THE FUNDAMENTALS OF THE AIR SAMPLER CALIBRATION-VERIFICATION PROCESS

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INTRODUCTION

The calibration of an air sampling instrument using a reference air flow calibrator requires attention to scientific detail in order to establish that the instrument's reported values are correctly stated and valid under the actual operating conditions of the air sampling instrument.

[1] DEFINITIONS

For the purposes of this paper, the following definitions shall apply:

Gas of Interest:	Air
Indicated Flow (F_{ind}):	The uncorrected volumetric air flow measured at the flow sensor under the actual conditions of temperature and pressure existing at the flow sensor after air circuitry line losses, pressure drop across the filters and dust loading conditions, if pertinent
Ambient Flow (F_{amb}):	The indicated air flow corrected to the dynamic conditions of local ambient temperature and pressure by either manual calculation or instrument calculation
Reference Flow (F_{ref}):	The indicated airflow corrected to fixed values of temperature and pressure conditions mandated by a regulatory agency or selected by the organization performing the air sampling activities. Often the reference flow is referred to as "Standard Flow" or "STP flow"
Reference Instrument (REF)	The instrument that reports a conventionally true value (CTV)

Device Under Test (DUT)	The instrument whose reported values are being compared to a REF
Calibration – Verification	The process of comparing a DUT against a REF to determine whether the DUT's reported results are within the manufacturer's stated accuracy range
Instrument Calibration	The process of adjusting one or more components of an instrument (DUT) to improve its reported values relative to the conventionally true value of a REF. The adjustment process can imply an automated computerized calibration of multiple sensors that interact dynamically to produce the best value or can be as simple as adjusting a potentiometer or a needle valve.

[2] THE BASICS OF THE IDEAL GAS LAWS

The ideal gas laws are utilized to normalize gas volumes, and/or volumetric gas flow rates (volume per unit of time) to a particular set of temperature and pressure conditions because the volume of a gas (air in our case) is a function of the temperature and pressure conditions at which the gas exists.

Charles' Law [1]

The volume of an ideal gas, when pressure and the molar mass are constant, is directly proportional to the absolute temperature of the gas (as temperature increases the volume of a gas increases).

$$V \alpha T \qquad (1)$$

Boyle's Law [2]

The pressure and volume of an ideal gas are inversely proportional (while one increases the other decreases) when the temperature and the molar mass of the gas are kept constant.

$$V \alpha \frac{1}{P} \qquad (2)$$

Combination of Charles' Law and Boyle's Law [3]

$$V_2 = V_1\left(\frac{T_2}{T_1}\right)\left(\frac{P_1}{P_2}\right) \qquad (3)$$

[3] THE OBJECTIVE OF AN AIR FLOW CALIBRATION-VERIFICATION

The primary objective of an air flow calibration-verification is to ensure that the DUT is within the manufacturer's stated accuracy range of temperature, pressure and humidity conditions under which the instrument was designed to operate.

The DUT output values are compared to those obtained from a reference instrument (REF) measuring the sample physical parameter that the DUT is measuring.

An accurate comparison of air flow rates or air volumes requires that the comparison of the DUT and REF values be made under the same temperature and pressure conditions, in accordance with the Ideal Gas Laws discussed in section II above. Therefore, the calibration technician must know what the T and P conditions are for each one of the displayed flow rate values of the DUT and the REF instruments during the calibration-verification process.

It is proper to note that the required volume correction formula to be utilized for an analog flow sensor may not be linear.

For example, rotameters [3], as well as venturi, orifice and other volumetric differential pressure sensors, require the application of a square root version of the combination of Charles' and Boyle's law equations. The equation applicable to variable area rotameters is presented in formula (6) below:

$$F_{REF} = F_{ind}\sqrt{\frac{T_{REF}}{T_{ind}} \bullet \frac{P_{ind}}{P_{REF}}} \qquad (6)$$

If both instruments (DUT and REF) display corrected values, but the T and P conditions are different, the Ideal Gas Law equations can be utilized by correcting the DUT output as described in formula (7) below and compared to the flow value displayed by the REF.

$$F_{REF} = F_{DUT}\left(\frac{T_{REF}}{T_{DUT}}\right) \bullet \left(\frac{P_{DUT}}{P_{REF}}\right) \qquad (7)$$

[4] REQUIRED ACCURACY OF THE REF RELATIVE TO THE DUT

If is absolutely necessary that the REF be more accurate than the DUT; otherwise, it can not be considered a reference instrument.

How much more accurate?

The REF should be at least twice as accurate and, if possible, it should be four times as accurate as the DUT.

For example, Table I below lists the recommended minimum and preferred accuracies that the REF should have for a given DUT accuracies.

