UCD IMPROVE Technical Information #226H

Calibration of Flow Check Devices Using Positive Displacement Flow Meter

Interagency Monitoring of Protected Visual Environments
Air Quality Research Center
University of California, Davis

July 15, 2022
Version 2.5

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DOCUMENT HISTORY

Date Modified	Initials	Section/s Modified	Brief Description of Modifications
05/14/21	SRS	All	Separated TI: A-H doc into individual TIs
5/17/21	IVP	2,3,4,5,10,11	Added missing sections
6/14/22	IVP	5	Added caution on calibration stability

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1. PURPOSE AND APPLICABILITY

This technical information (TI) document describes the procedures for calibrating the flow check devices necessary for performing flow rate measurements on IMPROVE aerosol samplers. The calibration of the flow check device is done by Air Quality Research Center (AQRC) personnel prior to and subsequent to flow rate measurements at an IMPROVE sampling site. Each flow check 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 flow check device files. The most current calibration equation for each flow check device is written on a sticker, which is pasted on the flow check device gauge following the calibration procedure.

2. SUMMARY OF THE METHOD

The primary flow measurement standard device the Field Technicians use to measure flow is too expensive and fragile to be taken into the field. To get around this we calibrate a number of transfer standards in the form of an arbitrary flow restriction and a pressure measurement device. These transfer standards called "Magnehelic Probes" are then used in the filed with the aid of a spreadsheet and calibration constants to measure flow rate. This TI explains probe calibration methods.

3. DEFINITIONS

- AQRC: Air Quality Research Center of UC Davis
- IMPROVE: Interagency Monitoring Program of Visual Environments
- $PM_{2.5}$: Particulate matter, aerodynamic diameter of 2.5 mm or less.
- PM_{10}: Particulate matter, aerodynamic diameter of 10 mm or less.
- TI: Technical Information
- Magnehelic Probe: the custom flow restriction and pressure measurement device we use as a transfer standard for flow measurements in the field

4. HEALTH AND SAFETY WARNINGS

Person protection equipment should be used/worn in accordance to university and lab safety policy.

5. CAUTIONS

Leaks in the sampler used to audit and calibrate the probe will change the measurement. Perform a leak check on the sampler before auditing or calibrating.

Historically transfer standard calibrations remain very stable or drift slowly over time. If the calibration constants change significantly from the last calibration look for pressure gauge damage, leaky hoses, hose kinks or other device defects. If calibration is found not to be stable after subsequent calibrations, consider retiring the device.

6. INTERFERENCES

Temperature is assumed to be 20 °C when calculating the field correction factors used after calibration. Make sure the room temperate is whiting 2 degrees of standard value prior to calibrating.

7. PERSONNEL QUALIFICATIONS

7.1 Field Specialist

The field specialist will:

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

7.2 Field Technician

The field technician will:

- Perform the calibration of the flow check device.
- Submit the derived calibration equation to the field specialist for approval.

8. EQUIPMENT AND SUPPLIES

The equipment required to calibrate a flow check device includes the following:

- Definer 220, Mesa Labs (drycal.mesalabs.com/definer-series/), accuracy 1%
    - 3/8” I.D. hose, 2’
    - ¼ NPT brass nipple for 3/8” I.D. hose
    - Stack inlet plug for top of IMPROVE $PM_{2.5}$ module tee inlet
    - 3/8” O.D. stainless steel tube, 2”
    - IMPROVE $PM_{2.5}$ module tee plug tapped for ¼ NPT fitting
- 1 flow check device (orifice meter) and calibration form
- 1 leak checked IMPROVE $PM_{2.5}$ module
- 1 IMPROVE controller
- 1 IMPROVE rocker piston pump with corresponding vacuum line
- 1 IMPROVE pump relay box
- 1 leak checked calibration filter cartridge

9. PROCEDURAL STEPS

This technical note covers the methods for calibrating orifice meters using a Definer 220 as a standard. Section 9.1 covers the theory describing the behavior of orifice meters, while section 9.2 describes the procedures used to calibrate orifice meters against a Definer 220.

