Air Pollution Control Division

Technical Services Program

APPENDIX PM7

Standard Operating Procedure for the Operation of the TAPI Model 633 Aethalometer

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TALBE OF CONTENTS

TABLES

FIGURES

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Standard Operating Procedure for the Determination of Black Carbon in Ambient Air

SCOPE AND APPLICABILITY

The Model 633 represents the "Next Generation" version of the real-time Aethalometer to measure Black Carbon (BC) particles in ambient air. Please refer to the original Magee Scientific Aethalometer manual for a full description and background information on the method.

Introduction

The Model 633 Aethalometer® instrument uses the principles of aerosol light absorption to measure Black Carbon (light absorbing) mass concentration. The measurement is done using an assumed aerosol cross sectional absorption coefficient from the raw light absorption measurements. The aerosol light absorption coefficient that is applied in the Aethalometer® instrument is a function of the filter media being used to collect the sample, and is dependent on the incident LED wavelength (λ). The Model 633 Aethalometer® uses a 7-wavelength (370, 470, 525, 590, 660, 880, and 940nm) light source, internal mass flow meters, and Teflon coated glass fiber filter tape. The Model 633 measures the attenuation of light at different wavelengths on two parallel spots drawn from the same input stream, but collected at different rates of accumulation. By combining the data from the two spots the Model 633 yields the value of BC extrapolated back to 'zero loading'; as well as a real-time output of the 'loading compensation parameter' (k) which provides insights into the aerosol nature and composition. This process is performed in real time for all wavelengths: examination of the 'k' values as a function of wavelength provides further information about the aerosol composition.

Method Overview

A sample of ambient air continually passes through a filter tape which collects the suspended particulates, creating a deposit of increasing density. A light beam projected through the deposit is attenuated by those particles which are absorbing ('black') rather than scattering ('white'). Measurements are made at successive regular time intervals. The increase in attenuation from one measurement to the next is proportional to the increase in the density of optically absorbing material on the filter: which, in turn, is proportional to the concentration of the material in the sampled air stream. The sample is collected as a spot on a roll of filter tape. When the density of the deposit spot reaches a pre-set limit, the tape advances to a fresh spot and the measurements continue. Measurement of the sample flow rate permits a calculation of the average concentration of absorbing particles in the gas stream during the sampling period. Aethalometers may operate on time-base periods as rapid as 1 second, providing quasi-real-time data. The TAPI 633 Aethalometer® reports BC concentrations at seven different wavelengths: 370, 470, 525, 590, 660, 880 and 940 nm and two time-base periods, 1s and 60s.

Format and Purpose

The sequence of topics covered in this SOP follows 2007 EPA guidance on preparing standard operating procedures (SOPs). This method was also written to help field operators understand why (not just how) key procedures are performed (US EPA, 2007).

SUMMARY OF DETECTION METHOD

The light attenuation (ATN) due to BC through an exposed section of a filter spot is defined as:

$$\boldsymbol{ATN = \ln\left(\frac{I_0}{I}\right)}$$

Where I_0 is the intensity of light passing through an unexposed portion of the filter and I is the intensity passing through the loaded filter. The particles embedded in the filter during a time interval, Δt, will increase attenuation so that the nth measure of the aerosol attenuation coefficient ($b_{ATN,n}$) of the sampled aerosol particles at any wavelength λ is obtained from:

$$\boldsymbol{b_{ATN,n}(\lambda)} = \frac{ATN_n(\lambda) - ATN_{n-1}(\lambda)}{\Delta t} \cdot \frac{\mathbf{A}}{\mathbf{V}}$$

Where
A = the cross sectional area of the sample spot
V = volumetric flow rate

The instrument then calculates the 'absorption coefficient' (b_{abs}) as:

$$b_{abs} = \frac{b_{atn}}{C}$$

Where C is a 'multiple scattering parameter'.

The instrument then calculates the measured BC concentration (BC_{meas}):

$$BC_{meas} = \frac{b_{abs}}{\sigma_{air}}$$

Where σ_{air} is the mass absorption cross section.

Finally a spot loading effect adjusted BC can be calculated by:

$$BC_{adj} = \frac{BC_{meas}}{(1 - k_\lambda * ATN)}$$

Where k_λ is the wavelength specific loading correction factor.

DEFINITIONS

The CDPHE/APCD/TSP QAPP contains an appendix of acronyms and definitions. Any commonly used shorthand designations for items such as the sponsoring organization, monitoring site, and the geographical area will be defined and included in this SOP or in the QAPP Appendix P2.

HEALTH AND SAFETY WARNINGS

Chemical Hazards:

Gas Hazards

Electrical Hazards

1. Always use a third ground wire on all instruments.

2. If it is necessary to work inside an analyzer while it is in operation, use extreme caution to avoid contact with high voltage inside the analyzer. The analyzer has high voltages in certain parts of the circuitry, including a 110 volt AC power supply. Refer to the manufacturer's instruction manual and know the precise locations of these components before working on the instrument

3. Avoid electrical contact with jewelry. Remove rings, watches, bracelets, and necklaces to prevent electrical burns.

4. Always unplug the analyzer whenever possible when servicing or replacing parts.

Physical Hazards

1. The TAPI Model 633 light source contains a light emitting diode (LED) radiating UV and visible light. Precautions must be taken to prevent looking directly at the UV light with unprotected eyes. NEVER touch or look directly into the Model 633 light source.

CAUTIONS

To prevent damage to the equipment, the following precautions should be taken:

1. In the event that it is necessary to clean the optical bench, be careful to avoid damaging the interior of the sample chamber. In addition, some instruments have a series of mirrors that deflect the light in order to increase the path length. The mirrors are aligned at the factory. If the mirrors become misaligned, the IR light beam will not be directed to the detector. Use extreme caution when cleaning or servicing the sample chamber(s). In addition, the mirrors are very fragile. Avoid dropping the instrument. This may damage, misalign or crack the mirrors and cause expensive repairs. Clean the optical bench carefully to avoid damaging the interior of the bench, cleaning should be performed only if needed. Use cleaning procedures outlined in the manufacturer's instruction manual. Avoid touching the mirrors unless cleaning is absolutely necessary.

2. Keep the interior of the analyzer clean.

3. Inspect the system regularly for structural integrity.

4. To prevent major problems with leaks, make sure that all sampling lines are reconnected after required checks and before leaving the site.

