Populations, Activity and Emissions of Diesel Nonroad Equipment in EPA Region 7

Standard Operating Procedures for Gaseous and PM Emissions Measuring Equipment Appendix F

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Prepared for EPA by
Eastern Research Group, Inc. (ERG)
EPA Contract No. EP-C-06-080

United States Environmental Protection Agency

EPA-420-R-12-009
July 2012

Standard Operating Procedures for Gaseous and PM Emissions Measuring Equipment

Prepared for ERG in support of Non-road Emissions Study

Sensors, Inc
August 4, 2008

Overview of Standard Operating Procedures

This list defines the basic standard operating procedures for the non-road emissions program. Details are left out of this list so that it can be used as a quick reference guide for setting up and operating the emissions equipment in the ERG program. Detailed instructions are provided in this document (see table of contents) where needed.

A. Daily Equipment preparation PRIOR to Installation

1. Power up all equipment on rack; allow 1 hour for warmup on SEMTECH; MPS can be calibrated within 20 minutes
2. Confirm that flow tube diameter is correct for the engine to be tested (see instructions).
    - If necessary, change flow tube to match engine exhaust/capacity.
    - If mounting new different flow tube, select the appropriate tube SN / diameter in the PPMD host software.
    - Enter best estimate of "Maximum Exhaust" flow in Proportional Sampling screen (based on table provided).
3. Disconnect pressure lines and backpurge manifold at Flow Tube before or after each day of testing. **Do NOT backpurge tubing to MPS!**
4. Perform Daily MPS Setup
    - Clean flow capillary with compressed air.
    - Zero all pressure sensors
    - Confirm / Adjust Major and Minor Block pressures
    - Generate Lookup Tables
    - Validate Lookup Tables
    - Calibrate Sample Flow Capillary
    - Set MPS to proportional flow and check major/minor/sample flows with no exhaust
5. Perform Daily Gravimetric Filter Setup
    - Change filters
    - Check N2 bottle pressure using SEMTECH; Install and turn on N2
    - Check solenoid switching; leave in Bypass mode
    - Set flow to 18 lpm, set MFC scale to 0.041, update E2
6. SEMTECH maintenance / setup
    - Install new heated filter (if differential pressure sample and barometric is approaching 300 mBar)
    - Install new FID fuel bottle if necessary (200 PSI / hour operation).
    - Leak check sample path
    - Check heated line operation
    - Enable auto-zero at 1-hour intervals

B. Install equipment on vehicle

1. Install generator
2. Lift rack in place with crane (battery can power rack for ten minutes)
3. Secure with 2 large ratchet straps and resume power to rack
4. Install ground strap (from Rack to vehicle chassis)
5. Attach RPM probe or Vehicle Interface
6. Secure wires loosely with tie-wraps etc
7. Route exhaust from stack to EFM tube, avoid pinched hoses.

C. Pre-test checkout on vehicle

1. Launch SensorTech-PC host software and Data Viewer
2. In SEMTECH Test screen, verify all accessories are functioning and reporting data
    - Vehicle interface (if available)
    - GPS
    - Weather probe
    - RPM probe
    - Exhaust flowrate and temperature (from MPS)
3. Open Data Viewer
    - confirm all MPS and Gravimetric data is present
    - Verify 18 lpm flowrate for gravimetric system, and is set to Bypass
    - Verify MPS is in Mode 1 (proportional sampling)
    - Verify that MPS Sample flow < 2 sccm with engine off
4. Run target engine and verify MPS performance
    - Collect short data file while ramping engine speed
    - Check max exhaust flowrate; update value in PPMD host software if necessary
    - Confirm that Qminor decreases at least 2 LPM from idle to max exhaust. (If not, decrease Min Dilution ratio by one until this is achieved)
    - Confirm that Qminor does not go to zero prior to maximum exhaust conditions. (if it does, increase Min Dilution ratio by 1 until this is avoided)
    - Verify expected exhaust flowrate at idle conditions and maximum exhaust.
5. Shut down all equipment if waiting overnight. Turn off N2 bottle and FID bottle.

D. Test Procedure

1. Startup equipment and allow to warmup. Light FID when ready.
2. Using PPMD host software, zero all pressure sensors with compressor off.
3. Turn on MPS Air Compressor and Grav Filter Vacuum Pump. Turn on FID bottle and N2 bottle.
4. Verify Gravimetric filter flowrate and Bypass position
5. Verify Proportional Sampling mode
6. Perform Look-Up tables and verify
7. Switch to SensorTech-PC host software and repeat steps C1, C2, and C3
8. Utilize external antenna or Cantenna, as well as amplifier for remote operations
9. Start data collection
    - Open Session Manager
    - Perform Zero calibration on ambient air
    - Perform Span calibration (Quad and NO2)
    - Start Test recording
    - Set Filter to #1 (always lowest available filter number) just prior to engine start
    - Activate filter switching timer (10, 20, 30 minutes for filters 1, 2, and 3)
10. **Monitor data during test (see part F)**
11. After 3 hours:
    - Ask for access to equipment
    - Fill fuel tank on generator
    - Stop Data collection (leave session open)
    - Zero SEMTECH if necessary (AutoZero should be on)
    - Change gravimetric filters
    - Remove exhaust transport tubing to MPS and shut off compressor
    - Zero MPS pressures
    - Zero Block and Sample pressures
    - Verify Proportional mode, and switch back to SensorTech-PC software
12. When ready, Start new test recording

E. End of Test Procedures

- Stop Test
- Perform Zero and Span calibration on SEMTECH
- Stop Session Manager; download data
- Process and QA data using charting macro
- Remove all equipment
- Retrieve gravimetric filters (do not replace until ready for next test)

F. Key Parameters to Monitor During Test

Gravimetric filter

- Grav Filter MFC flow: should be approx 18. If it is 30 or more, you will need to reset the flow using PPMD software)
- Grav Filter Number: verify that solenoids are switching
- Monitor temperatures: Cyclone, Manifold, and Filter

MPS:

- Major flowrate: typically 8 at idle, 10 – 11 at high exhaust flows.
- Minor flowrate: should be 2.5 – 3.5 at idle, 0 – 0.5 at max exhaust flow.
- Sample flowrate: 0 – 0.2 with no exhaust flow, 0.5 – 1 at idle, > 2 at high exhaust flows
- Exhaust flow rate: verify consistent values at idle conditions. Check if it is close to expected value for given engine size.

SEMTECH DS:

- Gaseous concentrations
- Sample pressure
- Temperatures

H. Weekly MPS Maintenance

- Zero Pressure Transducers
- Perform lookup table separately for Major and Minor dilution systems.
- Check/adjust critical orifice flowrates
- Perform Dilution Flow calibrations: Major & Minor.

I. Data Entry

- Process Data File (*.XML) into *.CSV data file
- Review *.CSV data file with Macro program
- Forward data to ERG FTP site and Carl Ensfield.

1 Daily Equipment Preparation

1.1 Power up all equipment in the cabinet.

Confirm that ground straps are in place to prevent damage to the equipment. The cabinet should be attached to shore power when possible. The cabinet battery is for short-term use, similar in nature to an uninterruptible power supply battery. The SEMTECH DS gas analyzer takes one hour to warm-up at 13 VDC, and the MPS takes twenty minutes.

Connector : AC Line Power

Portable Power Generator

Air compressor toggle

Heated Line Controller

MPS Power/Air Filter

SEMTECH DS Power Switch

Vacuum Pump Switch

Power Strip/Breaker

1.2 Daily MPS Setup

1.2.1 Select flow tube to match engine size

- Choose the proper flow tube from the table below
- Install the flow tube and MPS securely on vehicle.

Flow Tube O.D.	2 inches	2 - 1/2 inches	3 Inches	4 Inches	5 Inches
Diesel Engine with turbo (liters)	less than 1.5	1.5 to 4.0	4 to 6	6 to 12	12 to 18
Gasoline engine (liters)	less than 2	2 - 5	5 - 7		

NOTE: Changing a flow tube will require the following two changes in the PPMD host software.

1.2.2 Backpurge pressure lines.

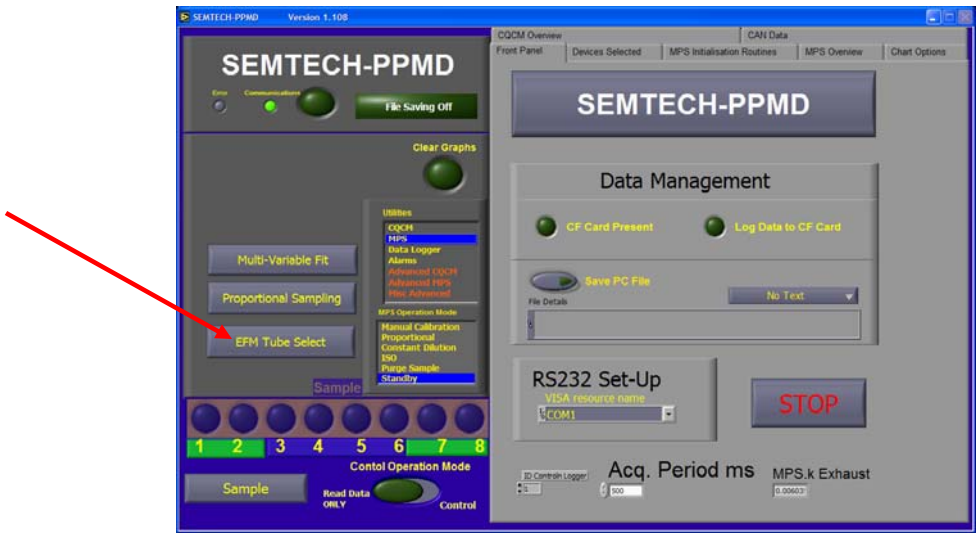
- Remove red, white, and blue pressure lines where they attach to manifold at Flow Tube
- Disconnect pressure lines at the MPS (VERY IMPORTANT!)
- Connect a source of dry, compressed air or N2 at the manifold going into the flow tube. Adjust pressure from 30 to 60 psig, and apply for at least 5 seconds for each line.
- Inspect the red, white, and blue pressure lines. If condensation or other contaminants are visible, backpurge these lines using the same procedure.

CAUTION: Do not backpurge the colored pressure lines if they are still attached to the MPS. This would damage pressure sensors.

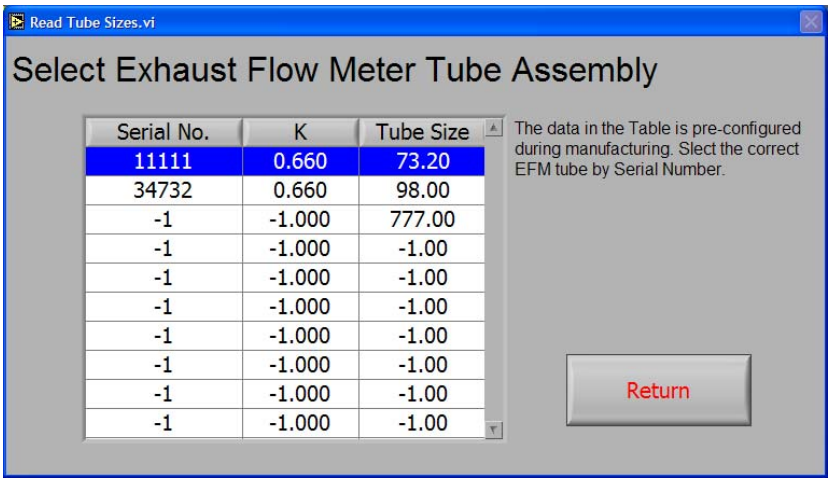
1.2.3 Select flow tube in PPMD Host software.

If you have changed the flow tube, you must select the appropriate flow tube in the PPMD host software.

→ ***Go to Tab: Front Panel***
→ ***Utilities Menu: Select MPS***
→ ***Press button: EFM Tube Select***



Now, make your flow tube selection.

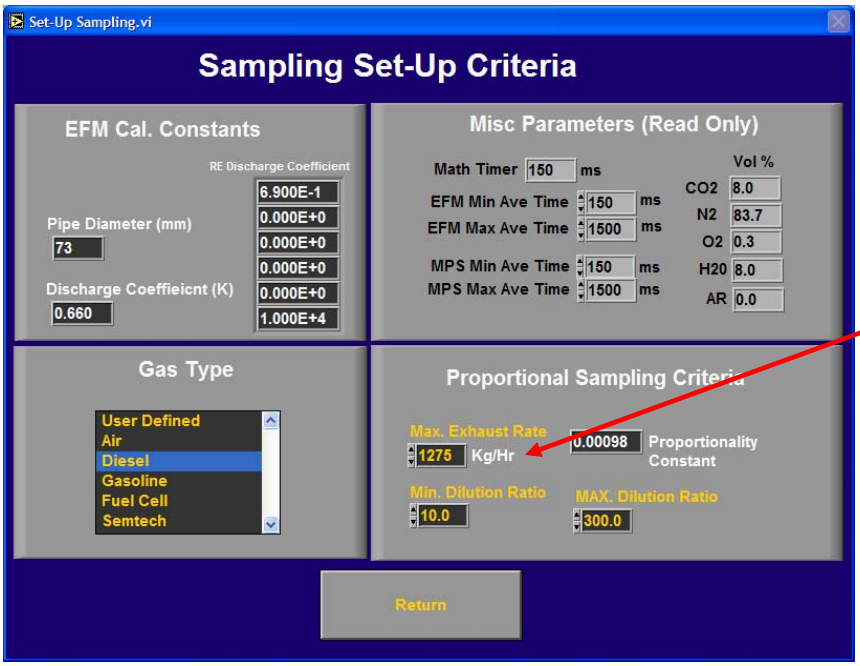


Note: If the flow tube you desire is not listed, please call for instructions on how to add a new flow tube and calibration coefficients to the menu.

1.2.4 Change maximum exhaust flowrate in PPMD Host software.

If you have changed the flow tube, you must also change the maximum expected exhaust flowrate in the PPMD host software Proportionality setup screen.

→ ***Go to Tab: Front Panel***
→ ***Utilities Menu: Select MPS***
→ ***Press button: Proportional Sampling***



You will need to change the "Max Exhaust Flow" value for the vehicle that you are intending to test. The performance of the MPS device is optimized when this parameter is entered correctly. You can estimate the maximum exhaust flowrates from the following tables.

Estimated maximum exhaust from diesel engines (Kg/hr)

Engine displacement, liters	Maximum engine speed, RPM	Max exhaust flowrate, non-turbo	Max exhaust flowrate, with turbo
1	3000	86	171
1.5	3000	128	257
2	3000	171	343
4	3000	343	685
6	2500	428	857
8	2500	571	1142
10	2500	714	1428
12	2500	857	1713
15	2500	1071	2141

Estimated maximum exhaust from spark-ignition engines (Kg/hr)

Engine displacement, liters	Maximum engine speed, RPM	Max exhaust flowrate, non-turbo	Max exhaust flowrate, with turbo
1	5000	143	214
1.5	5000	214	321
2	5000	286	428
3	5000	428	642
4	5000	571	857
5	5000	714	1071
6	5000	857	1285

Note that the tables are approximations only. If the engine you are testing operates at a higher or lower maximum RPM than indicated, the estimates will be off accordingly. Also, if the application of the vehicle under test does not induce the maximum engine RPMs listed, then it is important to determine the actual engine speed during testing and estimate exhaust flow from that.

Another approach is to simply conduct a "practice" test on the vehicle, and measure the exhaust flowrates under its normal application. Just use the maximum exhaust flowrate observed. Before doing this however, make sure you complete the remaining daily equipment preparations in this section.

1.2.5 Adjust Minimum Dilution Ratio in PPMD Host software.

Once the maximum exhaust flowrate is entered correctly, you may need to adjust the "minimum dilution ratio" in the Proportional Sampling screen. Normally you will not have to adjust this value, once it has been set up for a particular MPS. This parameter is used to ensure that the full range of Minor flowrate is used during a test (when operating at the maximum exhaust flowrate, the Minor flow should be close to zero).

Use the following table to determine what changes, if any, you should make to minimum dilution ratio. You will have to make this determination experimentally with the vehicle to be tested.

