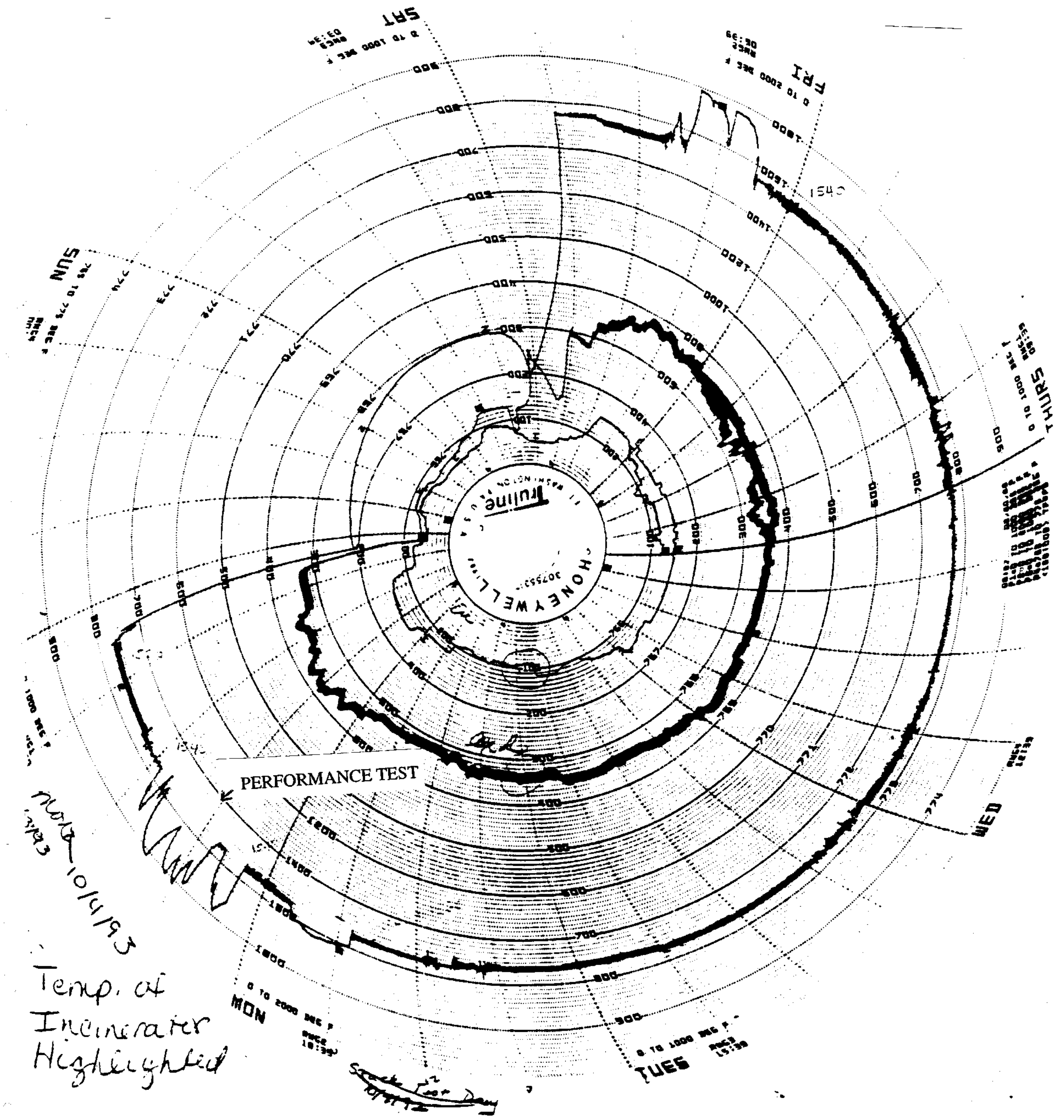
NOTE 1: CO monitoring also is a requirement in the facility's permit; however, for the purposes of this example CAM Plan, CO monitoring was not selected as an indicator. See CAM plan No. A.1b.

NOTE 2: Submittal of proposed data availability is optional; it is not a requirement of a CAM submittal.

NOTE 3: Submittal of a QIP threshold is optional; it is not a requirement of a CAM submittal.



Attachment 1. Direct-flame afterburner efficiency as a function of temperature.
Air Pollution Engineering Manual, Chapter 5 - Control Equipment for Gases and Vapors.



Attachment 2. Temperature chart during October 1993 performance test.

A.1b. THERMAL INCINERATOR FOR VOC CONTROL–FACILITY A

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EXAMPLE COMPLIANCE ASSURANCE MONITORING

Thermal Incinerator for VOC Control: Facility A - Example 1b

I. Background

A. Emissions Unit

Description:	Coater 1, Coater 2, and Coater 3
Identification:	Stack No. XXX/ Ct. YYYYY
Stack designation:	Incinerator
APC Plant ID No.	XXXXX
Facility:	Facility A Anytown, USA

B. Applicable Regulation, Emission Limit, and Monitoring Requirements

Regulation No.:	Permit
Regulated pollutant (PSEU):	VOC
Emission limit:	95 percent reduction
Monitoring requirements in permit:	Continuously monitor chamber temperature Continuously monitor CO concentration

C. Control Technology: Thermal oxidizer

II. Monitoring Approach

The key elements of the monitoring approach, including the indicators to be monitored, indicator ranges, and performance criteria are presented in Table A.1b-1.

Note that this CAM submittal is intended as an example of monitoring the operation of the incinerator and does not address capture efficiency. Capture efficiency is a critical component of the overall control efficiency of the air pollution control system, and indicators of the performance of the capture system should be incorporated into the monitoring approach. However, sufficient information was not available from this case study to include monitoring of the capture system performance.

III. Data Availability [NOTE 1]

The minimum data availability for each semiannual reporting period, defined as the number of hours for which monitoring data are available divided by the number of hours during which the process operated (times 100) will be:

Chamber temperature:	90 percent
Outlet CO concentration:	95 percent

The data availability determination does not include periods of control device start up and shut down. For an hour to be considered a valid hour of monitoring data, a minimum of 45 minutes of data must be available.

TABLE A.1b-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2
I. Indicator	Chamber temperature	Outlet CO concentration
Measurement Approach	The chamber temperature is monitored with a thermocouple.	The CO concentration is measured with a CEMS meeting 40 CFR 60 Appendix B, Performance Specifications.
II. Indicator Range	An excursion is defined as temperature readings less than 1500°F; excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion is defined as a 1-hr average greater than 50 ppm (emission limit); excursions trigger an inspection, corrective action, and a reporting requirement.
QIP Threshold[a]	No more than six excursions below the indicator range in any semiannual reporting period.	No more than 14 excursions above the indicator range in any semiannual reporting period.
III. Performance Criteria A. Data Representativeness[b]	The sensor is located in the incinerator chamber as an integral part of the incinerator design. The minimum tolerance of the thermocouple is ±4°F or ±0.75% (of temperature measured in degrees Celius), whichever is greater. The minimum chart recorder sensitivity (minor division) is 20°F.	The system meets 40 CFR 60 Appendix B, Performance Specification 4 criteria.
B. Verification of Operational Status	Not applicable	Not applicable
C. QA/QC Practices and Criteria[b]	Accuracy of the thermocouple will be verified by a second, or redundant, thermocouple probe inserted into the incinerator chamber with a hand held meter. This validation check will be conducted at least annually. The acceptance criterion is ±30°F.	Calibration drift will be automatically checked every 24 hours by zero air and span gas.
D. Monitoring Frequency	Measured continuously.	CO concentration is measured continuously.
Data Collection Procedure	Recorded continuously on a circular chart recorder.	The average of six 10-second readings are recorded once per minute by the DAS (electronic record).
Averaging Period	No average is taken.	1-hour average of 60 1-minute readings.

[a]The QIP is an optional tool for States; QIP thresholds are not required in the CAM submittal.

[b]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

Note: Capture efficiency is a critical component of the overall control efficiency of the air pollution control system, and indicators of the performance of the capture system should be incorporated into the monitoring approach. However, sufficient information was not available from this case study to include monitoring of the capture system performance.

MONITORING APPROACH JUSTIFICATION

I. Background

This facility performs polyester film coating and paper liner coating with solvent based coatings. Three coaters are operated. Emissions from the three coaters are vented to the thermal incinerator. Emissions from mixing, coating, and drying operations are vented to this incinerator; some mixing vessels can also be vented to other oxidizers. A total of 27 sources are connected to the thermal incinerator.

II. Rationale for Selection of Performance Indicators

The incinerator chamber temperature was selected because it is indicative of the thermal incinerator operation (combustion occurring within the chamber). If the chamber temperature decreases significantly, complete combustion may not occur.

It has been shown that the control efficiency achieved by a thermal incinerator is a function of its operating temperature, or outlet temperature. By maintaining the operating temperature at or above a minimum, a level of control efficiency can be expected to be achieved. Attachment 1 presents information from the literature on incinerator control efficiency as a function of temperature.

The CO concentration at the outlet of the thermal incinerator is an indicator of incomplete combustion. Significant increases in CO indicate that combustion efficiency has decreased and corrective action should be taken.

[Sufficient information regarding bypass of the control device is not available. The damper on the bypass line, or purge line, on each coater must be closed during coating process operation to ensure that the vent stream is routed to the thermal incinerator.]

III. Rationale for Selection of Indicator Ranges

A. Thermal Incinerator Temperature

The selected indicator range for the incinerator chamber temperature is "greater than 1500°F at all times." When an excursion occurs corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. Furthermore, if the duration of a temperature excursion exceeds 10 minutes, the coating line operation will be curtailed. All excursions will be documented and reported. The selected QIP threshold level is six excursions per semiannual reporting period (see NOTE 2). This level is less than 0.05 percent of the process operating time (based on 2,800 operating hours). If the QIP threshold is exceeded in a semiannual reporting period, a QIP will be developed and implemented. This QIP is supported by 6 months of monitoring data following the performance test.

The air pollution control permit issued by the State agency specifies that the incinerator must be designed to operate with a minimum operating temperature of 1500°F measured at the center of the incinerator chamber. Attachment 1 indicates that a thermal incinerator is expected to achieve 95 percent or greater destruction efficiency (DRE) at this temperature. The permit requirement is 95 percent DRE. The incinerator employs a temperature controller that maintains the desired chamber temperature by using a natural gas-fired auxiliary burner; the temperature controller is set to maintain a temperature of at least 1500°F.

Review of historical monitoring data for a 6-month period (July to December 1993) indicates that 1500°F can be maintained on a routine basis with some excursions. The historical monitoring data for temperature indicate that normal loading to the incinerator will result in chamber temperatures of 1500°F and higher loadings to the device will result in periods of higher operating temperatures for short durations, such as during the performance test. The historical monitoring data indicate that the indicator range was exceeded seven times in the 6-month period; two of the excursions were momentary.

The performance test confirms acceptable performance of the incinerator; the incinerator achieved the required DRE of 95 percent. During the performance test, the incinerator was operating with a temperature of at least 1500°F (in the range of 1540° to 1800°F). During the performance tests the incinerator temperature was generally nearer 1700°F than 1500°F. The higher temperatures during the performance test occurred because the facility was operated near the maximum production rate with higher VOC loadings to challenge the incinerator with maximum VOC loading. The higher operating temperatures during the performance test are not the result of a change in operation of the incinerator (i.e., changing the burner set point temperature).

The performance test of the thermal incinerator was conducted in October 1993 using EPA Reference Method 25. Three test runs (1 hour each) were conducted with 11 out of 27 sources operating and venting to the incinerator; this number of operating sources is considered normal. During the performance test, the chamber temperature was measured continuously and recorded on a circular chart (Attachment 2).

The THC emission limit is 154 pounds per hour (lb/hr); this limit was met during the test. The facility's operating permit requires 95 percent reduction from the thermal incinerator. During the performance test, the thermal incinerator achieved a destruction efficiency of greater than 95 percent for all three runs (95.4, 95.5, and 97.8); the average DRE for the three test runs is 96.2 percent. The average outlet CO concentration for each of the three performance test runs was 2.3, 10.2, and 1.6 ppmvd.

The production rate during the performance test was representative of highest VOC loading to the incinerator. During the performance test, the VOC input calculated from coating usage and content was XXX lb/hr [facility requested coating usage not be presented]. By comparison, for the 6-month period for which monitoring data were reviewed, the average VOC loading to the system when all three coaters were operating (calculated as the sum of the average VOC input rate, lb/hr, of each coater) was 80 percent of the amount during the performance test.

B. Outlet CO Concentrations

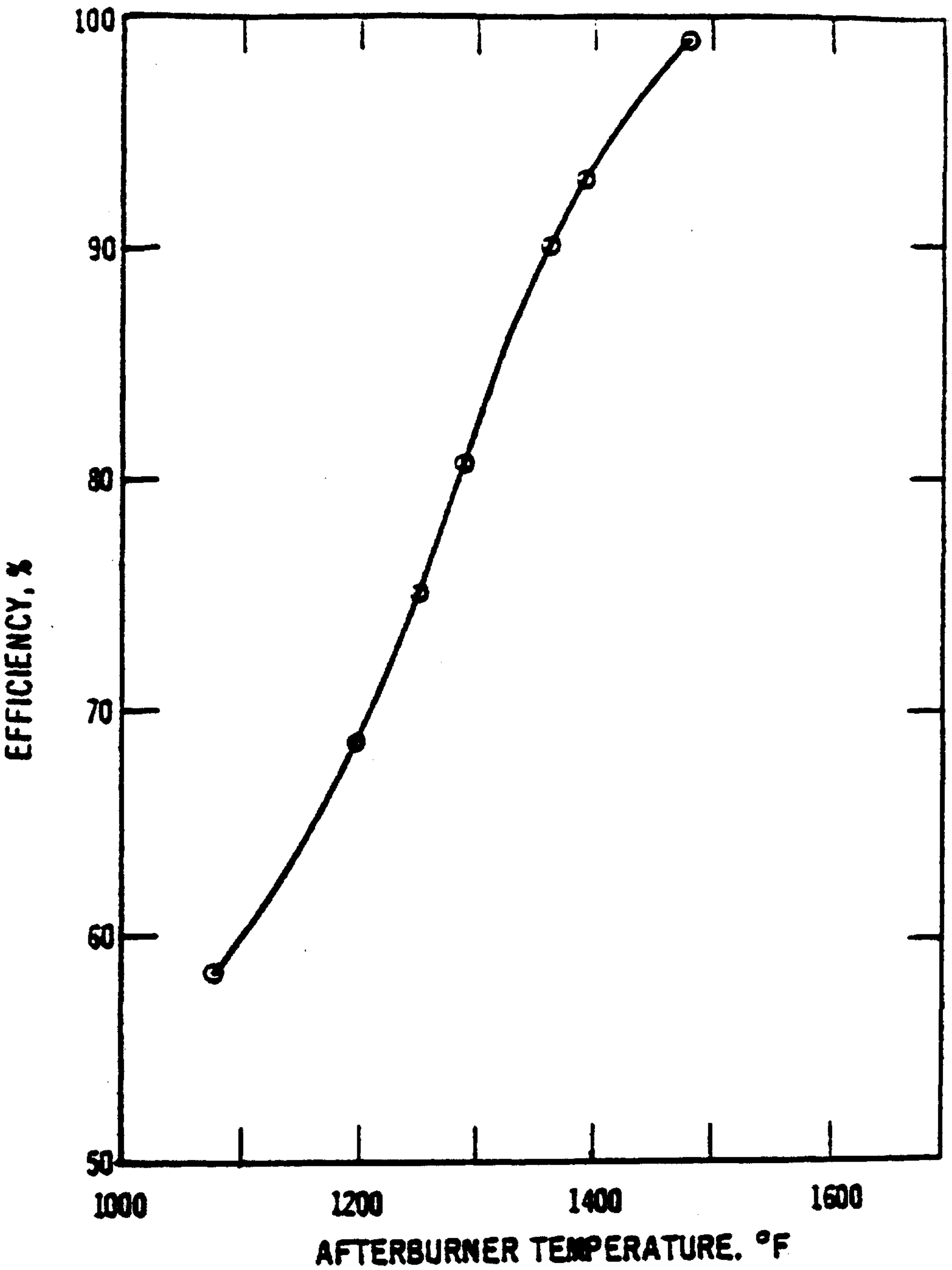
The selected indicator range for the 1-hour average CO concentration is "less than 50 ppmvd, as measured." When an excursion occurs corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported. The selected QIP threshold level is 14 excursions per semiannual reporting period. This level is less than 0.5 percent of the process operating time (based on 2,800 operating hours). If the QIP threshold is exceeded in a semiannual reporting period, a QIP will be developed and implemented. This QIP is supported by 3 months of monitoring data following the performance test.

Review of historical monitoring data for a 3-month period (September through December 1993) indicates that the 50 ppmvd CO concentration limit can be maintained on a routine basis with some excursions. The historical monitoring data indicate that the indicator range was exceeded eight times in the 3-month period. Based upon these historical data, the threshold for excursions is no more than 14 excursions above 50 ppmvd in a 6-month period (i.e., 7 excursions per quarter).

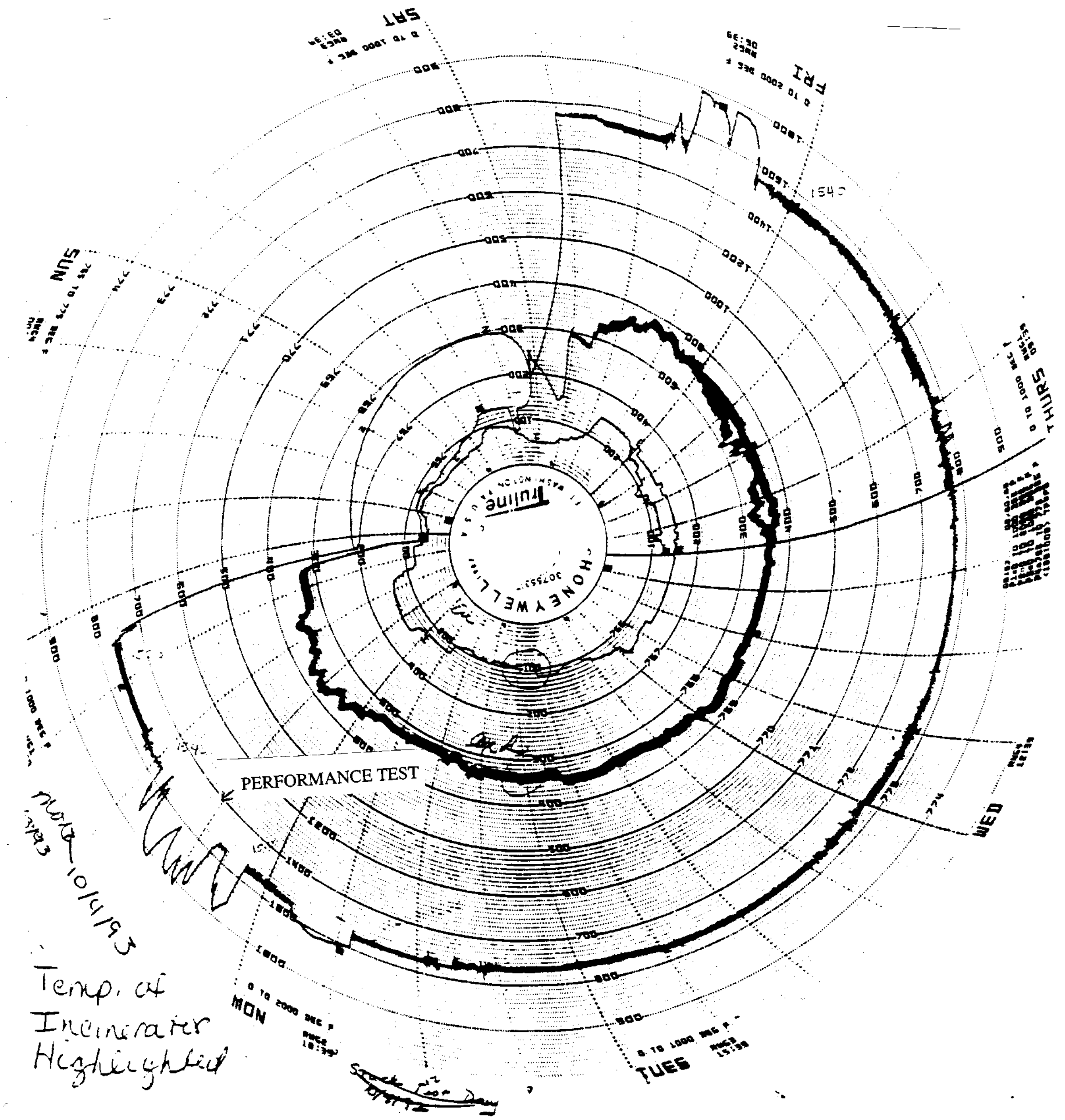
The performance test conducted in October 1993 is discussed above in section III.A. The CO concentrations were well under the 50 ppmvd limit (measured CO) for all three runs during the test.

NOTE 1: Submittal of proposed data availability is optional; it is not a requirement of a CAM submittal.

NOTE 2: Submittal of a QIP Threshold is optional; it is not a requirement of a CAM submittal.



Attachment 1. Direct-flame afterburner efficiency as a function of temperature.
Air Pollution Engineering Manual, Chapter 5 - Control Equipment for Gases and Vapors.



Attachment 2. Temperature chart during October 1993 performance test.

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A.2 VENTURI SCRUBBER FOR PM CONTROL--FACILITY B

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EXAMPLE COMPLIANCE ASSURANCE MONITORING:
VENTURI SCRUBBER FOR PM CONTROL--FACILITY B

I. Background

A. Emissions Unit

Description:	FCCU catalyst regenerator
Identification:	
Facility:	Facility B Anytown, USA

B. Applicable Regulation, Emission Limits, and Monitoring Requirements

Regulation No.:	40 CFR 60 Subpart J
Regulated pollutant:	Particulate matter
Emission limit (particulate matter):	1 lb/1,000 lb coke burned
Monitoring requirements:	Coke burn rate, air blower rate, number of venturis online (permit) [Note: Although Subpart J requires a COMS, this alternate monitoring approach was approved by the State permitting authority and is reflected in the facility's permit.]

C. Control Technology:

Four parallel venturi scrubbers

II. Monitoring Approach

The key elements of the monitoring approach for particulate matter, including the indicators to be monitored, indicator ranges, and performance criteria are presented in Table A.2-1.

TABLE A.2-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2	Indicator No. 3
I. Indicator	Liquid to gas ratio	Scrubber exhaust temperature	Coke burn rate
Measurement Approach	Water flow–magnetic flowmeter. Air rate–venturi flowmeter. L/G calculated.	Scrubber exhaust temperature measured using a thermocouple.	Calculated using NSPS (§ 60.106) equation.
II. Indicator Range[a]	An excursion is defined as a 3-hour average liquid to gas ratio less than 8. Excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion is defined as a 3-hour average scrubber exhaust temperature greater than 165°F. Excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion is defined as a 3-hour average coke burn rate greater than 56,000 lb/hr. Excursions trigger an inspection, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness[b]	The magnetic flow meter (minimum accuracy of ±1.0% of flow rate) is located in the water inlet line. The venturi flowmeter (minimum accuracy of ±0.75% of flow rate) is located in the gas inlet duct.	Thermocouple located at scrubber exhaust with a minimum accuracy of ±3°F.	Analyzers and monitors are located in the regenerator inlet and exhaust duct.
B. Verification of Operational Status	Not applicable	Not applicable	Not applicable
C. QA/QC Practices	Magnetic water flowmeter and venturi flowmeter–calibrated once/ 6 months.	Thermocouple–calibrated once/ 6 months.	Gas analyzers: per 60.13 and Appendix B of 40 CFR 60. Flowmeter, thermocouple, and pressure indicator–calibrated once/ 6 months.
D. Monitoring Frequency	Water flow and air rate are measured continuously.	Temperature is measured continuously.	O_2, CO, CO_2, air rate, off gas temperature and pressure are measured continuously.
Data Collection Procedure	L/G is calculated and recorded each minute.	Temperature is recorded each minute.	A coke burn rate is calculated and recorded each minute.
Averaging Period	3-hour average.	3-hour average.	3-hour average.

[a]An excursion of any single indicator triggers an inspection, corrective action, and a reporting requirement.
[b]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

JUSTIFICATION

I. Background

The pollutant specific emissions unit is particulate matter from the catalyst regenerator of a fluid catalytic cracking unit (FCCU). The catalyst regenerator is equipped with a wet gas scrubber. The catalyst regenerator exhaust gases pass through four parallel venturi scrubbers. These scrubbers are the primary control devices for particulate matter emissions. After passing through the scrubbers, the off gases pass through a separating vessel and a spray grid prior to being vented to the atmosphere. The emission unit is regulated under 40 CFR 60 Subpart J--NSPS for petroleum refineries. The monitoring approach is reflected as a specific permit condition in the air permit. Based on the pollutant specific emissions unit design, bypass of the control device is not possible.

II. Rationale for Selection of Performance Indicators

The following parameters will be monitored:

- Liquid-to-gas (L/G) ratio;
- Scrubber exhaust temperature; and
- Coke burn rate.

The licensor of the wet scrubber provided a graph relating the number of operating scrubbers required to maintain the design liquid to gas ratio, to the FCCU regenerator air blower rate. The regenerator air rate and the number of venturis in operation are an indirect measure of liquid to gas ratio, which is an indicator of scrubber performance. The regenerator air rate and the number of venturis in operation are monitored to ensure that these limitations are met.

Although the air permit only requires monitoring of coke burn rate, air blower rate, and number of venturis online, L/G ratio and scrubber exhaust temperature were added to the monitoring approach in early 1997 as further indicators of control device performance. The L/G ratio is determined by measuring scrubber water flow rate and comparing it to the regenerator air blower rate. In addition, the scrubber temperature is monitored downstream of the spray grid. The scrubber exhaust gas temperature was selected because it is indicative of scrubber operation and adequate water flow. With the scrubber water off, the scrubber exhaust temperature would be noticeably higher.

The coke burn rate is an indication of the PM loading to the scrubber.

III. Rationale for Selection of Indicator Ranges

As mentioned above, a graph relating the regenerator air blower rate to the number of venturis necessary to maintain the design L/G ratio, was provided by the licensor of the scrubber. This graph, presented in Figure A.2-1, shows that at regenerator air rates of less than 100 kscfm at least two scrubbers must be operating to maintain the design L/G ratio. At regenerator air rates of greater than or equal to 100 kscfm to less than 136 kscfm, at least three scrubbers must be operating. At air rates of greater than 136 kscfm all four scrubbers must be operating. The facility monitors the regenerator air rate and the number of venturis in operation to ensure that these limitations are met.

The indicator range for L/G ratio is based on results of a January 1996 performance test and historical data. Three 1-hr test runs were conducted and the average measured PM emissions were

0.78 lb PM/1,000 lb coke burned, which is below the 1 lb/1,000 lb PM emission limit. During the performance test, L/G ratio was measured and recorded continuously, concurrent with each of the 1-hour test runs. The average L/G ratio for the three 1-hour test runs was 7.1. Hourly L/G ratio data for a 3-month period (October through December 1996) following the performance test were reduced to three-hour averages and evaluated to determine whether the L/G ratio during normal operation was above the minimum level selected based on the January 1996 performance test demonstrating compliance. Figure A.2-2 graphically presents these data. During the 3-month period, the 3-hour average L/G ratio ranged from 8.5 to 14.9, and averaged 11.4, showing consistent operation at a L/G ratio above the level where compliance was demonstrated. The indicator range selected is a minimum L/G ratio of 8. No QIP threshold has been established.

The maximum scrubber outlet temperature was selected based on data obtained during a performance test conducted at the facility and historical data. The scrubber exhaust gas temperatures during the test averaged 144°F. Hourly scrubber outlet temperature data over a 3-month period (October through December 1996) were reduced to 3-hour averages and are shown in Figure A.2-3. Scrubber outlet temperatures during this 3-month period generally ranged from 132° to 150°F, and averaged 137.5°F. As seen in Figure A.2-3, a significant drop in temperature occurred over a 24-hour period. During this 24-hour period, the thermocouple was reading ambient temperatures because it had been removed from its housing for testing purposes. These ambient readings were not included in the evaluation of the data.

The selected indicator range for scrubber outlet temperature is less than 165°F. This range was selected by adding a 15 percent buffer to the average temperature demonstrated during the performance test (144°F) to account for variability among the data; the 3-months of monitoring data indicate that this temperature operating range can be achieved consistently. No lower action level is necessary. No QIP threshold has been established.

To date, compliance has been demonstrated at a coke burn rate of 55.5 thousand (M) lb/hr. The performance test data obtained in January of 1996 indicate that while operating at a coke burn rate of 55.5 Mlb/hr (average of three 1-hour runs) the emissions unit was in compliance with the PM emission limit. The indicator range is established as less than 56 Mlb/hr. If operation at a higher coke burn rate is planned, additional testing will be conducted to demonstrate compliance with all emission limitations at the higher burn rate. No QIP threshold has been set for this indicator.

When an excursion of any of the indicator ranges occurs corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported.

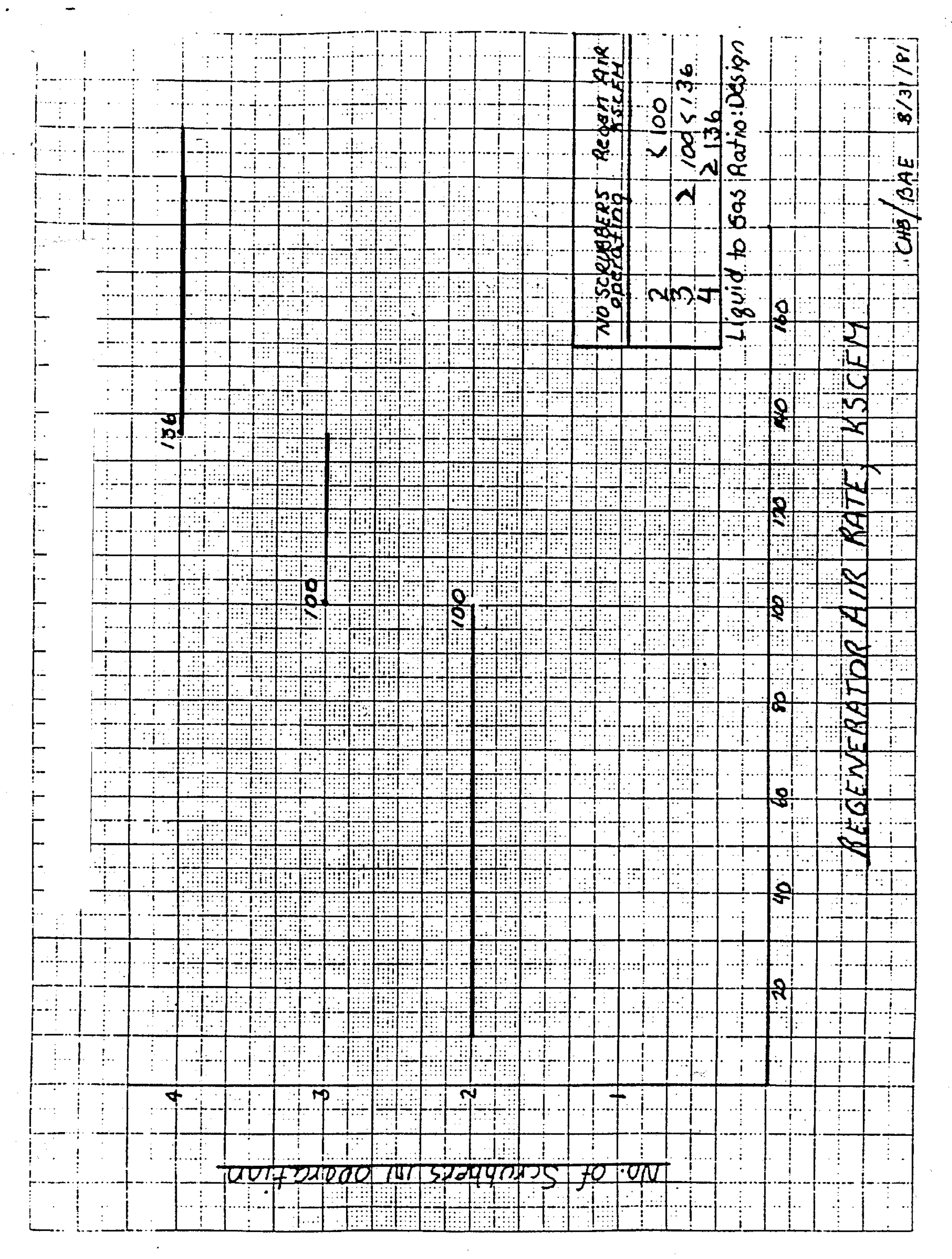

Figure A.2-1. Regenerator Air Rate vs. Number of Scrubbers in Operation.

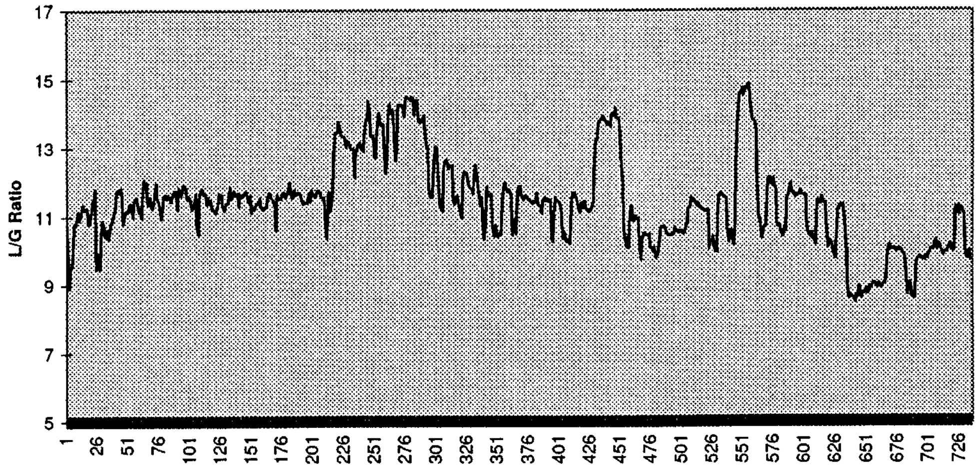

Figure A.2-2. Liquid to Gas Ratios (3-hour averages) for October-December 1996.

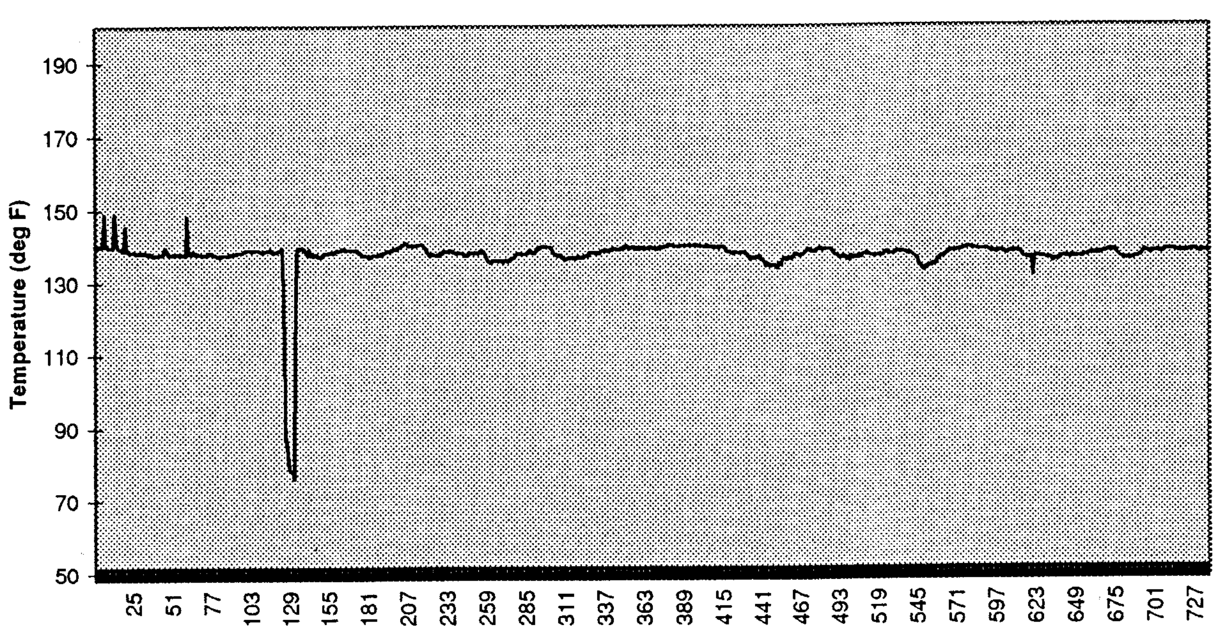

Figure A.2-3. Scrubber Outlet Temperatures (3-hour averages) for October-December 1996.

A.3 CONDENSER FOR VOC CONTROL--FACILITY C

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EXAMPLE COMPLIANCE ASSURANCE MONITORING:
CONDENSER FOR VOC CONTROL--FACILITY C

I. Background

A. Emissions Unit

Description:	Storage tank
Identification:	T-200-7
Facility:	Facility C Anytown, USA

B. Applicable Regulation, Emission Limit, and Monitoring Requirements

Regulation No.:	40 CFR 63, Subpart G [Note 1]
Regulated pollutant (PSEU):	VOC
Emission limit:	95 percent reduction
Monitoring requirements:	Continuously monitor outlet vent temperature.

C. Control Technology: Two refrigerated condensers

II. Monitoring Approach

The key elements of the monitoring approach for VOC, including the indicators to be monitored, indicator ranges, and performance criteria, are presented in Table A.3-1.

TABLE A.3-1. MONITORING APPROACH

I. Indicator	Outlet vent temperature
Measurement Approach	The outlet vent temperature is monitored with a thermocouple.
II. Indicator Range	An excursion is defined as a daily average condenser outlet temperature of greater than -60°F. Excursions trigger an inspection, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness[a]	The sensor is installed at the outlet vent of the condenser sufficiently close (within 2 feet) to the condenser to provide a representative outlet temperature. The minimum accuracy is ±4°F.
B. Verification of Operational Status	N/A
C. Quality Assurance and Control Practices	Annual calibration is performed: (1) on the thermocouple by measuring the voltage generated and (2) on the transmitter by attaching a calibrator to the input of the transmitter, generating a voltage, and checking the corresponding output of the transmitter.
D. Monitoring Frequency	Temperature is measured continuously.
Data Collection Procedures	15-minute data points are sent to the DCS.
Averaging Period	Hourly averages of four 15-minute temperature readings are calculated for tracking of the outlet temperature. A daily average of all 15-minute temperature readings is recorded for compliance purposes.

[a]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

JUSTIFICATION

I. Background

The pollutant specific emissions unit (PSEU) is the propionaldehyde storage tank (fixed roof). The storage tank capacity is 173,000 gallons. Emissions from the propionaldehyde storage tank are vented to two refrigerated condensers. The propionaldehyde emissions are vented to one of the two condensers at all times; one condenser is online while the other is defrosting on a 4-hour cycle. The condensers are used to reduce VOC emissions. Maximum uncontrolled emissions from this tank are estimated to vary from 154 lb/hr in the winter to 175 lb/hr in the summer. Based on the design of the PSEU, bypass of the control device cannot occur.

II. Rationale for Selection of Performance Indicators

Reduction of the emissions from storage tanks is required; these emissions are reduced with a refrigerated condenser. Monitoring of the outlet vent temperature indicates the level of condensation occurring in the condenser. Outlet vent temperature is a good indicator of the operation of the condenser because the concentration of the outlet vent stream can be determined based on temperature of the stream and vapor pressure equilibrium data. To achieve the outlet concentration, the outlet vent temperature must be maintained below a certain level (i.e., a maximum temperature). If the outlet vent temperature increases above the maximum temperature limit, condensation of the components to the level expected will not occur. An increase in outlet vent temperature indicates a reduction of performance of the condenser.

III. Rationale for Selection of Indicator Ranges

The indicator range was established based upon engineering calculations and historical monitoring data. The emission standard requires a 95 percent reduction efficiency. Maximum emission conditions for this tank are during tank loading at the highest ambient temperature the tank experiences (summer conditions). Engineering calculations were used to establish the required condenser vent temperature to achieve a 95 percent reduction under these conditions. The temperature of the vapor in the tank and at the inlet to the condenser were assumed to be ambient. The tank vapor was assumed to be at atmospheric pressure. The concentration of propionaldehyde in the vapor (calculated based on the vapor pressure of propionaldehyde at ambient conditions) and the fill rate during tank loading were used to determine the maximum uncontrolled emission rate. The emissions at a 95 percent reduction efficiency were calculated, and the corresponding temperature needed to achieve the allowed propionaldehyde concentration (vapor pressure) was determined. The maximum allowed outlet vent temperature was determined to be 7°F. The outlet vent temperature must be maintained at this temperature or lower to achieve 95 percent reduction in the summer. Under winter conditions, a 95 percent reduction is achieved at an outlet vent temperature of -50°F. No lower limit to the indicator range is necessary. No performance test has been performed on the control device, and no test is planned.

In addition to the engineering calculations performed, monitoring data were reviewed to determine whether the condenser temperature could be maintained during normal operation of the storage tank and condenser. Six weeks of monitoring data for outlet vent temperatures (April 23 through June 3, 1997) have been collected and reviewed. These outlet vent temperature data include hourly average temperatures for periods when the condensers were online (i.e., offline cycles, lasting 4 hours each, are not included on the graph). Figure A.3-1 presents these data. During the 6-week period, the hourly average outlet vent temperatures while online ranged from-85° to -64°F. Daily average temperatures while online for the 6-week period ranged from-80° to -78°F. The daily average temperatures are shown in Figure A.3-2. The condenser was consistently operating with both hourly and daily average outlet vent temperatures below the maximum temperature determined in calculations. Data for 15-minute temperature readings were also available for 4 days for both the online and offline cycles for both condensers. Two days of 15-minute readings are shown in Figure A.3-3, and 4 days of 15-minute readings are shown in Figure A.3-4. The 15-minute readings range from approximately -89° to -77°F.

The selected indicator range is "a daily average temperature of less than -60 °F." This range was selected by taking the highest daily average observed temperature value (-78°F) during the 6-week period for which monitoring data were available (April through June) and adding a 20 percent buffer. At the selected indicator range, the condenser will still be operating well below temperature required to achieve compliance (-50°F). When an excursion occurs, corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported. No QIP threshold has been selected.

NOTE 1: This source is exempt from CAM because 40CFR63, Subpart G was proposed after November 15, 1990. Nonetheless, a CAM plan was prepared from information and data obtained from this facility as an example of a monitoring approach and the selection of an indicator range.

