Laboratory

3

Laboratory 3: Calibration of a $PM_{2.5}$ Sampler

3.1 Introduction

Appendix L in 40 CFR Part 50 requires periodic multi-point calibration and single-point verification of a reference or equivalent method (Class I) $PM_{2.5}$ sampler's flow rate measurement system. This is done to establish and maintain traceability of flow measurements to a certified flow rate standard. If there is any doubt about the calibration of the temperature and pressure sensors, these sensors should be calibrated before calibrating the flow rate measurement system. Also, internal and external leak checks should be performed before proceeding with the calibration of the flow rate measurement system. In addition, if temperature and barometric pressure verification and calibration are needed, they must precede flow rate verification and calibration.

The flow rate standard used for calibrating or verifying the sampler's flow rate measurement system must be capable of providing an accuracy of $\pm$ 2%. The flow rate device must have its own certification and be traceable to a National Institute of Standards and Technology (NIST) primary standard for volume or flow rate. The NIST traceability requirement is contained in Appendix A of 40 CFR Part 58.

Calibration of the flow rate must be in terms of the actual volumetric flow rate, (Q_a) at prevailing ambient conditions of temperature and pressure, instead of the standard volumetric flow rate (Q_{std}), which is corrected to EPA standard conditions of 25°C or 298 K and 760 mm Hg or 101 kPa.

Because $PM_{2.5}$ samplers may employ various types of flow control and flow measurement devices, the detailed procedures used for calibrating or verifying the flow rate measurement device will vary depending on the particular $PM_{2.5}$ sampler employed. As a result the calibration procedures presented here are generic procedures intended to show the common steps involved in calibrating a $PM_{2.5}$ sampler. The manufacturer's Sampler Operation/Instruction Manual for the sampler to be used in this laboratory exercise contains the specific instructions necessary to conduct the following experiments. A copy of the procedures appropriate for the $PM_{2.5}$ sampler to be used for these laboratory exercises will be provided by the laboratory instructor.

Keep in mind that there are several steps that should ALWAYS be performed during any type of calibration:

- Turn on the sampler and allow it to warm to operating temperature and equilibrate.
- Check the sampler and any other equipment thoroughly – look for cracks, dents, chips, or other damage.
- Be sure that all necessary equipment is available and in good working order.

This laboratory will consist of four experiments:

Experiment 1: External and internal leak checks. (Note that some samplers call for one combined leak check.)

Experiment 2: Calibration of the sampler temperature sensor.

Experiment 3: Calibration of the sampler pressure sensor.

Experiment 4: Calibration of the sampler flow rate measurement system.

Objectives

At the conclusion of this laboratory session, you will be able to:

1. conduct internal and external leak tests (or one combined leak test) of a $PM_{2.5}$ sampler,
2. calibrate the $PM_{2.5}$ sampler's temperature sensor,
3. calibrate the $PM_{2.5}$ sampler's pressure sensor, and
4. calibrate the $PM_{2.5}$ sampler's flow rate measurement system.

Lab Report

Your report for this lab session should include the following (for grading convenience, please arrange your report in the order shown below):

1. Internal and external leak check data sheet
2. Temperature sensor data sheet
3. Pressure sensor data sheet
4. Flow rate measurement data sheet.

3.2 Experiment 1: External and Internal Leak Checks

Introduction

$PM_{2.5}$ samplers have the potential for leaks, both external and internal, which could cause an error in the sampler's measurement of the total volume of air that passes through the sample. As a result, reference (FRM) or equivalent method (FEM) $PM_{2.5}$ samplers must have an external air leak-test capability and an internal filter bypass leak check capability. The external and internal leak test capabilities are designed to allow the operator to conduct a leak test of the sampler at a field monitoring site without additional equipment. The leak test capabilities include appropriate sampler components, accessory hardware, operator interface controls, and a written procedure documented in the $PM_{2.5}$ Sampler's Operation/Instruction Manual. The leak check procedure verifies the integrity of the WINS Impactor or, the alternative, Very Sharp Cut Cyclone (VSCC), and air handling tubes and fittings up to and including the FRM's flow rate measurement sensor. Since each manufacturer's equipment is different, the operations manual should be consulted for the specific procedures applicable to that sampler. The generic procedures for conducting these tests are described below.

