

Chapter 6

Certification Methods for Transfer Standards

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1.0 Introduction

1.1 Scope

Traditionally all transfer standards were transported to the Quality Assurance Certification Facility for certification, calibration or verification. The permanent installation of transfer standard devices at almost 50 air monitoring stations across Indiana required a modification of previously used certification techniques and frequencies. While most transfer standard certification activities are still performed in the Quality Assurance Certification Facility some verification activities must be performed at the air monitoring station.

This chapter presents the requirements for the use, certification, calibration and verification of transfer standards used for air monitoring in the state of Indiana.

1.2 Definitions

A transfer standard is defined as an instrument, device or apparatus which, together with associated operational procedures, is capable of accurately reproducing standard values (e.g., pollutant concentrations, flows) or producing accurate assays of these standard values which are quantitatively related to an authoritative primary standard.

Certification procedures and recertification frequencies change based on the use of transfer standard. Based on their use, transfer standards are divided into two types.

1. Portable Transfer Standards, (PTS),
2. Stationary Transfer Standards, (STS).

Portable Transfer Standards are used for Quality Control (QC) and Quality Assurance (QA) activities such as flow rate calibrations and verifications, accuracy audits, and occasionally precision audits. Portable Transfer Standards are kept at the IDEM Shadeland facility in Indianapolis or at IDEM regional offices throughout Indiana and are transported to each site for audit, verification and calibration activities and then returned to their respective locations. Most standards are classified as portable transfer standards.

Stationary Transfer Standards are used for activities such as calibrations, daily zero/span checks and weekly precision checks. A Stationary Transfer Standard is permanently located at each of Indiana's continuous air monitoring stations (CO, SO₂, O₃, and NO₂).

1.3 Applicability

The requirements of this chapter apply to those organizations (state, local, industrial, and consulting) that monitor ambient air and associated parameters and use transfer standards in the state of Indiana.

2.0 General Use of Transfer Standards

All transfer standards (portable and stationary) used in Indiana are subject to Indiana Department of Environmental Management (IDEM), Office of Air Quality (OAQ), and Quality Assurance Section (QAS) requirements. Primary standards provide a standard reference throughout the State and supersede all other standards except for standards maintained at the National Institute of Standards and Technology (NIST). The QA primary standards may be NIST Standard Reference Material (SRM), traceable to NIST SRM, U.S. EPA/NIST-approved NIST Traceable Reference Material (NTRM), or Gas Manufacturer's Intermediate Standards (GMIS).

3.0 Certification of Cylinder Gaseous Transfer Standards (SO₂, CO, NO/NO_x)

Certification of gaseous transfer standards (Portable or Stationary Transfer Standards) is a three step process.

1. Certification of mass flow controllers of the blending device (calibrator),
2. Calibration of the transfer analyzer,
3. Certification of the gas cylinder using the blending device.

3.1 Certification Differences between Portable and Stationary Transfer Standards

An SO₂, CO or NO/NO_x Portable Transfer Standard consists of a gas blending device, gas cylinder(s), a regulator, sample delivery lines, and a clean air (zero air) system. A portable standard is certified and then used as a unit in which a specific gas cylinder is certified with the blending device. Certifications on the mass flow controllers and gas cylinder are performed in the QA Lab every 6 months.

An SO₂, CO or NO/NO_x Stationary Transfer Standard consists of a gas blending device, gas cylinder(s), a regulator, sample delivery lines, and a clean air (zero air) system. A stationary standard is certified as individual components and then assembled and used as a unit at its assigned air monitoring station. Annually the blending device is returned to the QA Lab for mass flow meter certification. The gas cylinder, regulator, sample delivery lines, and a clean air (zero air) system remain at the station. All gas cylinders using a Stationary Transfer Standard are certified in the QA Lab with the lab's primary gas blending device (the same brand as used at all air monitoring stations).

3.2 Lab Certification of Mass Flow Controllers (MFC)

In the Quality Assurance Certification Facility (QA Lab): Portable Transfer Standard mass flow controllers are certified every six (6) months and Stationary Transfer Standard mass flow controllers are certified every twelve (12) months by comparison with a NIST-traceable primary flow rate standard. The Quality Assurance Certification Facility uses two types of flow rate standards:

1. Cal Technix, Molbox1, or

2. Hastings bubble meter.

The Cal Technix Molbox uses laminar flow theory and known thermodynamic properties of gases in determining the flows. For each calibration, at least five (5) calibration flows are measured. The slope and intercept for this comparison is computed using the least-squares linear regression of the transfer standard display (x) and the standard flow rate (y).

The second flow rate standard, the Hastings bubble kit, includes three NIST-traceable volumes and a NIST-traceable certified stopwatch. Using the Hastings bubble kit, mass flow rates must be calculated using Equation 1. Equation 2 converts the measured flow rates at actual conditions to measured flow rates at standard reference conditions. The vapor pressure (VP) of water is subtracted from the barometric pressure (BP) because a solution of mostly water in the bubble meter is used for the flow rate measurement. Equation 4 is used to calculate the measured flow rate by using the mass flow meter display value.

Equation 1

$$Q_{\text{uncorr}} = \frac{\text{Vol}}{(\text{Time}/60)}$$

Where:

Q_{uncorr}	=	Uncorrected flow rate as measured with the bubble meter in cubic centimeters per minute (cc/min)
Vol	=	Volume of the bubble meter in cubic centimeters
Time	=	Elapsed Time in Seconds of bubble

Equation 2

$$Q_{\text{@SRC}} = Q_{\text{uncorr}} \times \frac{(P_{\text{amb}} - P_{\text{vap}}) \times 298}{(T_{\text{amb}} \times 760)}$$

Where:

$Q_{\text{@SRC}}$	=	Flow Rate corrected to Standard Reference Conditions, 298 °K & 760 mmHg
Q_{uncorr}	=	Uncorrected flow rate as measured with the bubble meter
P_{amb}	=	Station barometric pressure (not corrected to sea level) in millimeters of mercury
P_{vap}	=	Vapor pressure of water in millimeters of mercury
T_{amb}	=	Ambient station temperature, (°K)
°K	=	Degrees Kelvin, °K = °C + 273

Vapor pressure may also be calculated using Equation 3.

Equation 3

$$P_{\text{vap}} = 2879.142295 - 20.588731 * (T_{\text{amb}} + 273) + 0.036936 * (T_{\text{amb}} + 273)^2$$

Where:

T_{amb} = ambient room temperature, °C

Table 1
Vapor Pressure

°C	°K	Vapor Pressure (mmHg)
20	293	17.5
21	294	18.6
22	295	19.8
23	296	21.1
24	297	22.4
25	298	23.8
26	299	25.2
27	300	26.7
28	301	28.3
29	302	30.0
30	303	31.8

Equation 4

$$\text{Mass Flow Controller Flow Rate} = (m * \text{meter display}) + b$$

Mass Flow Controller certifications must meet the following requirement: The percent difference between the curve flows and the true flows must be within $\pm 2.0\%$. If the curve flow exceeds $\pm 2.0\%$ the failed flow point(s) must be repeated. If all of the flows still do not meet the requirement, the flow controller should be considered suspect and corrective action should be taken.

Many models of mass flow controlled gas blenders have software that allows the displayed flow rate to equal the true flow rate. After mass flow meter calibration flow data is entered into the gas blender that compensates each flow meter so that displayed flow rates equal true flow rates. In this case no slope or intercept is applied (slope = 1.000, intercept = 0.0).