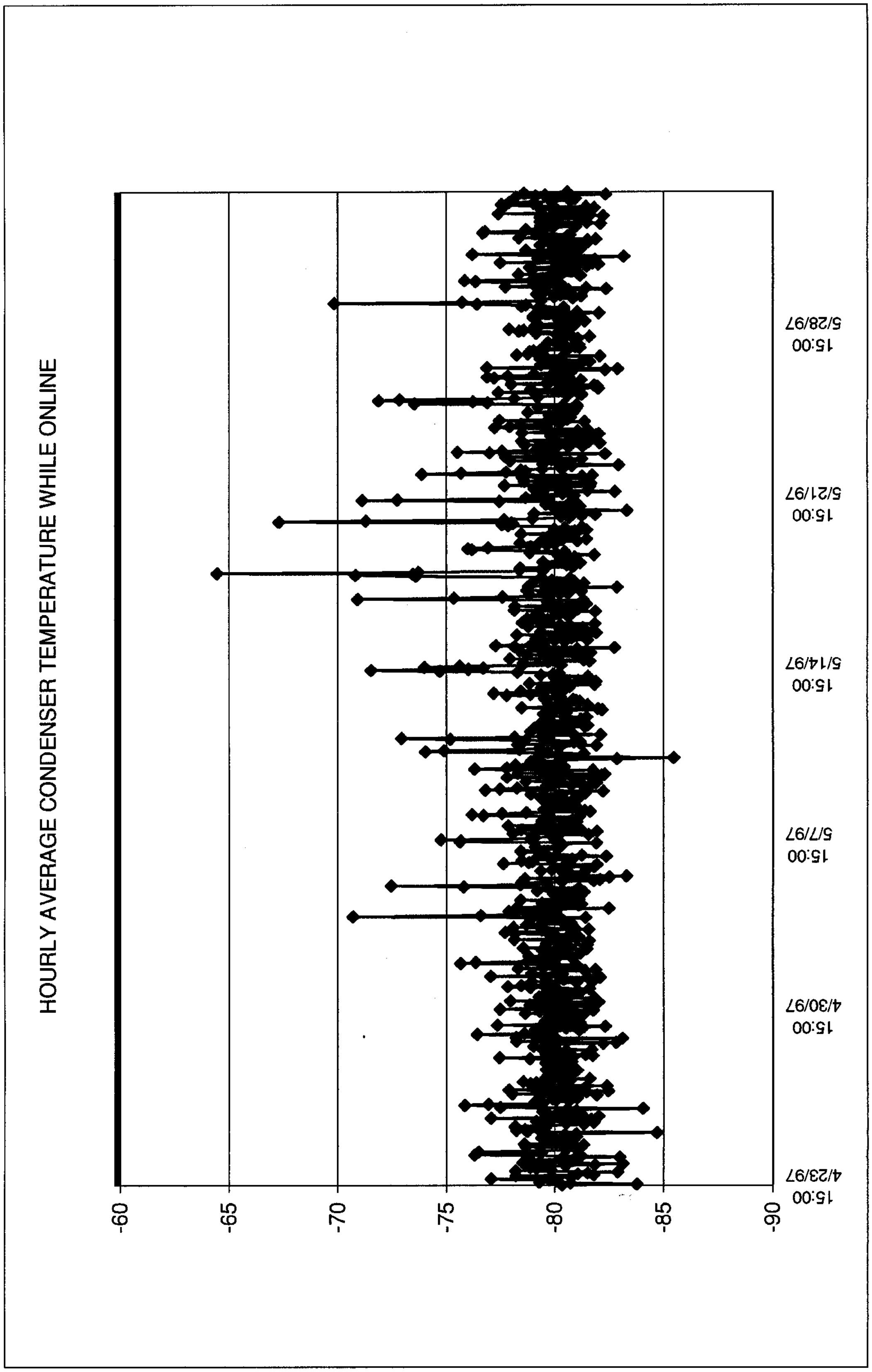
HOURLY AVERAGE CONDENSER TEMPERATURE WHILE ONLINE
-60
-65
-70
-75
-80
-85
-90
15:00 4/23/97
15:00 4/30/97
15:00 5/7/97
15:00 5/14/97
15:00 5/21/97
15:00 5/28/97

Figure A.3-1.

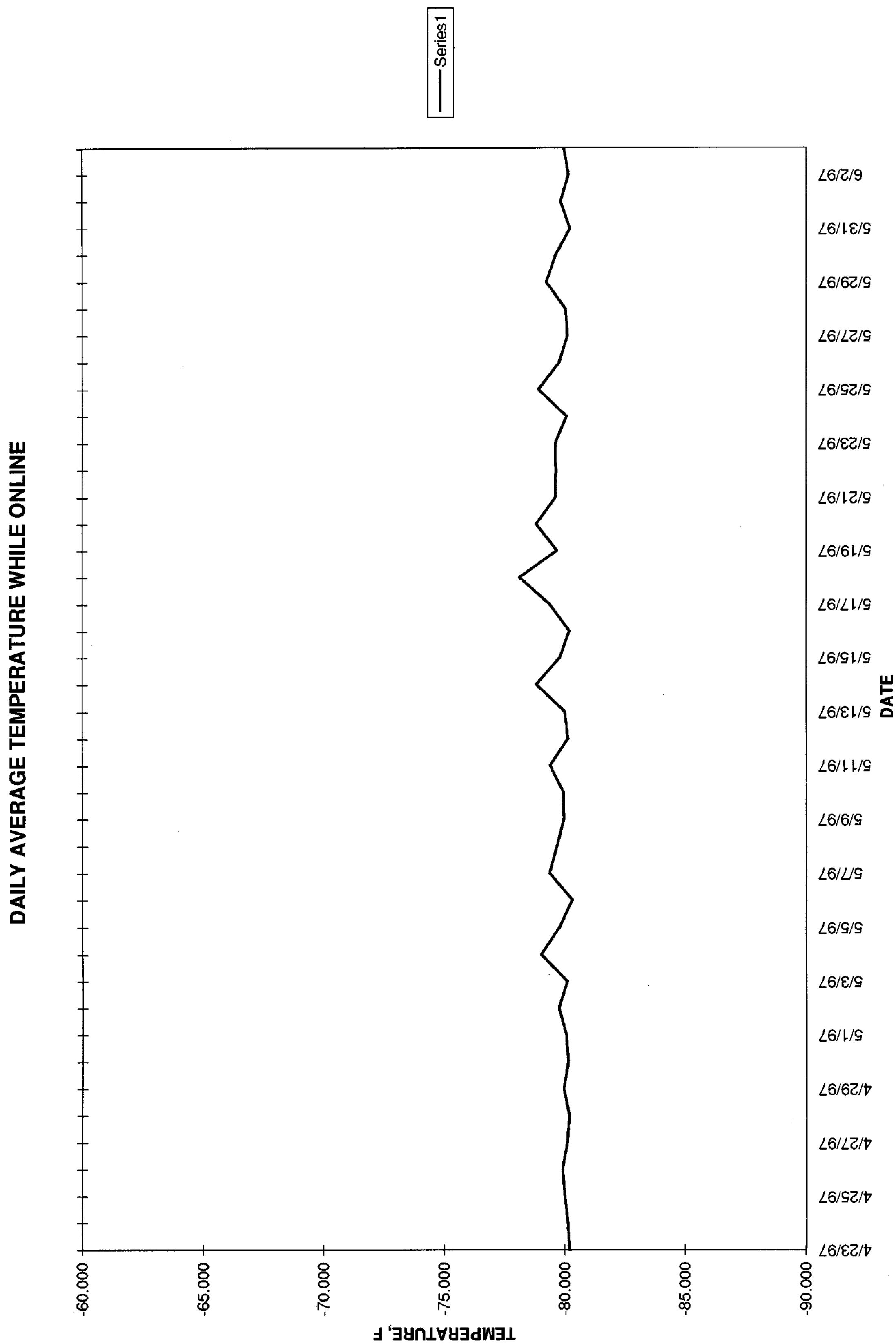
DAILY AVERAGE TEMPERATURE WHILE ONLINE
Series1
TEMPERATURE, F
-60.000
-65.000
-70.000
-75.000
-80.000
-85.000
-90.000
DATE
4/23/97
4/25/97
4/27/97
4/29/97
5/1/97
5/3/97
5/5/97
5/7/97
5/9/97
5/11/97
5/13/97
5/15/97
5/17/97
5/19/97
5/21/97
5/23/97
5/25/97
5/27/97
5/29/97
5/31/97
6/2/97

Figure A.3-2

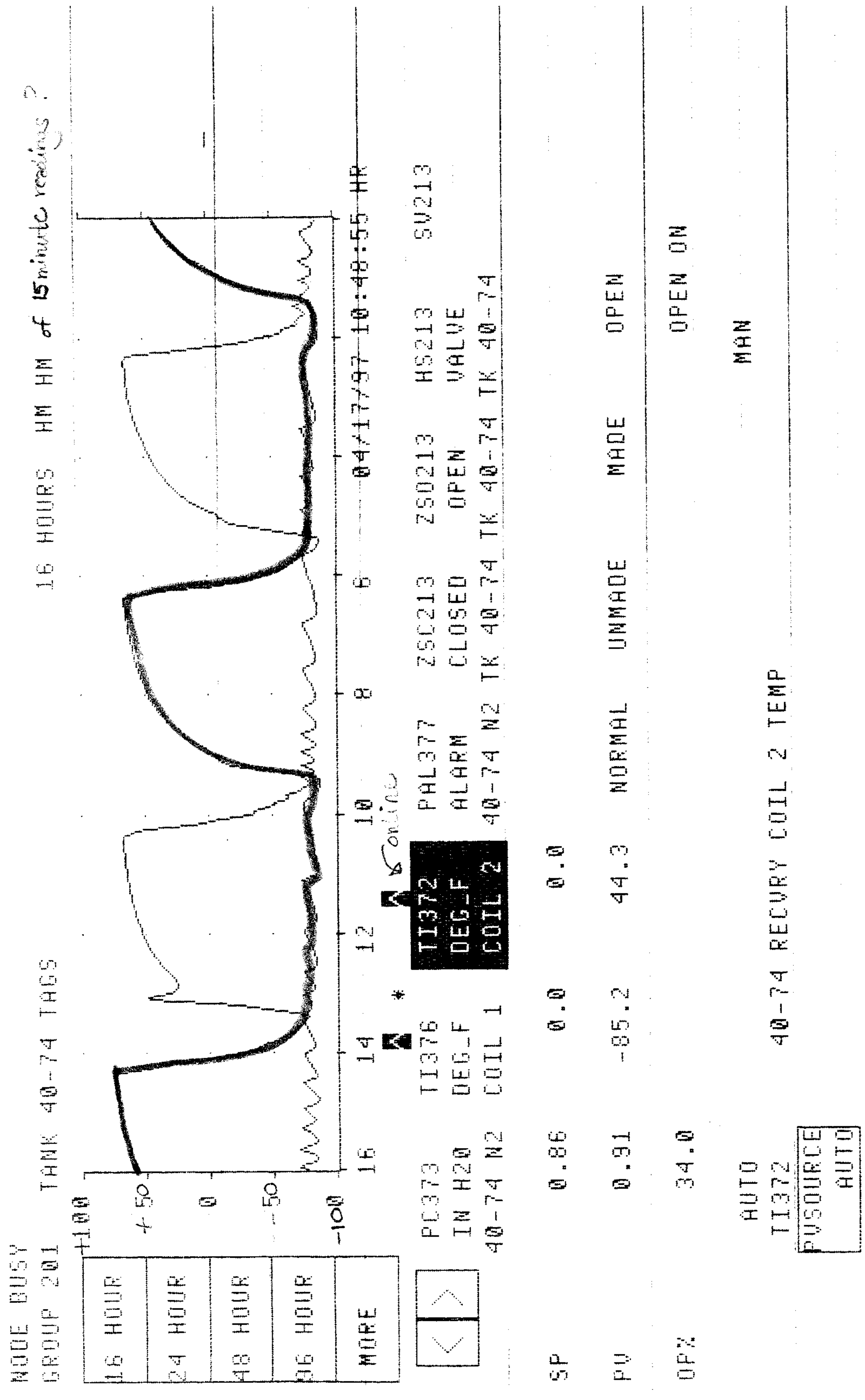
NODE BUSY
GROUP 201
TANK 40-74 TAGS
16 HOURS HM HM of 15 minute readings ?
17 Apr 97 10:49:39 2
16 HOUR
24 HOUR
48 HOUR
96 HOUR
MORE
+100
+50
0
-50
-100
16
14
12
10
8
6
04/17/97 10:48:55 HR
online
PC373 IN H2O 40-74 N2
TI376 DEG_F COIL 1
TI372 DEG_F COIL 2
PAL377 ALARM 40-74 N2
ZSC213 CLOSED TK 40-74
ZSO213 OPEN TK 40-74
HS213 VALVE TK 40-74
SV213
SP 0.86 0.0 0.0
PV 0.91 -85.2 44.3 NORMAL UNMADE MADE OPEN
OP% 34.0
OPEN ON
AUTO
MAN
TI372
40-74 RECVRY COIL 2 TEMP
PVSOURCE AUTO

Figure A.3-3.

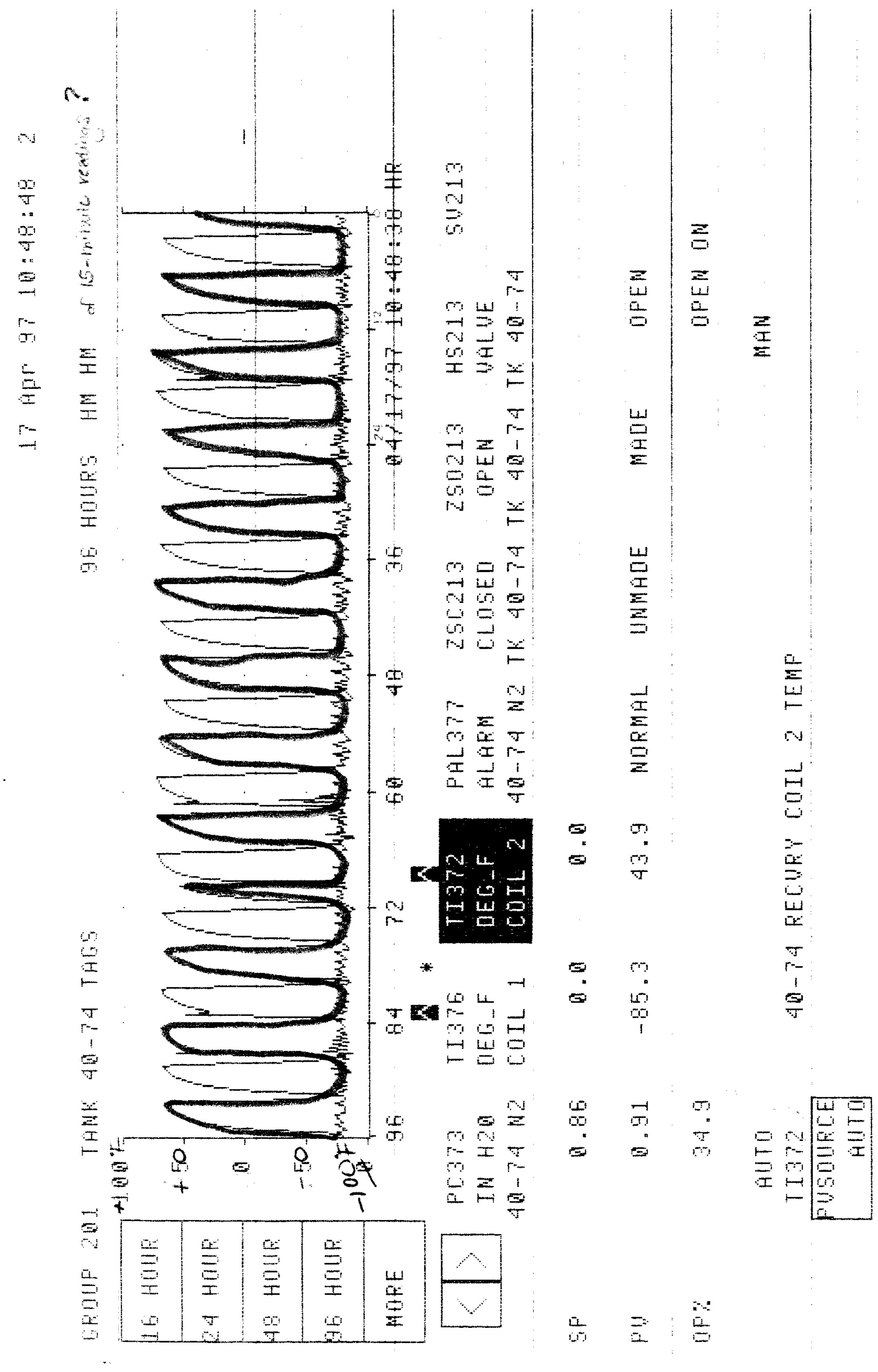
GROUP 201 TANK 40-74 TAGS
96 HOURS HM HM
17 Apr 97 10:48:48 2
of 15-minute readings ?
16 HOUR
24 HOUR
48 HOUR
96 HOUR
MORE
+100%
+50
0
-50
-100%
96 84 72 60 48 36 24 12 0 HR
04/17/97 10:48:30
PC373 IN H2O 40-74 N2
TI376 DEG_F COIL 1
TI372 DEG_F COIL 2
PAL377 ALARM 40-74 N2
ZSC213 CLOSED TK 40-74
ZSO213 OPEN TK 40-74
HS213 VALVE TK 40-74
SV213
SP 0.86 0.0 0.0
PV 0.91 -85.3 43.9 NORMAL UNMADE MADE OPEN
OP% 34.9 OPEN ON
AUTO MAN
TI372 40-74 RECVRY COIL 2 TEMP
PVSOURCE AUTO

Figure A.3-4.

A.4 SCRUBBER FOR VOC CONTROL--FACILITY D

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EXAMPLE COMPLIANCE ASSURANCE MONITORING:
SCRUBBER FOR VOC CONTROL--FACILITY D

I. Background

A. Emissions Unit

Description:	Process tanks
Identification:	B-352-1, Vent A
Facility:	Facility D Anytown, USA

B. Applicable Regulation, Emission Limit and Monitoring Requirements

Regulation No.:	Permit
Regulated pollutant (PSEU)	VOC
Emission limit:	99 percent reduction
Monitoring requirements:	Continuously monitor water flow rate.

C. Control Technology: Packed bed scrubber

II. Monitoring Approach

The key elements of the monitoring approach for VOC, including the indicators to be monitored, indicator ranges, and performance criteria, are presented in Table A.4-1.

TABLE A.4-1. MONITORING APPROACH

	Permit Indicator No. 1
I. Indicator	Water flow rate
Measurement Approach	The water flow rate is monitored with an orifice plate and differential pressure gauge.
II. Indicator Range	An excursion is defined as a daily average scrubber water flow rate of less than 1.2 gal/min. Excursions trigger an inspection, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness[a]	The orifice plate is installed in the scrubber water inlet line. The minimum accuracy is ± 0.05 gal/min.
B. Verification of Operational Status	NA
C. Quality Assurance and Control Practices	Weekly zero and quarterly upscale pressure check of transmitter.
D. Monitoring Frequency	Measured continuously.
Data Collection Procedures	Recorded once per minute.
Averaging Period	Hourly averages of 60 1-minute flow rates are calculated. A daily average of all hourly readings is calculated and recorded.

[a]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

JUSTIFICATION

I. Background

The PSEU includes the tanks in the acetic anhydride department. Emissions from seven tanks are vented to a packed bed water scrubber. Six of these tanks are batch filled and one is continuously filled. The scrubber is used to reduce VOC emissions. Maximum emissions from these tanks are 39 lb/hr. Based on the PSEU design, bypass of the control device is not possible.

II. Rationale for Selection of Performance Indicators

The emissions from the process tanks are controlled using a packed bed water scrubber using once-through water. The performance indicator selected is liquid flow to the scrubber. To achieve the required emission reduction, a minimum water flow rate must be supplied to absorb the given amount of VOC in the gas stream, given the size of the tower and height of the packed bed. The L/G ratio is a key operating parameter of the scrubber. If the L/G ratio decreases belowz the minimum, sufficient mass transfer of the pollutant from the gas phase to the liquid phase will not occur. The minimum liquid flow required to maintain the proper L/G ratio at the maximum gas flow and vapor loading through the scrubber can be determined. Maintaining this minimum liquid flow, even during periods of reduced gas flow, will ensure the required L/G ratio is achieved at all times.

III. Rationale for Selection of Indicator Ranges

The minimum water flow is based on engineering calculations using ASPEN® programming and historical data. Computer simulation (modeling) of the scrubber system was performed for the maximum gas flow rate and VOC loading to the scrubber; the water flow rate necessary for achieving control at this gas flow rate was determined. The scrubber was modeled using an equilibrium-based distillation method and two ideal stages were assumed. Ideal behavior of the gas phase was assumed; liquid phase activity coefficients were estimated from an in-house vapor-liquid equilibria data base (parameters regressed from actual vapor-liquid equilibria data and UNIFAC) using the Wilson equations for binary systems. The minimum water flow rate to the scrubber (calculated based on maximum VOC emissions and gas flow rate) was determined to be 1.1 gal/min. The water flow rate to the scrubber must be maintained at this level or higher to achieve 99 percent emission reduction.

Monitoring data were reviewed to determine the minimum scrubber water flow rate maintained during normal operation of the process tanks and scrubber. Daily average data for a 60-day period (January 17 through March 17, 1997) were reviewed. The daily average flow rate ranges from 1.18 to 1.39 gal/min with 95 percent of the values equal to or greater than 1.2 gal/min; if values greater than 1.15 are rounded to 1.2, then 100 percent of the daily averages are equal to or greater than 1.2 gal/min. Attachment 1 lists the daily average values for the 60-day period. Hourly average data for a 30-day period (February 17 through March 17) also were reviewed. The hourly averages for this period range from 1.19 to 1.21. The scrubber has been consistently operated with both the hourly and daily average water flow rate equal to or greater than 1.2 gal/min.

The selected indicator range is a minimum daily average water flow rate of 1.2 gal/min (defined as greater than 1.15 gal/min). When an excursion occurs corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported. The indicator range was selected by establishing the excursion level at the minimum water flow rate that has been established as the operational level and has been consistently maintained at all times as indicated by 2 months of monitoring data. This water flow rate is above the minimum level (1.1 gal/min) necessary to achieve compliance during maximum gas flow and VOC loading to the scrubber, as established through modeling. A daily average, rather than an hourly average, was selected for the indicator range because the historical data indicate that the flow rate is very constant with little hourly variation. Consequently, the daily average is a sufficient indicator of performance. No performance test has been conducted on the scrubber.

Attachment 1.
Daily average water flow to Vent A scrubber in gal/min.

DATE	TIME	32FC80
01/17/97	0:00	1.183
01/18/97	0:00	1.392
19/97	0:00	1.211
01/20/97	0:00	1.200
01/21/97	0:00	1.200
01/22/97	0:00	1.200
01/23/97	0:00	1.200
01/24/97	0:00	1.200
01/25/97	0:00	1.200
01/26/97	0:00	1.200
01/27/97	0:00	1.200
01/28/97	0:00	1.200
01/29/97	0:00	1.200
01/30/97	0:00	1.200
01/31/97	0:00	1.200
02/01/97	0:00	1.200
02/02/97	0:00	1.200
02/03/97	0:00	1.200
02/04/97	0:00	1.200
02/05/97	0:00	1.200
02/06/97	0:00	1.200
02/07/97	0:00	1.200
02/08/97	0:00	1.200
02/09/97	0:00	1.200
02/10/97	0:00	1.200
02/11/97	0:00	1.200
02/12/97	0:00	1.200
13/97	0:00	1.200
02/14/97	0:00	1.200
02/15/97	0:00	1.200
02/16/97	0:00	1.200
02/17/97	0:00	1.200
02/18/97	0:00	1.200
02/19/97	0:00	1.200
02/20/97	0:00	1.200
02/21/97	0:00	1.200
02/22/97	0:00	1.200
02/23/97	0:00	1.200
02/24/97	0:00	1.199
02/25/97	0:00	1.200
02/26/97	0:00	1.200
02/27/97	0:00	1.200
02/28/97	0:00	1.200
03/01/97	0:00	1.200
03/02/97	0:00	1.200
03/03/97	0:00	1.200
03/04/97	0:00	1.200
03/05/97	0:00	1.200
03/06/97	0:00	1.200
03/07/97	0:00	1.200
03/08/97	0:00	1.200
03/09/97	0:00	1.200
0/97	0:00	1.200
03/11/97	0:00	1.200
03/12/97	0:00	1.200
03/13/97	0:00	1.200
03/14/97	0:00	1.199
03/15/97	0:00	1.200
03/16/97	0:00	1.200
03/17/97	0:00	1.200

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A.4b PACKED BED SCRUBBER FOR VOC CONTROL OF A BATCH PROCESS – FACILITY Q

EXAMPLE COMPLIANCE ASSURANCE MONITORING:
PACKED BED SCRUBBER FOR VOC CONTROL – FACILITY Q

I. Background

A. Emissions Unit

Description:	Batch mixers and tanks used in a chemical process
Identification:	Scrubber B-67-2
Facility:	Facility Q Anytown, USA

B. Applicable Regulation, Emissions Limit, and Monitoring Requirements

Regulation:	Permit, State regulation
Emissions limit:	
VOC:	3.6 pounds per hour
Monitoring requirements:	Inlet water flow, acetic acid concentration in scrubber underflow

C. Control Technology: Packed bed scrubber

II. Monitoring Approach

The key elements of the monitoring approach for VOC are presented in Table A.4b-1. The selected indicators of performance are the scrubber inlet water flow rate and the acetic acid concentration in the scrubber water underflow. The scrubber inlet water flow rate is measured continuously and recorded twice daily. The scrubber water underflow is sampled twice daily; the acetic acid concentration of each sample is determined by titration.

TABLE A.4b-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2
I. Indicator	Scrubber inlet water flow rate.	Acetic acid concentration in underflow.
Measurement Approach	The scrubber inlet water flow rate is measured using a radiometer.	A sample of the underflow is taken and the acetic acid concentration determined by titration.
II. Indicator Range	An excursion is defined as any operating condition where the scrubber inlet water flow rate is less than 4 gpm. An excursion will trigger an investigation of the occurrence, corrective action, and a reporting requirement.	An excursion is defined as any operating condition where the underflow acetic acid concentration is greater than 10 percent. An excursion will trigger an investigation of the occurrence, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness	The scrubber inlet water flow rate is measured using a variable area flow meter (radiometer) located in the scrubber water inlet line. The minimum acceptable accuracy of the meter is ±5 percent of the measured value and the range is 0 to 15 gpm.	The acetic acid concentration in the scrubber water effluent is measured by titrating a water sample extracted from the scrubber underflow.
B. Verification of Operational Status	NA	NA
C. Quality Assurance and Control Practices	Annual calibration and cleaning of radiometer. Acceptance criteria: ±5 percent of the measured value.	Only trained personnel perform sampling and titration. Laboratory QA/QC procedures are followed. Calibration standards are prepared to ensure the sample titration is being performed accurately.
D. Monitoring Frequency	The scrubber inlet water flow rate is measured continuously and recorded twice daily.	The scrubber water outlet acetic acid concentration is measured twice daily.
Data Collection Procedures	The scrubber inlet water flow rate is recorded twice daily. (The post-control emissions from this unit are less than the major source threshold, so continuous monitoring and recording is not required.)	A water sample is taken and titrated manually with phenolphthalein and NaOH solution. (The post-control emissions from this unit are less than the major source threshold, so continuous monitoring and recording is not required.)
Averaging Period	None.	None.

MONITORING APPROACH JUSTIFICATION

I. Background

The pollutant specific emissions unit (PSEU) consists of process equipment in the cellulose esters division controlled by a packed bed scrubber. The process consists of batch mixers that are used to convert cellulose into cellulose ester. Each mixer may be started at a different time and may be used to make several batches per day. While in the mixers, the intermediate product is dissolved in acetic acid. The ester solution is transferred to storage tanks before being pumped into the next step in the process. A vent system collects the vapors from the mixers and tanks and a fan operated at constant speed pulls the vapors through the vent lines and into the scrubber. It is not possible for the gas to bypass the scrubber. The VOC load to the scrubbers in this division primarily consists of acetic acid (and other carboxylic acids).

The scrubber is 4 feet in diameter and has about 8 feet of 2-inch packing. Fresh water is sprayed at the top of the packing at 4 to 6 gpm; water from the underflow is recirculated to the middle of the scrubber. The normal exit gas flow rate is approximately 1800 acfm.

II. Rationale for Selection of Performance Indicators

A packed bed scrubber is used to reduce VOC emissions from part of a chemical manufacturing process. Both batch mixers and process tanks are vented to this scrubber. The processes in this area of the facility are mostly semi-batch operations, so the production rate at any one time varies. Therefore, it is difficult to relate the production rate to the VOC load vented to this scrubber.

To comply with the applicable emission limit, a minimum water flow rate must be supplied to the scrubber to absorb a given amount of VOC in the gas stream, given the size of the tower and height of the packed bed. The liquid to gas (L/G) ratio is a key operating parameter of the scrubber. If the L/G ratio decreases below the minimum, sufficient mass transfer of the pollutant from the gas phase to the liquid phase will not occur. The minimum liquid flow required to maintain the proper L/G ratio at the maximum gas flow and vapor loading through the scrubber can be determined. Maintaining this minimum liquid flow, even during periods of reduced gas flow, will help ensure that the required L/G ratio is achieved at all times. The concentration of acetic acid in the scrubber underflow can be related to the water flow rate and acetic acid emissions, based on emissions test results and process modeling.

III. Rationale for Selection of Indicator Ranges

The indicator ranges were selected based on engineering calculations using ASPEN® process modeling software, emissions test data, and historical data. Computer modeling of the scrubber system was performed for the maximum allowable VOC concentration in the scrubber exhaust; the inlet water flow rate necessary for achieving adequate control was determined for several concentrations of acetic acid in the underflow. The scrubber efficiency was calculated using data obtained from emissions testing. The scrubber was modeled using an equilibrium-based distillation method and ideal behavior of the gas phase was assumed; liquid phase activity coefficients were estimated from a Wilson parameter fit of vapor-liquid equilibria data. It was assumed that the control device delivers three actual stages of counter-current mass transfer with a recycle stream pumped from the effluent to the center of the column to ensure adequate distribution of the liquid over the packing. The engineering model was calibrated for accuracy using the results of source testing conducted while at normal operating conditions.

Figure A.4b-1 is a plot of the modeled operating conditions (inlet water flow and scrubber underflow acetic acid concentration) necessary to maintain compliance. The line represents the operating conditions at maximum allowable emissions (3.6 lb VOC/hr); the scrubber's VOC emissions are below the limit when the scrubber is operated at conditions that fall below this line. For example, operating at a scrubber water flow rate of 4 gpm with an acetic acid concentration in the scrubber underflow of 12 percent provides a margin of compliance with the permitted VOC emission rate. The selected indicator ranges for inlet water flow and underflow acetic acid concentration were chosen based on the compliance curve and normal operating conditions. The indicator range (acceptable operating range) is defined as any operating condition where the scrubber inlet water flow is greater than 4 gpm and the scrubber underflow acetic acid concentration is less than 10 percent.

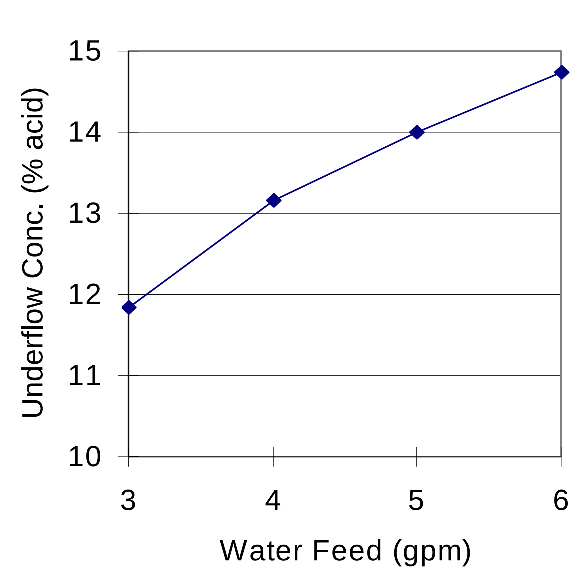

Figure A.4b-1. Compliance curve.

The 4 gpm level was chosen because it is the lower end of the preferred operating range. The 10 percent value was chosen because it is less than any point on the compliance curve (see Figure A.4b-1), and the 1997 historical data show that all measured concentration data were less than 8.4 percent (typical values were between 2 and 6 percent). When an excursion occurs (scrubber inlet water flow of less than 4 gpm and/or scrubber underflow acetic acid concentration of greater than 10 percent), corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported.

The scrubber typically operates at a water flow rate of 4 to 6 gpm. Figure A.4b-2 shows scrubber water flow data collected in 1997. The range for the 1997 data is 3 to 9.5 gpm; the mean scrubber water flow rate was 5.3 gpm. There are four values less than 4 gpm, indicating four excursions. The bulk of the data falls between 5 and 6 gpm. Corrective action typically is taken (the flow is increased) when the scrubber water flow begins to fall below 5 gpm in order to avoid an excursion.

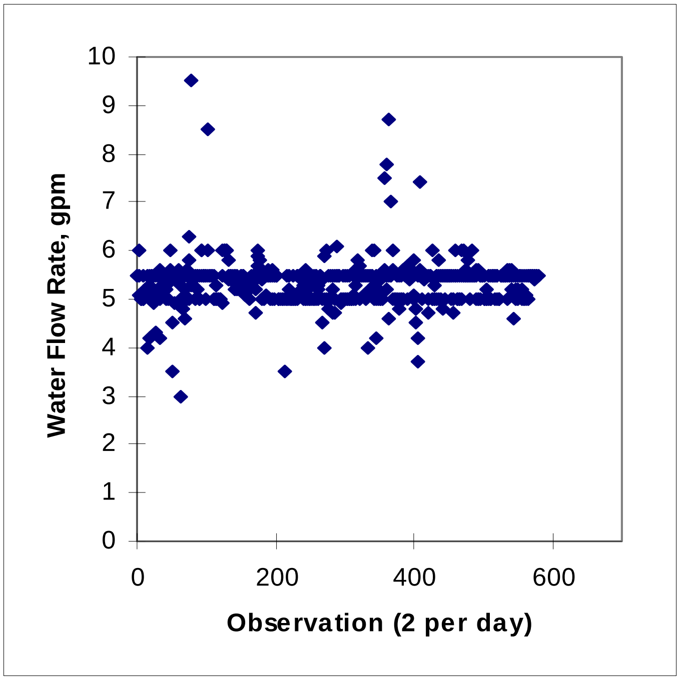

Figure A.4b-2. 1997 scrubber water flow rate data.

Historical data from 1997 show the acetic acid concentration in the underflow is typically less than 6 percent. Figure A.4b-3 shows scrubber underflow acetic acid concentration data for 1997. The maximum concentration was 8.4 percent, which is within the CAM indicator range. The mean concentration was 3.9 percent. The values decrease toward the end of the year because production was decreased due to temporary changes in the market for a key product. This further verifies the correlation between the acid concentration in the underflow and the VOC load to the scrubber. Because historical data show that the scrubber routinely operates within the indicator range, there is not much variability in the data during typical production periods, and the post-control emissions from this scrubber are below the major source threshold, the water flow rate and acid concentration are recorded only twice daily.

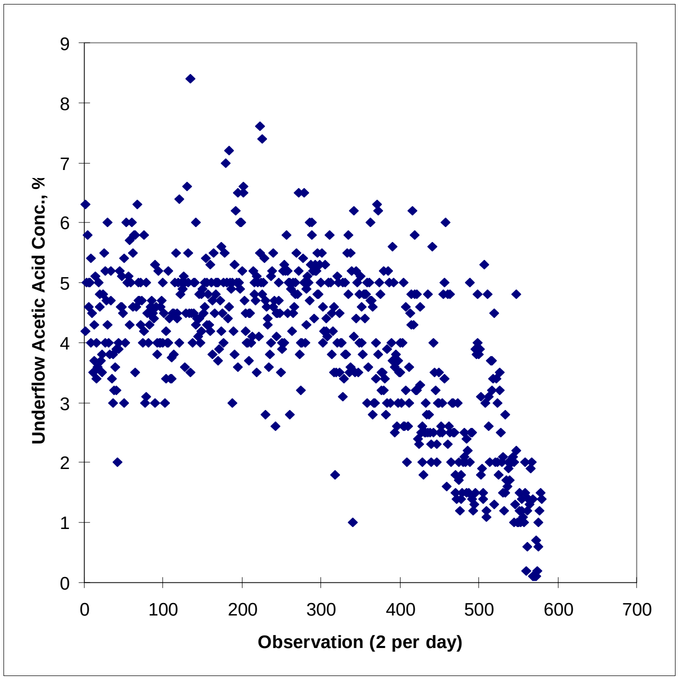

Figure A.4b-3. 1997 underflow acetic acid concentration data.

An emissions test was conducted on this scrubber in December 1994. An acetic acid sampling train validated using EPA Method 301 was used to measure acetic acid emissions and EPA Methods 1 through 4 were used to determine vent gas volumetric flow rates. The permitted emission limit is 3.6 lb VOC/hr. The average emissions during testing were 0.2 lb/hr, well below the emissions allowed for this scrubber. The inlet water flow rate was 5 gpm and the average scrubber underflow acetic acid concentration was 5 percent. The test parameters and measured emissions and underflow concentration were used in the ASPEN® computer model to calculate the efficiency of the scrubber. The model was then used with that same efficiency to generate the compliance curve in Figure A.4b-1.

Figure A.4b-4 shows the underflow acetic acid concentration versus the scrubber water flow rate for 1997. There were four excursions in 1997; the flow rate was less than 4 gpm during those excursions, but the underflow acid concentration was always less than 10 percent.

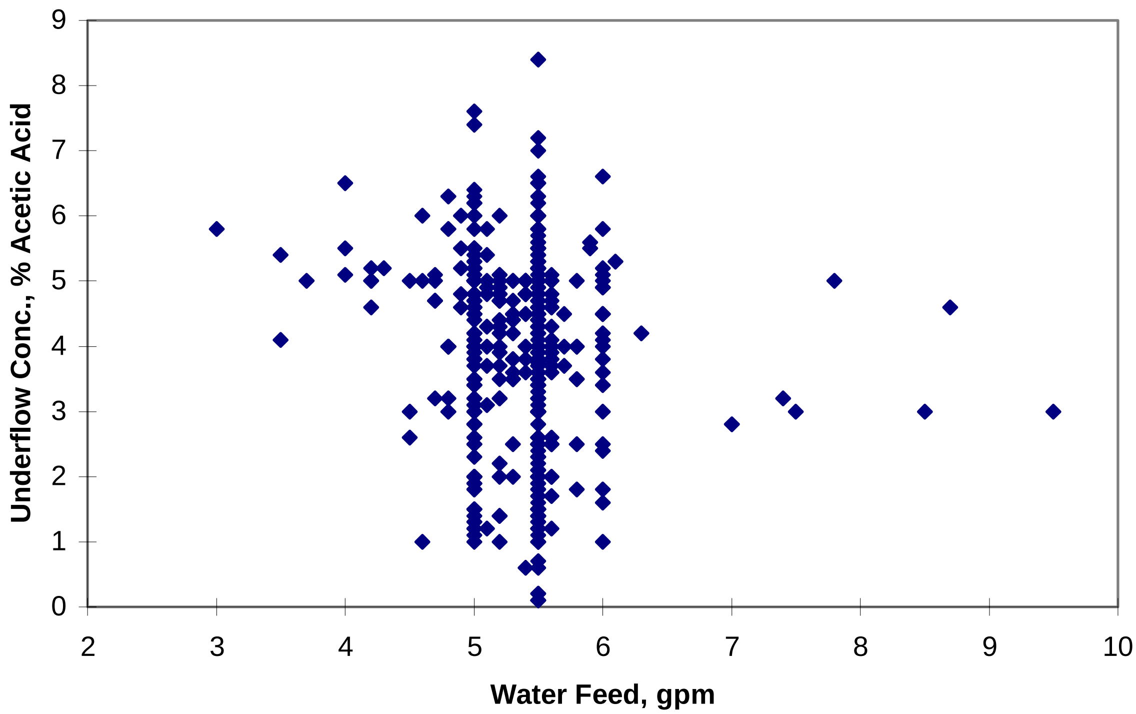

Figure A.4b-4. 1997 underflow acetic acid concentration vs. scrubber water flow. (2 measurements per day)

A.5 CARBON ADSORBER FOR VOC CONTROL–FACILITY E

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EXAMPLE COMPLIANCE ASSURANCE MONITORING:
CARBON ADSORBER FOR VOC CONTROL--FACILITY E

I. Background

A. Emissions Unit

Description:	Chemical Process
Identification:	NA
Facility:	Facility E Anytown, USA

B. Applicable Regulation, Emission Limit, and Monitoring Requirements

Regulation No.:	Permit
Regulated pollutant (PSEU):	VOC
Emission limit:	95 percent reduction by cycle
Monitoring requirements:	Continuously monitor inlet and outlet VOC concentration.

C. Control Technology: Three carbon adsorbers

II. Monitoring Approach

The key elements of the monitoring approach for VOC, including the indicators to be monitored, indicator ranges, and performance criteria, are presented in Table A.5-1.

TABLE A.5-1. MONITORING APPROACH

I. Indicator	VOC removal efficiency
Measurement Approach	The inlet and outlet VOC concentrations are monitored with VOC analyzers.
II. Indicator Range	An excursion is defined as an efficiency less than 95.5 percent for each bed cycle. Excursions trigger an inspection, corrective action, and a reporting requirement.
QIP Threshold[a]	Six excursions per semiannual reporting period.
III. Performance Criteria	
A. Data Representativeness[b]	Two analyzers are installed on the carbon adsorber, one at the inlet and one at the outlet vent. The minimum accuracy is ±1 percent of span.
B. Verification of Operational Status	NA
C. Quality Assurance and Control Practices	Monthly calibration is performed on the analyzers using calibration gas. Maximum calibration drift is ±2.5 percent of span. Operators may request that additional calibration checks be performed in between the scheduled monthly checks. Monthly health checks of the monitors are also performed. Annual preventive maintenance procedures are performed.
D. Monitoring Frequency	VOC concentrations are measured every 2 minutes.
Data Collection Procedures	Efficiencies are determined (based on VOC concentration measurements) and recorded every 2 minutes.
Averaging Period	Average efficiencies are determined by cycle, per bed for tracking of the bed efficiency.

[a]Note: The QIP is an optional tool for States; QIP thresholds are not required in the CAM submittal.
[b]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

JUSTIFICATION

I. Background

Emissions from the chemical process are vented to three carbon adsorber beds in parallel. The emissions are vented to one or two of the three carbon adsorbers at all times; one or two beds are online while the other(s) is regenerating. The carbon adsorbers are used to recover VOC. Bypass of the control device is not possible based on the PSEU design.

II. Rationale for Selection of Performance Indicators

VOC emissions from the chemical process are recovered with three carbon adsorbers in parallel. Monitoring of the inlet and outlet VOC concentration to calculate the recovery efficiency of the control device has been selected as the monitoring approach. This monitoring method is a direct measure of the control device performance and provides the best assurance that the carbon beds are operating properly. A decline in recovery efficiency indicates reduced performance of the carbon adsorber. For this system, maintaining a high recovery efficiency is desirable because the recovered VOC is reused in the process. The facility opted to install VOC CEMS that provide a direct measure of recovery efficiency. This information allows the facility to maximize VOC recovery.