External Leak Test Procedure

1. Remove the sampler inlet and install the flow rate measurement adapter supplied with the sampler. The operation manual typically specifies the insertion of a filter cassette containing a new 46.2 mm filter in the sampling position of the sampler. In addition, the operation manual will direct the operator to call up the appropriate software screen or menu (usually the leak test menu) and then follow the instrument specific instructions displayed on the screen.
2. Close the valve on the flow rate measurement adapter and use the sampler air pump to draw a partial vacuum in the sampler of at least 55 mm Hg (75 cm water) measured at a location downstream of the filter holder assembly. The partial vacuum should include (at least) the impactor or cyclone, filter holder assembly with filter in place, flow measurement device, and interconnections between these devices. Typically, this step down through step 6 will be done automatically by following the instructions on the leak test screen.
3. Plug the flow system downstream of these components to isolate the components under vacuum from the pump using, for example, a built in valve.
4. Stop the pump.

5. Measure the trapped vacuum in the sampler with a built-in pressure measuring device.
6. Measure the trapped vacuum in the sampler again at least 10 minutes after the first pressure measurement.
7. After completing the test, slowly open the adapter valve, remove the adapter and plug, and restore the sampler to the normal operating configuration.

   REMEMBER: Open adapter valve SLOWLY.

   To pass the external leakage test, the difference between the two pressure measurements should not be greater than the number of mm Hg (specified by the manufacturer) corresponding to a leak of less than 80mL/min. For some samplers, a pass or fail message is automatically displayed at the end of the leak check cycle and no pressure measurements are displayed. Variations of this suggested leak test technique may be conducted, if they were approved as part of the manufacturer's reference or equivalent method application for the sampler.

Internal Filter Bypass Leak Check – to be performed if a problem is detected with the External Check

1. Perform an external leak test as described above.
2. Install a **flow-impervious** membrane material in the filter cassette, either with or without a filter as appropriate for the sampler used in this exercise. The installation of the membrane material effectively prevents air flow through the filter.
3. Use the sampler's air pump to draw a partial vacuum in the sampler, downstream of the filter holder assembly of at least 55 mm Hg (75 cm water).
4. Plug the flow system downstream of these components to isolate the components under vacuum from the pump using, for example, a built-in valve or an automatically activated solenoid valve.
5. Stop the pump.
6. Measure the trapped vacuum in the sampler with a built-in pressure measuring device.
7. Measure the trapped vacuum in the sampler again at least 10 minutes after the first pressure measurement.
8. Remove the flow plug and membrane material and restore the sampler to its normal operating configuration.

To pass the internal filter bypass leakage test, the difference between the two pressure measurements should not be greater than the number of mm Hg (specified by the manufacturer) corresponding to a leak of less than 80 mL/min. For some samplers, a pass or fail message is automatically displayed at the end of the leak check cycle and no pressure measurements are displayed. Similar to the external leak test, variations of the suggested technique may be used, provided that they were approved as part of the manufacturer's reference of equivalent method application for the sampler.

If the leak rate for either of the leak tests conducted exceeds 80 ml/min (equivalent to, for example, 10 cm of water) or indicates Fail on the leak test screen, document the problem on the leak test data sheet. Items that could cause excessive leaks include faulty flow rate adapter O-rings, a loose WINS impactor or Very Sharp Cut Cyclone, and nicks, wear, or permanent flattening of O-rings. In addition, inspect the outside of the sampler's downtube for dirt or deep scratches that could be the cause of the leaks, and check the filter holder assembly to see that it is properly seated. Finally, check component connections for loose connections and tighten if needed. Attempts should be made to correct any leaks and after corrective actions the leak tests should be repeated. In some cases the manufacturer may need to be contacted for further advice on correcting the problem.