Minor flowrate	**Recommended adjustment**
0 – 500 sccm at Max Exhaust flowrate	None required
> 500 sccm at Max Exhaust flowrate	Decrease value
0 at less than Max Exhaust flowrate	Increase value

Adjust the Minimum Dilution Ratio until you have achieved 0 – 500 sccm Minor flowrate.

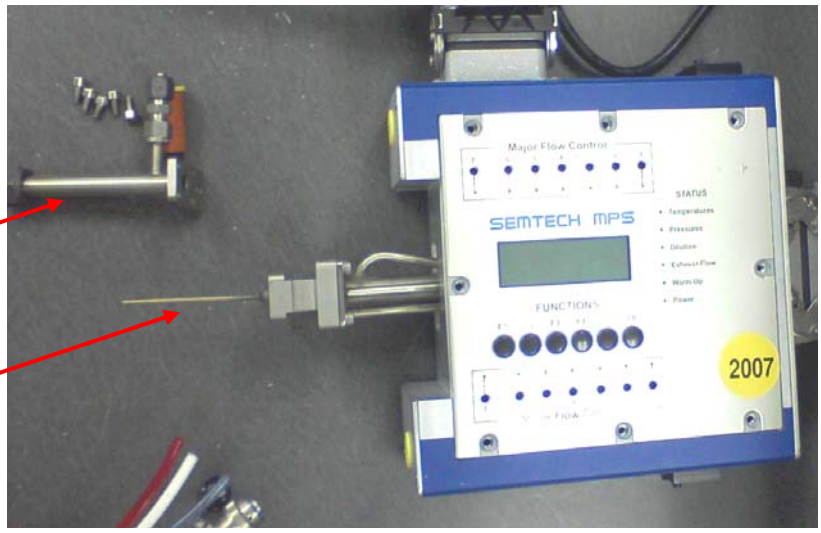
NOTE: Before making an adjustment other than Minimum Dilution Ratio, make sure you complete the remaining daily equipment preparations in this section.

1.2.6 Clean flow capillary with compressed air.

- The Sample Capillary is shown to the left side in the drawing below.
- Remove capillary housing, being careful to retain o-rings.
- Remove capillary
- Back flush capillary with dry compressed air or CO2.
- Replace capillary and housing, making sure to replace O-rings. If O-rings are worn or damaged, replace them.

Removed capillary housing

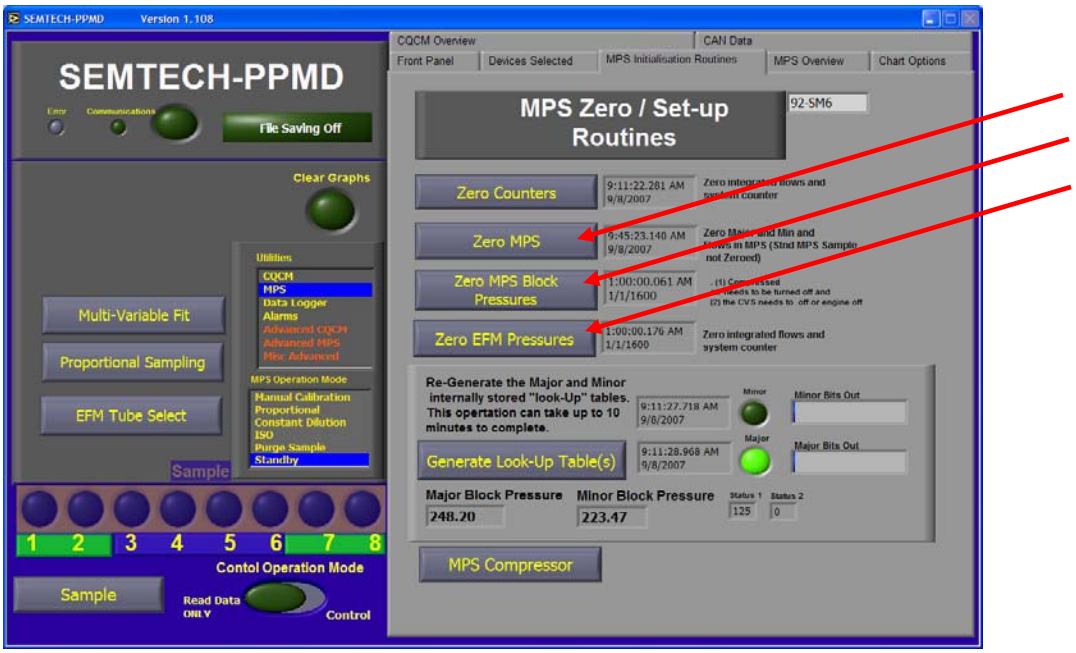
Sample capillary



1.2.7 MPS Initialization and Zeroing

- Turn on power at MPS air control box (minimum warm-up time is 20 minutes).
- Turn off compressed air supply to MPS
- Plug in RS232 Cable from CAN interface to your PC.
- Start up PPMD Host Software, and go to MPS Initialization Screens
- ***Important:*** **Before zeroing pressure sensors, Verify that there is no exhaust flow or residual major or minor block pressure (pressures should read approximately barometric)**

Go to Tab: MPS Initialisation Routines



- Press "**Zero MPS" button**. This will zero the MPS major and minor flow sensors
- Press "**Zero EFM Pressures**". This will zero the EFM pressure sensors
- Press "**Zero Block & Sample Pressures**". This will zero the block pressure sensors and the Sample flow pressure sensors.

NOTE: If during Zero Block & Sample Pressures, you receive the screen message: "Block Pressure is too High – Operation is cancelled", then there is probably residual pressure in the major and minor block manifold. Set MPS operation mode to "Manual" and let the pressure bleed down. Then, set the MPS operation mode back to "Standby".

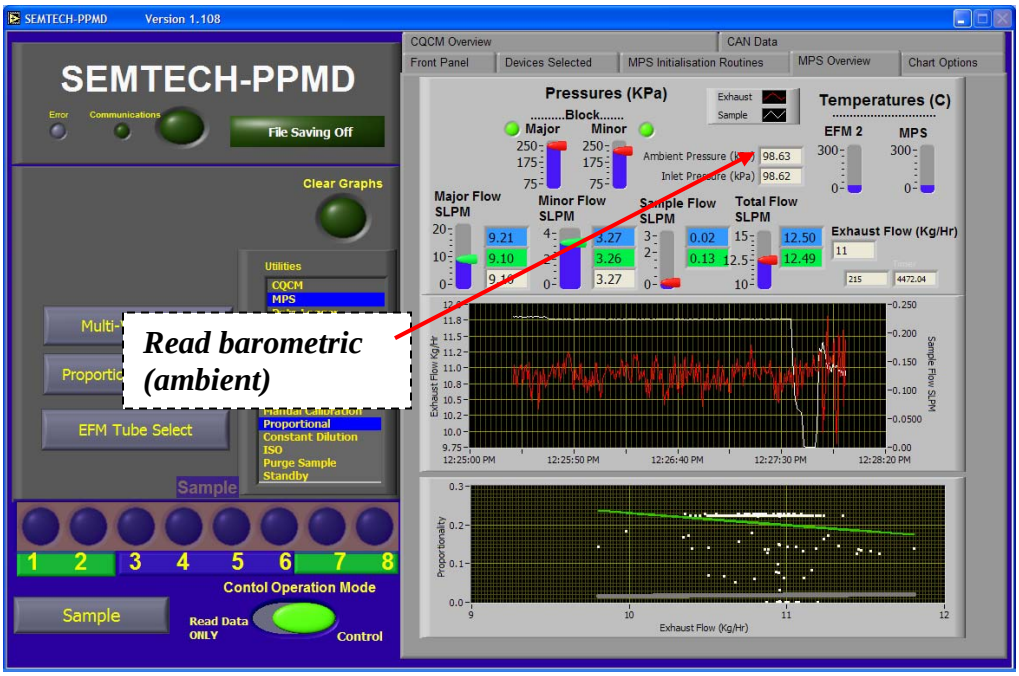
1.2.8 Confirm / Adjust Major and Minor Block pressures

The major and minor manifold blocks must be controlled to a constant pressure. These pressures are now displayed on the MPS Zero / Setup screen at the bottom of the page. The recommended pressures are:

- Major block pressure = 150 Kpa + barometric
- Minor block pressure = 125 Kpa + barometric

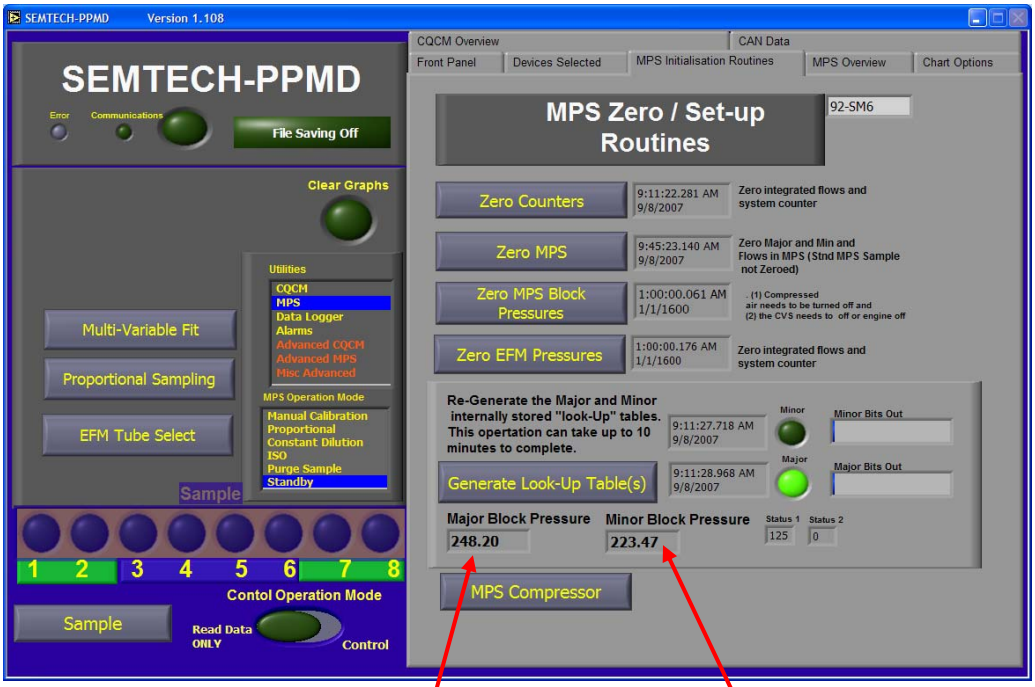
Currently, the major and minor block pressures are displayed in units of absolute pressure, so you will have to add barometric pressure to the target values to determine the proper reading. You can read barometric pressure from the MPS Overview tab.

Go to Tab: MPS Overview



Read barometric (ambient)

Go back to tab: MPS Initialization Routines



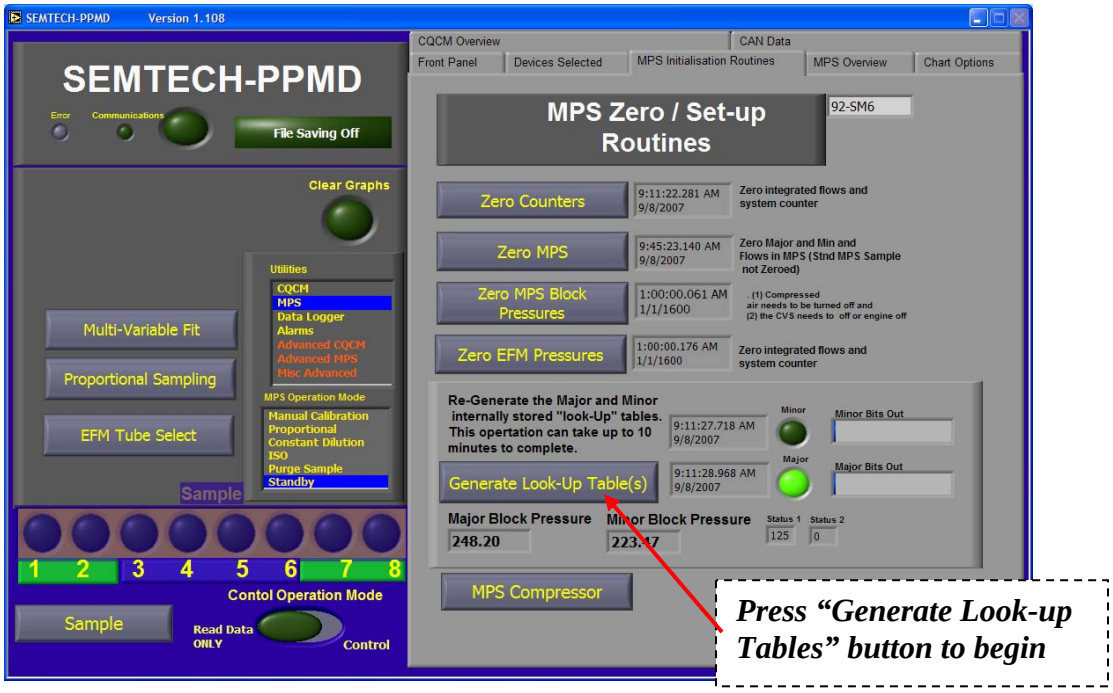
Set Major block pressure to 150 Kpa + barometric

Set Minor block pressure to 125 Kpa + barometric

1.2.9 Generate Lookup Tables

After the major and minor pressures are set, you must generate a Lookup Table for both the major and minor solenoid blocks. The PPMD host software will toggle through every combination of solenoids on the major or minor flow block, recording the measured major or minor flowrates for each combination. The MPS uses the Lookup Table on a 10 hz frequency to determine which combinations of solenoids to utilize to achieve the desired flow.

Go to the tab: MPS Initialization Routines.



Begin the process by pressing the "Generator Look-up Table" button on the MPS Initialization screen.

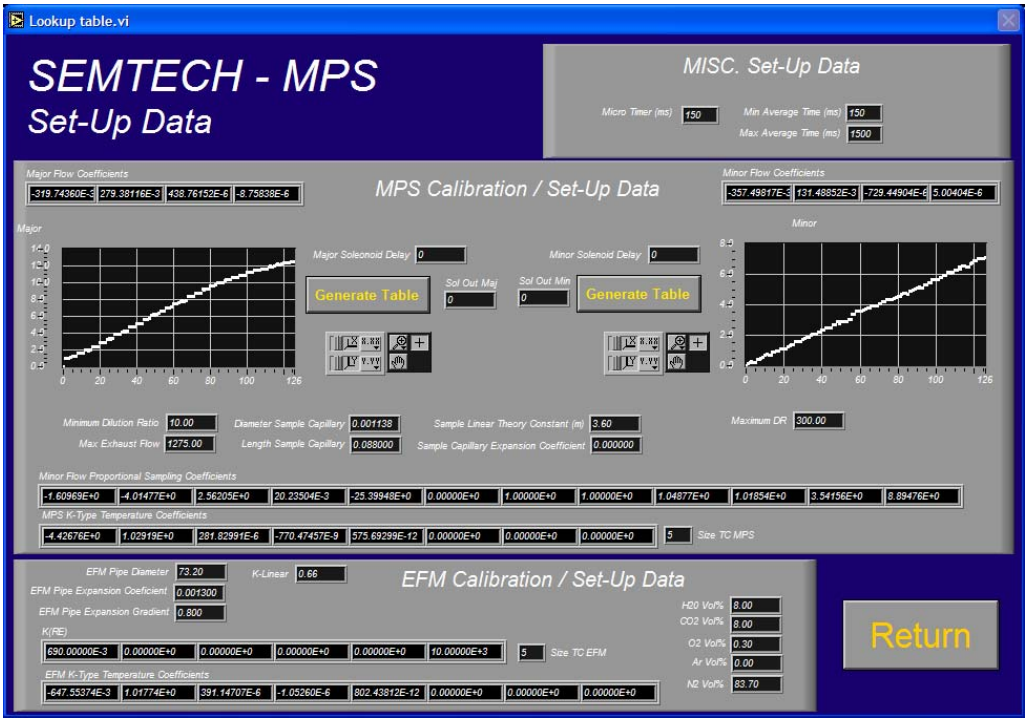
NOTE: The software will allow you to perform the major and minor lookup tables simultaneously, but you should always perform the major and Minor lookup tables separately.

