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Industrial Health & Safety Instrumentation

Calibration Reliability and Advancements in Calibration Technology

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Calibration Reliability

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Presentation Overview

- ❖What is Reliable Calibration?
- ❖Supporting Documentation
- ❖Advancements in Calibration Technology


Calibration Reliability

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Presentation Overview

This presentation will discuss the importance of reliable calibration in air sampling and how calibration records should be maintained.

Additionally we will cover advancements in air sampling calibration technology and methodology, that allows users to track pump stability, and create permanent reports in defense of sample integrity.

Calibration Reliability

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What is Calibration?

Calibration is the process of adjusting a device to meet the manufacturer’s specifications that are well within industry standards and requirements.

Calibration is also defined as the issuing of a report or certificate of calibration that declares a product’s conformance with specifications and standards. This second definition of calibration is more properly referred to as certification.

Calibration Reliability

What is Reliable Calibration?

- 3rd Party Traceability
- Accuracy
- Precision
- Stability

Calibration Reliability

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3rd Party Traceability

- ❖ National Metrological Institutes (NMIs)
  - ➢ National Institute of Standards and Technology (NIST - USA)
    - ✓ NIST Traceable – Report of Calibration
    - ✓ Master Volumetric Device used for Primary Calibrators

NIST National Institute of Standards and Technology U.S. Department of Commerce

Calibration Reliability

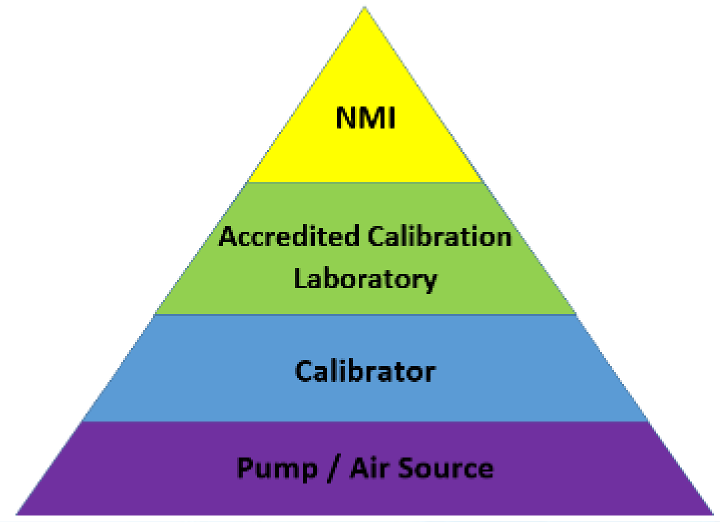
3rd Party Traceability

- ISO/IEC 17025
  - Main ISO standard used by testing and calibration laboratories
  - Labs must hold accreditation in order to be deemed technically competent

Calibration Reliability

3rd Party Traceability

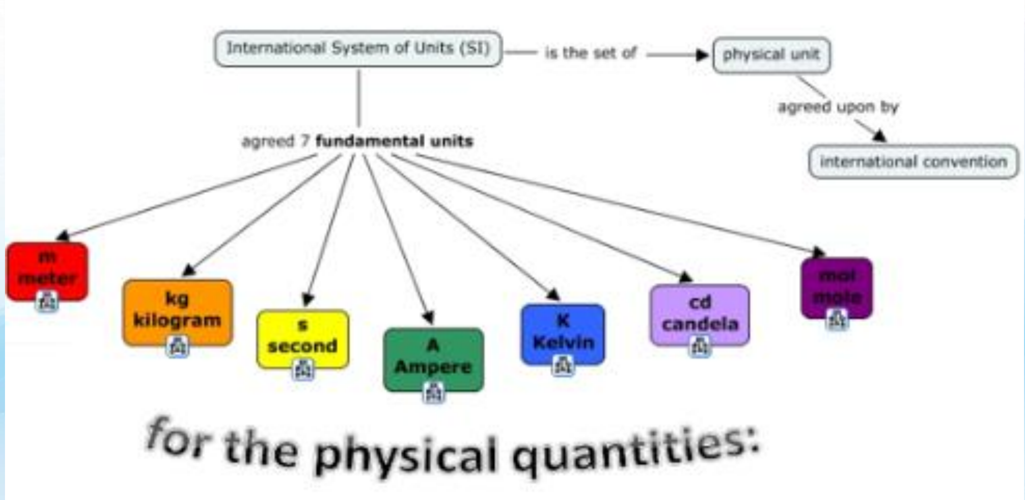
National Metrological Institutes (NMIs) are at the top of the measuring equipment hierarchy. They represent the basis for determining the values of all subordinate standards of a measured quanti



Calibration Reliability

3rd Party Traceability

The National Institute of Standards and Technology (NIST), part of the U.S. Department of Commerce, oversees the development of measurement standards and technology consistent with the International System of Units (SI). NIST is also charged with imparting these standards to the American system of measurements through calibrations and other services.



Calibration Reliability

3rd Party Traceability

Countries around the world utilize their own regional metrological institutes and laboratories to set the basis for their own standards of a measured quantity. Because of this hierarchy a traceable calibration exhibits an unbroken chain of measurements all the way to a national standard or measurement standard.

Calibration Reliability

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3rd Party Traceability

All the measurement results obtained with traceable measuring equipment are traceable to this standard and are also comparable to each other. This allows for measuring equipment that is traceable to both national standards and international standards, to have worldwide comparability of the measurement results.

Calibration Reliability

3rd Party Traceability

The provider of NIST-traceable measurements may be NIST itself or another organization. Thousands of companies tie their measurement standards to NIST. They may then follow these standards in providing measurement services to their customers, in meeting regulations, and in improving quality assurance.

Calibration Reliability

3rd Party Traceability

The International Organization for Standardization, whose ISO 9001 and 17205 standards are used around the world as the preferred criteria, form the basis for guiding the calibration and certification processes. Scientists and Industrial Hygienists utilize these standards to ensure that occupational health sampling is reliable and the results of the sampling can be used with confidence.