3.3 Field Verification of Mass Flow Controllers (MFC)

Prior to being deployed to an air monitoring station, stationary transfer standard mass flow controllers receive a complete 20-point flow certification (20-point cylinder MFC and 20-point dilution MFC).

3.4 Transfer Analyzer Calibration

Transfer standard certifications for SO₂, CO, and NO/NO_x are performed by “transferring” the authority of a primary standard to an ambient air analyzer. This transfer is accomplished by calibration of the analyzer with a primary standard.

The following sections present the requirements and techniques of a transfer analyzer calibration.

Transfer standard certifications for SO₂, CO, and NO/NO_x are performed using analyzers designated by USEPA as reference method or equivalent method. The Quality Assurance Certification Facility room temperature during calibrations/certifications is maintained in the range of 25 °C ±5 °C. All tubing and manifolds are constructed of non reactive materials such as borosilicate glass and TFE Teflon. Calibration procedures for each transfer analyzer are listed in the appropriate chapter of this manual. The calibration must include an external zero and at least four upscale concentrations which are equally spaced (see Table 2). The span point or high concentration introduced to the transfer analyzer should be approximately 80% of the measuring range of that analyzer.

Table 2
Transfer Analyzer Calibration Points

Transfer Analyzer Range, (ppm)	Recommended Calibration Points (ppm)				
	0.5	0.40 to 0.45	0.28 to 0.32	0.18 to 0.22	0.09 to 0.14
50	40 to 45	28 to 32	18 to 22	9 to 14	0.00

Concentrations generated by a master calibrator gas dilution system and primary standard cylinder are determined using Equations 5 and 6.

Equation 5

$$Q_{cyl} = (m_{cyl} \times D_{cyl}) + b_{cyl}$$

$$Q_{dil} = (m_{dil} \times D_{dil}) + b_{dil}$$

Where:

Q_{cyl}	=	True flow rate of cylinder (gas) mass flow meter, (cc/min)
m_{cyl}	=	Calibration slope of the cylinder (gas) mass flow meter
b_{cyl}	=	Calibration intercept of the cylinder (gas) mass flow meter
D_{cyl}	=	Cylinder (gas) mass flow meter display
Q_{dil}	=	True flow rate of air gas flow meter, (cc/min)
m_{dil}	=	Calibration slope of the dilution (or air) mass flow meter
b_{dil}	=	Calibration intercept of the dilution (or air) mass flow meter
D_{dil}	=	Dilution (air) mass flow meter display

Equation 6

$$[C]_{\text{out}} = \frac{Q_{\text{cyl}} \times [C]_{\text{cyl}}}{Q_{\text{cyl}} + Q_{\text{dil}}}$$

Where:

$[C]_{\text{out}}$	=	¹ Calibrator Output Concentration in ppm
Q_{cyl}	=	Cylinder Gas flow rate in cc/min
$[C]_{\text{cyl}}$	=	Cylinder Gas Concentration in ppm
Q_{dil}	=	Dilution flow rate in cc/min
Q_{tot}	=	² Total flow rate, $Q_{\text{cyl}} + Q_{\text{dil}}$

¹The same concentration is calculated if cylinder gas flow rate and dilution flow rate are in units of liters per minute (l/m). 1000 cc/min = 1.0 l/min

²Many gas calibration systems use the total flow rate (Q_{tot}) on their displays.

The slope, intercept, and correlation coefficient for the transfer analyzer calibration is computed by the least-squares linear regression of the standard concentration (y) and the analyzer response (x), $y = mx + b$. The measured values from the analyzer can then be determined by using Equation 7.

The transfer analyzer calibration must meet the following criteria in order to be acceptable:

1. All calibration points must fall within $\pm 3.0\%$ of the line of best fit. This is determined using Equation 8:

Equation 7

$$[C]_{\text{meas}} = (m * R_{\text{analyzer}}) + b$$

Equation 8

$$\% D = \frac{[C]_{\text{meas}} - [C]_{\text{std}}}{[C]_{\text{std}}} \times 100$$

2. The difference between the highest and lowest percentages must be less than or equal to 4.0%.
3. The correlation coefficient must be at least 0.999.

One or more of the calibration points must be repeated if the calibration does not meet the above criteria. Failure to meet the above criteria after several calibration attempts may indicate a problem with the analyzer. At that time, the analyzer should be considered suspect and not used to perform certifications.

Some calibrator gas dilution systems have software that allows the mass flow meter display to equal the true flow rate. For those systems the slope (m) equals 1.000 and the intercept (b) equals 0.000 for both the gas and dilution mass flow meters (see Equation 6-4).

3.5 Certification of Portable and Stationary Gas Cylinders

Most gas dilution systems consist of a blending device, cylinder, regulator, sample delivery lines, and clean air (zero air) system. If the system has mass flow meters, the meter display must be certified with a NIST-traceable flow standard. If the system does not have mass flow meters, flow rates should be measured at each certification concentration using an NIST-traceable flow standard.

Normally four certification concentrations and a zero are introduced into the transfer analyzer. The certification concentrations should be evenly spaced and fall within the calibration curve of the transfer analyzer (e.g., .400, .300, .200, and .100). Once certified, NO cylinders are good for 3 years, SO₂ cylinders are good for 4 years, and CO cylinders are good for 8 years (Table 2-3, EPA Traceability Protocol for Assay and Certification of Gaseous Calibration Standards, May 2012).

An average cylinder concentration is determined from the mean of the calculated concentrations from Equation 9.

Equation 9

$$[C]_{\text{cyl}} = \frac{[C]_{\text{meas}} \times (Q_{\text{cyl}} + Q_{\text{dil}})}{Q_{\text{cyl}}}$$

Where:

$[C]_{\text{cyl}}$	=	calculated cylinder concentration
$[C]_{\text{meas}}$	=	measured concentration from the transfer analyzer
Q_{cyl}	=	cylinder flow rate, cc/min or l/min
Q_{dil}	=	dilution (air) flow rate, cc/min or l/min

Note: cylinder and dilution flow rate may be substituted with the total flow rate,

where:

$$Q_{\text{tot}} = Q_{\text{cyl}} + Q_{\text{dil}}$$

3.6 Direct Gas Cylinder Certification

Direct cylinder gas (cylinder gas not requiring zero air dilution) is introduced into the transfer analyzer at ambient pressure using a manifold or a tee delivery line. Flow to the manifold or tee delivery line should exceed the transfer analyzer's flow demand by at least 25 percent. A certified rotameter is recommended to control the amount of flow.

Cylinder gas must be introduced into the analyzer at least two times per cylinder with either zero air or a cylinder gas with a different concentration introduced between each certification point. Zero air should be introduced to the transfer analyzer a minimum of once per every six cylinders.

An average cylinder concentration is determined from the mean of the two calculated concentrations using Equations 10 and 11.

Equation 10

$$[C]_{\text{dir}} = (MR \times m) + b$$

Equation 11

$$[C]_{\text{davg}} = \frac{[C]_{\text{dir}1} + [C]_{\text{dir}2}}{2}$$

Where:

$[C]_{\text{dir}}$	=	calculated direct cylinder concentration
MR	=	transfer analyzer response
m	=	calibration slope of transfer analyzer
b	=	calibration intercept of transfer analyzer
$[C]_{\text{davg}}$	=	average calculated direct cylinder concentration

3.7 Certification Limits

Cylinder transfer standards must meet the limits listed below. If these limits cannot be achieved, the cylinder cannot be used for ambient analyzer calibrations or audits.