Once the process begins, you will see the blue status bar indicating completion status. The process will take up to 10 minutes for both the major and minor solenoid blocks.

1.2.10 Validate Lookup Tables

Once the major and minor lookup tables are complete, you should review the results. This is possible by pressing the "Read Parameters" button that is displayed when "Advanced MPS" is selected under the Utilities menu.

→ ***Utilities Menu: Select "Advanced MPS"***
→ ***Press button: "Read Parameters" to arrive at SEMTECH – MPS Set-Up Data***



It is common to see some small discontinuities in the flow vs solenoid combination chart. That is because the critical orifices are probably not set perfectly. If you see large irregularities with the Look-up Table, it may be necessary to re-set the critical orifices.

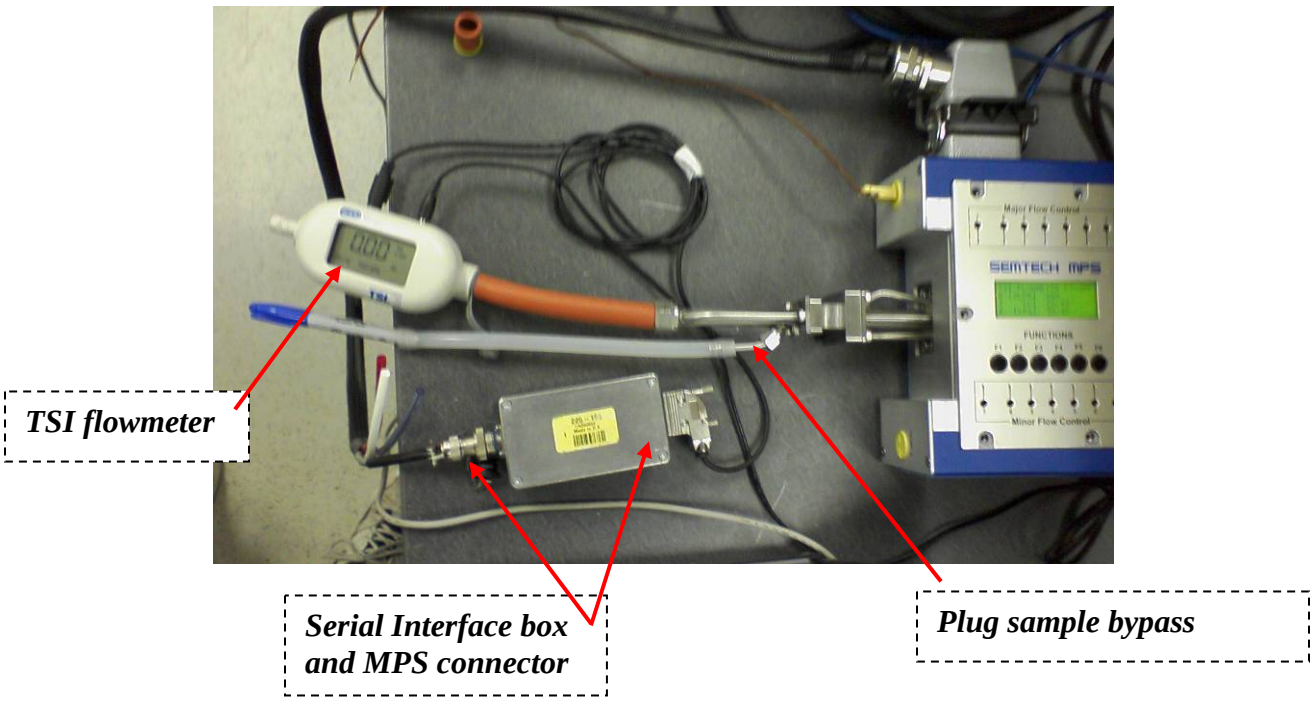
Note that in the above example, there is some flattening of the major flow at the higher solenoid combinations. That is common, and typically not a concern, as long as the major flowrate can achieve at least 80% of the total MPS flowrate setpoint.

1.2.11 Calibrate Sample Flow Capillary

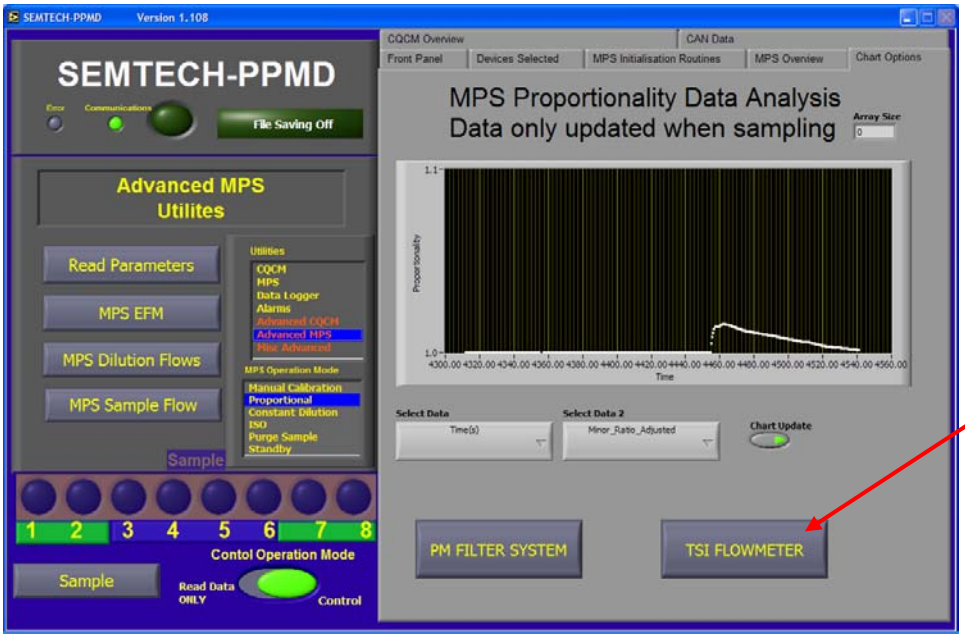
Once the sample flow capillary is cleaned, and all other steps listed above are complete, you can now calibrate the sample flow.

- Attach a TSI reference flow meter to the sample inlet of MPS Diluter as shown in the following photograph
- Ensure proper direction of flow for reference flow meter
- The TSI reference offers two connections:
    - Connect serial output to interface box and then to connector located at the end of the MPS pressure line harness.
    - Connect to 110 VAC source (required with this TSI model).

- Plug MPS sample bypass

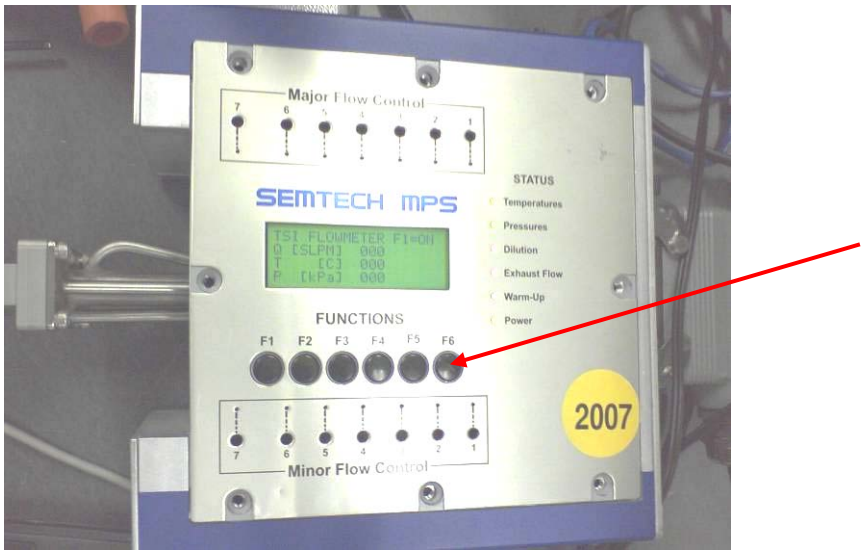


To enable the TSI flowmeter in the host software, select the “Chart Options” tab, and then press the “TSI Flowmeter” button at the bottom of the page.



If you have recently updated firmware on the MPS, you will need to enable the TSI flowmeter (once) using the front panel LCD display:

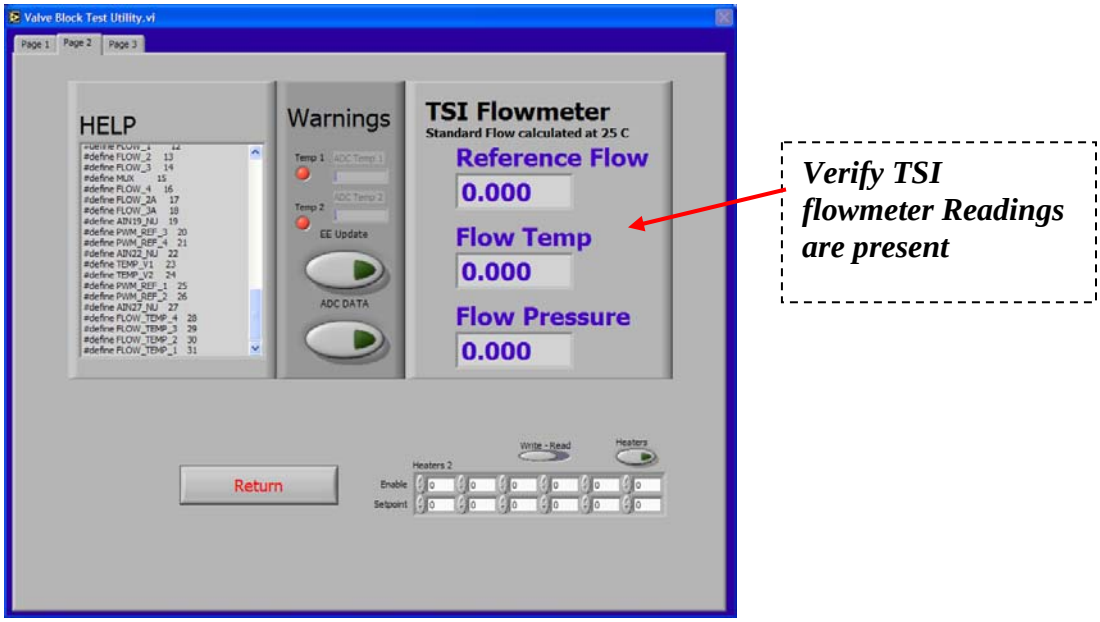
- From the MPS Display: Press F6 (21 times) until the “TSI flowmeter enable” screen is dislplayed
- Press F1 to enable the TSI reference meter
- Verify that the MPS Display now provides reference flow
- Access the Display Microprocessor and update the EEPROM (X17).



To check that the TSI reference is enabled within the PPMD host software, go to the MPS dilution flows screen under “Advanced MPS” utility. On page 2, view the reference flow meter data for Flow rate, temperature, and pressure.

From any screen,

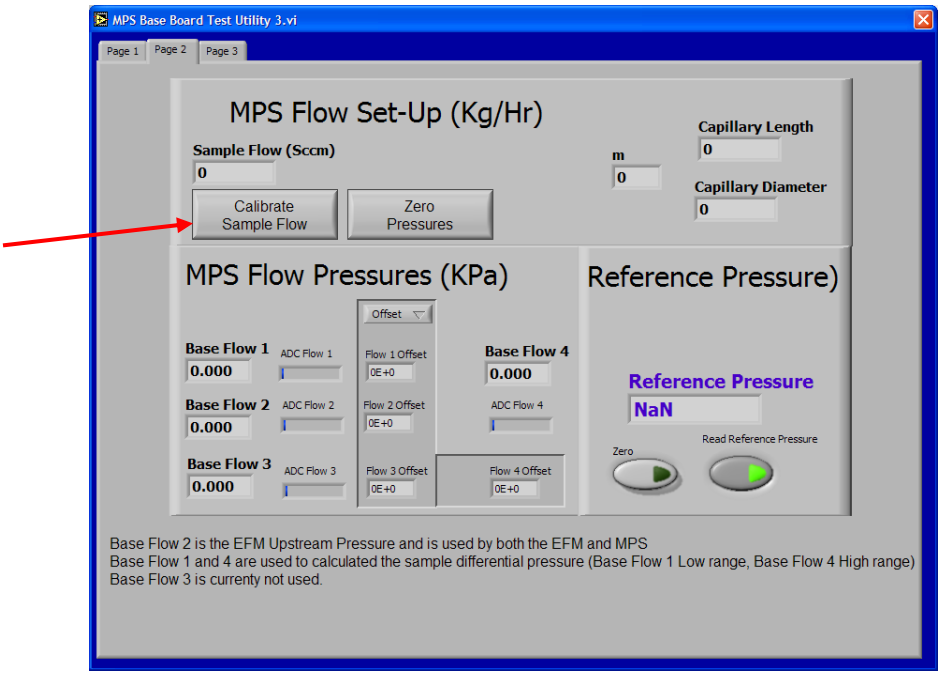
→ ***Utilities Menu: Select “Advanced MPS”***
→ ***Press button: “MPS Dilution Flows”***
→ ***Select Page 2***



If the values are unchanging, go to screen 1 and select a major dilution critical orifice, and confirm that reference flow INCREASES. Then, select a minor dilution critical orifice, and confirm that reference flow DECREASES. Turn off these critical orifices when finished.

- Having established communication with the TSI reference flowmeter, we can now proceed to the sample flow calibration screen:

  From any screen,
  → ***Utilities Menu: Select "Advanced MPS"***
  → ***Press button: "MPS Sample Flow"***
  → ***Select Page 2***



- Press button: Calibrate Sample Flow (a process screen will pop-up)
- Flow calibration sequence will begin automatically. You can view new data points from the Calibration Data Table.
- During data acquisition, note the status light for each point's Stability.

Note: Sometimes the process will not be able to complete automatically if flow stability cannot be achieved at some conditions (typically after the 12 data point). If stability is not achieved after two minutes at a given data point, just press the "Continue" button at the bottom of the page to proceed.

IMPORTANT: Before accepting the new data, confirm the following conditions:

1. The chart of pressure versus flow in the lower left corner of the screen. The data points need to be always increasing in an orderly fashion so that final flow fit is robust.
2. The Slope displayed in Micro Q vs. Reference Flow chart is 1.00 +/- 0.05
3. The Std. Diameter Capillary (mm) is +/- 5% of Diameter Capillary (mm) Micro.

Caution: For deviations greater than these limits, always try to troubleshoot system before accepting new coefficients. For instance, confirm that your MPS inlet bypass is plugged so that all sample flows through your TSI reference flow meter.

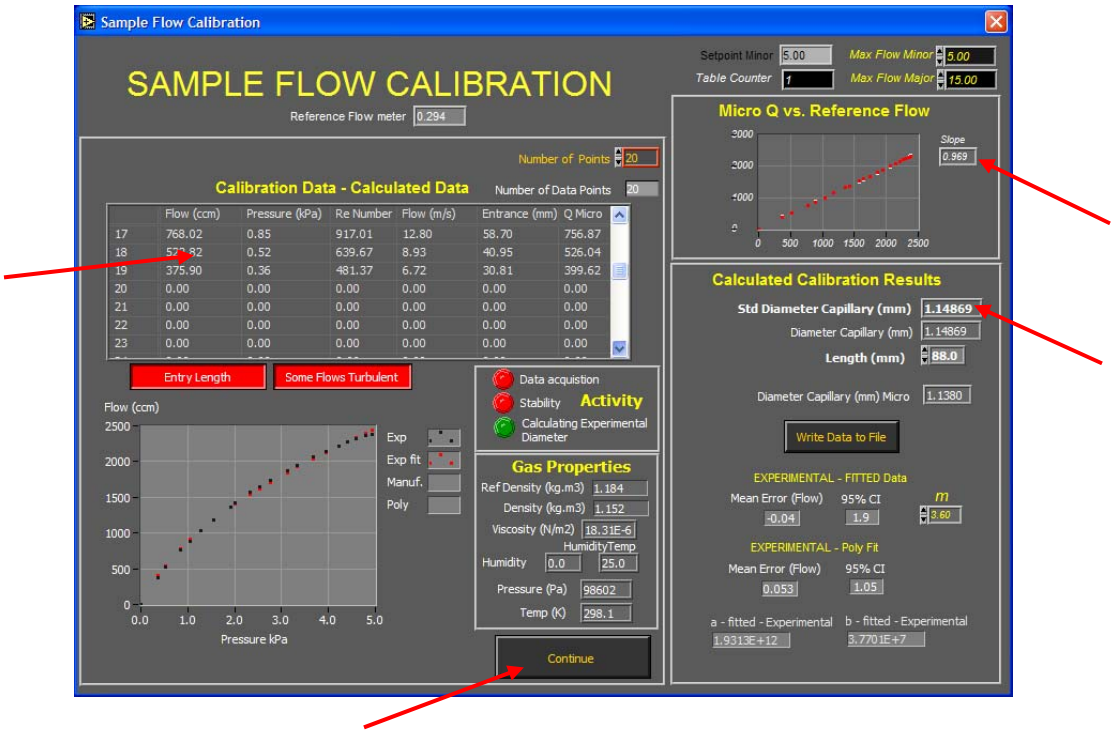


Chart explanation: At each data of the 20 target data points, the process will look for stability and then save the data point. Near the 12th data point, the values will likely be unstable. After two minutes of non-stability, press the "Continue" button to proceed.