5. Inspect tubing for cracks and leaks.

6. It is recommended that the analyzer be leak checked after replacement of any part of the sampling train.

INTERFERENCES

All real-time Aethalometers exhibit a common interference, in which the incremental instrumental response factor shows a dependence on the sample loading on the filter. The Model 633 Aethalometer uses the patented DualSpot™ method to compensate for the 'spot loading effect' The 'spot loading effect' is a variable phenomenon which appears as a gradual reduction of instrumental response as the aerosol deposit density of the filter tape increases from zero to the predetermined limit of 'Maximum Attenuation'. When the filter tape advances to a fresh spot, the data undergoes a discontinuous jump from its previous lower value, calculated when the spot was heavily loaded; to a higher value, calculated from collection on a fresh spot at zero loading. In the Aethalometer the reduction of data at increasing loadings is well described by a linear function of attenuation, but its magnitude cannot be predicted: some aerosols in some locations in some seasons may show a small or zero 'loading effect'; while under other conditions, the effect may be larger and noticeable. Empirically, it is found that fresher aerosols closer to their combustion sources will show a larger 'spot loading effect'; while well-aged aerosols under atmospheric conditions of chemical reactivity may show an almost zero effect. The effect is revealed statistically by processing data collected over a large number of tape advances, representing many data points collected at loadings ('ATN values') ranging from zero to the preset maximum. The data is collected into bins according to ATN. If there is a systematic reduction of the calculated result as a function of loading, the data will show a clear negative slope, with the intercept representing the 'zero loading' value. Any method intended to compensate for the 'spot loading effect' must be auto-adaptive and able to adjust dynamically to different situations. An instrument based on firmware with a fixed 'loading non-linearity' parameter will not operate correctly at all locations, this parameter must be measured. It is clear that the effect, when present, is linear with loading. This can be represented as:

$$\boldsymbol{BC(reported) = BC(zero\ loading) * (1 - \mathbf{k} * \mathbf{ATN})}$$

Where *BC(zero loading)* is the measured ambient BC value that would be obtained from a clean tape spot; and k is the 'loading compensation parameter'. The analysis of a large number of datasets from a wide variety of locations shows that this relationship is linear in all cases studied; but with different values of k. It is therefore possible to eliminate the 'loading effect' of k by making two simultaneous identical measurements BC_1 and BC_2 at different degrees of loading ATN_1 and ATN_2.

$$\boldsymbol{BC_1 = BC * (1 - \mathbf{k} * \mathbf{ATN_1})}$$
$$\boldsymbol{BC_2 = BC * (1 - \mathbf{k} * \mathbf{ATN_2})}$$

From these two linear equations we may calculate the 'loading compensation parameter' k; and the desired value of BC compensated back to zero loading, removing the attenuation-related response to the sample loading.

PERSONNEL QUALIFICATIONS

General Personnel Qualifications are discussed in the CDPHE/APCD/TSP QAPP main body.

APPARATUS AND MATERIALS

Monitoring Equipment

8.0.1 Analyzers

8.0.1.1 API 633 Aethalometer

8.0.2 Instrument Shelter

A shelter is required to protect the analyzer from precipitation and adverse weather conditions, maintain operating temperature, provides security and electrical power. The following are operation shelter temperature requirements for the SLAMS and NCore networks (US EPA, 2013) (US EPA, 2005).

SLAMs: 5-38 C (20-30 C preferred), evaluated on hourly averages at <± 2C Standard Deviation over 24 hours.

NCore: 20-30°C, evaluated on hourly averages, daily changes in hourly temperature should not exceed ±5 °C over a 24-hour period.

8.0.3 Data Acquisition System

The APCD employs three different models of onsite, data acquisition system equipment (DAS) in the operations of its air monitoring network. These are the ESC 8816 data logger, the ESC 8832 data logger, and the Agilaire 8872 data logger. The 8816 model is the oldest type of data logger in the network and is a predecessor to the 8832 and 8872 data loggers. The following are descriptions of these data loggers.

ESC 8816 Data Logger

The ESC Model 8816 Data System Controller is a microprocessor-based data acquisition system designed to acquire, process, store, report, and telemeter data in a multi-tasking environment. The 8816 is designed around an expansion bus that gives the user great flexibility in configuring the unit with a combination of analog and serial input and output (I/O) types.

For more details, refer to Appendix D1 of this QAPP, APCD's Datalogger & Central SOP or the individual operator manuals (Environmental Systems Corporation, 2001).

ESC 8832 Data Logger

The ESC Model 8832 Data System Controller is a microprocessor-based data acquisition system designed to acquire, process, store, report, and telemeter data in a multi-tasking environment. The 8832 is designed around an expansion bus that gives the user great flexibility in configuring the unit with almost any combination of input and output types. It is the successor to the 8816 data logger and is more robust in numerous areas. Of significance is expanded memory, faster processing speeds, faster communication speeds, remote Ethernet communications and polling and Modbus enabled communications with peripheral devices.

For more details, refer to Appendix D1 of this QAPP, APCD's Datalogger & Central SOP or the individual operator manuals (Environmental Systems Corporation, 2006).

Agilaire 8872 Data Logger

The Model 8872 is a Windows-based data logger, a departure from the earlier 8816 / 8832 embedded systems designs. The 8872 includes a number of hardware and software features to ensure that the device matches the field reliability of the 8832, while offering the convenience of a Windows-based platform and integration with Agilaire's AirVision software.

The core of the 8872 is a fan-less PC, typically equipped with 2 GB of RAM. The device can be equipped with a 160 GB standard hard drive or, more commonly, a 64 GB solid state flash drive (SSD). For all digital versions of the 8872, the remainder of the enclosure simply provides convenient universal serial bus (USB), serial, and VGA I/O connections in a standard 3U rack mount enclosure, a form factor similar to the 8816 / 8832 family. However, the 8872 also supports traditional analog/discrete I/O via a variety of internal I/O modules and a protection / connector board to provide familiar detachable terminal block connections to the back. The layout of the connections is designed to make the unit easy to use as a 'drop in' replacement for an 8816 or 8832. (Agilaire, 2013)

For more details, refer to Appendix D1 of this QAPP, APCD's Datalogger & Central SOP or the individual operator manuals.

8.0.4 Wiring, Tubing and Fittings

The instrument is supplied with several meters of black conductive sample line tubing designed to minimize electrostatic particle losses in the sampling system. When installing the sample line, try to avoid sharp bends or long horizontal runs with the sample tubing as either of these conditions can promote particle losses in the sample tube. Insulate the sample lines inside the instrument shelter and avoid exposing them to indoor air currents.

8.0.5 Spare Parts and Incidental Supplies

The following table offers the spare parts available from the instrument manufacturer. Refer to the Troubleshooting and Maintenance sections of the Instrument Manual for a complete description of the parts and their use.