1. All calculated concentrations must be within $\pm 4.0\%$ of the average concentration.
2. The difference between any two calculated concentrations must be less than or equal to 5.0%.
3. The new average concentration should be within $\pm 4.0\%$ of the previous concentration.

4.0 Ozone Traceability Levels & Certification Requirements

4.1 Introduction

A photometer is an instrument that measures light intensity. Ozone photometers are designed to measure the light intensity (absorption of ozone) at ultra-violet wavelengths. Ozone photometer-generators are designed to produce ozone at precise concentrations as measured by the photometer part of the instrument. A feedback system in the instrument ensures that the desired ozone concentration is produced.

The U. S. Environmental Protection Agency has designated ozone photometer certification traceability levels. The levels are:

- Level 1 – USEPA Standard Reference Photometers
- Level 2 – Indiana Primary Standard Photometers
- Level 3 – Indiana Portable or Stationary Transfer Standards
- Level 4 – Indiana Portable or Stationary Transfer Standards verified using a Level 3

Based on their use, ozone Transfer Standards are divided into two types:

1. Portable Transfer Standards, (PTS),
2. Stationary Transfer Standards, (STS).

The type of ozone transfer standard determines certification procedures, calculations, and re-certification frequencies.

4.1.1 Stationary Ozone Transfer Standards

Stationary ozone transfer standards are defined as photometer-generators permanently located at each of Indiana's ozone monitoring sites. They are designed to automatically (via an internet based data acquisition system) calibrate, zero/span and perform weekly precision checks. A stationary ozone transfer standard consists of a photometer and an ozone generator which may be an ozone only calibrator (i.e., API Model 703) or in a gas blending device (i.e., API 700E). Annually each stationary ozone standard is returned to the QA Lab for photometer calibration. After photometer calibration a 6-day six point verification is performed on the calibrator. While at the air monitoring station the calibrator's accuracy is verified with a 1-day six point field verification within six months after the 6-day verification. A field verification is a comparison of the stationary transfer standard output concentration to an independent portable transfer standard output concentration.

4.1.2 Portable Ozone Transfer Standards

A portable ozone transfer standard is defined as photometer-generator that is transported to the monitoring site for each audit and then returned to the IDEM Shadeland facility in Indianapolis or at IDEM regional offices throughout Indiana. A portable ozone transfer standard consists of a photometer and an ozone generator which is an ozone only calibrator (i.e., Sabio Model 2030). A portable ozone transfer standard can also be housed in a gas dilution system such as an API 700E. Portable ozone transfer standards are used for Quality Control (QC) and Quality Assurance (QA) activities such as accuracy audits and occasionally validation/precision audits. Portable ozone transfer standards are certified every three months in the QA Lab (1-day certification).

4.2 Level 2 Primary Standard Photometer

Indiana's ozone primary standard photometer is a Thermo Environmental Instruments Model 49i UV Photometric Analyzer. Four criteria must be satisfied for this instrument to be designated as Indiana's primary standard photometer:

1. The instrument is exclusively dedicated to the verification of Level 3 ozone transfer standards and remains in the Quality Assurance Certification facility. It is removed from the lab only for the annual verification with the Environmental Protection Agency Region 5 National Institute of Standards and Technology Standard Reference Photometer (EPA NIST SRP) in Chicago, IL.
2. The instrument's ozone scrubbing canister is removed so that zero reference air must be provided by the transfer standard under verification.
3. Sample measurements are corrected for temperature and pressure.
4. Annually, the instrument must pass a comparison test with the EPA NIST SRP at USEPA Region 5 laboratory in Chicago, IL. The comparison test limits are a range of the slope and intercept from a linear regression of the NIST SRP readings versus Indiana's Primary Standard photometer readings (slope must be 1.00 ± 0.03 and intercept 0 ± 3 ppb). In addition, each point must be within $\pm 3.0\%$ of the SRP concentration, the relative standard deviation of slope must be $<3.7\%$, and the standard deviation of the intercepts must be <1.5 ppb.

4.2.1 Verification of Level 2 Standard with Level 1 EPA SRP

Annually (usually in November or December) a comparison with the EPA NIST SRP (S/N 6) is conducted on Indiana's primary standard photometer and backup primary standard photometer. For each instrument: six comparisons consisting of a zero concentration and six upscale ozone concentrations ranging from 80 ppb to 450 ppb (Indiana's Level 2 Standard versus USEPA's Level 1 Standard). A slope & intercept are calculated for each of the three comparisons. The average of the 3 slopes and intercepts must meet the following limits:

- Slope: 1.00 ± 0.03
- Intercept: 1 ± 3 ppb

4.2.2 Backup Standard Photometer

Indiana maintains one backup ozone standard photometer. This backup Standard Photometers must meet the same criteria as that of the Primary Standard Photometer.

4.2.3 Primary Standard Field Photometer

Indiana's single primary standard field photometer (PSFP) is a Thermo Environmental Instruments Model 49i UV Photometric Analyzer. The following criteria apply to the primary standard field photometer:

1. The instrument is exclusively dedicated to the verification of stationary transfer standards in the field. (When verified during the off-season, stationary transfer standards are brought from the field to the lab to be verified with the Level 2 Primary Standard

Photometer, making them Level 3 primary transfer standards. When verified in-season and on-site with the Level 3 PSFP, the primary transfer standards become Level 4 instruments until they are brought in for their off-season verification in the laboratory.

2. The instrument's ozone scrubbing canister is removed so that zero reference air must be provided by the primary transfer standard under verification.
3. Sample measurements are corrected for temperature and pressure.
4. Annually, the PSFP must pass a comparison test with the Level 2 Primary Standard Photometer.
5. Starting in late 2015 the QA Section plans to annually have the PSFP pass a comparison test with the EPA NIST SRP at USEPA Region 5 laboratory in Chicago, IL. The comparison test limits are a range of the slope and intercept from a linear regression of the NIST SRP readings versus Indiana's Primary Standard photometer readings (slope must be 1.00 ± 0.03 and intercept 0 ± 3 ppb). In addition, each point must be within $\pm 3.0\%$ of the SRP concentration, the relative standard deviation of slope must be $<3.7\%$, and the standard deviation of the intercepts must be <1.5 ppb.

4.3 Stationary Ozone Transfer Standard Verification Requirements

Stationary ozone transfer standard must meet the following requirements to be verified by Indiana's Primary Standard Photometer and used as a transfer standard.

1. Each stationary transfer standard must have an initial verification demonstrating that it can maintain a slope (both individual and average) of 0.975 to 1.025 (or $\pm 2.5\%$ of 1.000) and an intercept (both individual and average) of ± 5 ppb ($\pm .005$ ppm) for six consecutive days .

Each standard's initial certification is conducted over a six day period with the same six settings used on each day. Ozone concentrations are in Table 3.

**Table 3
Ozone Calibration Points**

Calibration Point	<u>Concentration</u>	
	(ppm)	(ppb)
1	0.450	450.0
2	0.350	350.0
3	0.250	250.0
4	0.150	150.0
5	0.050	50.0

2. Each stationary transfer standard must be capable of providing at least 25% more output sample flow and 25% more zero reference air flow than required by the primary standard photometer.

The excess output and zero reference air flows are vented through a tee or manifold. This technique ensures that sufficient flows are provided to the primary standard at atmospheric pressure. Pressurized flows may cause damage to analyzers.