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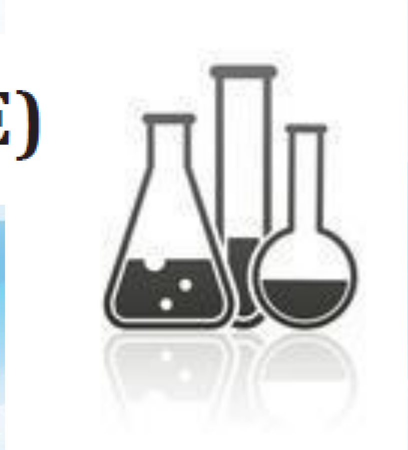
Calibration Reliability

3rd Party Traceability

This ISO 17025 standard addresses the requirements for the competence of testing and calibration laboratories. In most major countries, ISO 17025 is the standard for which most labs must hold accreditation in order to be deemed technically competent. In many cases, suppliers and regulatory authorities will not accept test or calibration results from a lab that is not ISO 17025 accredited.

ISO/IEC 17025:2017(E)



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3rd Party Traceability

The essential characteristic of a calibration certificate is the traceability of measurement results and thus its international comparability.

Note: There are several types of certificates that are offered on the market to document the accuracy of measurement equipment.


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Calibration Certificate


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ISO 17025 Calibration Certificate

Calibration Reliability

3rd Party Traceability

It is important to note that an ISO 17025 accredited calibration certificate includes the statement of measurement uncertainties, which includes the determination of the measurement process. Independent assessors must also examine the suitability of the process, and the measurement process, in order to assure traceability.

Calibration Reliability

3rd Party Traceability

According to international agreements (ILAC), only inspection laboratories accredited to ISO 17025 are permitted to carry out traceable calibrations and thus guarantee complete international comparability of the calibration results. Therefore, equipment that was simply calibrated with a traceable measuring device is not itself traceable since the measurement process was not performed in accordance with an accredited procedure. User or “field” calibrations are more accurately defined as calibration verification rather than an actual calibration.

Calibration Reliability

Accuracy

Air sampling for environmental and occupational health purposes cannot be depended on unless the equipment utilized is calibrated. Through calibration, adjustments made to a piece of equipment ensure that it performs as expected, and can be relied on to deliver predictable, accurate results that meet required quality standards.

Calibration Reliability

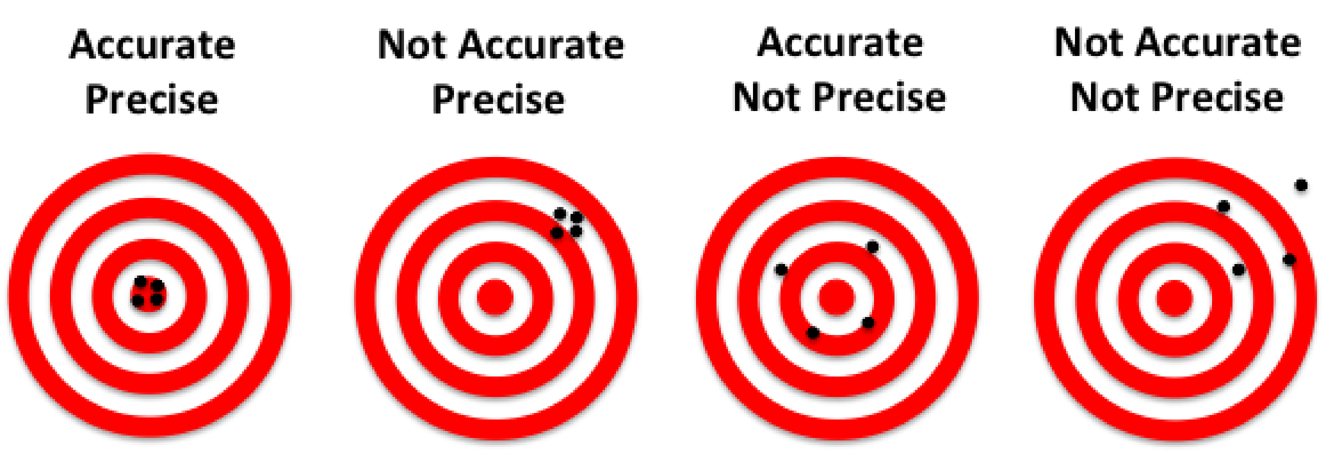
Accuracy

The accuracy of a calibration device, or calibrator, should be at least two times greater than the equipment being calibrated, although four times greater is the preferred minimum. The equipment usually has a calibration range over which the end user will check specifications.

Calibration Reliability

Accuracy

Accuracy and precision are two ways of measuring targeting. Although accuracy is intuitively understood and desirable, precision is often confused with accuracy, where the measurements are not representing the true value. If successive results agree, a false sense of confidence may be formed that is not merited. When a group of results are precise, they have minimal deviation. When they are accurate, they are close to the desired target.



Calibration Reliability

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Accuracy

When considering the accuracy of your calibrator, several basic questions should be considered:

- Who calibrated the calibrator?
  - Did a competent trained individual calibrate my calibrator?
  - Do I have a signed and dated calibration certificate?
- What was it calibrated against?
  - Do I have a calibration certificate that references a NIST traceable Master Device?
  - Can the laboratory provide the traceability documentation?
  - Have you ever challenged the calibration lab?

Calibration Reliability

Accuracy

When considering the accuracy of your calibrator, several basic questions should be considered:

- When was the calibrator last calibrated?
  - Is the date of last calibration printed on the device or certificate?
  - It is important to note that most calibrators will NOT hold a calibration indefinitely. As they get used and, sometimes abused (bumped / knocked / banged around), that the calibration may become less accurate.
  - Most manufacturers recommend a minimum of annual calibration.
  - Most regulatory agencies require an annual calibration for their calibrators.