Laboratory 3, Experiment 1: Example Leak Check Data Sheet

$PM_{2.5}$ Sampler Manufacturer ___________________ Name____________________

Model Number _______________ Date _____________________

Group No. ________________

External			Internal		
Reading	**Trapped Vacuum Pressure (mm Hg)**	**Pass/Fail**	**Reading**	**Trapped Vacuum Pressure (mm Hg)**	**Pass/Fail**
1st		NA	**1st**		NA
2nd		NA	**2nd**		NA
Difference					
Repeat			**Repeat**		
1st		NA	**1st**		NA
2nd		NA	**2nd**		NA
Difference			**Difference**		

Problems/Comments:

Laboratory 3, Experiment 1: Example Leak Check Data Sheet

$PM_{2.5}$ Sampler Manufacturer ____________________ Name____________________

Model Number ________________ Date ______________________

Group No. _________________

External			Internal		
Reading	**Trapped Vacuum Pressure (mm Hg)**	**Pass/Fail**	**Reading**	**Trapped Vacuum Pressure (mm Hg)**	**Pass/Fail**
1st		NA	**1st**		NA
2nd		NA	**2nd**		NA
Difference					
Repeat			**Repeat**		
1st		NA	**1st**		NA
2nd		NA	**2nd**		NA
Difference			**Difference**		

Problems/Comments:

3.3 Experiment 2: Temperature Sensor Calibration

Introduction

A calibration of each sampler's ambient temperature sensor and filter temperature sensor must be performed at the time of initial installation of the sampler and then annually to ensure traceability to an authoritative temperature standard. Ambient air and filter temperature sensor calibrations are typically conducted by removing the temperature sensors from their mounting on the sampler and placing them in a constant temperature environment such as a liquid bath or within a block of metal. Samplers using dual-flow systems contain two filter temperature sensors and both filter temperature sensors must be calibrated. Some $PM_{2.5}$ systems are designed so that the temperature sensors can be calibrated using a thermocouple calibrator or using reference temperatures. The thermocouple calibrator method is quicker and can be easily done in the field. The reference temperature method takes longer and is best done in the laboratory.

The thermocouple calibrator method requires the following items:

- A digital thermocouple calibrator that is NIST-traceable and accurate to ±2% over the expected range of use (-30 to 45°C).
- Appropriate calibration cable to connect to the sampler and the thermocouple calibrator.
- A thermometer which reads in degrees Celsius, NIST-traceable and accurate to ±2% over the expected range of use (-30 to 45°C). The thermometer is used as an independent check on the thermocouple calibration.

The temperature reference method for calibrating the sampler requires the following items:

- A cold temperature source, such as an ice water bath or a chilled block of metal, in which the temperature sensor can be placed. The cold temperature source must be able to maintain a constant temperature between 0°C to 5°C for the length of the calibration process (about 20 to 30 minutes).
- A hot temperature source, which can be heated water or a heated block of metal. The hot temperature source must be able to hold a constant temperature between 35°C to 40°C for the length of the calibration process.
- A thermometer which reads in degrees Celsius, NIST-traceable and accurate to ±2% over the expected range of use (-30 to 45°C).
- A precision calibrated, digital volt meter (**not required for all samplers**).

The specific steps to follow in calibrating the $PM_{2.5}$ sampler air temperature sensor and filter temperature sensor are contained in the manufacturer's operator's instruction manual and must be followed. The specific procedures vary according to the sampler and typically refer the operator to the appropriate menu selection for calibrating the temperature sensors, location of the temperature sensor boards, test points, span trimmer pots, thermocouple plug-in locations, etc.