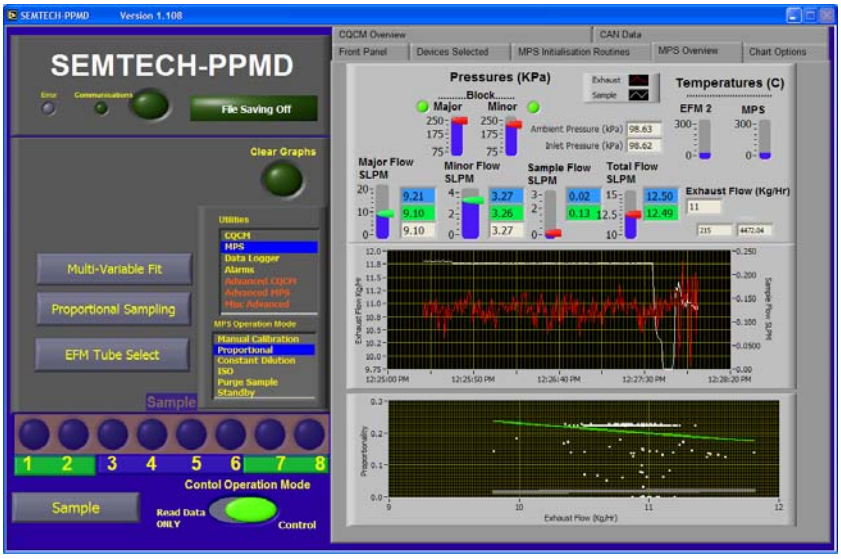
- When the process is complete, and the data looks acceptable, Exit screen by pressing the button: Continue,
- Choose to accept or decline the new coefficients.

1.2.12 Set MPS to proportional flow and check performance

When all of the above daily preparations are complete, you may now set the MPS to Proportional mode, ready for testing.

→ ***Utilities: select MPS***
→ ***Set Control Operation Mode: Control***
→ ***Select MPS Operational Mode: Proportional***

You may now want to clear the graphs if you want to view proportionality of live data, and proceed to the "MPS Overview" tab.



The following table is a guide to evaluate the MPS performance at various conditions. It is recommended to verify these criteria on each vehicle prior to conducting tests.

Ideal MPS Performance Criteria

Engine condition	**Q Minor**	**Q Sample**
off	> 4 slpm	< 200 sccm
idle	> 2.5 slpm	na
Max exhaust flow **	0.2 to 0.5 slpm	Proportional over flow range

** Note that if you are setting the engine speed without load to the engine, you will not be achieving nearly as high of exhaust flow as you would under load. If that is the case, make sure you have sufficient Q minor (at least 1 slpm) at maximum (unloaded) engine speed.

If the above criteria are met, then the MPS is ready for testing. If the MPS fails to meet one or more of the above criteria by a small amount, it is not necessarily a problem. It just means that it is likely that the proportionality parameters are not optimal for the vehicle you are testing, or the flow model could be improved. The proportionality parameters are easy to configure, and retest in this screen. The flow model is a bit more difficult to optimize (see next section). In any case, you can certainly proceed to test, as long as the sample flowrate is proportional over the flow range to be tested.

If there are significant deviations from the criteria listed above, then it would be advisable to investigate further before testing.

1.3 Daily Gravimetric Filter Setup

1.3.1 Change Filters

Gravimetric filters must be changed prior to testing, or when they have reached their desired sample duration.

STEP 1: **Turn off** vacuum pump to gravimetric filter (and leave off until indicated)
STEP 2: Remove all filter holders

47 mm filter cup, opened

47 mm filter cup assembly

Install with filter element facing <u>downward</u>

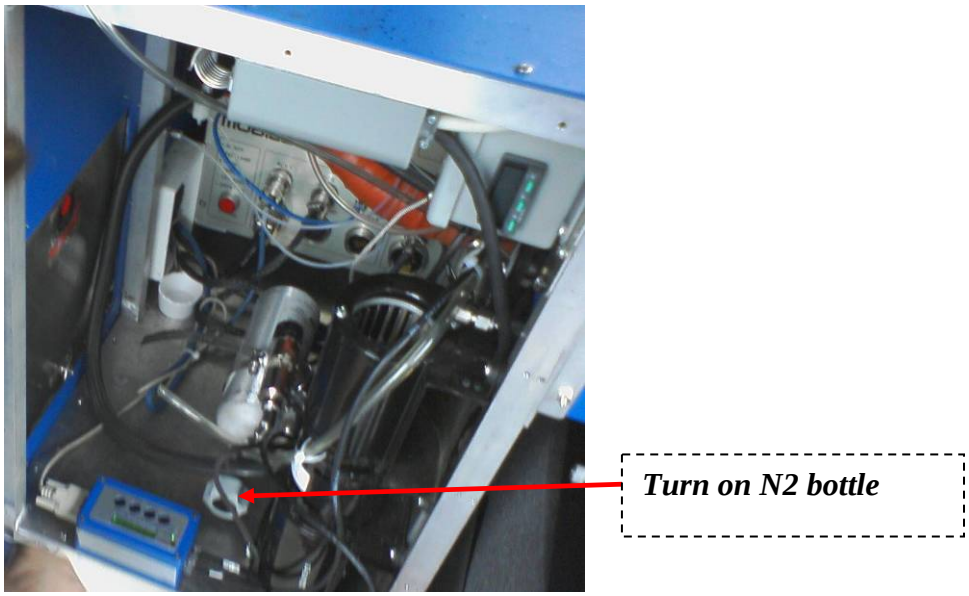
STEP 3: Carefully place the filters in the filter holders, with the filter element facing DOWNWARD (the sample flows upward). Replace the filter holders.

1.3.2 Check / Open Nitrogen Cylinder

The gravimetric filter sampling system uses compressed nitrogen to operate pneumatic valves in order to switch between the three filter holders and bypass.

STEP 1: Check the remaining pressure of the N2 bottle by plugging into the SEMTECH FID fuel electronic pressure connector (will have to remove bottle).

STEP 2: Open the N2 cylinder when ready for testing, and verify that the pressure is set to 80 PSIG.



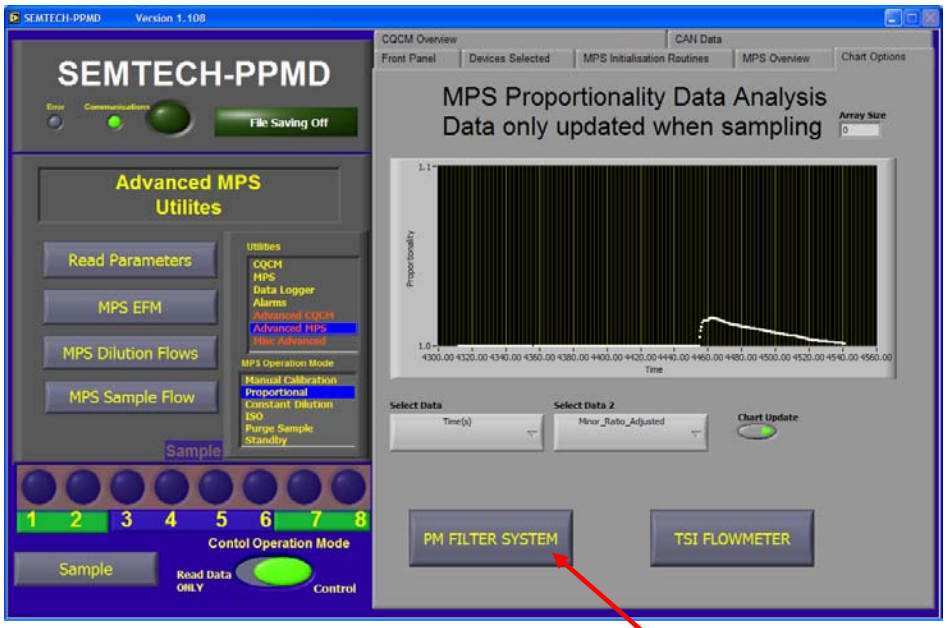
Note: *Each time you replace the N2 cylinder (or if the usage rate seems excessive), you will need to* ***leak test*** *the N2 pneumatic connection. Open the cylinder valve, and then close again. Verify that the gage still reads 80 psig after 10 minutes.*

1.3.3 Setup the Gravimetric Filter in PPMD software

You will need to access the Gravimetric Filter operating window in the PPMD host software in order to set the sample flowrate. Filter switching can be performed here, or in the SensorTech-PC software for the SEMTECH-DS.

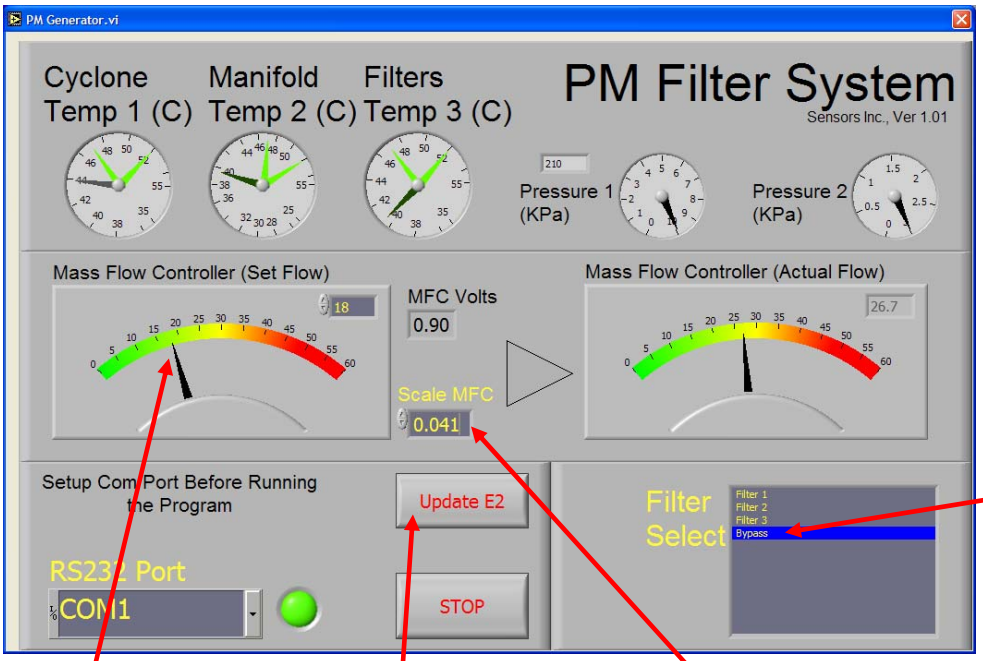
IMPORTANT: Any Interruption of 120 VAC power will reset the flow setting and require you to repeat the following steps.

→ ***Got to tab: "Chart Options"***
→ ***Press button: "PM Filter System"***



Access Gravimetric Filter System

Gravimetric Filter System Operating Window



1. Verify you are in bypass mode

2. Set flowrate to 18 lpm by moving dial

3. Set scale factor to 0.041

4. Update E2

Once in the Gravimetric Filter operating window, perform the following steps:

STEP 1: With vacuum pump still off, toggle the solenoids that control the filter selection to ensure that they all work. Leave in BYPASS MODE.

STEP 2: Turn on vacuum pump

STEP 3: Set the flowrate to 18 liters per minute by moving the left hand dial with your mouse. After about 10 seconds, the actual flow (right-hand display) should move to match the target flow.

Note: if flow control does not respond, reset the AC power to the gravimetric filter system and try again.

STEP 4: Set the scale factor for the mass flow controller to 0.041

STEP 5: Update the E2

STEP 6: When these steps are complete, you may press the "STOP" button to exit

NOTE: (DO NOT EXIT SCREEN BY PRESSING THE "x" IN THE UPPER RIGHT HAND CORNER OF WINDOW)

1.4 Daily SEMTECH-DS Maintenance

The following steps should be performed PRIOR to installation:

- Install new heated filter (if differential pressure sample and barometric is approaching 300 mBar)
- Install new FID fuel bottle if necessary (200 PSI / hour operation).
- Leak check FID fuel, and Close FID bottle
- Leak check sample path
- Check heated line operation (A/C line controlled through controller external to SEMTECH)

1.5 Install RPM Probe

Install the RPM probe so that the optical signal may be read from reflective tape affixed to a rotating crankshaft pulley. The magnetically-secured RPM mounting base may typically be used to secure the optical sensor.

NOTE: Some software setup is required in the SensorTech-PC host software. See Section 2 for details.

1.6 Prepare ECU Data Collection Equipment

Collection of the ECU datastream should be investigated and attempted for all electronically-controlled equipment. For Caterpillar equipment, this will involve utilization of the Caterpillar Communication Adapter and CAT ET Software application operating on an additional laptop (as provided by EPA). This laptop should either be placed in the cab in a secure area, or in the PEMS rack. Remote control of the ECU data collection laptop may be required by way of a wi-fi or Internet-based network. For non-Caterpillar equipment, collection of ECU data should be attempted using appropriate-protocol communication adaptors in conjunction with either the SEMTECH or an external laptop, as needed.

2 Data Acquisition using SEMTECH-DS with PPMD

Newer versions of SensorTech-PC host software for the SEMTECH-DS now support integrated data acquisition with the PPMD.

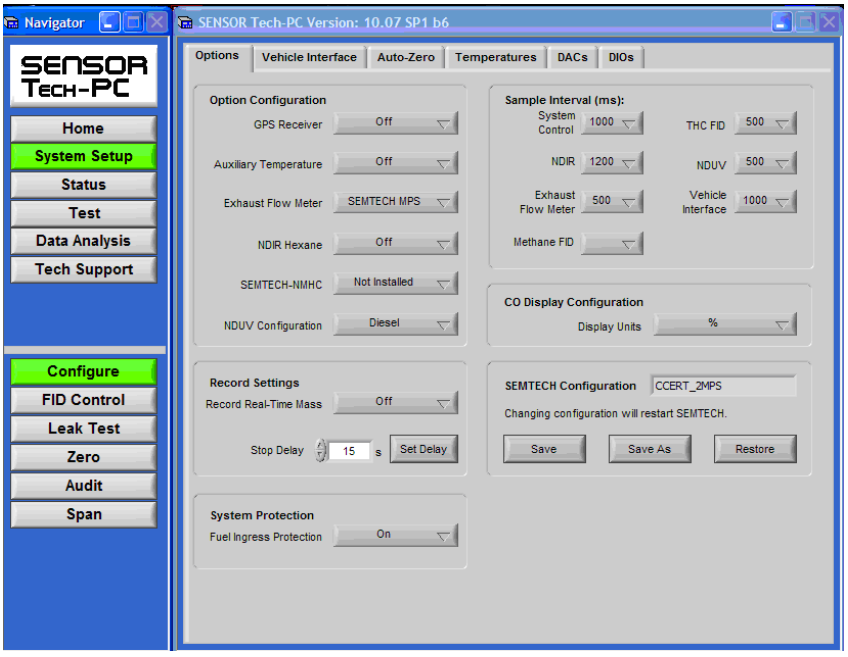
2.1 Connect CAN network from PPMD system to SEMTECH

A special cable is required that connects the serial interface of the CAN module to the Aux-1 port on SEMTECH-DS. Please install this cable before proceeding.

