

## Fundamentals of Pressure and Temperature Measurement

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Correctly measuring Pressure and Temperature is one of the most important elements in the accurate measurement of Natural Gas. The basic theories on Pressure and Temperature Compensation were established many years ago by two men, Robert Boyle an Anglo Irish philosopher, chemist, and physicist and Jacques Charles, a French Inventor, scientist and mathematician.

Since we are discussing Fundamentals we will try to keep our discussion as simple possible.

### Boyles Law

In 1662 Robert Boyle first published what today is known as Boyles Law. This law can be simply stated as: For a fixed amount of ideal gas kept at a fixed temperature, Pressure [P] and Volume [V] are inversely proportional. That is when pressure is doubled the volume is halved.

### Simple Pressure Factor

Using the basic principle of Boyles Law we can easily calculate a simple pressure factor (Fp) to be used for calculating changes in volume caused by increases or decreases in pressure.

$$Fp = \frac{\text{Guage (psig)} + \text{Atm Pressure (psia)}}{\text{Base Pressure (psia)}}$$

*Base Pressure* (Pb) is commonly stated in our Gas Contracts. It's the pressure that we have agreed to base all purchases and sales on for the contract area. For our example we will use 14.95 psia as our base pressure.

*Atmospheric Pressure* we will use is the standard atmospheric pressure for the Region. Typically the standard Atmospheric

Pressure is part of the base conditions in the Gas Contracts. For our example we will use 14.7 psi for our atmospheric pressure. The average atmospheric pressure at sea level is 14.7 psia. At 5,000 ft the average atmospheric pressure would be 12.22 psia

Our *Gauge Pressure* (psig) is the gas pressure we read on the meter with an accurate gauge. For our example we will use the common residential delivery pressure of .25 psi.

### Example - Calculation at .25 psig

Now let's plug our numbers into our formula:

$$Fp = \frac{.25 \text{ gauge} + 14.7 \text{ atm}}{14.95 \text{ base}} = 1.0$$

For this example the answer would be 1.0. We would then multiply our Acf volume by 1.0 which would not change the Acf volume. In this case we could just read meter index differences as the volume.

### Example - Calculation at 5.0 psig

In this example we will keep everything constant except Gauge Pressure. Let's say the customer called and needed more pressure for a new pool heater or standby generator they installed. As a result a Service Tech was dispatched and raised the pressure on the meter to 5.0 psig. This requires that we use a new pressure factor.

$$Fp = \frac{5.0 \text{ gauge} + 14.7 \text{ atm}}{14.95 \text{ base}} = 1.3177$$

For this example our answer is 1.3177. So to obtain a volume corrected for pressure we must now multiply our Acf volume by 1.3177. In this case we would read the meter index difference and multiply it by 1.3177 to obtain the volume corrected for pressure.

To think of it in a simple way, if you raised the pressure you would be able put more gas in the same sized box.

### **Supercompressibility**

All gases deviate slightly from Boyles Law. The volume of gas at higher pressures is typically higher than the theoretical pressure. As such we must calculate a Supercompressibility Factor (Fpv) to make this correction. This factor is increasingly important at higher pressures and lower temperatures. The most common current standard for the calculation of Supercompressibility is AGA8. A simpler but less accurate method is NX-19. AGA8 is quite complex so in the interest keeping things fundamentally simple we won't delve into the details here. The best way to handle Supercompressibility calculations is to use one of the commonly available AGA 3 or AGA7 calculation programs which have Fpv calculation imbedded in them.

### **Example of Fpv Effect**

Let's consider Natural Gas with a typical gas composition, at the 5.0 psig and 60 deg F such as in our example above. The Fpv Factor at 5 psig is 1.00350 which would make a .35% adjustment on our volume. At 25 psig the Fpv Factor doesn't change much to 1.00382 or a .38% adjustment on our volume. However at 500 psig the Fpv Factor changes significantly to 1.04030 or a 4.0% adjustment on our volume.

### **Charles Law**

Up to this point we have just discussed the effect pressure has on volume. In 1772 Jacques Charles began his unpublished work on what is now referred to as Charles Law. It addressed the effect that temperature has on volume. This law can be simply stated as: At constant pressure a volume of a given mass of ideal gas increases or decreases by the same factor as its temperature on the absolute temperature scale. That is as temperature increases the gas expands and as temperature decreases the gas contracts.

### **Simple Temperature Factor**

Using the principles of Charles Law we can calculate a simple Temperature Correction Factor (Ft)

$$Ft = \frac{\text{Base Temp} + 460}{\text{Flow Temp} + 460}$$

Our Base Temperature is the temperature we have agreed to either purchase or sell gas at in our Gas Contract. When we deviate from Base Temperature we must correct for that deviation. By far the most common base temperature is 60 degrees Fahrenheit so that's what we will use in our example.

The Flowing Temperature is the actual temperature of the gas as measured using approved AGA methods. For our example we will use 40 deg F as the Flowing Temperature.

### **Calculation at 40 deg F**

$$Ft = \frac{60 + 460}{40 + 460} = 1.040$$

For this example our answer would be 1.0400. So to correct our volume for temperature we would multiply our Acf volume by this factor. Since the temperature has caused the gas to contract we can fit more gas into the same space.