3. The stationary transfer standard must be capable of providing at least 25% more output sample flow for any audited or calibrated ozone analyzer. For example, if an ozone analyzer requires 2.0 liters per minute of sample, the generator must have a minimum output sample flow of 2.5 liters per minute.
4. During the winter months when most ozone sites are not collecting data, the stationary standards are returned to IDEM Shadeland facility for maintenance, photometer calibration and either an one day or six day ozone verification, depending on the status of the calibrator.
5. While at each ozone monitoring site, stationary standards will be re-verified by the QA Field Primary Standard within six months after the verification that was performed in the lab.

4.3.1 Stationary Ozone Standards Certification Summary Procedure

Stationary ozone standards are certified by recording its displayed output concentration at a specific setting and the primary standard photometer displayed reading. The standard's output flow is introduced into the sample inlet of the primary standard. At the same time the stationary standard's zero air supply is used to supply zero reference air to (the zero air inlet) the primary standard at ambient pressure.

1. Ten readings from the primary standard display and ten readings from the stationary ozone standard display are averaged for each of the six settings (zero plus five upscale points).
2. A slope and intercept is computed using the least-squares linear regression of the primary standard average reading (x) versus and the transfer standard's average reading (y).
3. The 1-day slope and intercept must meet the following limits:
Slope: 0.975 to 1.025 (or $\pm 2.5\%$ of 1.000)
Intercept: ± 5 ppb ($\pm .005$ ppm).
4. Stationary ozone standards that pass the slope & intercept limits are stationed at an ozone monitoring site for the duration of the ozone season. Displayed ozone concentration equals the true ozone concentration (no slope and intercept correction).
5. While at the monitoring site stationary standards will be re-verified by the field ozone primary standard.

4.4 Portable Ozone Transfer Standards Certification Requirements

Ozone portable standards must meet the following requirements to be certified by Indiana's Primary Standard Photometer and used as a transfer standard.

1. Each portable standard must have an initial 6-day certification (zero plus 5 upscale concentrations). After each day's certification linear regression is used to calculate a slope and intercept (x =primary standard, y =transfer standard). The slopes and intercepts from each day are averaged and must meet the requirements listed in Table 4.
2. Three months after the 6-day certification a 1-day certification must be performed. The slope and intercept from Day 1 of the 6-day certification is dropped and the slope and intercept from the new 1-day certification is used for the new 6-day average calculation. A new 1-day certification is required every three months. Each time a 1-day certification is performed the oldest slope/intercept is dropped and the new slope/intercept is added to the 6-day average calculations. If more than three months have elapsed then a new 6-day certification must be performed.
3. Each portable standard must be capable of providing at least 25% more output sample flow and 25% more zero reference air flow than required by the primary standard photometer. The excess output and zero reference air flows are vented through a tee or manifold. This technique ensures that sufficient flows are provided to the primary standard at atmospheric pressure. Pressurized flows may cause damage to analyzers.

The portable standard must also be capable of providing at least 25% more output sample flow for all ozone analyzers it will be used for calibrations or audits. For example, if an ozone analyzer requires 2.0 liters per minute of sample, the generator must have a minimum output sample flow of 2.5 liters per minute.

4. Each portable photometer-generator must be capable of providing at least 25% more output sample flow and 25% more zero reference air flow than required by the primary standard photometer.
5. Each photometer-generator must measure concentrations with the photometer portion of the device and provide automatic correction for temperature and pressure for the ozone output. In addition the photometer-generator should have a feedback mechanism activated which maintains the selected concentration.

4.4.1 Portable Ozone Transfer Standards Certification Summary Procedure

The ozone portable transfer standards certification procedure is contained in United States Environmental Protection Agency's Technical Assistance Document "Transfer Standards for Calibration of Air Monitoring Analyzers for Ozone" (EPA-454/B-13-004, October 2013). Generally the procedure is as follows:

Ozone portable transfer standards are certified by comparing their display readings against the primary standard photometer's display. For each certification, six concentrations are produced from the ozone generator portion of the ozone photometer-generator and introduced into both the transfer standard photometer portion of the instrument and the primary standard photometer. The photometer-generator's clean air supply should be used to supply zero reference air to the primary standard photometer. If possible, the same clean air supply used for field use should be used for the certification. All clean air supplies must be free of contaminants (i.e. charcoal column) and be free of moisture (drying column, i.e. silica gel).

Both the photometer-generator's ozone output flow and zero air flow must be delivered to the primary standard photometer at atmospheric pressure. Excess flow from the photometer-generator must be vented with a Teflon tee or glass manifold.

1. For each day's verification, six settings (five upscale and one zero) are used to produce six concentrations from the ozone generator-photometer. Ten readings from the ozone generator-photometer display and ten readings from the primary standard display are averaged for each of the six settings.
2. For each day's verification a slope and intercept is computed using the least-squares linear regression using the average readings from the photometer-generator's display versus the primary standard photometers display.
3. When day six is complete, six slopes and six intercepts have been calculated. From these six slopes and intercepts an average slope, intercept, relative standard deviation of the slopes, and the relative standard deviation of the intercepts is computed. Each six-day certification must meet the limits specified in Table 4.

An ozone concentration (Standard Ozone Concentration) is calculated for any upscale ozone concentrations with the following formula:

Equation 12

$$\text{Standard Ozone Concentration} = (\text{Indicated Concentration} - \text{Average Intercept}) * (1/\text{Average Slope})$$

Where:

Indicated Concentration = Photometer Generator Upscale Display Reading – Display Reading for Zero.

4. Within three months from the last day of the 6-day certification a one-day re-certification must be performed. The day 1 slope and intercept from the original six-day certification is dropped from the calculations and the new one-day re-certification data is added to the calculations. These six most recent comparisons are used to calculate the new average slope and intercept as well as the new relative standard deviation of the slopes and the intercepts. One-day recertification must meet the limits specified in Table 4.

**Table 4
Ozone Certification Requirements**

Criteria	Limit	Comment
Std Dev (S_m) of Average Slope \bar{m} (expressed as a percentage)	$S_m \leq 3.7\%$	The standard deviation of the average of 6 slopes. Calculated from either the initial 6-day certification or the 1-day recertification.
Std Dev (S_I) of Average Intercept \bar{I} (expressed as a percentage)	$(S_I) \leq 1.5\%$	The standard deviation of the average of 6 intercepts. Calculated from either the initial 6-day certification or the 1-day recertification.
Slope of 1-day recertification (m)	$M \pm 5\%$	1-day recertification slope must be with $\pm 5\%$ of the average slope of the current 6-day certification.

5. Standard Ozone Concentration Calculation

Use Equation 6-9 to calculate the transfer standard ozone concentration portable ozone transfer standards.

Equation 13

$$[C]_{\text{Std Out}} = \frac{([C]_{\text{Ind}} - b)}{m}$$

Where:

$[C]_{\text{Std Out}}$	=	Standard concentration out of the photometer
$[C]_{\text{Ind}}$	=	Indicated concentration, photometer displayed value
m	=	slope
b	=	intercept

Note: Some formulas may use S to indicate slope and I to indicated intercept.

5.0 Certification of Flow Rate Transfer Standards

5.1 Types of Flow Rate Transfer Standards

Indiana uses a variety of flow rate transfer standards for a variety of air samplers. Hi-Volume samplers used for lead require flow rate transfer standards that measure flow rates around 1.30 cubic meters per minute (Hansen Regular & Variable Orifice). Filter-based PM₁₀ and PM_{2.5} samplers require flow rate transfer standards that measure flow rates in the 16.7 liters per minute range (Chinook Streamline™ FTS and Chinook Streamline™ Pro MultiCal). Continuous PM₁₀

monitors, PM_{2.5} monitors, and Aethalometers require flow rate transfer standards that measure flow rates in the 3.0-16.7 liters per minute range (BGI tetraCal, BGI deltaCal, and BGI triCal).