Table 1: Model 633 Aethalometer Spare Parts List

Part #	Description
DU0000146	Filter Tape for 633
DU0000196	Flow calibration pad
TU0000034	Static dissipative inlet tubing (8-ft)
DU0000148	PM2.5 inlet at 5-lpm
KIT0000400	Inlet mounting kit
WR0000008	Power Cord
WR0000101	RS-232 Cable (6-ft)
WR0000258	RS-232 Null Modem adapter
FT0000338	3/8”-1/4” NPTF Reducer

Calibration Equipment

8.1.1 Flow Calibration

- Flow Transfer Standard (1.0 – 6.0 lpm)
- Digital Manometer (± 0.1 inH_2O)
- Ambient temperature sensor (± 0.1°C)
- Ambient pressure sensor (± 0.1 mmH_2O)

OPERATION AND MAINTENANCE

Logs and Forms

All actions at the site, scheduled and non-scheduled, are logged on forms. These forms are collected monthly, reviewed and filed together; three complete calendar years of forms are maintained by APCD. The intent of these forms is to be able to recreate events and actions taken well after the fact. The forms in routine use are:

1. MONTHLY VERIFICATION/MAINTENANCE REPORT FORM

Figure 1: Monthly Verification/Maintenance Form

COLORADO DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT

Air Pollution Control Division - Technical Services Program
API 633 Aethalometer Service/Maintenance Form

SITE/SAMPLER DATA — Site Visit

Site Name: I-25 Near Road Aeth Sampler Model: TAPI 633 Aeth Sampler S/N: 0

AQS ID: 08-031-0027

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Operator										
Date										
Time										
Vis. Insp										
INSPECTION										
Inst Condition										
Data Logger Check										
Tape Check OK?										
Chan1 Flow										
Status Code										

FTS S/N: Tetra Cal FTS m = n/a FTS b = n/a Therm. S/N: 0 Bar.S/N: 0

Four Week Instrument Verification

	Leak Rate			Ambient Pres.		Ambient Temp.			Three Point Flow Check Results					
				Inst.	Stnd.	Inst.	Stnd.	Flow						
Visit #	Ftape	Fpad	%	± 10 mmHg		± 4°C		Level	Fact	Fin	F1	& Diff	Fc	% Diff
								1						
								2						
								3						
								1						
								2						
								3						

Day	Time	Describe Action Due/Action Taken	Time On	Initials

TIME PERIOD: 02.01.16 to 02.29.16

LIST OF SCHEDULED EVENTS/ SCHEDULED DATES:

Scheduled Events: # 2 4-wk verification, 1st Stage Inlet Cleaning

SCHEDULED DATE: 02.01.16

Comments: **DOWNLOAD DATA FROM ANALYZER EVERY TWO WEEKS!!!**

General Operations

Routine Preventative Maintenance and Scheduled Activities

The Model 633 Aethalometer requires regular maintenance, system checks, and verifications. The manufacturer recommends these activities be performed according to the following schedule.

Table 2: Routine Service and Maintenance Activities

Item	Frequency
Instrument status check	Weekly
Verify time and date (if not set to update automatically)	Weekly
Inspect the sample line tubing	Monthly
Clean Cyclone	Monthly
Inspect optical chamber, clean if necessary	Monthly
Perform leak check	Monthly
Flow Verification, calibrate if necessary	Monthly
Install a new filter tape roll	As needed
Manual stability test	Every six months
Manual clean air test	Every six months
Clean optical head	Every six months
Change by-pass cartridge filter	Every six months
Calibrate tape sensor	When measurement chamber has been removed/replaced

Maintenance Procedures

9.3.1 Disable/Enable Analyzer in Data Logger

ESC 8816/ 8832

Disable analyzer data channel:

From the top level menu, to disable a data channel from reporting to the data logger, the user must:

1. Choose menu options **CDM** (**C Configuration Menu** > **D Configure (Data) Channels** > **M Disable/Mark Channel Offline)** to view the list of available channels.
2. From the keyboard, using the down arrow button, scroll to the target channel name and hit the **Enter** or **Return** key.
3. Next, hit the **Esc** (Escape) key twice to get back to top level menu.
4. Select menu option **DF** (**D Real-Time Display Menu** > **F Display Readings w/flags**) to ensure the proper machine was disabled. You should see the letter “D” within parenthesis and adjacent to the targeted channel indicating it has been disabled.

Enable analyzer data channel:

From the top level menu to enable the data channel to resume reporting to the data logger, the user must:

1. Choose menu options **CDE** (**C Configuration Menu** > **D Configure (Data) Channels** > **E Enable /Mark Channel Online)** to view the list of available channels.
2. From the keyboard, using the down arrow button, scroll to the target channel name, and hit the **Enter** or **Return** key.

3. If all machines/instruments and/or channels are already on line, the user will receive a message stating "No channels are offline" at the bottom left screen. Otherwise a list of channel names will appear.

4. Next, hit the **Esc** key twice to get back to the top level menu.

5. Select menu option **DF** (**D Real-Time Display Menu** > **F Display Readings w/flags**) to ensure the proper channel was enabled. You should see parenthesis adjacent to the targeted channel without the letter "D" inside indicating the machine/instrument channel is enabled and reporting to the data logger.

<u>Agilaire 8872</u>

Disable analyzer data channel:

1. After logging in to AirVision™, if the Site Node Logger Toolbox is not open, from the top level menu select the **Home** tab > **Utilities** > **Site Node Logger Toolbox** > then select the **Channels** tab.

2. Identify the channel to be disabled. At the right side of the form, under the "Disabled" heading, click on the row with the target channel name. This action will change the channel state from "False" to "True" indicating that it is now disabled and not reporting to the data logger.

Enable analyzer data channel:

1. After logging in to AirVision™, if the Site Node Logger Toolbox is not open, from the top level menu select the **Home** tab > **Utilities** > **Site Node Logger Toolbox** > then select the **Channels** tab.

2. Identify the channel name to be enabled. At the right side of the form, under the "Disabled" heading, click on the row with the target channel name. This action will change the channel state from "True" to "False" indicating that it is now enabled and will now report to the data logger.

9.3.2 Instrument Status Check

The instrument's current status condition is displayed in decimal format on the front panel HOME screen and in the Status column of the data download. The status condition relates to various subcomponents of the instrument, e.g., Detector, Flow, LED, etc. The decimal number represents a sum of all of the status conditions occurring at any given time. Multiple status conditions are interpreted using subtraction of the largest possible Status Condition value using the table below.

