

F&J SPECIALTY PRODUCTS, INC.

The Nucleus of Quality Air Monitoring Programs

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**STP
Has a Different Meaning to
Different People**

By

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OVERVIEW

- 1. Introduction to Ideal Gas Laws**
- 2. Concept of a reference temperature and pressure for comparison of two different gas volumes or two different flowrates**
- 3. Commonly utilized Reference T and P for Testing and Documentation of Chemical and Physical Process**
- 4. How does REMP or RETS air sampling activities get involved with reference T and P issues?**
- 5. The Solution**
- 6. Recommendations to the RETS/REMP Organization**

1. Introduction to the Ideal Gas Laws

I. Gas Law Basics

A. Gases

- In the gas phase, molecules are relatively far apart. This makes gases very compressible.
- A gas expands to fill the volume of its container.
- Gases are usually measured by volume so a relationship between **volume** and **number of moles** is needed.

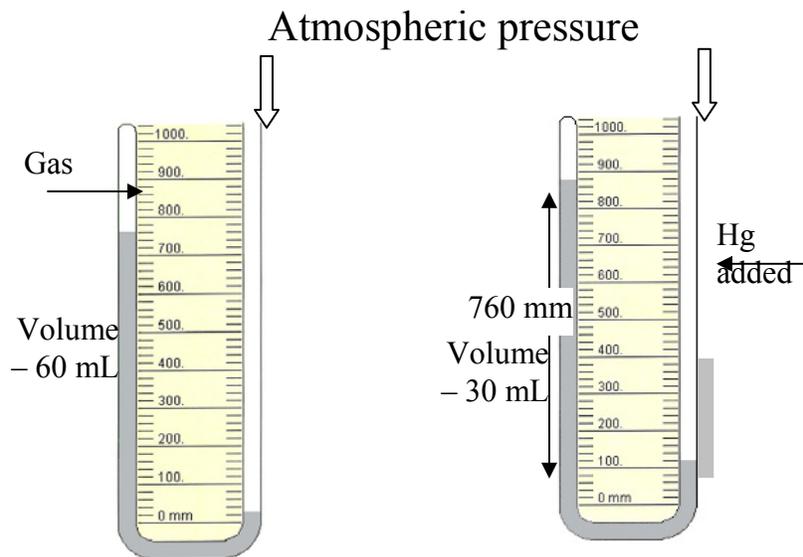
B. The Gas Laws

- The gas laws are experimental relationships among pressure (P), volume (V), temperature (T) and moles (n).
 - Boyle's law (V, P)
 - Charles' law (V, T)
 - Avogadro's law (V, n)
 - Ideal gas law (V, P, T, n)
- All gases behave similarly. The gas laws assume *ideal* behavior.

C. Boyle's Law

In 1662, Robert Boyle discovered that volume is inversely proportional to pressure.

$$V \propto \frac{1}{P} \text{ (constant T, n)}$$



D. Charles' Law

- Lord Kelvin proposed an absolute temperature scale defined by:

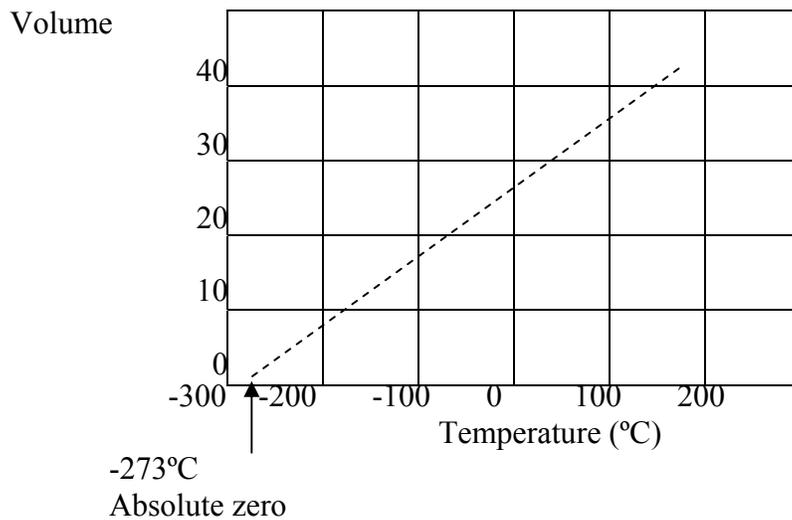
$$T(K) = T(C) + 273.15$$

- Expressed in absolute temperature, Charles' law is:

$$V \propto T \text{ (constant } P, n)$$

Charles discovered that volume is directly proportional to temperature.