Types of Flow Rate Transfer Standards

1. Hansen (Regular) Orifice
2. Hansen (Variable) Orifice
3. Chinook Streamline™ FTS (white, black & “H” hi-flow)
4. Chinook Streamline™ Pro MultiCal
5. BGI tetraCal
6. BGI deltaCal
7. BGI triCal
8. Bios Dry Piston

5.1.1 Hansen Orifice Certification Requirements

Transfer standard orifices are certified by comparing a pressure drop (measured with a manometer in inches of water) to a NIST-traceable positive displacement standard volume meter (a.k.a. Roots Meter). Detailed orifice certification procedures are listed in "Quality Assurance Handbook for Air Pollution Measurement Systems: Volume II, Ambient Air Quality Monitoring Program (EPA-454/B-13-003, May, 2013).

Transfer standard orifices must be certified against a positive displacement standard volume meter annually (every 12 months). If an orifice is damaged or a part is replaced that affects the flow, the orifice must be certified prior to use.

The following criteria must be met in order for the certification to be valid:

1. A minimum of five (5) flow rates must be used for the certification.
2. All certification flow rates should be in the range of 1.0 to 1.8 cubic meters per minute. At least three of these flows must be in the flow rate range of 1.02 to 1.24 cubic meters per minute and at least three of the points must be from 1.1 to 1.7 cubic meters per minute.
3. All certification points must fall within $\pm 1.0\%$ of the calibration curve.
4. The certification should be within $\pm 2.0\%$ of the previous certification. Comparing at least two reference points (e.g., 1.13 m³/min and 1.30 m³/min) on the current certification to the previous certification should determine if the curve has shifted more than the $\pm 2.0\%$. If the comparison is greater than $\pm 2.0\%$ the certification should be repeated and the comparison should be performed using the last three slopes and intercepts.

5.1.2 Hansen Orifice

Hansen orifice (regular and variable) calibration is performed by changing the flow rate with a voltage varying device (e.g., Variac) and using an 8" x 11" quartz filter for flow resistance. An electronic manometer scaled in inches of water is used to measure the pressure drop across the orifice during the certification. A second electronic manometer, measuring in inches of water (must be converted to mm of Hg), is used to measure the standard volume meter inlet pressure drop.

Liquid manometers normally used with the orifice must contain only water (a water soluble dye may be used to improve visibility). Adding liquids such as ethylene glycol will change the calibration of the orifice and cause errors in flow rate calculations. If the manometer normally used with the orifice does not contain water (e.g., water and ethylene glycol mixture) then the orifice must be calibrated with that manometer.

Place the orifice on a base plate and for a variable orifice; ensure that resistance holes are fully open. Attach a filter cone to the roots meter and place a quartz filter on the cone's metal support screen. Using the cone's wing nuts secure the base plate with the attached orifice onto the cone. Vary the flow rate by changing the voltage to the motor on the roots meter with the Variac.

5.1.3 Orifice Formulas and Calculations

The following formulas are used to in orifice certification:

Equation 14

$$^{\circ}\text{K} = ^{\circ}\text{C} + 273$$

Where:

$^{\circ}\text{K}$	=	Degrees Kelvin (absolute zero temperature scale)
$^{\circ}\text{C}$	=	Degrees Celsius (metric temperature scale)

Equation 15

$$\text{mmHg} = 1.87 * \text{“ H}_2\text{O}$$

Where:

mmHg	=	millimeters of Mercury (a measure of pressure drop)
“ H ₂ O	=	inches of Water (a measure of pressure drop)
1.87	=	conversion factor

Equation 16

$$\text{Volume @SRC} = \frac{3.00 * (\text{BP}_{\text{amb}} - \text{RMM})}{760 * (298 / \text{LT})}$$

Where:

SRC	=	Standard Reference Conditions of barometric pressure and temperature of 760 mmHg and 298 °K
3.00	=	volume of air in cubic meters as measured by a Roots Meter
BP _{amb}	=	Ambient Station (not corrected to sea level) Barometric Pressure measured in millimeter of Mercury (mmHg)
RMM	=	Roots Meter Manometer Reading in mmHg. This value is measured in inches of water (H ₂ O) and converted to mmHg using Equation 11
LT	=	Lab Temperature in °K

Equation 17

$$\text{Standard Flow Rate} = \frac{\text{Volume @SRC}}{\text{ET}}$$

Where:

ET	=	Elapsed Time in minutes
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Equation 18

$$\text{CM} = \sqrt{\text{MR} * \frac{\text{BP}_{\text{amb}}}{760} * \frac{298}{\text{LT}}}$$

Where:

CM	=	Corrected Manometer Reading
MR	=	Orifice Manometer Reading

Equation 19

$$\text{CFR} = \frac{1}{\text{S}} * (\text{CM} - \text{I})$$

Where:

CFR	=	Curve Flow Rate
S	=	Certification Slope
I	=	Certification Intercept

Table 5
Example Orifice Certification Data

Example Orifice Certification Data							
Lab Temperature: 19.8 °C Barometric Pressure; 739.5				292.8 °K Equation 6-10			
Measured Data				Equation 6-15	Equation 6-16	Equation 6-17	Equation 6-18
Voltage Setting	Orifice Manometer Reading MR ("H ₂ O)	Roots Meter Manometer Reading RMM ("H ₂ O)	Elapsed Time (seconds)	Roots Meter Manometer Reading RMM (mmHg)	Volume @SRC (m ³)	[x] Standard Flow (m ³ /min)	[y] Corrected Manometer CM ("H ₂ O)
100	7.77	22.10	119.50	41.327	2.8058	1.408794	2.774877
90	6.08	17.20	137.06	32.164	2.8446	1.245272	2.454624
80	5.47	15.40	144.87	28.798	2.8543	1.182129	2.328236
70	4.95	13.90	151.49	25.993	2.8636	1.134158	2.214807
60	4.71	13.20	155.91	24.684	2.8737	1.105913	2.160448
Slope: 2.0311395				Intercept: -0.0817510			

Linear regression (least squares) is used to calculate a slope and intercept using the data pairs from the Standard Flow and Corrected Manometer columns.

When the certified orifice is used for calibrations and audits in the field Equation 19 is used to calculate the true flow rate in cubic meters per minute (m³/min).

To simplify calculations a Range Factor system is used to determine the true flow rate. A range factor is calculated using Equation 20. Equations 21a and 21b are used to calculate a Range Factor lookup table. This lookup table is posted on all orifices certified by IDEM.

Equation 20

$$\text{Range Factor} = \text{MR} * \frac{\text{BP}_{\text{amb}}}{\text{ST}}$$

Where:

MR = Orifice Manometer Reading in inches of water ("H₂O)

BP_{amb} = Station (not corrected to sea level) Barometric Pressure in millimeters of Mercury (mmHg)

ST = Site Temperature in degrees Kelvin (°K)

Equation 21a

$$\text{Low Range Factor} = (((\text{TF} - 0.005) * \text{S}) + \text{I}) * (((\text{TF} - 0.005 * \text{S}) + \text{I}) / 0.3921) - 0.001$$

Equation 21b

$$\text{High Range Factor} = (((\text{TF} + 0.005) * \text{S}) + \text{I}) * (((\text{TF} + 0.005 * \text{S}) + \text{I}) / 0.3921) - 0.001$$

Where:

TF = True Flow Rate.

