CHAPTER 5

SOURCES OF BIAS IN FLOW MONITORING SYSTEMS

Chapter 5 Highlights

Flow (Velocity) Monitoring System Problems

Problem: Name	Problem: Description	Corrective Actions	Page Refs
General			
Stack Area Miscalculation	Use of incorrect cross-sectional area in calculating volumetric flow can produce measurement error.	Directly measure and re-calculate.	5-2
Gas Density and Temperature Distortions	Bias can be introduced if the temperature profile is different from the velocity profile.	Verify temperature profile and use new assumptions if there is a disparity with velocity profile.	5-2
Differential Pressure Sensing Monitors			
Improper Angle of Probe Tube to Gas Flow	Measurement error can result if probe tube is not oriented perpendicular to flue gas flow.	Rectify improper orientation. Avoid using where cyclonic flow is present.	5-3
Plugging	Probe plugging can prevent accurate pressure measurements.	Increase frequency and/or pressure of blowback.	5-3, 5-4
Thermal Sensing Monitors			
Particulate Build-Up on Sensors	Particulate build-up can slow instrument response by forming an insulating layer on the probe's temperature sensors.	Remove by flash heating or blowing off deposits. Avoid by employing aerodynamic cavity design.	5-4, 5-5
Water Droplets and Acid Corrosion	Heat lost to evaporation can bias measurements. Acid droplets can eat into the metal junctions of probe arrays.	Repair and change probe design.	5-4
Ultrasonic Monitors			
Improper angle of transducers	Measurement errors can result under pitched or cyclonic flow conditions.	Orient measurement path perpendicular to the flow pitch. Where pitched flow is variable, consider using two sets of transducers in X-pattern.	5-5, 5-6
Particulate build-up on sensors.	Build-up on sensors can introduce measurement error.	Use blowers to keep transducer sensors clean.	5-6

CHAPTER 5

SOURCES OF BIAS IN FLOW MONITORING SYSTEMS

5.1 INTRODUCTION

The major bias problems associated with flow monitoring systems are attributable to velocity stratification in the duct or stack. This issue has been discussed in Chapter 2, but will be amplified here with respect to specific instrumentation.

There are other sources of bias in volumetric flow monitoring systems. From Eq. 2–1, it is obvious that the measurement cross-sectional area is included in the pollutant mass rate expression. Stack and duct cross-sectional measurements obtained from old blueprints or out-dated drawings can introduce biases of from 1% to 2% into the volumetric flow / pollutant mass rate measurement (Traina, 1992). Warping or settled fly ash in horizontal ducts can lead to further errors. This bias will, however, not become evident if the same incorrect dimensions are used in both the CEM system and the source tester RATA calculations. Cross-sectional dimensions should therefore not be assumed, but measured directly. These dimensions can be obtained by measuring the outside circumference of the stack and accounting for the depth of the stack walls and insulation, or more directly, by making surveyor transit measurements through the ports.

Differential pressure and thermal sensing systems must also determine the gas density in order to calculate the flue gas velocity. Gas density is obtained by measuring the flue gas molecular weight, temperature, and pressure. However, most systems monitor the flue gas temperature only and assume values for the molecular weight and pressure. Temperature is relatively easy to measure and normally introduces no significant bias into the flow measurement. Bias could be introduced here if the temperature profile is different than the velocity profile and the temperature sensors are monitoring at locations other then the velocity monitor locations.

Some ultrasonic systems monitor temperature to convert flow in units of actual cu. ft / hr to standard cu. ft / hr. The calculation requires a knowledge of the speed of sound, which again depends on the flue gas composition. Bias can be introduced here if assumptions made for this composition are not valid or not corrected for changing operating conditions.

5.1.1 Differential Pressure Sensing Systems

Differential pressure systems can be designed to measure at single points or at multiple traverse points, using an averaging probe.

As discussed in Chapter 2, for fully developed, uniform flow, only one or two points need to be monitored to obtain consistent velocity values. Pitot tubes that use electronic pressure transducers may be the simplest approach to monitoring an ideal flow pattern. For more variable velocity profiles, an averaging probe may be more appropriate. Figure 5–1 illustrates different techniques used to obtain averaged volumetric flow measurements in differential flow systems.

