DRI STANDARD OPERATING PROCEDURE

Performance Audit of Andersen Dichotomous Sampler

DRI SOP #4-103.2

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Title: Performance Audit of Andersen Dichotomous Sampler	Number:	4-103.2
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1.0 GENERAL DISCUSSION

1.1 Purpose of Procedure

This standard operating procedure is intended to provide the procedures for conducting a performance audit of the Andersen Dichotomous Sampler operated by Atmospheric Research and Analysis (ARA), Inc. at the Southeastern Aerosol Research Characterization (SEARCH) study sites.

This procedure will be followed by all audit personnel of the Division of Atmospheric Science of the Desert Research Institute.

1.2 Underlying Principles

The Andersen Dichotomous Sampler is a two channel sampler designed to collect 24-hour integrated samples of particulate matter in the PM_{10} and $PM_{2.5}$ size fractions for the analysis of mass, trace elements, and major ions. The inlet to the Dichotomous Sampler has a impactor with a 50% cutpoint of 10 µm to remove large particles. A virtual impactor separates the aerosol into a coarse fraction (particles with aerodynamic diameters of 2.5 to 10 µm) and a fine fraction (particles with aerodynamic diameters < 2.5 µm). Particles are collected on 37 mm diameter filter material. The sample on the coarse filter also contains 10% of the fine fraction. As operated in SEARCH, only the coarse filters are analyzed routinely. The fine filters are exposed for 3 to 6 sample periods and are only analyzed during special studies.

The performance audit consists of flow rate measurements at the inlet of the Dichotomous Sampler and through the two sample lines with an audit flow meter. These flows are converted to standard flow rate at 1 atmosphere and 25 °C and compared to the mass flow rate of the each Dichotomous Sampler channel. The ambient pressure is measured with a portable altimeter. The ambient temperature is measured with a portable thermocouple.

1.3 Method Interferences and Their Minimization

The audit flow meter has a pressure drop that may differ from the pressure drops in the sample line. The mass flow controller should be able to compensate for these differences. The air flow through a bubble type flow meter can have a slight reduction in temperature because of evaporation of water in the soap solution. In the humid Southeast, this reduction is slight. Temperature measurements can be affected by direct solar radiation. The thermometer and flow meter are shaded from direct insolation during the measurements.

1.4 Ranges and Typical Values of Measurements

The mass flow controllers maintain a fine flow rate of 15.03 sl/min and a coarse flow rate of 1.67 sl/min for a total flow rate of 16.7 sl/min. The ambient pressure ranges from 960 to 1020 mb at the SEARCH sites. The ambient temperature ranges from 10 to 40 °C.

1.5 Typical Lower Quantifiable Limits, Precision, and Accuracy

The accuracy of the audit flow meter is approximately ±2%. The accuracy of the pressure standard is ±2 mb. The accuracy of the temperature sensor is ±0.2 °C. The audit flow meter is checked with a NIST-traceable bubble flow meter. The pressure standard is compared to a Fortin-type mercury-in-glass barometer. The temperature standard is compared to a NIST-traceable mercury-in-glass thermometer in a water bath.

1.6 Personnel Responsibilities

The Field Auditors should read and understand the entire standard operating procedure prior to conducting a performance audit. Familiarity with the operation of the sampling equipment and the audit equipment is necessary for valid measurements. In addition the Field Auditor generates a preliminary report of the audit results at the time of the audit to be presented to the site operator.

It is the responsibility of the Audit Supervisor to ensure the audit procedures are properly followed, to examine and document all documentation, to arrange for maintenance and repair of audit equipment, to maintain the supplies necessary to insure uninterrupted measurements, and to generate a report summarizing the audit results.

1.7 Definitions

The following terms are used in this document:

Performance audit:	Comparison of instrument response to audit standards.
Audit standards:	Standards provided by auditor for comparison.