S = Orifice certification slope
I = Orifice certification intercept

5.2 Verification and Certification of Flow Transfer Standards (FTS)

Flow transfer standards (FTS) (i.e., Streamline manufactured by Chinook Engineering) must be certified annually (every 12 months) with a NIST-traceable primary flow rate standard. A manometer that is going to be used with the Chinook should also be used during the certification. Within the six to eight point certification an evaluation of three certification points is performed. This three point evaluation is known as a verification. The points represent flow rates the FTS routinely uses for sampler calibrations and audits. The evaluation uses the previous slope and intercept and if all three points pass the 1.0% limit the previous slope and intercept is retained for another 12 months.

FTS flow rate ranges vary depending on the size (diameter) of the capillary contained in the device. There are four types of FTS in general use:

- White FTS – flow rate range of 8 to 20 liters per minute (l/min),
- Black FTS – flow rate range of .5 to 9 l/min.
- ‘H’ FTS – flow rate range of 5 to 30 l/min
- Electronic FTS – reads directly in l/min and corrects flow rate to Standard Reference Conditions (SRC) with built-in temperature and barometric pressure sensors.

For a white or black FTS use the current slope and intercept for the three point flow verification (Equation 23) and for the electronic FTS use the direct readings of the flow rate in l/min for the three point flow verification. If all three verification points for the FTS are less than 1% difference as calculated with Equation 22 then the current slope and intercept is valid for one year.

Equation 22

$$\% D = \frac{(Q_{act} - Q_{std})}{Q_{std}} * 100$$

Where:

% D	=	Percent difference between the FTS actual flow rate and the flow rate of the primary standard
Q_{act}	=	Actual Flow Rate of the FTS, l/min
Q_{std}	=	Standard Flow Rate of the Primary Standard, l/min

Equation 23

$$Q_{act} = m * \left[\sqrt{\frac{\Delta P * T_{amb}}{P_{amb}}} \right] + b$$

m	=	FTS calibration slope
b	=	FTS calibration intercept
ΔP	=	Manometer reading (pressure drop), inches of water
T_{amb}	=	Ambient temperature, °K
P_{amb}	=	Barometric pressure, atmospheres
		1 atmosphere = 760 mmHg

Certification of a high-flow (white) FTS is an eight point calibration which must contain all three of the flow rates used in the verification. A slope and intercept is calculated using the flow rate of the primary standard and the manometer reading of the FTS. All eight calibration points must less than 1% difference as calculated with Equation 22. If the FTS fails the verification then the new slope and intercept must be used.

Certification of a low-flow (black) FTS is a six point calibration which must contain all three of the flow rates used in the verification. A slope and intercept is calculated using the flow rate of the primary standard and the manometer reading of the FTS. All six calibration points must less than 1% difference. If the FTS fails the verification then the new slope and intercept must be used.

Certification of an electronic FTS is a six-point calibration of the flow rates between the primary standard and the l/min reading of the FTS. A slope and intercept is not applied to this device. All six certification points must less than 1% difference. The accuracy of the barometric pressure and two temperature sensors is also verified. If the FTS fails the certification then the device must be returned to the manufacturer for repairs and recalibration.

6.0 Certification of Thermometers & Electronic Temperature Devices

Thermometers and Electronic Temperature Devices (digital thermometers) must be certified traceable to the OAQ/QAS Certification Facility's NIST-traceable temperature standard. Mercury and organic fluid thermometers must be certified prior to use and annually (every 12 months) thereafter. Electronic thermometers must be certified prior to use and annually thereafter.

Table 6 lists the three ranges that must be used when certifying thermometers and electronic temperature devices:

Table 6
Temperature Certification Points

Temperature Range	Temperature Range	General Use Limit	Meteorological Limit
Ambient temperature	20 °C to 30 °C	±1.0 °C	±0.2 °C
Cold temperature	-15 °C to -10 °C		
Hot temperature	40 °C to 45 °C		

The general use transfer standard must agree within ±1.0 degree Celsius (°C) of the NIST-traceable temperature standard for all ranges. Thermometers and electronic devices used for meteorological purposes must agree within ±0.2 °C. A device that fails the ±0.2 °C limit may not be used for meteorological purposes but may be used for general purposes if it passes the ±1.0 °C limit. A device that fails either standard may be replaced or a correction factor must be applied.

7.0 Certification of Barometers (Aneroid & Digital)

Barometers (aneroid and digital) must be certified traceable to the OAQ/QAS Certification Facility's primary standard mercury column barometer prior to use and annually (every 12 months) thereafter.

Aneroid and digital barometers must be verified with the OAQ/QAS Certification Facility's mercury barometer at station pressure annually (every 12 months). The transfer standard barometer must agree within ±1.0% of the primary standard reading. Deviations greater than 1.0% require the barometer to be recalibrated (i.e. if primary standard barometric pressure reading = 740 mmHg then the limit is 740 ±7.4 mmHg). Some models of barometers may be adjusted to the primary standard while other models may require a factory adjustment. Consult the instrument's manual for calibration procedures.

8.0 Certification of Single Speed and Selectable Wind Speed Motors

Wind Speed Motors (single speed and selectable) must be certified traceable to the OAQ/QAS Certification Facility's primary photo tachometer annually (every 12 months).

Wind speed transfer standards must be certified annually (every 12 months) to the NIST-traceable OAQ/QAS Certification Facility's Photo Tachometer. Two runs of clockwise and counterclockwise measurements are recorded. The transfer standard must agree within one (±1.0) RPM of the Certification Facility's Photo Tachometer. If not, the instrument must be taken out of service or a correction factor applied.

9.0 Certification of Relative Humidity Devices

Relative humidity transfer standards (e.g., hygrothermographs, hygrometers, and sling psychrometers) must be certified traceable to the OAQ/QAS Certification Facility's primary standard annually (every 12 months). For hygrometer sensors, at least two (2) comparison points must be performed (e.g., one (1) indoors and one (1) outdoors). The transfer standard must agree within \pm six (6) percent relative humidity of the primary standard. If not, then a calibration must be performed. A sling psychrometer is certified by performing the certification on the two thermometers (see Section 6.0). The two thermometers must agree within \pm 1.0 degree Celsius of the NIST-traceable thermometer unless they are being used for meteorological applications, then the limit is \pm 0.2 degree Celsius. Relative humidity/dew point sensors used for meteorological audits must compare to the primary standard within \pm 0.7 degree Celsius dew point.

10.0 Certification of Elapsed Time Meters (ETM) & Stop Watches

Elapsed time meters (ETM) to be used as transfer standards (field auditing purposes) must be certified annually (every 12 months) by performing a comparison with an NIST-traceable stop watch. The transfer standard elapsed time meter must agree within two (\pm 2) minutes of the stop watch over a 24-hour period.

The certified ETM can be used to certify/audit ETMs used for field measurements.

Stop watches must be certified against a NIST-traceable source annually (every 12 months). These certifications can be performed by the manufacturer, the agency, or the Quality Assurance Section.

11.0 Certification of Multimeters (Digital Volt Meter)

Multimeters must be certified annually (every 12 months) by performing a comparison with a NIST-traceable power supply. All ranges used must be certified. Normally this includes the 0 to 200 millivolt, 0 to 2 volt, and 0 to 20 volt ranges. Approximately ten evenly spaced readings are taken for each range. The transfer standard multimeter must agree with the NIST-traceable power supply within \pm 0.2% of the full range being certified.