The generic procedure for performing the multipoint temperature calibration is as follows:

Multipoint Temperature Sensor Calibration

1. Remove the ambient temperature sensor from the radiation shield so that it can be placed in a constant temperature bath with a NIST-certified thermometer or thermocouple while it is still connected to the sampler's signal conditioner. Alternately, hang the certified thermometer or thermocouple close to the radiation shield and at the same height. Follow the specific procedures in the operations manual regarding removal of the filter temperature sensors from their respective housings.
2. Three target temperatures (0°C to 5°C, ambient or room temperature at about 23°C, and an elevated temperature at about 40°C) will be used for the calibration. It is not necessary to achieve the target temperatures precisely, as long as a NIST-traceable temperature standard is available to indicate the exact temperature. Note: Some samplers only call for an ambient temperature calibration rather than three target temperatures.
3. When using the temperature reference method for calibration, select a convenient container (such as an insulated vacuum bottle) or a metal block for preparing the three temperatures. Wrap the sensor(s) and a thermometer or thermocouple together with a rubber band and hold them together and immerse them in the temperature bath. If using a liquid bath, cover the open end of the insulated bottle and stir the bath to ensure a uniform bath temperature.
4. For each target temperature, make a series of five measurements, taken about a minute apart or until equilibrium is achieved. Take the average of the multiple readings and record the results on the data sheet as the sampler sensor temperature and the thermometer or thermocouple temperature. The multipoint response is satisfactory if the agreement between the sampler sensors and the temperature standard agrees to within 1°C. If the multipoint calibration is not satisfactory, it is necessary to make adjustments as described in the $PM_{2.5}$ sampler's operations manual. **NOTE: Some samplers will only require a single point calibration – refer to the sampler's instruction manual.**
5. Adjustments using a temperature bath are usually made while the sensors are immersed in the temperature bath. $PM_{2.5}$ samplers that use the thermocouple calibrator rather than the thermometer calibrator method do not require the use of a temperature bath – they use a digital thermocouple calibrator for use

with type K thermocouples. It is possible, however, to use both methods. The thermocouple calibrator must be NIST-traceable and accurate to within $\pm 2\%$ over the expected range of use (-30 to 45°C). A NIST-certified thermometer accurate to within $\pm 2\%$ over this same range is to be used as an independent check on the thermocouple temperature check calibration.

Laboratory 3, Experiment 2: Temperature Calibration Data Sheet

$PM_{2.5}$ Sampler Manufacturer ___________________ Name _________________
Model Number ____________________ Date __________________
Group no. _____________

Thermocouple Calib. Std. Make/Model ____
Thermometer Calib. Std. Make/Model ____

Thermocouple Calibration Method (Ambient Air Sensor)

Target Condition	Sampler (a) Reading °C	Transfer Standard (b) Reading °C	Difference (a-b) Reading °C
Ambient	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Reduced	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Elevated	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________

Thermometer Calibration Method (Ambient Air Sensor)

Target Condition	Sampler (a) Reading °C	Transfer Standard (b) Reading °C	Difference (a-b) Reading °C
Ambient	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Reduced	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Elevated	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________

Thermocouple Calibration Method (Filter Temperature Sensor 1)

Target Condition	Sampler (a) Reading °C	Transfer Standard (b) Reading °C	Difference (a-b) Reading °C
Ambient	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Reduced	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________

Elevated	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________

Thermometer Calibration Method (Filter Temperature Sensor 1)

Target Condition	**Sampler (a) Reading °C**	**Transfer Standard (b) Reading °C**	**Difference (a-b) Reading °C**
Ambient	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Reduced	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Elevated	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________

Thermocouple Calibration Method (Filter Temperature Sensor 2)

Target Condition	Sampler (a) Reading °C	Transfer Standard (b) Reading °C	Difference (a-b) Reading °C
Ambient	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Reduced	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Elevated	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________

Thermometer Calibration Method (Filter Temperature Sensor 2)

Target Condition	Sampler (a) Reading °C	Transfer Standard (b) Reading °C	Difference (a-b) Reading °C
Ambient	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Reduced	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Elevated	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________