1.8 Related Procedures

DRI SOP #4-208.1: Calibration of Gilibrator Bubble Flow Meter
DRI SOP #4-209.1: Calibration of Pressure Transfer Standard
DRI SOP #4-210.1: Calibration of Temperature Transfer Standard

2.0 APPARATUS, INSTRUMENTATION, REAGENTS, AND FORMS

2.1 Apparatus and Instrumentation

2.1.1 Description

Audit flow meter: Gilibrator bubble meter, model H (2-30 lpm) with printer
Audit pressure sensor: Thommen altimeter
Audit temperature sensor: Fluke Thermocouple Model 52 K/J
Inlet adapters: Flow adaptor to 1¼ inch OD pipe
Tubing to connect adapter to Gilibrator
Audit filters for coarse and fine channels
Shade to cover Gilibrator to prevent stray light from activating sensor.

2.1.2 Instrument Characterization

2.1.3 Maintenance

Regular maintenance for the Gilibrator includes:

- Emptying bubble solution from reservoir after each day's use
- Cleaning reservoir annually
- Replacement of printer paper

2.1.4 Spare Parts and Supplies

Bubble solution, P/N 800450
Paper for printer, P/N A-400681

2.3 Forms and Paperwork

Audit form for the Dichotomous Sampler audit, paper copy, Figure 2-1.
Electronic copy of Dichotomous Sampler on portable computer that includes computation formulas.

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DICHOT SAMPLER AUDIT RECORD

REV 08/01

Sampling Network:
Auditor:
Operator:
Site Name:
Site ID:
AIRS #:
Date:
Start Time: EDT
End: EDT

Site Instrument Data:

Reference Method: NA

	Manufacturer	**Model Number**	**Serial Number**
Coarse Flow MFC:			
Fine Flow MFC:			
Sampler Head:			
Site Flow Meter:			

Slope:
Intercept:

Audit Instrument Information:

	Manufacturer	**Model Number**	**Serial Number**	**Cert. Date**
Flow Meter 1:				
Flow Meter 2:				
Barometer:				
Thermometer:				

FM1	Slope:	Intercept:	Corr.:
FM2	Slope:	Intercept:	Corr.:

Audit Results

	---------------------- Audit Flow				----------------------	----- Site Flow	-----	Deviation
	Pressure mmHg	Temp C/F	Qind LPM	Qcorr LPM	Qstd LPM	Qset LPM	Qind LPM	Qact % Dev.
Coarse S-flow meter								
							Average	
							Std Dev	
Fine H-flow meter								
							Average	
							Std Dev	
Total H-flow meter								
							Average	
							Std Dev	
Sum coarse and fine								
							Average	
							Std Dev	

Comments:

Figure 2-1: Blank Worksheet for Dichotomous Sampler Audit

3.0 CALIBRATION STANDARDS

3.1 Preparation, Ranges, and Traceability of Standards

The Gilibrator Bubble Flow Meter is calibrated with a Hastings Bubble flow meter, model HBM-1A, 1000 cm^3 tube, S/N 1476, that is NIST-traceable.

The Thommen altimeter is checked with a Fortin-type mercury-in-glass barometer. The barometer reading is corrected for temperature and altitude using corrections provided by the Smithsonian Meteorological Tables (List, 1951).

The Fluke thermocouple is calibrated at approximately 0 and 30 °C in a water bath using a Brooklyn Thermometer (29 – 31 °C) S/N 10772 NIST-traceable.

3.2 Use of Standards

The audit equipment are calibrated prior to the field audit. If questions arise as to audit results, the audit equipment are calibrated after the audit.