III. Rationale for Selection of Indicator Ranges

The selected indicator range is “greater than 95.5 percent efficiency for each carbon bed cycle.” No upper indicator range limit is necessary. When an excursion occurs corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported. The selected QIP threshold level is six excursions per bed per semiannual reporting period. (Note: Establishing a proposed QIP threshold in the monitoring submittal is optional.) This level is less than 0.5 percent of the number of bed cycles in a semiannual reporting period. If the QIP threshold is exceeded in a semiannual reporting period, a QIP will be developed and implemented.

To monitor and evaluate performance, the carbon bed efficiency of each cycle for each bed is charted and evaluated using statistical techniques. The average and the upper and lower control limits (±3 standard deviations) are graphed. The process target level is 96 percent efficiency. The indicator range has been established at a level that is above the emission limitation (95 percent efficiency) but below the lower control limit during normal operating conditions.

Monitoring data were reviewed to determine whether the control efficiency is maintained during normal operation of the process and carbon adsorber. The average recovery efficiency per online cycle and the average daily efficiency for a 16-day period (May 6 to May 21, 1997) were reviewed for carbon bed 12; a total of 181 cycles for bed 12 were completed in these 16 days.

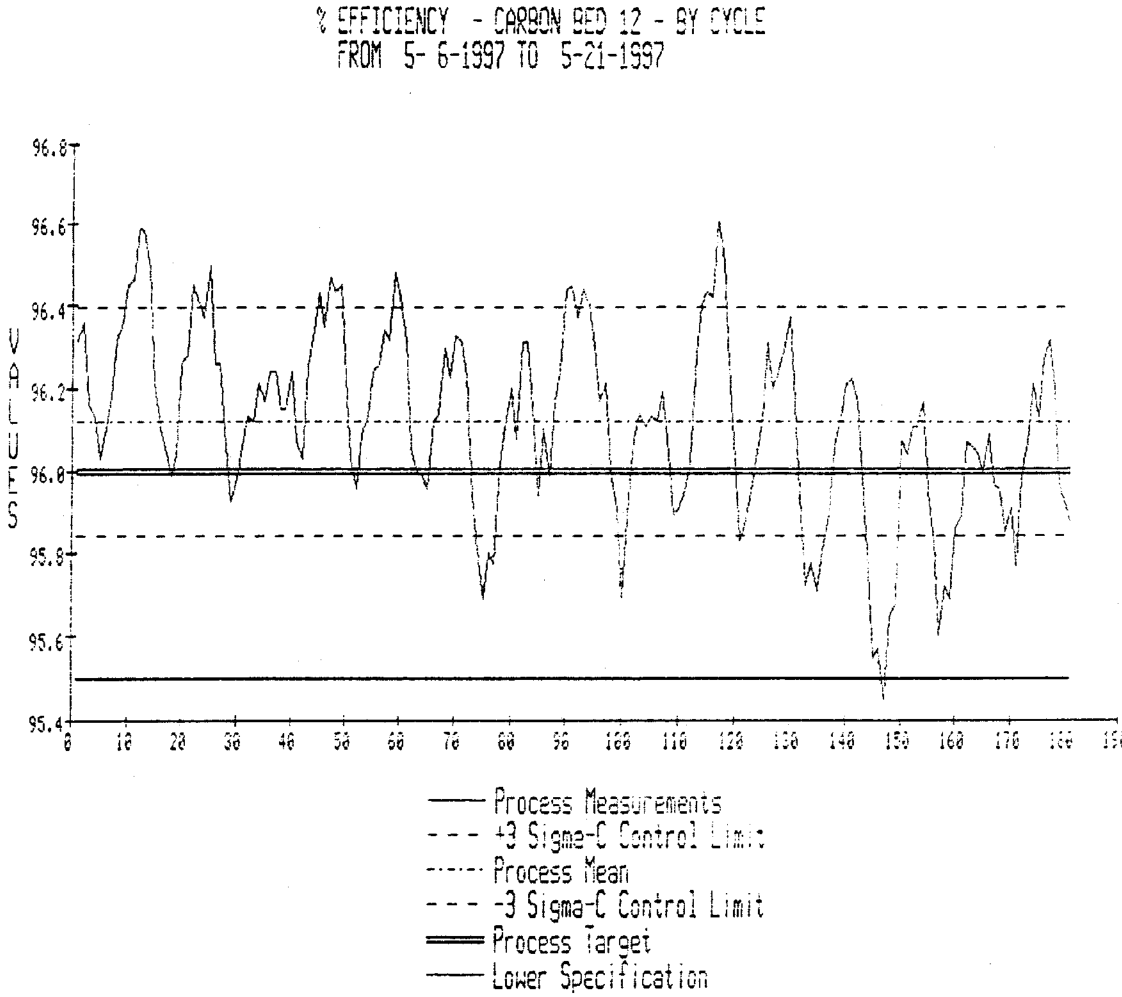
The cycle efficiency data are presented in Figure A.5-1. The average cycle efficiency ranged from 95.5 to 96.6 percent.

The upper and lower control limits (3 standard deviations) are 96.4 and 95.8 percent, respectively. During this 16-day period the selected indicator range of 95.5 percent (identified as the “lower specification” in Figure A.5-1) was exceeded once; i.e., one excursion occurred.

The daily average efficiencies are presented in Figure A.5-2. The daily average efficiencies ranged from 95.8 to 96.3 percent. During this 16-day period, the carbon adsorber bed was consistently operating with a recovery efficiency greater than or equal to 95 percent.

No performance test has been conducted on this control device and a performance test is not planned for the purpose of establishing the indicator range. The control efficiency is determined based upon the relative measurement of the inlet and outlet concentrations.

The monitors are calibrated monthly using calibration standards comprised of the single VOC present in the exhaust stream. Monthly calibrations were found to be sufficient based on calibration drift data collected over a 1 year period. These data indicate that calibration readings are consistent from month to month and rarely drift by more than ±2.5 percent of the span value.

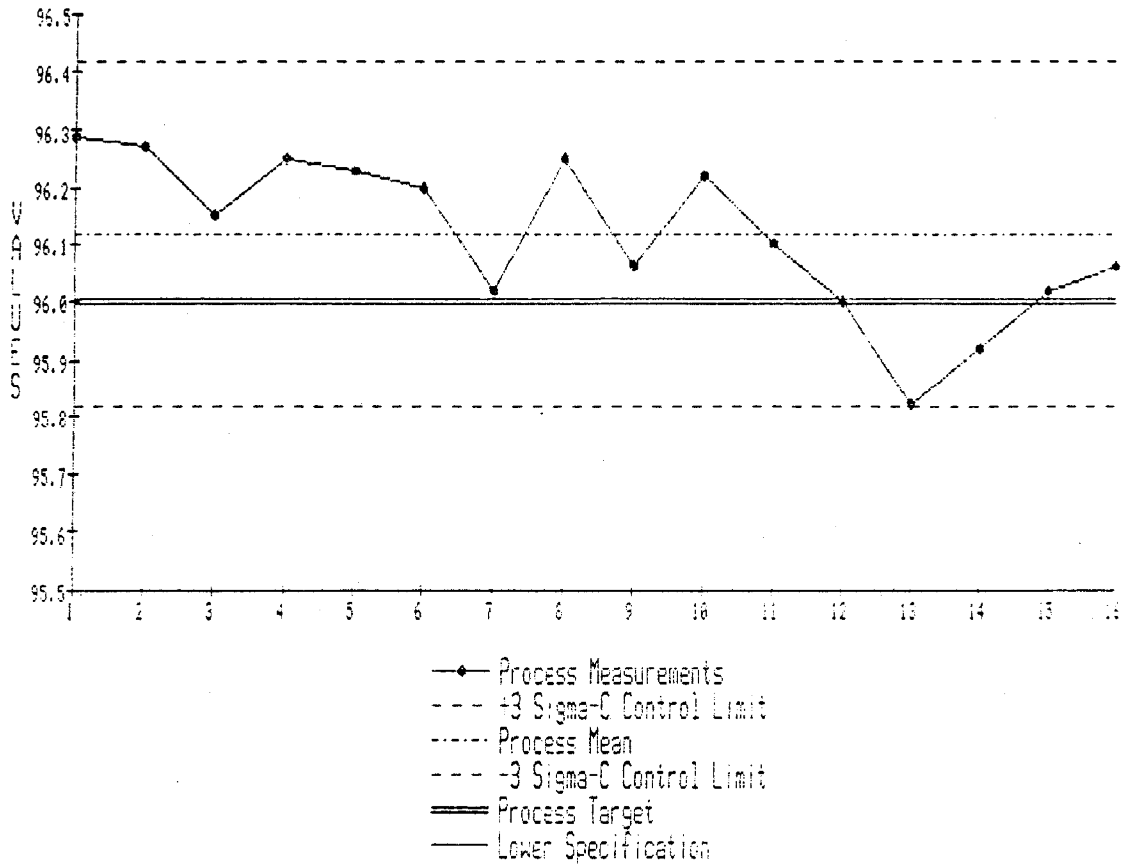


44 Points (24.3%) Out-of-Control: 10 11 12 13 14 22 23 25 45 47 48 49 59 60 74 75 76 77 90 91 93 94 100
1 Points (0.6%) Out-of-Spec: 147

Upper Control Limit	96.3931	Points > UCL	23
Process Average	96.1191	Points < LCL	21
Lower Control Limit	95.8451	Points > USL	0
Upper Specification	None	Points < LSL	1
Process Target	96.0000	Cycling ?	Yes
Lower Specification	95.5000	Run of 8 ?	Yes
Sigma-S	0.2256		
Sigma-C	0.0913		
Sigma-S / Sigma-C	2.4705		
N	181.0000		

Figure A.5-1.

% EFFICIENCY - CARBON BED 12 - DAILY AVERAGE
FROM 5- 6-1997 TO 5-21-1997



Points Out-of-Control: none
Points Out-of-Spec: none

Upper Control Limit	96.4159	Points > UCL	0
Process Average	96.1162	Points < LCL	0
Lower Control Limit	95.8166	Points > USL	0
Upper Specification	None	Points < LSL	0
Process Target	96.0000	Cycling ?	No
Lower Specification	95.5000	Run of 8 ?	No
Sigma-S	0.1382		
Sigma-C	0.0999		
Sigma-S / Sigma-C	1.3834		
N	16.0000		

Figure A.5-2.

A.8 SCRUBBER FOR PM CONTROL--FACILITY H

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EXAMPLE COMPLIANCE ASSURANCE MONITORING:
SCRUBBER FOR PM CONTROL--FACILITY H

I. Background

A. Emissions Unit

Description:	Dry Dryers 1-4
Identification:	401, 403, 406, 407
Facility:	Facility H Anytown, USA

B. Applicable Regulation and Emission Limit

Regulation No.:	OAR 340-21, permit
Emission limits:	
Particulate matter:	0.2 gr/dscf (3 hour average)
Monitoring requirements:	Scrubber exhaust temperature

C. Control Technology

Wet scrubber

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.8-1.

TABLE A.8-1. MONITORING APPROACH

I. Indicator	Wet scrubber exhaust temperature	Work practice: periodic check of scrubber water filter
Measurement Approach	The wet scrubber exhaust temperature is monitored with a thermocouple.	When the scrubber is shut down for weekly maintenance, the scrubber water filter is inspected and cleaned.
II. Indicator Range	An excursion is defined as a scrubber exhaust temperature greater than 150°F for a 6-minute period, continuously. Excursions trigger an inspection, corrective action, and a reporting requirement.	The filter will be replaced as needed; if there is excess buildup of particulate on the filter, the blowdown will be increased if necessary.
QIP Threshold[a]	Six excursions in a 6-month reporting period.	NA
III. Performance Criteria A. Data Representativeness[b]	The monitoring system consists of a thermocouple at the scrubber exhaust with a minimum accuracy of ±4°F or ±0.75%, whichever is greater.	The filter is visually inspected for holes or other damage.
B. Verification of Operational Status	NA	NA
C. QA/QC Practices and Criteria	The thermocouple will be calibrated annually.	NA
D. Monitoring Frequency	The scrubber exhaust temperature is measured continuously.	The filter is inspected and cleaned weekly.
Data Collection Procedures	Temperature is recorded as a 6-minute average by the DAS.	Maintenance records.
Averaging Period	6 minute average.	NA

[a]Note: The QIP is an optional tool for States; QIP thresholds are not required in the CAM submittal.
[b]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

MONITORING APPROACH JUSTIFICATION

I. Background

The pollutant-specific emission units are the four dry dryers (finish dryers) which dry wood chips. The dryers are Heil three pass horizontal rotary drum dryers, and burn natural gas or distillate fuel oil or receive heat indirectly from the boilers via steam. Dryers No. 1 and No. 2 are face material dryers; dryers No. 3 and No. 4 are core material dryers. The main wood species dried is Douglas fir. Wood entering the dryers may range from 10 to 20 percent moisture and exit with 4 to 6 percent moisture prior to particleboard production. The dryer exhaust streams are controlled by American Air Filter wet scrubbers. The scrubber water is filtered and recycled.

II. Rationale for Selection of Performance Indicators

The scrubber exhaust gas temperature was selected because it is indicative of scrubber operation and adequate water flow. When the water flow rate is sufficient, contact between the exhaust gas and the scrubber water causes the temperature of the exhaust gas to drop. The temperature range of the exhaust gas stream during normal operation was determined. With the scrubber water off, the scrubber exhaust is approximately 30°F hotter than normal. When the dryers and scrubbers are shut down for maintenance or cleaning, the temperatures drop.

The scrubber water is filtered and recycled, with a fixed amount of blowdown and makeup water. Checking the filter ensures particulate is being removed from the recycled water. Excess particulate in the scrubber water will reduce control efficiency. Any holes or degradation of the filter will be discovered during the weekly inspection.

The dryer exhaust will only bypass its associated scrubber if the scrubber is shut down for maintenance while the process is operating. These periods are documented and reported.

III. Rationale for Selection of Indicator Range

The selected indicator range for scrubber exhaust temperature is less than 150°F. An excursion is defined as any period during which the scrubber exhaust temperature exceeds 150°F for more than 6 minutes, continuously. When an excursion occurs, corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported. The level for the exhaust temperature was selected based upon the data obtained during normal scrubber operation and the performance test. Examination of operating data show that the scrubber outlet temperature increases slightly as the ambient temperature increases during the year. During normal operation, outlet temperatures approach 150°F during the summer months, and this value was selected as the upper indicator level (see Figure A.8-1 for a typical summer day's scrubber exhaust temperatures). No lower indicator level is necessary.

The most recent performance test using compliance test methods (ODEQ Method 7 for particulate) was conducted at this facility on April 9-11, 1996. Three test runs were conducted on each of the four dry dryers. During testing, the measured PM emissions ranged from 0.024 to 0.054 gr/dscf. During source testing, the scrubber exhaust gas temperatures ranged from 98° to 128°F, and dry dryer scrubber exhausts were found to be well below the compliance limit for particulate emissions. Dryer exhaust temperatures ranged from 149° to 162°F, 30 to 40 degrees hotter than the scrubber exhaust. During the emissions tests, the scrubber exhaust gas temperatures were measured continuously, and 6-minute averages were charted. The complete test results are documented in the test report dated April 1996. During the performance test, the measured particulate emissions were well under the emission limitation of 0.2 gr/dscf.

Three months of operating data (October through December 1996) were reviewed, which include dry dryer scrubber temperature alarm data, maintenance log book entries, and temperature graphs for those days on which alarms occurred. The scrubber temperature alarm was activated on 4 days out of the 3-month operating period for which data were collected. One alarm was caused due to a data processor malfunction, while the others were caused by lack of water flow to the scrubber or excess temperature during shutdown.

Based on the performance test data and a review of historical data, the selected QIP threshold for the wet scrubber exhaust gas temperature is six excursions in a 6-month reporting period (Note: Establishing a proposed QIP threshold in the monitoring submittal is optional). This level is less than 1 percent of the scrubber operating time. If the QIP threshold is exceeded in a semiannual reporting period, a QIP will be developed and implemented.

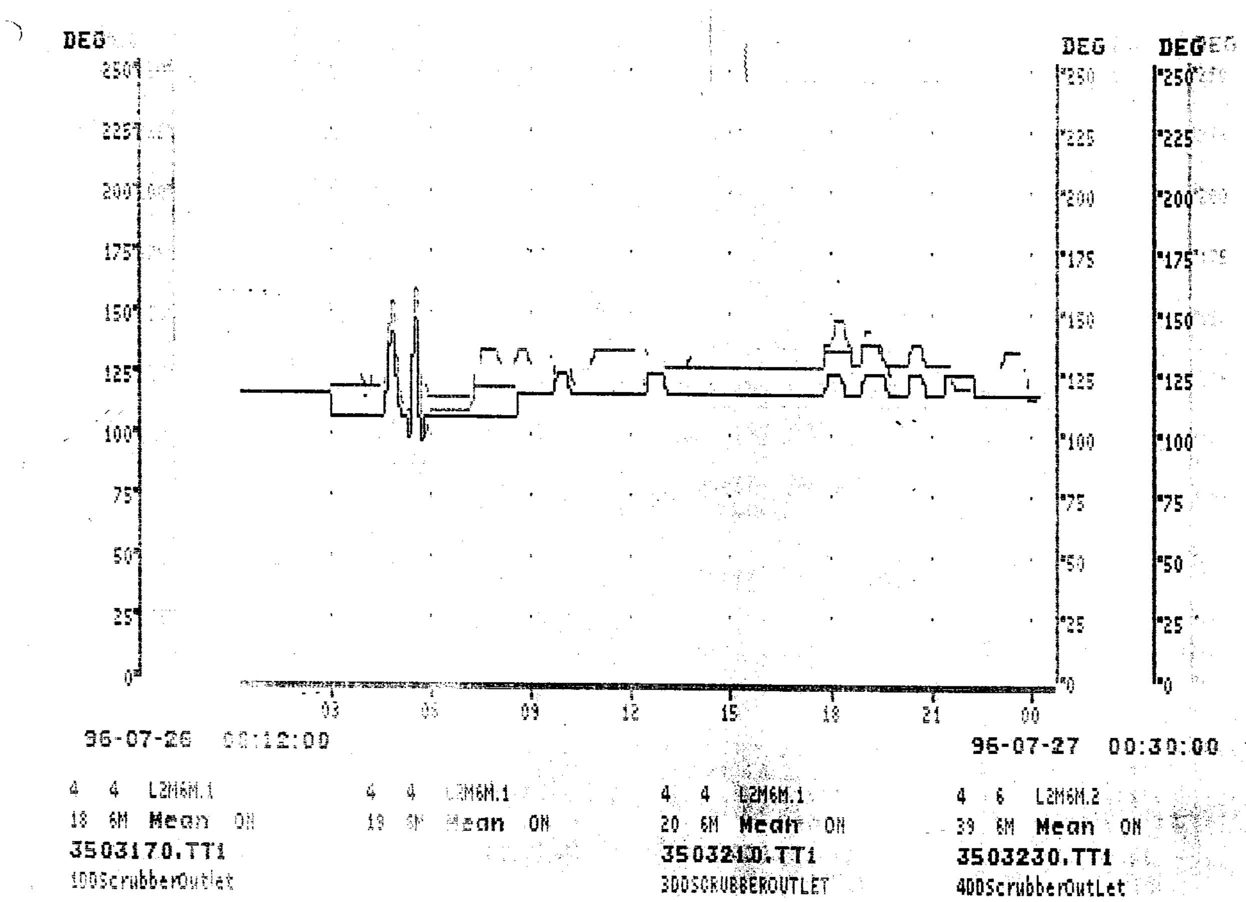

Figure A.8-1. Typical Scrubber Exhaust Temperature (7/27/96)

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A.9 WET ELECTROSTATIC PRECIPITATOR FOR PM CONTROL--FACILITY I

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EXAMPLE COMPLIANCE ASSURANCE MONITORING:
WET ELECTROSTATIC PRECIPITATOR FOR PM CONTROL--FACILITY I

I. Background

A. Emissions Unit

Description:	Green Dryers No. 1 & 2
Identification:	203, 205
Facility:	Facility I Anytown, USA

B. Applicable Regulation, Emission Limits, and Monitoring Requirements

Regulation No.:	OAR 340-21, permit
Emission limits :	
Particulate Matter:	0.2 gr/dscf (No. 1) 0.1 gr/dscf (No. 2) (3-hour average)
Monitoring requirements:	WESP secondary voltage

C. Control Technology

Wet electrostatic precipitator (WESP).

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.9-1.

TABLE A.9-1. MONITORING APPROACH

I. Indicator	WESP voltage.
Measurement Approach	The WESP voltage is measured using a voltmeter.
II. Indicator Range	An excursion is defined as a voltage less than 30 kV for more than 6 minutes, continuously. Excursions trigger an inspection, corrective action, and a reporting requirement.
QIP Threshold[a]	Six excursions in a 6-month reporting period.
III. Performance Criteria A. Data Representativeness[b]	The voltmeter is part of the WESP design and is included in the transformer/rectifier set. It has a minimum accuracy of $\pm$1 kV.
B. Verification of Operational Status	NA
C. QA/QC Practices and Criteria	Confirm voltmeter zero when unit not operating (at least semi-annually).
D. Monitoring Frequency	Measured continuously.
Data Collection Procedures	Recorded as a 6-minute average.
Averaging Period	6-minute average.

[a]Note: The QIP is an optional tool for States; QIP thresholds are not required in the CAM submittal.
[b]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

MONITORING APPROACH JUSTIFICATION

I. Background

The pollutant-specific emission units are green dryers No. 1 and No. 2. The dryers are three pass horizontal rotary drum dryers, with direct heat sources of sanderdust, natural gas, distillate fuel oil, boiler flue gas, or any combination thereof. Green dryer No. 1 was manufactured by Heil and green dryer No. 2 was manufactured by Westec America. Green wood shavings are dried in these dryers before mixing with dry wood shavings and drying in the dry dryers. Wood entering the green dryers may range from 25 to 50 percent moisture and exit with 15 to 20 percent moisture. The green dryer exhaust streams are each controlled by a Geoenergy WESP.

II. Rationale for Selection of Performance Indicator

In a WESP, electric fields are established by applying a direct-current voltage across a pair of electrodes: a discharge electrode and a collection electrode. Particulate matter and water droplets suspended in the gas stream are electrically charged by passing through the electric field around each discharge electrode (the negatively charged electrode). The negatively charged particles and droplets then migrate toward the positively charged collection electrodes. The particulate matter is separated from the gas stream by retention on the collection electrode. Particulate is removed from the collection plates by an intermittent spray of water. The WESP voltage was selected as a performance indicator because the voltage drops when a malfunction, such as grounded electrodes, occurs in the WESP. When the voltage drops, less particulate is charged and collected.

The dryer exhaust will bypass its associated WESP if the WESP is shut down while the process is operating. These periods are documented and reported.

III. Rationale for Selection of Indicator Range

The selected indicator level is a voltage of greater than 30 kV. An excursion is defined as any period during which the voltage is less than 30 kV for more than 6 minutes, continuously. When an excursion occurs, corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported.

The indicator range for the WESP voltage was selected based upon the level maintained during normal operation and during the performance test. The normal operating voltage is set at the highest level achievable without having an excessive spark rate. Based on field experience, voltage levels less than 30 kV during normal operation result in unacceptable opacity readings. During abnormal operation or a malfunction (such as grounded electrodes), the WESP kV levels are appreciably lower than normal operational levels. A time interval of 6 minutes was chosen to account for the routine 2-minute flush cycles the WESP's undergo, which cause the voltage to drop below 30 kV. Data obtained during the most recent performance test confirmed the unit was in compliance with the particulate matter emissions limit. During testing, the WESP's operated with voltages in the range of 34 to 45 kV.

The most recent performance test using compliance test methods (ODEQ Method 7 for particulate and RM 9 for visible emissions) was conducted on April 22 and 25, 1996. Three test runs were conducted on each dryer. During this test, the measured PM emissions ranged from 0.009 to 0.013 gr/dscf. Visible emission opacity observations were conducted during the particulate testing. All visible emissions observations during the performance test were 0 to 5 percent opacity (no reading exceeded the permit limit of 20 percent). During the emissions tests, the WESP voltages were measured continuously, and 6-minute averages were charted. During the performance test, the measured particulate emissions were well below the emission limitations (0.2 gr/dscf for green dryer No. 1 and 0.1 gr/dscf for green dryer No. 2). The complete test results are documented in the test report.

Indicator data for the period of October through December of 1996 have been reviewed. These data include 6-minute average WESP voltage graphs and copies of entries in the logbook used to record equipment malfunctions and maintenance. Voltage excursions resulting in an alarm occurred two times during the 3-month period on the WESP on dryer No. 1. One alarm was the result of recycle water overflow and one was the result of a full E-tube chamber. Voltage excursions resulting in an alarm occurred three times during the 3-month period on the WESP on dryer No. 2; once because the recycle water system was plugged, once due to a recycle flow warning, and once because 4 probes were misaligned. Normal operation was in the range of 40 to 50 kV, except during the short flush cycles. Based on the data collected, the indicator level of 30 kV is adequate.

Based on a review of historical data, the QIP threshold established for the WESP voltage is six excursions in a 6-month reporting period. This level is less than 1 percent of the WESP operating time. If the QIP threshold is exceeded in a semiannual reporting period, a QIP will be developed and implemented. (Note: Submitting a proposed QIP threshold with the monitoring approach is not required.)

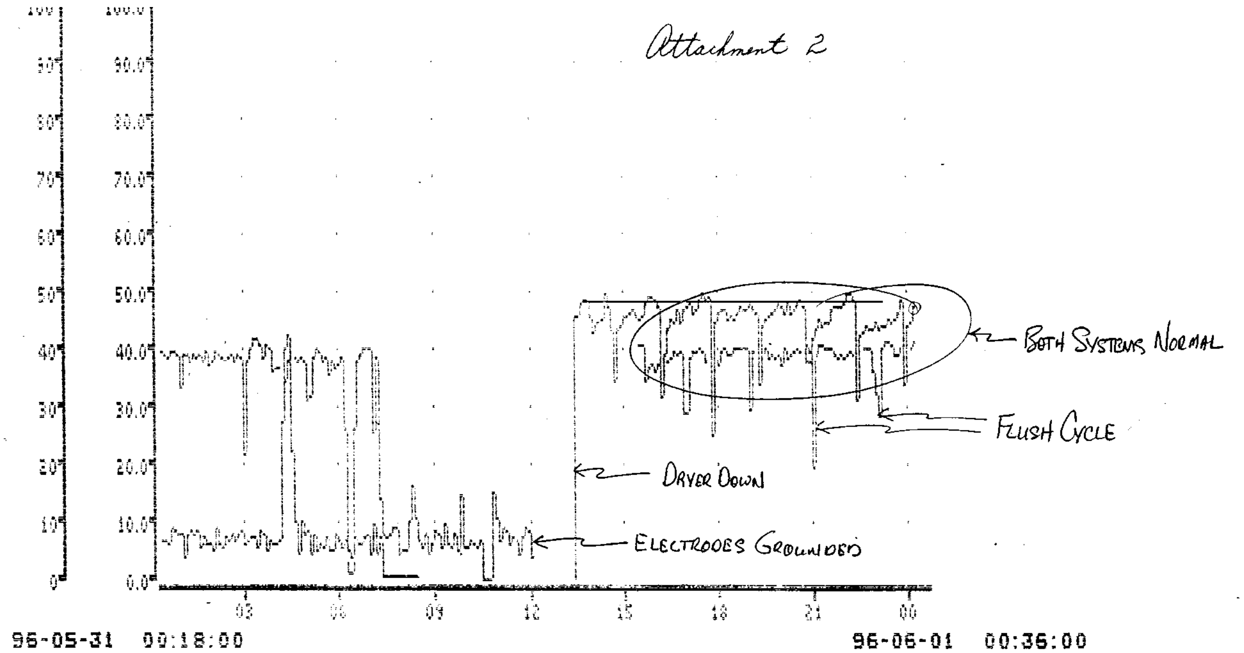

Figure A.9-1. WESP voltage levels.

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A.9b WET ELECTROSTATIC PRECIPITATORS (WESP) FOR PM CONTROL OF VENEER DRYERS – FACILITY P

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EXAMPLE COMPLIANCE ASSURANCE MONITORING
WET ELECTROSTATIC PRECIPITATORS (WESP) FOR PM CONTROL – FACILITY P

I. Background

A. Emissions Unit

Description:	Steam-heated dryers used in plywood manufacturing
Identification:	Veneer Dryers 1-6 (EU2)
APCD ID:	WESP 1, WESP 2
Facility:	Facility P Anytown, USA

B. Applicable Regulation and Emission Limit

Regulation No.:	Permit, State Regulation
Emission limits:	
Particulate Matter (PM):	0.3 lb/1,000 ft^2 (MSF) dried (3/8-inch thickness basis)
Monitoring Requirements:	Monitor WESP secondary voltage, quench inlet temperature, and WESP outlet temperature.

C. Control Technology — Wet electrostatic precipitator

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.9b-1. The selected indicators of performance are: WESP secondary voltage, quench inlet temperature, and WESP outlet temperature. The selected indicator ranges are based on hourly average values.

TABLE A.9b-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2	Indicator No. 3
I. Indicator	WESP secondary voltage.	Quench inlet temperature.	WESP outlet temperature.
Measurement Approach	The WESP secondary voltage is monitored using a voltmeter.	The gas temperature is measured with a thermocouple at the quench inlet.	The gas temperature is measured with a thermocouple at the WESP outlet.
II. Indicator Range	An excursion is defined as an hourly average voltage less than 35 kV. Excursions trigger an investigation, corrective action, and a reporting requirement.	An excursion is defined as an hourly average quench inlet temperature >375˚F. Excursions trigger an investigation, corrective action, and a reporting requirement.	An excursion is defined as an hourly average outlet temperature >175˚F. Excursions trigger an investigation, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness	The monitoring system consists of a voltmeter that is part of the WESP instrumentation (TR controller). The minimum accuracy of the voltmeter is ±0.5 kV.	The monitoring system consists of a thermocouple located in the quench inlet ductwork. The minimum accuracy of the thermocouple is ±2.2˚C (±4˚F) or 0.75 percent of the measured temperature in ˚C, whichever is greater.	The monitoring system consists of a thermocouple located in the WESP outlet ductwork. The minimum accuracy of the thermocouple is ±2.2˚C (±4˚F) or 0.75 percent of the measured temperature in ˚C, whichever is greater.
B. Verification of Operational Status	NA	NA	NA
C. QA/QC Practices and Criteria	Voltmeter zero check during scheduled maintenance performed every 3 weeks.	Thermocouples calibrated annually by comparison against an instrument of known accuracy. The acceptance criteria is ±4˚F.	Thermocouples calibrated annually by comparison against an instrument of known accuracy. The acceptance criteria is ±4˚F.
D. Monitoring Frequency	The voltage on each WESP is monitored continuously (one data point per minute).	The quench inlet temperature is monitored continuously (one data point per minute).	The WESP outlet temperature is monitored continuously (one data point per minute).
Data Collection Procedure	Data are recorded on the continuous parameter monitoring system (CPMS) computer.	Data are recorded on the CPMS computer.	Data are recorded on the CPMS computer.
Averaging Period	Hourly block average.	Hourly block average.	Hourly block average.

MONITORING APPROACH JUSTIFICATION

I. Background

The pollutant-specific emissions units (PSEU) are the two WESPs that control six veneer dryers. The dryers are longitudinal, steam-heated dryers manufactured by Coe and Moore and are used in the manufacture of plywood. Veneer is introduced into the dryer either manually or using automated veneer sheet feeders. The dried veneer sheets pass through a moisture detector as they exit the dryer where any sheets not meeting moisture specifications are marked and sorted for redrying. Dry veneer sheets are coated with mixed glue and formed into panels.

Two WESPs, also referred to as E-tubes, remove particulate matter from the dryer exhaust. WESP No. 1 serves dryers Nos. 1, 5, and 6 and WESP No. 2 serves dryers Nos. 2, 3, and 4.

II. Rationale for Selection of Performance Indicators

A WESP is designed to operate at a relatively constant voltage. A significant decrease in voltage is indicative of a change in operating conditions that could lead to an increase in emissions. Low voltage can indicate electrical shorts or poor contacts that require maintenance or repair of electrical components. However, the regular flush cycles the WESPs undergo to remove the particulate from the collection surfaces may also cause drops in voltage of short duration. These brief voltage drops are part of the normal operation of the WESP.

Monitoring gas stream temperature can provide useful information about the performance of a WESP. Quench inlet temperature primarily is an indication that the inlet gas stream is not so hot that a fire may develop in the duct work or WESP. In addition, the gas stream needs to be cooled in order for some of the pollutants to condense. The WESP outlet temperature indicates that the gas stream has been sufficiently saturated to provide for efficient particle removal, and that the water spray prior to the WESP inlet is functioning. High outlet temperatures could be the result of plugged nozzles, malfunctioning pumps, or broken or plugged piping.

III. Rationale for Selection of Indicator Ranges

The selected indicator ranges are given below:

Secondary voltage:	$\geq$35 kV
Quench inlet temperature:	$\leq$375°F
Stack outlet temperature:	$\leq$175°F

An excursion is defined as (1) an hourly average voltage less than 35 kV; (2) an hourly average quench inlet temperature greater than 375˚F; or (3) an hourly average WESP outlet temperature greater than 175˚F. When an excursion occurs, corrective action will be initiated beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported. An hourly average was chosen to account for the intermittent flush cycles the WESPs undergo that cause the voltage to drop temporarily.

The indicator level for the WESP voltage was selected based upon the level maintained during normal operation. Typical operating voltages range from 35 to 55 kV. During the most recent performance test, the voltage ranged from 35 to 54 kV and the PM emissions were below allowable levels. An indicator level at the low end of the normal operating range was selected (35 kV). During a malfunction (such as an electrical short), the WESP voltage levels are appreciably lower than normal operational levels. The voltage also drops for a short period during the normal flush cycles that are performed every few hours to clean the tube surface where particulate is collected. Figure A.9b-1 displays the hourly average WESP secondary voltage during October 1997 for WESP No. 1.

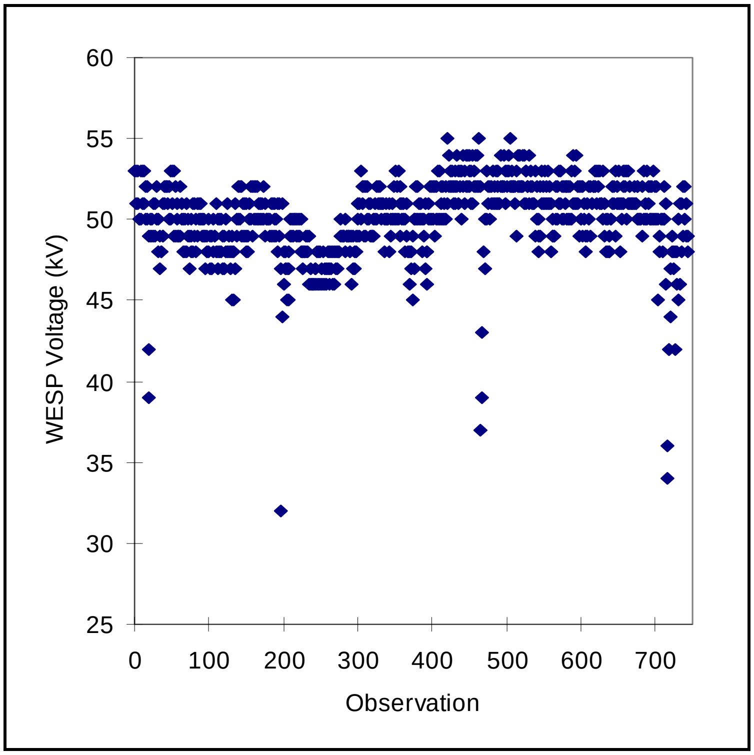

Figure A.9b-1. October 1997 hourly average secondary voltage (WESP No. 1).

The indicator levels for the quench inlet and WESP outlet gas temperatures also were selected based on levels maintained during normal operation. High temperatures may indicate a fire in the dryer or ductwork or a lack of water flow to the WESP. Temperature action levels were selected that are slightly higher than normal operating temperatures. If the water flow to the WESP is lost, the WESP outlet temperature will begin to approach the inlet temperature, which is much higher than 175˚F. Figures A.9b-2 and A.9b-3 display the hourly average quench inlet and WESP outlet temperature during October 1997 for WESP No. 1.

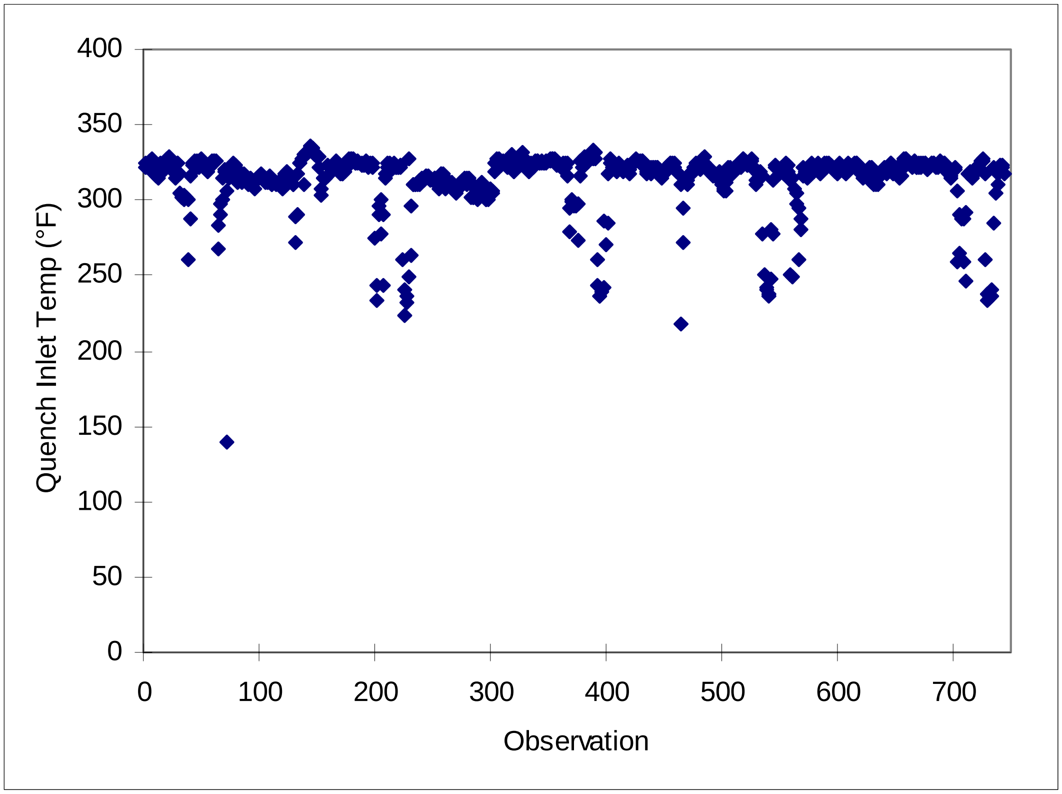

Figure A.9b-2. October 1997 Hourly Average Quench Inlet Temperature (WESP No. 1)

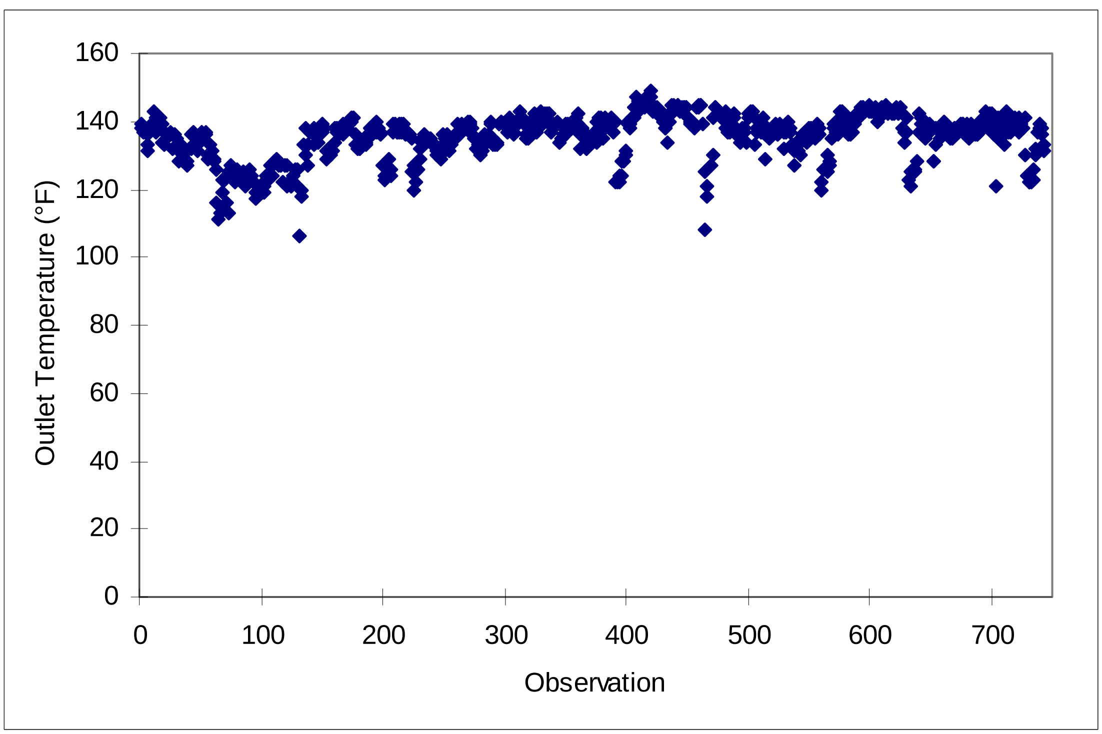

Figure A.9b-3. October 1997 Hourly Average WESP Outlet Temperature (WESP No. 1)

Indicator data for December 1995 to January 1996 and for October 1997 through December 1997 were reviewed. These data included hourly average WESP secondary voltage, quench inlet temperature, and WESP outlet temperature measurements. The maximum hourly average quench inlet temperature for WESP No. 1 was 336˚F, while the maximum for WESP No. 2 was 352˚F. The maximum hourly average stack outlet temperature for WESP No. 1 was 151˚F, while the maximum stack outlet temperature for WESP No. 2 was 178˚F. The average monthly voltages ranged from 47 to 51 kV for WESP No. 1 and from 40 to 46 kV for WESP No. 2.

Data obtained during the most recent performance test (October 1996) confirmed the unit was in compliance. During this test, the average measured PM emissions were 0.19 lb/MSF dried for WESP No. 1 and 0.21 lb/MSF dried for WESP No. 2. The measured particulate emissions were below the emission limitation of 0.3 lb/MSF dried (3/8-inch thickness basis). The WESP operating parameters during the performance test are summarized in Table A.9b-2.

