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THERMOMETRY IN GAS MEASUREMENT

Class # 1310.1

Stephen T. (Steve) Stark
Stark & Associates, Inc.
11101 South Harvard Avenue
Tulsa, Oklahoma 74137
United States of America

INTRODUCTION

Measured several times between the wellhead and its final point of consumption, natural gas temperature is dynamic; it changes frequently and constantly. Gas molecules heat up when packed tightly together, such as when they undergo compression. As gas expands after flowing through a regulator or other restriction, it cools down. Natural gas temperature is also affected by the temperature of the pipe through which it flows.

The measurement of gas temperature contributes directly to measurement accuracy. The greater the temperature measurement error, the higher the overall measurement uncertainty becomes. Even relatively small temperature measurement errors can have a large impact on the bottom line.

THERMOMETRY

Thermometry is the measurement of temperature or the technology of temperature measurement. A common definition of the word *temperature* is “the specific degree of hotness or coldness of an object or environment as indicated on, or referred to, a standard scale.” Temperature can be measured using many different scales including the four shown in Figure 1.

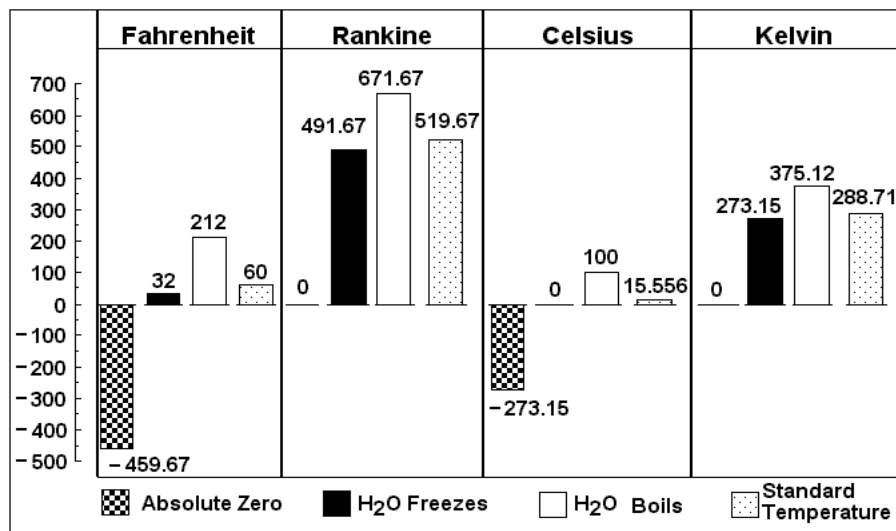


Fig. 1 – Common temperature scales

The Rankine (°R) temperature scale is used in many gas measurement calculations. Gas temperature is often measured and recorded in degrees Fahrenheit and converted to degrees Rankine. To convert from Fahrenheit to Rankine, simply add 459.67 to degrees Fahrenheit.

$$^{\circ}\text{F} + 459.67 = ^{\circ}\text{R}$$

Therefore, gas flowing at 60° F would also be flowing at a temperature of 519.67° R. In another example, gas flowing at 80° F would convert to a temperature of 539.67° R. Figure 2 shows the relationship between these two temperature scales.