The volume of a gas extrapolates to zero at -273°C . This must be the lowest temperature possible.



E. Avogadro's Law

- In 1811, Avogadro proposed that: Equal volumes of gases at the same temperature and pressure contain equal numbers of molecules.
- It follows that the volume of a gas at constant temperature and pressure is proportional to number of moles.

$$V \propto n \text{ (constant } T, P)$$

F. The Ideal Gas Equation

Combining the gas laws gives:

$$V \propto \frac{nT}{P} \text{ or } V = R \frac{nT}{P}$$

Where R is called the Gas constant: $R = 0.08206 \frac{L \cdot atm}{mol \cdot K}$

The Ideal gas law is usually written as: $PV = nRT$

Processes Involving Ideal Gases

Let's describe a process by which an ideal gas is transferred from conditions at State 1 to conditions at State 2:

(Actual Conditions) State 1 \longrightarrow State 2 (Reference Conditions)
or: $P_1, V_1, n_1, T_1 \longrightarrow P_2, V_2, n_2, T_2$

State 1: $P_1V_1 = n_1RT_1$ State 2: $P_2V_2 = n_2RT_2$

Solving for R:
$$R = \frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

If the number of moles stays constant ($n_1 = n_2$):

$$\frac{P_2V_2}{T_2} = \frac{P_1V_1}{T_1} \text{ or}$$

$$\frac{P_{Ref} \cdot V_{Ref}}{T_{Ref}} = \frac{P_{ACT} \cdot V_{ACT}}{T_{ACT}}$$

thus
$$V_{REF} = V_{ACT} \frac{P_{ACT}}{P_{Ref}} \bullet \frac{T_{Ref}}{T_{ACT}}$$

2. **Concept of Reference Temperature and Pressure**

In order to compare the volumes of the same gas or the corresponding gas flowrate (volume/unit time) of two different gas samples, it is necessary to ensure that the T and P are the same for both gas volumes or flowrates.

This results in the ideal gas law equation $V = n \frac{RT}{P} = n \cdot k$

Therefore, the volume of the gas is only a function of the number of moles of gas present in each of the two different samples collected **assuming the pressure and temperature are the same.**

It is erroneous to compare two different volumes of the same gas without comparing these volumes at the same reference temperature and pressure. The same applies to flowrates (volume/unit time).

3. **Commonly Utilized Reference T and P for Testing and Documentation of Chemical and Physical Processes**

A. Standard Temperature and Pressure (Classical)

STP – Standard Temperature and Pressure is defined as air at:

T = 0°C (273.15°K) or 32°F (460°R)

P = 1 Atmosphere (atm) or 760 torr, 14.7 psia, 29.92 in. Hg, 101.325 kPa

Approximates freezing point of water and atmospheric pressure at sea level.

B. Normal Temperature and Pressure

NTP – Normal Temperature and Pressure is defined as air at:

T = 20°C (293.15°K), 68°F

P = 1 atm., 14.7 psia, 760 mm Hg, 29.92 in. Hg, 101.325 kPa

NTP is common for testing and documentation of fan capacities

C. Standard Ambient Temperature and Pressure

SATP – Standard Ambient Temperature and Pressure is defined as air at:

$$T = 25^{\circ}\text{C} (298.15^{\circ}\text{K}), 77^{\circ}\text{F}$$
$$P = 101 \text{ kPa} (1 \text{ atm.})$$

The temperature and pressure where the equilibrium constant for the auto ionization of water is 1.0×10^{-14} .