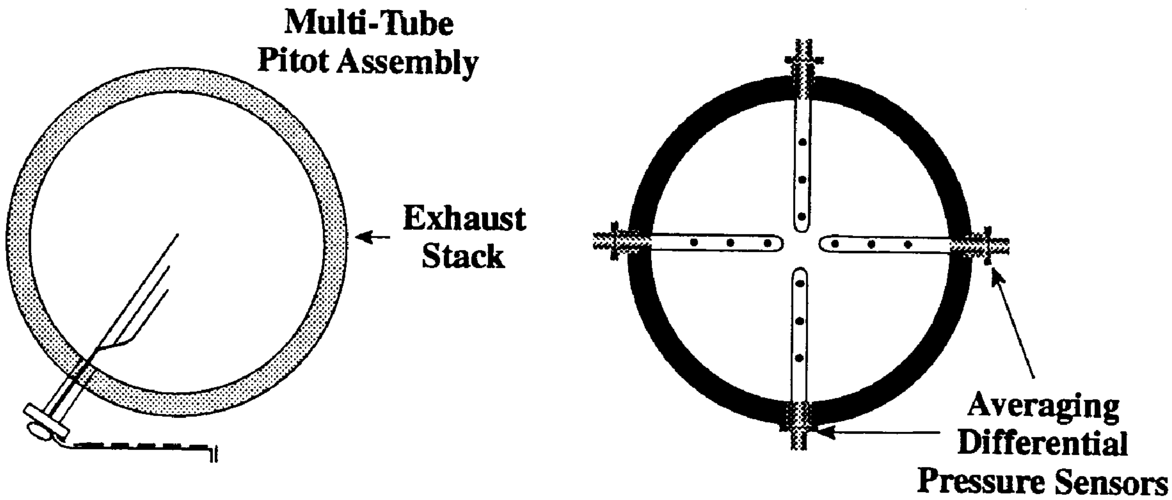

Figure 5–1. Approaches for Obtaining Averaged Volumetric Flow Using Differential Pressure Systems

Differential pressure systems are designed around pressure sensing tubes. Small openings in the tubes sense impact or wake pressures; gas is not extracted into the tube. Bias problems, outside of stratification effects, can occur with respect to these tube openings.

For example, the ideal performance of a differential pressure sensing system requires the flue gas flow to be perpendicular to the tube. If the gas approaches at an angle, the differential pressure between the impact and wake pressure ports will be different. Since the flue gas velocity is calculated from the square root of the differential pressure, the velocity will be biased. The velocity can be biased either high or low, depending upon the probe design and the angle of the flow with respect to the facing plane of the tube.

The flow direction may be non-normal to the tube if (1) the probe is twisted, sags, or oscillates with the flow; (2) the flow itself is swirling; or (3) the flow direction otherwise changes over the cross-section. Swirling, cyclonic flow can contribute to some of the greatest errors in flow measurement, because the angles of attack to the probe are far from perpendicular. Differential pressure sensors are not calibrated to such arbitrary angles, so installation of these systems where cyclonic flow is present should be avoided.

Probe plugging is also of some concern in differential pressure sensing systems. If the probe system is calibrated versus Reference Method 2 over the cross-section, by conducting a pre-RATA as mentioned in Chapter 2, a plugged opening on an averaging probe will not contribute to the pressure average and may cause a bias. Such bias is difficult to quantify. However, with probe blowback systems, probe plugging is rarely a problem. In severe situations the probe blowback frequency and / or pressure can be increased. Condensation of effluent moisture by molecular diffusion can occur in the pitot lines. This problem can be eliminated if the lines are included in the periodic blowback.

Differential pressure system calibration checks are usually performed behind the probe. The checks are designed to test the performance of the pressure transducer, by first sealing off the probe from the system and then pressurizing the remaining plumbing of the system. This procedure does not actually check the probe problems discussed above and serves principally to test for leaks and electronic problems.

5.1.2 Thermal Sensing Systems

Thermal sensing systems monitor the electrical resistance of a heated wire. Flowing gas will cool the wire and change the monitored resistance. Another approach maintains the wire at a fixed temperature and monitors the current necessary to keep that temperature constant. These systems are relatively simple and easy to deploy in arrays across a stack or duct cross-section. A single thermal sensing element suffers the same problems of representativeness in a situation of stratified flow, but when a grid of sensors are deployed at Reference Method 2 traverse points (Figure 5–2), it becomes relatively easy to meet certification requirements (Olin, 1993).