TABLE A.9b-2. WESP OPERATING PARAMETERS DURING THE MOST RECENT PERFORMANCE TEST

WESP No.	Run	Production, ft^2/hr	Particulate, lb/MSF dried (3/8-inch basis)	WESP voltage, kV	Quench inlet T (˚F)	WESP outlet, T (˚F)
1	1	22,760	0.24	54	317	134
	2	23,419	0.17	54	318	134
	3	23,075	0.17	--	--	--
	Average	23,085	0.19	54	318	134
2	1	23,899	0.24	35	328	147
	2	32,238	0.17	38	332	143
	3	26,897	0.20	40	331	147
	Average	27,678	0.21	38	330	146

A.10 FABRIC FILTER FOR PM CONTROL--FACILITY J

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EXAMPLE COMPLIANCE ASSURANCE MONITORING:
FABRIC FILTER FOR PM CONTROL--FACILITY J

I. Background

A. Emissions Unit

Description:	Line 3 Particleboard Sander
Identification:	M2
Facility:	Facility J Anytown, USA

B. Applicable Regulation, Emission Limit, and Monitoring Requirements

Regulation No.:	OAR 340-21, permit
Emission limits:	
Particulate matter:	0.1 gr/dscf, 3 hr avg.
Monitoring requirements:	Visible emissions, periodic monitoring (RM22)

C. Control Technology

Pulse-jet baghouse operated under negative pressure.

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.10-1.

TABLE A.10-1. MONITORING APPROACH

I. Indicator	Visible emissions	Pressure drop
Measurement Approach	Visible emissions from the baghouse exhaust will be monitored daily using EPA Reference Method 22-like procedures.	Pressure drop across the baghouse is measured with a differential pressure gauge.
II. Indicator Range	An excursion is defined as the presence of visible emissions. Excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion is defined as a pressure drop greater than 5 in. H_2O. Excursions trigger an inspection, corrective action, and a reporting requirement. APCD bypass checked if less than 1 in. H_2O.
QIP Threshold[a]	The QIP threshold is five excursions in a 6-month reporting period.	None selected
III. Performance Criteria A. Data Representativeness[b]	Measurements are being made at the emission point (baghouse exhaust).	Pressure taps are located at the baghouse inlet and outlet. The gauge has a minimum accuracy of 0.25 in. H_2O.
B. Verification of Operational Status	NA	NA
C. QA/QC Practices and Criteria	The observer will be familiar with Reference Method 22 and follow Method 22-like procedures.	The pressure gauge is calibrated quarterly. Pressure taps are checked for plugging daily.
D. Monitoring Frequency	A 6-minute Method 22-like observation is performed daily.	Pressure drop is monitored continuously.
Data Collection Procedure	The VE observation is documented by the observer.	Pressure drop is manually recorded daily.
Averaging Period	NA	None.

[a]Note: The QIP is an optional tool for States; QIP thresholds are not required in the CAM submittal.

[b]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

JUSTIFICATION

I. Background

The pollutant-specific emission unit is the Line No. 3 Sander, which is used to sand particleboard to the customer's desired thickness. It is controlled by a Western Pneumatic pulse-jet baghouse with 542 bags, which filters approximately 50,000 ft^3 of air from the sander.

II. Rationale for Selection of Performance Indicators

Visible emissions was selected as the performance indicator because it is indicative of good operation and maintenance of the baghouse. When the baghouse is operating properly, there will not be any visible emissions from the exhaust. Any increase in visible emissions indicates reduced performance of a particulate control device, therefore, the presence of visible emissions is used as a performance indicator.

In general, baghouses are designed to operate at a relatively constant pressure drop. Monitoring pressure drop provides a means of detecting a change in operation that could lead to an increase in emissions. An increase in pressure drop can indicate that the cleaning cycle is not frequent enough, cleaning equipment is damaged, the bags are becoming blinded, or the airflow has increased. A decrease in pressure drop may indicate broken or loose bags, but this is also indicated by the presence of visible emissions, indicator No. 1. A pressure drop across the baghouse also serves to indicate that there is airflow through the control device.

III. Rationale for Selection of Indicator Ranges

The selected indicator range is no visible emissions. When an excursion occurs, corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported. An indicator range of no visible emissions was selected because: (1) an increase in visible emissions is indicative of an increase in particulate emissions; and (2) a monitoring technique which does not require a Method 9 certified observer is desired. Although RM 22 applies to fugitive sources, the visible/no visible emissions observation technique of RM-22 can be applied to ducted emissions; i.e., Method 22-like observations.

The selected QIP threshold for baghouse visible emissions is five excursions in a 6-month reporting period. This level is 3 percent of the total visible emissions observations. If the QIP threshold is exceeded in a semiannual reporting period, a QIP will be developed and implemented. (Note: Proposing a QIP threshold in the CAM submittal is not required.)

The indicator range chosen for the baghouse pressure drop is less than 5 in. H_2O. An excursion triggers an inspection, corrective action, and a reporting requirement. The pressure drop is recorded daily. As the pressure drop approaches 5 in. H_2O, the bags are scheduled for replacement. The bags are typically changed yearly. This indicator is also used to monitor for bypass of the control device. If the pressure drop falls below 1 in. H_2O during normal process operation, the possibility of bypass is investigated. No QIP threshold has been selected for this indicator.

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A.11 ELECTRIFIED FILTER BED FOR PM CONTROL OF VENEER DRYERS – FACILITY K

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EXAMPLE COMPLIANCE ASSURANCE MONITORING
ELECTRIFIED FILTER BED (EFB) FOR PM CONTROL – FACILITY K

I. Background

A. Emissions Unit

Description:	Natural gas-fired dryers used in plywood manufacturing
Identification:	Veneer Dryer 1, Veneer Dryer 2
Facility:	Facility K Anytown, USA

B. Applicable Regulation, Emission Limit, and Monitoring Requirements

Regulation:	Permit, State regulation
Emission Limits:	
Particulate matter (PM):	0.30 lb/1000 ft^2 (MSF) dried (3/8-inch thickness basis), 4.1 lb/hr
Monitoring Requirements:	EFB inlet temperature, EFB voltage, and EFB ionizer current.

C. Control Technology — EFB

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.11-1. The selected indicators of performance are: EFB inlet temperature, voltage, and ionizer current. The selected indicator ranges are based upon hourly average values.

TABLE A.11-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2	Indicator No. 3
I. Indicator	EFB inlet temperature.	EFB voltage.	EFB ionizer current.
Measurement Approach	Temperature is measured using a thermocouple.	Voltage is measured with a voltmeter.	Ionizer current is measured with an ammeter.
II. Indicator Range	An excursion is defined as an hourly average EFB inlet temperature greater than 170˚F (>145˚F when drying pine veneer). Excursions trigger an investigation, corrective action, and a reporting requirement.	An excursion is defined as an hourly average EFB voltage less than 8 kV. Excursions trigger an investigation, corrective action, and a reporting requirement.	An excursion is defined as an hourly average EFB ionizer current less than 2 mA. Excursions trigger an investigation, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness	The monitoring system consists of a thermocouple installed at the inlet of the EFB. The minimum accuracy of the thermocouple is ±2.2˚C (±4˚F) or 0.75 percent of the measured temperature in ˚C, whichever is greater.	The monitoring system consists of a voltmeter on the EFB unit. The minimum accuracy of the voltmeter is ±0.5 kV.	The monitoring system consists of an ammeter on the EFB unit. The minimum accuracy of the ammeter is ±0.5 mA.
B. Verification of Operational Status	NA	NA	NA
C. QA/QC Practices and Criteria	The accuracy of the thermocouple is checked annually (or as needed) by calibration using a signal transmitter. The thermocouple wells are periodically checked and cleaned (at least annually).	Voltmeter zero is checked when the unit is not operating.	Ammeter zero is checked when the unit is not operating.
D. Monitoring Frequency	The EFB inlet temperature is measured continuously (at least 4 times per hour).	The EFB voltage is measured continuously (at least 4 times per hour).	The EFB ionizer current is measured continuously (at least 4 times per hour).
Data Collection Procedure	Data are stored electronically and archived for at least 5 years..	Data are stored electronically and archived for at least 5 years..	Data are stored electronically and archived for at least 5 years..
Averaging Period	Hourly block average.	Hourly block average.	Hourly block average.

MONITORING APPROACH JUSTIFICATION

I. Background

The pollutant-specific emissions unit (PSEU) consists of two natural gas direct-fired veneer dryers controlled by an EFB. Dryer 1 is manufactured by Moore and has one zone and four decks. Dryer 2 is manufactured by Coe and has two zones and five decks. The dryers are used in the manufacture of plywood.

II. Rationale for Selection of Performance Indicators

Wood dryer exhaust streams contain dry PM, products of combustion and pyrolysis, and aerosols formed by the condensation of hydrocarbons volatilized from the wood chips. Since some of the pollutants from the dryers are in a gas phase at the normal dryer exhaust temperature of 250˚ to 300˚F, these pollutants must be condensed in order to be collected by the EFB. The gas stream is cooled to a temperature of about 180˚F by the evaporative gas cooler that precedes the EFB, using a water mist. The pollutants condense into fine liquid droplets and are carried into the EFB. The EFB ionizer gives the particles in the gas stream an electrical charge. The high voltage electrode in the gravel bed creates charged regions on the gravel. As the gas passes through the bed, the charged particles are removed from the gas and transferred to the surface of the bed. Liquid and dust continuously build up on the gravel surface; the liquid slowly travels through the bed and is allowed to drip into the drain outlet in the bottom of the unit. The gravel is periodically replaced (about one-third of the gravel is replaced each month).

Factors that affect emissions from wood dryers include wood species, dryer temperature, dryer residence time, dryer loading rate, and previous drying history of the wood. The rate of hydrocarbon aerosol formation (from vaporizing the extractable portion of the wood) is lower at lower dryer temperatures. Small increases in dryer temperature can produce relatively large increases in the PM emission rate. If particles are held in the dryer too long, the surfaces can volatilize; if these emissions are released into the ambient air, a visible blue haze can result.

The CAM indicators selected are EFB inlet temperature, EFB voltage, and EFB ionizer current. The EFB must be maintained at the proper temperature to allow collection of the hydrocarbon aerosol and particulate matter from the dryer. The EFB inlet temperature is monitored to indicate the gas stream was cooled to the proper temperature range before entering the EFB and that the bed is operating at the proper temperature. Information from the EFB manufacturer indicates that high EFB temperatures (e.g., temperatures in excess of 200˚F) may result in excess stack opacity, as will low gravel levels (a low gravel level may cause insufficient PM collection). The voltage on the gravel and the current on the ionizer must be maintained so negatively charged particles in the exhaust gas are attracted to positively charged regions on the gravel bed. An adequate ionizer current level indicates the corona is charging the particles in the gas stream. The bed voltage level indicates the intensity of the electric field in the bed. A drop in voltage or current could indicate a malfunction, such as a short or a buildup of dust or hydrocarbon glaze on the ionizer or the gravel. A short in the bed will show as high current with little or no voltage. A foreign object in the gravel bed which bridges the gap between the electrode and grounded louvers can short the bed, as can a cracked electrical insulator. The bed's PM collection efficiency increases as the voltage and current increase within the unit's operating range.

The parameters selected for monitoring are consistent with technical information on the operation, maintenance, and emissions for EFB's and dryers provided in EPA's September 1992 draft Alternative Control Technology (ACT) document for PM-10 emissions from the wood products industry. These parameters also were recommended by the manufacturer as parameters to monitor to ensure proper operation of the EFB unit.

III. Rationale for Selection of Indicator Ranges

Indicator data for June through August were collected and reviewed. These data include EFB cooler inlet and outlet temperature, bed temperature, bed voltage, and ionizer current measurements. No indicator ranges are specified in the current operating permit, but the permit does state that the EFB bed temperature shall not exceed 145˚F when pine veneer is being dried. Based on the manufacturer's recommendations, historical data, and data obtained during source testing, the following indicator ranges were selected:

EFB bed inlet temperature:	<170˚F (<145˚F when drying pine veneer)
EFB bed voltage:	>8 kV
EFB ionizer current:	>2 mA

An excursion is defined as an hourly average of any parameter which is outside the indicator range. When an excursion occurs, corrective action will be initiated beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported.

Figure A.11-1 shows the hourly average EFB inlet temperature for June. The permit requires that the EFB bed temperature be less than 145˚F while drying pine veneer. The EFB inlet temperature is used as a surrogate for bed temperature. During normal operation, the typical inlet temperature was 160 to 165˚F when drying species other than pine. There were short periods of operation at 130 to 140˚F when drying pine veneer, and lower temperatures that indicate the dryers were not operating (e.g., on Fridays during the routine maintenance shutdown). Similar operating ranges were observed for July and August. The maximum hourly average EFB inlet temperatures for June, July, and August were 174˚F, 173˚F, and 176˚F, respectively. The manufacturer recommends maintaining the EFB at a temperature of 160 to 180˚F. Therefore, based on this recommendation and on normal operating conditions, the indicator range chosen was an hourly average inlet temperature less than 170˚F (less than 145˚F when drying pine veneer). If the EFB inlet temperature exceeds 170˚F (145˚F when drying pine), corrective action will be initiated.

Figure A.11-2 shows the hourly average EFB voltage for June. From Figure A.11-2, it can be observed that the EFB typically operates in the range of 10 to 15 kV. Some short periods of operation occur from 5 to 10 kV. The mean hourly voltages for June, July, and August are given below. These statistics do not include data from periods during which the EFB was not operating and the voltage was recorded as 1.0 or zero. (For example, the EFB is shut down every Friday for maintenance.)

Month	Mean hourly average voltage, kV
June	12.4
July	11.6
August	10.9
Average	11.6

The manufacturer's recommended bed voltage range is 5 to 10 kV. The average voltages during the 1992, 1993, and 1996 performance tests were 6.7 kV, 11 kV, and 14 kV, respectively. Based on all data reviewed, greater than 8 kV was chosen as the indicator range for the hourly average EFB bed voltage. If the hourly average bed voltage drops below 8 kV during periods of normal operation (excludes shutdown periods), corrective action will be initiated.

Figure A.11-3 shows the hourly average EFB ionizer current for the month of June. From Figure A.11-3 it can be seen that the EFB typically operates at an ionizer current in the range of 2 to 5 mA. The mean hourly average currents for June, July, and August are shown below. In addition, the manufacturer's recommended range is 2 to 4 mA. Therefore, the indicator range chosen was an hourly average current greater than 2 mA. If the hourly average ionizer current drops below 2 mA during normal operation (excludes shutdown periods), corrective action will be initiated.

Month	Mean hourly average current, mA
June	2.8
July	2
August	2
Average	2.3

Emissions test results and indicator data are presented below for the 1992, 1993, and 1996 performance tests. The 1992 and 1993 tests were conducted while drying pine; the 1996 test was conducted while drying Douglas fir. The EFB is subject to a PM emission limitation of 0.30 lb/MSF (4.1 lb/hr). Both limits were met during all three performance tests.

Year	PM emissions, gr/dscf	PM emissions, lb/MSF	PM emissions, lb/hr	Average voltage, kV	Average ionizer current, mA	Average EFB inlet temperature, ˚F
1992	0.016	0.16	1.5	6.7	4.9	153
1993	0.015	0.22	2.0	10.8	2.8	154
1996	0.02	0.30	1.1	14	1.4	189

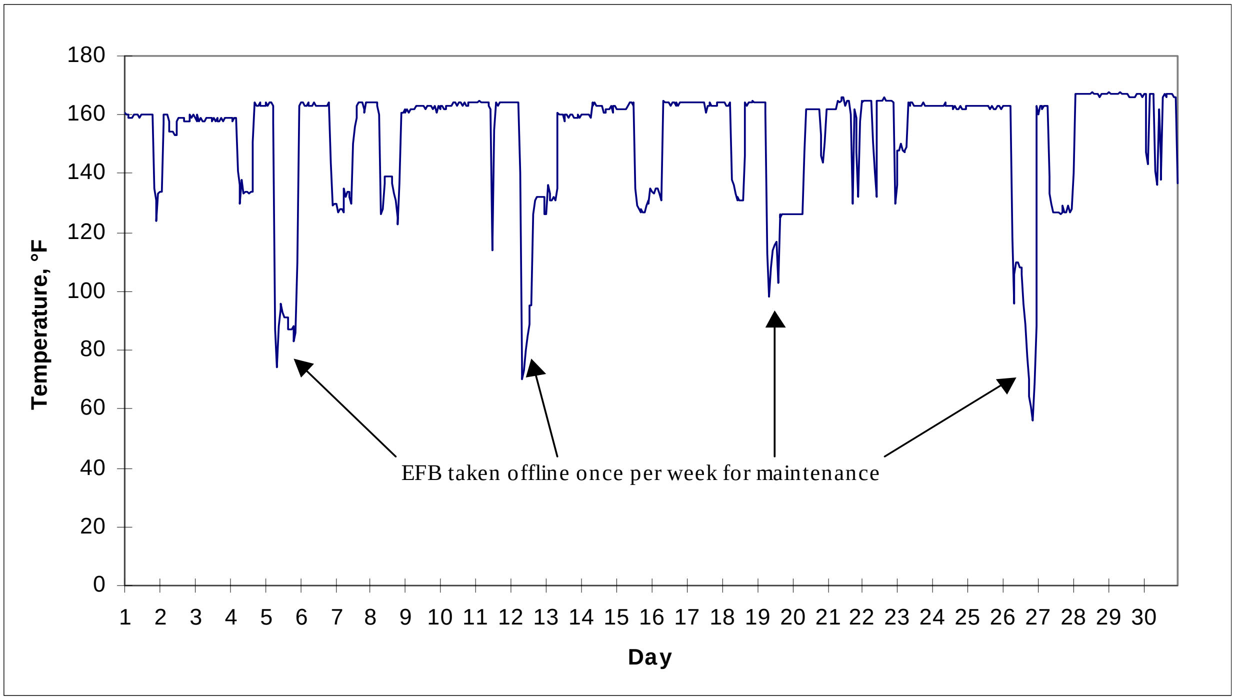

Figure A.11-1. June EFB inlet temperature (hourly average).

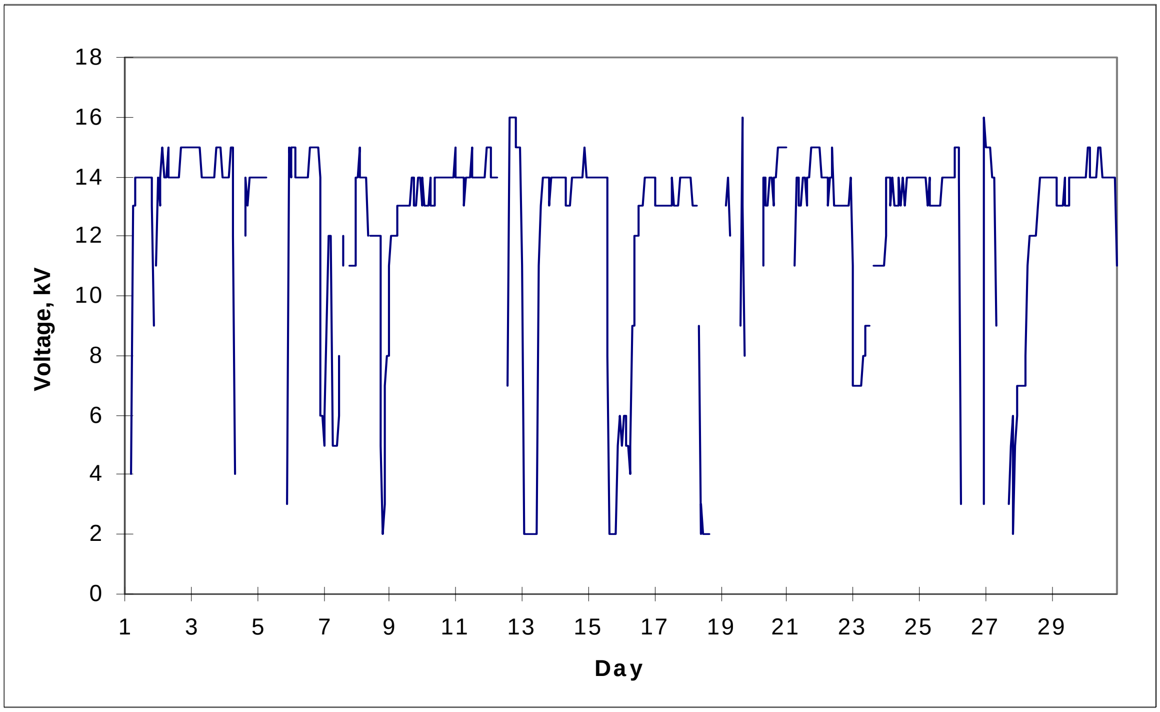

Figure A.11-2. June EFB bed voltage (hourly average).

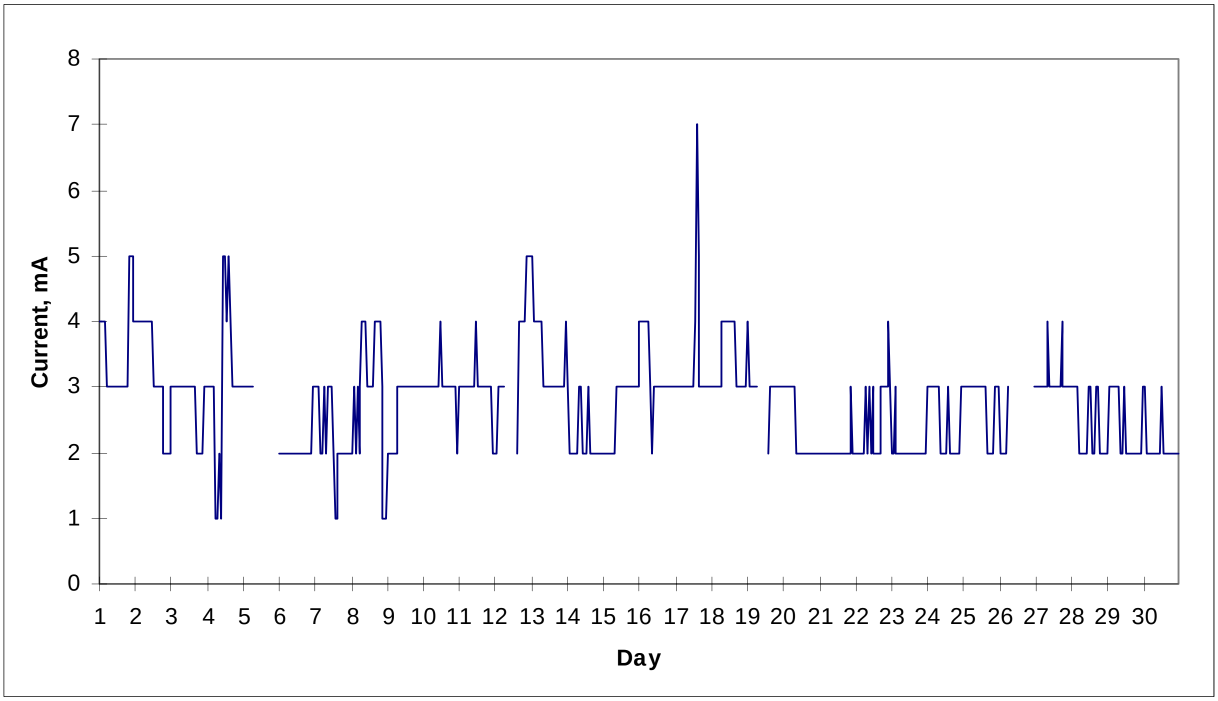

Figure A.11-3. June EFB ionizer current (hourly average).

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A.12 FABRIC FILTER FOR PM CONTROL--FACILITY L

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EXAMPLE COMPLIANCE ASSURANCE MONITORING
FABRIC FILTER FOR PM CONTROL -- FACILITY L

I. Background

A. Emissions Unit

Description:	Ceramic Fiber Blanket Manufacture
Identification:	Zone 1 Node 8
Facility:	Facility L Anytown, USA

B. Applicable Regulation, Emission Limit, and Monitoring Requirements

Regulation:	Permit
Emission limits (particulate matter):	0.35 lb/hr
Monitoring requirements:	Bag leak detector required on baghouse exhaust

C. Control Technology

Pulse-jet baghouse operated under negative pressure

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.12-1.

TABLE A.12-1. MONITORING APPROACH

I. Indicator	Triboelectric Signal
Approach	A triboelectric monitor is installed at the baghouse exhaust. An alarm will sound when the signal remains over a preset limit for 15 seconds to indicate a broken filter bag.
II. Indicator Range	An excursion is defined as a triboelectric signal greater than 70 percent of scale for 15 seconds. Excursions trigger an inspection, corrective action, and a reporting requirement. A triboelectric signal of zero during process operation will trigger an investigation for control device bypass.
III. Performance Criteria A. Data Representativeness	The data are collected at the emission point - the probe is located inside the baghouse exhaust duct. The triboelectric signal is directly proportional to the amount of particulate in the exhaust if factors such as velocity and particle size remain relatively constant.
B. Verification of Operational Status	NA
C. QA/QC Practices and Criteria	The triboelectric probe is inspected periodically (at least monthly) for dust buildup. The monitor has an automatic internal calibration function for the electronics.
D. Monitoring Frequency	The triboelectric signal is monitored continuously.
Data Collection Procedures	One hour of data are displayed on the monitor in the control room at 2 second intervals. When an alarm occurs (signal over 70 percent for 15 seconds), it is logged electronically. Six-minute averages also are archived on the computer network as a historical data record.
Averaging Period	None.

JUSTIFICATION

I. Background

The baghouse controls emissions from a ceramic fiberboard felting process and a production line in the spun fiber area that is used to manufacture ceramic fiber blankets used for insulation. The raw material (kaolin) is transferred to melting furnaces that are heated using electric current. The liquid melt stream flows from the bottom of the furnace and is spun into fiber in the collection chamber and formed into a fiber mat on a conveyor traveling below the chamber. Needling is used to lock the fibers together and an oven dries the blanket. The blanket then passes over a cooling table and is cooled by the passage of air through the blanket. It is then trimmed to size and packaged. Dust emission points ducted to the baghouse include the board felting process and cooling table.

The process stream exhaust is controlled by a pulse-jet baghouse operated under negative pressure. The controlled air stream is at ambient conditions. The baghouse was manufactured by Sly and is a single compartment baghouse containing 16 rows and a total of 176 bags. The air flow through the baghouse is approximately 12,000 dscfm. Air flow through the system is maintained by a single induced-draft fan downstream of the baghouse. The cleaned gas is exhausted from a 24-inch wide rectangular duct. The baghouse residue is continuously discharged from the collection hopper into a bin by a screw feeder.

II. Rationale for Selection of Performance Indicators

The bag leak monitor operates using the principles of frictional electrification (triboelectricity) and charge transfer. As particles in the baghouse exhaust gas stream collide with the sensor rod mounted on the inside of the exhaust duct, an electrical charge is transferred, generating a small current that is measured and amplified by the triboelectric monitor. The processing electronics are configured to produce a continuous output and an alarm at a specified level.

The signal produced by the triboelectric monitor is generally proportional to the particulate mass flow, but can be affected by changes in a number of factors, such as humidity, exhaust gas velocity, and particle size. However, in baghouse applications, these factors are not expected to vary considerably during normal operation. Therefore, an increase in the triboelectric signal indicates an increase in particulate emissions from the baghouse.

Pulse-jet baghouse filters are cleaned using a burst of air, which dislodges the filter cake from the bags and causes a momentary increase in particulate emissions until the filter cake builds up again. The triboelectric monitor can be configured with a short (or no) averaging time to display the baghouse cleaning cycle activity and monitor increases in a particular row's cleaning peak, or with a long signal averaging period to detect an overall increasing trend in the baghouse's emissions. Trends in the cleaning peaks are monitored and high cleaning peaks that may indicate leaking or broken bags requiring maintenance trigger an alarm.

Bypass of the control device will only occur if the baghouse fan is not operating. In this case, the triboelectric signal would be zero.

III. Rationale for Selection of Indicator Ranges

An excursion is defined as a triboelectric monitor signal greater than 70 percent of scale for 15 seconds. When an excursion occurs, corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported.

The triboelectric monitoring system has the capability for dual alarms: an early warning alarm and a broken bag alarm. The early warning alarm is set just above the normal cleaning peak height (40 percent of scale). The broken bag alarm was set by injecting dust into the clean air plenum of the baghouse and noting the signal level just before the point at which visible emissions were observed at the baghouse exhaust (70 percent of scale). A 15-second delay time is also used, so the alarm won't activate due to short spikes that are not associated with the cleaning cycle and do not indicate broken bags (e.g., a short spike due to a small amount of particulate that accumulates on the duct wall and then breaks free).

The most recent performance test using EPA Method 5 was conducted on April 22-24, 1997. Three Method 5 test runs (one 240-minute, one 384-minute, and one 288-minute run) were conducted, one test per day. The average measured PM emissions were extremely low: 0.01 lb/hr. During the emissions tests, the triboelectric signal was recorded continuously at a 1-second frequency. Figure A.12-1 shows the triboelectric signal for 1 hour during Run 2. The sharp peaks represent the brief increase in emissions immediately following the baghouse cleaning cycle, before the filter cake builds up again. All cleaning peaks shown on this graph are less than 35 percent of scale, which is below both alarm levels. There was one momentary spike that could not be explained. The alarms were not activated during the emission testing and the emissions were below the emission limit of 0.35 lb/hr.

Monitoring data for a period of approximately 2 months (January 29 - April 2, 1997) were reviewed, including 6-minute average archived triboelectric signal data and the electronic alarm log. Review of these data indicated that the early warning alarm was activated eight times and the broken bag alarm was activated once (i.e., there was one excursion). Based on all data reviewed, the selected indicator and indicator level appears to be appropriate for this facility.

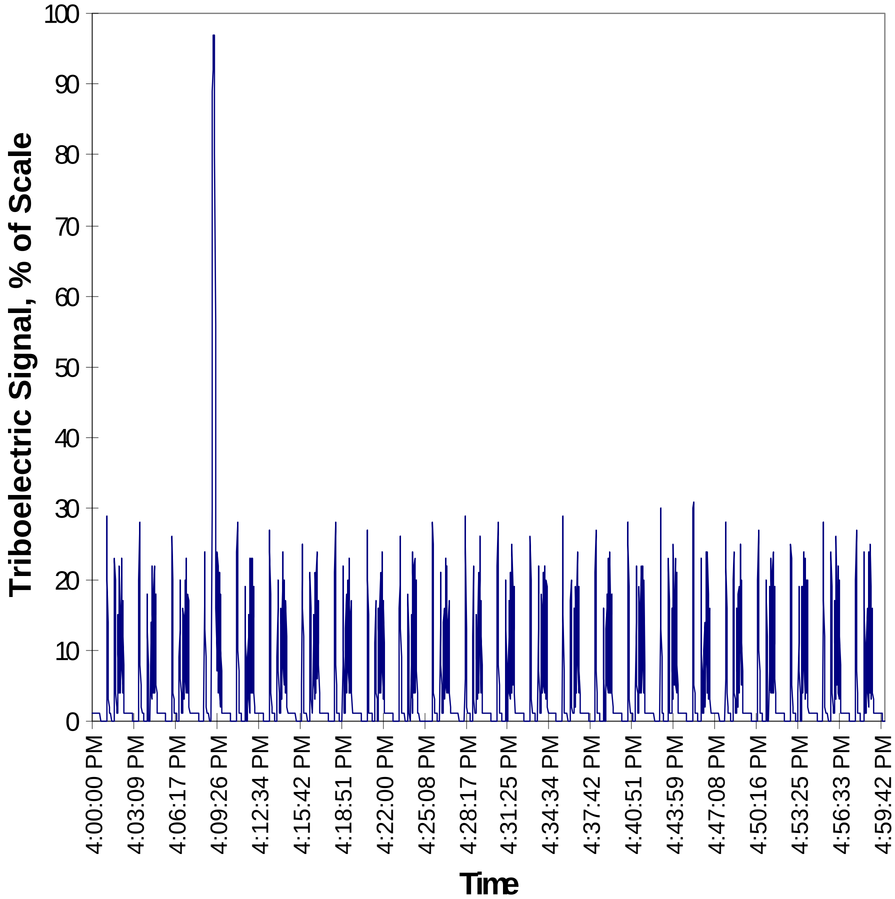

Figure A.12-1. Triboelectric signal during 1-hour of Method 5 Run 2.

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A.13 FABRIC FILTER FOR PM CONTROL--FACILITY M

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EXAMPLE COMPLIANCE ASSURANCE MONITORING:
FABRIC FILTER FOR PM CONTROL -- FACILITY M

I. Background

A. Emissions Unit

Description:	Primary nonferrous smelting and refining
APCD ID:	17-DC-001, 17-DC-002
Facility:	Facility M Anytown, USA

B. Applicable Regulation, Emission Limits, and Monitoring Requirements

Regulation:	Permit; OAR 340-025-0415, 340-021-0030
Emission limits:	
Opacity:	20 percent
Particulate matter:	0.2 gr/dscf
Monitoring requirements:	Visible emissions (VE), pressure drop, fan amperage, inspection and maintenance program

C. Control Technology:

Reverse-air baghouses operated under negative pressure

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.13-1.

TABLE A.13-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2	Indicator No. 3	Indicator No. 4
I. Indicator	Visible emissions	Pressure drop	Fan amperage	Inspection/maintenance
Measurement Approach	Method 9 observations performed daily.	Pressure drop through the baghouse is measured continuously using a differential pressure gauge.	Fan amperage is measured continuously using an ammeter.	Daily inspection according to I/M checklist; maintenance performed as needed.
II. Indicator Range	The indicator range is an opacity less than 20 percent (6-min. avg.). Excursions trigger an inspection, corrective action, and a reporting requirement.	The indicator range is a pressure drop between 5 and 15 in. H_2O. Excursions trigger an inspection, corrective action, and a reporting requirement.	The indicator range is fan amperage above 100. Excursions trigger an inspection, corrective action, and a reporting requirement. Fan operation also indicates control device is not being bypassed.	NA
III. Performance Criteria A. Data Representativeness[a]	Observations are performed at the baghouse exhaust while the baghouse is operating.	Pressure drop across the baghouse is measured at the baghouse inlet and exhaust. The minimum accuracy of the device is ±0.5 in. H_2O.	Fan amperage is measured at the fan by an ammeter. The minimum accuracy is ±5A.	Inspections are performed at the baghouse.
B. Verification of Operational Status	NA	NA	NA	NA
C. QA/QC Practices and Criteria	Observer is certified annually.	Pressure gauge calibrated quarterly. Pressure taps checked daily for plugging.	Fans checked during daily inspection. Ammeter zeroed when unit not operating.	Qualified personnel perform inspection.
D. Monitoring Frequency	Daily 6-minute observation.	Pressure drop is measured continuously.	Fan amps are monitored continuously.	Daily inspection.
Data Collection Procedures	Method 9 observations are conducted by a certified RM9 observer.	A strip chart records the pressure drop continuously.	A strip chart records the fan amps continuously.	Records are maintained to document the daily inspection and any required maintenance.
Averaging period	6 minutes	None	None	NA

[a]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

MONITORING APPROACH JUSTIFICATION

I. Background

Primary nonferrous metal smelting and refining operations include mining; drying; crushing, screening, and rejecting; calcining and melting; refining; casting; and other operations. The ore is dried to remove most of the free moisture. The dried ore is then calcined to remove the remaining free moisture and a portion of the chemically-combined moisture. A portion of the iron is reduced, using carbon. The ore is then melted and reduced. The refined metal is cast into ingots or shot, as requested by the customer.

The monitoring approach outlined here applies to melt furnace baghouses Nos. 1 and 2. These baghouses control dust from four 23 MW electric melt furnaces (Nos. 1 through 4) and two rotary kilns. They are ICA reverse-air baghouses with 12 compartments apiece; each compartment contains 128 bags. Air flow through each baghouse is maintained by two induced-draft variable speed fans downstream of each baghouse. The capacity of each baghouse is 275,000 acfm.

II. Rationale for Selection of Performance Indicators

Visible emissions (opacity) was selected as a performance indicator because it is indicative of good operation and maintenance of the baghouse. When the baghouse is operating optimally, there will be little visible emissions from the exhaust. In general, an increase in visible emissions indicates reduced performance of the baghouse (e.g., loose or torn bags). These emissions units have an opacity standard of 20 percent. A 6-minute Method 9 observation is performed daily.

The pressure drop through the baghouse is monitored continuously. An increase in pressure drop can indicate that the cleaning cycle is not frequent enough, cleaning equipment is damaged, or the bags are becoming blinded. Decreases in pressure drop may indicate significant holes and tears or missing bags. However, opacity is a much more sensitive indicator of holes and tears than pressure drop.

Good operation of the fan is essential for maintaining the required air flow through the baghouse. The fan amps setting is selected to be high enough to draw the air required to collect the dust from the four melting furnaces and two rotary kilns. Excess gas velocity can cause seepage of dust particles through the dust cake and fabric. Fan amperage is an indicator of proper fan operation and adequate air flow through the baghouse (the exhaust gas is not bypassing the baghouse).

Implementation of a baghouse inspection and maintenance (I/M) program provides assurance that the baghouse is in good repair and operating properly. Once per day, proper operation of the compressor is verified to ensure that the bags are being cleaned. Proper operation of the cleaning cycle facilitates gas flow through the baghouse and the removal of particulate, and also helps prevent blinding of the filter bags. Operation at low pressures can result in inadequate cleaning, especially near the bottoms of the bags. Other items on the daily I/M checklist include the dust pump, induced-draft fans, reverse air fan, dust screws, rotary feeders, bins, cleaning cycle operation, leak check, and compartment inspection for bad bags.

III. Rationale for Selection of Indicator Ranges

The indicator range for opacity is a 6-minute average opacity of less than 20 percent. This indicator range was selected based on the facility's permit requirements and historical operating data. Review of data collected in May 1997 indicate an average opacity of 10.9 percent (6-minute average) for baghouse No.1, with 6-minute daily average readings ranging from 2.9 to 19.8 percent. For baghouse No. 2, the average was 11.5 percent, with 6-minute average readings ranging from 3.1 to 18.8 percent. The 6-minute average is made up of observations taken at 15-second intervals.

The indicator range for baghouse pressure drop is a pressure drop between 5 and 15 in. H_2O. This range was selected based on historical data obtained during normal operation. The pressure drop is typically around 10 to 11 in. H_2O. A review of data collected during April and May of 1997 show a range of about 9 to 14 in. H_2O. The indicator range selected for the fan amperage is an amperage greater than 100. This range was set based on the level maintained during normal operation. The fan is operated at a high enough setting to draw the required air for dust collection from the four furnaces and two rotary kilns. It typically operates in the 100 to 157 amp range, with an average of 125 amps. When a problem with the baghouse is detected during an inspection, the problem is recorded on the inspection log and corrective action is initiated immediately.

The most recent performance test using compliance test methods (RM 5) was conducted on July 8-9, 1997. During this test, the average measured PM emissions were 0.080 gr/dscf for baghouse No. 1 and 0.053 gr/dscf for baghouse No. 2 (both were below the compliance limit of 0.2 gr/dscf). Opacity observations during testing averaged 17 percent for both baghouses. The complete test results are documented in the test report. Prior to the performance test, an inspection of the baghouse was performed to ensure that it was in good working order, with no leaks or broken bags.

A.14 SCRUBBER FOR PM CONTROL--FACILITY N

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EXAMPLE COMPLIANCE ASSURANCE MONITORING:
SCRUBBER FOR PM CONTROL--FACILITY N

I. Background

A. Emissions Unit

Description:	Wood Fiber Dryer
Identification:	Dryer No. 3
Facility:	Facility N Anytown, USA

B. Applicable Regulation, Emission Limit, and Monitoring Requirements

Regulation:	OAR 340-30-021
Emission limit:	
Particulate matter:	0.55 lb/1,000 sqft dried or 15.5 lb/hr total PM limit for all sources at MDF plant, excluding boiler, truck dump, and storage areas.
Monitoring requirements:	Pressure drop across wet scrubber, scrubber inlet and outlet temperature.

C. Control Technology

Wet scrubber

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.14-1.

TABLE A.14-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2
I. Indicator	Pressure drop across wet scrubber	Wet scrubber inlet and exhaust gas temperatures
Measurement Approach	The pressure drop is monitored with a differential pressure transducer.	The wet scrubber inlet and exhaust gas temperatures are monitored with RTD's.
II. Indicator Range	An excursion is defined as a pressure drop greater than 6.5 inches of water. Excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion is defined as a 1-hour average scrubber exhaust gas temperature greater than 150°F. Scrubber inlet gas temperature must be greater than the exhaust gas temperature during scrubber operation. Excursions trigger an inspection, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness[a]	The monitoring system consists of a differential pressure transducer which compares the pressure in the duct immediately upstream of the water spray to the atmospheric pressure. Its minimum accuracy is ± 2 percent.	The monitoring system consists of two RTD's located in the ductwork immedately upsream and downstream of the scrubber. Their minimum accuracy is ± 2 percent.
B. Verification of Operational Status	NA	NA
C. QA/QC Practices and Criteria	The differential pressure transducer reading is compared to a U-tube manometer monthly.	The RTD's are calibrated monthly by comparison to a calibrated thermocouple, and annually using a NIST traceable thermometer.
D. Monitoring Frequency	The signal from the differential pressure transducer is sampled several times per minute.	The signal from the RTD is sampled several times per minute.
Data Collection Procedures	1-minute averages are computed and displayed. The PC then computes a 1-hour average using each 1-minute average and stores it.	1-minute averages are computed and displayed. The PC then computes a 1-hour average using each 1-minute average and stores it.
Averaging Period	1-minute and 1-hour averaging periods.	1-minute and 1-hour averaging periods.

[a]Values listed for accuracy specifications are specific to this example and are not intended to provide the criteria for this type of measurement device in general.

JUSTIFICATION

I. Background

The pollutant-specific emission unit is a wood fiber dryer denoted as the face system and used in the manufacture of medium density fiberboard. Fiber from the dryer is removed by a low energy cyclone. The exhaust from the cyclone is ducted to the scrubber. In the last 20 feet of the duct, water is sprayed into the air stream. The emissions then enter the scrubber, where baffling removes the suspended water droplets. The temperature drop across the spray section and the pressure drop between the inlet to the spray section and the scrubber discharge are monitored.

II. Rationale for Selection of Performance Indicators

Pressure drop was selected as a performance indicator because it indicates the water level in the scrubber. Maintaining an adequate water flow insures adequate particulate removal. A high pressure drop indicates the water level in the scrubber is too high. Usually, high water level problems are caused by a malfunction of the scrubber water level controller. A low pressure drop is caused by a loss of water in the scrubber.

Temperature was selected because a temperature drop across the scrubber indicates that the water sprays are operating. A loss of temperature differential indicates little or no water is being applied to the exhaust gas stream, which in turn causes little particulate to be removed from the exhaust. The most common cause of water loss is plugged nozzles due to wood fibers in the recycled water.

Bypass of a scrubber only occurs if the scrubber is shut down during process operation. The dryer is then controlled only by the cyclone. These periods are documented and reported.

III. Rationale for Selection of Indicator Ranges

The selected indicator range for the scrubber exhaust gas temperature is less than 150°F (1 hour average). The selected indicator range for scrubber pressure drop is less than 6.5 in. H_2O. There is no lower limit for the pressure drop, since a high exhaust temperature will indicate a loss of water flow. When an excursion occurs, corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported.

The indicator levels for the scrubber pressure drop and inlet and exhaust gas temperatures are based on normal scrubber operation and performance test results. During source testing, the scrubber was operating under normal conditions and the average scrubber exhaust gas temperature was 132°F. With no water flowing through the scrubber, the exhaust temperature would be about 30 degrees hotter. Therefore, the exhaust temperature limit was set at 150°F. During the most recent performance test, the average pressure drop was 5.7 in. H_2O.