D. International Standard Atmosphere

ISA – International Standard Atmosphere is defined as air at sea level where:

$$T = 15^{\circ}\text{C} (59^{\circ}\text{F})$$
$$P = 101.325 \text{ kPa}, 1 \text{ atm}$$
$$\text{RH} = 0\%$$

ISA is utilized as a reference for aircraft performance figures such as endurance, range, airspeed and fuel consumption.

E. Army Standard Metro Atmosphere

ASM – Army Standard Metro atmosphere is defined as sea level conditions of

$$T = 15^{\circ}\text{C} (59^{\circ}\text{F})$$
$$P = 750 \text{ mm Hg} (29.5275 \text{ in Hg})$$
$$\text{RH} = 78\%$$

Utilized only for ballistics

US Army Ballistic Research Laboratory Aberdeen Proving Ground

F. Modified Normal Temperature and Pressure (USA only)

$$T = 70^{\circ}\text{F} (21.1^{\circ}\text{C})$$
$$P = 1 \text{ atm}; 29.92 \text{ in. Hg}, 760 \text{ mm Hg}$$

G. Mass Flow Reference Conditions

The mass flow of a gas is defined as the rate at which mass crosses an imaginary cross-sectional area in a conduit.

Typical units for mass flow can be:

grams per minute or kilograms per hour
pounds per second or pounds per hour

True Mass flow (M) can also be obtained by measurement of volumetric flow at any T and P and converting the volumetric flow to the reference classical STP conditions of 0°C and 1 atm and multiplying by the gas density at classical STP. This is represented by the following formula:

$$\text{True Mass Flow (M)} = Q \cdot \frac{T_s}{T_a} \cdot \frac{P_a}{P_s} \cdot \rho_g = M_v \cdot \rho_g$$

Where

Q = Volumetric Flowrate at actual T and P conditions
T_s = Absolute T @ standard condition in Kelvin (273.15°K)
T_a = Absolute T @ flow condition in Kelvin
P_s = Absolute pressure at standard conditions (1ATM)
P_a = Absolute pressure at flow conditions
ρ_g = Density of gas classical STP conditions (0°C, 1atm)

To convert to mass flow (M_v) in volumetric units from flow at actual conditions use the following formula:

$$M_v = Q \cdot \frac{T_s}{T_a} \cdot \frac{P_a}{P_s}$$

Where M_v = Mass flow in volumetric units at STP (0°C, 1ATM)

The density of various gases at STP is presented on the following page.

To compute True Mass Flow (M) multiply M_v by the density of the gas at 0°C, 1 atm.

$$\text{True Mass Flow (M)} = M_v \cdot \rho_g$$

Mass flow sensors which are currently utilized for many airflow measurements are generally reporting volumetric flow values at 0°C, 1 ATM. (classical STP). These volumes can easily be corrected to any reference T and P utilizing the gas law formulas.

DENSITY of GASES at STP

Gas	Density (g/L)
air, dry	1.2929
Ammonia	0.771
Carbon dioxide	1.977
Carbon monoxide	1.250
Chlorine	3.214
Dinitrogen monoxide	1.977
Ethyne (acetylene)	1.171
Helium	0.1785
Hydrogen	0.0899
Hydrogen chloride	1.639
Methane	0.7165
Sulphur dioxide	2.927
Nitrogen	0.716
Nitrogen monoxide	1.251
Oxygen	1.429

4. How does REMP or RETS air sampling activities get involved with reference T and P issues?

The RETS/REMP air monitoring specialist gets involved with reference T and P issues simply by the fact he is making flow measurements for purposes of determining volumes of air passing through particulate and/or radioiodine collection cartridges over a duration of time (sample duration).

He then integrates the volume measurements (or determinations) with radioactivity analysis in downstream calculations to determine radioactivity concentrations (radioactivity per unit volume).

The volume of the sample is determined by either by calculation of flowrate (measured by typically a rotameter) multiplied by elapsed sample time or by the difference between ending and beginning reading on a volume totalizer (such as a dry gas test meter). Some facilities employ volume totalizer systems that display the calculated volume corrected to a reference T and P.