Laboratory 3, Experiment 2: Temperature Calibration Data Sheet

$PM_{2.5}$ Sampler Manufacturer ________________ Name ______________
Model Number ________________ Date ______________
Group no. ____________

Thermocouple Calib. Std. Make/Model ________________________________
Thermometer Calib. Std. Make/Model ________________________________

Thermocouple Calibration Method (Ambient Air Sensor)

Target Condition	Sampler (a) Reading °C	Transfer Standard (b) Reading °C	Difference (a-b) Reading °C
Ambient	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________
Reduced	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________
Elevated	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________

Thermometer Calibration Method (Ambient Air Sensor)

Target Condition	Sampler (a) Reading °C	Transfer Standard (b) Reading °C	Difference (a-b) Reading °C
Ambient	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________
Reduced	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________
Elevated	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________

Thermocouple Calibration Method (Filter Temperature Sensor 1)

Target Condition	Sampler (a) Reading °C	Transfer Standard (b) Reading °C	Difference (a-b) Reading °C
Ambient	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________
Reduced	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________	1. 2. 3. 4. 5. Average ________

Elevated	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________

Thermometer Calibration Method (Filter Temperature Sensor 1)

Target Condition	Sampler (a) Reading °C	Transfer Standard (b) Reading °C	Difference (a-b) Reading °C
Ambient	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Reduced	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Elevated	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________

Thermocouple Calibration Method (Filter Temperature Sensor 2)

Target Condition	Sampler (a) Reading °C	Transfer Standard (b) Reading °C	Difference (a-b) Reading °C
Ambient	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Reduced	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Elevated	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________

Thermometer Calibration Method (Filter Temperature Sensor 2)

Target Condition	Sampler (a) Reading °C	Transfer Standard (b) Reading °C	Difference (a-b) Reading °C
Ambient	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Reduced	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________
Elevated	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________	1. 2. 3. 4. 5. Average __________

3.4 Experiment 3: Barometric Pressure Sensor Calibration

Introduction

Each reference or Class I equivalent $PM_{2.5}$ sampler must have a built-in atmospheric pressure sensor whose output is processed to control the sampling flow rate to the design value of 16.7 L/min under actual ambient temperature and pressure conditions. The sampler must have the capability to measure the barometric pressure of the air surrounding the sampler over a range of 600 to 800 mm Hg. The pressure calibration equipment required to conduct the pressure calibration include the following:

- A NIST-traceable barometer with a range of at least 500 to 900 mm Hg absolute. The device should have a readability of 1 mm Hg and an accuracy of $\pm 5\,\text{mm Hg}$.
- A method to change the pressure applied to the $PM_{2.5}$ sampler and the pressure measurement device. Syringes and lab hand pumps are two methods of generating the pressure range of 500 to 900 mm Hg absolute.
- A tee ("T") connection between the $PM_{2.5}$ sampler, the pressure measurement device, and the pressure changing device.
- Appropriate tubing to connect the various devices.
- Tubing clamp or hemostat (required for some systems).

The specific steps to follow in calibrating $PM_{2.5}$ sampler barometric sensors are contained in the manufacturer's operator's instruction manual and must be followed. The generic procedure for performing the multipoint pressure calibration includes calibration at three target pressures: ambient, reduced, and elevated.

Barometric Pressure Multipoint Calibration

(**Note:** Some devices will only require a single-point calibration – refer to the sampler's instruction manual for details.)

1. From the pressure calibration screen read the sampler barometric pressure reading and compare it to the NIST-traceable barometer. Adjust the "OFFSET" port or the other appropriate control specific to the sampler until they agree. (Note: On some systems this first step is omitted. On another system the ambient pressure calibration is the only calibration conducted and consists of determining the ambient pressure with the NIST barometer and entering the measured pressure in the pressure sensor calibration screen.)