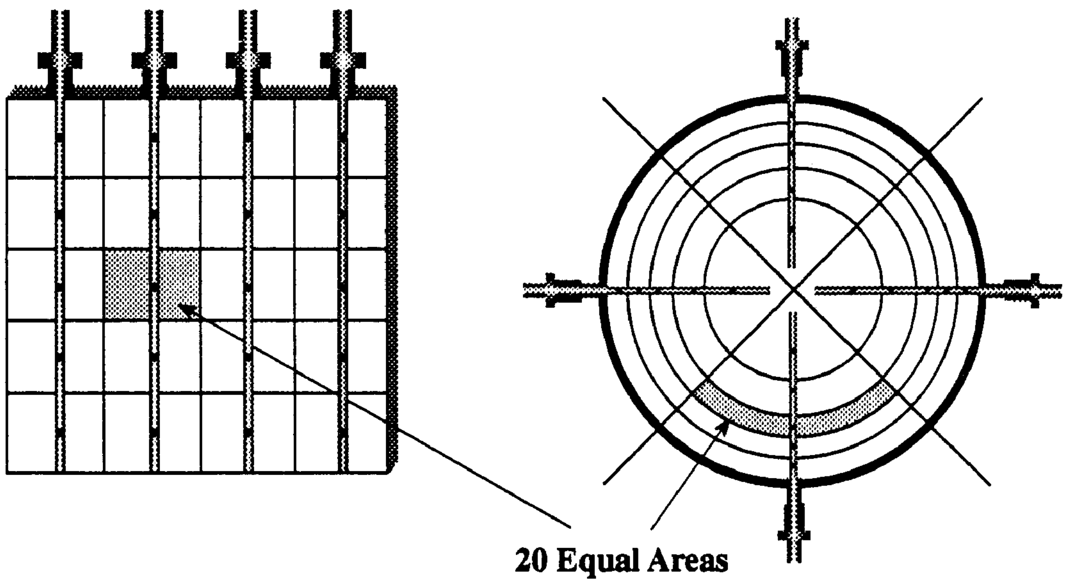

Figure 5–2. A Grid of Thermal Sensors Monitoring at Reference Method 2 Traverse Points

Water droplets will cause errors in thermal sensing systems, since heat from the sensor will be used to evaporate droplets adhering to the sensor. This loss of heat by evaporation is interpreted as heat loss to the flowing gas and will result in a high-biased flow reading. Therefore, thermal monitors are not applicable to flue gases containing entrained water droplets. Thermal sensing systems are also subject to corrosion and particulate build-up. Acid droplets can eat into the metal junctions of probe arrays and cause catastrophic failures rather than systematic bias. Particulate build-up will slow instrument response by forming an insulating layer on the probe temperature sensors. Various stratagems have therefore been devised to minimize this problem. Techniques such as flash heating the sensors (as in a self-cleaning oven), blowing off deposits with instrument air, or designing aerodynamic measuring cavities to reduce accumulation have all been applied.

Calibration checks of thermal sensing systems again do little to check bias problems associated with the thermal sensors themselves. The calibration checks merely test the back-end electronics of the system with simulated signals and do little to indicate potential in-stack bias problems.

5.1.3 Ultrasonic Monitors

Ultrasonic monitors measure on a line, and as has been pointed out in Chapter 4, Section 4.2.2, a line average is not the same as an area average. However, Traina (1992) has calculated that for typical circular stacks, the difference between the two measurement methods will be on the order of 3–5%. This bias can be easily incorporated into the calculation algorithms of the monitor control system.

Problems of stratification are not as straightforward, but can be minimized either by cleverly choosing the measurement path or by adjusting the monitor data to match Reference 2 results through the calculation algorithms.

The choice of measurement paths have been discussed in detail by both Traina (1992) and Kearney (1993). Presented with the problem of measuring volumetric flow in a highly stratified duct, Kearney developed a computer program to match possible measurement paths against the velocity average determined by Reference Method 2. Although this procedure was successful in this application, its success was dependent upon several assumptions: (1) the stratification pattern was stable and independent of load, and (2) the Reference Method 2 data could be correlated with a measurement path not in the cross-section, but at an angle to it (on the order of 45E). The validity of the second assumption depends on the stratification pattern persisting through the duct.

It has been recommended not to site flow monitoring systems in locations where swirling, non-axial flow is present. However, it is often difficult to find such locations where the flow is completely axial. Figure 5–3 shows a typical situation in which the flow is pitched in the upward direction due to a bend in the duct.