9.1 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 Magnehelic to measure the pressure drop. The flow check devices consist 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 five modules, the probe blocks the normal flow through the inlet, forcing all air entering the system to pass through the probe orifice. The flow check device probe is a machined piece with slight variations between the holes drilled and geometry. The results in the need to calibrate each device probe. The digital magnehelics all agree within 1% and no individual calibration is needed for each. The digital magnehelics are, therefore, interchangeable. The probe and magnehelic, hereafter called the flow check device, are calibrated at the Air Quality Research Center (AQRC) at UC Davis (UCD) using a Definer 220.

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:

$$Q = Q_1 (\delta P)^{\beta} \sqrt{\frac{P_{\circ}}{P}} \sqrt{\frac{T + 273}{293}} \qquad \text{(TI226-1)}$$

Where P is atmospheric pressure, T is temperature in ℃, and Q_1, β, and P_° are constants. For laminar flow, β =0.5. We express Equation TI226-1 in parameterized form using the magnehelic reading, M, for the pressure drop:

$$Q = 10^{a} M^{b} \sqrt{\frac{P(sea\ level)}{P(site)}} \sqrt{\frac{T + 273}{293}} \qquad \text{(TI226-2)}$$

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 UCD. 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 *UCD IMPROVE SOP #201: Sampler Maintenance* in sections 9.3.3 and 9.4.2.

The reference flow rate is provided by a Definer 220 located in the sampler laboratory at AQRC. Taking the logs of Equation TI226-2, the flow rate equation for the flow check device is:

$$\log(Q) = a_\circ + log\sqrt{\left(\frac{29.92}{P}\right)\left(\frac{T+273}{293}\right)} + b_\circ * \log(M_\circ) \qquad \text{(TI226-3)}$$

The log of the meter reading – Mo – 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" Hg) and 20 °C are calculated using

$$a_c = intercept - log\sqrt{\left(\frac{29.92}{P}\right)\left(\frac{T+273}{293}\right)} \qquad b_\circ = slope \qquad \text{(TI226-4)}$$

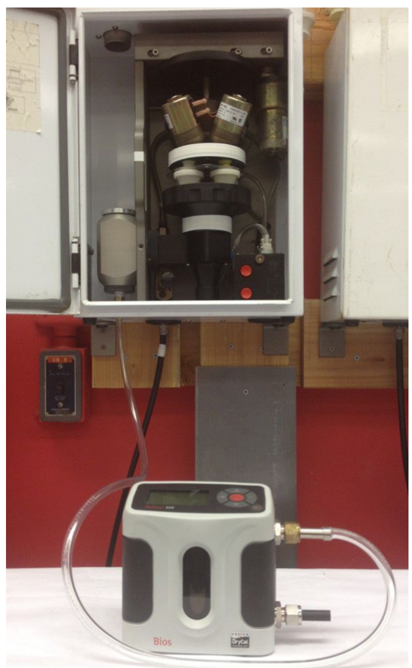
9.2 Calibration of an Orifice Meter Using a Definer 220

The flow check device, or orifice meter, is used as the standard against which each module in the field is calibrated. The flow check device probe is calibrated against a primary flow device — a Definer 220 — at AQRC both prior to and following calibration at a site. The calibration equation for the flow check device probe is printed on a sticker within the magnehelic side, along with the date of calibration and name of the technician responsible for the equation. A flow restricting device and a filter cartridge with twelve filters with distinct pressure drops is used to change the flow rate to develop the equation. Finally, a spreadsheet to complete logs and linear regressions is required.

1. Install the calibration cartridge shown in Figure 1 in the module. This cartridge is set up with four cassettes that produce a range of flow rates.
2. Insert Definer 220 probe at bottom of tee and tee plug on top of tee as shown in Figure 2. Ensure that both probe and plug are inserted fully.

Figure 1. Calibration Cartridge.

Figure 2. Calibration system with Definer 220.