Calibration Reliability

Accuracy

When considering the accuracy of your calibrator, several basic questions should be considered:

- Where it was last calibrated?
  - Did a competent laboratory, which is 17025 certified, perform the calibration?
- Has anything changed since the calibration equipment was last used?
  - One way to confirm this is by performing an internal test, such as a leak check.

Calibration Reliability

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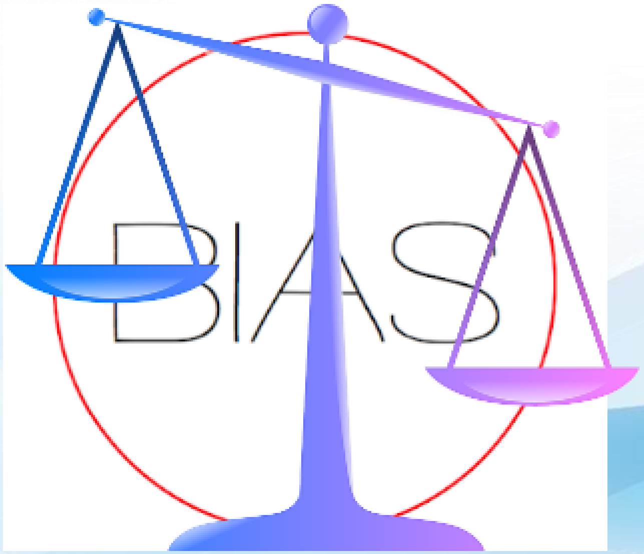
Precision

When considering the precision of your air sampling calibration results, you must also take into account any factors that introduce bias. This may either come from the equipment being calibrated, the sampling train, the calibrator, or the environment.



Calibration Reliability

Precision

- ❖ Can a calibrator be accurate but not precise?
  - ➢ What is Constant Flow?
  - ➢ What is Volumetric vs STP?
  - ➢ Can Pulsation Impact Flow Rates?

Calibration Reliability

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Constant Flow

Most air sampling pumps these days operate in a constant flow mode. The pump will maintain the same flow rate regardless of the backpressure that accumulates, and must fault (i.e. stop running), when the flow rate goes outside of the required accuracy specification. This process works like the cruise control on a car. The pump senses when the flow rate is trying to drop, similar to a car driving up a slope, and speeds up the pumps motor to maintain speed. Industry standards require the actual flow rate to be within 5% of the set flow.

Calibration Reliability

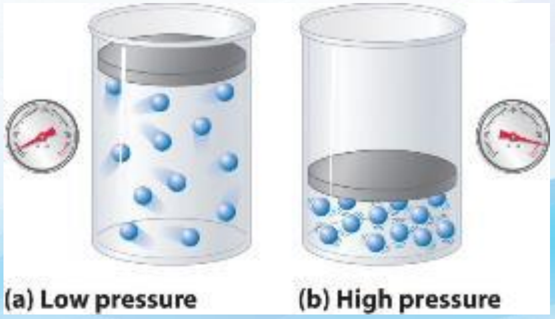
Precision

However, if your pump is yawing a bit, the motor is probably trying to compensate for an observed change in backpressure. In some cases, this can be pulsation caused by the pump, tubing, or media holder, and in other cases, it can be attributed to the calibrator being used to calibrate the pump. These biases can affect the average flow rate based on the pumps attempt to maintain constant flow.

Calibration Reliability

Precision

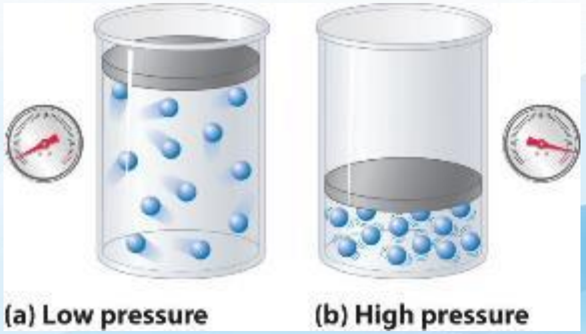
Environmental factors may also impact the precision and accuracy of your calibration results. Relationships between Pressure, Temperature, Density and Volume must be considered when performing volumetric calculations. It should also be noted that gas measurements are related by the material's density, which depends greatly upon pressure, temperature and to a lesser extent, composition.



Calibration Reliability

Relationships of Pressure, Temperature, Density and Volume

Gases are compressible and will change volume when placed under pressure, are heated or are cooled. A volume of gas under one set of pressure and temperature conditions is not equivalent to the same gas under different conditions. This relationship can be illustrated by using the combined gas law, derived from the ideal gas laws, also known as Charles' and Boyles' laws of classic chemistry.



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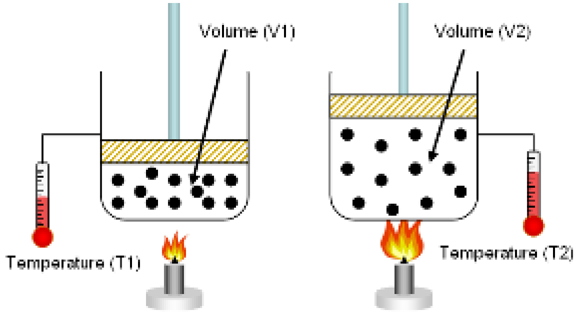
Ideal Gas Laws

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 most cases, is a function of the temperature and pressure conditions at which the gas exists.

Charles' Law $(V_1/T_1) = (V_2/T_2)$

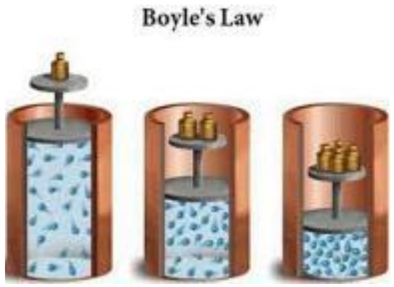
$$V \propto T_{(Kelvin)}$$



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.