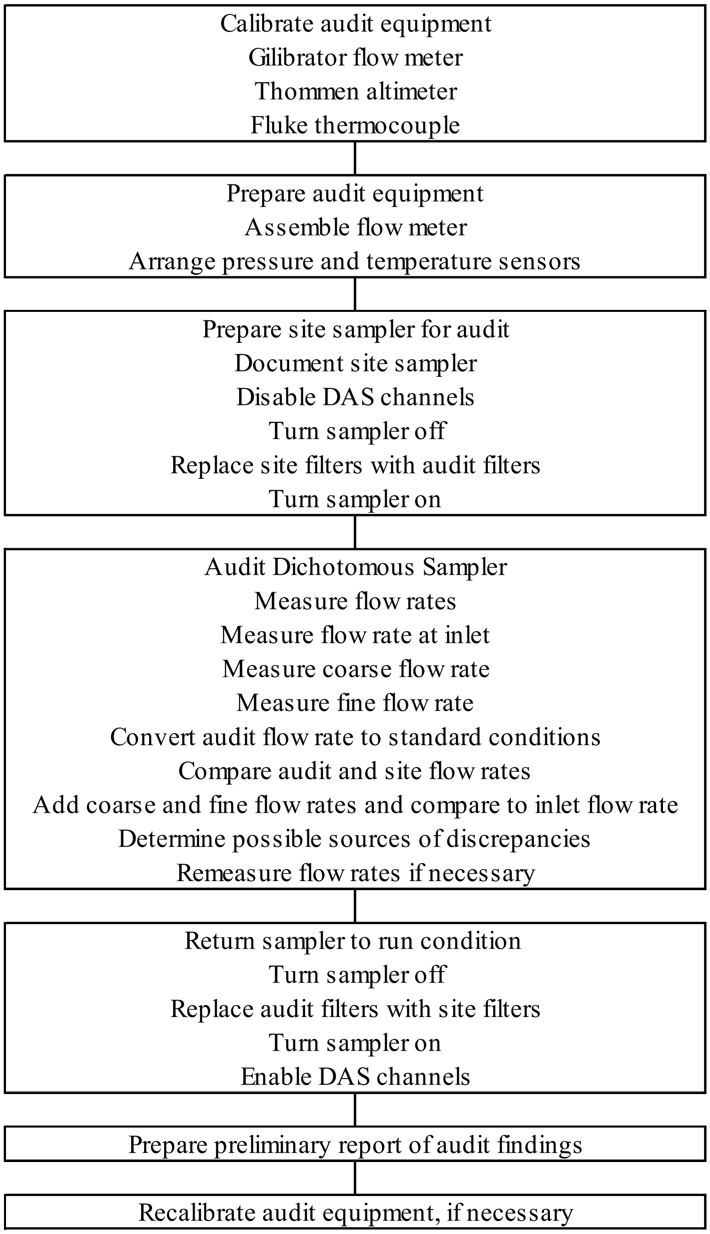
3.3 Typical Accuracy of Calibration Standards

The accuracy of the flow rates are ±2%. The accuracy of the pressure standard is ±1 mb. The accuracy of the temperature standard is ±0.01 °C.

4.0 PROCEDURES

4.1 General Flow Diagram

The typical flow of the audit procedures for the Dichotomous sampler is given in the following figure.



4.2 Audit Procedures

The following sections describe in detail the audit procedures for the Dichotomous Sampler. This section must be read and understood in its entirety before beginning audit. When all aspects of the analysis procedure are understood, the abbreviated checklist appearing in Section 4.3 may be used for reference.

4.2.1 Audit Equipment Preparation

1) Unpack Gilibrator size H flow cell and control unit.
2) Attach flow cell to control unit. Twist flow cell by turning base of cell, not top. Attach connector from control unit to back of flow cell.
3) The flow meter can operate on batteries for several hours. For longer periods of use, the control unit will have to be plugged into 110 VAC power with the transformer. The batteries should be kept charged when the flow meter is not in use, as the batteries will not charge sufficiently to operate if the batteries have been completely discharged. For long periods of use, the flow meter should be plugged into 110 VAC power. While the flow meter is not in use, the flow meter should be plugged into 110 VAC power with its power switch turned off.
4) Fill the reservoir of the flow cell with bubble solution by introducing the solution in the small solution bottle into the lower opening of the flow cell. The cell should be filled so that when the plunger ring is depressed, it comes in contact with the solution. The solution should not be as high as the opening to the base of the flow cell.
5) Before the flow meter can be used, the insides of the cell need to be wetted with bubble solution. An efficient way to do this is to attach a piece of ¼ inch Tygon tubing to the lower opening of the flow cell, i.e., the inlet, and blow gently into the tube while periodically depressing the plunger to release soap bubbles into the flow tube. Continue doing this until the bubbles reach the top of the flow cell. The flow tube may need to be wetted again if there is a long pause between measurements. Flow from the site instrument can also be used to wet the tube sides. In this case, the tube is attached to the upper opening of the flow cell, i.e., the outlet, and ambient air is pulled through the flow meter in the same way as it normally operates with repeated depressions of the plunger until soap bubbles reach the top of the flow cell.
6) When the Gilibrator flow meter is used out doors in direct sun light, the sensors on the flow cell cannot distinguish the passing of the bubble and so need to be protected from the light. A small card board box can be used to shade the flow meter. It should cover the flow cell and have one opening to access the plunger and a second opening to view the bubble. The box also serves as a shield to direct solar radiation that might change the temperature of the flow cell.
7) Plug the printer ribbon strip into the control box. The printer obtains its power from the control box. It also has its own power switch.
8) It is also necessary to measure the ambient pressure and temperature during the audit to convert the flow rate from the Gilibrator flow meter from ambient conditions to standard conditions. The altimeter can be placed nearby in a convenient location so that it can be read periodically. The probe of the temperature sensor should be placed