Table 3: Model 633 Aethalometer Status Conditions

Parameter	Status Condition	Description
Detector	0	Measuring (no status condition)
	1	Not Measuring (tape advance or fast calibration in progress
	2	Calibrating (LED, Flow, Tape Sensor)
	3	Stopped
Flow	0	Flow OK
	4	Flow deviate from setpoint more than 0.25 lpm
	8	Flow check status history
	12	Flow deviate and check status history
LED	0	LEDs OK
	16	Calibrating

	32	Calibration error in one or more channels
	48	LED error (all channels calibration error, COM error)
Tape Advance	0	Tape advance OK
	128	Tape warning (less than 10 spots left)
	256	Tape last warning (less than five spots left)
	384	Tape error (tape not moving, end of tape)
Tests	0	No test
	1024	Stability test
	2048	Clean air test
	3072	Change Tape

For a complete description on deciphering status codes refer to Section 4.2 of the TAPI *Model 633 Aethalometer® Black Carbon Monitor User Manual*. Note the presence of any status condition on the Aethalometer Field Form

9.3.3 Verify Date/Time (Weekly)

1. Compare the Date/Time on the Aethalometer with logger date/time.
2. If Date/Time deviates from logger time for more than 15 minutes then change Aethalometer date/time (Time & Date in OPERATION>GENERAL screen).

9.3.4 Inspect sample tubing

1. Check for flow obstructions of the inlet, verify the tubing is intact without any creases/obstructions.

9.3.5 Clean cyclone

Remove the cyclone and disassemble (Refer to Section 5.1 of the User Manual for detailed images), cleaning the various parts thoroughly. The recommended cleaning method is immersion in an ultrasonic cleaner with water and mild soap. However, wiping with a water-dampened and lint-free cloth is sufficient.

1. Remove cyclone assembly from instrument.
2. Remove inlet cover.
3. Loosen the three set screws that hold the inlet body in place
4. Remove inlet body
5. Remove dust cup
6. Remove allen cap screws from cyclone top.
7. Clean all parts and thoroughly dry; then reassemble in reverse order.

9.3.6 Inspect optical chamber (Clean if necessary)

1. From the OPERATION Menu on the GENERAL tab press STOP to halt sampling activity.
2. Manually lift the chamber, secure in place by sliding the retention pin on top of the optical chamber.

3. While pressing the optical head release button upward, grasp optical head and turn to loosen and remove.

4. Use compressed air (AVOID spraying liquid) or a cotton swab to remove dust/debris from the optical head and top and bottom surfaces.

5. Reinstall the optical head aligning the notched marker and then turning to secure in place. When installed correctly the optical head release button will return to the locked position.

6. Depress the release button to return the chamber to its down position.

9.3.7 Leak test (Monthly)

Note: While performing this procedure the instrument will be lifting and lowering the sample chamber multiple times. The operator must wait to perform the next step of the procedure until after the chamber has stopped moving, at all steps the operator will be informed and prompted appropriately.

1. From the OPERATION Menu on the GENERAL tab press STOP to halt sampling activity, if not already stopped.

2. From the OPERATION Menu on the GENERAL tab press ‘Leakage Test’, press ‘Manual’.

3. The tape will advance automatically, install a flowmeter on the inlet of the 633, press ‘OK’.

4. Select flowrate (4 lpm), press ‘OK’, the pump will start.

5. Allow the flow to stabilize, press the flow field (the box adjacent to the word, ‘Flow’), using the keypad enter the actual flow rate in milliliters per minute, press ‘Enter’, then press ‘OK’.

6. The chamber will lift, remove tape, install calibrating pad (tabs of the pad parallel to direction of tape, notch in front aligned with center line of chamber), press ‘OK’ when finished. The pump will turn on.

7. Allow the flow to stabilize, press flow field, enter flow rate in milliliters per minute, press ‘Enter’, press ‘OK’.
   Note: If operator is going to perform a flow verification leave the calibrating pad and flowmeter in place, otherwise remove the pad and replace the tape, press ‘OK’.

8. Wait for the chamber to fall to home position. On the verification form record F_{tape}, F_{pad}, and leakage %. Press ‘OK’ when ready to proceed.
   Note: Leakage (ζ), expressed as a percentage is measured from the difference in flow, F_{tape} and F_{pad} by the following equation:

$$\zeta = 1 - \left(\frac{Ftape}{Fpad}\right)$$

9.3.8 Verification Procedure (For monthly QC verifications or for quarterly audits.)

Note: While performing this procedure the instrument will be lifting and lowering the sample chamber multiple times. The operator must wait to perform the next step of the procedure until after the chamber has stopped moving, at all steps the operator will be informed and prompted appropriately.

1. After having performed a leak check with the calibrating pad in position from the OPERATION Menu on the GENERAL tab press ‘Verify Flow’, press ‘Manual’.

2. If the calibrating pad is still in place press ‘Skip’, the chamber will move into place.

3. If not already connected then connect flowmeter, press 'OK'.

4. Tap the Temp field, enter actual ambient temperature, degC, press 'Enter'. Note the current ambient temperature on the verification form in the 'Ambient Temp.' under 'Stnd.'

5. Tap the Pressure field, enter actual ambient pressure in pascals (to convert to pascals from mmHg divide by 760 then multiply by 101325), press 'Enter'. Note the current ambient pressure on the verification form in the 'Ambient Pres.' under 'Stnd.'

6. Allow flow to stabilize, tap flow field, enter first actual flow rate, press 'Enter', press 'OK'. Note the value on the verification form under $F_{act,}$ level 1.
Note: The first verification check point is near 1.2 lpm, make sure to use a flowmeter than can accurately measure flow on this scale.

7. Allow flow to stabilize, tap flow field, enter second actual flow rate, press 'Enter', press 'OK'. Note the value on the verification form under $F_{act,}$ level 2.
Note: The second verification check point is near 4 lpm, make sure to use a flowmeter than can accurately measure flow on this scale.

8. Allow flow to stabilize, tap flow field, enter third actual flow rate, press 'Enter', press 'OK'. Note the value on the verification form under $F_{act,}$ level 3.
Note: The final verification check point is near 6 lpm, make sure to use a flowmeter than can accurately measure flow on this scale.

9. Record the flow results (where Fact is the reading from the external flowmeter) and press 'OK':

F_{act}	F_{in}	F_1	%	F_c	%
1148	1157	1145	99	1156	100
3690	3770	3730	100	3775	100
6230	6280	6299	100	6284	100

Where:

F_{act} = flow rate at actual ambient conditions measured by external flowmeter

F_{in} = F_{act} adjusted to instrument reported conditions

F_1 = flow at Mass Flowmeter 1 (see Figure 4)

F_c = flow at Mass Flowmeter C (see Figure 4)

% = F_1/F_{in}

% = F_c/F_{in}

10. Also displayed on the results screen are current instrument ambient temperatures and pressure, note these values on the verification form (convert pressure from pascal to mmHg by dividing instrument pressure by 101325 then multiplying by 760).