It is evident that the air temperature of the air sample is a function of the geographical location, elevation, season of year and time of day.

The absolute pressure of the air sample is a function of the elevation, the short term local atmospheric weather conditions that influences the local barometric pressure, the pressure drop of the filter(s) utilized, the inherent sample system line losses attributing to pressure drop and dust loading, if any.

The above expected variations in both T and P which a large number of users will experience at approximately 60 different plant sites in the USA will result in sample volume determinations that are not truly comparable with each other and thus any calculated results involving these volumes are not in and of themselves comparable to each other. Of concern is that in the vast majority of cases no data is being collected to enable a future correction of data even if such an adjustment was required after the sample event.

Special Formula for Rotameters

It is necessary to consult the manufacturer of any analog or digital flow measurement device to confirm the temperature and pressure conditions that the scale or digital display represents.

It is also necessary to confirm with the manufacturer of the measurement device what the proper formula is for correcting indicated or displayed flowrate to a standard reference T and P.

In the specific case of a variable area rotameter, the formula for correcting from conditions actual T and P at the outlet of the rotameter to a reference T and P is as follows:

$$F_{\text{Ref}} = F_{\text{ACT}} \sqrt{\frac{T_{\text{Ref}}}{T_{\text{ACT}}} \cdot \frac{P_{\text{ACT}}}{P_{\text{Ref}}}}$$

This is required because the flow vs. ΔP relationship is a square root relationship.

Not all rotameters are variable area rotameters, therefore that formula is not applicable universally to rotameters.

THE SOLUTION:

The only way to ensure reliability of comparison of data between air monitoring results published by USA NPP is to report all measured or calculated volumes to a mutually agreed upon reference T and P. This will remove the data inconsistency due to geographical elevation, seasonal variations, uniqueness of sample systems, differences in pressure drop of filters utilized, local dust loading effects, etc.

What should be the Reference T and P?

Four good options are: STP, SATP, NPT or MNPT

Is there a precedent regulatory guideline or standard?

ANSI/HPS N13.1-1999

There is a recent precedent in ANSI/HPS N13.1-1999 Section 3.1
This ANSI Standard applies to emissions from nuclear power plant facilities such as stacks, ducts and other exit pathways.

Standard Conditions:

“Used to convert air densities to a common basis. The standard conditions adopted in this standard are a temperature of 25°C and a pressure of 760 mm Hg.”

These are the reference conditions for Standard Ambient Temperature and Pressure.

Recommendations to the RETS/REMP Organization

- 1) The RETS/REMP organization should consider its authority and responsibility to make an organizational decision to recommend that all NPP members correct measured or calculated volumes that are determined for air samples reported to any regulatory agency to a reference temperature and pressure definable by the RETS/REMP organization.
- 2) The RETS/REMP organization should determine and recommend an appropriate reasonable phase in time period of reporting corrected sample volumes in order to achieve uniformity of reported results that involve volume determinations.
- 3) The RETS/REMP organization should possibly recommend the selection of SATP in order to maintain consistency with ANSI/HPS N13.1-1999 standard that applies to the NPP community.
- 4) The RETS/REMP organization notify the USNRC of the official position that the RETS/REMP organization is taking and request that they provide within a reasonable time a comment letter indicating any adverse consequences they see in implementing the new volume reporting strategy for purposes of achieving consistency among all NPP. Additionally, the USNRC should comment as to whether any existing agency regulation, guideline or other document would prohibit the implementation of determining volumes to SATP (25°C,1ATM) similar to that adopted by ANSI/HPS N13.1-1999 that is applicable to emissions from NPP.

CONCLUSION:

The RETS/REMP organization has an opportunity to take a bold step forward and make a significant contribution to the uniformity of reported data and to implement a strategy that will provide for consistent reporting of sample volumes that are utilized to determine compliance with emission limits, source term calculations or for comparison with data from other NPP worldwide.