Table 7 lists the limits that must be met for the certification to be acceptable:

Table 7
Multimeter Certification Limits

Range	Limit
0 - 200 millivolt	\pm 0.4 millivolts
0 - 2 volt	\pm 0.004 volts
0 - 20 volt	\pm 0.04 volts

Multimeters not meeting these limits may use a slope and intercept to meet the limits.

12.0 BIOS and other Piston-Type Flow Systems

BIOS and other piston-type flow systems must be verified annually (every 12 months) by comparison to the State-QAS Primary Standard Cal Technix Flow System. Those units which agree within $\pm 2.0\%$ of the primary standard will not require a slope and intercept correction. Units which do not meet the verification limit may use a slope and intercept correction; however, all points must fall within $\pm 2.0\%$ of the least squares calibration line of best fit. The same formula for Mass Flow Controller flow rates (Equation 4) is used for the Bios.

13.0 Electronic Manometer

Electronic manometers must be certified annually (every 12 months) according to the user's manual. Manometers used with a Chinook/Orifice/etc. need to be certified with its respective unit.

14.0 Pyranometer/Radiation Sensor

Radiometers should be calibrated annually (every 12 months). Pyranometers and any other radiation measuring sensors must be calibrated every two (2) years. Calibrations for these instruments must be performed by the manufacturer because the QAS Certification Facility does not have a radiation source.

15.0 Summary of Certification Limits

Certification/calibration/verification procedures are available from OAQ/QAS upon request, for the transfer standards listed below. The requirements for each type of transfer standard are summarized in Table 8. All transfer standards must be certified/calibrated/verified to OAQ/QAS primary standards or be approved by OAQ/QAS.

Table 8
Summary of Certification Requirements

Type	Device	Freq (months)	Primary Standard	Limit
Portable	MFC	6	Hastings Bubble Meter	$\pm 2\%$
Stationary	MFC	12	Hastings Bubble Meter	$\pm 2\%$
Portable	SO ₂ , NO or CO Cylinder blended using calibrator	6	NIST Traceable Cylinder Gas	$\pm 4\%$ of Previous Certified Conc.
Stationary	SO ₂ , NO or CO Cylinder blended using calibrator	48 SO ₂ 36 NO 96 CO	NIST Traceable Cylinder Gas	$\pm 4\%$ of Previous Certified Conc.
Portable	O ₃ Generator-Photometer	3	IDEM-QAS Primary Standard Photometer	Numerous limits see Section 4.0
Stationary	O ₃ Photometer	12	IDEM-QAS Primary Standard Photometer	Numerous limits see Section 4.0
Temperature Device		12	NIST Traceable Temperature Device	$\pm 1.0^{\circ}\text{C}$ Non-Met $\pm 0.2^{\circ}\text{C}$ Met Use
Barometer (aneroid or electronic)		12	Mercury Barometer	$\pm 1.0\%$ of primary standard reading
Single Speed and Selectable Speed Wind Motor		12	Photo Tachometer	± 1 RPM
White Chinook	FTS	12	Cal Technix, Molbox	$\pm 1.0\%$
Black Chinook				
'H' Chinook				
Electronic Chinook				
BGI tetraCal				
BGI deltaCal				
Hansen Regular Orifice	FTS	12	Dresser Roots Meter	$\pm 1.0\%$
Hansen Variable Orifice				
UV Radiation Sensor		12	Manufacturer's radiation sensor	Manufacturer's requirements
Solar Radiation Sensor		24	Manufacturer's radiation sensor	Manufacturer's requirements
Elapsed Time Meter –Transfer Standard		12	Stop Watch NIST Traceable	± 2 minutes/24 hours
Stop Watch		12	Atomic Clock	Manufacturer's requirements
Electronic Manometer		12	Liquid Manometer	Manufacturer's requirements
Direct (Direct) CO Cylinder		96	NIST Traceable Cylinder Gas	$\pm 4\%$ of Previous Certified Conc
O ₃ Primary Standard Photometer		12	EPA Region 5 NIST Primary Photometer	Numerous limits see Section 5.0

16.0 Acronyms

USEPA-Reg 5	United States Environmental Protection Agency – Region 5
IDEM	Indiana Department of Environmental Management
OAQ	Office of Air Quality
AMB	Air Monitoring Branch
QAS	Quality Assurance Section
SRC	Standard Reference Conditions (298 °K & 760 mmHg)

17.0 Abbreviations and Alternate Terms

Cert	Certification
Calib	Calibration
Cyl	Cylinder, gas cylinder, calibration gas, tank, bottle
Lab	QA Lab, Quality Assurance Certification Facility
Calibrator	Blender, gas blender, dynamic gas blender
Zero Air	Clean Air, dilution air, zero air generator

18.0 Units of Measurement & Conversions

ppm or PPM ppb or PPB Conversion: 1 ppb = ppm * 0.001	Parts per Million Parts per Billion	Concentration
cc/min, ccpm, cc/m sccm l/min, lpm, l/m slpm Conversion: 1000 cc/min = 1.0 l/min m ³ /min, ft ³ /min, CFM	cubic centimeters per minute standard cubic centimeters per minute liters per minute standard liters per minute Cubic meters per minute Cubic feet per minute	Flow Rate
°F °C °K Conversion: °F = [(°C * 9)/5] + 32 °C = (°F -32)/9 * 5 °K = °C + 273.17	Degrees Fahrenheit Degree Celsius Degrees Kelvin (absolute zero)	Temperature
mmHg atm “ Hg Pa Conversion: Atm = mmHg/760 mmHg = “ Hg * 25.4 Bars = atm * 1.01325 Pa = mmHg * 133.3221	Millimeter of mercury Atmospheres Inches of mercury Pascals	Barometric Pressure
µg/min	Micrograms per Minute	Permeation Rate

19.0 Summary of Equations

1	Uncorrected flow rate as measured with the bubble meter in cc/min.
	$Q_{\text{uncorr}} = \frac{\text{Vol}}{(\text{Time}/60)}$
Where:	<p>Q_{uncorr} = Uncorrected flow rate as measured with the bubble meter</p> <p>Vol = Volume of the bubble meter in cc's</p> <p>Time = Elapsed time in seconds</p> <p style="text-align: center;">60 converts seconds to minutes</p>

2 Measured flow rate by using the mass flow meter display value.

$$Q_{@SRC} = Q_{uncorr} \times \frac{(P_{amb} - P_{vap}) \times 298}{(T_{amb} \times 760)}$$

Where: $Q_{@SRC}$ = Flow Rate corrected to Standard Reference Conditions, 298 °K & 760 mmHg
 Q_{uncorr} = Uncorrected flow rate as measured with the bubble meter
 P_{amb} = Station barometric pressure (not corrected to sea level) in millimeters of mercury
 P_{vap} = Vapor pressure of water in millimeters of mercury
 T_{amb} = Ambient station temperature, (°K)
°K = Degrees Kelvin, °K = °C + 273

3 Vapor Pressure

$$P_{vap} = 2879.142295 - 20.588731 * (T_{amb} + 273) + 0.036936 * (T_{amb} + 273)^2$$