inside the box covering the flow meter near the flow cell. The meter for the temperature sensor should be placed at a location that can be read.

9) An adapter that slips over the 1¼ inch inlet pipe and connects to a ¼ inch tube on the other connects the flow meter to the site instrument through one or more pieces of tubing depending on the location of the flow meter and the location of the measurement. Plastic couplers are used to connect the pieces of tubing together.

4.2.2 Site Instrument Inspection and Preparation

1) Prepare audit forms or audit notebook by entering site name and date of audit.
2) Record serial numbers of instrument, mass flow controllers, and size selective inlet.
3) Disable the Dichotomous Sampler flow channels on data acquisition system (DAS). Record time that channels were disabled. Turn off sample pumps if sampler is operating.
4) If installed, remove sample filters from sampler and place in Petri dishes. The coarse filter is held with the ring with the larger knurls and is located directly below the inlet tube. Install audit filters. Take care to line the threads of the retaining rings properly when screwing them into the base of the virtual impactor. Turn pump on. Record site mass flow rate.

4.2.3 Instrument Audit

1) Remove PM_{10} inlet impactor by lifting off of inlet pipe. Inspect the exterior of the impactor for cleanliness and foreign material. It is not recommended at this time to dismantle the impactor to inspect the interior impaction plates.
2) Attach adapter to inlet. Attach other end of the tube to the outlet of the flow meter. Be careful that the tubing does not become kinked, particularly by the shade box.
3) Before turning the flow meter on, depress the plunger to see that the inside of the flow tube is wet. If not, depress the plunger several times until the inside is wet. Do not press the plunger too fast as this will generate multiple bubbles in the solution reservoir that interfere with the generation of single bubbles.
4) Turn on power switches on printer and control box. A header of 4 lines will be generated on the printer paper. The site, instrument, channel, measurement location and date should be noted on the printer paper.
5) Record instrument and measurement location on log sheet or in notebook.
6) Record pressure and temperature on log sheet or in notebook.
7) Bubbles are generated by pushing the plunger down. Bubbles may also be generated when the plunger is released. If this happens too fast, there will be 2 bubbles in the chamber at a time. The proper practice is to generate the first bubble by pushing the plunger down and holding until that bubble reaches the top of the cell, the shape of

the bubble is determined to be good, and the flow rate is near the expected value and then to generate the next bubble by releasing the plunger. As the amount of solution in the reservoir decreases, releasing the plunger will not always generate a bubble and so the generation of the second bubble needs to be confirmed. The state of the bubble also needs to be checked for each measurement. Sometimes multiple bubbles are generated if the solution reservoir is too full. Other times bubbles will form in the solution chamber and give odd shaped bubbles in the flow tube. Odd bubbles generally result in flow rates that are significantly different from the rest. These flow rates can be deleted from the calculation of the average flow rate by pressing the Delete key on the control unit before the next bubble is generated.