Calibration Reliability

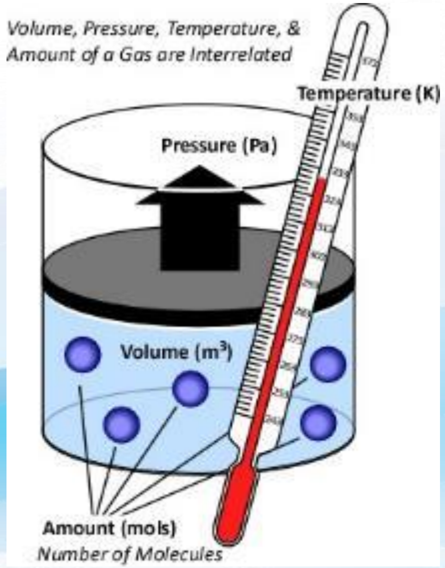
Ideal Gas Laws



Boyle's Law $(P_1/V_1) = (P_2/V_2)$

$$V \propto 1/P$$

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.



Combined Gas Law $(P_1V_1 / T_1) = (P_2V_2 / T_2)$

$$V_2 = V_1\ (T_2/T_1)\ (P_1/P_2)$$

Where:
P = ambient pressure
V = air volume in liters or cubic meters (1 m^3 = 1000 L)
T = temperature in Kelvin (Kelvin = 273 + ^{0}C)

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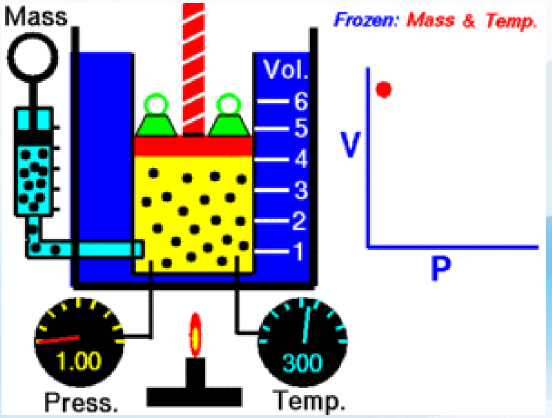
Ideal Gas Laws

Assuming the makeup of the air is constant, changing the temperature or pressure, will change the volume. However, in the case of volumetric devices with a fixed volume (space), what changes is the speed at which the gas moves through that fixed volume. Therefore, it is important to know if your calibrator calculates the impacts of temperature and pressure on air flow.



Calibration Reliability

Standard Temperature and Pressure

Another aspect to consider is correcting volume based on a reference STP or NTP. Standard temperature and pressure (STP), typically refers to nominal conditions in the atmosphere at sea level. This value is important to physicists, chemists, engineers, and pilots. It should be noted that different agencies around the world determine their own STP values.

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Calibration Reliability

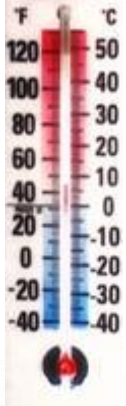
Standard Temperature and Pressure

It is important that you list your STP values when a corrected volume is given. The most used standards are those of the International Union of Pure and Applied Chemistry (IUPAC) and the National Institute of Standards and Technology (NIST), although these are not universally accepted standards. Since 1982, the IUPAC defines STP with a temperature of 273.15 K (0 °C, 32 °F) and an absolute pressure of exactly 105 Pa (100 kPa, 1 bar, 750 mmHg, 14.5 psi, 29.53 inH20).

Calibration Reliability

Standard Temperature and Pressure

In order to correct volume to a reference STP or NTP, the following equation is utilized:



$$V_S = (V_M \times P_M \times T_S) \;/\; (T_M \times P_S)$$

Where:

V_S = air volume in liters at referenced STP or NTP

V_M = air volume in liters as measured **(Calculated from flow rate and time sampled)**

P_M = ambient pressure in mmHg

T_S = temperature in Kelvin at referenced STP or NTP

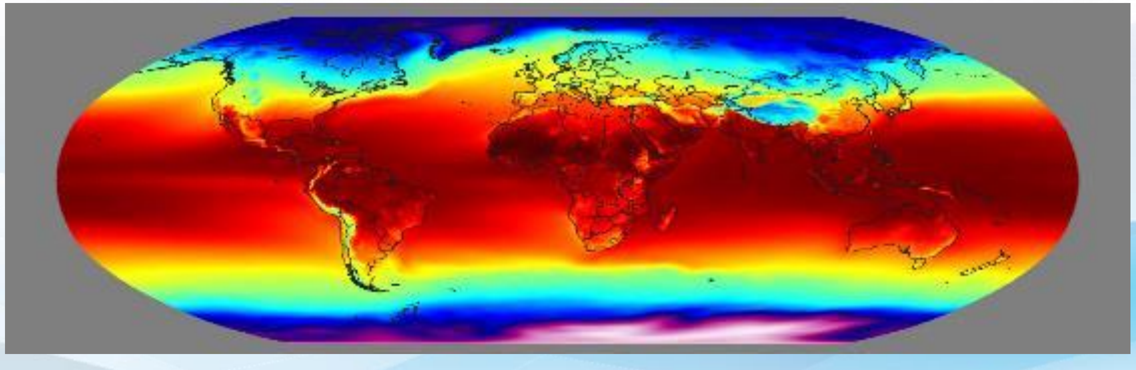
T_M = temperature of the sample air in Kelvin (273 + ^{0} C)

P_S = ambient pressure in mm Hg at referenced STP or NTP

Calibration Reliability

Standard Temperature and Pressure

This should not be confused with Normal Temperature and Pressure (NTP), which NIST and the United States Environmental Protection Agency (US-EPA) list as a temperature of 293K (20 ° C, 68 ° F) and an absolute pressure of 101.325 kPa (760 mmHg, 14.7 psi, 29.92 inH20). The NTP values are commonly substituted as the reference STP, which is acceptable as long as these values are noted with the corrected volume.



