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White Paper

Pressure, Its Units of Measure and Pressure References

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This technical note is a summary reference on the nature of pressure, some common units of measure and pressure references. Read this and you won't have to wait for the movie!

PRESSURE

Gas and liquid molecules are in constant, random motion called "Brownian" motion. The average speed of these molecules increases with increasing temperature. When a gas or liquid molecule collides with a surface, momentum is imparted into the surface. If the molecule is heavy or moving fast, more momentum is imparted.

All of the collisions that occur over a given area combine to result in a force. The force per unit area defines the pressure of the gas or liquid. If we add more gas or liquid to a constant volume, then the number of collisions must increase, and therefore pressure must increase. If the gas inside the chamber is heated, the gas molecules will speed up, impact with more momentum and pressure increases. Pressure and temperature therefore are related (see table at right).

The lowest pressure possible in nature occurs when there are no molecules at all. At this point, no collisions exist. This condition is known as a pure vacuum, or the absence of all matter.

It is also possible to cool a liquid or gas until all molecular motion ceases. This extremely cold temperature is called "absolute zero", which is -459.4° F. Temperature is measured in degrees, which is rather meaningless. The Kelvin scale of temperature has a zero point of absolute zero whereas the Celsius scale uses a zero point equal to the freezing point of water. There is nothing significant about 0° F in the Fahrenheit scale.

When measuring pressure, the zero point of the scale is the "reference". An absolute reference uses a pure vacuum as the zero point. Therefore all pressure measurements in the absolute scale are positive.

Some fundamental laws of gases:

Boyles Law—In 1662, Robert Boyle did the first quantitative experiments with gases and pressure. He found that the volume of a gas is inversely proportional to the pressure of the gas at constant temperature.

So $\mathbf{PV - k}$

Charles Law—Charles found that the constant, k changes with temperature and that the volume of a gas changes linearly with temperature.

Ideal Gas Law: Combine Boyle's law and Charles' law, we get the ideal gas law:

$$\mathbf{PV = nrT}$$

Where **nr** is constant for a particular gas analogous to the number of molecules and the relative size of the molecule. the ideal gas law is very important in the study of gases.

Cole's Law—Thinly sliced cabbage.

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UNITS OF MEASURE

There are numerous units of measurement for pressure. Since pressure is defined as a force per area, the United States commonly uses units of pounds per square inch (PSI), as well as pounds per square foot (PSF). In Europe and Japan, the metric system uses Kilograms per square centimeter (Kg/cm2).

Pressure can also be stated in terms of the height of a liquid column. If one pound of water were poured into a glass tube with an area of one square inch, the weight of the water on that area at the bottom of the tube is one pound, and the pressure is therefore one PSI. At 39° F, the water column would be 27.68 inches tall. One inch of water column is annotated as 1"WC.

If we replace the water with a heavier liquid, the pressure generated increases. For example, it only takes 2.036 inches of mercury to generate 1 PSI versus 27.68" water column because mercury is so heavy. 1 PSI is equal to 2.036"Hg.

In Europe the metric system is prevalent, so inches are replaced with millimeters. 25.4 mmHg is equal to 1"Hg.

Evangelista Torricelli did a lot of the early work in pressure measurement and invented the barometer. One mmHg has been renamed the Torr in his honor. The Pascal is named after Blaise Pascal, another early mathematician who discovered that air pressure decreases with altitude and that fluid pressure is the same in all directions.

Other pressure units of measure are the Atmosphere and the Bar, which are both roughly equivalent to atmospheric pressure at sea level on a “standard” day.

Here is a list of the more common units of pressure measurement; all refer to the good old “American” PSI.

Units of Pressure Measurement

Referred to 1 PSI

1 PSI = 27.68"WC (inches of water column)

1 PSI = 2.036"Hg (inches of mercury)

1 PSI = 51.715 mmHg or Torr

1 PSI = 0.068947 Bar

1 PSI = 0.06804 Atmospheres. (Note that 1 Bar is not exactly 1 atmosphere.)

1 PSI = 6.8947 KiloPascals or KPa

1 PSI = 0.0703 Kg/cm2

1 PSI = 2.307 feet of Water

Pressure Unit Conversion Constants							
	PSI[(1)]	**In. H_20[(2)]**	**In. Hg[(3)]**	**K Pascal**	**milli Bar**	**cm H_2O[(4)]**	**mm Hg[(5)]**
PSI[(1)]	1.000	27.680	2.036	6.8947	68.947	70.308	51.715
In. H_20[(2)]	3.6127×10^{-2}	1.000	7.3554×10^{-2}	0.2491	2.491	2.5400	1.8683
In. Hg[(3)]	0.4912	13.596	1.000	3.3864	33.864	34.532	25.400
K Pascal	0.14504	4.0147	0.2953	1.000	10.000	10.1973	7.5006
milli Bar	0.01450	0.40147	0.02953	0.100	1.000	1.01973	0.75006
cm H_2O[(4)]	1.4223×10^{-2}	0.53525	3.9370×10^{-2}	0.09806	0.9806	1.000	0.7355
mm Hg[(5)]	1.9337×10^{-2}	0.53525	3.9370×10^{-2}	0.13332	1.3332	1.3595	1.000
Notes: (1) PSI - Pounds per square inch (2) at 39°F (3) at 32°F (4) at 4°F (5) at 0°C							

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REFERENCES

Now that the units of measure are defined, there are 5 commonly used pressure references that need to be explained. Again, the reference simply describes the zero point on the scale.