2.2 Enable MPS Exhaust Flow from Semtech DS

- Within SensorTech-PC Software, go to Set Up / System Configure
- Turn exhaust flow sensor choice to OFF, and then select MPS
- ***You are now prompted to select the appropriate PPMD.XML file which describes your PPMD configuration. Variables in the PPMD.XML file which are not present in the physical configuration of the PPMD equipment slows down the network.***
- ***Contact Sensors Service for assistance in identifying the appropriate file for your system.***
- Set the Exhaust Flow Meter update rate to 500 msec.

→ **Screens: System Setup, Configure.**
→ **Tab: Options.**

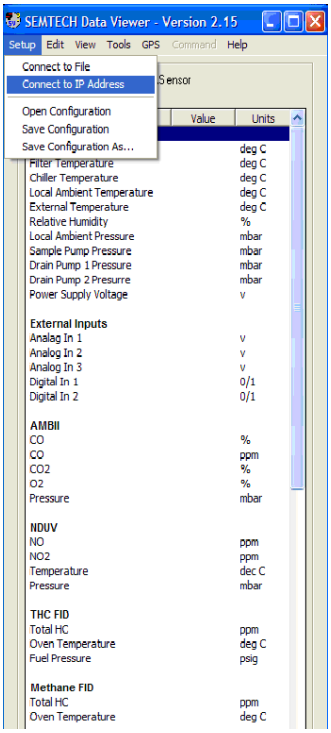


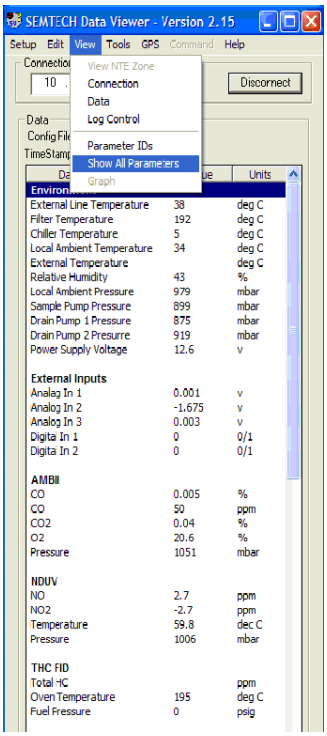
The SEMTECH-DS should now be communicating with the PPMD system. To verify, go to Road Test screen and verify that Exhaust Flow and Exhaust Temperature parameters are present.

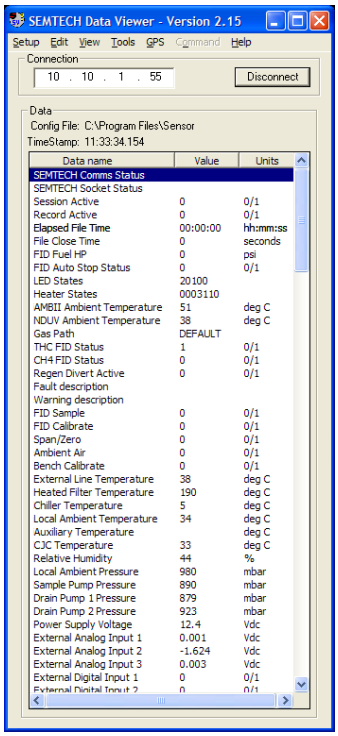
2.3 Launch "Data Viewer" to View PPMD Data

Launch the Data Viewer utility found in the SensorTech-PC program group in the Start menu of Windows.

- Connect to IP Address, (typically 10.10.1.55 for the Semtech DS)
- Press the Connect button
- Press View tab, and select "Show all parameters"
- Scroll to the bottom, and you will find all PPMD related parameters.







You can use Data Viewer to check and monitor your PPMD parameters through the wireless (or wired) SEMTECH Ethernet connection to your laptop. Furthermore, anytime you record a datafile, all PPMD parameters are recorded.

IMPORTANT: For the ERG project, make certain that the PPMD.XML file contains parameters for one MPS and the gravimetric system. Check that these parameters are present in Data Viewer.

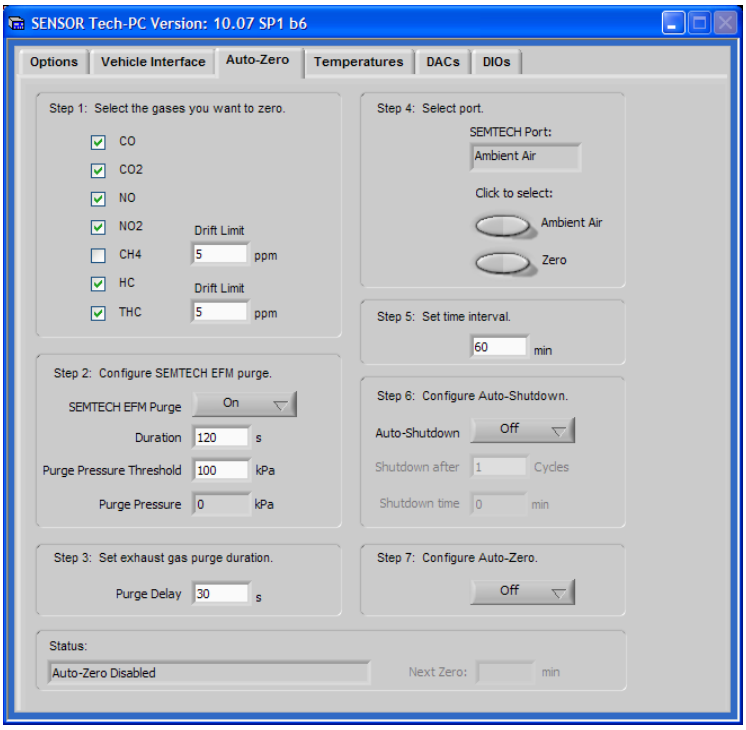
IMPORTANT: Check MPS Operation Mode: The MPS mode displayed in the Data Viewer is defined below. It represents the mode that the MPS is set to. In general, you want the MPS in proportional mode (mode 1).

Value	MPS Operational Mode
0	Manual Calibration
1	***Proportional (used for MPS #1)***
2	DR Constant Dilution (used for MPS #2)
3	ISO
4	Purge Sample
5	Standby

2.4 Setup AutoZero

Utilize this function to automatically zero Semtech DS analyzers each hour. You may also select to manually zero the SEMTECH DS from this screen,
For instance after the completion of grav filter sampling.

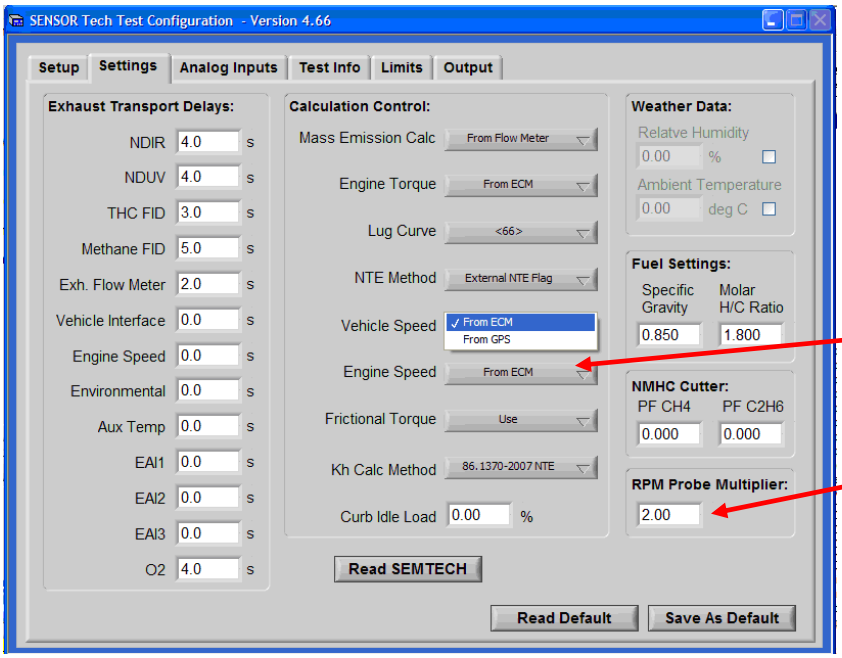
→ ***Screen: system setup, configure***
→ ***Tab: Auto-Zero***



2.5 Setup RPM Probe

The RPM probe is setup in the Test / Configure menu. Press the "Edit Test Configuration" button to access the screen shown below. For Engine Speed, select "External Probe". Set RPM Probe Multiplier appropriate to allow actual RPM to be displayed and stored.

→ ***Screen: Test / Configure***
→ ***Press button: Edit Test Configuration***
→ ***Tab: Settings***



Switch from ECM to External Probe

Make sure RPM probe multiplier is set to 2

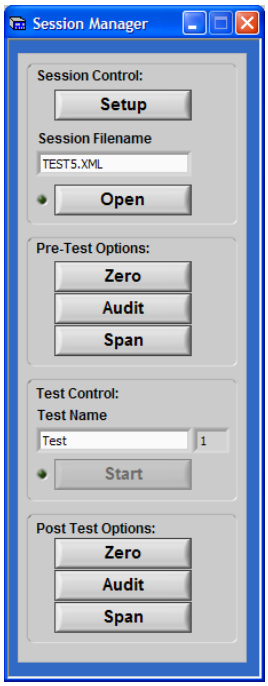
2.6 Recording ECU Data

Prior to the day's testing, attempt to establish communication with and acquire data (1 Hz) from the equipment's ECU. Use the appropriate data collection software to collect relevant data streams of interest, such as RPM, percent torque, load and throttle, and oil temperature (among other parameters) from the broadcast datastream.

2.7 Recording Test Data

All test data for the ERG project will be recorded from the SEMTECH data logger. Typically, each day of testing will be recorded in a single Session, with multiple tests as needed.

STEP 1: Make sure all setup steps are completed
STEP 2: Open Session Manager Window
STEP 3: Name the Session, and press "OPEN"
STEP 4: Just before test is to begin, perform Zero and Span calibrations.
STEP 5: Under Test Control, press "START". You are now recording data.
STEP 6: Just before the engine starts, change filter control from Bypass to the desired filter number
STEP 7. Start the engine and monitor data.
STEP 8: Switch filters according to schedule.



2.8 Gravimetric Filters -Timed Switching

The gravimetric filters can be switched automatically based on pre-set sampling intervals. This is performed using a Telnet window as described below.

NOTE: Session Manager must be already be Open and Recording a test file.

STEP 1: Go to PC's Run Command and type : "Telnet 10.10.1.55". You will see a log-on screen
STEP 2: Enter user name: "Sadmin" (***xadmin for Msn XP users***)
STEP 3: Enter password: "sem2002"
STEP 4: Type: ***Call GravFilter.scr.*** This starts the batch utility for timed filter switches.

NOTE: Allow the Telnet screen to continue to operate during testing so that user can note Timer countdown and filter number selection.

The filter switching batch utility will begin a timer countdown. The user can also over-ride the timers and perform actions as shown.

PRESS	**FUNCTION**
SPACE BAR	to skip to next particulate filter cup.
ESCAPE	to abort the Filter sampling.

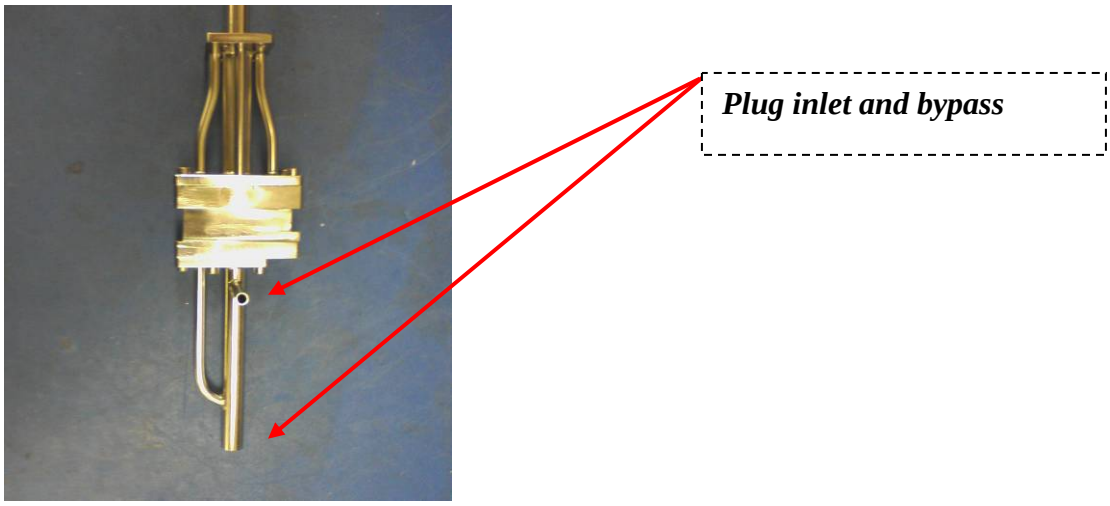
Filter Switching follows the Default setting below:

Minutes	**Description**
10	cold start
20	warm operation
30	warm operation

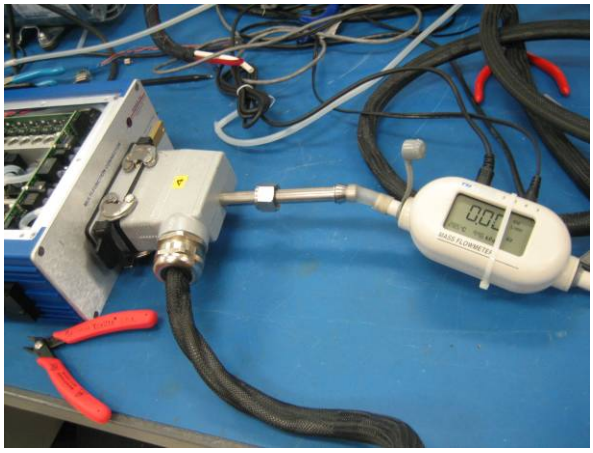
3 Weekly MPS Maintenance

3.1 *Calibrate Major and Minor Dilution Block Flows*

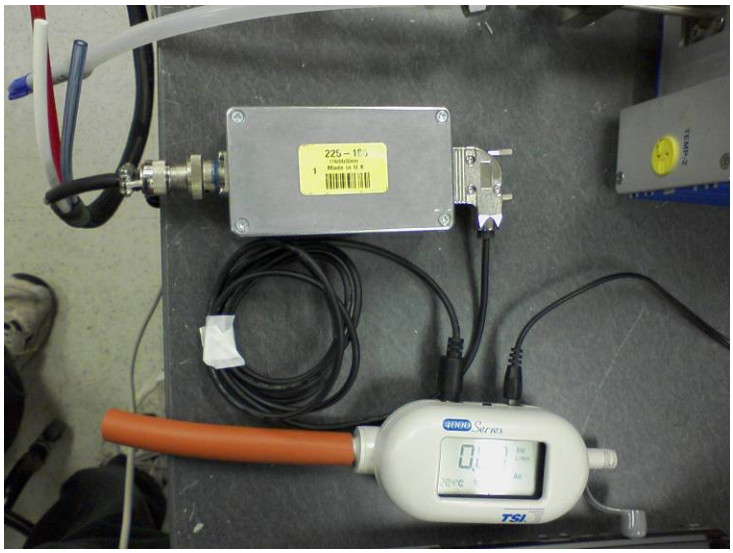
- Zero Major and Minor flows
- Plug Sample Inlet and Sample Bypass (which eliminates sample flow to the reference flowmeter).