11. Remove calibrating pad, reinstall tape, press 'OK'. The chamber will move to the home position, wait until prompted.

12. When the 633 prompts, 'Flow Verification Finished', press 'OK'. If to return to normal operation then press 'Start'.

9.3.9 Installing a new tape roll (As needed)

1. From the OPERATION Menu on the GENERAL tab press 'Stop'.

2. From the ADVANCED tab of the OPERATION Menu press 'Change Tape'.

3. The chamber will lift, wait to change tape until prompted that the chamber has been lifted.
4. Remove the transparent covers from the spools.
5. Remove the tape from underneath the optical chamber.
6. Remove both spools from the instrument.
7. Install a fresh roll of tape on the supply (left of the chamber) spool, and orient the tap counterclockwise on the spool.
8. Route the tape under both guides underneath each spool on either side of the sample chamber.
9. Tape the end of the sample tape to a spare cardboard spool and wrap the tape around the spool enough times to secure it in place.
10. Place the tape spool on the take up (right) spool.
11. Install the transparent covers on the spools.
12. Close the door, press 'OK'. Wait for the instrument prompt, press 'OK' when finished.

Note: If the instrument is powered down the tape can be replaced by lifting the chamber manually.

9.3.10 Manual Stability Test

A manual stability test is conducted **without flow** to determine the performance of the light source – detector pair.

1. Under the Operation>General tab select desired timebase (use default)
2. Click 'Stability' button to start test
3. Manually stop the test when the desired test duration is complete (20 minutes)

Interpretation of the results:

- The instrument will generate a stability test report, like this:

Stability test report.
Serialnumber: AE33-S02-00232
Date and time: 02 Dec 2014 11:46:03
Duration: 00:20:00, Timebase: 1 sec, Flow: 0 mlpm

	AverageBC		PPBC	(ng/m3)
	Spot1	Spot2	Spot1	Spot2
Ch1	-13	-4	261	645
Ch2	-5	-3	357	934
Ch3	-3	8	365	899
Ch4	0	16	348	956
Ch5	-2	11	369	1023
Ch6	-23	-29	402	1118
Ch7	-16	-24	473	1230

Result of stability test is acceptable.

- Average BC values should be close to zero if the Aethalometer is warmed up.
- Point to point variation of BC (PPBC) is calculated as an average absolute difference between the consecutive BC measurements. For example at a 1s timebase PPBC61 = approximately 400 ng/m^3).

9.3.11 Manual Clean Air Test

A manual clean air test is conducted using the built-in filter to determine the performance of the Aethalometer under the standard flow condition.

1. Under the Operation>General tab select the desired timebase and flow rate (user should generally use the default settings).
2. Click the 'Clean Air' button to start the test.
3. The test will run for 20 minutes and prompt the user when completed. The following output will be generated:

Clean air test report.
Serialnumber: AE33-S02-00232
Date and time: 01 Dec 2014 13:41:03
Duration: 00:20:00, Timebase: 1 sec, Flow: 5000 mlpm

	AverageBC		PPBC	(ng/m3)
	Spot1	Spot2	Spot1	Spot2
Ch1	92	160	193	398
Ch2	38	76	255	592
Ch3	37	89	268	600
Ch4	46	128	307	672
Ch5	47	108	308	668
Ch6	24	94	385	848
Ch7	32	107	437	916

The user will be notified is the results are acceptable. If unacceptable results are indicated the test should be run again and the output downloaded onto a data stick. The information should be communicated to the manufacturer for the purpose of troubleshooting.

9.3.12 Cleaning the Optical Head

1. STOP measurements from the OPERATION>GENERAL menu.
2. Manually lift the chamber (pressing down the retention pin at top, front, and center).
3. Locate the release button, while pressing the release button upward grasp the optical head and turn to loosen and remove.
4. Using compressed air or a clean cotton swab remove dust/debris from the optical head surfaces and platform.
5. Return the optical head by aligning the notched marker and then inserting and turn to secure in place.

9.3.13 Changing the bypass cartridge filter

1. STOP measurements from the OPERATION>GENERAL menu.

2. Hold down bottom fitting on one side while pulling up on cartridge fitting, repeat on other side.
3. Remove the cartridge.
4. Carefully pry fittings from both ends of the filter.
5. Slide fitting onto ends of new filter.
6. Place new cartridge on chamber optical head, ensuring that the arrow printed on the filter points to the right.

9.3.14 Calibrating the tape sensor

Note: Tape sensor calibration is performed at the factory and requires special calibration equipment.

9.3.15 Flow Calibration

Note: Operators must have proper calibration equipment including an external flowmeter that can report actual flow rates from 1.0 to 6.5 lpm, a calibrated barometer, certified manometer (if appropriate), and the maintenance/verification form to document results.

1. From the ADVANCED tab on the OPERATIONS Menu select ‘FlowCal’, select ‘Manual’.
   Note: If calibration pad in place press ‘Skip’, otherwise wait for chamber to lift.
2. Remove tape, install calibration pad, press ‘OK’. The chamber will fall back to home position.
3. Connect flowmeter to inlet, press ‘OK’, wait for pump to stabilize.
4. Tap the temperature field, and enter actual ambient temperature in degC.
5. Tap the pressure field, and enter actual ambient pressure in pascals, (to convert from mmHg, divide by 760, multiply by 101325), press ‘Enter’.
6. Allow the pump to stabilize at the first calibration flow rate, tap flow field, enter actual flow rate in mlpm, press ‘Enter’, press ‘OK’.
   Note: The first flow calibration point is near 1.2 lpm, make sure to use a flowmeter than can accurately measure flow on this scale.
7. Allow the pump to stabilize at the next calibration flow rate, tap flow field, enter actual flow rate in mlpm, press ‘Enter’, press ‘OK’.
   Note: The next flow calibration point is near 4 lpm, make sure to use a flowmeter than can accurately measure flow on this scale.
8. Allow the pump to stabilize at the last calibration flow rate, tap flow field, enter actual flow rate in mlpm, press ‘Enter’, press ‘OK’.
   Note: The last flow calibration point is near 6 lpm, make sure to use a flowmeter than can accurately measure flow on this scale.
9. After the third calibration point the chamber will lift, remove calibration pad, insert tape, press ‘OK’, chamber will move to home position
10. Flow calibration is complete, press ‘OK’. Return 633 to normal operation.

Refer to the Standards Verification/Calibration SOP, or Appendix QA2 in the CDPHE/APCD/TSP QAPP for more detailed information traceability of standards.

Handling and Preservation

Although BC is monitored continuously samples are collected on the filter tape. While secondary analysis of individual spots is possible it is not likely. However, filter tape should be preserved to verify proper 'spotting' location.

SAMPLE PRESERVATION AND ANALYSIS

Black Carbon samples receive no special preparation prior to analysis.