8) Depress and hold down plunger to generate the first bubble. There should be a single bubble and it should progress all the way to the top of the flow chamber. If the measurement is correct, a flow rate will be printed out that is approximately 16.7 lpm. Sometimes the first few bubbles do not work correctly and several bubbles are necessary before operations are correct. If necessary, reset the control unit output by pressing the Reset button or turning the power switch on the control unit off and on to start a new header and average flow measurement.
9) Generate 10 good flow measurements. Visually inspect the printer record of the 10 flow rate measurements. They should be within ±0.1 lpm of each other. If any of the measurements differ by more, the set of 10 measurements should be generated again. Record the average flow rate. Press Reset on the control unit to start the next average flow measurement. Record pressure and temperature. Record at least 2 more sets of 10 good flow measurements with pressure and temperature readings with each set. The flows measured with the Gilibrator flow meter tend to decrease 0.1 to 0.2 lpm from their initial value as more flow measurements are made. It may require 2 or 3 sets of 10 measurements before the flow rates equilibrate. The decrease in flow rate may be due to a decrease in the temperature inside the flow meter as the soap solution evaporates. In the humid Southeast, the evaporation effect should only be slight.
10) For pressures near 1 atm (1013.25 mb, 760 mm Hg) and temperatures near 25 °C, the actual flow rate measured by the Gilibrator flow meter approximately equals the standard flow rate and can be compared directly to the site flow rate for an initial comparison. An audit flow rate of less than 16 lpm or more than 1 lpm less than the site flow indicates a possible problem in the sample train. For a more precise comparison, convert the audit flow rates to standard conditions before comparing flow rates.
11) Disconnect the sample line directly downstream of the coarse filter holder. Attach the Gilibrator flow meter tubing to the sample tube. The nominal flow rate for the coarse sample is 1.67 lpm. Generate several sets of 10 measurements so that 3 consecutive sets have flow rates that are ±0.02 lpm of each other. Record the ambient pressure and temperature with each measurement set. Compute audit flow rate at

standard conditions. Compare the audit flow rate to the site mass flow rate. Reconnect tube to filter holder.

12) Disconnect the sample line directly downstream of the fine filter holder. Attach the Gilibrator flow meter tubing to the sample line tube. The nominal flow rate for the fine sample is 15.03 lpm. Generate several sets of 10 measurements so that 3 consecutive sets have flow rates that are ±0.02 lpm of each other. Record the ambient pressure and temperature with each measurement set. Compute audit flow rate at standard conditions. Compare the audit flow rate to the site mass flow rate. Reconnect tube to filter holder.
13) Add coarse and fine audit flow rates and compare to inlet flow rate and to sum of site flows. If the flow rate at the sampler inlet that is significantly lower than the sum of sample flow, there may be a leak some where in the sample line, most likely at the filter holder. All connections should be tightened and the inlet flow checked again.

4.2.4 Return Site Instrument to Sampling Mode

1) Turn pumps off. Replace inlet impactor. Replace sample filters.
2) Enable Dichotomous Sampler channels on DAS. Turn pump on if sample day was interrupted. Record time that Dichotomous Sampler was returned to operational status.
3) Check that the correct samples are operating.

4.2.5 Final Audit Procedures

1) Remove printer tape with flow rates for the audit from printer, fold, and place in envelop to save.
2) If no more flow measurements are to be made, disconnect printer from control unit and place in case. Disconnect cable from back of flow cell. Remove flow cell from control unit by twisting 90 degrees while holding onto base of cell. Pour bubble solution out of Gilibrator reservoir into large bubble solution bottle. Connect piece of tube between inlet and outlet of flow cell. Place flow cell and control unit in case.
3) Enter the average flow rates for at least 3 sets of audit flow rates and the associated pressure and temperatures and the site standard flow rates for each of the Dichotomous Sampler measurements into the electronic form. Calculate the average audit flow rates for the audit and site standard flow rates and calculate the differences and averages. Compare the differences of the flow rates to the audit criteria of ±5%.
4) Generate a preliminary report of audit findings that includes the differences between the audit and site standard flow rates. Problems should be identified.