2. Remove the existing tubing attached to the pressure port and attach another piece of the rubber or plastic hose to the port.
3. Attach a "T" adapter to the other end of the hose. Using additional pieces of tubing, attach one end of the "T" to the NIST-traceable portable barometer's pressure inlet fitting. Attach a gas-tight syringe or hand pump to the other end of the "T" and draw back on the plunger to apply a light suction until the NIST-traceable barometer reads approximately 100 mm Hg below ambient pressure for the low pressure target (for example, 660 mm Hg if the ambient pressure is 760 mm Hg). Some systems require clamping of the hose with a tubing clamp or hemostat to prevent leakage and to maintain a constant pressure.
4. Observe the displayed value on the pressure calibration screen of the sampler. It should agree with the value displayed by the NIST-traceable barometer within 10 mm Hg. If it does not agree, adjust the "GAIN" or other appropriate control until they do agree within 10 mm Hg or better. (After making a gain adjustment, the "OFFSET" may require readjustment.) Record the pressure and "GAIN" settings on your data sheet. (On some systems the sampler calibration menu requests the operator to enter the target pressure input first and then prompts the operator to carefully adjust the pressure measurement device to the target value. In this situation no supplemental adjustment of the "GAIN" is made.)
5. Remove the tubing and syringe and read the ambient pressure on the NIST-traceable barometer and the sampler's barometer. The two readings should agree within 10 mm Hg. Repeat steps 1 through 5 until the sampler agrees within 10 mm Hg pressure with the NIST-traceable barometer at both target pressures (ambient and reduced pressure). Record both readings on your data sheet.
6. Reinstall the tubing and syringe and push the plunger of the syringe or hand pump to provide a pressure about 30 to 100 mm Hg higher than the ambient pressure. Record the values shown by the NIST-traceable barometer and the sampler on your data sheet. The calibration is complete when the sampler and standard barometer readings agree within 10 mm Hg for the three target pressures.

Laboratory 3, Experiment 3: Barometric Pressure Multipoint Calibration Data Sheet

$PM_{2.5}$ Sampler Manufacturer ___________________ Name __________________
Model Number ____________________ Date ___________________
Calibration Standard Make/Model _______________________________

Target Condition	(a) Sampler Reading (mm Hg)	(b) Transfer Standard Reading (mm Hg)	(a-b) Difference Reading (mm Hg)
Ambient	1. 2. 3. 4.	1. 2. 3. 4.	1. 2. 3. 4.
Reduced	1. 2. 3. 4.	1. 2. 3. 4.	1. 2. 3. 4.
Elevated	1. 2. 3. 4.	1. 2. 3. 4.	1. 2. 3. 4.

Laboratory 3, Experiment 3: Barometric Pressure Multipoint Calibration Data Sheet

$PM_{2.5}$ Sampler Manufacturer ____________________ Name ___________________
Model Number _____________________ Date ____________________
Calibration Standard Make/Model _________________________________

Target Condition	(a) Sampler Reading (mm Hg)	(b) Transfer Standard Reading (mm Hg)	(a-b) Difference Reading (mm Hg)
Ambient	1. 2. 3. 4.	1. 2. 3. 4.	1. 2. 3. 4.
Reduced	1. 2. 3. 4.	1. 2. 3. 4.	1. 2. 3. 4.
Elevated	1. 2. 3. 4.	1. 2. 3. 4.	1. 2. 3. 4.

3.5 Experiment 4: Flow Measurement System Calibration

Introduction

A reference or Class I equivalent $PM_{2.5}$ sampler consists of a specially designed sample air inlet, a size-fractioning impactor or cyclone, and a sample flow rate control system. In order to perform as a $PM_{2.5}$ sampler, strict adherence to specific internal air velocities must be maintained since the particle size discrimination characteristics of both the inlet and the impactor are critically dependent on the specific internal air velocities.

In order to control the size-fractioning cutpoints and to accurately measure the total volume, the sampler's flow rate must be maintained at a constant value that is within $\pm 2\%$ of the design flow rate of 16.67 L/min. Consequently, a multipoint calibration of the flow rate measurement system must be conducted at the time of initial installation of the sampler and annually thereafter, as well as upon failure to meet a flow rate verification check of the $\pm 5\%$ tolerance agreement criteria.