TROUBLESHOOTING

Environmental Factors

Environmental conditions can play a role in the operational characteristics of analyzers. Some external factors may be constant while others are sporadic in nature. External factors to check include:

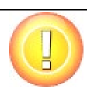
1. Is the shelter temperature stable throughout the day?
2. Is vibration from other equipment causing an effect?
3. Is the air conditioner or heater blowing directly on the instrument?

General Factors

Instrument Troubleshooting

11.2.1 Instrument Status

Instrument status is noted using the following symbols:

	Normal Operation
	Warning: Instrument is still performing measurements, but there is/was an issue, that needs to be checked
	Instrument stopped. Immediate response needed.

Instrument status number and status icon are shown on the Home screen. Pressing the status icon opens the status code page. Critical status codes are identified in Table 4, as well as an ordered list of things to check to alleviate the status code:

Table 4: Status Code Solutions

Status Codes	Description	Problem	Solution
4,8,12	Flow status	flow not calibrated or clogged sample line	calibrate flow, clear sample lines

32, 48	LED Status	LED calibration error	Remove flow calibration pad (if installed), update firmware, contact manufacturer.
64	Chamber status	Chamber locked	unlock optical chamber
128, 256	Filter tape status	Not much filter tape remaining	schedule filter tape replacement
384	Filter tape status	No filter tape or tape not moving	replace filter tape, tighten right spool nut
8192	External device status	Connection with the external device not working	verify physical connection, verify correct COM port

11.2.2 Start Up Checks

Figure 2: 633 Start Up Screen

Should there be an issue with instrument startup refer to Table 5 to begin to identify the specific issue

Table 5: Startup Screen Errors

Check	Description	Error	Solution
Communication	Communication PC to optical chamber controller	hardware problem	check cables
Instrument Data	Obtain SN from the optical chamber controller	hardware problem	check cables
Storage	CF card operation	CF card error	get new CF card & software
Configuration Settings	read setting from the setup file	setup file error	restore setup file from one of the older setup files
Valves	operation of the ball valve	ball valve not moving	check cables
Chamber	optical chamber movement test	locked chamber or hardware error	unlock chamber or service needed
Pump & flow	test if pump is working	pump fail or tubing connections	service or verify tubing connections

Device Monitoring	Win CE operating system test	faulty application file	Install new software, get new CF card

11.2.3 Unacceptable quality control results

The 633 is programmed to understand the range of acceptable quality control checks. Should a test fall outside of these given ranges an instrument status code will be generated. The following table identifies the possible errors, the associated cause, and proposed solutions.

Test	Criteria	solution
Leakage test	Fail > 10%	lubricate optical chamber sliders
Flow verification	Measured flows differ from reported by more than 10%	Check flow reporting standard (actual vs. standard), calibrate flow
Stability test	PPBC61 > 450 ng/m	Clean optical chamber, requires service
Clean air test	PPBC61 > 550 ng/m	Clean optical chamber, verify shelter stability

11.2.4 Additional Troubleshooting

Additional troubleshooting can be arranged by contacting the manufacturer.

Data Acquisition, Calculations, and Data Reduction

All data are now collected, stored, and retrieved digitally from data loggers. The terms data logger and onsite data acquisition system are used interchangeably throughout this SOP.

Data Acquisition

The APCD/TSP data acquisition system (DAS) is comprised of three components: an onsite primary data acquisition system that collects data from all continuous monitoring equipment, an onsite secondary data acquisition system, or back-up system that collects data from the continuous monitoring equipment, and a centralized central polling system that routinely collects data from the primary data acquisition system and stores it in a SQL database for processing and validation.

12.0.1 Primary Onsite Data Acquisition Systems

The APCD employs three different models of onsite DAS in the operations of its air monitoring network. These are the ESC 8816 data logger, the ESC 8832 data logger, and the Agilaire 8872 data logger. The 8816 data logger is the oldest type of data logger in the network and is a predecessor to the 8832 and 8872 data loggers. See Section 8.0.3 for a more detailed description of these data loggers and Appendix D1 of this QAPP.

12.0.2 Secondary Onsite Data Acquisition Systems

The 633 carries substantial on board memory. The data can be downloaded to a flash drive by using the 'Export' tab in the 'Data' menu. Data should be downloaded from the unit once per month soon after the end of each month.

12.0.3 Central Polling System

The APCD uses the AirVision software package for its central data management system. "AirVision is a centralized data management and polling software system that is used to acquire, edit, validate, analyze, and report air quality data. AirVision supports open data acquisition and data imports thru modular drivers that can be added to provide connectivity to a data source. The system has combined data editing and quality control tools that can be utilized in evaluating and validating data in the post-processing environment. The post-processing environment allows user control of the data from the management of raw data within the server environment through the exporting of validated data through built in reports or for external statistical evaluations and reporting. A more detailed description of this application can be found in Appendix D1 of this QAPP, APCD's Data Logger and Central Polling Standard Operating Procedure." (Agilaire, 2009)

<u>Central Polling Daily Tasks</u>

1. Task managers within Air Vision polls data from remote air quality monitoring sites at the top of each hour, at a minimum. Some sites may be polled at a greater frequency depending upon data needs. Data from each site is stored in a SQL database and made available for review and analysis after polling has been completed.

2. Ambient data on the AirVision Central polling computer is reviewed every business day in the morning, the previous 24 hours (or 3 days on Mondays) worth of data is reviewed for completeness and accuracy. This data review is used to determine if a physical site visit is required.

3. Low level (precision) and high level (span) test gas sequences are run on alternate days. The precision and span level tests are followed by a zero test and a two-minute recovery period. The results are reviewed each morning and plotted on control charts. It is the responsibility of one individual within TSP to review the daily Zero/Span results, plot them on the control charts, and notify the technician responsible of any out of control condition. "Out of control" is defined as:

    a. trending toward warning limit as defined on the control chart

    b. points plotted exceeding the warning limit

    c. points plotted exceeding the action limit as defined on the control chart

Calculations and Data Reduction

As mentioned above, data collected on a DAS are available as soon as the averaging period is complete. Data are polled automatically via modems (analog phone, wireless cellular, or DSL) by the Central polling computer hourly. If needed, sub-hourly polls or remote checks can also be performed.

Data from the continuous air monitoring equipment are generally stored at hourly and minute resolution averages. The software on the Central polling computer stores the downloaded minute and hourly averages and is capable of aggregating these averaging intervals into larger averaging intervals such as 8-hour or 24-hour averages.

A more detailed description of the DAS is given in Appendix D1 of the CDPHE/APCD/TSP QAPP and in the manufacturers' manual.