Calibration Reliability

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Stability

During air sampling, end users strive to have a consistent air flow across the entire sample period, with a max deviation of 5%. The closer the deviation is to zero, the more accurate the calculated volume is over that period, noting that volume is a function of flow rate and time.

Calibration Reliability

Stability

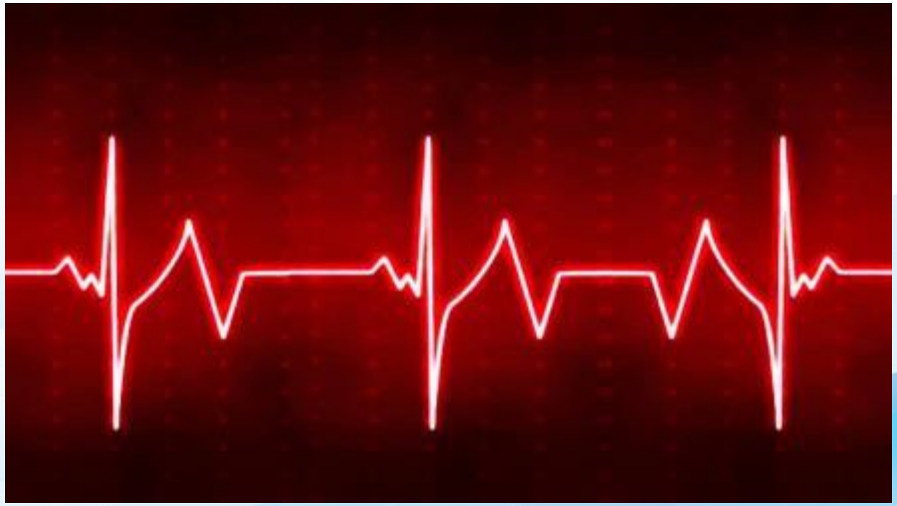
❖Why are stable readings important?

- ➢Pre-Calibration and Post-Calibration (+/- 5%)
- ➢Back Pressure Artifacts

Calibration Reliability

Stability

With every cycle of the pump, air is drawn in and then exhausted. The resulting airflow will not be completely smooth, and includes an alternating or pulsating component, due to the pump's action. The pulsation performance is expressed as the ratio of the pulsating component amplitude to the mean flow rate.

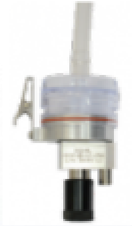


Calibration Reliability

Stability

As sampling heads, like cyclones, rely on a steady flow to maintain a specific size “cut,” it is important for pulsation to be as small as possible. Deviation from the specified airflow for a cyclone will result in the sampled air not accurately reflecting the respirable size fraction.



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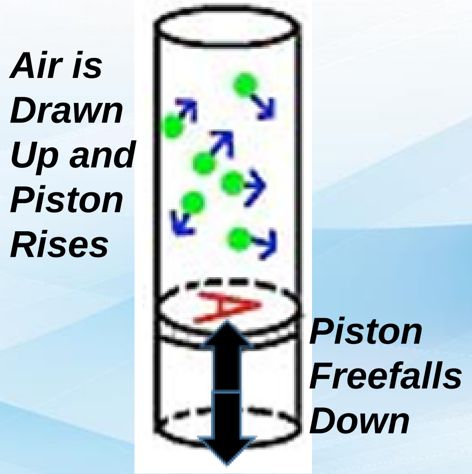
Stability

With some piston style calibrators, the piston itself can create an artifact back pressure pulse, which the constant flow pump will respond, and thereby create the yawing effect. This in turn creates an instable flow.

Calibration Reliability

Stability

In the case of some mechanical piston style calibrators, the piston moves from a bottom position, gets drawn upwards, passes the start and stop sensors, and then falls back to the bottom of the cylinder in a free fall. This free fall creates a pulse that can affect the pump. The end result is that the flow rate is variable under the conditions biased by the calibrator, which will not be present during sampling. Ideally, and more correctly, the piston should move up and down the cylinder at the same rate so as not to cause this disturbance of the airflow.



Calibration Reliability

How to you preserve your records

- Why is recordkeeping important?
  - Sample Integrity
  - Report Preparation
  - Legal Deposition

Calibration Reliability

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What Is Support Documentation For Air Sampling

- What is considered support documentation in legal cases?
  - Chain of Custody (COC)
  - Field Notes
    - ✓ Pump Model
    - ✓ Pump ID
    - ✓ Sample ID
    - ✓ Worker/Area ID
    - ✓ Start/Stop Time
    - ✓ Flow Rate
    - ✓ Volume
    - ✓ Relevant Activities
  - Calibration Log

Calibration Reliability

Supporting Documentation For Air Sampling

Documentation and recordkeeping are fundamental aspects of air sampling. In order to maintain integrity before, during, and after a sampling event, the operator/facilitator must record relevant data that corresponds with that event.

Calibration Reliability

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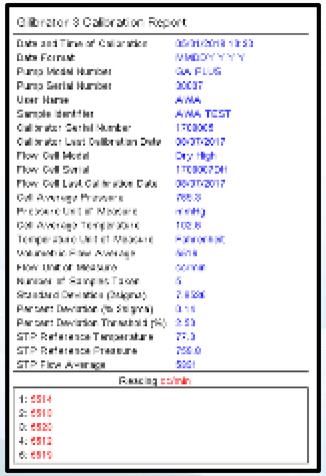
Supporting Documentation For Air Sampling

There are several key documents that should be maintained as part of every sampling event. These include a calibration log, field notes, and Chain of Custody (COC). These three documents are interrelated and have overlapping information that should be consistent across all three.