The most recent performance test using compliance test methods (ODEQ Method 7 for particulate) was conducted at this facility on November 20-21, 1996. Three test runs were conducted on the fiber dryer. During testing, the measured PM emissions from Dryer No. 3 averaged 0.008 gr/dscf (3.6 lb/hr). During the compliance test the scrubber exhaust particulate emissions were below the permit limit of 15.5 lb/hr. During the emissions test, the pressure drop and the scrubber inlet and outlet temperatures were measured continuously. The complete test results are documented in the test report.

Figures A.14-1 and A-14.2 show average hourly temperature and differential pressure data for scrubber No. 3 for the month of August 1997. The dips in the differential pressure and the temperatures indicate periods when the scrubber was not operating. Figure A.14-1 shows that the facility did not exceed the maximum outlet temperature limit of 150°F, and the inlet temperature exceeded the outlet temperature during periods of scrubber operation. The average hourly scrubber inlet temperature was 157°F, with a maximum hourly inlet temperature of 189°F, and the average scrubber outlet temperature was 129°F, with a maximum hourly outlet temperature of 142°F. The average temperature differential was 28°F. Figure A.14-2 shows that the facility did not exceed the maximum pressure drop during the month of August. The average differential pressure was 4.5 in. H_2O during the month of August, with a maximum of 6 in. H_2O.

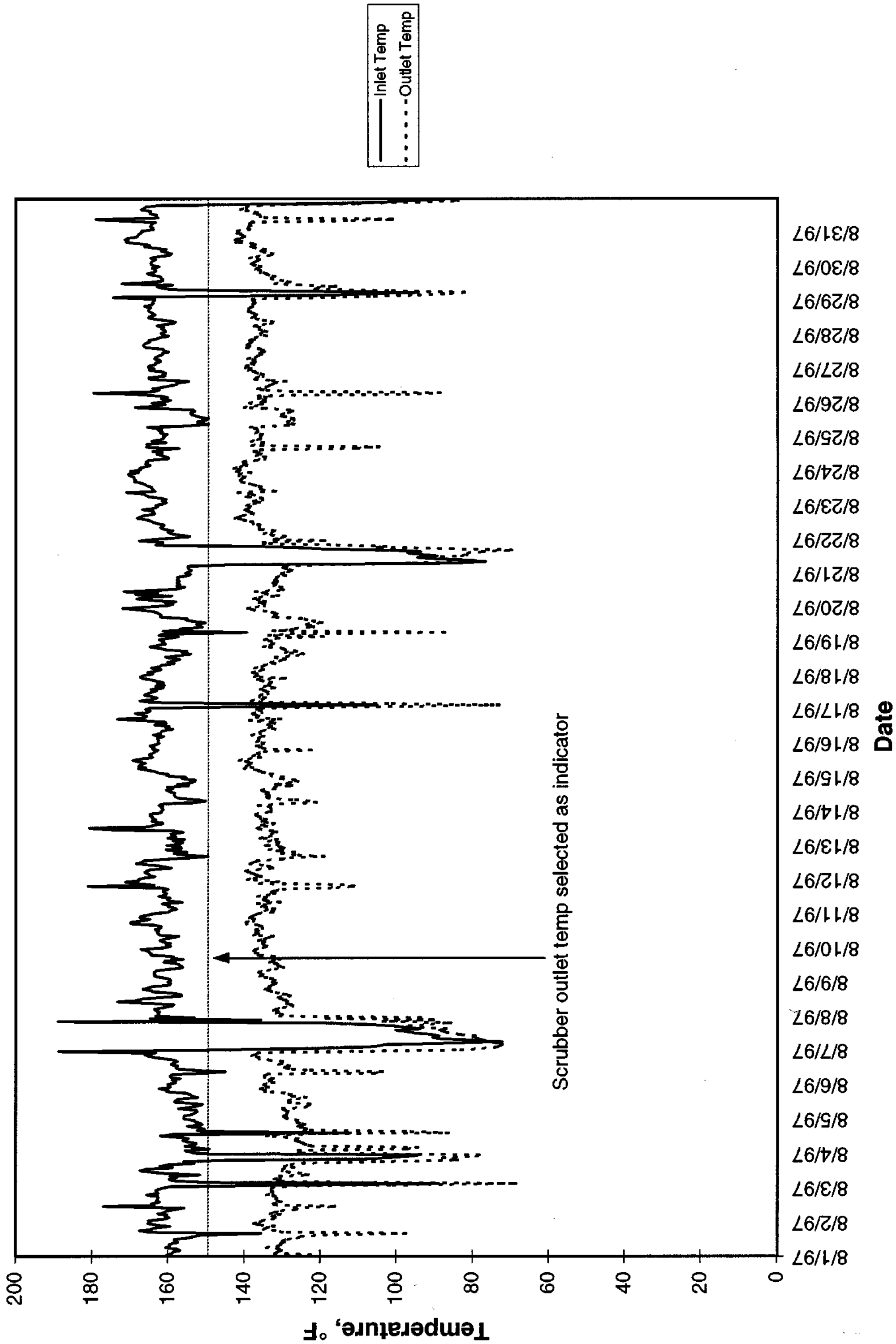

Figure A.14-1. August 1997 scrubber inlet and outlet temperatures.

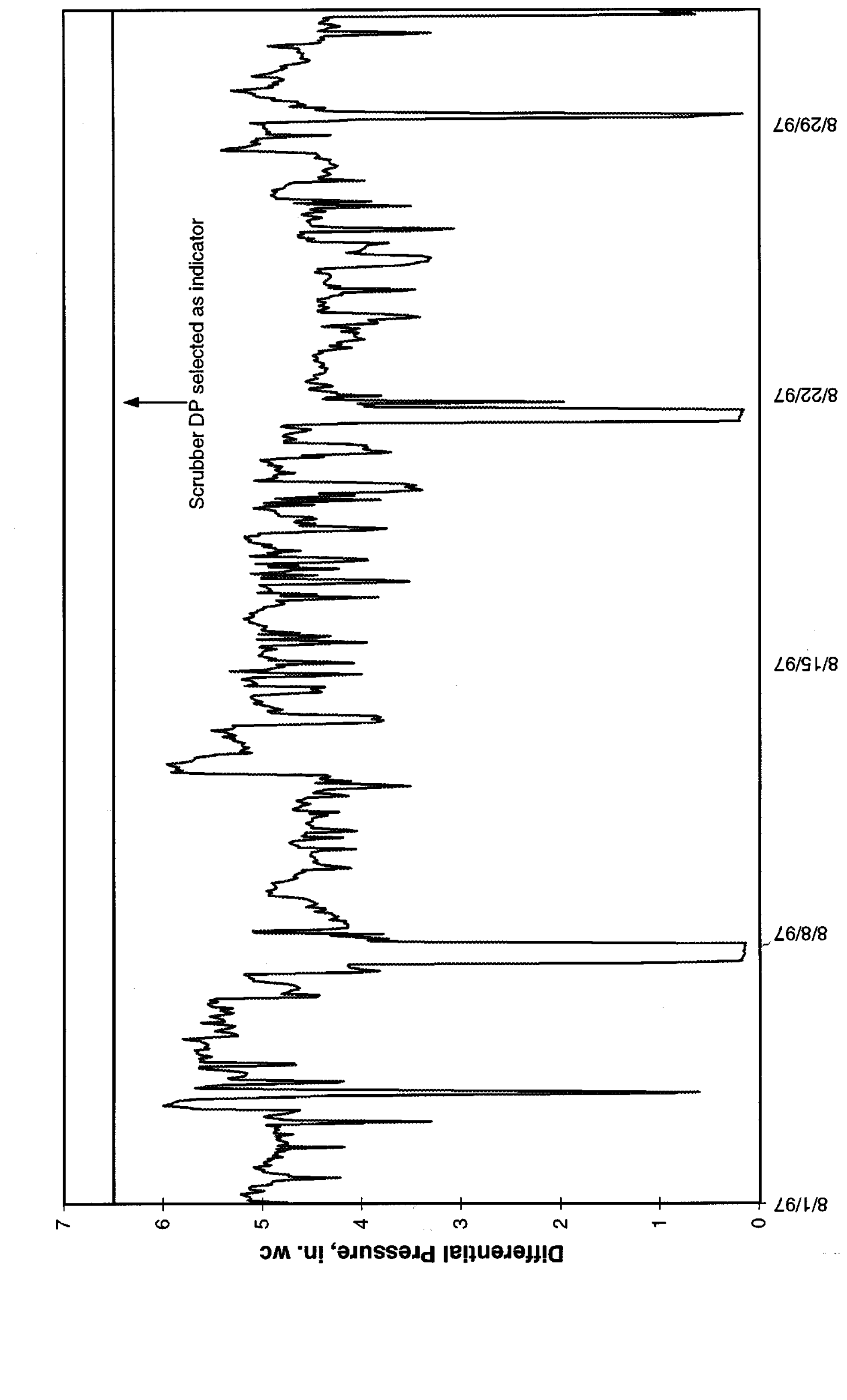

Figure A.14-2. August 1997 scrubber differential pressure.

A.16 CONTROL DEVICE (BOILER) BYPASS – FACILITY R

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EXAMPLE COMPLIANCE ASSURANCE MONITORING
CONTROL DEVICE (BOILER) BYPASS – FACILITY R

I. Background

A. Emissions Unit

Description:	APCD (boiler) bypass valve
Identification:	East and West boilers
Facility:	Facility R Anytown, USA

B. Applicable Regulation, Emissions Limit, and Bypass Monitoring Requirements

Regulation:	Permit, State regulation
Emissions Limits: CO:	 200 ppm
Monitoring Requirements:	Temperature downstream of bypass valve.

C. Control Device

Two boilers in parallel.

II. Monitoring Approach

The key elements of the bypass monitoring approach are presented in Table A.16-1. The selected indicators are the temperatures in the horizontal and vertical portions of the bypass line downstream of the boiler bypass valve. The temperatures are measured continuously; instantaneous temperature values are recorded every 15 minutes.

Note: This compliance assurance monitoring example is presented as an illustration of one approach to monitoring for control device bypass. The example presents only the parameters monitored to ensure the control device is not being bypassed. Parameters to ensure the control device is operating properly also are monitored, but are not discussed in this example.

TABLE A.16-1. BYPASS MONITORING APPROACH

I. Indicator	Vertical and horizontal bypass line temperatures
Measurement Approach	Thermocouples downstream of bypass valve.
II. Indicator Range	An excursion is defined as a vertical line temperature of greater than 550˚F or a horizontal line temperature of greater than 250˚F. An excursion shall trigger an inspection, corrective action as necessary, and a reporting requirement.
III. Performance Criteria A. Data Representativeness	Gas temperature is measured using thermocouples in two locations downstream of the bypass valve, prior to the common exhaust stack. The minimum accuracy of the thermocouples is 2.2˚C (±4˚F) or ±0.75 percent of the temperature measured in ˚C, whichever is greater.
B. Verification of Operational Status	NA
C. QA/QC Practices and Criteria	The thermocouples are checked annually with a redundant temperature sensor. Acceptance criteria: ±15˚F of the measured value.
D. Monitoring Frequency	The temperatures are measured and recorded every 15 minutes.
Data Collection Procedures	The temperatures are recorded by the computer control system every 15 minutes.
Averaging period	None.

MONITORING APPROACH JUSTIFICATION

I. Background

The FCCU regenerator flue gas contains approximately 10 percent CO by volume, and is referred to as “CO gas.” The CO gas is routed to two tangentially-fired boilers (East and West) in parallel, designed with sufficient residence time, turbulence, and temperature to fully combust the CO to CO_2. The exhaust from each boiler enters a common stack, where an emission limit of 200 ppm CO must be met. The FCCU regenerator is equipped with piping that enables the CO gas to bypass the boilers and flow directly to the common stack. Use of the bypass line is essential for the safe operation of the boilers during startup and shutdown periods. The piping is equipped with a butterfly valve. The position of this valve is monitored by the computer control system, and is kept fully closed during normal operation. The operators routinely pack the valve with ceramic fiber insulation to prevent leaks. A process schematic is shown in Figure A.16-1.

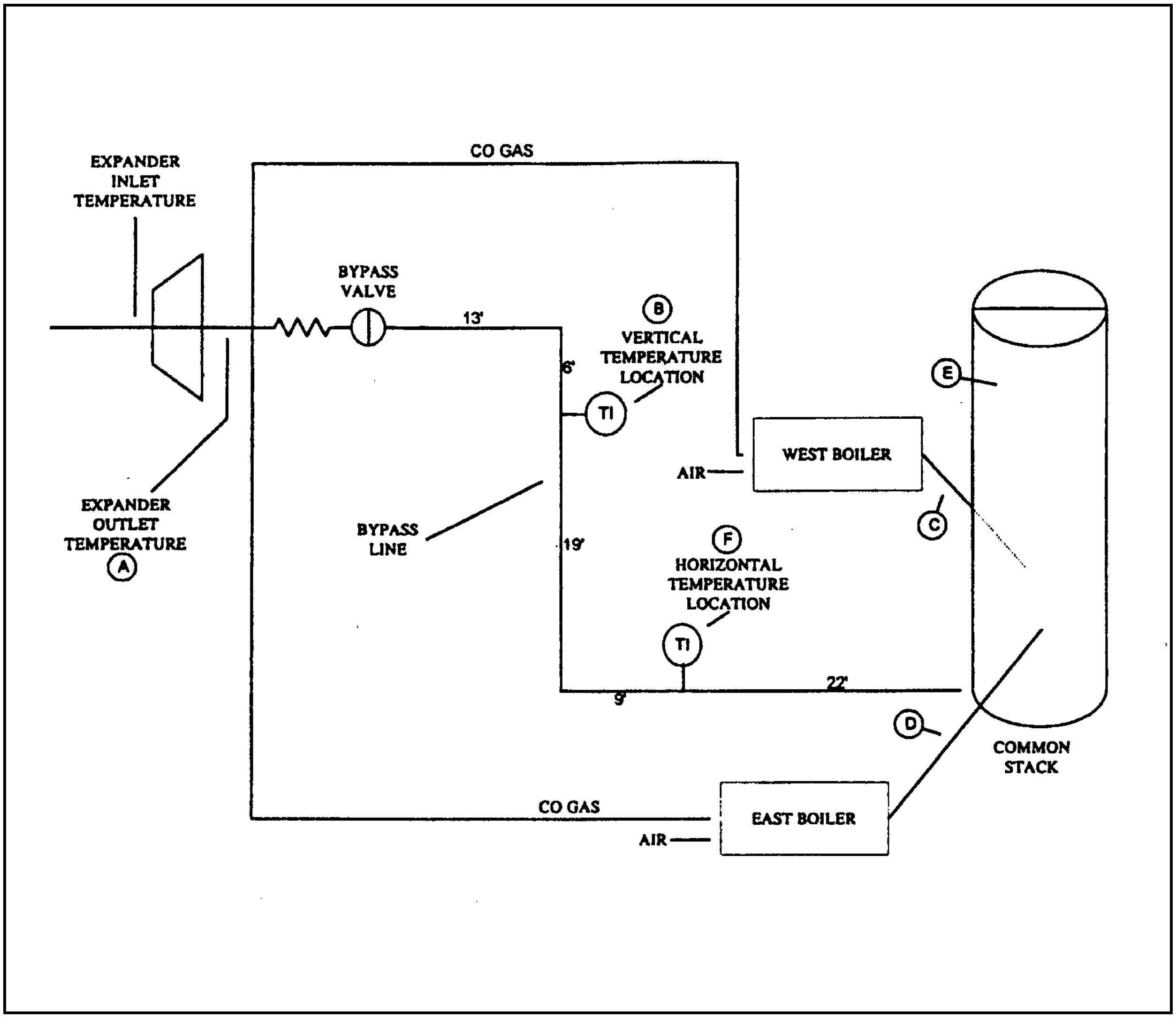

Figure A.16-1. Process schematic.

II. Rationale for Selection of Performance Indicator

Although the bypass valve position is computer-controlled, it has a tendency to leak if not tightly packed with insulation. Therefore, the operators need an indicator to detect leakage of the valve that might cause excess CO emissions. Testing was performed to determine the effect of boiler load on CO emissions. The results showed the boilers emitted negligible CO regardless of operating load. The effect of a leaky valve on CO emissions (measured in the stack) and the gas temperature downstream of the bypass valve then was examined. The results showed that as the amount of valve leakage increases and the CO concentration in the common stack increases, the temperature downstream of the valve also increases because of the high temperature of the CO gas (the temperature of the CO gas upstream of the valve is approximately 960˚F). Therefore, the selected indicator of a leaky or open bypass valve is the temperature downstream of the bypass valve.

III. Rationale for Selection of Indicator Range

A test program was conducted to determine the relationship between the gas temperature downstream of the bypass valve and the CO emissions. The gas temperature in the bypass line and the CO concentration in the common stack were measured at baseline conditions (no leakage) and for eight different leak conditions. Temperature was measured at two locations: the vertical section of the bypass line (19 feet downstream of the valve) and the horizontal section of the bypass line (47 feet downstream of the valve). During normal conditions, when the CO level in the common stack was less than 50 ppm, the temperature in the vertical section was roughly 410˚F, while the temperature in the horizontal section was 110˚F.

To induce leakage of the valve, the valve was opened 5 percent on day 1 and 3 percent on day 2, and immediately closed. The packing material broke loose during each opening. On inducing the leaks, the temperature downstream of the valve rose quickly and eventually reached a stable temperature. To evaluate the effect of adding packing to the valve on downstream temperatures and CO levels in the common stack, the valve was progressively packed with ceramic fiber insulation and allowed to stabilize. The level of CO in the stack and the downstream temperatures decreased with the amount of insulation added.

For each of the seven test runs or conditions, multiple data points were collected and recorded for the temperatures and the CO concentrations. Rather than calculating the average as the representative value for each run as is traditionally done with performance test data, a percentile measure was determined from the data for each run. The percentile value for temperature and for CO concentration were selected independently. All of the temperature readings for the run were ranked from lowest to highest, and the value that coincides with the 5^{th} percentile for all of the temperature readings for that run was selected. Then, all of the CO concentration readings for the run were ranked lowest to highest, and the value that coincides with the 95^{th} percentile for all of the CO concentration readings for that run was selected. These percentile values were selected to represent the test run instead of an average value. Table A.16-2 shows a summary of the readings for each test condition or run; both the average values and the percentile values are shown. Table A.16-2 shows data for the vertical duct temperature, horizontal duct temperature, and CO concentration for each test condition.

Figures A.16-2 and A.16-3 show the relationship between CO emissions and the gas temperature at the horizontal and vertical locations. The 5^{th} percentile temperature readings reflect levels at the lower end of the range for each condition that can alert the boiler operator to bypass valve leakage. Conversely, since the CO levels varied during each test condition, the 95^{th} percentile CO levels for each test condition were selected to be conservative (on the high side). For added confidence, indicator ranges were developed for both measurement locations (it is expected that the two thermocouples will not fail at the same time). Based on the data collected during testing, an excursion is defined as a vertical duct temperature of greater than 550˚F or a horizontal duct temperature of greater than 250˚F. An excursion will trigger an inspection, corrective action as necessary, and a reporting requirement.

TABLE A.16-2. SUMMARY OF TEMPERATURE AND CO EMISSIONS LEVELS DURING TEST CONDITIONS

Condition	Test Period (minutes)	Vertical Temperature Readings (°F)		Horizontal Temperature Readings (°F)		CO Level (ppmvd at 50% excess air)	
		Average	5th Percentile	Average	5th Percentile	Average	95th Percentile
Baseline -- Normal operation, minimal leakage	222	410	405	112	109	39.5	44.5
Open1 -- Open/close bypass valve to force leakage (day 2)	8	*Transient Data Period*					
Leak -- Monitoring period following valve open/close	98	683	641	463	426	351	358
Pack1 -- Monitoring period after one tube of packing was injected into valve	10	*Transient Data Period*					
Pack2 -- Monitoring period after a second tube of packing was injected	57	676	671	453	449	229	230
Pack3 -- Monitoring period after a third tube of packing was injected	1084	634	629	341	307	169	191
Pack 45 -- Monitoring period after a fourth and fifth tube of packing was injected	176	482	443	179	160	30.0	35.7
Open 2 -- Close/open bypass valve to force leakage a second time (day 3)	9	*Transient Data Period*					
Leak 2 -- Monitoring period following valve open/close #2	105	641	604	443	411	242	248
Pack1X -- Monitoring period after one tube of packing was injected into valve after Leak 2	20	*Transient Data Period*					
Pack 2X -- Monitoring period after a second tube of packing was injected into valve after Leak2	122	588	577	397	389	123	127

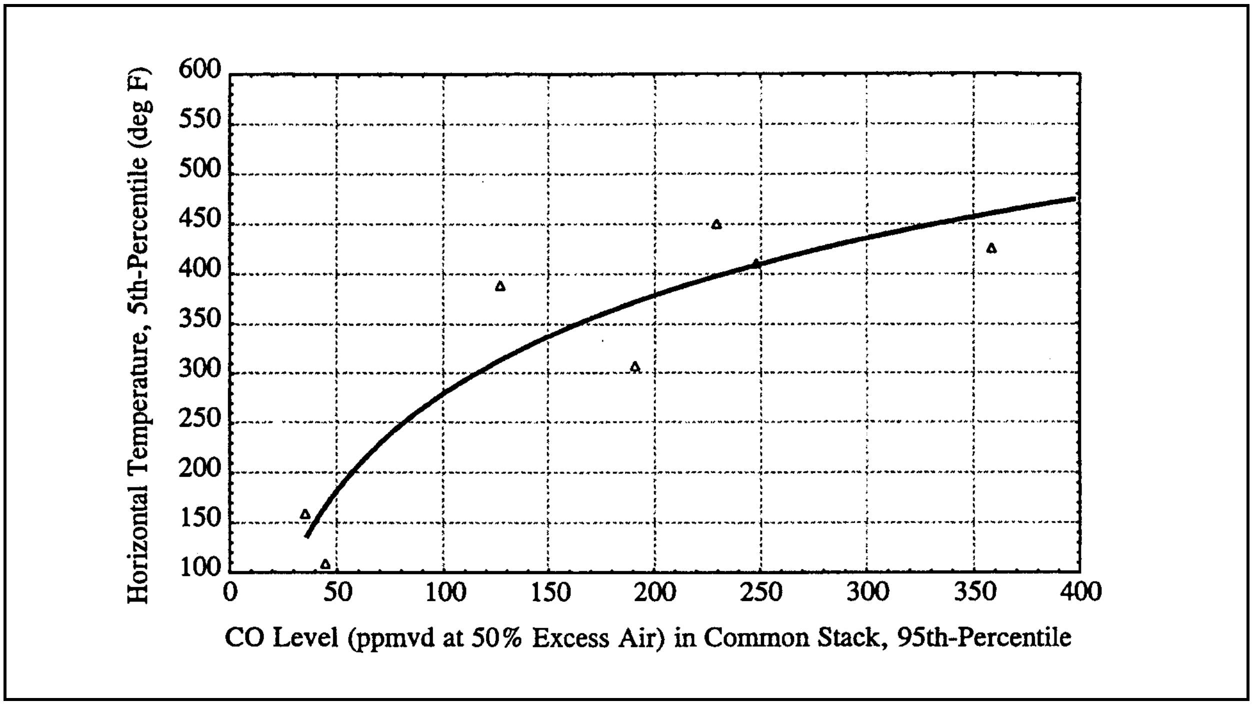

Figure A.16-2. CO Level (95th Percentile) in the Common Stack vs. Horizontal Temperature Measurement (5th Percentile).

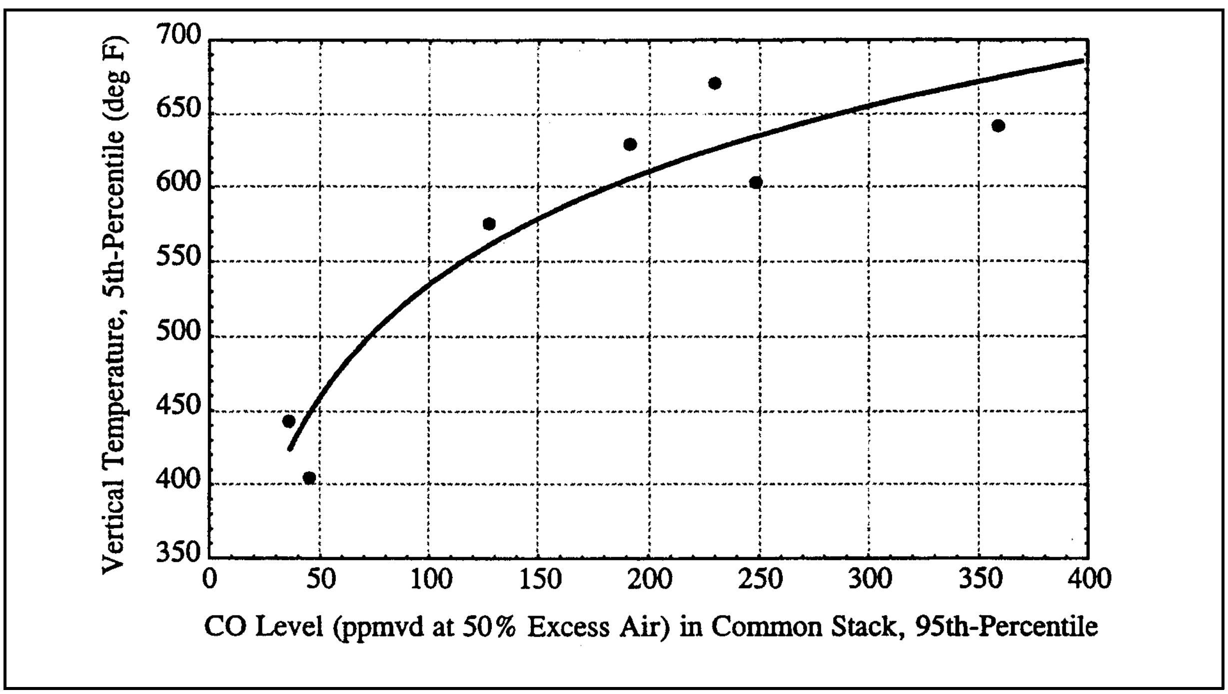

Figure A.16-3. CO Level (95th Percentile) in the Common Stack vs. Vertical Temperature Measurement (5th Percentile).

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A.17 VENTURI SCRUBBER FOR PM CONTROL--FACILITY S

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EXAMPLE COMPLIANCE ASSURANCE MONITORING
VENTURI SCRUBBER FOR PM CONTROL: FACILITY S

I. Background

A. Emissions Unit

Description:	Wood-fired boiler
Identification:	Boiler A
Facility:	Facility S Anytown, USA

B. Applicable Regulation, Emissions Limit, and Monitoring Requirements

Regulation: State regulation (Federally enforceable)

Emissions Limit:
Particulate Matter (PM): Determined using the following equation:

$$P = 0.5 *(10/R)^{0.5}$$

where:

P = allowable weight of emissions of fly ash and/or other PM in lb/mmBtu.

R = heat input of fuel-burning equipment in mmBtu/hr based on the measured percent of O_2 and volumetric flow rate.

The State rule also specifies that the opacity of visible emissions cannot be equal to or greater than 20 percent, except for one 6-minute period per hour of not more than 27 percent.

Monitoring Requirements: Continuous Opacity Monitoring System (COMS)

C. Control Technology

Venturi scrubber

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.17-1. The indicators of performance are the boiler exhaust O_2 concentration (a measure of excess air level) and the differential pressure across the scrubber venturi.

TABLE A.17-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2
I. Indicator	Exhaust gas oxygen concentration	Scrubber differential pressure
Measurement Approach	O_2 monitor	Differential pressure transducer.
II. Indicator Range	An excursion is defined as an hourly boiler exhaust O_2 concentration of less than 11 or greater than 16 percent. Excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion is defined as a 1-hour average differential pressure below 10.0 inches of water. Excursions trigger an inspection, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness	The O_2 monitor is located in the boiler exhaust.	The differential pressure transducer monitors the static pressures upstream and downstream of the scrubber's venturi throat.
B. Verification of Operational Status	NA	NA
C. QA/QC Practices and Criteria	Daily zero and span checks. Adjust when drift exceeds 0.5 percent O_2.	Quarterly comparison to a U-tube manometer. Acceptance criteria is 0.5 in. w.c.
D. Monitoring Frequency	Measured continuously.	Measured continuously.
Data Collection Procedures	1-minute averages are computed and displayed. The PC then computes and stores a 1-hour average using the 1-minute averages.	1-minute averages are computed and displayed. The PC then computes and stores a 1-hour average using the 1-minute averages.
Averaging period	1-hour.	1-hour.

MONITORING APPROACH JUSTIFICATION

I. Background

The pollutant-specific emissions unit (PSEU) is PM from a wood-fired boiler. Particulate matter in the boiler's exhaust stream is controlled by a venturi scrubber. A COMS is required by the applicable State rule. However, water droplets in the boiler exhaust will interfere with the COMS measurements and consequently make the use of a COMS impractical. An alternative monitoring program utilizing parametric monitoring has been proposed. The monitoring approach includes continuous monitoring of the wood-fired boiler's excess air, the steam production rate, and the differential pressure across the scrubber's venturi throat.

II. Rationale for Selection of Performance Indicators

The operating conditions for this type of source (wood-fired boiler) can have a significant impact on the amount of particulate emissions created. Furthermore, for a venturi scrubber, the inlet particulate matter loading to the scrubber will have an impact on the emissions level from the scrubber (i.e., emissions from the scrubber are expected to increase as the loading to the scrubber increases for the same scrubber operating conditions). Site-specific emissions test data confirm these expectations. Therefore, indicators of performance of both the control device and process were selected for this source.

The scrubber differential pressure was selected as the indicator of control device performance. The differential pressure is proportional to the water flow and air flow through the scrubber venturi throat and is an indicator of the energy across the scrubber and the proper operation of the scrubber within established conditions.

Excess air levels can have a significant impact on boiler performance. Excess air is defined as that air exceeding the theoretical amount necessary for combustion. Insufficient excess air will result in incomplete combustion and an increase in emissions. A minimum of about 50 percent excess air is necessary for combustion of wood or bark fuels. Provision of too much excess air causes the furnace to cool and also can result in incomplete combustion. Therefore, the proper excess air level is important for proper operation of the boiler. The percent oxygen in the exhaust gas stream is an indicator of the excess air level (0 percent oxygen would equal 0 percent excess air, 8 percent oxygen is approximately 50 percent excess air, and 12 percent oxygen is approximately 100 percent excess air).

III. Rationale for Selection of Indicator Ranges

Baseline information on the relationship among process operating conditions, control device operating conditions, and emissions was necessary to establish the indicators and ranges. A series of test runs was performed at several different boiler operating conditions because parametric monitoring is being proposed as an alternative to COMS.

Emissions tests were performed to establish a basis for indicator ranges that correspond to compliance with the PM emissions limit. A set of nine test runs was performed on the boiler at three different levels of steam generation (three test runs were performed at each steam generation level). Emissions sampling was based on EPA Methods 1 through 5 (40 CFR 60, Appendix A). The results of the first series of emissions tests indicated a problem meeting the emissions limits at the lower load level; the lack of a means to control excess air levels during boiler operation was suspected as the cause of the excess emissions. A second series of tests were performed a year later after automatic boiler control equipment was installed. The second series of tests also was comprised of nine runs at three operating loads. The results of these 18 tests were used in selecting the indicator ranges. The results of these tests are presented and discussed in the following paragraphs.

Figure 1 graphically presents the excess air level versus the nominal boiler load (steam generation rate) for the tests. During the first series of tests, before automatic boiler controls were added, the boiler operated at a very high level of excess air (over 500 percent) at the low-level operating load, at a high level of excess air (over 200 percent) at the mid level operating load, and below 200 percent at the high-level operating load. Without the automatic boiler controls, the same amount of air was being introduced to the boiler regardless of the operating load (wood feed rate), resulting in a significant increase in excess air levels as wood feed rate decreased. After the automatic controls were added, the excess air was maintained at lower levels for the low-level and mid-level load conditions (less than 300 percent and 200 percent, respectively).

The results of the two test series are summarized in Table A.17-2. Three test runs were performed at each steam generation rate.

TABLE A.17-2. TEST RESULTS[a]

	Nominal steam generation rate (lb/hr)	Venturi differential pressure (in. H_2O)	Boiler exhaust O_2 (%)	Particulate emissions (lb/MMBtu)	Allowable particulate emissions (lb/MMBtu)
Series 1: (Before Boiler Control Modifications)	25,000	15.6	18.1	0.73	0.25
	40,000	22.9	16.2	0.43	0.21
	60,000	22.2	12.6	0.06	0.16
Series 2: (After Boiler Control Modifications)	33,000	12.0	15.5	0.07	0.25
	52,000	12.1	13.9	0.06	0.21
	77,000	12.0	13.0	0.05	0.17

[a] All values are 3-run averages.

At the first level of steam generation (25,000 lb/hr), the amount of excess air ranged from 544 percent to 752 percent by volume. The particulate emissions rate ranged from 0.528 to 1.12 lb/MMBtu. The maximum allowable emissions ranged from 0.23 to 0.27 lb/MMBtu. The maximum allowable emissions varies because it is based on the heat input rate. The allowable emissions rate was exceeded for all three test runs. The second set of test runs was performed at a nominal steam generation level of 40,000 lb/hr. The amount of excess air ranged from 244 to 830 percent. The particulate emissions rate ranged from 0.21 to 0.82 lb/MMBtu. The maximum allowable emissions ranged from 0.17 to 0.28 lb/MMBtu. The maximum allowable emissions rate was exceeded for all three test runs. The third set of test runs was operated at a nominal steam generation level of 60,000 lb/hr. The steam generation level actually ranged from 60,000-70,000 lb/hr but dropped below 50,000 lb/hr midway through the third of the three tests performed. The amount of excess air for these three test runs ranged from 123 to 188 percent. The particulate emissions rate ranged from 0.05 to 0.06 lb/MMBtu. The maximum allowable emissions ranged from 0.15 to 0.17 lb/MMBtu. The boiler was well within the maximum allowable emissions rate for all three test runs.

For the test series conducted after the addition of automatic controls, at the first level of steam generation (33,000 lb/hr nominal), the amount of excess air ranged from 255 to 341 percent by volume (15 to 16 percent oxygen). The particulate emissions rate ranged from 0.062 to 0.081 lb/MMBtu. The maximum allowable emissions ranged from 0.23 to 0.29 lb/MMBtu. The particulate emissions were less than the allowable emissions rate for all three test runs. The second set of test runs was performed at a nominal steam generation level of 77,000 lb/hr. The amount of excess air ranged from 128 to 194 percent (12 to 14 percent oxygen). The particulate emissions rate ranged from 0.045 to 0.057 lb/MMBtu. The maximum allowable emissions ranged from 0.16 to 0.18 lb/MMBtu. The particulate emissions were less than the allowable emissions rate for all three test runs. The third set of test runs was performed at a nominal steam generation level of 52,000 lb/hr. The amount of excess air for these three test runs ranged from 196 to 223 percent (13 to 14 percent oxygen). The particulate emissions rate ranged from 0.056 to 0.067 lb/MMBtu. The maximum allowable emissions ranged from 0.20 to

0.21 lb/MMBtu. The boiler operated within the maximum allowable emissions rate for all three test runs.

Figure 2 presents the particulate emissions rate versus boiler load for the two test series. Figures 3 and 4 present the particulate emissions rate versus excess air and boiler exhaust oxygen level, respectively. The test results show that during the first test series the emissions increase significantly as the excess air increases. The allowable emissions limit was exceeded at the low- and mid-level operating loads. The results of the second test series conducted after automatic boiler controls were added also show a relationship among the excess air level, boiler load, and particulate emissions rates. However, the particulate emissions rates were well within the allowable emissions rates for all test runs at all load conditions. Note that the performance of the system (boiler and venturi scrubber) was significantly better during the second series of tests when the automatic boiler controls were being used to control air levels even though the venturi scrubber was operating at a lower pressure drop (12 versus 22 in. w.c.).

The indicator selected for monitoring boiler operation is exhaust gas oxygen concentration. The selected indicator range for the boiler exhaust gas oxygen is greater than 12 and less than 16 percent O_2 (one-hour average). The indicator range was chosen based upon the 1-hr test run averages for the January 1999 test data. During these tests, the average oxygen concentration was maintained between 12 and 16 percent. The oxygen concentration is measured continuously. An excursion triggers an inspection, corrective action, and a reporting requirement. The selected range will promote maximum efficiency and provide a reasonable assurance that the boiler is operating normally.

The indicator range selected for monitoring venturi scrubber operation is a pressure differential of greater than 10 in. w.c. (one-hour average). An excursion triggers an inspection, corrective action, and a reporting requirement. The differential pressure is measured several times per minute. A one-minute average is calculated, and an hourly average is calculated from the one-minute averages. The selected indicator range was chosen by examining the January 1999 test data. During these tests, the differential pressure was maintained between 10 and 15 in. w.c. The measured particulate emissions limit during these tests at all three boiler loads was approximately one third of the allowable emissions rate (large margin of compliance). Therefore, a differential pressure of greater than 10 in. w.c. was selected as the indicator range.

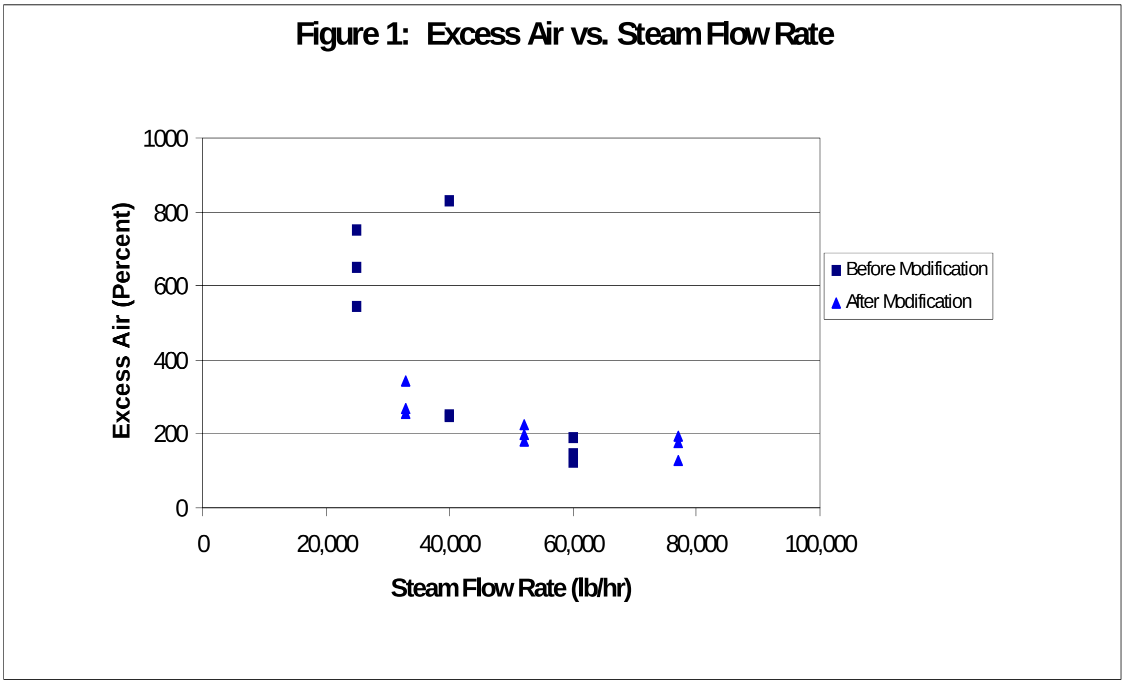
Figure 1: Excess Air vs. Steam Flow Rate
Excess Air (Percent)
1000
800
600
400
200
0
0
20,000
40,000
60,000
80,000
100,000
Steam Flow Rate (lb/hr)
Before Modification
After Modification

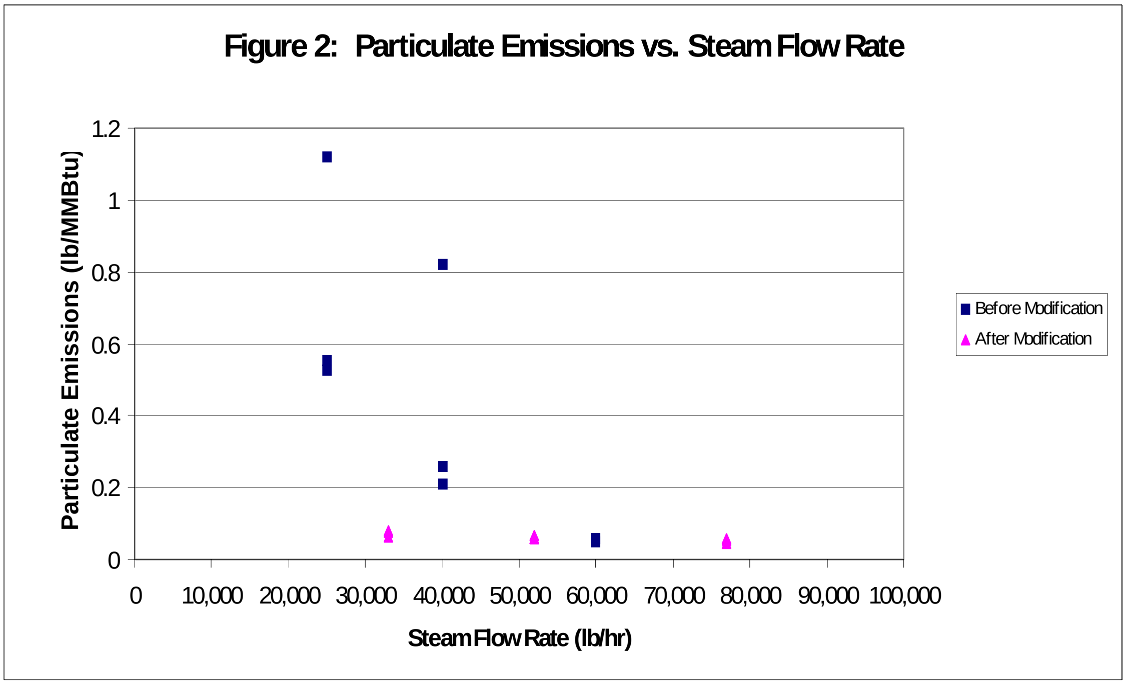
Figure 2: Particulate Emissions vs. Steam Flow Rate
Particulate Emissions (lb/MMBtu)
1.2
1
0.8
0.6
0.4
0.2
0
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
Steam Flow Rate (lb/hr)
Before Modification
After Modification

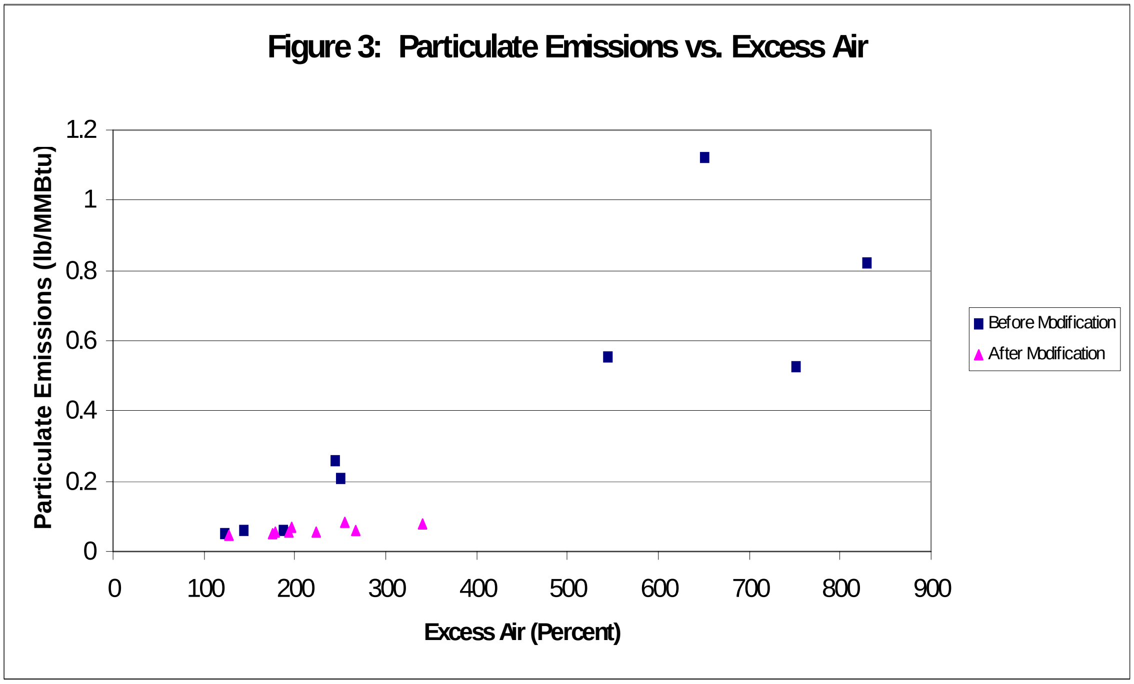
Figure 3: Particulate Emissions vs. Excess Air
Particulate Emissions (lb/MMBtu)
1.2
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
900
Excess Air (Percent)
Before Modification
After Modification

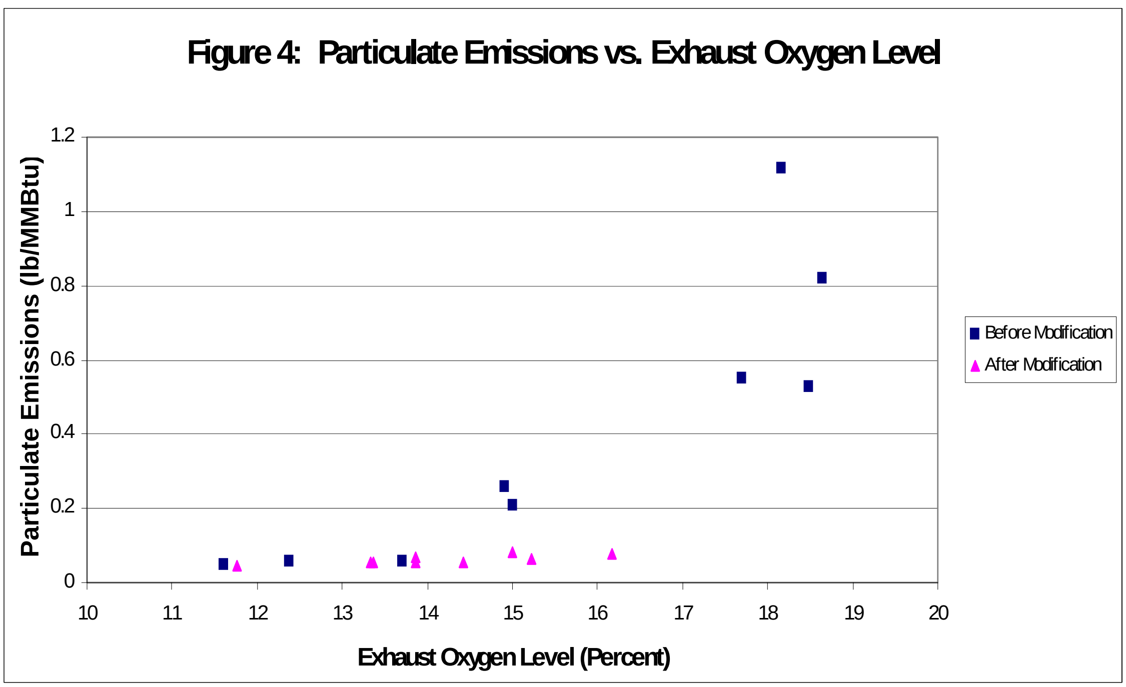
Figure 4: Particulate Emissions vs. Exhaust Oxygen Level
Particulate Emissions (lb/MMBtu)
1.2
1
0.8
0.6
0.4
0.2
0
10
11
12
13
14
15
16
17
18
19
20
Exhaust Oxygen Level (Percent)
Before Modification
After Modification

A.18 CARBON ADSORBER FOR VOC CONTROL – FACILITY T

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EXAMPLE COMPLIANCE ASSURANCE MONITORING
CARBON ADSORBER FOR VOC CONTROL – FACILITY T

I. Background

A. Emissions Unit

Description:	Loading Rack
Identification:	LR-1
APCD ID:	SRU-1
Facility:	Facility T Anytown, USA

B. Applicable Regulation, Emission Limit, and Monitoring Requirements

Regulation:	Permit
Emission Limits: VOC:	 0.67 lb/1,000 gallons transferred (80 mg/L transferred)
Monitoring Requirements:	Monitor carbon adsorber outlet VOC concentration, monitor position of APCD bypass valve, conduct a leak detection and repair program.