TABLE I

Minimum and Preferred Reference Instrument Accuracy Relative to the Accuracy of the Device Under Test

DUT Accuracy (±%)	Minimum REF Accuracy (±%)	Recommended REF Accuracy (±%)
10	5.0	2.5
8	4.0	2.0
6	3.0	1.5
4	2.0	1.0

[5] TYPE OF ACCURACIES:

Full Scale Accuracy (FS) vs. At Reading Accuracy

Monitoring instruments have an accuracy stated either on the instrument nameplate label or in the operator manual.

Instruments having an accuracy related to **Full Scale** require the indication of the observed value ± the absolute value of error calculated by formula 10 below.

$$\text{Absolute Error} = \%\text{FS accuracy} \times \text{Top of Range Flow Value} \qquad (10)$$

For example, an air sampler that has a ±4% FS accuracy and whose top-of-the-measurement range is 100 LPM has a ±4 LPM error anywhere within the operating range. Thus, a measurement made at 30 LPM should be expressed as 30 ±4 LPM. If the measurement is made at 90 LPM the value should be expressed as 90 ±4 LPM.

If the instrument has an **At Reading** accuracy of ±4% the accuracy is more precise and is expressed as 30 LPM ±1.2 LPM. As the value of the reading increases, the absolute value of the possible error also increases.

[6] STATISTICS OF AN AIR FLOW CALIBRATION

The calibration or calibration-verification of a DUT with a REF involves at least two measurements and that both of them display output values at the same reference T and P conditions. In this ideal case the maximum accuracy that can be assigned to the output values of the DUT is determined by formula (8)

$$TotalError\left(E_T\right) = \sqrt{E^2{}_{REF} + E^2{}_{DUT}} \qquad (8)$$

For a DUT having a manufacturer's stated accuracy of ±8% FS and a REF having a manufacturer's stated accuracy of ±4% FS, the maximum accuracy assignable to the DUT is represented by implementing formula (8), utilizing the accuracy values stated above.

$$E_T = 100\sqrt{(.08)^2 + (.040)^2} = \sqrt{.0080} = 9\%$$

[7] CALIBRATION-VERIFICATION vs. CALIBRATION

There are DUTs that enable a technician to adjust their flow rate to match that of the REF more closely when there are one or more points in the initial calibration-verification procedure outside of the manufacturer's stated accuracy range. Rotameters may have top mounted needle valves that adjust back pressure, magnehelic gauges have adjustment screws, mass flow meters may have potentiometers, etc.

If the instruments do not provide such an adjustment, then only a calibration-verification can be made with the DUT. The DUT must be sent to the manufacturer for the latter to assess the out-of-tolerance condition and perform the repair work, followed by a factory recalibration.

An air flow measurement instrument is calibrated when one or more sensors or components can be adjusted to provide a volumetric flow rate within the instruments designed accuracy over the instrument's entire operating range.

If there are some points at the top or bottom of the operating range that can not be adjusted to be within the manufacturer's stated accuracy range, then, it may be appropriate to declare the DUT a "Limited-Use-Instrument" and the instrument should only be operated as such.

[8] DOCUMENTATION OF DUT CALIBRATION ACCEPTANCE

Upon confirmation that the DUT meets the manufacturer's accuracy criteria, the technician must place a calibration sticker or label indicating the date of calibration, the expiration date of the calibration and an authorized signature. If it is a limited-use instrument, the label should state the limited-use operating range. The serial number and model number of the instrument should also be shown on the calibration sticker.

A specific calibration file for each instrument by serial # should be kept in the calibration laboratory file records.

CONCLUSION

Dissecting the many elements of an air sample instrument calibration or calibration-verification obliges air monitoring professionals to obtain a considerable amount of information about the DUT's accuracy, design operating conditions, possible flow sensor adjustment techniques and whether the instrument reports corrected flow rates at specified T and P conditions.

An effort must be made to utilize the most accurate REF that is economically acceptable in order to exceed, as much as possible, the accuracy of the DUTs utilized in one's air monitoring program.

Instruments that display gas flow or gas volume values corrected to a reference temperature and pressure are very desirable. The ideal situation is when both the DUT and the REF output flow rate or volume values are at the same conditions of T and P. The calibration-verification is, then, a simple process.

The credibility of an air flow calibration laboratory and of an air monitoring program is maximized by utilizing high quality REF and DUT instruments that are microprocessor-controlled and designed to display air flow rates and/or air volumes at recognized reference T and P conditions.

[1] http://wikipedia.org/wiki/charles%27s_law
[2] http://wikipedia.org/wiki/Boyle%27s_Law
[3] Craig D.K. The Interpretation of Rotameter Air Flow Reading. Health Physics, Pergamon Press 1971 Vol 21 (August), pp. 328-332