4.3 Abbreviated Operational Checklist

1) Prepare audit equipment
    a) Assemble flow meter
    b) Arrange pressure and temperature sensors
2) Prepare site sampler for audit
    a) Document site sampler
    b) Disable DAS channels
    c) Turn sampler off
    d) Replace site filters with audit filters
    e) Turn sampler on
3) Measure flow rates
    a) Measure flow at inlet
    b) Measure coarse flow
    c) Measure fine flow
    d) Compare audit and site flow rates at inlet
    e) Compare audit and site flow rates for coarse and fine fractions
    f) Add coarse and fine flow rates and compare to inlet flow rate and to 16.7 slpm
    g) Determine possible sources of discrepancies and fix if possible
    h) Remeasure flow rates if necessary
4) Return sampler to run condition
    a) Turn sampler off
    b) Replace audit filter holders with site filter holders
    c) Turn sampler on
    d) Enable DAS channels

5.0 QUANTIFICATION

5.1 Calibration procedures

5.1.1 Gilibrator bubble flow meter

The Gilibrator Bubble Flow Meter is calibrated with a Hastings Bubble flow meter, model HBM-1A, 1000 cm^3 tube, S/N 1476, that is NIST-traceable.

1) Prepare Gilibrator for operations.
2) Connect outlet of Gilibrator to vacuum source (pump or laboratory vacuum) with valve between flow meter and vacuum.
3) Invert Hastings 1000 cm^3 tube and secure chain clamp to ring stand. Connect tube from tapered end of Hastings tube to inlet of Gilibrator. Tubing of different sizes will be necessary with reducing unions between. Place bubble solution in a small dish that is wider than the inlet to the Hastings. Bubbles are generated in the Hastings by quickly touching the bubble solution to the inlet of the inverted Hastings tube to pull a bubble into the tube.
4) Turn vacuum on and wet inside of the Hastings tube and the Gilibrator.
5) Set valve so that flow rate is approximately 24 lpm on the Gilibrator. Record ambient temperature and pressure. Generate bubble in the Hastings tube and measure time required to pass by several lines. The bubble may not be stable for the lowest line or two and may break before reaching the top line. A typical volume is 700 cm^3. Record time and volume. Repeat four times. Generate three sets of ten Gilibrator readings and record average values.
6) Repeat step 5) at flow rates near 20, 16, 12, and 8 lpm.
7) Calculate Hastings flow rates using $Q_{Hast} = V_{Hast}t$, where V_{Hast} is volume of time bubbles in liters and t is time in minutes. The Hastings flow rates do not need correction for water vapor pressure because the air entering the tube is at ambient conditions. The air entering the Gilibrator does need to be corrected for the water vapor added by the Hastings. The Gilibrator flow rate is corrected for water vapor by

$$Q_{Gil-cvp} = Q_{Gil}\left(\frac{p + p_v}{p}\right)$$

where $Q_{Gil\text{-}cvp}$ is average Gilibrator flow rate in lpm corrected for vapor pressure,
Q_{Gil} is average Gilibrator flow rate in lpm,
p is ambient pressure in mb or mm Hg, and
p_v is saturation vapor pressure in same units as p.

The saturation vapor pressure is found from the following expression given by Buck (1981):

$$p_v = \left(1.0007 + 3.46x10^{-6}\ p\right) 6.1121\ \mathbf{exp}\left(\frac{17.502\ T}{240.97 + T}\right)$$

where p$_v$ is saturation vapor pressure in mb,
p is ambient pressure in mb, and
T is ambient temperature in °C.

8) Generate a linear least squares fit using the Hastings flow rates as the x variable and the Gilibrator flow rates as the y variable to obtain

$$Q_{Gil-cvp} = MQ_{Hast} + B$$

where M and B are the slope and intercept from the least squares fit.

The corrected Gilibrator flow rate relative to the Hastings bubble meter is given by

$$Q_{Gil-corr} = \frac{\left(Q_{Gil-cvp} - B\right)}{M}$$

5.1.2 Thommen altimeter

The Thommen altimeter is checked with a Princo Fortin-type mercury-in-glass barometer. The barometer reading is corrected for temperature and altitude using corrections provided by the Smithsonian Meteorological Tables.