### **Calculation at 80 deg F**

Now let's hold everything constant except change the flowing temperature to 80 deg F.

$$Ft = \frac{60 + 460}{80 + 460} = .9629$$

For this example our answer would be .9629. So to correct our volume for temperature we would multiply our Acf volume by this factor. Since the temperature has caused the gas to expand we can fit less gas into the same space.

Flowing Temperatures above our Base Temperatures will have Ft lower than 1.0. Flowing Temperatures below our Base Temperatures will have Ft above 1.0.

If you cool gas down you can put more gas in the same size box.

As a rule of thumb, there is about a 1% change in volume for each 5 deg F change in temperature.

### **Standard cubic Foot**

A standard cubic foot is the measure of 1 cubic foot at 60 Deg F and 14.73 psia. It is represented by Scf. This allows us to have a common standard to compare to. As they are likely measured at different contract conditions a cubic foot from a cubic foot at another company. When discussing a Standard Cubic Foot both companies will be referring the same thing.

### **Apples to Apples**

When comparing any two volumes it's important that we compare them on an equal basis. We can't compare apples to oranges and not expect to see a difference. For instance if we buy gas at one contracted Base Pressure and sell it at another Base Pressure then we need to compare them at a common Base pressure.

For our example let's say we purchase 9,946 mcf @ 14.73 pressure base. Then we sell 10,000 mcf @ 14.65 pressure base. It appears that 10,000 mcf sales minus 9,946 mcf purchase = 54 mcf gain. However the exact amount of gas was purchased and sold. They were just at calculated at different pressure bases.

To convert the 14.73 pressure base volume to 14.65:

$$Pb \text{ Conversion} = \frac{Pb \text{ Converting from}}{Pb \text{ Converting to}}$$
$$\frac{14.73}{14.65} = 1.0054$$

$$9946 \text{ mcf @ } 14.73 \text{ Pb} \times 1.0054 \\ = 10,000 \text{ mcf @ } 14.65 \text{ pb}$$

### **Methods of Calculation or Pressure and Temperature Correction**

The following are the most used today:

1. EFM – Using a field device such as a Flow Computer or Electronic Corrector to read the process variables, hold the configuration parameters and perform an internal calculation.
2. Fixed Factor – Holding a variable such as pressure constant and making the pressure correction in the accounting / billing system.
3. Mechanical – Such as Pressure Compensated Indexes which have gear ratios designed to compensate for a fixed pressure. Also Temperature Compensated Indexes that use bi-metallic elements to compensate for changes in temperature.

### **Key Elements**

- Make all Measurements according to AGA and Manufacturers Guidelines. This is very important in meter station design as well as installing Measurement devices in the field.
- Select accurate and reliable Measurement devices.
- Formulate and adhere to a good calibration program.
- Properly train your Measurement Staff.

### **Formulate a good Calibration Plan.**

This can vary from company to company based on factors such as Staffing, Geographic area coverage, volume, Gas Contracts, etc. There is no "one size fits all".

Some important elements to consider:

- Understand the accuracy requirements stated in your Gas Contracts. What is my goal in terms of accuracy?
- Possible financial impact. What is the value of .25% of the Gas we measure?

- Consider the size of your Field Tech Staff and the number of metered locations. How often will this allow you to perform calibrations at locations?
- Evaluate risk at each location in terms of volume and Contract. What does your Contract State in terms of volume adjustment requirements?
- How do you determine what accuracy the Field Tech calibrates to? You can use some good error calculators for this.
- Choose accurate, easy to use and reliable calibration equipment. Digital is preferred as they are read more often without error. As a general rule of thumb calibration equipment should be four times as accurate as the device it is calibrating.
- How often do you verify your calibration equipment? Can you trace it back to NIST Standards?
- Your calibration program will never be better than your documentation. How will you accurately document all your important calibration information?

### **Summary**

Fundamentals are always the key to success. You can't do Algebra without the fundamentals of addition, subtraction, multiplication and division. Similarly without the proper Pressure and Temperature Measurement fundamentals you can't have a successful Measurement Program. Properly addressing the fundamentals will install the proper building block to success.

### **Terms**

**Acf** – Actual Cubic Feet. Also referred to as the “uncorrected volume” or “Index Volume”. Volume measured by a positive displacement meter before it's corrected for temperature

**Base Conditions** – The Delivery Pressure, Base Pressure, Atmospheric Pressure and Base Temperature that Natural Gas in

Purchased and sold. These are stated as part of a Gas Contract.

**Cf** = Cubic Foot

**Fp** = Pressure Correction Factor

**Ft** = Temperature Correction Factor.

**Pb** = Base Pressure or Pressure Base.

**Psig** – Pound per square inch gauge. The pressure indicated by a gauge above atmospheric pressure.

**Psia** – Pounds per square inch absolute. Gauge pressure + atmospheric pressure. If you have a gauge pressure of 5 psig at atmospheric pressure of 14.7 you have an absolute pressure 19.7 Psia