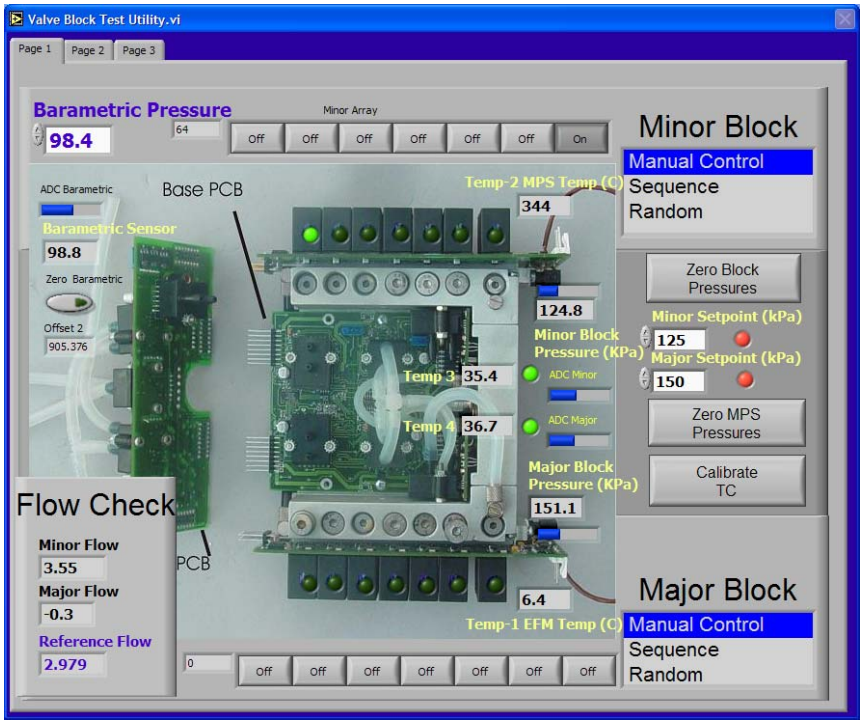
- Connect a reference flowmeter to outlet of MPS diluter.
- Ensure that direction of flow is correct (see backside of meter)



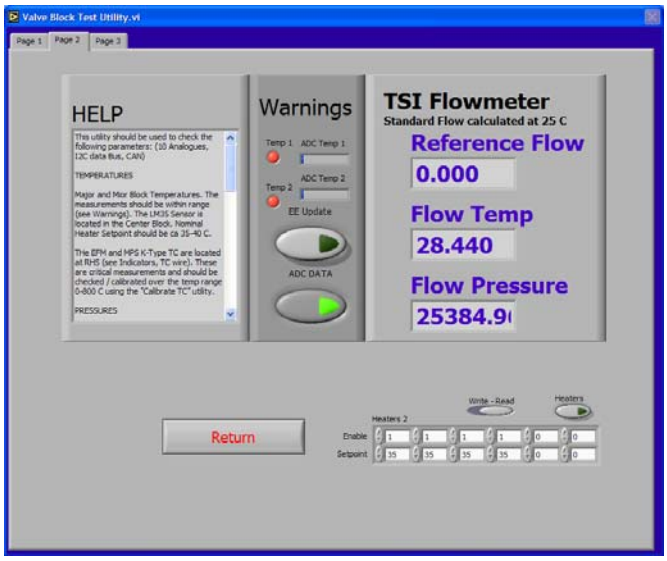
- Connect reference flow meter to flow box and flow box to MPS signal cable to provide signal to the CAN network.
- Connect power to flowmeter
- Flowmeter should display: MPS Dilution Flow, Temperature, and Pressure.



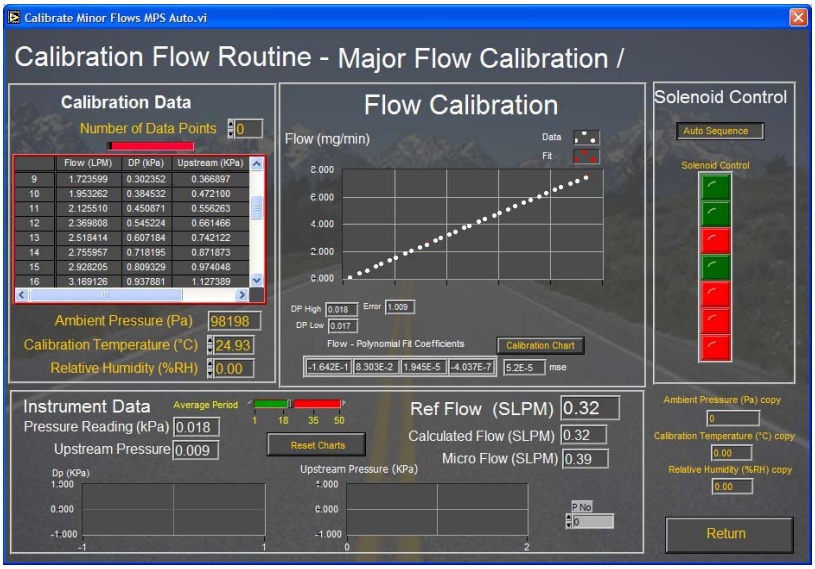
→ ***Utility Menu: Select "Advanced MPS"***
→ ***Press button: "MPS Dilution Flows"***



Note presence of Reference flow in lower left corner (blue text). Confirm reference temperature and pressure values by going to tab: Page 2



- Go to page 3.
- Press Button: Major Flow Calibration / Test
- Press button: Calibrate Flow to Generate Table for Major Flow.
- Cycle through the Major orifices until the Mean Standard Error < 5 x $10^{-3.}$
- Look for irregularities in the linearity charts for flow.
- User can accept new coefficients. (Message: Change calibration file & write coefficients to the Micro).



- Repeat the process and Choose Minor Flow Calibration / Test,
- Press Calibrate Flow to Generate Table for Minor Flow.
- Cycle through the minor orifices until the Mean Standard Error < 5 x $10^{-3.}$ then Press Return.

- As necessary, a user can accept new coefficients. (Message: Change calibration file & write coefficients to the Micro).

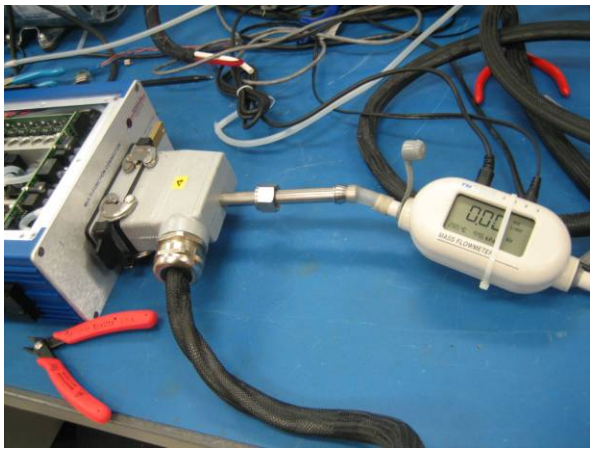
  If major and minor dilution flow values are linear and without significant outliers, you have successfully completed this section.
  Go to page 2 and press RETURN.

  If Major and Minor Dilution Flow values have significant outliers, recheck the setup. Make sure the sample and bypass are blocked. Repeat process.

3.2 Check / Adjust Critical Orifice Flow rates (as needed)

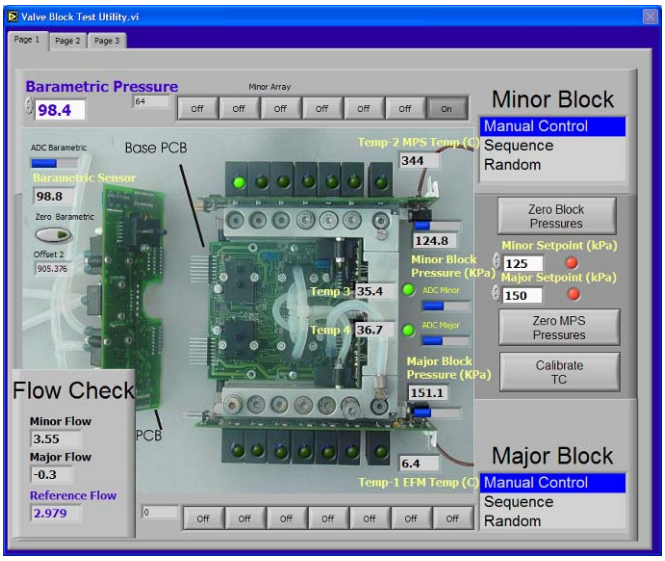
The critical orifices only need to be adjusted if the Lookup Table has significant discontinuities. If that is the case, then use the following procedure.

- Eliminate sample flow by plugging the MPS sample inlet and sample bypass.
- Connect reference flowmeter to outlet of MPS diluter.
- Ensure that direction of flow for reference flow meter is correct**.**



- Connect reference flow meter to flow box and then to MPS cable which provides power and signal.
- Enable the TSI flowmeter as described in section 1.

  → ***Utility Menu: Select "Advanced MPS"***
  → ***Press Button: "MPS Dilution Flows"***



- **Check / Set block pressures** as described in Section 1
- **Adjust major flow orifices**,

  Use PC valve block test utility .vi, and select an SOV.
  Utilize reference flow meter to read flow.
  Adjust largest SOV needle valve to 8.0 LPM dilution flow.
  Step flow down in half for next SOV.
  Settings: 8.0, 4.0, 2.0, 1.0, 0.5, 0.25, 0.125 LPM.
  The critical orifice valves may be adjusted with an allen wrench while the MPS Display cover is in place. We recommend approaching flow set point from high while decreasing flow to minimize offset.
- **Adjust minor flow orifices**,

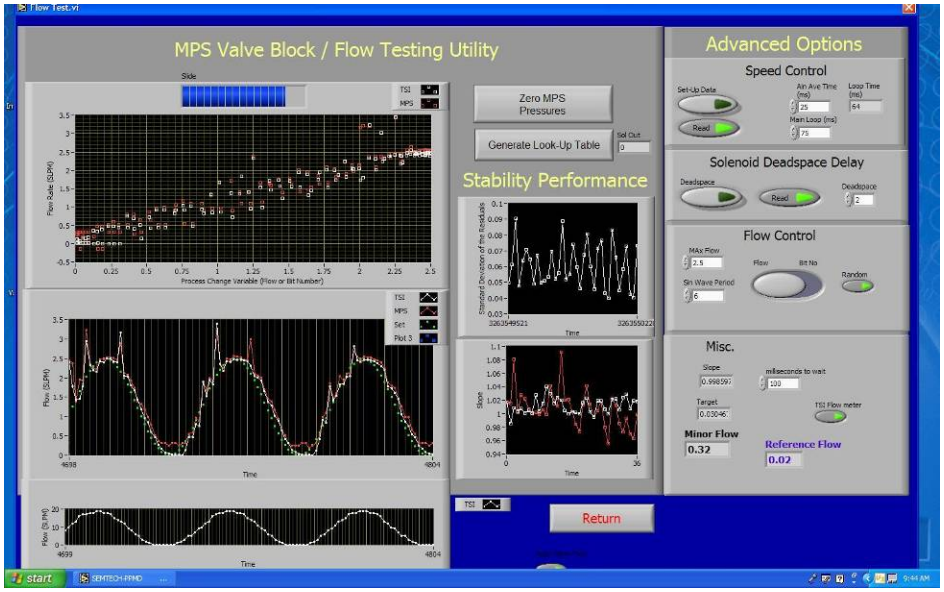
  Use PC valve block test utility .vi, and select an SOV.
  Utilize reference flow meter to read flow.
  Adjust largest SOV needle valve to 2.4 LPM dilution flow.
  Step flow down in half for next SOV.
  Settings: 2.4, 1.2, 0.6, 0.3, 0.15, 0.08, 0.04 LPM.
  The critical orifice valves may be adjusted with an allen wrench while the MPS Display cover is in place. We recommend approaching flow set point from high while decreasing flow to minimize offset.
- **Update Lookup table** using procedure from Section 1. The reference flow meter is not required for the Look-Up Table, but can be used to confirm dilution flow readings (provided that the sample inlet and inlet bypass are plugged).

3.3 Flow Testing Utility

Flow testing is required to confirm ability of MPS Valve Block to track requested flows. Modify Flow Control values to:

- 0 to 4.8 LPM for Minor Flow

- 0 to 16.0 LPM for Major Flow



This diagnostic reads expected versus actual dilution flow as measured by both internal MPS dilution flow meters and also by reference flow meter.

3.4 Generate Flow Model

The multi-variable model is pre-configured by Sensors. This should only be adjusted based on detailed review of data.

4 Data Quality Assurance

4.1 Exhaust flowrate at idle

If the exhaust flowmeter is working correctly, it should read within approximately 10% of the flowrates listed in the table below when idling at 600 RPM. If the idle speed is not 600 RPM, you can adjust the expected flow as follows:

Flow Expected @ Actual RPM = Flow at 600 RPM x (Actual RPM / 600)

Expected Flowrates at Idle

Engine size, liters	Engine Speed, rpm	Exhaust Flow, kg/hr
3	600	51
4	600	69
5	600	86
6	600	103
7	600	120
8	600	137
9	600	154
10	600	171
11	600	188
12	600	206
13	600	223
14	600	240
15	600	257

If the flowrate is significantly different from this value, do the following:

- Verify that the proper tube diameter is selected in the PPMD software.
- If the actual flowrate is significantly lower than expected, try backpurging the pressure lines at the manifold of the flow tube. Be certain not to backpurge the colored plastic pressure lines leading to the MPS, unless you disconnect them at the MPS.

4.2 Verify MPS Flows

Perform the following MPS checks either with live data or from a recorded data file. Whenever the MPS is in proportional mode:

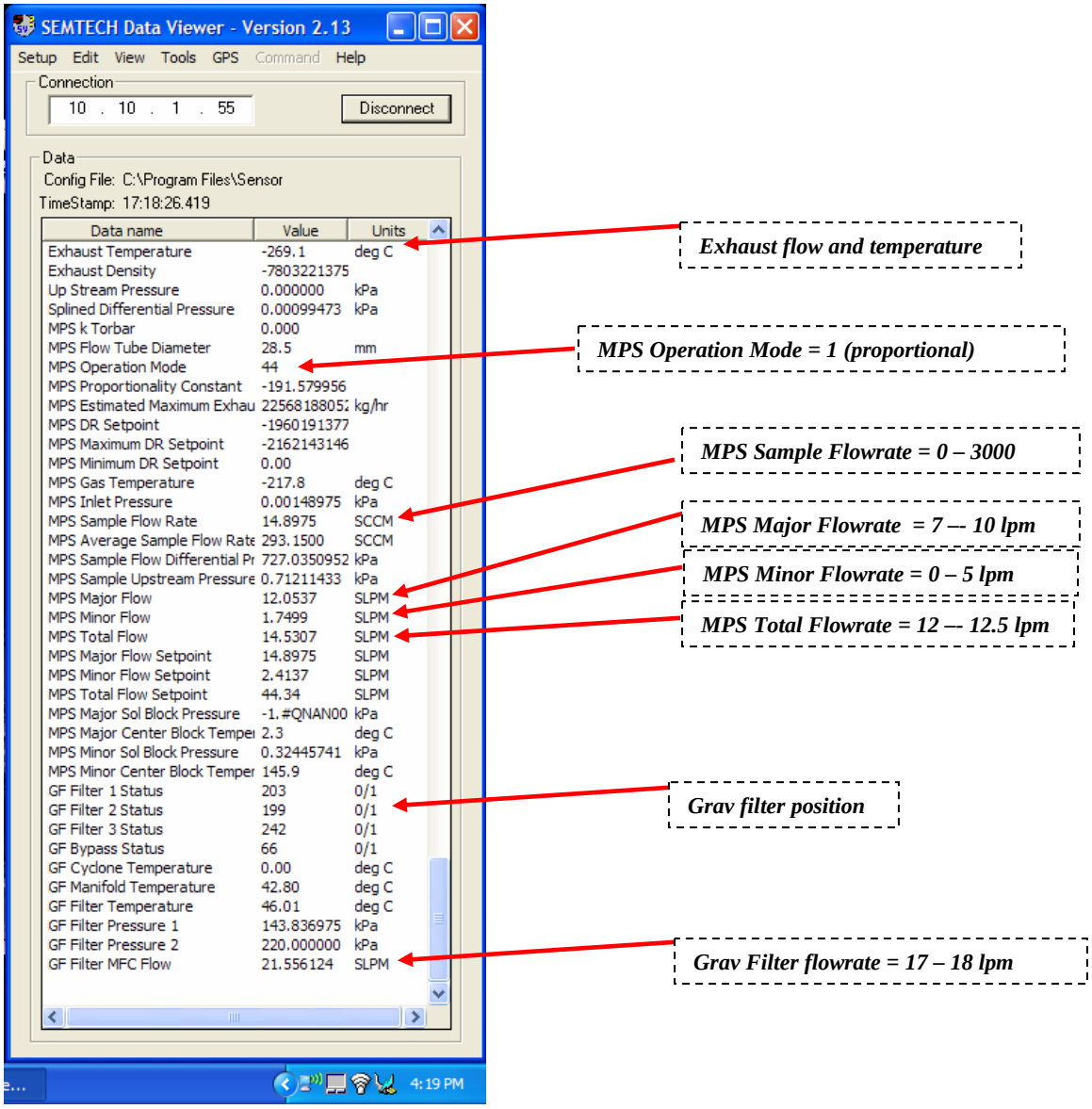
- Qtotal should be 12.5 lpm, +/- 0.5.
- At zero exhaust flow (engine off), Qsample should be less than 0.2 lpm
- At zero exhaust flow, Qminor should be > 4 lpm
- At max exhaust flow, Qminor should be slightly positive, or zero. If Qminor reaches zero at lower exhaust flowrates, or is greater than 0.5 lpm at max exhaust flow, perform adjustments as described in section 1.2.5.

