TI 176A Calibration of Audit Devices using Spirometer

TABLE OF CONTENTS

LIST OF FORMS

LIST OF FIGURES

1.0 PURPOSE AND APPLICABILITY

This technical instruction document describes the procedures for calibrating the audit devices necessary for performing flow rate audits on an IMPROVE aerosol samplers. The calibration of the audit device is done by Air Quality Group personnel prior to and subsequent to flow rate audits at an IMPROVE sampling site. Each audit device is labeled so that its calibration can be tracked through time. All calibrations are stored on the computer network and in the field specialist's audit device files. The most current calibration equation for each audit device is written on a sticker which is pasted on the audit device gauge following the calibration procedure.

2.0 RESPONSIBILITIES

2.1 Field Specialist

The field specialist shall:

- Train field technicians in the use of the audit device calibration equipment.
- Approve and file the audit device calibration equation.
- Maintain an accurate database of audit device calibrations.

2.2 Field Technician

The field technician shall:

- Perform the calibration of the audit device
- Submit the derived calibration equation to the field specialist for approval

3.0 REQUIRED EQUIPMENT AND MATERIALS

The equipment required to calibrate and audit device includes the following:

a. Survey Spirometer, Collins, Catalog #06031, 8 Liter capacity, accuracy ±1%
    - Spirometer chart paper, Catalog #22035
    - Spirometer recording pens, Catalog #22413
    - Coupler, spirometer to vacuum line quick connect fitting, PVC
    - 1/4 NPT pipe extender
    - Female quick connect fitting with 1/4 NPT thread
    - Male quick connect fitting with 1/8" nipple
    - 1/8" I.D. hose, 2'
    - 1/4 NPT brass nipple
    - diaphragm pump,
    - brass elbow , 1/4 NPT to vacuum line
    - vacuum line compression fitting
    - vacuum line, 2’, Parker Parflex™ 3/8” O.D. x 0.062 wall, W.P. 300 PSI
    - brass coupler, male vacuum line to 1/4 NPT
    - valve, female 1/4 NPT
    - Swagelock™ 1/4 NPT to hose fitting
    - Swagelock™ hose line fitting
    - tygothane tubing, 1', 0.30” I.D., 0.40” O.D.
    - female quick connect
    - 1 leak checked IMPROVE cyclone, cover plate, and stack Tee assembly
    - 1 audit filter cassette, and three port plugs installed on the cyclone cover plate

b. 1 audit device (orifice meter) and calibration form

c. 1 calculator capable of linear regression

d. 1 audit filter cassette

4.0 METHODS

This technical note covers the methods for calibrating orifice meters using a spirometer as a standard. Section 4.1 covers the theory describing the behavior of orifice meters, while section 4.2 describes the procedures used to calibrate orifice meters against a spirometer.

4.1 Orifice Meter Theory

An orifice meter consists of a restriction in the air path and a device to measure the pressure drop across the restriction. Orifice meters in the IMPROVE network use magnehelics to measure the pressure drop. The audit devices consists of a magnehelic, tubing, and a probe that fits into the base of the inlet tee of the $PM_{2.5}$ (fine) sampling modules and at the base of the inlet stack in the PM_{10} (coarse) module. For the fine modules, the probe blocks the normal flow through the inlet, forcing all air entering the system to pass through the probe orifice. The probe and magnehelic, hereafter called the audit device, are calibrated at Davis using a spirometer.

The flow rate through an orifice meter, Q, depends on the pressure drop across the restriction, δP, and the square root of the density of the air:

$$Q = Q_1 \, (\delta P)^{\beta} \sqrt{\frac{P_o}{P}} \; \sqrt{\frac{T+273}{293}} \qquad \text{(TI176-1)}$$

where P is atmospheric pressure, T is temperature in °C, and Q_1, β, and P_o are constants. For laminar flow, $\beta = 0.5$. We express Equation TI176-1 in parameterized form using the magnehelic reading, M, for the pressure drop:

$$Q = 10^{a} \, M^{b} \sqrt{\frac{P(\text{sea level})}{P(\text{site})}} \; \sqrt{\frac{T+273}{293}} \; . \qquad \text{(TI176-2)}$$

We have arbitrarily defined all pressures relative to the standard pressure at sea level and all temperatures relative to 20°C. Thus, the parameters, a and b, are always calculated relative to 20°C and Davis. The value of b should be similar to that of β, around 0.5. The advantage in expressing the parameters relative to sea level is that all modules should have parameters with similar values independent of the site elevation.

Because of the difficulties in measuring the ambient pressure at each sample change, we have chosen to use an average pressure based on the elevation of the site. The pressure-elevation function is discussed in TI 176B.