Before conducting the flow rate calibration however, the sampler must pass the checks for external and internal leaks, as well as satisfy the temperature and pressure calibration criteria. A multipoint calibration should consist of three separate flow rate measurements evenly spaced over the range of -10% to +10% of the sampler's operational flow rate of 16.67 L/min. Typically, and for this laboratory exercise, the three calibration flow rates will be 15.00, 16.67, and 18.33 L/min.

The following items are required to conduct the flow measurement calibration:

- A flow rate transfer standard (examples include a dry-piston flowmeter; an orifice device with an accurate differential pressure measurement instrument such as a digital manometer or an aneroid differential pressure gauge; and a dry gas meter).
- A second flow rate transfer standard that will be used to verify that the calibrated sampler is operating within $\pm 4\%$ of the design flow rate of 16.67 L/min.

  (Optional part of the laboratory exercise.)
- Flow rate multipoint verification/calibration data sheet.

The specific steps to follow in calibrating the flow measurement system of the $PM_{2.5}$ sampler are contained in the manufacturer's operator's instruction manual and must be followed. The generic procedure for performing the multipoint pressure calibration includes calibration at three flow rates.

Flow Rate Multipoint Calibration

1. Before conducting the flow rate calibration, be sure to check the accuracy of the sampler's temperature and pressure readings. If they are not within acceptance criteria, calibrate the sensors.
2. Install a filter cassette with a clean 46.2 mm filter in the sampler. Allow the sampler to warm up for 10 or 15 minutes and check the flow rate display to assess stability.
3. Remove the sampler inlet. Attach a flow adapter device to the downtube if the flow transfer standard (calibration device) requires it. (Some flow transfer standards such as an orifice can be attached directly to the downtube.)
4. Attach the flow rate calibration device to the flow rate adapter, making sure the valve in the flow rate adapter is in the open position.
5. Place the sampler in the calibration mode according to the instructions in the operations manual used in this exercise.
6. Follow the specific calibration instructions contained in the operations manual.
7. Enter the flow rate readings of the sampler, the transfer standard, and the percent difference between the two on your data sheet.
8. Reverify the flow rate with the manufacturer's design flow rate and enter results on your data sheet.

Laboratory 3, Experiment 4: Flow Rate Multipoint Calibration Data Sheet

$PM_{2.5}$ Sampler Manufacturer ___________________ Name _________________
Model Number ____________________ Date ___________________
Flow Rate Calibration Standard Make/Model _______________________________

Target Condition	(a) Sampler Reading (L/min)	(b) Transfer Standard Reading (mm Hg)	(a-b) Difference Reading (mm Hg)
Design Flow Rate (DFR) (16.67 L/min)	1. 2. 3.	1. 2. 3.	1. 2. 3.
DFR -10%	1. 2. 3.	1. 2. 3.	1. 2. 3.
DFR +10%	1. 2. 3.	1. 2. 3.	1. 2. 3.
Reverification DFR	1.	1.	1.

Laboratory 3, Experiment 4: Flow Rate Multipoint Calibration Data Sheet

$PM_{2.5}$ Sampler Manufacturer ____________________ Name ____________________
Model Number ____________________ Date ____________________
Flow Rate Calibration Standard Make/Model ________________________________

Target Condition	(a) Sampler Reading (L/min)	(b) Transfer Standard Reading (mm Hg)	(a-b) Difference Reading (mm Hg)
Design Flow Rate (DFR) (16.67 L/min)	1. 2. 3.	1. 2. 3.	1. 2. 3.
DFR -10%	1. 2. 3.	1. 2. 3.	1. 2. 3.
DFR +10%	1. 2. 3.	1. 2. 3.	1. 2. 3.
Reverification DFR	1.	1.	1.