12.1.1 Post Collection Processing

DATA MANAGEMENT AND RECORDS MANAGEMENT

Data Management

Data are generated from the analyzer at intervals internally set, ranging from an averaging time of 1 minute to 1 hour. The data is collected by the on-site data logger as near-real-time data (1 minute averages from the instrument provide data stability) and is aggregated into 15 minute averages, which are in turn aggregated into 1-hour averages. Note the capacity of the on-site data logger is limited to three time-base averaging intervals. The Central polling computer collects these averages routinely. The data channels from the aethalometer collected by the on-site data logger are presented here, in Table 6:

Table 6: API 633 Data Collection

Data Field	Description	Purpose
BC1 (370 nm)	Spot adjusted Black Carbon concentration derived from attenuation of light of wavelength 370 nm due to BC	To report what's commonly referred to as 'UVPM'
BC2 (470 nm)	Spot adjusted Black Carbon concentration derived from attenuation of light of wavelength 470 nm due to BC	BC (470 nm)
BC3 (525 nm)	Sport adjusted Black Carbon concentration derived from attenuation of light of wavelength 525nm due to BC	BC (525 nm)
BC4 (590 nm)	Spot adjusted Black Carbon concentration derived from attenuation of light of wavelength 590. nm due to BC	BC (590 nm)
BC5 (660 nm)	Spot adjusted Black Carbon concentration derived from attenuation of light of wavelength 660 nm due to BC	BC (660 nm)
BC6 (880 nm)	Spot adjusted Black Carbon concentration derived from attenuation of light of wavelength 880 nm due to BC	To report what's commonly referred to as 'BC'
BC7 (940 nm)	Spot adjusted Black Carbon concentration derived from attenuation of light of wavelength 940 nm due to BC	BC (940 nm)
F_C	Total flow (alpm) through the analyzer	Valid range of F_2/F_1 (or $(F_C - F_1)/F_1$)between 0.2 to 0.75, range requiring recalibration 0.3 to 0.65, target between 0.4 and 0.5
F_1	Flow (alpm) at spot 1	
F_r	Flow Ratio $(F_c – F_1)/F_1$	
k_1	BC loading correction factor, 370 nm	Verify data, range of acceptable values should be between 0.002 and 0.006
k_6	BC loading correction factor, 880 nm	Verify data, range of acceptable values should be between -0.002 and 0.012
FVRF	Flow Velocity Ratio Factor	Nominal value of 1.0 ± 10%, outside of range requires flow recalibration
Status	Instrument Status	See Table 3 for an explanation of Instrument Status Codes

Valid data are sent to the EPA centralized Air Quality System (AQS) database for long-term storage. Additionally, the data are stored and archived by the APCD/TSP in electronic format. Monthly electronic data files and related material packets (maintenance forms, etc.) are produced.

A more detailed description of the data management is given in Appendix D1, Datalogger & Central SOP in the CDPHE/APCD/TSP QAPP.

Records Management

Continuous ambient air monitoring data are archived in electronic format. Electronic data and calibration files from the primary DAS are archived. Data from the backup electronic strip chart recorders, where used, are downloaded annually and archived on a computer hard drive.

QUALITY ASSURANCE AND QUALITY CONTROL

Quality assurance and quality control are two terms commonly discussed, but often confused. Quality assurance refers to the overall process of ensuring that the data collected meet previously stated Data Quality Indicators (DQI) and associated measurement quality objectives (MQOs). The principal DQIs are precision, bias, representativeness, completeness, comparability, and sensitivity. The principal MQO's are parameter specific and are listed in CDPHE's Appendix MQO of this QAPP. Guidance for developing DQI's and MQO's is given in EPA's Quality Assurance Handbook (US EPA, 2013). Quality control covers specific procedures established for obtaining and maintaining data collection within those limits.

Quality Assurance

The goal of the quality assurance program is to control measurement uncertainty to an acceptable level through the use of various quality control and evaluation techniques. The entire Quality Assurance effort put forward by the APCD is too large to include here. The scope of this SOP will describe efforts taken by site operators and data validation personnel to ensure the quality of the data collected meets standards set forth in various sections of the *Code of Federal Regulations*. For a complete description of the Quality Assurance and Quality Control process undertaken by the APCD, see the appropriate quality assurance appendices in the QAPP. Two of the most significant Quality Assurance procedures are described below.

14.0.1 Audits

Audits are evaluation processes used to measure the performance of effectiveness of a system and its elements. APCD quality assurance staff performs two types of audits. These audits are performedat a frequency as described in APCD QAPP.

Systems Audits - A systems audit is an on-site review and inspection of an ambient air monitoring program or air monitoring site to assess its compliance with established regulations governing the collection, analysis, validation, and reporting of ambient air quality data.

Performance Audits - A performance audit is a type of audit in which the quantitative data generated in a measurement system are obtained independently and compared with routinely obtained data to evaluate the proficiency of an analyst, laboratory, or measurement system. Two types of performance audits discussed below.

- Monitoring Organization Performance Audits - These performance audits are used to provide an independent assessment of the measurement operations of each instrument being audited. This is accomplished by comparing performance samples or devices of "known" concentrations or values to the values measured by the instruments being audited. Detailed information about how specific audits are performed can be found in the Quality Assurance SOPs section.

- National Performance Evaluation Program (NPEP) – These performance audits are implemented at the federal level although some programs may be implemented by the monitoring organizations if certain requirements are met.

14.0.2 Data Quality Assessment

Data Quality Assessment is used to assess the type, quantity, and quality of data in order to verify that the planning objectives, Quality Assurance Project Plan components, and sample collection procedures were satisfied and that the data are suitable for its intended purpose. Data Quality Assessment is a five-step procedure for determining statistically whether or not a data set is suitable for its intended purpose. This assessment is a scientific and statistical evaluation of data to determine if it is of the type, quantity, and quality needed and is performed annually by quality assurance staff to check if objectives were met.

Quality Control

Quality Control is the overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the EPA. Quality control includes establishing specifications or acceptance criteria for each quality characteristic of the monitoring/analytical process, assessing procedures used in the monitoring/analytical process to determine conformance to these specifications, and taking any necessary corrective actions to bring them into conformance.

Quality control refers to procedures established for collecting data within pre-specified tolerance limits. These pre-specified tolerances are defined in the Measurement Quality Objectives as defined in APCD's QAPP. While all Quality Control procedures are important, the most significant procedure employed by the APCD is the routine measurement of a known test gas by gaseous analyzers. All procedure documented in this SOP are Quality Control procedures because they allow the analytical systems to continue running in exceptional condition and serves to minimize out-of-control conditions as defined by APCD MQO's. By definition, the creation and use of this SOP is a Quality Control function. All Quality Control procedures are described in various Sections of this SOP. Three of the most significant Quality Control procedures are described below.