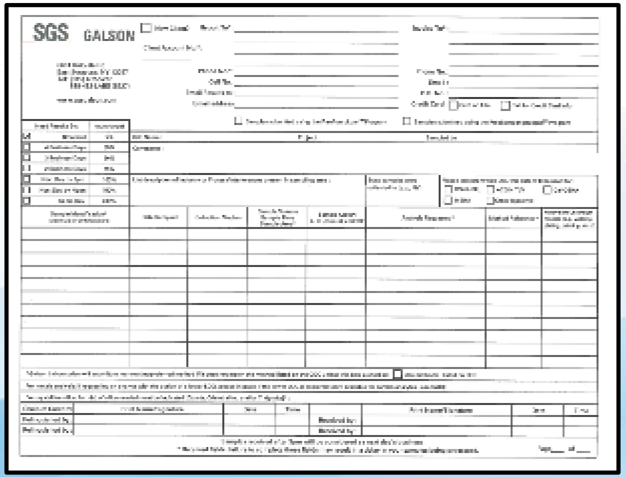


Calibrator 3 Calibration Report

Date and Time of Calibration	[illegible]
Date Format	MMDDYYYY
Pump Model Number	GA PLUS
Pump Serial Number	[illegible]
User Name	[illegible]
Sample Identifier	[illegible]
Calibrator Serial Number	[illegible]
Calibrator Last Calibration Date	[illegible]
Flow Cell Model	Dry High
Flow Cell Serial	[illegible]
Flow Cell Last Calibration Date	[illegible]
Cell Average Pressure	[illegible]
Pressure Unit of Measure	mmHg
Cell Average Temperature	[illegible]
Temperature Unit of Measure	Fahrenheit
Volumetric Flow Average	[illegible]
Flow Unit of Measure	cc/min
Number of Samples Taken	5
Standard Deviation (Sigma)	[illegible]
Percent Deviation (% Sigma)	[illegible]
Percent Deviation Threshold (%)	[illegible]
STP Reference Temperature	77.0
STP Reference Pressure	760.0
STP Flow Average	[illegible]

Reading cc/min

1: [illegible]
2: [illegible]
3: [illegible]
4: [illegible]
5: [illegible]



Calibration Reliability

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Supporting Documentation For Air Sampling

The calibration log has specific details that should be captured as it relates to each pump and sample used during calibration.

These details generally include:

- Calibration Log
  - Date and time of Calibration
  - Pump Model
  - Pump Serial Number
  - User Name
  - Sample ID
  - Calibrator ID
  - Date of Last Calibration
  - Temperature/Pressure
  - Flow Average (Volumetric)
  - Flow Average (STP)
  - Number of Samples in Averaged Sample Set
  - Standard Deviation
  - Flow Rate Readings

Calibration Reliability

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Calibration Log

Gilibrator 3 Calibration Report

Date and Time of Calibration	05/17/2018 09:34
Date Format	MMDDYYYY
Pump Model Number	GILIAN 12
Pump Serial Number	029
User Name	GDW
Sample Identifier	HIGH FLOW TEST
Calibrator Serial Number	20180501001
Calibrator Last Calibration Date	08/07/2017
Flow Cell Model	Dry High
Flow Cell Serial	20180501002
Flow Cell Last Calibration Date	01/01/2008
Cell Average Pressure	763.1
Pressure Unit of Measure	mmHg
Cell Average Temperature	87.3
Temperature Unit of Measure	Fahrenheit
Volumetric Flow Average	10.13
Flow Unit of Measure	L/min
Number of Samples Taken	10
Standard Deviation (2sigma)	0.0277
Percent Deviation (% 2sigma)	0.27
Percent Deviation Threshold (%)	2.50
STP Reference Temperature	77.0
STP Reference Pressure	760.0
STP Flow Average	9.987

Reading L/min

1: 10.15	6: 10.12
2: 10.12	7: 10.14
3: 10.13	8: 10.17
4: 10.13	9: 10.13
5: 10.12	10: 10.13

Calibration Reliability

Supporting Documentation For Air Sampling

Calibration documentation varies from one service provider/manufacturer to another. Maintaining a copy of the calibration certificate is essential for identifying measurement uncertainty, guard-banded acceptance limits, accreditation body symbol, and other provider specific details.


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ISO 17025 Calibration Certificate

Certificate Number: 20180901005-H 09-25-2018-0

Calibrated

Customer Information
Sensidyne LP
St. Petersburg, FL 33716

Gilibrator 3 High Flow Dry Cell | V1.1 R389 | September 25, 2018

High Wet Cell (Master) | February 21, 2019

Gilibrator Base | 1728089 | September 25, 2019

27.3 | 1022.0

EXTECH Pressure/Humidity/Temp Meter | April 4, 2020

25.8 | 1016.8 | 53.3

Reference Standard cc/Min (Mean Value of 3 samples)	Unit Under Test cc/min (Mean Value of 3 samples)	Relative Difference cc/min (of Averages)	Percent Difference (%) (of Averages)
2053	2063	-10	-0.49
10120	10153	-33	-0.33
20010	20072	-62	-0.31

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Meets Does Not Meet

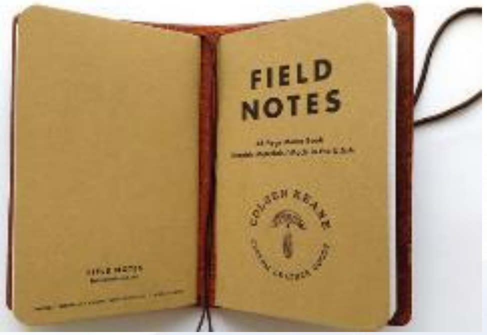
Calibrated By | Date | Authorized By | Date

Calibration Reliability

Supporting Documentation For Air Sampling

Field notes should capture precise details about the sampling event. These details should align with those in the calibration log and incorporate those activities specific to the pump and media that was used in calibration