Further information is provided in section 1.2.12.

4.3 Monitor Key Parameters during Tests

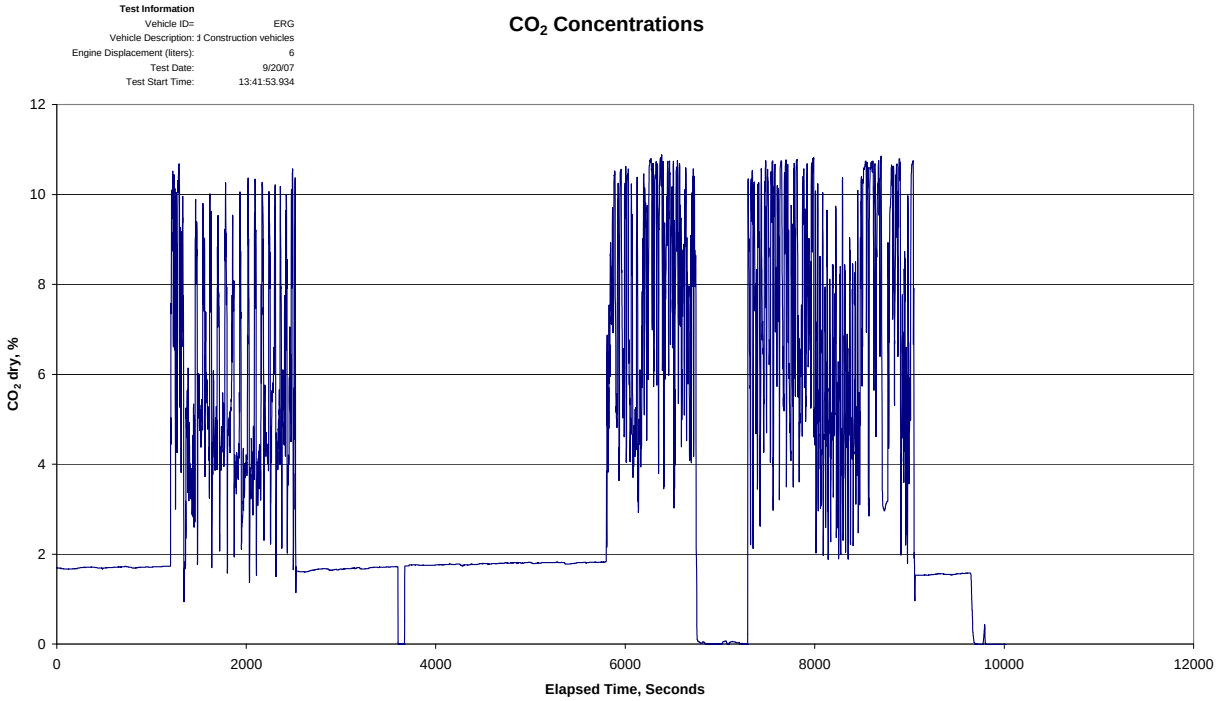
The Data Viewer utility allows us to monitor all key parameters during a test through the wireless Ethernet connection to the SEMTECH-DS. Here is a list of the most important parameters to monitor.

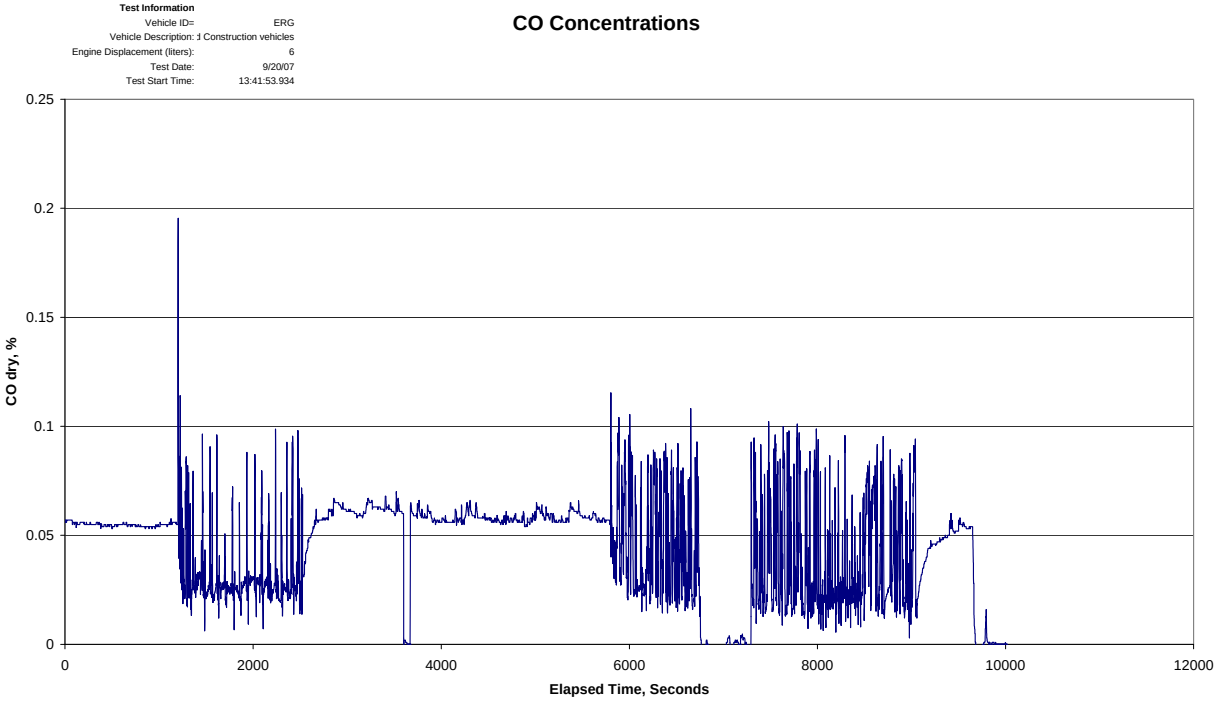
Note: The values in this screenshot are invalid and erratic. If this occurs, you must disable, and then re-enable the MPS in the System Setup / Configuration / Options screen of the SensorTech-PC software.

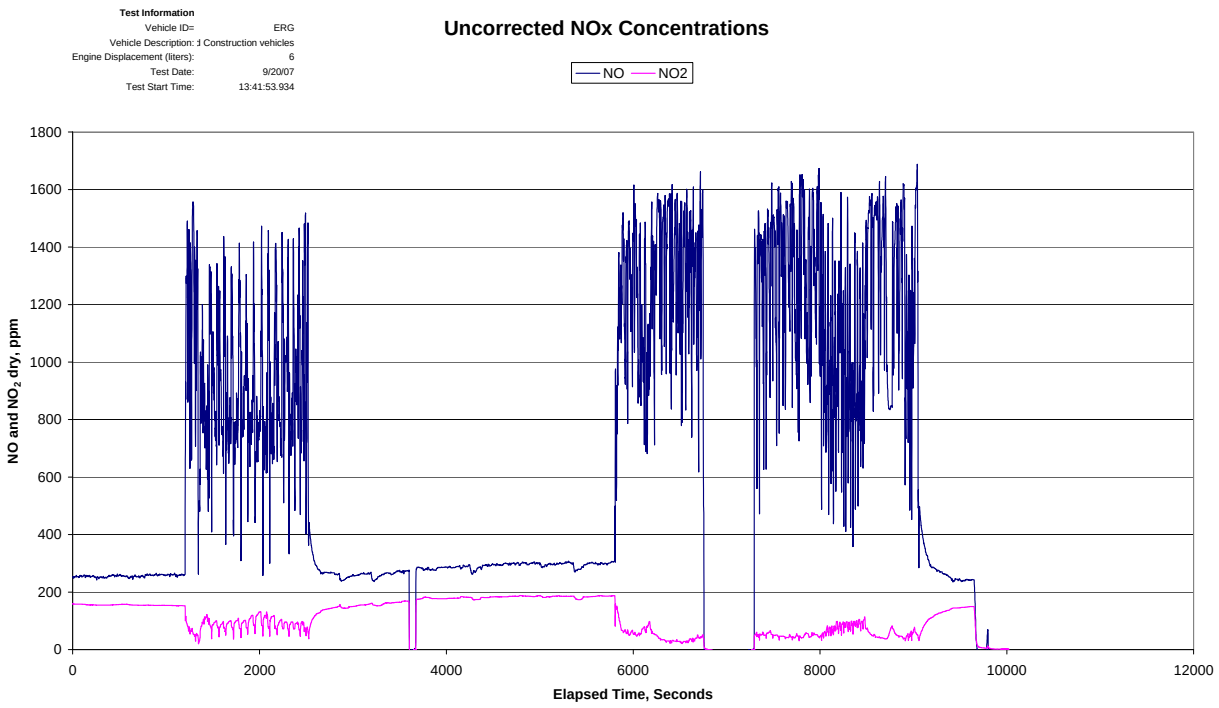


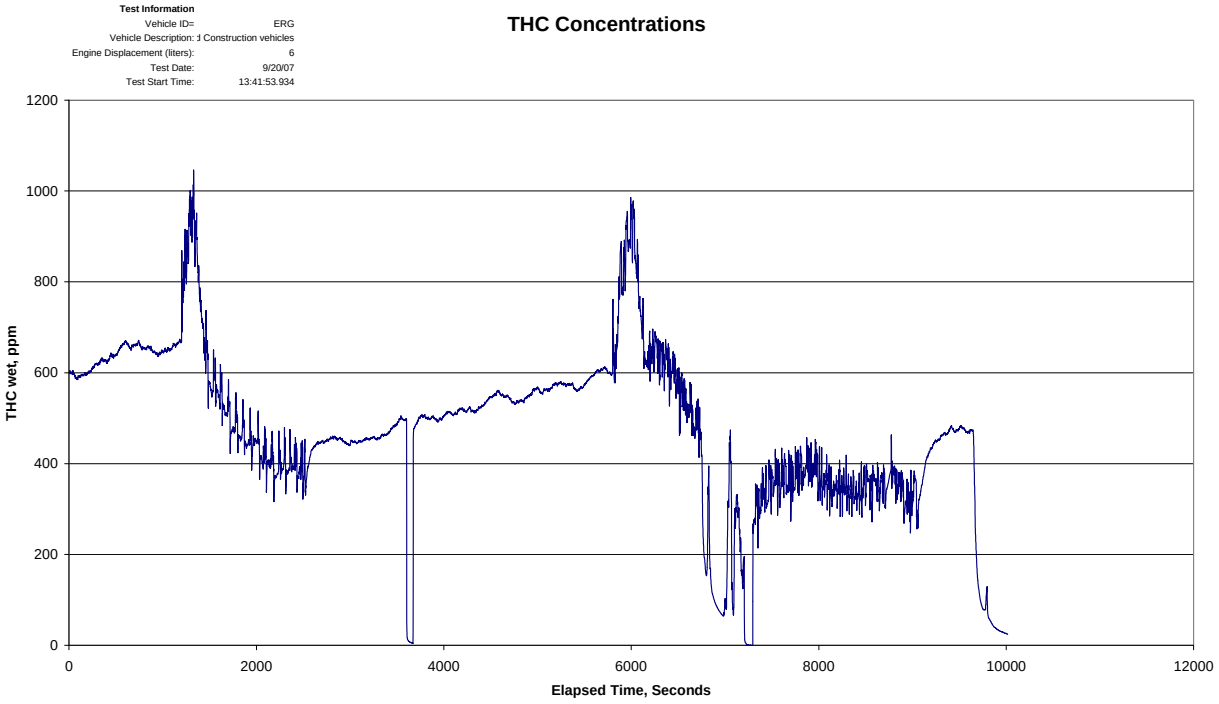
4.4 Data Quality Assurance Check after Tests

After testing, field technicians will chart the key parameters from the test for initial quality assurance verification. A charting macro has been developed, which will create the charts automatically. Below are examples of "good" data collected during a practice test.



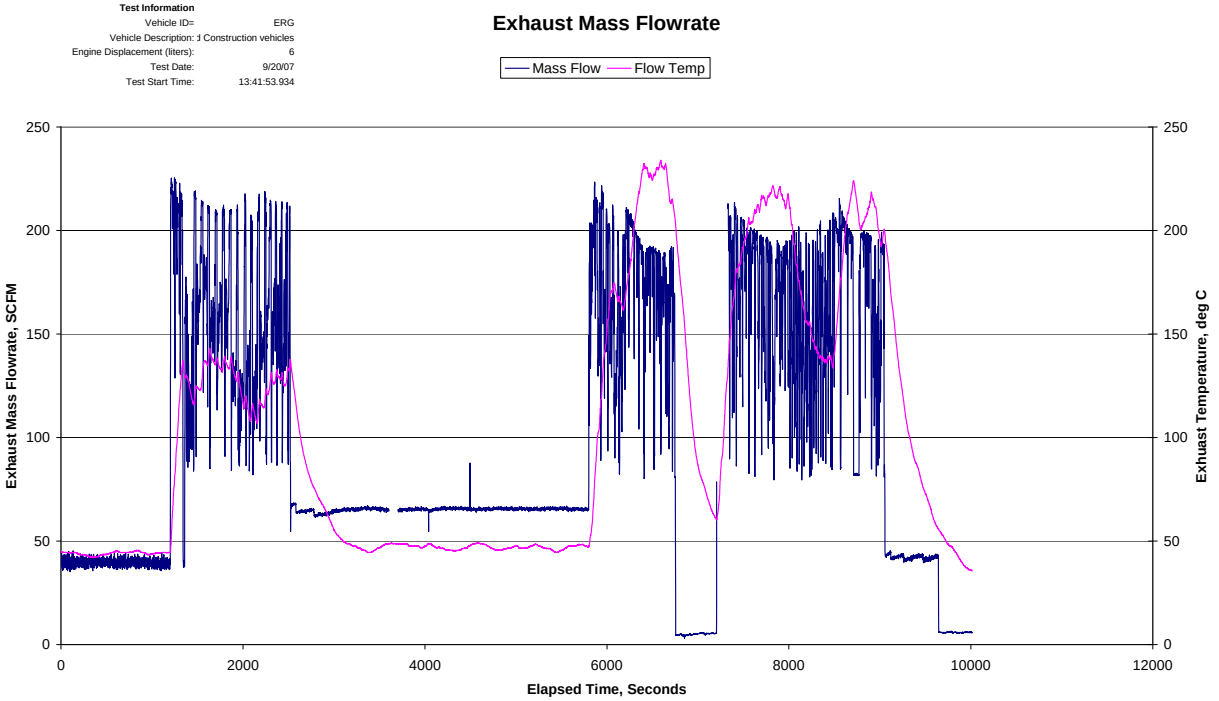



Test Information
Vehicle ID= ERG
Vehicle Description: 1 Construction vehicles
Engine Displacement (liters): 6
Test Date: 9/20/07
Test Start Time: 13:41:53.934
Uncorrected NOx Concentrations
NO
NO2
NO and NO2 dry, ppm
Elapsed Time, Seconds