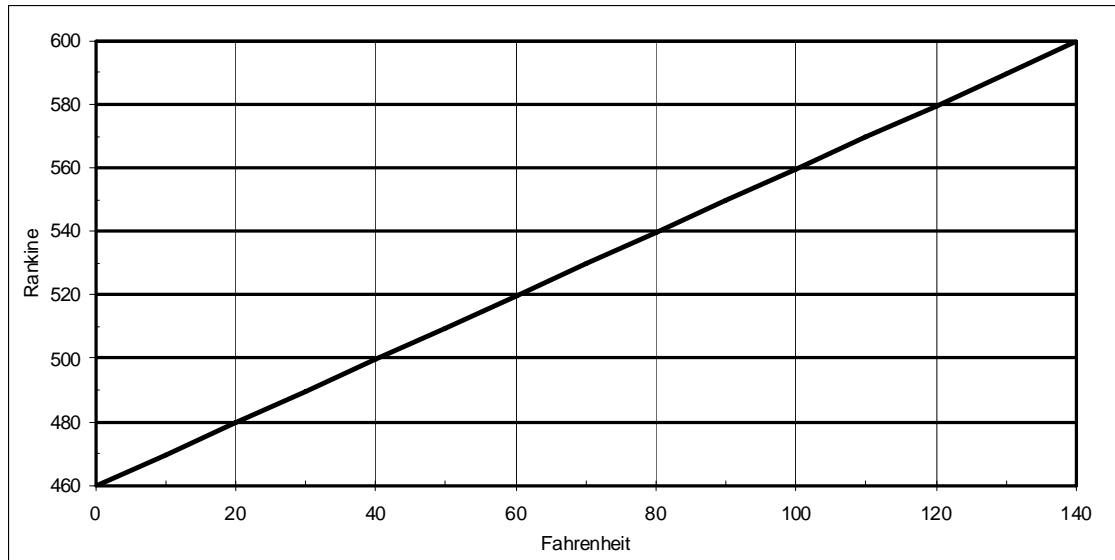


Fig. 2 – Linear relationship between Fahrenheit and Rankine temperature scales

Gas temperature is used in many different ways in the calculation of gas flow including the following.

- Adjusting for Charles' Law
- Calculating gas density
- Calculating gas compressibility
- Adjusting meter tube diameter for thermal expansion
- Adjusting orifice plate bore for thermal expansion
- Estimating or predicting hydrocarbon and water vapor dew point and phase changes
- Estimating water vapor content
- Estimating speed of sound

GAS VOLUME AND GAS TEMPERATURE

Jacques Charles (1746-1823) investigated the relationship between gas volume and gas temperature; he understood that as gas temperature increases, so does gas volume. From his work, we have one of the fundamental gas laws, called Charles' Law, which states, "At a fixed pressure, the volume of a confined ideal gas varies directly with its absolute temperature." The following equation expresses Charles' Law:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

T = Absolute temperature (°R)

V = gas volume (actual cubic feet)

As can be seen from this simple equation, absolute gas temperature and gas volume are directly related. If the absolute temperature of the gas doubles, then the gas volume increases by a factor of two, but only if the gas absolute pressure remains fixed. Charles' Law clearly demonstrates the importance of reliable temperature measurement.

CALCULATED GAS DENSITY

Using equations of state, natural gas density can be calculated using gas composition, gas temperature, and gas pressure.³ Fig. 3 helps to demonstrate the importance of temperature in calculating gas density for a typical pipeline-quality natural gas at pressures from 500 to 900 psia. From Figure 3, it is clear that a ten degree Fahrenheit temperature measurement error would cause a density measurement error of more than 2.5 percent. In an orifice meter application, this error would result in a measurement error of roughly 1.3 percent.