C. Control Technology:

Carbon adsorber.

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.18-1. The carbon adsorber outlet VOC concentration in percent by volume as propane is continuously monitored. The selected indicator range is based on a 1-hour rolling average concentration. Periodic leak checks of the vapor recovery unit also are conducted and the position of the carbon adsorber bypass valve is monitored to ensure bypass of the control device is not occurring.

Note: Facility T also monitors parameters related to the vapor tightness of connections and tank trucks and other parameters of the vapor recovery system, but this example focuses on the monitoring performed on the carbon adsorber.

TABLE A.18-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2
I. Indicator	Outlet VOC concentration (percent).	Equipment leaks.
Measurement Approach	Breakthrough detector (NDIR analyzer).	Monthly leak check of vapor recovery system.
II. Indicator Range	An excursion is defined as an hourly average outlet VOC concentration of 4 percent by volume (as propane) or greater. When this level is reached or exceeded, the loading rack will be shut down via an automated interlock system. An excursion will trigger an investigation, corrective action, and a reporting requirement.	An excursion is defined as detection of a leak greater than or equal to 10,000 ppm (as methane) during normal loading operations. An excursion will trigger an investigation, corrective action, and a reporting requirement. Leaks will be repaired within 15 days.
III. Performance Criteria A. Data Representativeness	The analyzer is located at the carbon adsorber outlet.	A handheld monitor is used to check for leaks in the vapor collection system during loading operations.
B. Verification of Operational Status	NA	NA
C. QA/QC Practices and Criteria	Daily zero/span drift. Adjust if drift is greater than 2.5 percent of span.	Follow procedures in 40 CFR 60, Appendix A, Method 21.
D. Monitoring Frequency	The outlet VOC concentration is monitored every 2 minutes.	Monthly.
Data Collection Procedures	The data acquisition system (DAS) collects the outlet VOC concentration every 2 minutes and calculates a rolling 1-hour average. Periods when breakthrough is detected and the interlock system shuts down the loading rack also are recorded.	Records of inspections, leaks found, leaks repaired.
Averaging period	1 hour (rolling).	None.
APCD Bypass Monitoring:	A pressure gauge on the vapor header line is used to detect if the relief valve is open. The valve opens if the pressure reaches 18 inches H_2O. The DAS records the instantaneous pressure reading every 2 minutes.	

MONITORING APPROACH JUSTIFICATION

I. Background

The pollutant specific emissions unit (PSEU) is a vacuum regenerative carbon adsorber used to reduce VOC emissions from a gasoline loading rack. (Note: This facility is not a major source of HAP emissions and is not subject to 40 CFR 63, Subpart R, or 40 CFR 60, Subpart XX.) The maximum throughput of the loading rack is 43,000,000 gallons per month, and the facility operates 24 hours per day, 7 days per week.

The carbon adsorber has two identical beds, one adsorbing while the other is desorbing on a 15-minute cycle. Carbon bed regeneration is accomplished with a combination of high vacuum and purge air stripping which removes previously adsorbed gasoline vapor from the carbon and restores the carbon's ability to adsorb vapor during the next cycle. The vacuum pump extracts concentrated gasoline vapor from the carbon bed and discharges into a separator. Non-condensed gasoline vapor plus gasoline condensate flow from the separator to an absorber column which functions as the recovery device for the system. In the absorber, the hydrocarbon vapor flows up through the absorber packing where it is liquefied and subsequently recovered by absorption. Gasoline product from a storage tank is used as the absorbent fluid. The recovered product is simply returned along with the circulating gasoline back to the product storage tank A small stream of air and residual vapor exits the top of the absorber column and is recycled to the on-stream carbon bed where the residual hydrocarbon vapor is re-adsorbed.

II. Rationale for Selection of Performance Indicators

A non-dispersive infrared (NDIR) analyzer is used to monitor the carbon adsorber outlet VOC concentration in percent by volume as propane and ensure breakthrough is not occurring. This monitor provides a direct indicator of compliance with the VOC limit since it continuously measures the outlet VOC concentration in percent. An interlock system is used to shut down loading operations when an excursion occurs.

A monthly leak inspection program also is performed to ensure that the vapors released during loading are captured and conveyed to the vapor recovery unit. A handheld monitor is used to detect leaks in the vapor collection system. The position of the vapor recovery unit’s relief valve is monitored to ensure the control device is not bypassed.

III. Rationale for Selection of Indicator Ranges

The indicator range for the breakthrough detector was selected based on engineering calculations. The VOC emission rate can be expressed as follows (see 40 CFR 60.503):

$$E = K \frac{V \times C}{L \times 10^6}$$

where:

E = emission rate of VOC, mg/L
V = volume of air/vapor mixture exhausted, scm
C = concentration of VOC, ppm
L = volume loaded, L
K = density of calibration gas, 1.83×10^6 mg/scm for propane

Assuming 100 percent displacement of all vapors into the vapor recovery unit (e.g., if 300,000 L are loaded, 300,000 L of vapor pass through the unit) and assuming that breakthrough is occurring, it may be conservatively assumed that V is equal to L (V is actually less than L if the carbon adsorber is operating properly). Converting the volume displaced/exhausted (300,000 L) to cubic meters (300 scm) and substituting 300 scm for V, 80 mg/L for E, and 1.83×10^6 mg/scm for K gives C equal to 43,700 ppm, or 4.4 percent. Therefore, the indicator range for the outlet VOC concentration is 4 percent (rolling hourly average), to provide a reasonable assurance of compliance with the VOC limit of 80 mg/L loaded. If the hourly average outlet VOC concentration reaches or exceeds 4 percent, the unit will be shut down and loading prevented via an automated interlock system. All excursions will be documented and reported. Figure A.18-1 presents both 2-minute instantaneous (dotted line) and hourly average (solid line) outlet VOC concentration data for a typical day's operation. The outlet VOC concentration typically is less than 0.5 percent as propane.

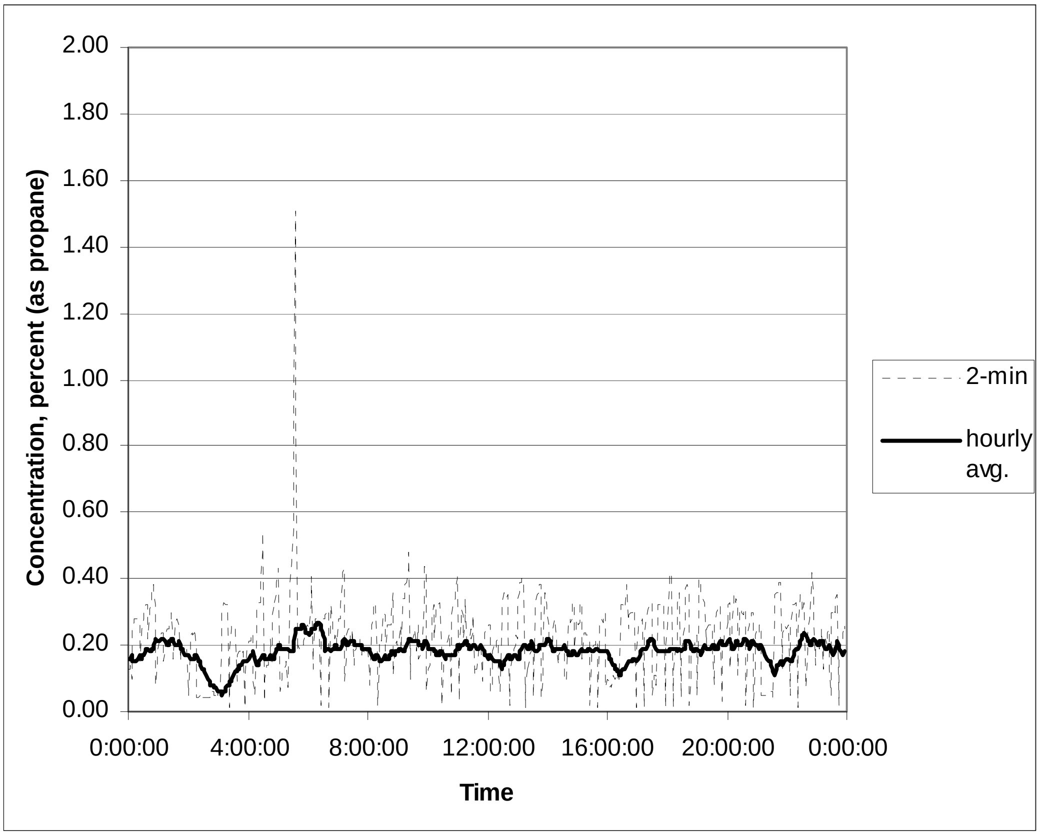

Figure A.18-1. A typical day's concentration data.

The most recent performance test conducted showed that the average hydrocarbon emissions were 10.37 mg/liter loaded. The average outlet concentration was 0.37 percent propane by volume, and the unit's efficiency was 98.6 percent.

For the second indicator, an excursion is defined as detection of a leak greater than or equal to 10,000 ppm (as methane) during normal loading operations. This is the limit established by the applicable requirement. If a leak is detected, corrective action will be initiated, and the leak will be repaired within 15 days. All excursions will be documented and reported.

Comment: During the review period, one commenter suggested setting an internal warning level for the bypass line pressure. For safety reasons, the bypass valve on the inlet APCD line is set to release at 18" w.c. With respect to APCD bypass, the CAM rule only requires that a facility monitor the bypass so that bypass events can be corrected immediately and reported. Consequently, establishing an indicator range at a level less than the release pressure is not required. However, if a facility wants to take extra precautions to avoid bypass events, it could establish a warning at a lower pressure, such as the 15" w.c., which would allow them to initiate corrective action before a bypass event, as suggested by this commenter.

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A.19 BAGHOUSE FOR PM CONTROL – FACILITY V

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INTRODUCTION

The examples in section A.19 were developed based on data collected during an EPA study of particulate matter (PM) continuous emissions monitoring systems (CEMS). Data were collected over a period of several months for three PM CEMS installed on a coal-fired boiler. Higher than normal PM concentrations were generated during testing by installing a baghouse bypass line and adjusting a butterfly valve on that line. Examples A.19a and A.19b present two approaches to the use of PM CEMS for CAM using data from one of the PM CEMS evaluated. The first example uses the procedures of proposed Performance Specification 11 (December 2001) to calibrate the PM CEMS over an extended range of PM concentrations. This approach provides a reasonable assurance of compliance over the extended operating range, establishes the indicator level near the high end of the demonstrated operating range, and allows the source flexibility to operate within the extended range without an excursion.

The second example uses a limited amount of test data collected with the APCD operating normally (i.e., no generation of increased emissions utilizing the APCD bypass) to calibrate the PM CEMS. During normal operation there is a large margin of compliance with the emissions limit. However, the indicator range is based on a smaller data set collected over a narrower range of operation. Consequently, the indicator range for an excursion is established at a lower value, near the normal operating range. This approach results in less operating flexibility but lower emissions testing costs because testing is only performed at normal operating conditions.

Details on the PM CEMS evaluation are contained in the report series, "Evaluation of Particulate Matter (PM) Continuous Emission Monitoring Systems (CEMS)," Volumes 1-5, prepared by Midwest Research Institute for the U. S. Environmental Protection Agency's Emissions Measurement Center. The EPA contact is Mr. Dan Bivins at (919) 541-5244, or bivins.dan@epa.gov.

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EXAMPLE COMPLIANCE ASSURANCE MONITORING: BAGHOUSE FOR PM CONTROL – FACILITY V

I. Background

A. Emissions Unit

Description:	375 mmBtu/hr coal-fired boilers
Identification:	Boilers 1 and 2
Facility:	Facility V Anytown, USA

B. Applicable Regulation, Emissions Limit, and Monitoring Requirements

Regulation:	40 CFR 60, Subpart Da Permit
Emissions Limits:	
PM:	0.02 lb/mmBtu
Monitoring Requirements:	A baghouse inspection and maintenance program is performed and a PM continuous emissions monitoring system (CEMS) is used as an additional indicator of compliance with the PM limit. [Note: A COMS is used to assure compliance with the opacity limit and NO_x and SO_2 CEMS are used to assure compliance with the NO_x and SO_2 limits, but that monitoring is not addressed here.]

C. Control Technology:

Both boilers have a pulse jet fabric filter to control particulate emissions from the boiler and the lime slurry spray dryer (used for flue gas desulfurization) that follows each boiler. The boilers exhaust to a common stack.

II. Monitoring Approach

The key elements of the monitoring approach for PM are presented in Table A.19a-1. The selected performance indicators are the signal from a PM CEMS and a baghouse inspection and maintenance program.

TABLE A.19a-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2
I. Indicator	PM concentration.	Bag condition.
Measurement Approach	A light scattering device is installed at a representative location downstream of the baghouse.	The inspection and maintenance program includes a semi-annual internal inspection of the baghouse and analysis of representative bag samples and bi-annual bag replacement.
II. Indicator Range	An excursion is defined as an hourly average PM concentration greater than 13 mg/acm. Excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion is defined as failure to perform the semi-annual inspection and bi-annual bag replacement. Excursions trigger an inspection, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness	The light scattering instrument is located where a representative sample can be obtained in the baghouse exhaust. The amount of light reflected back at the optical sensor is proportional to the amount of particulate present in the exhaust. A field test was performed to correlate the monitor's response to PM concentration measured by Method 17.	Baghouse inspected visually for deterioration and bag samples taken to determine bag condition and remaining bag life.
B. Verification of Operational Status	Initial correlation test conducted August 1999.	NA
C. QA/QC Practices and Criteria	Daily drift checks, quarterly absolute calibration audit (ACA), and annual response calibration audit (RCA). Daily zero/span drift cannot exceed 4 percent of the upscale value for 5 consecutive days or more than 8 percent of the upscale value in any one day. The ACA involves challenging the PM CEMS with an audit standard at three operating levels, per Performance Specification (PS) 11. The RCA involves gathering simultaneous CEMS response and manual Reference Method data over a range of operating conditions, per PS 11.	Trained personnel perform inspections and maintenance.
D. Monitoring Frequency	Continuous.	Varies.

(TABLE A.19a-1. Continued)

	Indicator No. 1	Indicator No. 2
Data Collection Procedures	The data acquisition system (DAS) collects a data point every second. The 1-second data are reduced to a 1-minute, a 15-minute, and then a 3-hour average PM emissions rate. The 3-hour average data are archived for at least 5 years.	Results of inspections and maintenance activities performed are recorded in baghouse maintenance log.
Averaging period	3-hour.	NA

MONITORING APPROACH JUSTIFICATION

I. Background

Two 375 mmBtu/hr traveling-grate, stoker-fired boilers are operated at this facility. Each boiler is rated at a nominal steam flow of 275,000 pounds per hour at 950˚F and 1,540 psig. The boilers are fired with bituminous coal that averages 13,000 Btu per pound. The boilers were constructed in 1990 and are subject to 40 CFR 60, Subpart Da.

The boilers include mechanical separators in the boiler back-pass section for cinder collection and re-injection into the furnace area. A separate dust collector is located after the air heater section for heavy fly ash collection. The ash from the traveling grate is collected at the front of the boiler for removal to the ash storage silos.

Each boiler is equipped with a dry flue gas desulfurization (FGD) system for SO_2 control and a pulse jet fabric filter for PM control. The FGD uses a motor-driven atomizer to spray a lime slurry mixture into the gas path to neutralize acid mists from the boiler gas. The particulate from the slurry injection and the fine fly ash from the combustion process are collected in the baghouse. The FGD is designed to reduce the average sulfur dioxide concentration by at least 90 percent. The baghouse is designed to collect at least 99 percent of the total particulate in the boiler gas. Exhaust from both baghouses is routed to a common stack that exhausts to the atmosphere.

II. Rationale for Selection of Performance Indicators

The performance indicators selected are the signal from a PM CEMS and baghouse inspections. The PM CEMS is a light-scattering device that detects particulate matter in the baghouse exhaust by reading the back-scattered light from a collimated, near-infrared (IR) light emitting diode (LED). Because this instrument measures in the near-IR range, the sensitivity to changes in particle size is minimal and the response to particles in the 0.1 to 10 µm range is nearly constant. Preventive maintenance is performed on the baghouse to ensure it continues to operate properly and that the bags are in good condition.

III. Rationale for Selection of Indicator Ranges

The unit's PM limit is 0.02 lb/mmBtu, which corresponds to approximately 17 mg/acm. For the light scattering device signal, an excursion is defined as a PM concentration of greater than 13 mg/acm. At this level, the upper tolerance interval is just below the emissions limit and the unit still has a small margin of compliance. Therefore, corrective action will be initiated when the PM CEMS shows the unit is at approximately 75 percent of the emissions limit. Figure A.19a-1 shows a typical day's worth of data while operating at peak load. The PM monitor's signal is normally 2 to 4 mg/acm. Comparing the 1-minute data on a 1-hr, 3-hr, and daily average basis showed that the averaging period made no difference in this case. A 3-hr averaging period was selected as representative.

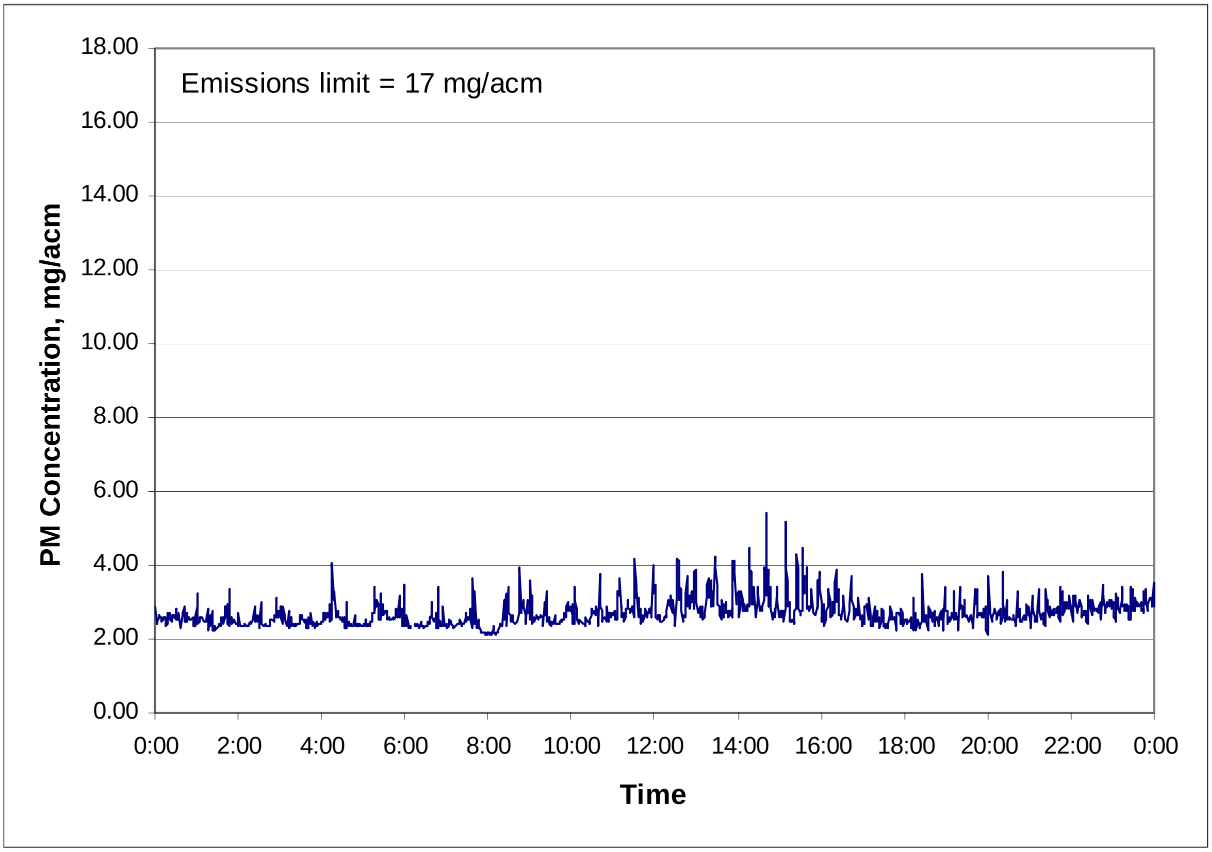

Figure A.19a-1. Light scattering monitor data for a typical day.

A total of 12 Method 17 test runs performed with paired sampling trains at varying PM concentrations were used to develop the relationship between the PM concentration in the baghouse exhaust and the monitor signal. Each test run was one hour in duration. Emissions, boiler load, opacity, and PM CEMS data from the test program are presented in Table A.19a-2. A baghouse bypass line and butterfly valve were installed for the purpose of generating higher than normal PM concentrations to calibrate the PM CEMS. Figure A.19a-2 shows the correlation curve developed during the initial testing, with the upper and lower confidence and tolerance limits calculated per proposed Performance Specification 11. The relationship is a linear equation with an R^2 of 0.96. The confidence interval (CI) is the interval within which one would predict the calibration relationship lies with 95 percent confidence. The tolerance interval (TI) is the interval within which 75 percent of the data are expected to lie with 95 percent confidence.

TABLE A.19a-2. PM CEMS INITIAL CORRELATION TEST DATA

Parameter	Test Run 1	2	3	4	5	6	7	8	9	10	11	12
Steam flow, 1,000 lb/hr	271	281	283	282	280	284	281	281	281	285	268	281
Method 17 result, mg/acm[1]	11.6	13.9	14.5	3.03	2.68	3.20	16.3	10.5	9.42	15.4	8.76	18.7
PM CEMS response, mA	9.60	10.0	10.5	5.87	5.78	6.00	12.0	9.45	8.97	13.2	9.57	14.5
Opacity, %	3.72	4.51	5.27	3.71	3.54	3.92	4.01	4.22	4.14	4.25	4.11	5.39

[1]The Method 17 result is the average of sampling train A and sampling train B.

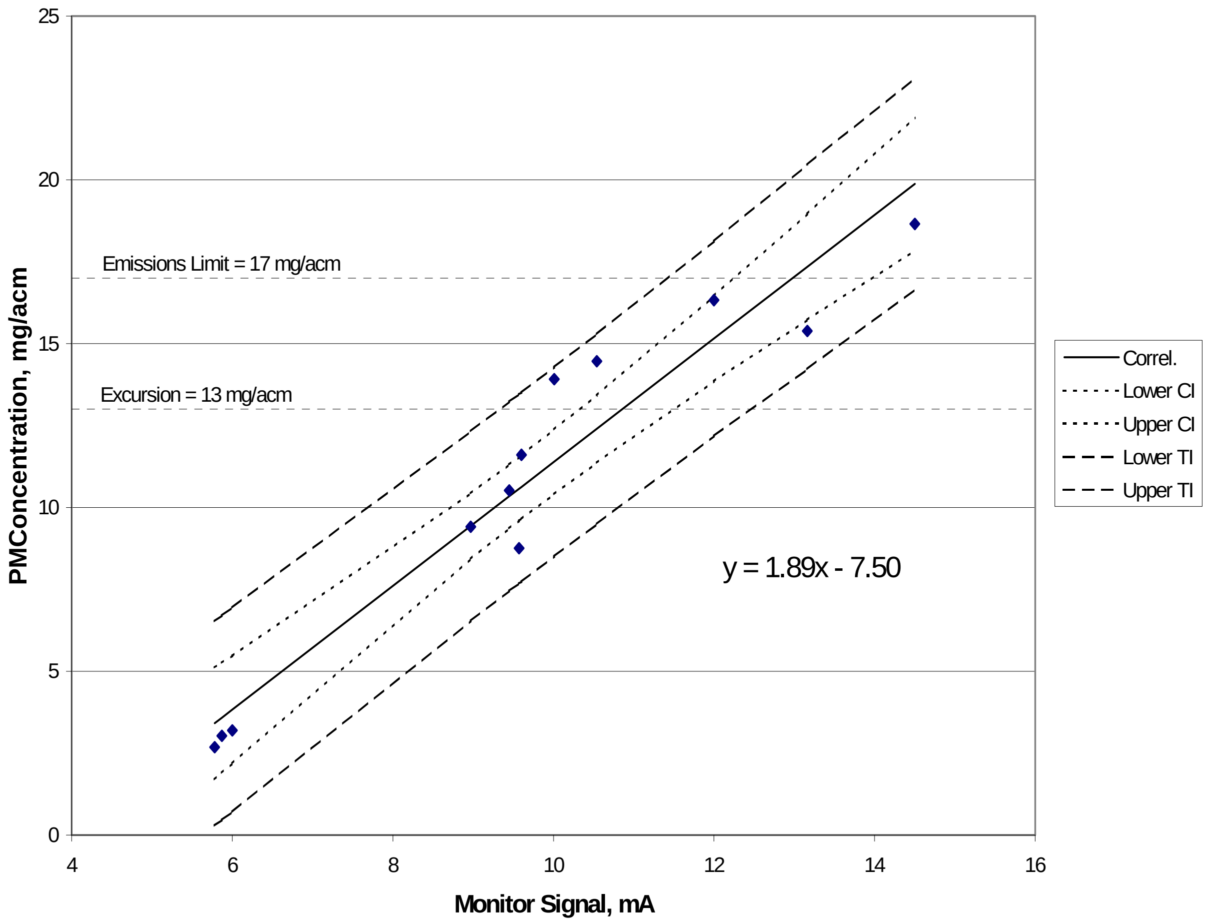

Figure A.19a-2. PM CEMS Correlation Curve.

EXAMPLE COMPLIANCE ASSURANCE MONITORING:
BAGHOUSE FOR PM CONTROL – FACILITY V

I. Background

A. Emissions Unit

Description:	375 mmBtu/hr coal-fired boilers
Identification:	Boilers 1 and 2
Facility:	Facility V Anytown, USA

B. Applicable Regulation, Emissions Limit, and Monitoring Requirements

Regulation:	40 CFR 60, Subpart Da Permit
Emissions Limits: PM:	 0.02 lb/mmBtu
Monitoring Requirements:	A baghouse inspection and maintenance program is performed and a PM continuous emissions monitoring system (CEMS) is used as an additional indicator of compliance with the PM limit. [Note: A COMS is used to assure compliance with the opacity limit and NO_x and SO_2 CEMS are used to assure compliance with the NO_x and SO_2 limits, but that monitoring is not addressed here.]

C. Control Technology:

Both boilers have a pulse jet fabric filter to control particulate emissions from the boiler and the lime slurry spray dryer (used for flue gas desulfurization) that follows each boiler. The boilers exhaust to a common stack.

II. Monitoring Approach

The key elements of the monitoring approach for PM are presented in Table A.19b-1. The selected performance indicators are the signal from a PM CEMS and a baghouse inspection and maintenance program.

TABLE A.19b-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2
I. Indicator	PM CEMS response.	Bag condition.
Measurement Approach	A light scattering type PM CEMS is installed at a representative location downstream of the baghouse.	The inspection and maintenance program includes a semi-annual internal inspection of the baghouse and analysis of representative bag samples and bi-annual bag replacement.
II. Indicator Range	An excursion is defined as an hourly average PM CEMS response greater than 7.5 mA. Excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion is defined as failure to perform the semi-annual inspection and bi-annual bag replacement. Excursions trigger an inspection, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness	The PM CEMS is located where a representative sample can be obtained in the baghouse exhaust. An increase in the PM CEMS signal indicates an increase in the PM concentration. A field test was performed to compare the PM CEMS response to PM concentration measured by Method 17.	Baghouse inspected visually for deterioration and bag samples taken to determine bag condition and remaining bag life.
B. Verification of Operational Status	Initial verification test consisting of 3 test runs.	NA
C. QA/QC Practices and Criteria	Daily drift checks and quarterly absolute calibration audit (ACA). Daily zero/upscale drift cannot exceed 4 percent of the upscale value for 5 consecutive days or more than 8 percent of the upscale value in any one day. The ACA involves challenging the PM CEMS with an audit standard at three operating levels, per PS 11.	Trained personnel perform inspections and maintenance.
D. Monitoring Frequency	Continuous.	Varies.
Data Collection Procedures	The data acquisition system (DAS) collects a data point every 5 seconds. Those 5-second data are reduced to a 1-minute, a 15-minute, and then a 3-hour average PM CEMS response. The 3-hour average data are archived for at least 5 years.	Results of inspections and maintenance activities performed are recorded in baghouse maintenance log.
Averaging period	3-hour.	NA

MONITORING APPROACH JUSTIFICATION

I. Background

Two 375 mmBtu/hr traveling-stoker grate, coal-fired boilers are operated at this facility. Each boiler is rated at a nominal steam flow of 275,000 pounds per hour at 950˚F and 1,540 psig. The boilers are fired with bituminous coal that averages 13,000 Btu per pound. The boilers were constructed in 1990 and are subject to 40 CFR 60, Subpart Da.

The boilers include mechanical separators in the boiler back-pass section for cinder collection and re-injection into the furnace area. A separate dust collector is located after the air heater section for heavy fly ash collection. The ash from the traveling grate is collected at the front of the boiler for removal to the ash storage silos.

Each boiler is equipped with a dry flue gas desulfurization (FGD) system for SO_2 control and a pulse jet fabric filter for PM control. The FGD uses a motor-driven atomizer to spray a lime slurry mixture into the gas path to neutralize acid mists from the boiler gas. The particulate from the slurry injection and the fine fly ash from the combustion process are collected in the baghouse. The FGD is designed to reduce the average sulfur dioxide concentration by at least 90 percent. The baghouse is designed to collect at least 99 percent of the total particulate in the boiler gas. Exhaust from both baghouses is routed to a common stack that exhausts to the atmosphere.

II. Rationale for Selection of Performance Indicators

The performance indicators selected are the signal from a PM CEMS and baghouse inspections. The PM CEMS is a light-scattering device that detects particulate matter in the baghouse exhaust by reading the back-scattered light from a collimated, near-infrared (IR) light emitting diode (LED). Because this instrument measures in the near-IR range, its sensitivity to changes in particle size is minimized and its response to particles in the 0.1 to 10 μm range is nearly constant. Preventive maintenance is performed on the baghouse to ensure it continues to operate properly and that the bags are in good condition.

III. Rationale for Selection of Indicator Ranges

The boiler’s PM limit is 0.02 lb/mmBtu, which corresponds to approximately 17 mg/acm. Three Reference Method (Method 17) test runs performed with paired sampling trains were conducted while operating the boiler at full load. These test data were used to develop the relationship between the PM concentration in the baghouse exhaust and the PM CEMS signal. Emissions, load, and PM CEMS data from the test program are presented in Table A.19b-2. Figure A.19b-1 shows a graphical representation of the PM CEMS response versus particulate concentration for the 3 test runs and the indicator range developed based on that data. The linear correlation was forced through the zero point (4 mA). The data showed that when the PM CEMS readings were at or below 6 mA, the PM concentration was less than 3.5 mg/acm, well below the

TABLE A.19b-2. PM CEMS RESPONSE VALIDATION TEST DATA

Parameter	Test Run 1	Test Run 2	Test Run 3
Steam flow, 1,000 lb/hr	282	280	284
Method 17 result, mg/acm[1]	3.03	2.68	3.20
PM CEMS response, mA	5.87	5.78	6.00

[1]The Method 17 result is the average of sampling train A and sampling train B.

PM limit (see Figure A.19b-1). Figure A.19b-2 shows a typical day's worth of 15-minute average PM CEMS data while operating at peak load. The PM monitor's signal normally is less than 6 mA. Based on the limited test data available and the source's low variability and large margin of compliance, the upper limit of the indicator range was set at 125 percent of the highest measured value. Therefore, for the PM CEMS, an excursion is defined as an hourly average PM CEMS response greater than 7.5 mA (corresponds to a predicted PM concentration of 5.5 mg/acm, about one-third of the PM limit).

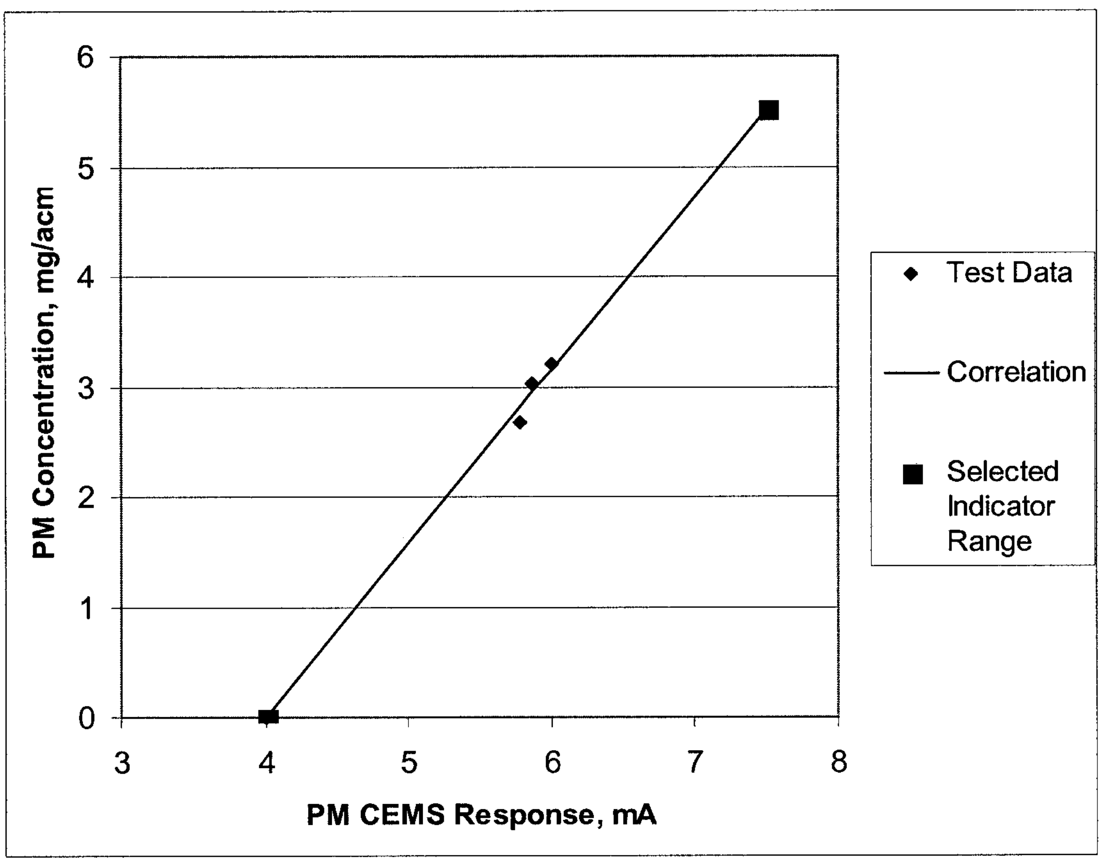

Figure A.19b-1. PM CEMS Calibration Curve and Indicator Range.

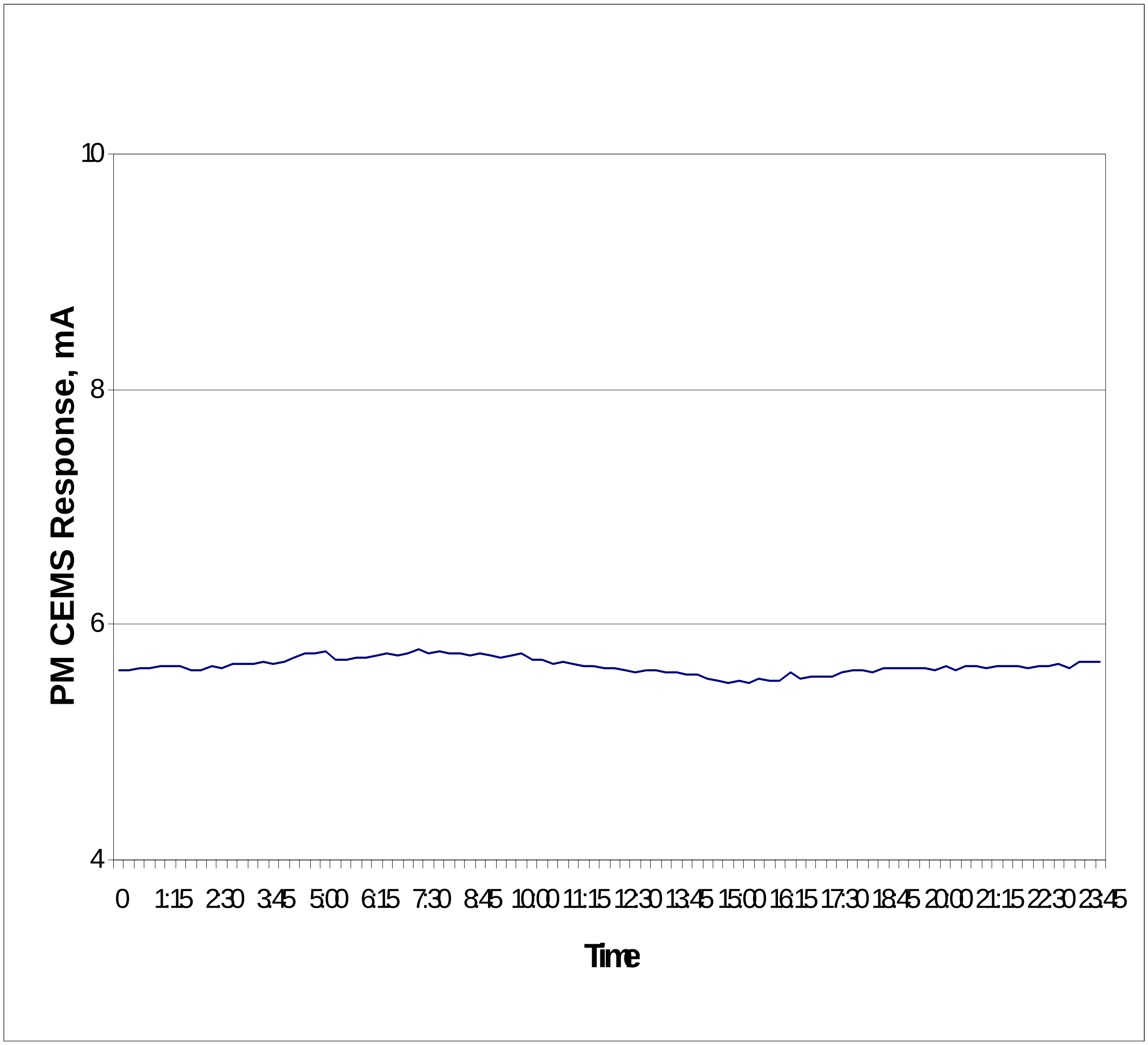

Figure A.19b-2. Typical daily output from PM CEMS while operating boiler at peak load (15-minute averages).