1) Place altimeter near Princo barometer. Gently tap altimeter and record reading.
2) Turn cistern adjustment screw at bottom of Princo barometer until white zero pointer in cistern just touches top of mercury.
3) Raise vernier above top of mercury meniscus and lower slowly until the front and back bottom edges of the vernier just appear to touch the top of the meniscus.
4) Read the millibar scale indicated by the vernier. The 1's, 10's and 100's places are given by the first line on the scale below the bottom of the vernier. The tenth's digit is given by the line on the vernier that aligns most closely with a scale line.
5) Read and record the temperature on the mercury-in-glass thermometer attached to the front of the Princo barometer.
6) Repeat steps 1) – 5) three times.
7) In Excel spreadsheet, "BARRCORR.XLS", for the next calibration, enter the Princo barometer and temperature readings and the altimeter reading. Duplicate calculations from previous calibrations to determine corrected barometer reading and difference between altimeter and Princo barometer.

8) If the altimeter reading differs from the corrected Princo barometer by more than ±3 mb, the altimeter should be adjusted. There is an adjustment small screw on the back side of the altimeter behind a small slider. Adjust and recheck against Princo barometer.
9) The following corrections are applied to the Princo barometer readings to correct for temperature, latitude, and altitude:

Temperature correction:

$$C_T = p_T - p_R = p_R\left(\frac{1+L(T-T_S)}{1+M(T-T_M)}-1\right)$$

where C_T is temperature correction,
p_T is pressure in mb corrected for temperature,
p_R is barometer pressure reading in mb,
L is coefficient of expansion for brass scale = 0.0000184 m/m°C,
T_S is standard temperature for brass expansion = 0 °C,
M is coefficient of expansion for mercury volume = 0.0001818 m^3/m^3°C,
T_M is standard temperature for mercury expansion = 0°C.

Altitude correction for gravity:

$$\begin{aligned} g_a = g &- [3.085462x10^{-4} + 2.27x10^{-7}\cos(2\varphi)]\,Z \\ &+ [7.254x10^{-11} + 10x10^{-18}\cos(2\varphi)]\,Z^2 \\ &- [1.517x10^{-17} + 6x10^{-20}\cos(2\varphi)]\,Z^3 \end{aligned}$$

where g is gravity at a latitude of 45° and elevation of 0 meters (= 980.616 cm-s^{-2}),
φ is latitude, and
Z is altitude above sea level in meters.

Latitude correction for pressure:

$$C_G = p_L - p_T = p_T\left\{\frac{g_a}{980.665}\left[1-2.6373x10^{-3}\cos(2\varphi)+5.9x10^{-6}\cos(2\varphi)\right]-1\right\}$$

where C_G is correction for latitude,
p_L is pressure in mb corrected for latitude, altitude, and temperature,
p_T is pressure in mb corrected for temperature, and
980.665 is gravity for which correction tables were developed.

Final corrected barometer reading:

$$p_L = p_R + C_T + C_G$$

5.1.3 Fluke thermocouple

The Fluke thermocouple is calibrated at approximately 0 and 30 °C in a water bath using a Brooklyn Thermometer (29 – 31 °C) S/N 10772 NIST-traceable. The water bath can be in a small vacuum bottle for a single thermometer or in a temperature controlled bath if more thermometers are calibrated at the same time.

1) Fill bottle with cold water and chipped ice. Stir vigorously with a stirring rod – not with the Brooklyn thermometer. Check temperature of bath with the Fluke probe.
2) As the temperature approaches 0 °C, place Brooklyn thermometer in the bath. Continue stirring of the bath but at a reduced intensity. The height of the mercury in the Brooklyn will eventually decrease to the point that it be in the near zero scale of the thermometer. The thermometer should be at the 6 inch immersion depth during the stirring but needs to be lifted out of the water to read the near zero scale. Read and record the Brooklyn thermometer values to 0.01 °C and Fluke readings to 0.1 °C.
3) If the Fluke and Brooklyn thermometer readings differ by more than ±0.2 °C, turn the Fluke adjust screw to bring the readings into agreement. Both channels of the Fluke should be checked with either the same probe or with a second probes if available.
4) Fill the vacuum bottle with water that is near 31 °C. Place Brooklyn thermometer and Fluke probe into water.
5) Hold Brooklyn thermometer and Fluke probe side-by-side with the end of the Fluke probe near the end of the bulb of the Brooklyn thermometer.
6) Gently stir water so that it is well-mixed. Be careful not to hit the side of the vacuum bottle with the thermometer.
7) Raise thermometer until the 6 inch immersion line is at top of water and read and record thermometer value to 0.01 °C and read and record Fluke reading to 0.1 °C.
8) Repeat stirring and reading values for at least 3 sets of readings as the temperature of the water in the vacuum bottle gradually decreases.
9) Average the differences between the Fluke probe and Brooklyn thermometer readings near 0 °C and near 30 °C. Add differences to 0 and 30 °C, respectively, to obtain Fluke probe responses to temperatures at 0 and 30 °C. Generate a linear fit to the Fluke and Brooklyn readings to obtain the following expression for the corrected Fluke reading:

$$CorrFluke = \frac{30}{(30 + \Delta_{30} - \Delta_0)}\left(Fluke - \Delta_{30}\right)$$

where CorrFluke represents the corrected Fluke temperature reading in °C,
Fluke represents the Fluke temperature reading in °C,
Δ_{30} is the difference between the Fluke and Brooklyn readings near 30 °C,

Δ_0 is the difference between the Fluke and Brooklyn readings near 0 °C.

5.2 Calculations

5.2.1 Standard Flow Rate Calculations

During the operation of the Gilibrator flow meter, ambient air is pulled into the flow meter where it passes over the solution of water and soap. Water vapor is added to the air as evaporation occurs in the vicinity of the solution. This water vapor slightly increases the volume passing through the Gilibrator to the mass flow controller. Since the Gilibrator and the mass flow meter both are exposed to the same water vapor-laden volume, the volume measured by the Gilibrator does not have to be corrected for the additional volume.

The audit flow meter measures flow rate at ambient conditions while the flow rate through the instrument is maintained at standard conditions (pressure of 1 atm and temperature of 25 °C) by a mass flow controller. The audit flow rates are converted to standard conditions for comparison to the site flows. The conversion of flow rate at ambient condition, Q_{Act}, to flow rate at standard conditions, Q_{Std}, follows the ideal gas law:

$$Q_{Std} = Q_{Amb}\left(\frac{p_{Amb}}{p_{Std}}\right)\left(\frac{T_{Std}}{T_{Amb}}\right)$$

where Q_{Act} is the flow rate measured by the audit flow meter in l/min,
Q_{Std} is the audit flow rate at standard conditions in sl/min,
p_{Amb} is the ambient pressure in the same units as p_{Std},
T_{Amb} is the ambient temperature in °K (°K = °C + 273.15),
p_{Std} is the standard pressure (1 atm, 1013.25 mb, 760 mm Hg), and
T_{Std} is the standard temperature, 298.15 °K(25 °C).

5.2.2 Differences between Instrument and Audit Measurements

The results of the audit are quantified by comparing the displayed instrument values to the audit measurements for those quantities. The comparison includes the computation of the difference and the percent difference between the instrument values and the audit values. The difference and percent differences are computed from the following expressions:

$$\mathit{Difference} = \mathit{Instrument} - \mathit{Audit}$$

$$\%\ \mathit{Difference} = \left(\frac{\mathit{Instrument} - \mathit{Audit}}{\mathit{Audit}}\right)100$$

where Instrument represents the value of the audited quantity displayed by the instrument or DAS and

Audit represents the measurement of the audited quantity with the audit equipment.

5.3 Data Acquisition

Data acquisition is done manually by entering audit flow rates, ambient pressures, ambient temperatures, and site flow rates on log sheets or in a notebook. The average of audit flow rates for the individual measurements is computed by the Gilibrator control unit and printed as the data are collected. Processing of the audit and site data is done in an Excel spreadsheet.

6.0 QUALITY CONTROL

Quality control is maintained by periodic calibration of audit transfer standards with laboratory standards that are traceable to the National Institute of Standards and Technology. Calibrations are performed on at least an annual basis and before a major audit trip. Calibrations may also be performed following an audit trip if major discrepancies arose between the audit standards and the audited equipment.

7.0 REFERENCES

Buck, A.L. (1981). New equations for computing vapor pressure and enhancement factor. *J. Appl. Meteor.*, **20**, 1527-1532.

List, Robert .J. (1951). “Smithsonian Meteorological Tables 6th Revised Edition.” Vol. 114, Smithsonian Institution, Washington, DC, 527 pp.