Absolute

As previously described, the zero point of an absolute reference is the absence of all matter. There is no pressure at absolute zero. All absolute pressure measurements made are therefore positive.

Absolute pressure measurements are abbreviated with an “A”. For example, 0 PSIA or 6"HgA.

Gage

To ignore the effects of changing weather, altitude or depth, a “Gage” pressure reference is sometimes useful. This reference measures pressure relative to the local atmosphere.
Changes in local atmospheric pressure occur due to weather, or if the instrument is moving because of changes in altitude and/or depth.

Gage pressure measurement is abbreviated as “G”. At sea level, 0 PSIG (Gage) is about 14.7 PSIA. In Denver, 0 PSIG is about 12.5 PSIA. It is possible to have a negative gage pressure. A vacuum would be about -14.7 PSIG at sea level.

Transducers with gage references are usually constructed by opening a hole into the pressure sensor so that the local atmosphere can enter the unit and counter the pressure being measured. This “back side” of the sensor usually houses the electronics and other apparatus that measures pressure. The reference hole (or “breather” hole) will usually be specified as “dry”. Only a clean, dry gas should be allowed inside the hole. Since the test side of most pressure transducers is rated for most gases or liquids, this side of the sensor is called “wet”. Gage pressure sensors are usually “wet/dry” construction.

Sealed Gage

By allowing local atmosphere to enter the dry side of a transducer, there exists a pathway for water, water vapor, or corrosive chemical mist to enter and cause damage. Some manufacturers will then seal the back side of the sensor to prevent this contamination. The zero point of the transducer is usually set at whatever the atmospheric pressure was at the time and location of manufacture. Changes in altitude and barometer will affect the reading, but if the pressure range of the sensor is high (>1,000 PSI) these effects may be considered negligible. Sealed Gage references are abbreviated as SG or S, example: PSIS, PSISG.

Vacuum

A vacuum reference can be thought of as the opposite of a gage reference. The transducer’s zero point is local atmosphere, but output increases as pressure is reduced. The sensor therefore measures the amount of vacuum.

Vacuum references are notated with “V”, for example PSIV or "HgV.

Differential

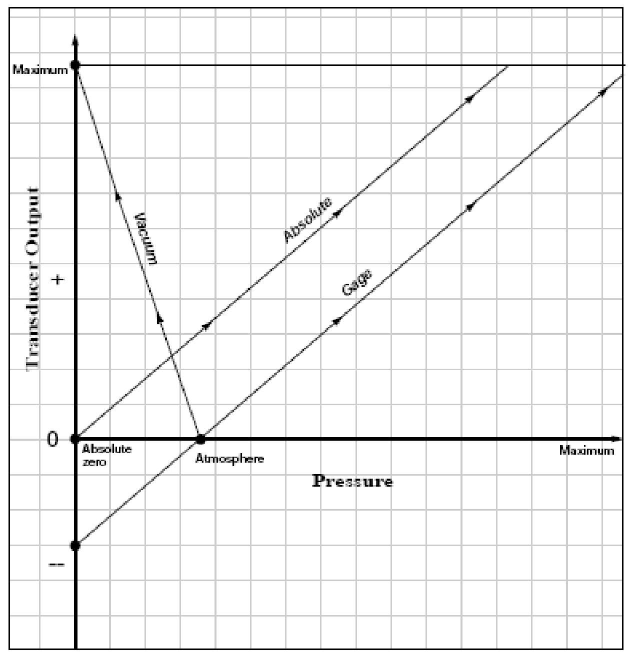
Differential pressure measurement is the difference between two unknown pressures. Output is zero when the two pressures are the same, regardless of magnitude.

Differential Pressures are notated as "D" (PSID). The magnitude of the common pressure is called "static" or "base" pressure. Differential transducers are usually "wet/wet" construction.

THE RELATIONSHIP BETWEEN ABSOLUTE, GAGE & VACUUM PRESSURE REFERENCES

Absolute

Absolute pressure transducers provide increasing output when pressure is increased. Output is zero when the pressure is absolute zero. There cannot be a negative output because there is no pressure less than absolute zero.



Examples of absolute pressure measurement include barometers and altimeters.

Gage

Gage pressure transducers are referenced to local atmospheric pressure, even if local pressure changes. Transducer output is zero when pressure is at local atmosphere. Output increases with pressure. If a vacuum is applied, output will fall below zero.

Examples of gage pressure measurement include tank level, air compressors, and depth sensors.

Vacuum

Vacuum pressure transducers are referenced to local atmospheric pressure, but measure the amount of vacuum instead of pressure. Transducer output is zero when pressure is at local atmosphere. Output increases with decreasing pressure (increasing vacuum). Output is at full scale when pressure is at absolute zero.

Examples of vacuum pressure measurement include vacuum pumps and altitude test chambers.

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