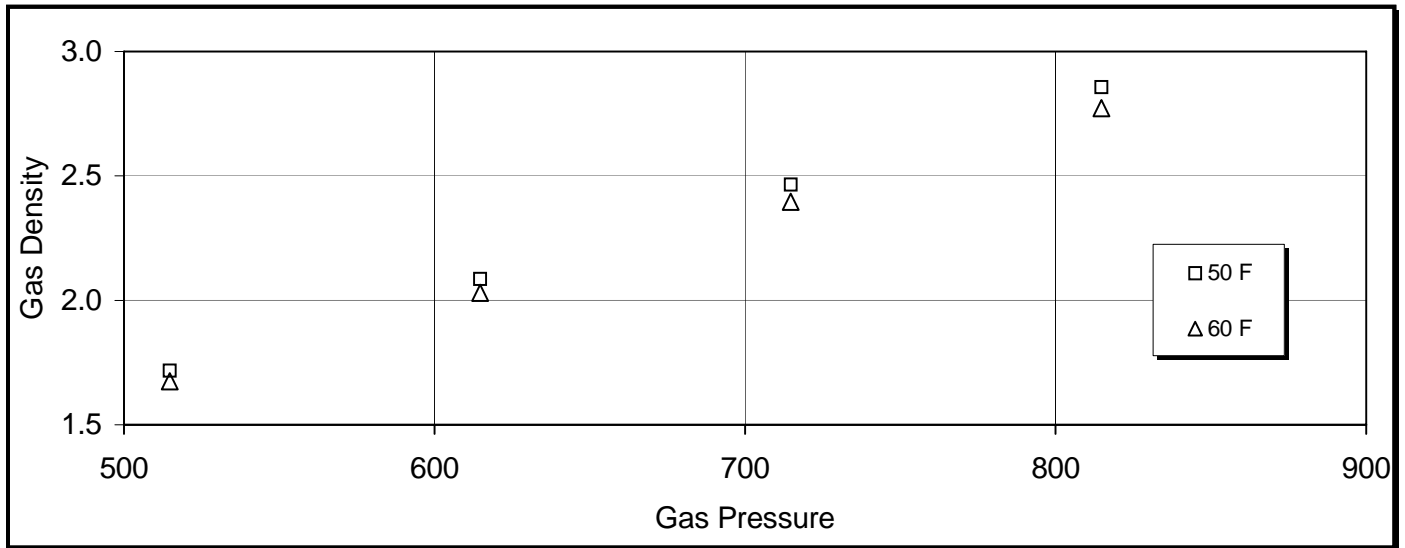


Fig. 3 – Temperature and calculated gas density at various pressures

TEMPERATURE WELL DESIGN

A temperature well (often called by various other names including *thermometer well*, *thermowell*, *thermal well*, *T-well*, etc.) is a pressure-retaining device usually made of stainless steel; it houses a temperature-sensing element, such as an RTD (resistance temperature detector) probe, chart recorder temperature bulb, or reference thermometer.

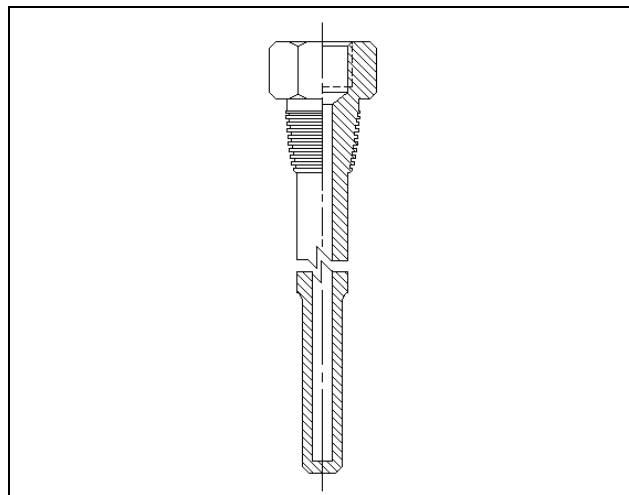


Fig. 4 – Typical temperature well design

Temperature wells protect the relatively delicate temperature-sensing elements from direct contact with the gas stream. They also allow easy removal of the temperature-sensing element during calibrations, calibration tests, or when replacement of the temperature-sensing element is necessary, without interrupting gas flow or allowing gas to escape.

Temperature wells are manufactured in many different shapes, sizes, lengths, and styles to serve a variety of needs depending on operating conditions. Regardless of the style selected, temperature wells should be of adequate length to protrude far enough into the flowing gas stream to sense gas temperature, rather than the pipe wall temperature. Temperature wells must also be strong enough to retain static pressures and to withstand stresses caused by flow-induced vibration, or noise; noise is sometimes caused by on-site equipment such as gas compressors.

DESIGN AND OPERATIONAL CONSIDERATIONS

Ideally, temperature would be measured at the exact point of measurement (e.g., in the bore of an orifice plate, inside a turbine meter or ultrasonic meter body, etc.). However, this is not practical due to flow disturbances caused by temperature well protrusion into the flowing stream that can adversely affect meter performance. Therefore, the temperature well is inserted either downstream of the metering element or far enough upstream of the metering element to prevent undesirable effects.