Where: T_{amb} = ambient room temperature, °C

4 Mass Flow Controller (MFC) Flow Rate

$$\text{Mass Flow Controller Flow Rate} = (m * \text{MFC display}) + b$$

Where: m = MFC certification slope
 b = MFC certification intercept

5 Cylinder Mass Flow Controller (MFC) Flow Rate
Dilution Mass Flow Controller (MFC) Flow Rate

$$Q_{cyl} = (m_{cyl} \times D_{cyl}) + b_{cyl}$$

$$Q_{dil} = (m_{dil} \times D_{dil}) + b_{dil}$$

Where: Q_{cyl} = True flow rate of cylinder (gas) mass flow meter, (cc/min)
 m_{cyl} = Calibration slope of the cylinder (gas) mass flow meter
 b_{cyl} = Calibration intercept of the cylinder (gas) mass flow meter
 D_{cyl} = Cylinder (gas) mass flow meter display
 Q_{dil} = True flow rate of air gas flow meter, (cc/min)
 m_{dil} = Calibration slope of the dilution (or air) mass flow meter
 b_{dil} = Calibration intercept of the dilution (or air) mass flow meter
 D_{dil} = Dilution (air) mass flow meter display

6 Calibrator Output Concentration

$$[C]_{out} = \frac{Q_{cyl} \times [C]_{cyl}}{Q_{cyl} + Q_{dil}}$$

Where: $[C]_{out}$ = ¹Calibrator Output Concentration in ppm
 Q_{cyl} = Cylinder Gas flow rate in cc/min
 $[C]_{cyl}$ = Cylinder Gas Concentration in ppm
 Q_{dil} = Dilution flow rate in cc/min
 Q_{tot} = ²Total flow rate, $Q_{cyl} + Q_{dil}$

¹The same concentration is calculated if cylinder gas flow rate and dilution flow rate are in units of liters per minute (l/m). 1000 cc/min = 1.0 l/min

²Many gas calibration systems use the total flow rate (Q_{tot}) on their displays.

7 & 8 Direct Cylinder Concentration

$$[C]_{meas} = (m * R_{analyzer}) + b$$

$$\% D = \frac{[C]_{meas} - [C]_{std}}{[C]_{std}} \times 100$$

Where: $[C]_{meas}$ = Measured concentration from the transfer analyzer in ppm
 $R_{analyzer}$ = Transfer analyzer response in volts
 m = Transfer analyzer calibration slope
 b = Transfer analyzer calibration intercept
 $\% D$ = Percent difference
 $[C]_{std}$ = Standard concentration from the calibrator in ppm

9 Cylinder Concentration

$$[C]_{cyl} = \frac{[C]_{meas} \times (Q_{cyl} + Q_{dil})}{Q_{cyl}}$$

Where: $[C]_{cyl}$ = calculated cylinder concentration
 $[C]_{meas}$ = measured concentration from the transfer analyzer
 Q_{cyl} = cylinder flow rate, cc/min or l/min
 Q_{dil} = dilution (air) flow rate, cc/min or l/min

10 Direct Cylinder Concentration

$$[C]_{\text{dir}} = (MR \times m) + b$$

Where: $[C]_{\text{dir}}$ = Calculated direct cylinder concentration in ppm
MR = Transfer analyzer response in volts
m = Transfer analyzer calibration slope
b = Transfer analyzer calibration intercept

11 Average Direct Cylinder Concentration

$$[C]_{\text{davg}} = \frac{[C]_{\text{dir1}} + [C]_{\text{dir2}}}{2}$$

Where: $[C]_{\text{davg}}$ = Average of two direct cylinder calculated cylinder concentrations
 $[C]_{\text{dir1}}$ = Direct cylinder calculated cylinder concentration 1
 $[C]_{\text{dir2}}$ = Direct cylinder calculated cylinder concentration 2

12 Standard O₃ Concentration (as displayed on a certification sticker, see 6-13)

$$\text{Std O}_3 \text{ Conc} = (\text{Indicated Conc} - \text{Avg Intercept}) * (1/\text{Avg Slope})$$

13 Standard O₃ Concentration from Portable Ozone Transfer Standard (formula)

$$[C]_{\text{Std Out}} = \frac{([C]_{\text{Ind}} - b)}{m}$$

Where: $[C]_{\text{Std Out}}$ = Standard O₃ concentration from portable ozone transfer standard
 $[C]_{\text{Ind}}$ = Indicated O₃ concentration from portable ozone transfer standard
m = Portable ozone transfer standard certified slope
b = Portable ozone transfer standard certified intercept

14 Convert Celsius to Kelvin

$$^{\circ}\text{K} = ^{\circ}\text{C} + 273$$

Where: $^{\circ}\text{K}$ = Degrees Kelvin
 $^{\circ}\text{C}$ = Degrees Celsius
273 = Conversion Factor

15 Convert inches of water to millimeters of Mercury

$$\text{mmHg} = 1.87 * \text{“ H}_2\text{O}$$

Where: mmHg = Millimeters of Mercury
“ H₂O = Inches of water
1.87 = Conversion factor

16 Volume at Standard Reference Conditions (Hansen Orifice)

$$\text{Vol @SRC} = \frac{3.00 * (\text{BP}_{\text{amb}} - \text{RMM})}{760 * (298 / \text{LT})}$$

Where: Vol @SRC = Timed Volume thru Roots Meter @ SRC
BP_{amb} = Ambient barometric pressure in mmHg
RMM = Roots Meter Manometer Reading in mmHg. This value is measured in inches of water (“H₂O) and converted to mmHg using Equation 6-15
LT = Lab Temperature in degrees Kelvin
3.00 = Volume measured through Roots Meter in cubic meters
760 = Standard Barometric Pressure in mmHg
298 = Standard Temperature in degrees Kelvin

17 Standard Flow Rate (Hansen Orifice)

$$\text{Std Flow Rate} = \frac{\text{Volume @SRC}}{\text{ET}}$$

Where: Std Flow Rate = Standard Flow Rate through the Hansen Orifice
Volume @SRC = Volume calculated in Equation 6-16
ET = Elapsed time in minutes

18 Corrected Manometer reading in “H₂O.

$$\text{CM} = \sqrt{\text{MR} * \frac{\text{BP}_{\text{amb}}}{760} * \frac{298}{\text{LT}}}$$

Where: CM = Corrected Manometer Reading
MR = Orifice Manometer Reading in “H₂O
BP_{amb} = Station Barometric pressure (not corrected to sea level) in mmHg
298 & 760 = Standard temperature (°K) and barometric pressure (mmHg)

19 Orifice Curve Flow Rate in m³/min

$$CFR = \frac{1}{S} * (CM - I)$$

Where: CM = Corrected Manometer reading calculated in Equation 6-18
S = Slope of the certified orifice
I = Intercept of the certified orifice

20 Range Factor (no units)

$$\text{Range Factor} = MR * \frac{BP_{amb}}{ST}$$

Where: MR = Orifice Manometer Reading in inches of water
BP_{amb} = Station Barometric pressure (not corrected to sea level) in mmHg
ST = Site Temperature in °K

21a Low Range Number (LRF, no units)

21b High Range Number (HRF, no units)

$$LRF = (((TF - 0.005) * S) + I) * (((TF - 0.005) * S) + I) / 0.3921) - 0.001$$

$$HRF = (((TF + 0.005) * S) + I) * (((TF + 0.005) * S) + I) / 0.3921) - 0.001$$

Where: TF = True Flow Rate
S = Orifice certification slope
I = Orifice certification intercept

22 Percent Difference between the Standard and Actual Flow Rate of a Mass Flow Meter (units may be in l/min or cc/min)

$$\% D = \frac{(Q_{act} - Q_{std})}{Q_{std}} * 100$$

Where: Q_{act} = Actual Flow Rate of the FTS, l/min
Q_{std} = Standard Flow Rate of the Primary Standard, l/min

23 Actual Flow Rate of an FTS in l/min

$$Q_{act} = m * \left[\sqrt{\frac{\Delta P * T_{amb}}{P_{amb}}} \right] + b$$