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A.20 SCRUBBER FOR SO_2 CONTROL – FACILITY W

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EXAMPLE COMPLIANCE ASSURANCE MONITORING
SCRUBBER FOR SO_2 CONTROL – FACILITY W

I. Background

A. Emissions Unit

Description:	Pulp Mill Blow Cyclone Vent
Identification:	PU2 - EP003
Facility:	Facility W Anytown, USA

B. Applicable Regulation, Emission Limit, and Monitoring Requirements

Regulation:	State regulation and permit
Emission Limits: SO_2:	 94 percent control
Monitoring Requirements:	Scrubber liquid pH, liquid flow

C. Control Technology: Wet scrubber to remove SO_2 from the digester system blow cyclone gases.

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.20-1. The selected performance indicators are the scrubber liquid pH and the scrubber liquid flow.

TABLE A.20-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2
I. Indicator	Scrubber liquid pH.	Scrubber liquid flow.
Measurement Approach	The scrubber liquid pH is measured using a pH sensor.	The scrubber liquid flow is measured using a magnetic flow tube element.
II. Indicator Range	An excursion is defined as an hourly scrubber pH value less than 9.0. An excursion shall trigger an inspection, corrective action as necessary, and a reporting requirement.	An excursion is defined as an hourly scrubber liquid flow value less than 175 gpm. An excursion shall trigger an inspection, corrective action as necessary, and a reporting requirement.
III. Performance Criteria A. Data Representativeness	The scrubber liquid pH sensor is located in the scrubber liquid recirculation line.	The scrubber liquid flow rate sensor is located on the scrubber liquid recirculation line.
B. Verification of Operational Status	Calibration of the pH sensor conducted by comparison with laboratory measurements of the scrubber recirculation fluid.	Factory calibration of the magnetic flow tube element before installation. Check the unit when installed to verify correct electrical output.
C. QA/QC Practices and Criteria	Monitoring equipment and process downtime is recorded in a log. The pH meter is checked for accuracy (±0.2 pH units) monthly. The pH sensor is calibrated weekly.	Monitoring equipment and process downtime is recorded in a log. The flow sensor is calibrated quarterly.
D. Monitoring Frequency	The scrubber liquid pH is measured continuously.	The scrubber liquid flow is measured continuously.
Data Collection Procedures	The operator records scrubber liquid pH once per hour on the scrubber operating log.	The operator records scrubber liquid flow once per hour on the scrubber operating log.
Averaging period	None. The pH is recorded once per hour.	None. The liquid flow rate is recorded once per hour.

MONITORING APPROACH JUSTIFICATION

I. Background

The pollutant specific emissions unit is a wet scrubber that is used to remove residual SO_2 from the digester system blow cyclone gases. The vapor flows out of the top of the blow cyclone into the bottom of the wet scrubber. The scrubbing liquid is a weak sodium carbonate (Na_2CO_3) solution. This liquid enters the top of the scrubber through a distribution header to ensure the scrubber packing is uniformly wetted. The liquid flow rate is approximately 200 gallons per minute. The gas flows through the packed column and through a mesh pad mist eliminator to remove entrained sodium carbonate solution and then exits through the top of the scrubber to the atmosphere. The scrubber is constructed of a fiber-reinforced plastic (FRP) material that has chemical resistance properties suitable for this application.

An overflow nozzle in the scrubber maintains the liquid level at the bottom of the scrubber. A small amount of fresh sodium carbonate solution is added to the recirculation flow as the solution is discharged; the discharged solution is returned to the sulfur burner absorption tower as an input in the production of cooking liquor used to digest wood chips in the pulping process.

II. Rationale for Selection of Performance Indicators

To ensure compliance with the applicable emissions limit, a minimum scrubbing liquid flow rate must be supplied to the scrubber to absorb a given amount of SO_2 in the gas stream, given the size of the tower and height of the packed bed. The liquid to gas (L/G) ratio is a key operating parameter of the scrubber. If the L/G ratio decreases below the minimum, sufficient mass transfer of the pollutant from the gas phase to the liquid phase will not occur. The minimum liquid flow required to maintain the proper L/G ratio at the maximum gas flow and vapor loading through the scrubber can be determined. Maintaining this minimum liquid flow, even during periods of reduced gas flow, will ensure that the required L/G ratio is achieved at all times.

As the pH of the scrubbing liquid decreases, the concentration gradient between the liquid and gas decreases, and less SO_2 is absorbed. The chemical equation that describes the primary scrubbing action is as follows:

$$SO_2 + Na_2CO_3 \rightarrow Na_2SO_3 + CO_2$$

It is important to maintain a minimum pH of the scrubbing liquid to drive this equation.

III. Rationale for Selection of Indicator Ranges

Because the wet scrubber is a new installation at this facility, indicator ranges for the scrubber liquid pH and flow rate have been developed based on the manufacturer's design and operating guidelines, the chemistry of the reaction products, and previous experience operating this scrubber on a similar application at another facility. The selected range for scrubber liquid pH is greater than 9.0, to ensure the reaction favors creation of the sodium sulfite (Na_2SO_3)

compound. This compound is subsequently utilized in the pulping process as an active cooking chemical. An excursion occurs and is documented if an hourly value is less than 9.0. The selected indicator range for scrubber liquid flow is greater than 175 gallons per minute. If an hourly value is less than 175 gallons per minute, an excursion occurs and is documented. Hourly readings are sufficient to ensure proper operation of the control device as operating experience with this scrubber has shown that the pH and flow do not vary appreciably over the course of a day (see Figure 1). In addition, since this unit is not a large CAM source (post-control emissions are less than the major source threshold), continuous monitoring is not required.

After data on these parameters are collected for 6 months and the operators have become familiar with the new scrubber system, a performance test will be conducted to verify that the removal efficiency standard can be met while operating within the selected indicator ranges. The performance test will be conducted at conditions that are representative of the operating conditions that prevailed during the previous 6-month period. The indicator ranges will be re-evaluated at that time.

Comment: During the review period, one commenter suggested that this example is not complete and sufficient data to establish indicator ranges were not available. We believe this example is appropriate. State agencies are likely to receive CAM submittals, which propose indicator ranges based upon limited historical data or data from similar sources before performance testing has been conducted or additional historical monitoring data can be collected. The CAM rule, 40 CFR part 64, paragraphs 64.4(d) and (e) discuss the submittal of a schedule to obtain additional information, as is shown in this example. The draft (or final) permit can be written to accommodate a revision to the indicator range based upon the performance test results.

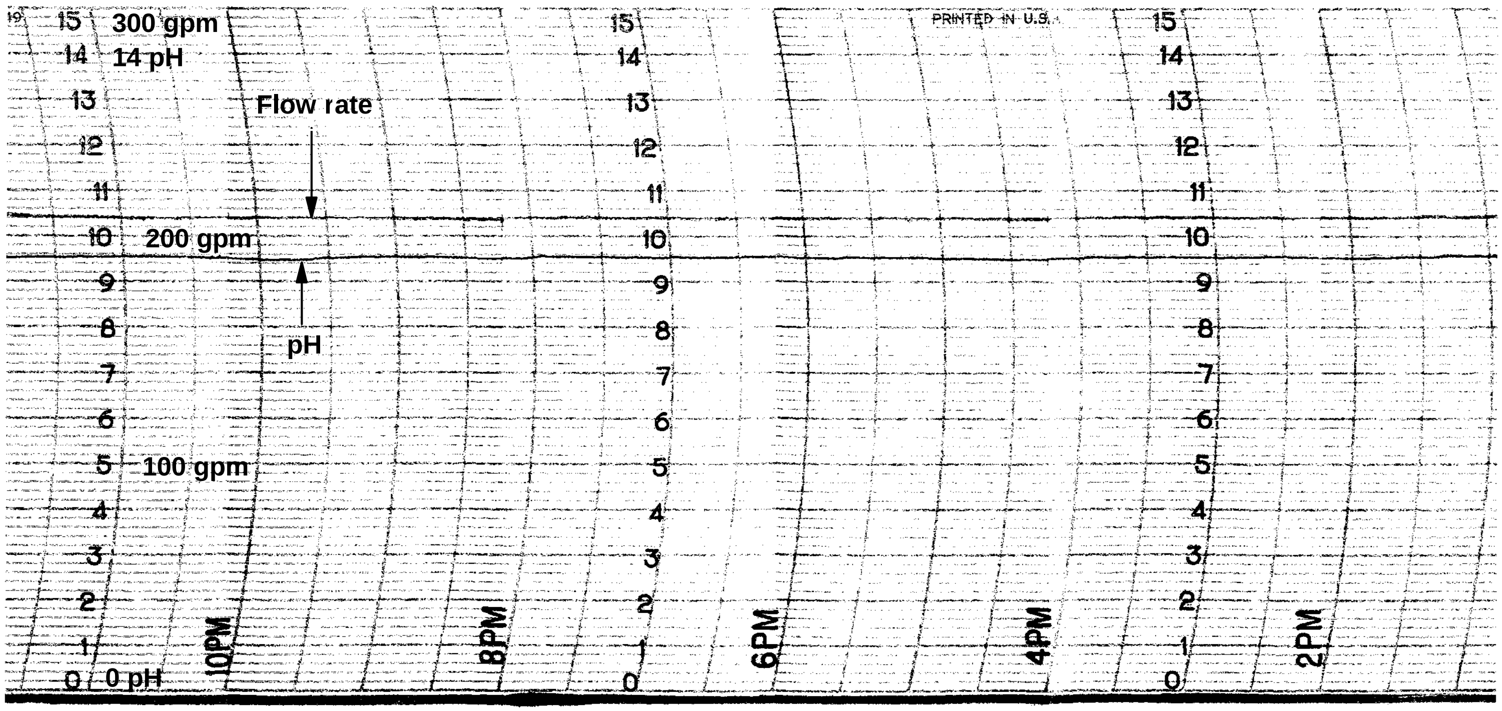

Figure 1. Typical scrubber flow rate and pH.

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A.24 CARBON ADSORBER FOR VOC CONTROL--FACILITY EE

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EXAMPLE COMPLIANCE ASSURANCE MONITORING
CARBON ADSORBER FOR VOC CONTROL: FACILITY EE

I. Background

A. Emissions Unit

Description:	Loading Rack
Identification:	LR-1
APCD ID:	VRU-1
Facility:	Facility EE Anytown, USA

B. Applicable Regulation, Emission Limit, and Monitoring Requirements

Regulation:	Permit, State regulation
Emission Limits:	
VOC:	45 mg/liter of product loaded
Monitoring Requirements:	Monitor vacuum profile during carbon bed regeneration cycle, monitor for APCD bypass, test the carbon periodically, and conduct an inspection and maintenance program and a leak detection and repair program.

C. Control Technology: Carbon adsorber.

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table A.24-1. The amount of time the regenerating carbon bed remains at or below -27 inches of Hg is monitored to ensure the bed has been fully regenerated. An inspection and maintenance program, including annual testing of the carbon activity, is conducted to verify proper operation of the vapor recovery unit (VRU). Periodic leak checks of the vapor recovery unit also are conducted and the carbon adsorber bypass valve is monitored to ensure bypass of the control device is not occurring.

Note: Facility EE also monitors parameters related to the vapor tightness of connections and tank trucks and other parameters of the vapor recovery system, but this example focuses on the monitoring performed on the carbon adsorber.

TABLE A.24-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2	Indicator No. 3
I. Indicator	Regeneration cycle vacuum. Specifically, the time the regenerating carbon bed remains at or below -27 inches Hg.	Documentation of inspection and maintenance program and annual carbon testing.	Equipment leaks.
Measurement Approach	Pressure transmitter.	Proper VRU operation is verified by performing periodic inspections and maintenance. Daily checks include verification of gasoline flow, purge air flow, cycle time, valve timing, and operating temperatures. Annual checks include carbon testing and pump and motor maintenance.	Monthly leak check of vapor recovery system.
II. Indicator Range	An excursion occurs when the regenerating carbon bed remains at or below -27 inches Hg for less than 2.5 minutes. When an excursion occurs, the loading rack will be shut down via an automated interlock system. An excursion will trigger an investigation, corrective action, and a reporting requirement.	An excursion occurs if the inspection or annual carbon test is not performed or documented or if corrective action is not initiated within 24 hours to correct any problems identified during the inspection of the unit or carbon testing. An excursion will trigger an investigation, corrective action, and a reporting requirement.	An excursion is defined as detection of a leak greater than or equal to 10,000 ppm (as methane) during normal loading operations. An excursion will trigger an investigation, corrective action, and a reporting requirement. Leaks will be repaired within 15 days.
III. Performance Criteria A. Data Representativeness	The pressure during the regeneration cycle is measured in the vacuum pump suction line. The minimum accuracy of the pressure transmitter is ±1.0 percent.	VRU operation verified visually by trained personnel using documented inspection and maintenance procedures. Representative carbon sample obtained from both beds.	A handheld monitor is used to check for leaks in the vapor collection system during loading operations.
B. Verification of Operational Status	NA	NA	NA
C. QA/QC Practices and Criteria	Pressure transmitter is calibrated annually.	Personnel are trained on inspection and maintenance procedures and proper frequencies.	Follow procedures in 40 CFR 60, Appendix A, Method 21.
D. Monitoring Frequency	Continuously during each regeneration cycle.	Varies. Carbon testing performed annually.	Monthly.

(TABLE A.24-1. Continued.)

	Indicator No. 1	Indicator No. 2	Indicator No. 3
Data Collection Procedures	The data acquisition system (DAS) records the pressure profile during each regeneration cycle. Periods when the interlock system shuts down the loading rack also are recorded.	Results of inspections and any maintenance necessary are recorded in VRU operating log. Results of carbon testing are maintained onsite.	Records of inspections, leaks found, leaks repaired.
Averaging period	None.	None.	None.
APCD Bypass Monitoring:	The pressure in the VRU vapor line is monitored with a pressure transmitter to ensure bypass of the control device is not occurring. If the pressure in the VRU vapor line exceeds 18 inches of water, the safety relief valve opens and bypass occurs. All instances of control device bypass are recorded.		

MONITORING APPROACH JUSTIFICATION

I. Background

The pollutant specific emissions unit (PSEU) is a vacuum regenerative carbon adsorber used to reduce VOC emissions from the loading of petroleum products (heating oil, diesel fuel, and gasoline). (Note: This facility is not a major source of HAP emissions and is not subject to 40 CFR 63, Subpart R, "National Emission Standards for Gasoline Distribution Facilities" or 40 CFR 60, Subpart XX, "Standards of Performance for Bulk Gasoline Terminals.")

The carbon adsorber has two identical beds, one adsorbing while the other is desorbing on a 15-minute cycle. Carbon bed regeneration is accomplished with a combination of high vacuum and purge air stripping which removes previously adsorbed gasoline vapor from the carbon and restores the carbon's ability to adsorb vapor during the next cycle. The vacuum pump extracts concentrated gasoline vapor from the carbon bed and discharges into a separator. Non-condensed gasoline vapor plus gasoline condensate flow from the separator to an absorber column which functions as the recovery device for the system. In the absorber, the hydrocarbon vapor flows up through the absorber packing where it is liquefied and subsequently recovered by absorption. Gasoline product from a storage tank is used as the absorbent fluid. The recovered product is returned along with the circulating gasoline back to the product storage tank A small stream of air and residual vapor exits the top of the absorber column and is recycled to the on-stream carbon bed where the residual hydrocarbon vapor is re-adsorbed.

II. Rationale for Selection of Performance Indicators

The carbon adsorber system was custom-designed specifically for this installation based on the maximum expected loading and types of products loaded. The carbon beds and vacuum pump were sized appropriately. The vacuum profile during regeneration is an important variable in the performance of the VRU. If the carbon bed is overloaded, the time to achieve certain vacuum levels will be longer, and the bed will not be fully regenerated during the 15-minute cycle. Monitoring of the vacuum profile during regeneration, coupled with regular inspection and maintenance activities (including, daily verification of proper valve timing, cycle time, gasoline flow, and purge air flow) and annual testing of a carbon sample from each bed, serves to verify that the VRU is operating properly and provide a reasonable assurance of compliance.

A monthly leak inspection program is performed to ensure that the vapors released during loading are captured and conveyed to the VRU. A handheld monitor is used to detect leaks in the vapor collection system. The VRU's relief valve in the VRU vapor line also is monitored to ensure the control device is not bypassed. Bypass occurs when the pressure in the vapor line exceeds the safe limit.

III. Rationale for Selection of Indicator Ranges

An engineering analysis was performed based on the worst case loading conditions expected. That analysis shows that if the regenerating carbon bed stays at or below -27 in Hg for at least 2.5 minutes the bed will be properly regenerated and will have the capacity to meet the VOC emissions limit under worst case loading conditions. Therefore, an excursion occurs when the regenerating bed does not stay at or below -27 in. Hg for at least 2.5 minutes. The expected vacuum profile during heavy loading is presented in Table A.24-2. All excursions will be documented and reported. An interlock system is used to shut down loading operations when an excursion occurs. Typical operating data show that the beds stay at or below -27 in. Hg for more than 5 minutes of the regeneration cycle, as shown in Table A.24-3.

The most recent performance test showed emissions of 3.8 mg/liter of gasoline loaded, less than 10 percent of the VOC limit. The unit's efficiency was calculated as 99.99 percent. The exhaust concentration equivalent of 45 mg/L loaded calculated at the time of the performance test was approximately 33,100 ppmv VOC. Table A.24-4 shows exhaust VOC concentration data for both beds collected over a period of several weeks using a portable VOC analyzer. The data show the carbon adsorber operated well under the VOC emission limit.

TABLE A.24-2. WORST-CASE MODELED VACUUM PROFILE (HEAVIEST LOADING)

Minute	Inches Hg Vacuum
1	14.0
2	19.6
3	22.3
4	24.3
5	25.0
6	25.3
7	25.6
8	26.0
9	26.2
10	26.5
11	26.8
12	27.0
13	27.3
13:30	27.5
14-15	At 13:30, the bed is re-pressurized.

TABLE A.24-3. TYPICAL VACUUM PROFILE DURING REGENERATION CYCLE

Bed 1		Bed 2	
Minute	Inches Hg Vacuum	Minute	Inches Hg Vacuum
1	12.5	1	10
2	20.5	2	18
3	24	3	23
4	25	4	26
5	26	5	27.5
6	26.5	6	27.6
7	26.8	7	27.6
8	27	8	27.7
9	27.1	9	27.8
10	27.1	10	27.8
11	27.2	11	27.9
12	27.3	12	27.9
13	27.4	13	28
14	At 13:30, the bed is re-pressurized.	14	At 13:30, the bed is re-pressurized.
15		15	

TABLE A.24-4. SAMPLE WEEKLY EXHAUST VOC CONCENTRATION DATA

Week	Bed 1 (ppmv)	Bed 2 (ppmv)
1	6,000	6,500
2	4,800	5,200
3	7,900	5,100
4	8,450	6,240
5	9,000	6,450
6	9,500	11,000
7	9,110	7,500
8	10,000	8,000
9	12,000	9,500
10	8,000	6,500

For the second indicator, an inspection and maintenance program is conducted, following documented procedures. This program is performed by terminal operators and contracted maintenance personnel. The results of all inspections and any maintenance performed are recorded in the VRU operating log. An excursion is defined as failure to conduct or document the required inspections or maintenance activities or failure to initiate corrective action within 24 hours to correct any problems identified during the inspection. All excursions will be documented and reported.

For the third indicator, an excursion is defined as detection of a leak greater than or equal to 10,000 ppm (as methane) during normal loading operations. If a leak is detected, corrective action will be initiated, and the leak will be repaired within 15 days. All excursions will be documented and reported. Control device bypass also is monitored. Bypass occurs when the pressure in the VRU vapor line exceeds 18 inches of water and the safety relief valve opens. All instances of control device bypass are recorded.

Comment: For regenerative carbon absorbers, an annual carbon activity check provides the facility with information on the condition and activity of the carbon. An alternative to periodic carbon activity checks would be periodic checks of the outlet VOC concentration using a portable monitor, or periodic (e.g., annual) Method 25A tests.

Furthermore, if an additional level of confidence in the monitoring approach were desired (e.g., if the unit had a small margin of compliance with the VOC limit), one option would be to require more frequent periodic (e.g., quarterly) monitoring of the carbon bed outlet concentration with a portable VOC analyzer in lieu of the annual carbon testing.

Comment: During the review period, one commenter suggested setting an internal warning level for the bypass line pressure. For safety reasons, the bypass valve on the inlet APCD line is set to release at 18” w.c. With respect to APCD bypass, the CAM rule only requires that a facility monitor the bypass so that bypass events can be corrected immediately and reported. Consequently, establishing an indicator range at a level less than the release pressure is not required. However, if a facility wants to take extra precautions to avoid bypass events, it could establish a warning at a lower pressure, such as the 15” w.c., which would allow them to initiate corrective action before a bypass event, as suggested by this commenter.

A.25 ELECTROSTATIC PRECIPITATOR (ESP) FOR PM CONTROL--FACILITY FF

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EXAMPLE COMPLIANCE ASSURANCE MONITORING
ELECTROSTATIC PRECIPITATOR (ESP) FOR PM CONTROL: FACILITY FF

I. Background

A. Emissions Unit

Description:	Coal-fired boilers
Identification:	B001, B002, B003
APCD ID:	ESP1, ESP2, ESP3
Facility:	Facility FF Anytown, USA

B. Applicable Regulation, Emissions Limit, and Monitoring Requirements

Regulation:	Permit, State regulation
Emissions Limits: PM:	 0.137 lb/mmBtu
Current monitoring requirements:	 None.

C. Control Technology: Electrostatic precipitator.

II. Monitoring Approach

The key elements of the monitoring approach, including the indicators to be monitored, indicator ranges, and performance criteria are presented in Table A.25-1. Secondary voltage and current are monitored in each field and the total power input to each ESP is determined.

TABLE A.25-1. MONITORING APPROACH

I. Indicator	ESP secondary voltage and current are measured for each field to determine the total power to each ESP.
Measurement Approach	The secondary voltage is measured using a voltmeter and the secondary current is measured using an ammeter. The total power (P) input to the ESP is the sum of the products of the secondary voltage (V) and current (I) in each field. ($P = V_1I_1 + V_2I_2$)
II. Indicator Range	An excursion is defined as a total power input less than 15 kW. Excursions trigger an inspection, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness	The voltage and current are measured using the instrumentation the manufacturer provided with the ESP.
B. Verification of Operational Status	NA
C. QA/QC Practices and Criteria	Confirm the meters read zero when the unit is not operating.
D. Monitoring Frequency	The secondary voltage and current are measured once each hour and used to calculate the total power input once each hour.
Data Collection Procedures	The 3-hr average total power input is calculated and recorded.
Averaging period	3-hr.

MONITORING APPROACH JUSTIFICATION

I. Background

There are three 2-field ESP's controlling three coal-fired boilers (the emissions from each boiler are controlled by one ESP). The pollutant-specific emission unit is each ESP used to control PM emissions from a boiler. Boiler Nos. 1 and 3 are rated at 120,000 pounds of steam per hour and Boiler No. 2 is rated at 50,000 pounds of steam per hour. The three boilers are not subject to any New Source Performance Standards (NSPS). Boiler No. 1 typically operates from December through February, Boiler No. 2 typically operates from March through November, and Boiler No. 3 typically operates from December through March. The boilers normally are not operated at full capacity, but all emissions tests have been performed at or near full load. These units are not "large" CAM sources (their post-control PM emissions are less than 100 tons per year) so continuous monitoring is not required.

II. Rationale for Selection of Performance Indicators

In an ESP, electric fields are established by applying a direct-current voltage across a pair of electrodes, a discharge electrode and a collection electrode. Particulate matter suspended in the gas stream is electrically charged by passing through the electric field around each discharge electrode (the negatively charged electrode). The negatively charged particles then migrate toward the positively charged collection electrodes. The particulate matter is separated from the gas stream by retention on the collection electrode. Particulate is removed from the collection plates by shaking or rapping the plates.

As a general rule, ESP performance improves as total power input increases. This relationship is true when particulate matter and gas stream properties (such as PM concentration, size distribution, resistivity, and gas flow rate) remain stable and all equipment components (such as rappers, plates, wires, hoppers, and transformer-rectifiers) operate satisfactorily. In an ESP with many fields, the power distribution also plays a key role in the performance of the ESP. In this case, however, measurement of total power input is acceptable because the ESP has only two fields.

The secondary voltage drops when a malfunction, such as grounded electrodes, occurs in the ESP. When the secondary voltage drops, less particulate is charged and collected. Also, the secondary voltage can remain high but fail to perform its function if the collection plates are not cleaned, or rapped, appropriately. If the collection plates are not cleaned, the current drops. Thus, since the power is the product of the voltage and the current, monitoring the power input will provide a reasonable assurance that the ESP is functioning properly. In other words, problems that would be detected by monitoring other parameters individually also will be manifested in the power input.

III. Rationale for Selection of Indicator Ranges

The total power input to the ESP is the sum of the products of the secondary voltage and secondary current for each field. An excursion is defined as a 3-hr. average total power input less than 15 kW. When an excursion occurs, corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All excursions will be documented and reported.

The indicator range for the total power was selected based upon the level indicated from recent operation. The facility records parameter data once each hour. The normal operating voltage is set at the highest level achievable without having an excessive spark rate. Based on field experience, power levels less than 5 kW during normal operation result in opacity readings that approach 20 percent (typically the opacity of the ESP exhaust is less than 5 percent). During abnormal operation or malfunction, the ESP power levels are appreciably lower than normal operational levels. Table A.25-2 shows that during normal operating conditions, the total ESP power input for boiler No. 2 typically is between 18 and 22 kW. If one field in the ESP goes out of service, the total power input drops below 15 kW. [Note: Historically, the facility has monitored ESP operating parameters but has not recorded the data. Several days of historical data were recorded manually by the facility specifically to provide representative data to EPA for development of this CAM submittal; the facility provided a 1-hr reading for every other hour in its data set. The data shown in Table A.25-2 are instantaneous hourly readings and are not averages.]

The opacity normally is below 5 percent. The opacities were measured using a continuous opacity monitor installed in the boiler exhaust stack; however, the equipment does not meet the criteria in 40 CFR 60, Appendix B, Performance Specification 1. Therefore, it is not used for compliance monitoring. In addition, compliance with the boiler's 20 percent opacity limit would not necessarily indicate compliance with the PM limit, and continuous opacity monitoring is not required of this source.

TABLE A.25-2. BOILER NO. 2 NORMAL OPERATING CONDITIONS

Time	Total ESP Power (kW)	Boiler Load (lb/hr)	Opacity, percent
1:00 AM	21	46,000	1.9
3:00 AM	21	47,000	2.0
5:00 AM	18	50,000	1.9
7:00 AM	18	47,000	2.0
9:00 AM	21	46,000	1.9
11:00 AM	22	44,000	1.7
1:00 PM	21	44,000	1.7
3:00 PM	20	44,000	2.1
5:00 PM	21	46,000	1.9
7:00 PM	21	50,000	1.9
9:00 PM	21	47,000	2.0
11:00 PM	21	46,000	1.9

The PM emissions measured during the most recent performance tests are between 4 and 22 percent of the emissions limit (0.137 lb/mmBtu); each ESP has a large margin of compliance with the PM limit. Table A.25-3 presents data from the past six performance tests.

Because no monitoring data are available for Boilers No. 1 and 3, the current indicator ranges for Boilers No. 1 and 3 have been selected based on monitoring data for a similar source (Boiler No. 2). After data on power have been collected for six months, the indicator range for Boilers No. 1 and 3 will be reevaluated based on the monitoring data for each individual boiler.

Comment: In this example, we set the indicator range based on the performance test data and the historical monitoring data. Each of the units is operating at less than approximately 20 percent of the emission limit and therefore has a large margin of compliance. Because the units have this large margin of compliance, we set the indicator range using the historical monitoring data as well. An alternative to this approach is to base the indicator range solely on the performance test; for example, set the range based on 90 percent of the 3-hr average from the performance test. This would also be correct, although somewhat more stringent.

Comment: Total secondary power would not be an adequate indicator for a large multi-field ESP. Monitoring for an ESP with many fields becomes more complicated because emissions are highly dependent on how each field is performing. With multiple fields, monitoring should be based on the secondary power parameter for each separate field. Total secondary power provides a reasonable assurance of compliance when the ESP has only a few fields (e.g., two fields) and when the emissions unit has a large margin of compliance.

TABLE A.25-3. PERFORMANCE TEST DATA

Boiler No.	Test Date	Average PM Emission Rate (lb/mmBtu)	Percent of Allowable PM Emissions Rate (%)	Average load (lb steam/hr)	Capacity (lb steam/hr)
1	1997	0.030	21.9	115,500	120,000
1	1991	0.013	9.5	114,500	120,000
2	1997	0.020	14.6	47,600	50,000
2	1994	0.017	12.4	51,800	50,000
2	1991	0.006	4.4	51,400	50,000
3	1994	0.015	10.9	120,900	120,000

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A.27 FLUE GAS RECIRCULATION (FGR) FOR NO_X CONTROL--FACILITY HH

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EXAMPLE COMPLIANCE ASSURANCE MONITORING
FLUE GAS RECIRCULATION FOR NO_X CONTROL: FACILITY HH

I. Background

A. Emissions Unit

Description:	187 mmBtu/hr boiler
Identification:	Unit 026
Facility:	Facility HH Anytown, USA

B. Applicable Regulation, Emissions Limit, and Monitoring Requirements

Regulation:	40 CFR 60, Subpart Db; State regulation
Emissions Limits: NO_x:	 0.20 lb/mmBtu
Monitoring Requirements:	NO_x predictive emissions monitoring system (PEMS), position of flue gas recirculation damper

C. Control Technology: Flue gas recirculation (FGR)

II. Monitoring Approach

The key elements of the monitoring approach, including the indicators to be monitored, indicator ranges, and performance criteria are presented in Table A.27-1. The parameters monitored are the exhaust gas oxygen concentration, fuel flow, and the FGR damper position.

TABLE A.27-1. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2	Indicator No. 3
I. Indicator	Fuel flow rate	Boiler exhaust O_2 concentration	FGR damper position
Measurement Approach	The hourly fuel flow rate is monitored as an input to the PEMS model.[1] Fuel heat content is obtained from the fuel supplier. (Steam output is used to predict heat input if fuel flow data are unavailable.)	The boiler exhaust gas O_2 concentration, used as a check of the boiler operating condition, is measured at the boiler outlet.	The position of the FGR damper is determined by the notch indicator.
II. Indicator Range	An excursion is defined as predicted NO_x emissions greater than 0.05 lb/mmBtu (rolling 30-day average). Excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion is defined as a boiler exhaust oxygen concentration greater than 3.3 percent (rolling 30-day average). Excursions trigger an inspection, corrective action, and a reporting requirement.	An excursion occurs when the FGR damper is closed further than 4 notches from the bottom. Excursions trigger an inspection, corrective action, and a reporting requirement.
III. Performance Criteria A. Data Representativeness	Fuel oil flow rate is measured with a positive displacement flow meter with a minimum accuracy of ±0.5 percent of the flow rate. The natural gas flow rate is measured with an orifice plate flow meter with a minimum accuracy of ±1 percent of the flow rate.	The in-situ O_2 monitor has a minimum accuracy of <2 percent calibration error to zero and upscale reference gases.	The FGR damper position is checked visually by an operator.
B. Verification of Operational Status	NA	NA	NA
C. QA/QC Practices and Criteria	Annual calibration of fuel flow meters (acceptance criteria: ±1 percent). Annual relative accuracy test of the PEMS (acceptance criteria: <20 percent). Data availability criteria: 75 percent of the operating hours and the operating days.	Weekly zero and upscale calibration of O_2 monitor.	None.
D. Monitoring Frequency	Fuel flow rate is monitored continuously. The NO_x emission rate is calculated hourly and daily using the PEMS model.	The boiler exhaust O_2 concentration is monitored continuously.	The position of the FGR damper is checked by an operator on a daily basis.

(TABLE A.27-1. Continued.)

	Indicator No. 1	Indicator No. 2	Indicator No. 3
Data Collection Procedures	The data acquisition system (DAS) records the hourly and 30-day rolling NO_x emission rates calculated using the PEMS model.	The DAS records the exhaust gas O_2 concentration hourly.	The position of the FGR damper is recorded daily in the boiler operating log.
Averaging period	Fuel flow rate: Hourly. NO_x emission rate: Hourly and 30-day rolling.	Hourly and 30-day rolling.	NA.

[1] PEMS algorithm:

heat input, mmBtu/hr = fuel flow rate * fuel heat content

For heat input values equal to or greater than 45 mmBtu/hr:
NO_x, lb/hr = 0.0002 * (heat input, mmBtu/hr)^2 + 0.0101 * (heat input, mmBtu/hr) + 0.8985
NO_x, lb/mmBtu = (NO_x, lb/hr) / (mmBtu/hr)

For heat input values less than 45 mmBtu/hr:
NO_x, lb/hr = 0.0379 * (heat input, mmBtu/hr)
NO_x, lb/mmBtu = (NO_x, lb/hr) / (mmBtu/hr)

MONITORING APPROACH JUSTIFICATION

I. Background

The pollutant specific emissions unit is a 187 mmBtu/hr boiler fired with fuel oil and natural gas. The boiler is equipped with low-NO_x burners and FGR and is subject to 40 CFR 60, Subpart Db. A PEMS is used in lieu of a continuous emissions monitoring system (CEMS) to calculate NO_x emissions. The parameters monitored for this PEMS are based on this specific application. Other PEMS might be designed to monitor different combinations of operating parameters to meet the accuracy criteria.

II. Rationale for Selection of Performance Indicators

A properly designed, operated, and validated PEMS provides accurate emissions data. This PEMS was developed from data collected over a 30-day period. An additional 75-day PEMS/CEMS comparison was conducted to verify the validity of the PEMS model. During the 75-day test, measured NO_x emissions averaged 2.8 lb/hr and predicted emissions averaged 3.0 lb/hr.

The limits on boiler exhaust O_2 concentration and the FGR damper position are to ensure the boiler operates within the operating envelope used during the PEMS development. A definite correlation exists between boiler O_2 and NO_x. As the combustion process is starved for air (i.e., fuel rich with low O_2) the combustion temperature is lower and the amount of NO_x produced is lower. During the PEMS development, the position of the FGR damper was found to have an impact on NO_x emissions. The position of the FGR damper is an indication of the amount of air recirculated to the primary combustion zone. As the damper is moved toward the closed position, the NO_x emissions increase.

III. Rationale for Selection of Indicator Ranges

For the NO_x emission rate, an excursion is defined as predicted NO_x emissions greater than 0.05 lb/mmBtu (rolling 30-day average). This boiler is operated with a large margin of compliance and the indicator range is set at 25 percent of the NO_x emissions limit so corrective action may be taken before the 0.20 lb/mmBtu emission limit is exceeded. During the 30-day emission test, the average NO_x emission rate was 0.0373 lb/mmBtu and no single hourly average exceeded 0.05 lb/mmBtu or 9.34 lb/hr.

For the boiler exhaust oxygen concentration, an excursion is defined as a concentration greater than 3.3 percent (rolling 30-day average). Since, during the 30-day development and 75-day verification periods, the average O_2 did not exceed 3.3 percent (except for startup and shutdown), the assumption that the PEMS maintains its accuracy at O_2 levels below 3.3 percent is reasonable. For the FGR damper, an excursion occurs when the FGR damper is closed further than 4 notches from the bottom. Because the FGR damper was set at notch position 4 during the PEMS development testing, the FGR damper must be closed no further than that position in order to maintain the accuracy of the PEMS. If the FGR damper is closed further than notch 4, less flue gas will be returned to the boiler and the PEMS will predict NO_x emissions that are lower than the actual emissions.

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APPENDIX B.

CAM ILLUSTRATIONS

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B.1 FABRIC FILTERS[1-6]

Fabric filters, frequently referred to as baghouses, are typically used to control particulate matter emissions in exhaust gas streams. Certain gases may also be removed through interactions with the dust layer. Fabric filters are normally used where a high control efficiency is required and where exhaust gas streams conditions are within the limitations of fabric filter operation. These limitations are high moisture, high temperatures, and exhaust gas constituents that attack the fabric or hinder the cleaning process (such as sticky particulate).

Three types of baghouses (pulse-jet, reverse-air, and shaker) are in common use, categorized by the method used for filter cleaning. Various fabric filter materials can be used in each type, depending on temperature, corrosiveness and moisture content of the gas stream, as well as dimensional stability and cost of the selected material. Important design parameters for baghouses are the gas-to-cloth (G/C) ratio (ft^3 per minute gas/ft^2 fabric), which is somewhat dependent on particle size and grain loading, as well as operating temperatures and the cleaning mechanism. Minimum operating temperature is especially important where acid gases are expected to be present in the gas stream, while cleaning mechanisms and maximum temperature may dictate the type of cloth that can be used.

Each type of baghouse presents different maintenance and monitoring challenges to the facility operators, particularly in relation to cleaning mechanisms and bag materials. Effective cleaning is desirable in order to maintain a low pressure-drop across the baghouse, which saves energy. This must be balanced, however, against the increased particulate removal efficiency which follows buildup of a dust layer on the fabric.

1. Pulse-jet systems use a blast of high-pressure (60 to 120 psi) air to back flush the bags. This can be accomplished with the baghouse on-line. Moisture and oil present in plant air must be removed, or potential bag blinding can result from caking particulate. Equipment must be able to withstand the repeated stress of the pulses.
2. Reverse-air systems use a longer, gentler back flush of low-pressure air (a few inches water column) to clean the bags. Cleaning air is provided to each compartment by a separate, smaller fan and duct system. Since the cleaning is at low pressure, each compartment must be effectively isolated from the gas stream during the cleaning cycle.
3. Many different shaking schemes have been introduced. Shaker systems must also be taken off-stream for cleaning, which is accomplished by a mechanism which vigorously shakes the bags. Combination reverse air/shaker systems are also in use.
4. Sonic horns have been developed which augment reverse-air and shaker cleaning. Acoustic vibration in the range of 150 to 550 Hz at 120 to 140 dB helps dislodge particles during the regular cleaning cycle.

Opacity is the typical method used for baghouse performance monitoring; a continuous opacity monitor may be used, or opacity (Method 9) or visible emissions (similar to Method 22) observations may be made by plant personnel. Triboelectric monitors, light scattering monitors, beta gauges, or acoustic monitors may also be used. Parameter monitoring usually includes pressure drop, sometimes in conjunction with exhaust gas temperature. An increase in pressure drop may indicate blinding of the fabric. A decrease in temperature may indicate inleakage of outside air, which may cool the exhaust gas stream below its dew point (important if condensible emissions are involved). Temperature excursions may damage the filter bags. Other parameters that may be monitored include gas flow rate, pulse jet compressed air pressures, and reverse air cleaning cycle static pressure drop.

Common baghouse problems and malfunctions include: broken or worn bags; blinding of the filter media; failure of the cleaning system; leaks in the system or between filter bag and tube sheet; reentrainment of dust; wetting of the bags; plugging of manometer lines; malfunction of dampers or material discharge equipment; and low fan speed. The following illustrations present compliance assurance monitoring options for fabric filters:

- 1a: Daily observations of visible emissions (VE) or opacity using RM 9 or modified RM 22.
- 1b: Continuous instrumental monitoring of opacity using COMS or other analytical device.
- 1c: Monitoring pressure drop across baghouse.
- 1d: Fabric filter condition monitoring.
- 1e: Use of a bag leak detection monitor.

CAM ILLUSTRATION
No. 1a. FABRIC FILTER FOR PM CONTROL

1. APPLICABILITY

1.1 Control Technology: Fabric filter (baghouse) [016, 017, 018].
Also applicable to other PM control devices

1.2 Pollutants
Primary: Particulate matter (PM, PM-10)
Other: Toxic heavy metals

1.3 Process/Emissions units: Industrial process vents and fuel combustion units

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Opacity of emissions or visible emissions (VE).

2.2 Rationale for Monitoring Approach: Changes in opacity and changes in VE observations indicate process changes, changes in baghouse efficiency, or leaks.

2.3 Monitoring Location: Per RM 9 (opacity) or RM 22 (VE) requirements.

2.4 Analytical Devices Required: Trained observer using RM 9 or visible/no visible emissions observation techniques (RM 22-like).

2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Daily or as weather permits
- Reporting units: Percent opacity or visible/no visible emissions
- Recording process: Observers complete opacity or VE observation forms and log into binder or electronic data base as appropriate.

2.6 Data Requirements
- Baseline VE observations concurrent with emission test or historical plant records of opacity observations. (No data are needed if indicator is “any visible emissions.”)

2.7 Specific QA/QC Procedures: Initial training of observer per RM 9 or RM 22, semi-annual refresher training per RM 9, if applicable

2.8 References: 1, 2, 3, 4, 5

3. COMMENTS

3.1 Although RM 22 applies to fugitive sources, the visible/no visible emission observation techniques of RM 22 can be applied to ducted emissions. For situations where no visible emissions are the norm, a technique focused towards identifying a change in performance as indicated by any visible emission is a useful and effective technique. The use of the visible/no visible emissions technique reduces the need for onsite certified RM 9 observers.

3.2 For large pollutant specific emission units (post control potential to emit equal to or greater than 100 percent of the amount required for a source to be classified as a major source), CAM requires the owner or operator to collect four or more data values equally spaced over each hour, unless the permitting authority approves a reduced frequency. Therefore, this monitoring approach may not be acceptable for large emission units unless used in conjunction with other appropriate parameter monitoring for which data are recorded at least four times each hour; e.g., baghouse pressure drop, air flow, temperature. (See Section 3.3.1.2.)

CAM ILLUSTRATION
No. 1b. FABRIC FILTER FOR PM CONTROL

1. APPLICABILITY

1.1 Control Technology: Fabric filter (baghouse) [016, 017, 018]; also applicable to other PM control devices

1.2 Pollutants
Primary: Particulate matter (PM, PM-10)
Other: Toxic heavy metals

1.3 Process/Emissions units: Industrial process vents and fuel combustion units

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Opacity

2.2 Rationale for Monitoring Approach: An increase in opacity indicates process changes, changes in baghouse efficiency, or leaks.