Test Information
Vehicle ID= ERG
Vehicle Description: 1 Construction vehicles
Engine Displacement (liters): 6
Test Date: 9/20/07
Test Start Time: 13:41:53.934
THC Concentrations
THC wet, ppm
Elapsed Time, Seconds

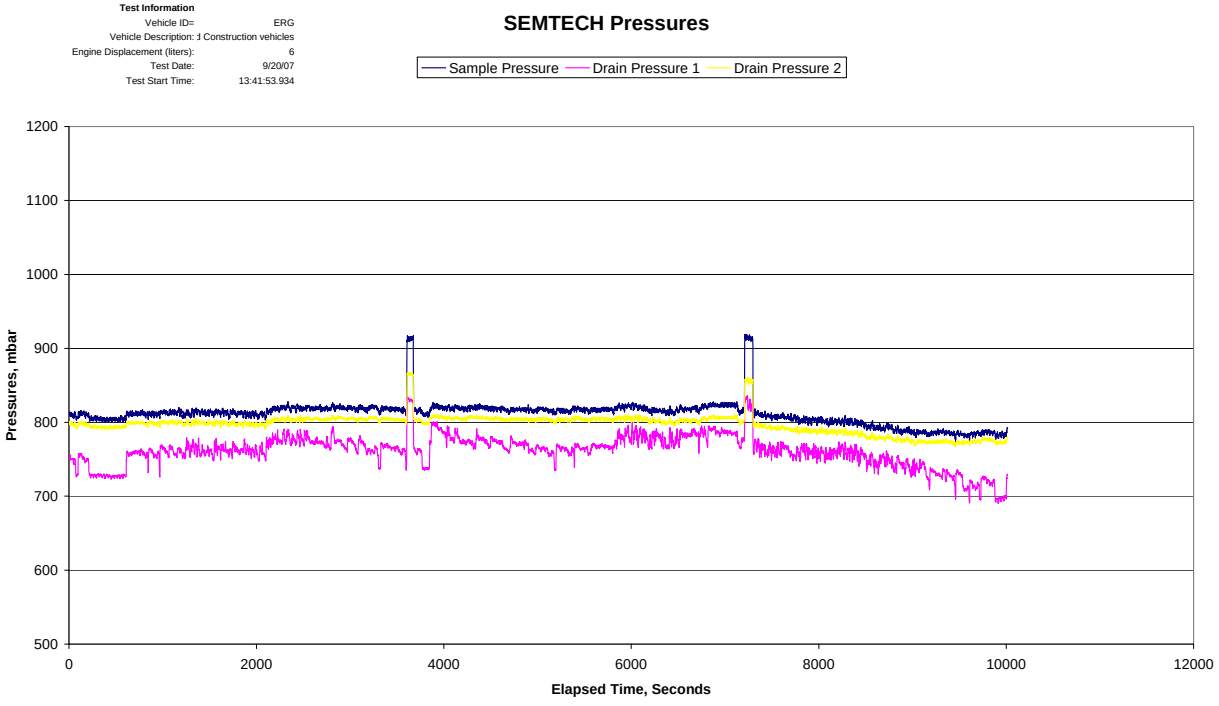
Test Information

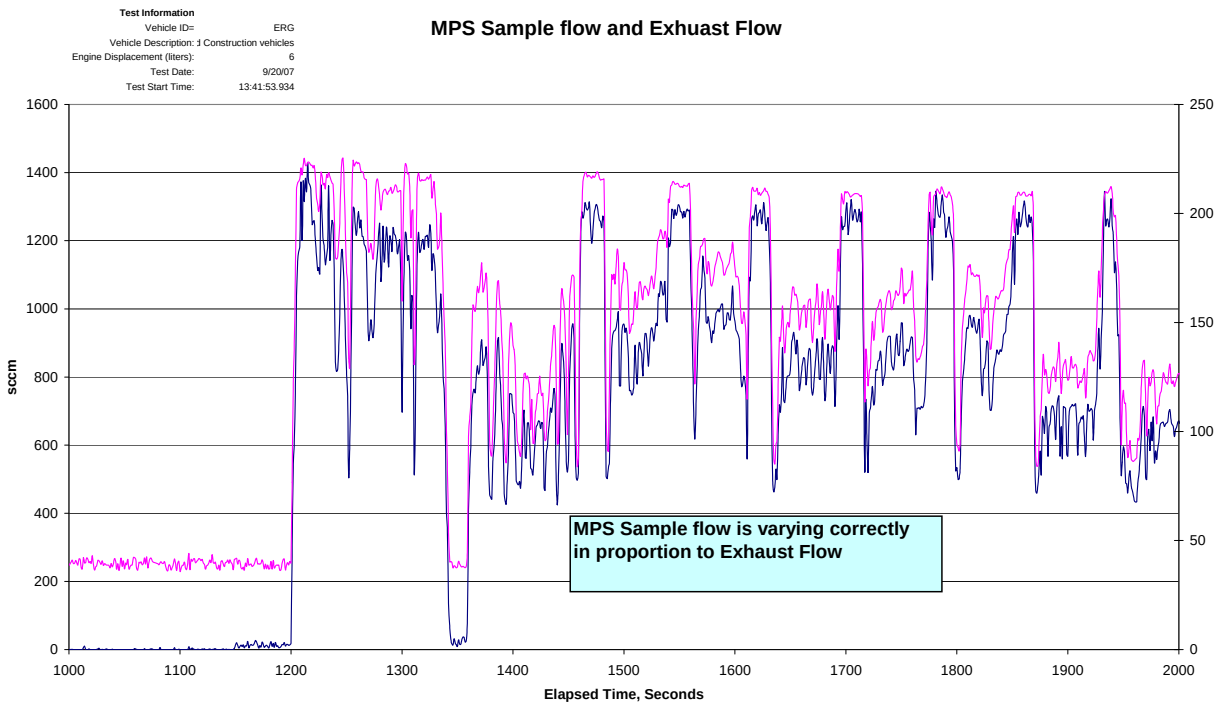
Vehicle ID=	ERG
Vehicle Description:	1 Construction vehicles
Engine Displacement (liters):	6
Test Date:	9/20/07
Test Start Time:	13:41:53.934

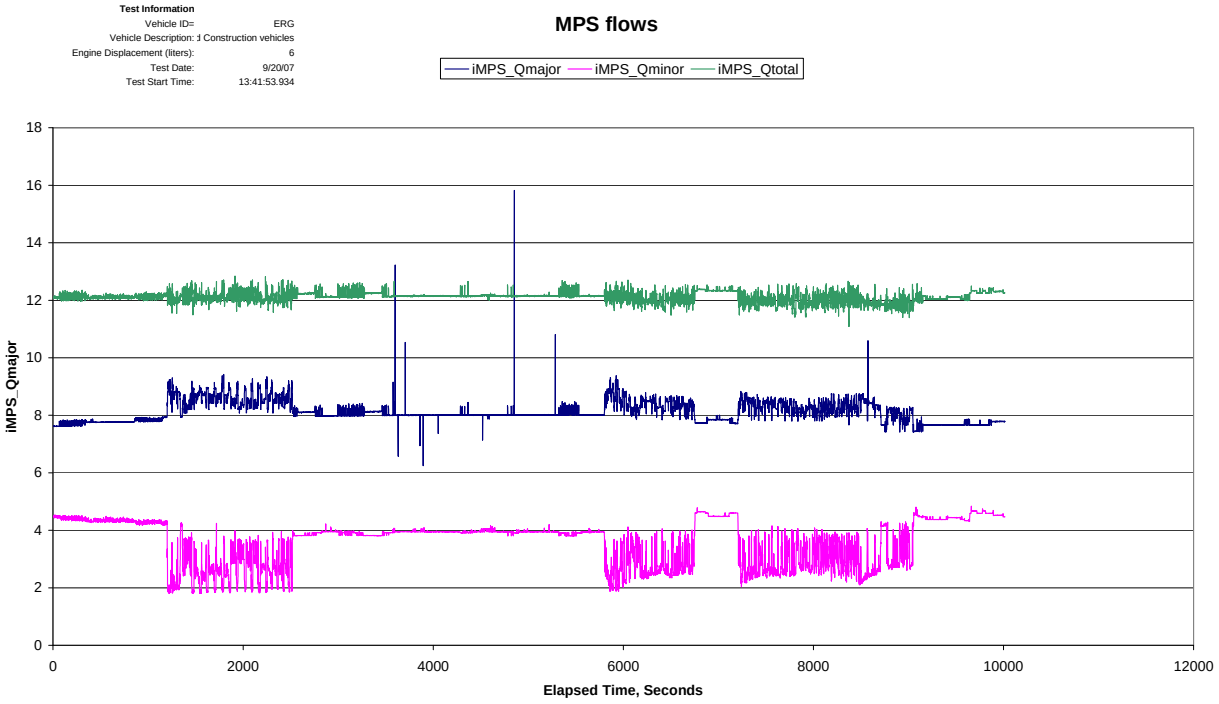


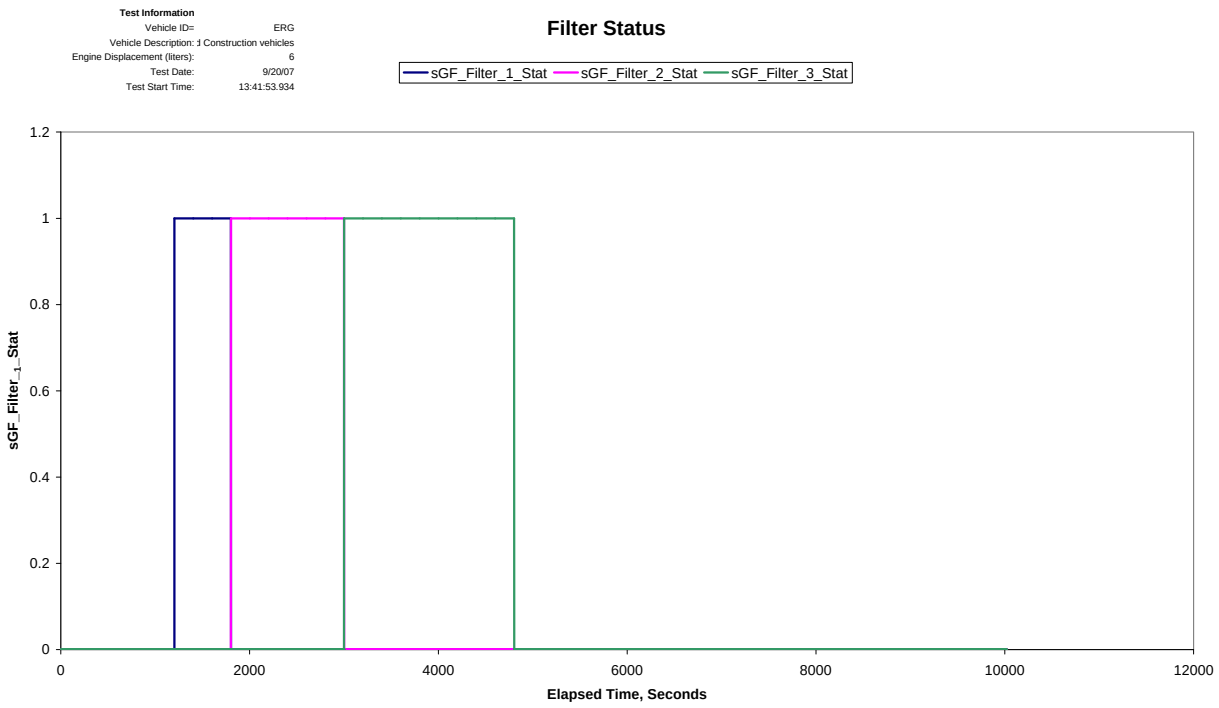
Test Information

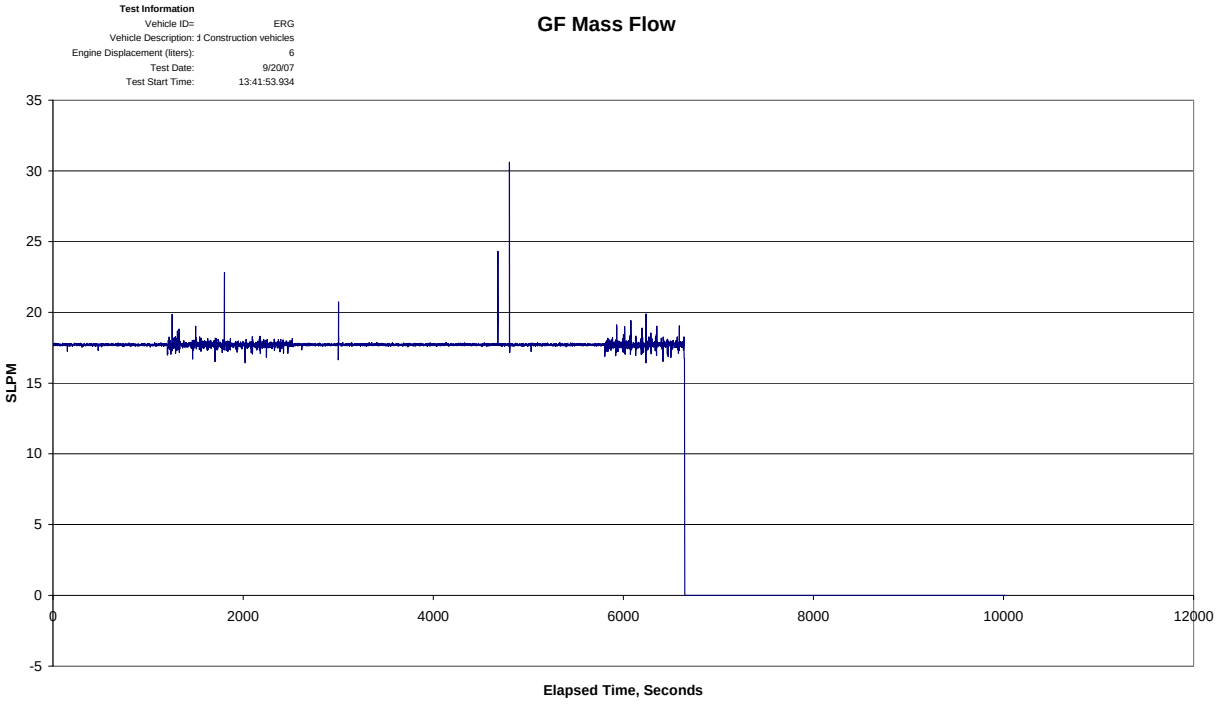
Vehicle ID=	ERG
Vehicle Description:	1 Construction vehicles
Engine Displacement (liters):	6
Test Date:	9/20/07
Test Start Time:	13:41:53.934




Test Information
Vehicle ID= ERG
Vehicle Description: 1 Construction vehicles
Engine Displacement (liters): 6
Test Date: 9/20/07
Test Start Time: 13:41:53.934
MPS Sample flow and Exhuast Flow
sccm
Elapsed Time, Seconds
MPS Sample flow is varying correctly in proportion to Exhaust Flow


Test Information
Vehicle ID= ERG
Vehicle Description: 1 Construction vehicles
Engine Displacement (liters): 6
Test Date: 9/20/07
Test Start Time: 13:41:53.934
MPS flows
iMPS_Qmajor
iMPS_Qminor
iMPS_Qtotal
iMPS_Qmajor
Elapsed Time, Seconds


Test Information
Vehicle ID= ERG
Vehicle Description: 1 Construction vehicles
Engine Displacement (liters): 6
Test Date: 9/20/07
Test Start Time: 13:41:53.934
Filter Status
sGF_Filter_1_Stat
sGF_Filter_2_Stat
sGF_Filter_3_Stat
1.2
1
0.8
0.6
0.4
0.2
0
sGF_Filter_1_Stat
0
2000
4000
6000
8000
10000
12000
Elapsed Time, Seconds


Test Information
Vehicle ID= ERG
Vehicle Description: 1 Construction vehicles
Engine Displacement (liters): 6
Test Date: 9/20/07
Test Start Time: 13:41:53.934
GF Mass Flow
35
30
25
20
15
10
5
0
-5
SLPM
0
2000
4000
6000
8000
10000
12000
Elapsed Time, Seconds