The reference flow rate is provided by a spirometer located in the sampler laboratory at UCD. The spirometer measurements are verified by a dry gas meter monitoring the exhaust to the calibration pump. Taking the logs of Equation TI176-2, the flow rate equation for the audit device is

$$\log(Q) = a_o + \log\sqrt{\left(\frac{29.92}{P}\right)\left(\frac{T+273}{293}\right)} + b_o * \log(M_o) \ . \qquad \text{(TI176-3)}$$

The log of the meter reading, M_o, is regressed against the log of the flow rate for a set of four flow rates covering the normal range of the device. The constants relative to the nominal sea level pressure (29.92) and 20°C are calculated using

$$a_c = \text{intercept} - \log\sqrt{\left(\frac{29.92}{P}\right)\left(\frac{T+273}{293}\right)} \qquad b_o = \text{slope} \ . \qquad \text{(TI176-4)}$$

4.2 Calibration of an Orifice Meter Using the Spirometer

The audit device, or orifice meter, is used as the standard against which each module in the field is calibrated. The audit device is calibrated against a primary flow device, a spirometer, at the Air Quality Group Lab both prior to and following calibration at a site. The calibration equation for the orifice meter is printed on a sticker on the face of the magnehelic, along with the date of calibration and name of the technician responsible for the equation. A flow restricting device, a valve having a low pressure drop, is used to change the flow rate to develop the equation. The flow restricting device must be carefully checked for leaks once installed, as leaks could cause significant error in the calibration. Finally, a calculator for doing logs and linear regressions is required. Plotting capabilities on the calculator are useful, but not required. The form for calibrating an audit device is shown in Form 1.

FORM 1 Audit Device Calibration Form

Audit Device # _______________ Date of Calibration: ____/___/____
Time:_________

Temperature:____________°C Barometric Pressure:____________ "Hg

Calibrated by: _____________________________

Spirometer Flow Rate Q_S (L/min)	Audit Device Reading ΔP ("H_2O)	Calculated Audit Flow Rate Q_C (L/min)	Error in Flow Rate %

Regression Equation: r^2 = ______ $\log_{10}(Q_S)$ = ___________ + ___________$\log_{10}(\Delta P)$
(from first 2 columns) (intercept) (slope)

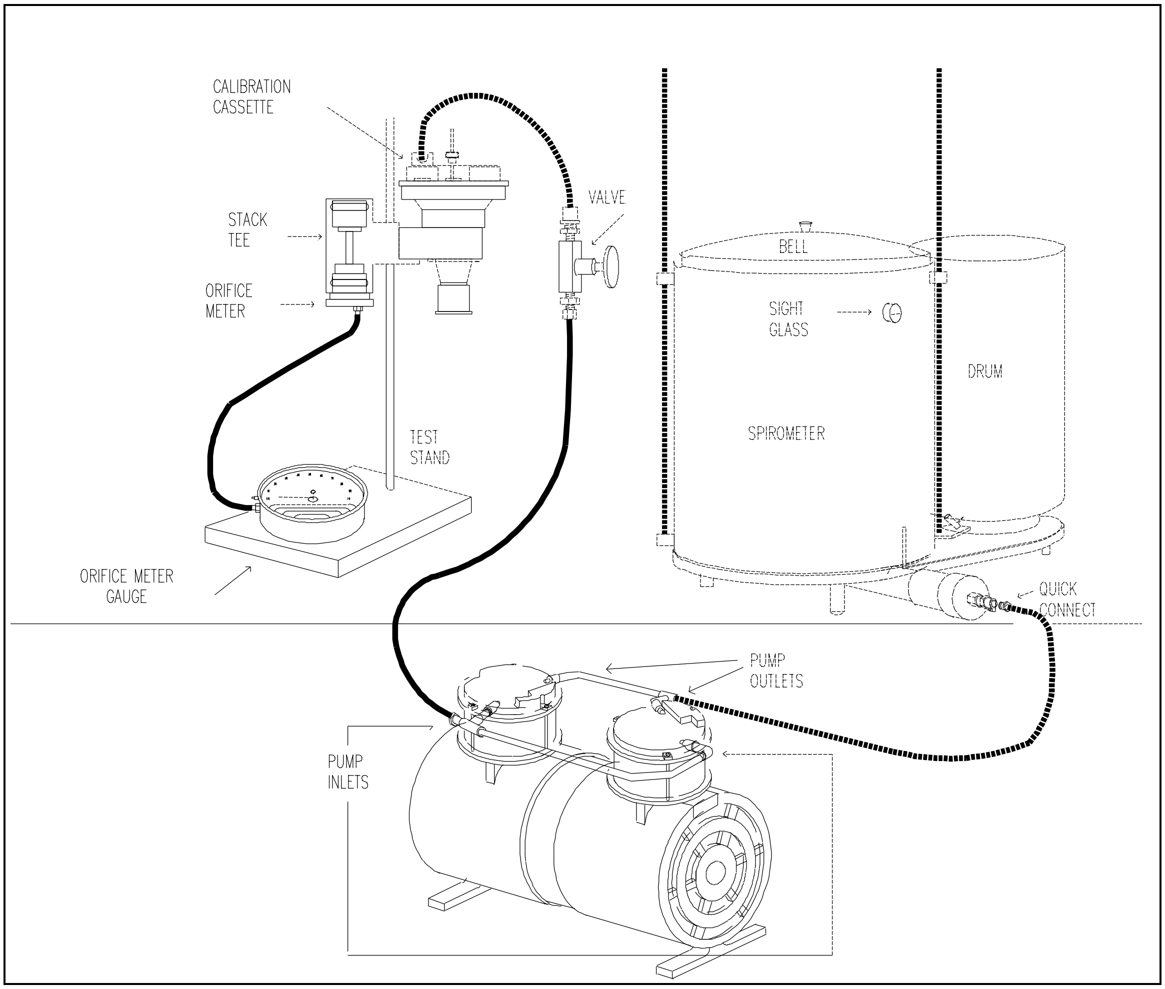
Calculate Audit Flow Rate for column 3: $Q_C = 10^{\text{intercept}} (\Delta P)^{\text{slope}}$

