Gas Volume Conditions

Even though this Topic occurs after the Topic on computations, you will soon realize that it is most efficient to convert ventilation from ATPS to STPD conditions prior to calculating VO_2 and VCO_2. Furthermore, knowing the gas laws helps you comprehend the physiology of gas exchange in the section on pulmonary function, as when concerned with pulmonary function, gas volumes are expressed as BTPS. When concerned with indirect calorimetry, which can be performed literally anywhere in the world based on today's technology, such gas volumes need to be standardized to STPD conditions.

Inspired and expired gas volumes are influenced by gas temperature, pressure and water vapor content. As these conditions can change over time in one location due to weather and season, and be extremely different from one location to another due to weather, climate and altitude, gas volumes obtained from expired gas analysis indirect calorimetry (EGAIC) need to be standardized to constant conditions for each of temperature, pressure and water vapor content.

The Gas Conditions

When concerned with EGAIC, there are three gas conditions of relevance.

1. Atmospheric temperature and pressure, saturated (**ATPS**)
2. Body temperature and pressure, saturated (**BTPS**)
3. Standard temperature and pressure, dry (**STPD**)

To be clear on which type of gas collection I am talking about, I will provide examples for expired air first, and then explain the gas conditions for inspired air.

<u>ATPS Condition</u>

The ATPS condition pertains to the conditions in which the expired gas volume was measured. The gas temperature will depend on where and based on what technology the expired gas volume was measured. For a gas turbine connected to the expired side of the mouthpiece, the temperature would be body core temperature, which, unless the exercise condition has caused excessive body heat storage, is 37 °C. All expired air is fully saturated with water vapor (100% **relative humidity**), and as shown in Table 1, varies in **water vapor** content with gas temperature as warmer air can hold more water vapor. For 37 °C, fully saturated air has a water vapor pressure of 47 mmHg. The data from Figure 1 are based on computations from Equation 1.

Table 1. Water vapor pressure for saturated air at different temperatures.

Temp (°C)	P_{H2O} (mmHg)
14	12.9
15	13.5
16	14.1
17	14.9
18	51.5
19	16.5
20	17.5
21	18.7
22	19.8
23	21.1
24	22.4
25	23.8
26	25.2
27	26.7
28	28.3
29	30.0
30	31.8
31	33.7
32	35.7
33	37.7
34	39.9
35	42.2
36	44.6
37	47.1
38	49.4
39	52.0
40	54.7

$$P_{H2O} = \left(13.955 - \left(0.6584 \times T\right)\right) + \left(0.0419\,T^{2}\right) \qquad \text{Equation 1}$$

For air not fully saturated, relative humidity must be known, and these measurements have historically been provided by **wet and dry bulb temperatures**. When humidity is known, and let's say it is 45% for air at 22 ºC, then calculating water vapor pressure is as simple as multiplying the saturated air water vapor pressure (19.8 mmHg from Table 1) by 0.45, which equals 8.91 mmHg.

Thus, ATPS conditions consist of the following;

1. Gas temperature during volume or flow measurement when the temperature equals room (atmospheric) temperature
2. Atmospheric pressure (mmHg)
3. 100% RH
4. Saturated water vapor pressure depends on gas temperature (Figures 1 and 2)

The ATPS conditions for different systems of EGAIC are presented in Figure 2.

Table 2. The ATPS conditions for different systems of EGAIC.

System	Temperature	Pressure	RH	Water Vapor
Douglas bag	Room Temp	Barometric pressure	100%	Depends on gas temp
Expired turbine at mixing chamber	Room Temp^	Barometric pressure	100%	Depends on gas temp
Expired turbine at mouthpiece	37 °C*	Barometric pressure	100%	Depends on gas temp
Inspired turbine or flow meter	Room Temp	Barometric pressure	depends on gas temp and water vapor pressure	Depends on gas temp and RH

^preferably, gas temp is measured at mixing chamber
* preferably, gas temp is measured at expired ventilation measurement device as air has rapid thermal conductivity (rapidly changes to room temperature once it leaves the mouth)

BTPS Condition

The gas conditions for BTPS consists of the following;

1. Body core temperature (assumed to be 37 °C, unless hypo- or hyperthermic)
2. Atmospheric pressure (mmHg)
3. 100% RH
4. Water vapor pressure depends on body core temperature (Figure 1)

The BTPS condition is used within the field of **pulmonology** for measurements of lung volumes, as it pertains to gas volumes inside the lung.