3. At the controller press **Menu** from the Home Screen, then **Advanced Menu**, then enter code **9051**.
4. From the Advanced Menu press **Calibration**. Turn on the pump and open solenoid one on module 1A.
5. Turn on the Definer 220 by pressing the red power button in the bottom of the right corner for 2 seconds.
6. When the Definer has been turned on press the red **Enter** button while "Measure" is selected as in Figure 3.
7. Select **Burst** mode and take flow reading for filter position 1 of the calibration

cartridge. Ensure that the Definer is set to measure volumetric flowrate

8. Record the average flow rate for each filter position in cell **B7** of the calibration spreadsheet shown in Figure 5.

Figure 3. Setting up the Definer 220.

Figure 4. Operating the Definer 220.

Figure 5. Flow check device calibration spreadsheet.

	F-07 PROB												
	Calib. Dat	1/22/2020	Calib. By:	FJ									
	ΔP_{DIGMAG} "H_2O	Q ALICAL lpm	Q_{DIGMAG} lpm	%Diff	LOG DiG_{MAG}	LOG ALICAL	R^2	a	b	23 lpm STP	16.9 lpm STP	Temp °C	BP "Hg
SET1	0.61	23.89	23.89	-0.01%	-0.215	1.378	1.000	1.502	0.575	0.570	0.334	21.9	766.00
	0.58	23.27	23.25	-0.09%	-0.236	1.367							
	0.47	20.61	20.61	-0.01%	-0.327	1.314							
	0.37	18.01	18.02	0.06%	-0.428	1.256							
SET2	0.62	24.12	24.14	0.06%	-0.208	1.382							
	0.59	23.35	23.37	0.06%	-0.232	1.368							
	0.53	22.16	22.13	-0.16%	-0.273	1.346							
	0.36	17.60	17.60	0.00%	-0.446	1.246							
SET3	0.63	24.30	24.34	0.15%	-0.201	1.386							
	0.59	23.50	23.48	-0.09%	-0.228	1.371	Comments:		Average (ABS) of difference between AliCal VS Digital MAG				
	0.49	21.03	21.03	0.01%	-0.312	1.323			0.01%				
	0.39	18.54	18.54	0.01%	-0.407	1.268							

9. Repeat steps 7 and 8 for the remaining filter positions.

10. Remove the Definer plug and tee inlet plug from the module.
11. Insert the flow check device probe into the bottom end of the inlet tee. Ensure that the probe is fully inserted. Attach the magnehelic gauge on a vertical metallic surface as shown in Figure 6. The back end of the gauge base is magnetic.

Figure 6. Calibration system with magnehelic flow meter.

12. Record the magnehelic reading for each filter position on cells B7-B18 of the calibration spreadsheet.
13. Record the calibration date, technician name, ambient temperature, and pressure on the spreadsheet.
14. The spreadsheet will generate values for R2, intercept, slope, nominal magnehelic value for a flow rate of 23 LPM, and 16.9 LPM at standard temperature and pressure.
15. If the r2 is not better than 0.990, the calibration is invalid. Repeat the orifice meter calibration procedure, beginning with step 2.
16. If the r2 is better than 0.990, write out the equation, the date, technician initials, temperature, and r2 value on a 3 7/16" x 9/16" file folder label and attach it to the side of meter magnehelic.
17. Save the calibration spreadsheet.
18. Share the results of calibration spreadsheet with the field or shop manager for approval.

10. DATA AND RECORDS MANAGEMENT

All calibration data is stored on a spreadsheet specific to each individual magnehelic probe on the network drive. It is the responsibility of the field technicians to immediately maintain a written record for all calibrations/audits performed on a device.

11. QUALITY ASSURANCE AND QUALITY CONTROL

The magnehelic probes are audited against the primary standard before and after every in-field use. If the calibration drifts more than 2% flow, then the probe is recalibrated and all flow checks performed by said probe are reviewed for accuracy.

The primary standard is sent to the manufacturer every year for recertification.

12. REFERENCES

UCD IMPROVE SOP #201: Sampler Maintenance