14.1.1 Performance and Precision Tests

A primary quality assurance task carried out by site operators is the performance of routine QC checks. The APCD performs two types of QC checks on the aethalometer. These two tests are leak checks and flow verifications.

14.1.2 Calibrations

Calibration of an analyzer or instrument establishes the quantitative relationship between the actual value of a standard, be it an environmental reading or volumetric flow, and the analyzer's response (chart recorder reading, output volts, digital output, etc.). It is the goal of APCD to perform calibrations on all analyzers quarterly, however, circumstances my require calibrations be performed at the longer frequency of every 6-months. A 6-month calibration frequency still meets EPA recommended calibration frequency criteria.

For instructions on performing a flow calibration, see Section 9.3.15, Flow Calibration.

Documentation is an important component of the quality control system. Extensive certification paperwork and log sheet must be rigorously maintained for procedures, standards and analyzers. APCD takes special care to prepare and preserve backup copies of all data, especially calibration data. All data and supporting documentation should be held on-site for a minimum of three calendar years then sent for offsite archive. See Section "Records Management" and the QAPP main body for additional information.

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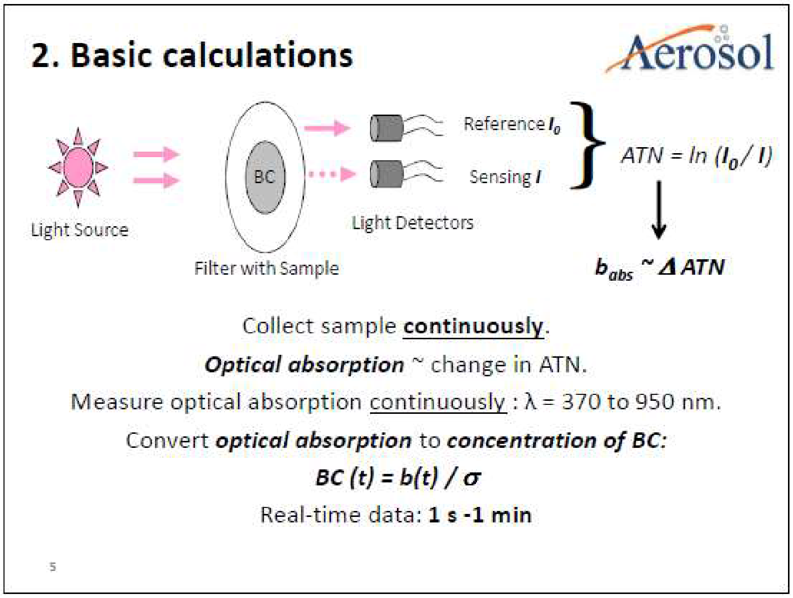

Figure 3. Model 633 Aethalometer Operating Principle

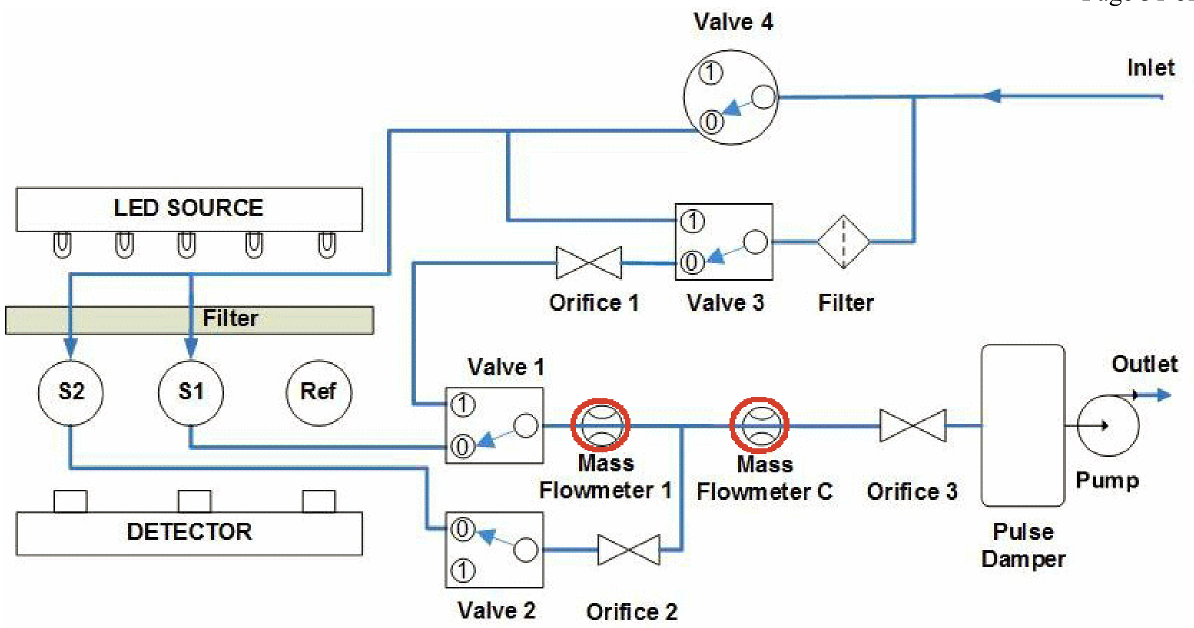

Figure 4. Model 633 Flow Diagram

Aethalometer Monthly Service/Maintenance Form

COLORADO DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT

Air Pollution Control Division - Technical Services Program
API 633 Aethalometer Service/Maintenance Form

SITE/SAMPLER DATA Site Visit

Site Name: I-25 Near Road Aeth Sampler Model: TAPI 633 Aeth Sampler S/N: 0

AQS ID: 08-031-0027

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Operator										
Date										
Time										
Vis. Insp										
INSPECTION										
Inst Condition										
Data Logger Check										
Tape Check OK?										
Chan1 Flow										
Status Code										

FTS S/N: Tetra Cal FTS m = n/a FTS b = n/a Therm. S/N: 0 Bar.S/N: 0

Four Week Instrument Verification

Visit #	Leak Rate			Ambient Pres.		Ambient Temp.		Flow Level	Three Point Flow Check Results					
				Inst.	Stnd.	Inst.	Stnd.							
	Ftape	Fpad	%	± 10 mmHg		± 4°C			Fact	Fin	F1	& Diff	Fc	% Diff
								1						
								2						
								3						
								1						
								2						
								3						

Day	Time	Describe Action Due/Action Taken	Time On	Initials

TIME PERIOD: 02.01.16 to 02.29.16

LIST OF SCHEDULED EVENTS/ SCHEDULED DATES:

Scheduled Events: # 2 4-wk verification, 1st Stage Inlet Cleaning

SCHEDULED DATE: 02.01.16

Comments: **DOWNLOAD DATA FROM ANALYZER EVERY TWO WEEKS!!!**