STPD Condition

The gas conditions for STPD consist of the following;

1. **Standard temperature** (0 °C = 273 °K)
2. **Standard atmospheric pressure** (1 Atmosphere (Atm) = 760 mmHg)
3. 0% RH
4. 0 mmHg water vapor pressure

Gas Volume Conditions

Converting From ATPS to STPD

As VO_2 and VCO_2 are measured in ATPS conditions, the main conversion of interest is that from ATPS to STPD conditions. I will explain this first and provide equation examples along the way. The explanation is important here, as you should be able to work all this out, and therefore never have to memorize these equations. These explanations are summarized below.

Now, let's look at temperature first. ATPS temperature is room temperature, and standard temperature is 0 °C, which is the freezing point of water. To go from ATPS to STPD, gas temperature is colder, which means the gas volume must shrink, causing a conversion factor less than 1.0.

For pressure, ATPS pressure is almost always taken at an altitude above sea level, which means that STPD pressure will most always be higher than ATPS pressure, which means the gas volume must shrink, causing a conversion factor less than 1.0.

For water vapor, this is an additional correction made to the pressure conversion factor. This is because water vapor is a gas, and takes up part of the pressure of the total gases in the air volume exhaled. Thus, once water vapor is computed, it must be subtracted from atmospheric pressure in the pressure conversion factor. The corrections result in the following equations.

The temperature conversion is expressed in Equation 2.

$$VE_{STPD} = VE_{ATPS} \times \left(\frac{273}{(273 + T_{room})} \right) \qquad \text{Equation 2}$$

The pressure conversion, including water vapor correction, is expressed in Equation 3.

$$VE_{STPD} = VE_{ATPS} \times \left(\frac{(PB - P_{H20})}{760} \right) \qquad \text{Equation 3}$$

Combining both temperature and pressure corrections results in Equation 4.

$$VE_{STPD} = VE_{ATPS} \times \left(\frac{273}{(273 + T_{room})} \right) \times \left(\frac{(PB - P_{H20})}{760} \right) \qquad \text{Equation 4}$$

Let me show how all this works in an example. Let's say the ATPS gas volume of interest was 100 L (VE_{ATPS} = 100 L), and the room temperature was 19 °C (T_{room} = 19 °C), and barometric pressure was 720 mmHg. To start with, let us assume that gas volume was measured at the mixing chamber and expired gas temperature had equilibrated to room air temperature. Thus water vapor pressure from Figure 1 is 16.5 mmHg, and computed data is presented in Equation 5.

$$VE_{STPD} = VE_{ATPS} \times \left(\frac{273}{(273+19)}\right) \times \left(\frac{(720-16.5)}{760}\right)$$
$$= 100 \times (0.9349) \times (0.9257) = 86.54\ L$$
Equation 5

For expired gas volumes measured at the mouth, where the expired gas temperature was 37 °C and water vapor pressure was 47 mmHg, computed data is presented in Equation 6.

$$VE_{STPD} = VE_{ATPS} \times \left(\frac{273}{(273+37)}\right) \times \left(\frac{(720-47)}{760}\right)$$
$$= 100 \times (0.8806) \times (0.8855) = 77.98\ L$$
Equation 6

Once again, note that both the temperature and pressure conversion factors are almost always both below 1.0 for ATPS to STPD conversion. The only conditions where this would not be the case are locations below sea level, above sea level in artificial **hyperbaria**, and for ambient temperatures below freezing.

Converting From BTPS to STPD

We actually performed an example of the BTPS conversion above for the ATPS condition. Which one was it and why? Yes, it was when we assumed expired air volume measurement at the mouth, where gas temperature equaled body temperature. Thus, Equation 6 presents the computation for BTPS to STPD conversion.

Glossary Words

ATPS is the abbreviation for the gas condition of atmospheric temperature and pressure, saturated.

BTPS is the abbreviation for the gas condition of barometric temperature and pressure, saturated.

STPD is the abbreviation for the gas condition of standard temperature and pressure, dry.

relative humidity is the percentage of water vapor in air relative to the maximal capacity of the air to hold water vapor.

water vapor is the water in air in the form of a gas or vapor.

wet and dry bulb temperatures are the temperatures measured from a wet wick applied to a mercury column thermometer (wet) and a typical mercury column thermometer (dry) that are used to compute relative humidity.

pulmonology is the field of physiology pertaining to lung function. Pulmonology is also

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the name for the clinical speciality concerning measurements of lung function, and the diagnosis and treatment of diseases of the lung.

standard temperature is 0 °C = 273 °K.

standard atmospheric pressure is 1 Atmosphere (Atm) = 760 mmHg.

hyperbaria refers to an increased pressure above standard (> 1 Atm = 760 mmHg).