Calculate Constants for Audit Device relative to sea level and 20°C

$$a_c = \text{intercept} - \log_{10} \sqrt{\frac{29.9}{P} \frac{(T+273)}{293}} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

$$b_c = \text{slope} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

Figure 1 Audit Device Calibration System



1. Verify there is water in the sight glass on the spirometer. If not, refill the spirometer by pouring distilled, de-ionized water into the gap between the body and the plastic bell.
2. Verify no leaks have developed in the spirometer.
   a. Slowly lift the bell of the spirometer, pulling 3 to 5 liters of air into the system (the bell should be roughly half way to it's maximum inflation).
   b. While holding the bell in this position, insert the male quick connect plug, stored in a bag on the side of the spirometer, into the female quick connect fitting on the spirometer.
   c. Release the bell, remove the cap from the spirometer pen, and place the pen against the spirometer chart paper.
   d. Wait for 15 minutes.
   e. Remove the pen. If the mark left by the pen is only a dot or a horizontal line, there are no leaks and the system is ready for use.

    f. If the pen left a vertical mark, there is a leak in the spirometer or the plug. Verify the integrity of the plug, the spirometer coupler, etc. Then repeat the test.
    g. If the leak appears to be within the spirometer itself, inform the lab and field managers. If necessary, the unit will be shipped back to the factory for repair.
3. Remove the spirometer drum and attach a clean piece of chart paper, using a small amount of scotch tape.
4. Fill out the current temperature, pressure, calibration orifice meter identification number, and technician's name on the calibration log sheet.
5. Replace the filter and cassette on the testing manifold with a clean filter in a leak checked cassette.
6. Leak check the orifice meter calibration system.
    a. Install two stack bottom plugs on the stainless steel tee of the testing manifold.
    b. Plug the spirometer into power; the drum should begin to turn at a rate of one revolution every 15 seconds.
    c. Remove the cap from the recording pen.
    d. Turn on the spirometer pump.
    e. Connect the hose from the pump to the spirometer inlet, firmly pressing the quick connect fitting in place.
    f. Gently, flick the pen against the chart paper on the spinning drum to make a mark approximately 1" long, then flick it back, being careful to avoid putting any vertical pressure on the pen, as it rides on the measurement bell.
    g. Monitor the system for 8 revolutions of the drum (2 minutes), flicking the pen against the chart paper each revolution, making a vertical column of marks.
    h. After 8 revolutions, or if the spirometer rises so fast that the pen is making marks higher than halfway up the drum during this procedure, immediately disconnect the hose from the pump by pressing in on the quick connect latch and pulling outward.
    i. Unplug the spirometer from power. The drum will stop rotating.
    j. Measure the distance between each consecutive mark on the chart. Use the scale provided on the chart paper. This number, multiplied by four, gives the magnitude of any leaks in the system in liters of ambient air per minute. (For better accuracy, measure the distance between the first and eighth revolution marks and divide by two). The leak must be less than 0.1 Liters per minute to be acceptable.
    k. If the leak is unacceptably high, find and eliminate the leak, then repeat the testing procedure.
    l. If the leak is within acceptable limits, remove the two stack bottom plugs from the stainless steel tee on the testing manifold.
7. Insert the orifice meter probe into the stainless steel tee on the testing manifold. Both o-rings on the orifice meter probe should be inside the tee.
8. Plug the spirometer into power; the drum should begin to turn at a rate of one revolution every 15 seconds.
9. Remove the cap from the recording pen.
10. Turn on the spirometer pump.