For an ultrasonic monitor installed in the plane of the bend, the vector component of flow along the path decreases the sound pulse time of flight to the downstream transducer and increases the time of flight to the upstream transducer. Since the velocity is determined by subtracting the reciprocals of the two times of flight, the flow will be biased high. One solution to this problem, suggested by Traina, is to orient the measurement path so that the monitoring system is perpendicular to the pitch (Figure 5–3). The path measurement will be less sensitive to the effect of the pitch and more amenable to stable correlations and bias corrections. [Note that this siting recommendation is opposite to that recommended for transmissometers (40 CFR 60 Appendix B PS1). Transmissometry is concerned with measuring an effect due to the presence of particulate matter, not velocity.]

In other situations, particularly where two ducts are exhausting into a single stack or the pitched flow is otherwise variable, an "X-pattern" technique is sometimes used. In this arrangement, two sets of ultrasonic transducers are purported to cancel out the pitch effect. One set exhibits a positive bias with respect to the pitch, the other a negative bias.

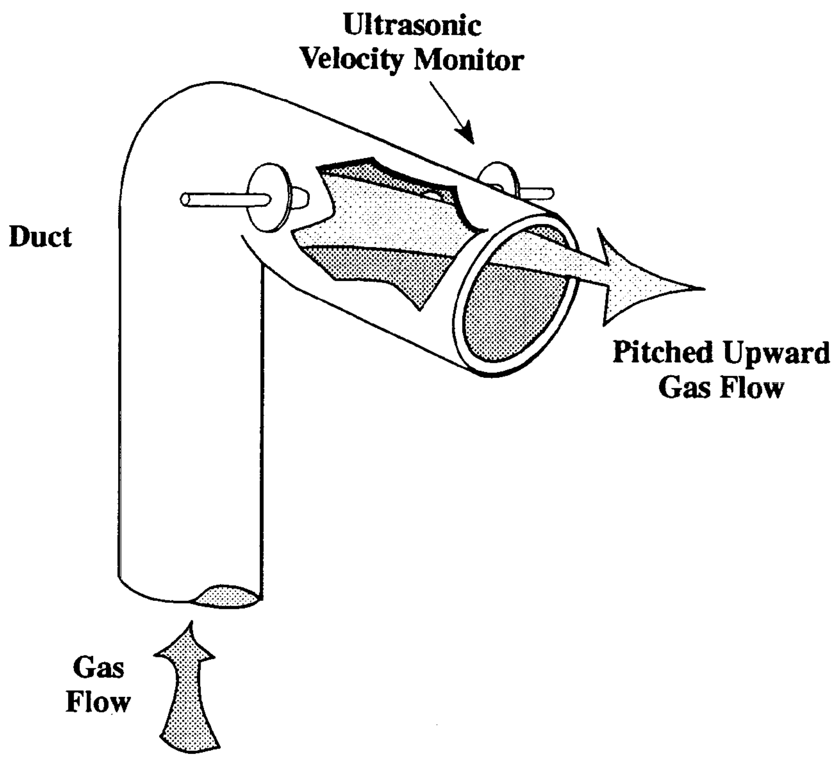

Figure 5–3. Pitched Flow After a Bend

Ultrasonic sensors check their calibration by electronically substituting signals to cross-check the electronics and by introducing a known delay in the pulse. Again, these methods are basically internal electronic checks and are not independent of the system.

Ultrasonic sensors are unique among the flow monitors in that the sensing elements of the system are not located in the duct or stack. However, the transducers can be exposed to the flue gas. Blowers, which pass clean air across the sensors, are designed to keep them clean and free of particulate build-up.

5.2 SUMMARY

The major problems that can produce bias in different types of flow monitors are summarized in the table on page 5-1. Choosing the most appropriate flow monitoring system is highly dependent on the specific characteristics of a particular site. Making the right choice can be the most important step toward avoiding bias problems in the future.

5.3 REFERENCES

Kearney, B.J. 1993. Successful Siting of an Ultrasonic Flow Monitor in a Rectangular Duct with Stratified Flow. Continuous Emission Monitoring — A Technology for the 90s. Air & Waste Mgmt. Assoc., Pittsburgh, pp. 42-52.

Olin, J.G. 1993. The Effect of Non-Uniform Flows on CEMS Flow Monitors. Air & Waste Mgmt. Assoc. Meeting Paper. Denver: 93-TA-32.01.

Traina, J.E. 1992. Feasibility of Installing Volumetric Ultrasonic Flow Monitors on Non-Optimal Ductwork. Air & Waste Mgmt. Assoc. Meeting Paper. Kansas City: 92-66.14.