These details generally include:

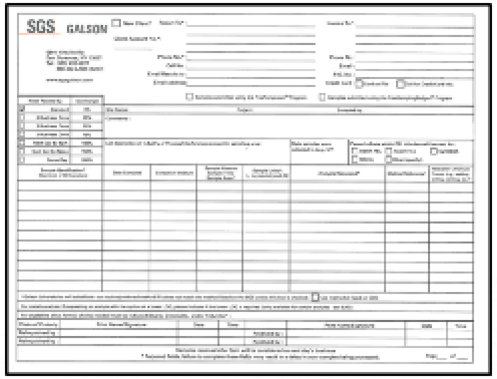


- Field Notes
  - Pump Model
  - Pump ID
  - Sample ID
  - Worker/Area ID
  - Sampling Method
  - Media
  - Start/Stop Time
  - Flow Rate (From Calibration Log)
  - Volume
  - Relevant Activities

Calibration Reliability

Supporting Documentation For Air Sampling

Once the post-calibration process is completed and documented, the information will be transferred to the COC. While many COC vary in format, common details are required.



These details generally include:

- Chain of Custody
  - Customer Information
  - Turnaround time
  - Sample ID
  - Date Sampled
  - Collection Media
  - Sample Volume
  - Sample Volume units
  - Analysis Type
  - Analysis Method
  - Relinquished and Received by Names, Date, and Signatures

Calibration Reliability

Supporting Documentation For Air Sampling

These documents should be kept on file together, along with the corresponding lab report, as the data may need to be reviewed at a later time and analyzed for consistency, or used for comparing historic data sets. In some instances, the data may be challenged in legal action, where this supporting documentation must be defensible.

Calibration Reliability

Supporting Documentation For Air Sampling

Be mindful of transcribing notes. Often pump identification, calibration data and sample name can get mixed up, especially when collecting multiple samples simultaneously. Time stamped digital documentation is more reliable than hand written field notes from five years ago. When applicable, download data, transcribe the hand-written field notes, and keep electronic files indefinitely, unless program requirements dictate otherwise.

Calibration Reliability

Advancement In Calibration Technology

Over the years, many advancements have been made in calibration technology. Although soap bubbles in volumetric burets are still used today, technological improvements allow users to increase convenience while maintaining accuracy, precision and stability, using advanced circuitry and sensors.

Calibration Reliability

Advancement In Calibration Technology

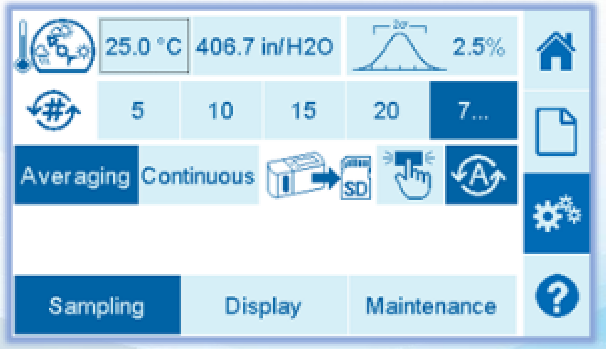
Newer primary dry cell calibrators have been introduced to the market that can be configured to meet the user’s calibration needs. These calibrators are more convenient to use compared to soap bubble calibrators, primarily due to eliminating the need to manually generate the soap bubble from the soap solution.

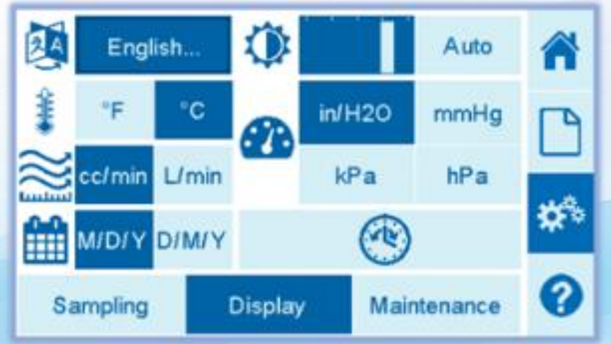
Calibration Reliability

Advancement In Calibration Technology

Additional advancements allow the user to take full advantage of:

- Ability to select between Continuous or Averaging modes. In an Averaging mode, the user may select a specific sample set to be averaged. Within other customizable settings, the user can define engineering units of measurement, date, time, temperature, and choose from a selection of languages in the devices library.



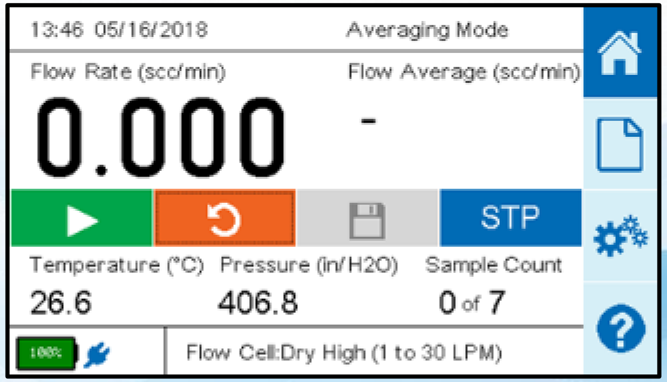


Calibration Reliability

Advancement In Calibration Technology

Additional advancements allow the user to take full advantage of:

❖ Internal sensors for standardizing flow rates based on reference temperatures and pressures (STP). The STP corrected flow rates allow you to compare data sets in varying environmental conditions, without the need for exterior calculations.