11. Use the valve to adjust the flow to a reading of 1.0 " H_2O on the orifice meter magnehelic gauge.
12. Connect the hose from the pump to the spirometer inlet, firmly pressing the quick connect fitting in place.
13. Gently, flick the pen against the chart paper on the spinning drum to make a mark approximately 1" long, then flick it back, being careful to avoid putting any vertical pressure on the pen, as it rides on the measurement bell.
14. Monitor the system, flicking the pen against the chart paper after one revolution, to make a second mark in the same vertical column as the first.
15. Immediately disconnect the hose from the pump by pressing in on the quick connect latch and pulling outward.
16. Unplug the spirometer from power, and turn off the spirometer pump. The drum will stop rotating.
17. Measure the distance between the two marks on the chart. Use the scale provided on the chart paper. This number, multiplied by four, gives the flow rate through the orifice meter in liters of ambient air per minute. Record this number as the spirometer flow rate on the calibration sheet in the same row as the corresponding magnehelic reading.
18. Repeat steps 7 through 16 for magnehelic gauge readings of 0.8, 0.6, 0.4, and 0.2.
19. Using a scientific calculator, do a linear regression of the $\log_{10}$ of the spirometer flow versus the $\log_{10}$ of the magnehelic reading.
20. Record the slope, y intercept, and r^2 value in the spaces provided.
21. If the r^2 is not better than 0.990, the calibration is invalid. Repeat the orifice meter calibration procedure, beginning with step 1.
22. If the r^2 is better than 0.990, write out the equation, the date, technician initials, temperature, and r^2 value on a 3 7/16" x 9/16" file folder label, and paste it to the lower portion of the orifice meter magnehelic face plate.
23. Make a copy of the calibration sheet to store in the box with the orifice meter and corresponding magnehelic.
24. Give the original calibration sheet to the field manager for approval and filing.

4.3 Calibration of the Spirometer using a Dry Gas Meter

Due to the heavy usage of the spirometer for calibration of orifice meters, it was deemed necessary to check its accuracy against a different standard at regular intervals. The field manager runs the dry gas meter in series with the spirometer to verify the volume of air measured by the spirometer. This test is done at quarterly intervals and is reported only as good agreement (within 0.1 liters per minute) or poor agreement in the field managers notes. If there is poor agreement, the entire system is carefully leak checked and run again. If the agreement is still poor, one or both instruments are sent for servicing. The procedure for calibrating the spirometer against the dry gas meter is as follows:

1. Verify there is water in the sight glass on the spirometer. If not, refill the spirometer by pouring distilled, de-ionized water into the gap between the body and the plastic bell.

2. Remove the spirometer drum and attach a clean piece of chart paper, using a small amount of scotch tape.
3. Replace the filter and cassette on the testing manifold with a clean filter in a leak checked cassette.
4. Leak check the orifice meter calibration system, following the procedures delineated in step 5 of section 4.1.2.
5. Connect the free end of the 1 1/4" hose with an orifice meter probe to the outlet side of the dry gas meter.
6. Reset the dials on the face of the dry gas meter to readings of 0.
7. Insert the orifice meter probe into the stainless steel tee on the testing manifold. Both o-rings on the orifice meter probe should be inside the tee.
8. Plug the spirometer into power; the drum should begin to turn at a rate of one revolution every 15 seconds.
9. Remove the cap from the recording pen.
10. Turn on the spirometer pump.
11. Connect the hose from the pump to the spirometer inlet, firmly pressing the quick connect fitting in place.
12. Gently, flick the pen against the chart paper on the spinning drum to make a mark approximately 1" long, then flick it back, being careful to avoid putting any vertical pressure on the pen, as it rides on the measurement bell.
13. If the spirometer bell rises too fast to monitor a complete revolution of the drum;

a. immediately disconnect the hose from the pump by pressing in on the quick connect latch and pulling outward
b. close the valve on the testing manifold slightly to reduce the flow rate of air.
c. reset the dials on the face of the dry gas meter to readings of 0.
d. start again at step 11.

14. Monitor the system, flicking the pen against the chart paper after one revolution, to make a second mark in the same vertical column as the first.
15. Immediately disconnect the hose from the pump by pressing in on the quick connect latch and pulling outward.
16. Unplug the spirometer from power, and turn off the spirometer pump. The drum will stop rotating.
17. Measure the distance between the two marks on the chart. Use the scale provided on the chart paper. This number, multiplied by four, gives the flow rate through the orifice meter in liters of ambient air per minute. Compare this number to the value recorded on the dry gas meter dials. It should be within 0.1 liters. If not, repeat the test, checking more thoroughly for leaks. If the problem persists, maintenance by the manufacturer may be required.