2.3 Monitoring Location: Exhaust gas outlet

2.4 Analytical Devices Required: Opacity meter or COMS as appropriate for gas stream

2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Once per shift if instruments read manually, or continuously recorded on strip chart or digital data acquisition system
- Reporting units: Percent opacity for COMS, or applicable units for other type monitors
- Recording process: Operators log data readings, or recorded automatically on strip chart or digital data acquisition system as appropriate

2.6 Data Requirements
- Baseline monitoring data (e.g., opacity for COMS) concurrent with emission test, or historical plant records of monitoring data

2.7 Specific QA/QC Procedures: Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: 1, 2, 3, 4, 5

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per shift would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION
No. 1c. FABRIC FILTER FOR PM CONTROL

1. APPLICABILITY

1.1 Control Technology: Fabric filter (baghouse) [016, 017, 018]
1.2 Pollutants
Primary: Particulate matter (PM, PM-10)
Other: Toxic heavy metals
1.3 Process/Emissions units: Industrial process vents and fuel combustion units

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Pressure drop
2.2 Rationale for Monitoring Approach
- Decrease in pressure drop indicative of bag failure
- Increase in pressure drop indicative of fabric blinding or decreased permeability

2.3 Monitoring Location: Across inlet and outlet of each compartment of control device
2.4 Analytical Devices Required: Pressure transducers, differential pressure gauges, manometers, other methods and/or alternative instrumentation as appropriate; see Section 4.3 for additional information on devices.
2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Once during each shift, or recorded continuously on strip chart or digital data acquisition system
- Reporting units: Inches of water column (in. w.c.) or pounds per square inch (psi)
- Recording process: Operators log data manually, or automatically recorded by data logger system

2.6 Data Requirements
- Baseline pressure drop measurements and cleaning cycle concurrent with emission test, or historical plant records on pressure drop measurements

2.7 Specific QA/QC Procedures: Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer's specifications.
2.8 References: 1, 2, 3, 4, 5

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per shift would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION
No. 1d. FABRIC FILTER FOR PM CONTROL

1. APPLICABILITY

1.1 Control Technology: Fabric filter (baghouse) [016]
1.2 Pollutants
Primary: Particulate matter (PM, PM-10)
Other: Toxic heavy metals
1.3 Process/Emissions units: Incinerators, furnaces, kilns, and other high temperature process units

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Pressure drop and inlet temperature
2.2 Rationale for Monitoring Approach
- Pressure drop: Decrease in pressure drop indicative of bag failure; increase in pressure drop indicative of fabric blinding or decreased permeability
- Temperature: Excessive temperature can lead to leaks, breakdown of filter material, and reduced lifetime of filter; temperatures below the dewpoint of the exhaust gas stream may also damage the filter bags

2.3 Monitoring Location
- Pressure drop: Across inlet and outlet of each compartment of control device
- Temperature: At fabric filter inlet duct

2.4 Analytical Devices Required
- Pressure drop: Pressure transducers, differential pressure gauges, manometers, other methods and/or alternative instrumentation as appropriate
- Temperature: Thermocouple, RTD, or other temperature sensing device; see Section 4.2 for additional information on devices.

2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Once during each shift, or recorded continuously on strip chart or digital data acquisition system
- Reporting units
  - Pressure drop: Inches of water column (in. w.c.) or pounds per square inch (psi)
  - Temperature: Degrees Fahrenheit (°F) or Celcius (°C)
- Recording process: Operators log data manually, or automatically recorded by data logger system

2.6 Data Requirements
- Baseline pressure drop measurements and cleaning cycle concurrent with emission test, or historical plant records on pressure drop measurements
- Temperature specifications for fabric filter material

2.7 Specific QA/QC Procedures: Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: 1, 2, 3, 4, 5

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per shift would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION
No. 1e. FABRIC FILTER FOR PM CONTROL

1. APPLICABILITY

1.1 Control Technology: Fabric filter (baghouse) [016, 017, 018], other PM control devices.

1.2 Pollutants

Primary: Particulate matter (PM, PM-10)

Other: Toxic heavy metals

1.3 Process/Source Type: Industrial process vents and fuel combustion units

2. MONITORING APPROACH DESCRIPTION

2.1 Indicator to be Monitored: Bag leak detection monitor signal.

2.2 Rationale for Monitoring Approach: Bag leak detectors that operate on principles such as triboelectricity, electrostatic induction, light scattering, or light transmission, produce a signal that is proportional to the particulate loading in the baghouse exhaust gas stream. When bag leaks occur, the cleaning peak height or baseline signal level will increase. Alarm levels based on increases in normal cleaning peak heights or the normal baseline signal can be set to detect filter bag leaks.

2.3 Monitoring Locations: Baghouse, control room

2.4 Analytical Devices Required: Bag leak detector and associated instrumentation.

2.5 Data Acquisition and Measurement System Operation

- Frequency of measurement: Continuous
- Reporting units: Amps, volts, or percent of scale
- Recording process: Strip chart or electronic data acquisition system

2.6 Data Requirements

- Historical signal data showing baseline level and cleaning peak height during normal operation or signal data concurrent with emission testing.

2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.

2.9 References: 1, 5, 6

3. COMMENTS

None.

B.2. ELECTROSTATIC PRECIPITATORS[1,7-9]

[To be completed]

The following illustration presents one approach to compliance assurance monitoring for an ESP:

2: Monitoring primary and secondary voltage and current, spark rate.

CAM ILLUSTRATION
No. 2. ESP FOR PM CONTROL

1. APPLICABILITY

1.1 Control Technology: Electrostatic precipitator (ESP) [010, 011, 012]
1.2 Pollutants
Primary: Particulate matter (PM)
Other:
1.3 Process/Emissions units: Furnaces, combustors

2. MONITORING APPROACH DESCRIPTION

2.1 Parameters to be Monitored: Primary and secondary voltage and current, spark rate.
2.2 Rationale for Monitoring Approach: Operating with these parameters outside of normal (design) specifications indicates a change in particulate collection efficiency.
2.3 Monitoring Location: Current and voltage at each transformer and spark rate in each section.
2.4 Analytical Devices Required: Ammeters, voltmeters, other methods or instrumentation as appropriate; see Section 4.6 for additional information on devices.
2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Hourly, if readings taken manually, or continuously, if recorded by distributed control system (DCS) or similar digital data acquisition system
- Reporting units: Amps, volts, sparks per minute, as appropriate
- Recording process: Operators periodically observe process and log data, or recorded automatically on strip chart or digital data acquisition system

2.6 Data Requirements
- Baseline ESP operating parameter records and sampling data concurrent with emission test or historical plant records of ESP performance parameters

2.7 Specific QA/QC Procedures: Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer’s specifications.
2.8 References: 1, 3, 7, 8, 9, 10, 11, 12

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

B.3 WET ELECTROSTATIC PRECIPITATORS[1,7-9,13]

[To be completed]

B.4 WET SCRUBBERS[8,9,14]

[To be completed]

The following illustrations demonstrate approaches to compliance assurance monitoring for wet scrubbers:

Particulate emissions:

4a: Monitoring pressure drop.

SO_2:

5: Monitoring scrubber liquid pH and liquid flow rate.

6: Monitoring pressure drop, alkali solution concentration, and flow rate.

CAM ILLUSTRATION
No. 4a. WET SCRUBBER FOR PM CONTROL

1. APPLICABILITY

1.1 Control Technology: Wet scrubber [001, 002, 003]; also applicable to spray towers [052], venturi scrubbers [053], impingement scrubbers [055], and wet cyclonic scrubber [085]

1.2 Pollutants
Primary: Particulate matter (PM)
Other:

1.3 Process/Emissions Unit: Combustors, mineral processing units, furnaces, kilns.

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Differential pressure

2.2 Rationale for Monitoring Approach: Increase in pressure drop indicates clogging or increased gas flow; decrease in pressure drop indicates decrease in gas or liquid flow or poor liquid distribution.

2.3 Monitoring Location: Across inlet and outlet ducts

2.4 Analytical Devices Required: Differential pressure transducer, differential pressure gauge, manometers, or alternative methods/instrumentation; see Section 4.3 for information on specific types of instruments.

2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Hourly, if manually read, or continuously, if by automatic system.
- Reporting units: inches of water column (in. w.c.) or pounds per square inch (psi)
- Recording process: Operators periodically observe gauges and log data, or recorded automatically on strip chart or digital data acquisition system

2.6 Data Requirements
- Baseline pressure drop records and sampling data concurrent with emission test; or
- Historical plant records of pressure drop

2.7 Specific QA/QC Procedures
- Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: 8, 9, 14

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION
No. 5. WET SCRUBBER FOR SO_2 CONTROL

1. APPLICABILITY

1.1 Control Technology: Wet scrubber [001, 002, 003]; also applicable to gas scrubbers (general) [013], gas column absorber (packed or tray type) [050, 051]
1.2 Pollutants
Primary: SO_2
Other: Acid gases
1.3 Process/Emissions Unit: Combustors

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Scrubber liquid pH and liquid flow rate
2.2 Rationale for Monitoring Approach: pH level and liquid flow rate indicative of proper operation for removal of SO_2 and other acid gases from exhaust stream
2.3 Monitoring Location: pH at scrubber liquor inlet; liquid flow rate at pump discharge or at scrubber liquor inlet
2.4 Analytical Devices Required: pH meter for pH; liquid flow meter, pump discharge pressure gauge, or other device for liquid flow; see Section 4.4 for information on specific types of instruments.
2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Hourly, if manually read, or continuously, if by automatic system; daily calculation of quantity of SO_2 removed based
- Reporting units: pH units for pH, cubic feet per minute (ft^3/min) for liquid flow
- Recording process: Operators periodically observe gages and log data, or recorded automatically on strip chart or digital data acquisition system

2.6 Data Requirements
- Baseline pH and liquid flow rate concurrent with emission test

2.7 Specific QA/QC Procedures
- Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: 9, 14

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION
No. 6. SPRAY DRYER FOR SO_2 CONTROL

1. APPLICABILITY

1.1 Control Technology: Spray drying
1.2 Pollutants
Primary: Sulfur oxides (SO_x)
Other:
1.3 Process/Emissions units: Combustors, furnaces, boilers

2. MONITORING APPROACH DESCRIPTION

2.1 Parameters to be Monitored: Pressure drop, alkali solution concentration and flow rate
2.2 Rationale for Monitoring Approach: Pressure drop is indicative of proper functioning of spray dryer. Removal of acid gas components is dependent on availability of adequate alkali as indicated by slurry alkalinity and flow rate.
2.3 Monitoring Location: Pressure drop measured across inlet and outlet of spray dryer. Alkali concentration measured at slurry header and recirculation pump discharge. Slurry flow rate at slurry header.
2.4 Analytical Devices Required: Differential pressure gauges, in-line pH meters, in-line flow meters, other methods and instrumentation as appropriate; see Sections 4.3 (Pressure), 4.4 (Flow), and 4.5 (pH and Conductivity) for additional information on devices.
2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Hourly pressure drop, pH measurements and flow; or monitored continuously by distributed control system (DCS) or similar means. Automatic alarm activated when pH or flow falls below indicator range.
- Reporting units: Inches of water column (in. w.c.) or pounds per square inch (psi); alkali concentration in pH units; flow in gal/hr.
- Recording process: Operators take readings and log manually, or automatically on strip chart recorder or digital data acquisition system. Alarm activation incidents manually recorded in log book

2.6 Data Requirements
- Historical operating data on flow and pH to give adequate warning to avoid noncompliance events

2.7 Specific QA/QC Procedures: Calibration, maintenance, and operation of pressure transducers, gauges, flow meters, and pH sensors using procedures that take into account manufacturer's specifications
2.8 References: 9, 14

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

B.5 THERMAL OXIDIZERS[1-2,15-16]

Thermal oxidizers or thermal incinerators are combustion systems that control VOC, CO, and volatile HAP by combusting them to carbon dioxide (CO_2) and water. The design of an incineration system is dependent on the pollutant concentration in the waste gas stream, type of pollutant, presence of other gases, level of oxygen, and stability of processes vented to the system. Important design factors include residence time (sufficient time for the combustion reaction to occur), temperature (a temperature high enough to ignite the waste-auxiliary fuel mixture), and turbulence (turbulent mixing of the air and waste-fuel). Time, temperature, turbulence, and sufficient oxygen concentration govern the completeness of the combustion reaction. Of these, only temperature and oxygen can be significantly controlled after construction. Time and turbulence are fixed by incinerator design and flow rate can be controlled only over a limited range.

The rate at which VOC compounds and CO are oxidized is greatly affected by temperature; the higher the temperature the faster the oxidation reaction proceeds. Because inlet gas concentrations are well below the lower explosive limit (LEL) to prevent preignition explosions, the gas must be heated with auxiliary fuel above the autoignition temperature. Thermal destruction of most organics occurs at combustion temperatures between 800°F and 2000°F. Residence time is equal to the incinerator chamber volume divided by the total flow of flue gases (waste gas flow, added air, and products of combustion). A residence time of 0.2 to 2.0 seconds, a length-to-diameter ratio of 2 to 3 for the chamber dimensions, and an average gas velocity of 10 to 50 feet per second are common. Turbulence, or good mixing, is necessary to ensure that all waste and fuel come in contact with oxygen. Because 100 percent turbulence is not achieved, excess air/oxygen is added (above stoichiometric or theoretical amount) to ensure complete combustion.

Normal operation of a thermal incinerator should include a fixed outlet temperature, or an outlet temperature above a minimum level. A variety of operating parameters that may be used to indicate good operation include: inlet and outlet VOC concentration, outlet incinerator temperature, auxiliary fuel input, fuel pressure (magnehelic gauge), fan current (ammeter), inlet waste gas temperature to heat exchanger, outlet waste gas temperature from heat exchanger, outlet carbon monoxide concentration, and outlet oxygen concentration. Common monitoring parameters for thermal incinerators include monitoring of incinerator combustion temperature, waste gas flow, fan current, and outlet CO concentration. Several different approaches to compliance assurance monitoring for thermal incinerators are presented in the following illustrations:

CO:

11a: Continuous combustion chamber temperature monitoring and annual burner inspection.

11b: Continuous outlet CO concentration monitoring.

VOC:

16a: Continuous combustion chamber temperature monitoring and annual burner inspection.

16b: Continuous combustion chamber temperature, annual burner inspection, and exhaust gas flow rate monitoring.

16c: Continuous combustion chamber temperature monitoring and continuous outlet CO concentration monitoring.

CAM ILLUSTRATION
No. 11a. THERMAL INCINERATOR FOR CO CONTROL

1. APPLICABILITY

1.1 Control Technology: Thermal incinerator [021]; also applicable to direct flame afterburners with or without heat exchangers [021, 022], boilers, or similar devices for controlling CO emissions by combustion

1.2 Pollutants

Primary: Carbon monoxide (CO)

Other: Volatile organic compounds (VOC's)

1.3 Process/Emissions units: Fluid catalytic cracking unit (FCCU) catalyst regenerators; petroleum refining

2. MONITORING APPROACH DESCRIPTION

2.1 Parameters to be Monitored: Combustion chamber temperature and annual burner inspection

2.2 Rationale for Monitoring Approach:
- Combustion chamber temperature: Low temperature indicates potential for insufficient destruction of CO.
- Annual burner inspection: Maintain proper burner operation and efficiency.

2.3 Monitoring Location: Outlet of combustion chamber

2.4 Analytical Devices Required: Thermocouples, or other temperature measurement device; see Section 4.2 for additional information on devices.

2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Hourly or recorded continuously on strip chart or digital data acquisition system
- Reporting units: Degrees Fahrenheit or Celsius (°F, °C)
- Recording process: Operators take readings and log data manually, or automatically recorded on digital data acquisition system.

2.6 Data Requirements: Baseline temperature measurements concurrent with emission test, historical plant records of temperature, or manufacturer's data and recommended operating ranges.

2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate thermocouples using procedures that take into account manufacturer's specifications.

2.8 References: 1, 2, 3, 4

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION
No. 11b. THERMAL INCINERATOR FOR CO CONTROL

1. APPLICABILITY

1.1 Control Technology: Thermal incinerator [021]; also applicable to direct flame afterburners with or without heat exchangers [021, 022], boilers, or similar devices for controlling CO emissions by combustion

1.2 Pollutants
Primary: Carbon monoxide (CO)
Other: Volatile organic compounds (VOC's)

1.3 Process/Emissions units: Fluid catalytic cracking unit (FCCU) catalyst regenerators; petroleum refining

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Outlet gas carbon monoxide concentration

2.2 Rationale for Monitoring Approach: Provides direct indicator of CO emissions.

2.3 Monitoring Location: Combustion chamber outlet

2.4 Analytical Devices Required: Nondispersive infrared (NDIR) analyzer or other methods or instrumentation.

2.5 Data Acquisition and Measurement System Operation

- Frequency of measurement: Hourly, if instruments read manually; continuously, if CEMS
- Reporting units: Parts per million by volume (ppm_v), dry basis
- Recording process: Operators take readings and log manually, or recorded automatically on strip chart or digital data acquisition system

2.6 Data Requirements

- Baseline CO concentration measurements, or historical plant records of CO concentrations or CEMS records.

2.7 Specific QA/QC Procedures: Calibrate, maintain, and operate CEMS using procedures that take into account manufacturer's specifications.

2.8 References: 1, 2, 3, 4

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

3.2 Concentration measurements, CO concentration in terms of ppm can be used as an indicator of control device performance even if the emission standard is a mass emissions standard (i.e., lb/hr); additional information (e.g., flow) to calculate/report emission in units of the standard is not required for CAM; however, such a measurement may be a monitoring requirement of the applicable requirement.

CAM ILLUSTRATION
No. 16a. THERMAL INCINERATOR FOR VOC CONTROL

1. APPLICABILITY

1.1 Control Technology: Thermal incinerator [021]; also applicable to direct flame afterburners with or without heat exchangers [021, 022], boilers, or similar devices for controlling VOC emissions by combustion

1.2 Pollutants
Primary: Volatile organic compounds (VOC's)
Other: Higher molecular weight organic compounds

1.3 Process/Emissions units: Coating, spraying, printing, polymer manufacturing, distillation units, wastewater treatment units, air oxidation units, petroleum refining, miscellaneous SOCMI units

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Combustion chamber temperature and annual burner inspection.

2.2 Rationale for Monitoring Approach:
- Combustion chamber temperature: Proper temperature range can be related to good performance
- Annual burner inspection: Maintain proper burner operation and efficiency.

2.3 Monitoring Location: Outlet of combustion chamber

2.4 Analytical Devices Required: Thermocouples, RTD's, or alternative methods/instrumentation as appropriate for specific gas stream; see Section 4.2 (Temperature) for additional information on devices.

2.5 Data Acquisition and Measurement System Operation:
- Frequency of measurement: Hourly, or recorded continuously on strip chart or digital data acquisition system.
- Reporting units: Degrees Fahrenheit or Celsius (°F, °C)
- Recording process: Operators take readings and manually log data, or recorded automatically on strip chart or digital data acquisition system.

2.6 Data Requirements:
- Baseline incineration temperature measurements and outlet VOC concentration or destruction efficiency measurements concurrent with emission test; or
- Historical plant records on incineration temperature measurements

2.7 Specific QA/QC Procedures:
- Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: 1, 2, 3, 4

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION

No. 16b. THERMAL INCINERATOR FOR VOC CONTROL

1. APPLICABILITY

1.1 Control Technology: Thermal incinerator [021]; also applicable to direct flame afterburners with or without heat exchangers [021, 022], for controlling VOC emissions by combustion

1.2 Pollutants

Primary: Volatile organic compounds (VOC's)

Other: Higher molecular weight organic compounds

1.3 Process/Emissions units: Coating, spraying, printing

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Combustion chamber temperature, annual burner inspection, and exhaust gas flow rate

2.2 Rationale for Monitoring Approach

- Combustion chamber temperature: Proper temperature range can be related to good performance.
- Exhaust gas flow rate: Maintaining proper flow through the entire control system is important for maintaining capture efficiency.
- Annual burner inspection: Maintain proper burner operation and efficiency.

2.3 Monitoring Location

- Combustion chamber temperature: Outlet of combustion chamber
- Exhaust gas flow rate: Incinerator outlet or fan instrumentation

2.4 Analytical Devices Required

- Combustion chamber temperature: Thermocouples, RTD's, or alternative methods/instrumentation as appropriate for specific gas stream.
- Exhaust gas flow rate: Differential pressure flow device, fan motor ammeter, or other type of device that measures gas velocity or flow rate

2.5 Data Acquisition and Measurement System Operation:

- Frequency of measurement: Hourly, or recorded continuously on strip chart or digital data acquisition system.
- Reporting units
  - Combustion chamber temperature: Degrees Fahrenheit or Celsius (°F, °C)
  - Exhaust gas flow rate: Cubic feet per minute (ft^3/min); amps if fan motor current
- Recording process: Operators take readings and manually log data, or recorded automatically on strip chart or digital data acquisition system.

2.6 Data Requirements:
- Baseline combustion chamber temperature measurements, exhaust gas flow rate measurements, and outlet VOC concentration or destruction efficiency measurements concurrent with emission test; or
- Historical plant records on combustion chamber temperature and exhaust gas flow rates

2.7 Specific QA/QC Procedures:
- Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: 1, 2, 3, 4

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION
No. 16c. THERMAL INCINERATOR FOR VOC CONTROL

1. APPLICABILITY

1.1 Control Technology: Thermal incinerator [021; also applicable to direct flame afterburners with or without heat exchangers [021, 022], boilers, or similar devices for controlling VOC emissions by combustion

1.2 Pollutants
Primary: Volatile organic compounds (VOC's)
Other: High molecular weight organic compounds

1.3 Process/Emissions Unit: Coating, spraying, printing, polymer manufacturing, distillation units, wastewater treatment units, air oxidation units, petroleum refining, miscellaneous SOCMI units

2. MONITORING APPROACH DESCRIPTION

2.1 Parameters to be Monitored: Combustion chamber temperature and outlet CO concentration.

2.2 Rationale for Monitoring Approach
- Combustion chamber temperature: Proper temperature range can be related to good performance.
- Outlet CO concentration: CO is a product of incomplete combustion and is an indicator of combustion efficiency.

2.3 Monitoring Location:
- Combustion chamber temperature: Outlet of combustion chamber
- Outlet CO concentration: Outlet to incinerator

2.4 Analytical Devices Required
- Combustion chamber temperature: Thermocouples, RTD's, or alternative methods/instrumentation as appropriate for specific gas stream.
- Outlet CO concentration: Nondispersive infrared (NDIR) analyzer calibrated to manufacturer's specifications, or other methods or instrumentation.

2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Hourly if manually read, or recorded continuously on strip chart or data acquisition system;
- Reporting units
  – Combustion chamber temperature: Degrees Fahrenheit or Celsius (°F, °C)
  – Outlet CO concentration: parts per million by volume (ppmv), dry basis
- Recording process: Operators take readings and manually log data, or recorded automatically on strip chart or digital data acquisition system.

2.6 Data Requirements

- Baseline combustion chamber temperature measurements, outlet CO concentration measurements, and outlet VOC concentration or destruction efficiency measurements concurrent with emission test; or
- Historical plant records on combustion chamber temperature and outlet CO concentrations.

2.7 Specific QA/QC Procedures:

- Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: 1, 2, 3, 4, 15, 16

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

B.6 CATALYTIC OXIDIZERS[1-2,15,16]

Catalytic oxidizers are oxidation systems (similar to thermal incinerators) that control VOC. Catalytic oxidizers use a catalyst to promote the oxidation of VOC's to carbon dioxide and water (i.e., increase the kinetic rate). Catalytic oxidizer control devices are common in surface coating industries.

The design of the incineration system is dependent on the pollutant concentration, type of pollutant, presence of other gases, level of oxygen, and stability of processes vented to the system. Important design factors for catalytic oxidizers include residence time (sufficient residence time in the catalyst bed for the oxidation reaction to occur), temperature (an operating temperature high enough to oxidize the waste gas on the catalyst), VOC concentration and species, catalyst characteristics, and the presence of poisons or masking agents in the waste gas. Time, temperature, turbulence, and the presence of sufficient oxygen govern the completeness of the combustion reaction. Of these, only the oxygen and the temperature can be significantly controlled after construction. Time and turbulence are fixed by incinerator design and flow rate can be controlled only over a limited range.

The rate at which VOC compounds are oxidized is greatly affected by temperature; the higher the temperature the faster the oxidation reaction proceeds. The operating temperature needed to achieve a particular VOC efficiency depends on the species of pollutants, concentration, and the catalyst type. Each pollutant has a temperature which must be reached to initiate the catalytic oxidation reaction. The initiation temperature is also dependent on the type of catalyst. The use of the catalyst allows the combustion reaction to occur at a lower temperature than the autoignition temperature. Catalytic oxidizers operate between 650°F and 1000°F.

The catalyst support and bed geometry influence the size and shape of the catalyst bed chamber and affects the pressure drop across the bed. The catalyst typically lasts 2 to 5 years. Thermal aging over the lifetime of the catalyst and particulates and catalyst poisons in the inlet gas streams reduce the catalyst's ability to promote the oxidation reaction by masking and coating the catalyst and preventing contact between VOC and the catalyst surface.

Turbulence, or good mixing, is necessary to ensure that all waste and fuel come in contact with oxygen. Good turbulence exposes the fuel and pollutants to oxygen in a rapid manner, promoting rapid combustion. Because 100 percent turbulence is not achieved, excess air/oxygen is added (above stoichiometric or theoretical amount) to ensure complete combustion. For catalytic oxidizers, good mixing of the waste gas and oxygen promotes uniform oxidation in the catalyst bed and avoids localized heating of bed sections.

Normal operation of a catalytic oxidizer should include a fixed inlet temperature and some increase in outlet temperature. A thermocouple is placed at the inlet to the catalyst bed to measure the temperature of the preheated waste gas stream. A thermocouple at the outlet to the catalyst bed chamber measures temperature; this thermocouple is connected to a controller that maintains the desired catalyst bed chamber temperature by altering the rate of auxiliary fuel. A variety of operating parameters that may be used to indicate good operation include: outlet VOC concentration, temperature prior to catalyst bed, temperature after catalyst bed, outlet waste gas temperature from heat exchanger, pressure drop across oxidizer sections (preheat, catalyst bed, heat exchanger), auxiliary fuel input, outlet carbon monoxide concentration, and outlet oxygen concentration.

The most common monitoring for catalytic oxidizers for indicators of normal oxidizer operation and heat recovery includes the inlet waste gas temperature, the catalyst bed temperature, the outlet gas temperature, and outlet CO concentration. Temperature rise across the bed is also an indication of VOC efficiency. One approach to compliance assurance monitoring for catalytic oxidizers is presented in the following illustration:

18: Continuous preheat chamber temperature (i.e., inlet to the catalyst bed) and outlet gas temperature monitoring.

CAM ILLUSTRATION
No. 18. CATALYTIC OXIDIZER FOR VOC CONTROL

1. APPLICABILITY

1.1 Control Technology: Catalytic incinerator [019]; also applicable to catalytic afterburners with or without heat exchangers [019, 020]

1.2 Pollutants
Primary: Volatile organic compounds (VOC's)
Other: High molecular weight organic compounds

1.3 Process/Emissions Unit: Coating, spraying, printing, polymer manufacturing, distillation units, wastewater treatment units, air oxidation units, petroleum refining, miscellaneous SOCMI units

2. MONITORING APPROACH DESCRIPTION

2.1 Parameters to be Monitored: Catalyst inlet and outlet gas stream temperatures

2.2 Rationale for Monitoring Approach
- Catalyst inlet gas temperature: Allows determination of temperature of gas flowing into catalyst bed to ensure bed is maintained within design temperature range
- Catalyst outlet gas temperature: Indication that combustion is occurring on the catalyst bed, allows for calculation of temperature differential across bed.

2.3 Monitoring Location:
- Inlet gas temperature: Preheat chamber outlet
- Outlet gas temperature: Catalyst bed outlet

2.4 Analytical Devices Required
- Inlet and outlet temperatures: Thermocouples, RTD's, or alternative methods/instrumentation as appropriate for specific gas stream.

2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Hourly if manually read, or recorded continuously on strip chart or data acquisition system; continuously if CEMS.
- Reporting units: Degrees Fahrenheit or Celsius (°F, °C)
- Recording process: Operators take readings and manually log data, or recorded automatically on strip chart or digital data acquisition system.

2.6 Data Requirements
- Baseline catalyst inlet and outlet gas temperatures or
- Historical plant records on catalyst inlet and outlet gas temperatures.

2.7 Specific QA/QC Procedures:
- Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: 1, 2, 3, 4, 15, 16

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

B.7 FLARES[2,9,15]

[To be completed]

The requirements for flares contained in § 60.18 (general control device requirements) have been designated as presumptively acceptable monitoring for CAM by the EPA. Section 60.18 requires that flares be operated with a pilot flame present at all times and that the presence of the flare pilot flame be monitored using a thermocouple or equivalent device to detect the presence of a pilot flame. Section 60.18 also states that flares shall be designed for and operated with no visible emissions, except for periods not to exceed a total of 5 minutes in any 2 consecutive hours, as determined by Method 22. There is no frequency of monitoring specified for Method 22 observations, however (i.e., § 60.18 does not require routine monitoring of VE). Owners or operators may propose presumptively acceptable monitoring without additional justification, except that (1) for new or modified monitoring systems, the owner/operator must submit information on the method to be used to confirm operational status of the monitoring equipment and, (2) unless specifically stated otherwise by an applicable requirement, the owner/operator must monitor indicators to detect any bypass of the control device, if such bypass can occur, as required in § 64.3(a)(2). Subparts NNN, RRR, and WWW of Part 60 already require monitoring of an indicator of diversion of gas flow from the flare.

B.8 CONDENSERS[1-2]

[To be completed]

Different approaches to compliance assurance monitoring for condensers are presented in the following illustrations:

21a: Continuous outlet gas temperature monitoring.
21b: Continuous inlet coolant temperature and outlet coolant temperature monitoring.

CAM ILLUSTRATION
No. 21a. CONDENSER FOR VOC CONTROL

1. APPLICABILITY

1.1 Control Technology: Condenser [072, 073, 074]
1.2 Pollutants
Primary: Volatile organic compounds (VOC's)
1.3 Process/Emissions Unit: Coating, polymer manufacturing, distillation units, equipment leaks, air oxidation units, miscellaneous reactors, pharmaceuticals

2. MONITORING APPROACH DESCRIPTION

2.1 Parameters to be Monitored: Outlet gas temperature
2.2 Rationale for Monitoring Approach: Condenser operating temperature affects removal efficiency; an increase in operating temperature decreases removal efficiency
2.3 Monitoring Location: Outlet vent of condenser
2.4 Analytical Devices Required: Thermocouples, RTD's, or alternative methods/instrumentation as appropriate for specific gas stream or specific equipment design; see Section 4.2 (Temperature) for additional information on devices.
2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Hourly, or recorded continuously on strip chart or data acquisition system.
- Reporting units: Degrees Fahrenheit or Celsius (°F, °C)
- Recording process: Operators take readings and manually log data, or recorded automatically on strip chart or digital data acquisition system.

2.6 Data Requirements
- Baseline outlet gas temperature measurements and outlet VOC concentration measurements;
- Calculations indicating outlet temperature necessary to achieve compliance; or
- Historical plant records on outlet gas temperature measurements.

2.7 Specific QA/QC Procedures:
- Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: 1, 2

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION
No. 21b. CONDENSER FOR VOC CONTROL

1. APPLICABILITY

1.1 Control Technology: Condenser [072, 073, 074]
1.2 Pollutants: Volatile organic compounds (VOC's)
1.3 Process/Emissions units: Coating, polymer manufacturing, distillation units, equipment leaks, air oxidation units, miscellaneous reactors, pharmaceuticals

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Inlet and outlet coolant temperature
2.2 Rationale for Monitoring Approach: Condenser operating temperature affects removal efficiency; an increase in operating temperature decreases removal efficiency
2.3 Monitoring Location: Front and rear end heads
2.4 Analytical Devices Required: Thermocouples, RTD's , or alternative methods/instrumentation as appropriate for specific gas stream or specific equipment design; see Section 4.2 (Temperature) for additional information on devices.
2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Hourly, or recorded continuously on strip chart or digital data acquisition system
- Reporting units: Degrees Fahrenheit or Celsius (°F, °C)
- Recording process: Operators take readings and log data manually, or recorded automatically on strip chart or digital data acquisition system.

2.6 Data Requirements:
- Baseline coolant temperature measurements exhaust gas measurements and outlet VOC concentration measurements concurrent with emission test;
- Calculations indicating outlet temperature necessary to achieve compliance, baseline outlet gas temperature measurements concurrent with coolant temperature measurements; or
- Historical plant records on coolant temperature measurements.

2.7 Specific QA/QC Procedures:
- Annual process review to determine process or materials changes that could affect the initial determination of condensation parameters
- Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: 1, 2

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

B.9 ELECTRIFIED FILTER BEDS[13]

[To be completed]

B.10 CARBON ADSORBERS

[To be completed].

The following illustration presents one approach to compliance assurance monitoring for carbon bed adsorbers used to control VOC:

23a: Monitoring outlet VOC concentration.

CAM ILLUSTRATION
No. 23a. CARBON ADSORBER FOR VOC CONTROL

1. APPLICABILITY

1.1 Control Technology: Carbon adsorption system [048]

1.2 Pollutants

Primary: Volatile organic compounds (VOC's)

Other: Higher molecular weight organic compounds

1.3 Process/Emissions units: Coating, spraying, printing, polymer manufacturing, distillation units, wastewater treatment units, dry cleaning, degreasing, pharmaceuticals, equipment leaks

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Outlet VOC concentration

2.2 Rationale for Monitoring Approach: Increasing outlet VOC concentration indicates breakthrough of VOC's through adsorbent bed

2.3 Monitoring Location: At adsorber outlet duct or stack

2.4 Analytical Devices Required: Flame ionization detectors (FID's), photoionization detectors (PID's), diffusion sensors, alternative methods/instrumentation as appropriate for specific gas stream

2.5 Data Acquisition and Measurement System Operation

- Frequency of measurement: Hourly, or recorded continuously on strip chart or digital data acquisition system
- Reporting units: Parts per million (ppm)
- Recording process: Operators take readings and manually log data, or recorded automatically on strip chart or digital data acquisition system.

2.6 Data Requirements:

- Baseline outlet VOC concentration and historical plant records on outlet VOC concentration measurements

2.7 Specific QA/QC Procedures: Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: 1, 2, 3, 4

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

B.11 CYCLONES

[To be completed].

The following illustrations provide example approaches for compliance assurance monitoring of cyclones and gravity collectors used to control PM:

24a: Monitoring cyclone inlet gas flow rate.
24b: Monitoring pressure drop across cyclone.
25: Monitoring gravity collector inlet gas flow rate.

CAM ILLUSTRATION
No. 24a. CYCLONE FOR PM CONTROL

1. APPLICABILITY

1.1 Control Technology: Cyclone [075]; also applicable to multiclones with or without fly ash reinjection [076, 077], centrifugal collectors [007, 008, 009], and other types of mechanical collectors and dry inertial separators

1.2 Pollutants
Primary: Particulate matter (PM)
Other: Heavy metals

1.3 Process/Emissions Unit: Combustors, mineral processing units, furnaces, kilns.

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Gas inlet velocity (flow rate)

2.2 Rationale for Monitoring Approach: Control efficiency increases with increased velocity; if inlet velocity exceeds a specific value, turbulence becomes excessive and control efficiency decreases

2.3 Monitoring Location: Gas inlet duct

2.4 Analytical Devices Required: Differential pressure flowmeter, anemometer, rotameter, or other type of device that measures gas velocity or flow rate; see Section 4.3 for information on specific types of instruments.

2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Once per shift, if manually read, or continuously, if by automatic system.
- Reporting units: Feet per minute (ft/min)
- Recording process: Operators periodically observe gauges and log data, or recorded automatically on strip chart or digital data acquisition system

2.6 Data Requirements
- Baseline gas velocity and sampling data concurrent with emission test; or
- Manufacturer's design specifications and efficiency curve/equation for inlet velocity or pressure drop.

2.7 Specific QA/QC Procedures
- Maintain and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: 1, 2

3. COMMENTS

3.1 Since this illustration applies to a PM source, visible emissions or opacity monitoring is also an appropriate performance indicator.

3.2 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION
No. 24b. CYCLONE FOR PM CONTROL

1. APPLICABILITY

1.1 Control Technology: Cyclone [075]; also applicable to multiclones with or without fly ash reinjection [076, 077], centrifugal collectors [007, 008, 009], and other types of mechanical collectors and dry inertial separators

1.2 Pollutants
Primary: Particulate matter (PM)
Other: Heavy metals

1.3 Process/Emissions Unit: Combustors, mineral processing units, furnaces, kilns.

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Pressure drop

2.2 Rationale for Monitoring Approach: Control efficiency is a function of inlet velocity, and changes in velocity result in changes in pressure drop across device; if inlet velocity exceeds a specific value, turbulence becomes excessive and control efficiency decreases.

2.3 Monitoring Location: Gas inlet and outlet ducts

2.4 Analytical Devices Required: Differential pressure transducer, differential pressure gauge, manometers, or alternative methods/instrumentation; see Section 4.3 for information on specific types of instruments.

2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Once per shift, if manually read, or continuously, if by automatic system.
- Reporting units: Inches of water column (in. w.c.) or pounds per square inch (psi)
- Recording process: Operators periodically observe gauges and log data, or recorded automatically on strip chart or digital data acquisition system

2.6 Data Requirements
- Baseline pressure drop and sampling data concurrent with emission test; or
- Manufacturer’s design specifications and efficiency curve/equation for inlet velocity and pressure drop.

2.7 Specific QA/QC Procedures
- Maintain and operate instrumentation using procedures that take into account manufacturer’s specifications.

2.8 References: 1, 2

3. COMMENTS

3.1 Since this illustration applies to a PM source, visible emissions or opacity monitoring is also an appropriate performance indicator.

3.2 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION
No. 25. GRAVITY COLLECTOR FOR PM CONTROL

1. APPLICABILITY

1.1 Control Technology: Gravity collectors [004, 005, 006], such as settling chambers, drop boxes, and other types of devices that use gravitational settling for PM control

1.2 Pollutants

Primary: Particulate matter (PM)

Other: Heavy metals

1.3 Process/Emissions Unit: Combustors, mineral processing units, furnaces, kilns.

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Gas velocity (flow rate)

2.2 Rationale for Monitoring Approach: Control efficiency is a function of residence time; an increase in velocity results in decreased residence time and collection efficiency.

2.3 Monitoring Location: Gas inlet duct

2.4 Analytical Devices Required: Differential pressure flowmeter, anemometer, rotameter, or other type of device that measures gas velocity or flow rate; see Section 4.3 for information on specific types of instruments.

2.5 Data Acquisition and Measurement System Operation

- Frequency of measurement: Once per shift, if manually read, or continuously, if by automatic system.
- Reporting units: Velocity--feet per minute (ft/min); flow rate--cubic feet per minute (ft^3/min)
- Recording process: Operators periodically observe gauges and log data, or recorded automatically on strip chart or digital data acquisition system

2.6 Data Requirements

- Baseline gas velocity or flow rate, and sampling data concurrent with emission test; or
- Manufacturer's design specifications and efficiency curve/equation for inlet velocity.

2.7 Specific QA/QC Procedures

- Maintain and operate instrumentation using procedures that take into account manufacturer's specification.

2.8 References: 21

3. COMMENTS

3.1 Since this illustration applies to a PM source, visible emissions or opacity monitoring is also an appropriate performance indicator.

3.2 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

B.12 OTHER SO_2 CONTROLS

[When drafted, will discuss flue gas desulfurization, acid plant neutralization, dual absorption systems, and dry sorbent injection.]

B.13 NO_X CONTROLS

[To be completed].

CAM ILLUSTRATION

No. 32a. SELECTIVE CATALYTIC REDUCTION FOR NO_x CONTROL

1. APPLICABILITY

1.1 Control Technology: Selective catalytic reduction [065]; also applicable to all other types of NO_x controls

1.2 Pollutants

Primary: Nitrogen Oxides (NO_x)

Other: HNO_3, NH_3

1.3 Process/Emission Units: Nitric acid production units, glass manufacturing, acrylonitrile process, municipal waste combustors, steel reheating/annealing furnaces, boilers

2. MONITORING SYSTEM/PROGRAM DESCRIPTION

2.1 Indicators Monitored: Exhaust gas NO_2 concentration using continuous emission monitoring system (CEMS)

2.2 Rationale for Monitoring Approach: CEMS provides direct measurement of NO_x emission concentrations

2.3 Monitoring Location: Absorber tower exhaust stack, at least 2 diameters downstream from the point of pollution generation and ½ diameter upstream from the effluent exhaust

2.4 Analytical Devices Required: NO_2 CEMS, tank level meters or flow totalizer, hydrometer or density meter

2.5 Data Acquisition and Measurement System Operation

- Frequency of measurement: Continuous
- Reporting units: CEMS output is parts per million by volume (ppm_v) NO_2, which is converted to kg NO_x (expressed as NO_2) per metric ton HNO_3 (as 100% nitric acid) for reporting.
- Recording process: Plant-specific conversion factor is used to convert NO_2 concentration measured by CEMS to units of standard. Results are recorded automatically on strip chart or digital data acquisition system.

2.6 Data Requirements

- Baseline NO_2 concentration records and sampling data concurrent with emission test, or
- Historical plant records of production rates in terms of 100% acid, acid strength, hours of operation, and corresponding NO_2 concentrations

2.7 Specific QA/QC Procedures:

- Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer's specifications; and
- Annual redetermination of conversion factor

2.8 References:

CAM ILLUSTRATION

No. 32b. SELECTIVE CATALYTIC REDUCTION FOR NO_x CONTROL

1. APPLICABILITY

1.1 Control Technology: Selective catalytic reduction [065]

1.2 Pollutants

Primary: Nitrogen Oxides (NO_x)

Other: HNO_3, NH_3

1.3 Process/Emission units: Nitric acid production units, glass manufacturing, acrylonitrile process, municipal waste combustors, steel reheating/annealing furnaces, boilers

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Catalyst deactivation, residual NH_3 concentration in flue gas (NH_3 slip causes ammonium sulfate fouling of the catalyst). The fuel sulfur content also has an impact on catalyst fouling.

2.2 Rationale for Monitoring Approach: SCR provides designed NO_x reduction until fouling occurs. Fouling of the catalyst is caused by ammonium sulfate salts, the formation of which can be avoided by limiting ammonia slip and limiting fuel sulfur content.

2.3 Monitoring Location: NH_3 monitored at outlet duct of catalytic converter.

2.4 Analytical Devices Required: NH_3 CEMS (other methods and instruments may be unit-specific).

2.5 Data Acquisition and Measurement System Operation

- Frequency of measurement: NH_3 monitored continuously, maintain records of fuel sulfur content.
- Reporting units: CEMS output is parts per million by volume (ppm_v) NH_3, fuel sulfur content in percent by weight.
- Recording process: CEMS results are recorded automatically on strip chart recorder or digital data acquisition system; fuel sulfur content manually recorded in SCR maintenance log.

2.6 Data Requirements

- Baseline NH_3 concentration records and sampling data concurrent with emission test; or
- Historical plant records of production rates in terms of 100% acid, acid strength, hours of operation, and corresponding NH_3 concentrations; and
- Historical plant records of fuel sulfur content

2.7 Specific QA/QC Procedures

- Calibrate, maintain and operate instrumentation using procedures that take into account manufacturer's specifications; and
- Annual redetermination of conversion factor

2.8 References:

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