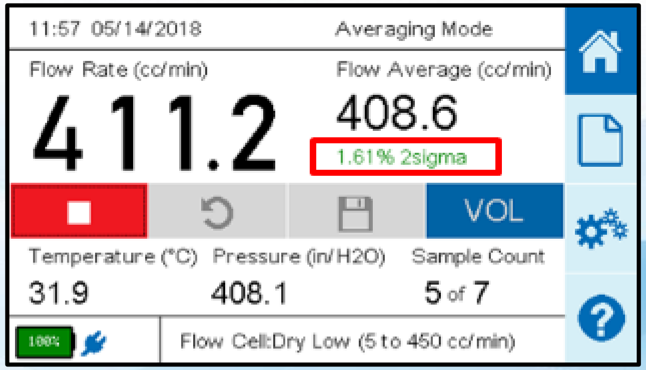


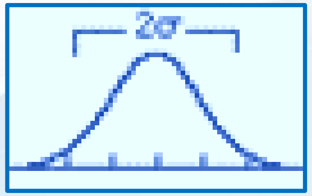
Calibration Reliability

Advancement In Calibration Technology

Additional advancements allow the user to take full advantage of:

- ❖ On board computing can data log the calibration events and perform statistical analysis on the deviations between readings. In addition, the user can define statistical parameters for standard deviation and percent deviation between sample sets.





Calibration Reliability

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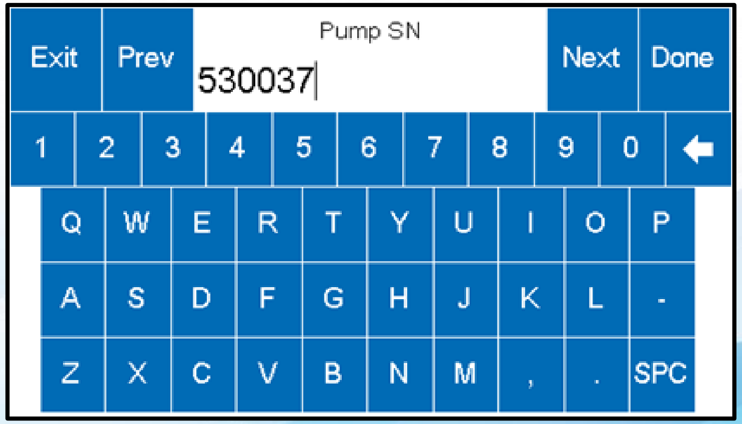
Advancement In Calibration Technology

Additional advancements allow the user to take full advantage of:

- ❖ Improved user interface capabilities with full touch screen keyboards for completing data input, and user defined fields for maintaining sample integrity.



Calibration Reliability

Advancement In Calibration Technology

Additional advancements allow the user to take full advantage of:

- ❖ Displayed date of last calibration, serial numbers, and reminders for next calibration due date.
- ❖ Tracking the usage of the calibrator through displayed cycle counts for both the base and flow cell.

	Base	Flow Cell
Serial Number	1708005	1708010DL
Last Calibration	08/07/2017	08/07/2017
Calibration Due	08/07/2018	08/07/2018
Cycle Count	172400	001937
Firmware Version	V1.0 R1300	V1.1 R1048
Battery Health	4350/4350(100%) 11/27/2017	
Filter Health	2.3/0.3(0%) 05/07/2018	

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info@sensidyne.com

Calibration Reliability

Advancement In Calibration Technology

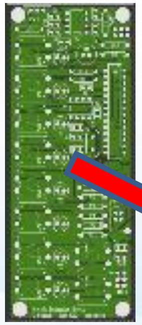
The newest piston style calibrators have “pulse free valve technology”, providing low back pressure to the devices being calibrated. This unique patented design equalizes pressure on the pump, regardless of puck travel direction. This feature also allows for minimal disturbance of the airflow generated by the instrument under calibration, providing high calibration accuracy.

STABLFLOW™

Calibration Reliability

Advancement In Calibration Technology

The newest piston style calibrators also utilize a fixed sensing array technology that eliminates the potential for misalignment of photo sensors. By collecting multiple flow rate data points, the fixed array system ensures accurate, reliable, calibration data throughout the calibration process.



Calibration Reliability

Advancement In Calibration Technology

Calibrators can now also generate printable calibration reports. These calibration reports display sample information, saved instrument settings, and individual sample results. This allows calibration data to be added directly into sampling reports, and historical records to be retrieved and reviewed for statistical analysis.

Calibration Reliability

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Resources

Annals of Occupational Hygiene: “Evaluation of Pump Pulsation in Respirable Size-Selective Sampling: Part II. Changes in Sampling Efficiency” (January 2014).

“Calibration and Traceability in Measuring Technology”, Author: Helmut Mitter, E+E Elektronik, Created: 2014-1-24, Version: 1.0

“Defining Accreditation and 17025”, Author: Keith Bennett, http://www.transcat.com/calibration-resources/white-papers/17025-accreditation-calibration-requirements-white-paper/

International Organization for Standardization: ISO 13137, “Workplace atmospheres—Pumps for personal sampling of chemical and biological agents—Requirements and test methods” (October 2013).

Calibration Reliability

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Resources

"Methods of Air Sampling and Analysis", Third Edition, Author: James P. Lodge Jr., 1988. Published by: CRC Press LLC, USA

MSHA: "Metal/Nonmetal Health Inspection Procedures Handbook," Chapter 4: Sampling Pumps & Airflow Calibrators.

NIOSH: "Manual of Analytical Methods," Chapter D: General Considerations for Sampling Airborne Contaminants.

OSHA: "Technical Manual," Section II, Chapter 1, Appendix F: Calibration.

"The Fundamentals of the Air Sampler Calibration-Verification Process", Author: Frank M. Gavila, F&J Specialty Products Inc., Rev.: 11 February 2011

Calibration Reliability

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Wikipedia, Boyle’s Law, https://en.wikipedia.org/wiki/Boyle%27s_law, Last edited on 21 September 2018

Wikipedia, Charles’s Law, https://en.wikipedia.org/wiki/Charles%27s_law, Last edited on 21 September 2018

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QUESTIONS?

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