- AGA Report No. 3 (AGA-3) – Orifice meters: Tables 2-7, 2-8a, and 2-8b in Part 2 of AGA-3 stipulates placement of the temperature well at various minimum and maximum distances downstream of the orifice plate based on the particular meter tube design selected. Alternatively, a temperature well may be installed upstream of a flow conditioner (if used), but not closer than thirty-six inches from the flow conditioner inlet end. Some flow conditioner designs can cause higher pressure drop than others, resulting in the possible additional cooling of the gas passing through it.
- AGA Report No. 7 (AGA-7) – Turbine meters: Suggests placement of the temperature well downstream of the meter to avoid upstream disturbances that might hamper meter performance. Temperature well placement between one and five nominal pipe diameters downstream of the meter body flange is typical.
- AGA Report No. 9 (AGA-9) – Ultrasonic meters: Recommends temperature well location at two to five pipe diameters downstream of the meter body downstream flange face. For bi-directional flow installations, the temperature well should be located at least three pipe diameters from both the meter body upstream and downstream flange face.

When a common header connects multiple meters in parallel or in series, separate temperature wells should be installed for each individual meter. Measuring gas temperature in a header or in adjacent piping (upstream or downstream) is poor practice and discouraged.

Temperature wells may be inserted at virtually any angle to the pipe centerline to allow better temperature transfer through longer immersion lengths, thus permitting more contact with the flowing gas stream.

Meters and meter tubes should be thermally insulated to offset the effect of ambient temperature caused by direct sunlight, cooling from precipitation, wind, and other ambient influences which always cause temperature measurement problems. Gas flowing at lower velocities is especially problematic and extreme care must be taken to ensure the gas temperature is recorded rather than the meter tube and adjacent pipe temperature.

Temperature measurement problems are always suspected when the indicated gas temperatures cycles in a day-to-night or day-to-day pattern.

Many operational conditions must be considered when designing a meter station. One essential element in measurement station design is conformance to applicable codes and standards. These policies are necessary not only for reliable operational purposes but also, and more importantly, for safety.

Attention is given to the following issues relating to temperature well selection and installation.

- Temperature well material and strength
- Length (including "U" length)
- Diameter
- Wall thickness

- Shape (e.g., straight, tapered, stair-step, etc.)
- Location
- Installation method (e.g., screwed, flanged, or welded)
- Tendency toward vibration and breakage
- Ease of removal of temperature sensing element for maintenance, testing, and calibration

Custody transfer meter design should include a reference (or “test”) temperature well located near the temperature well used for flow measurement. A reference temperature well provides a quick and practical means of spot-checking the “flow computer indicated” gas temperature against a thermometer of known uncertainty. It is important that this comparative temperature check be performed only when gas is flowing because the temperature of stationary gas is unreliable.

In addition to the primary and reference temperature wells, other temperature wells are sometimes installed for operational purposes to allow the checking of gas temperature at the inlet and outlet of gas regulators, gas controllers, and even some flow conditioners. Obtaining temperature measurements at these additional locations can be especially useful in estimating the potential for changes in gas phase.

Where meter tubes and other components equipped with temperature wells are not isolated from cathodic protection (or from other potentially troublesome sources of electrical interference such as RFI or EMI), design changes may be necessary to electrically isolate the temperature-sensing equipment such as RTDs and temperature transmitters. At least one patented RTD probe design may help alleviate this problem in some cases.

Because the temperature-sensing device (e.g., RTD) is not in direct contact with the gas flow, a temperature well can actually act as a thermal insulator, thus preventing the measurement of the true gas temperature. In other words, although temperature wells are a practical necessity, they can impede our efforts to measure gas temperature reliably in some cases. This problem can also occur when temperature wells become dirty or coated with grease, oil, glycol, or other contaminants that can slow response time or impede heat transfer. Other biases in temperature measurement can occur through temperature transfer from the pipe wall through the temperature well or by radiated heat transfer from outside the pipe.

Traditionally in the gas industry, the closed end of a temperature well is located in the center one-third of the flowing stream, which is commonly thought to be the point at which the most representative temperature is obtained.

Liquids are sometimes placed into temperature wells to improve heat transfer efficiency. Glycol and water mixtures or special heat-transfer liquids are often used for this purpose. The removal of temperature probes can sometimes be difficult when the probe's diameter is in close tolerance to the bore of the temperature well, especially when using heat transfer liquids that may partially evaporate, thus leaving a sticky residue.

When a glass reference thermometer is used for calibration and testing, it is important that the scale remain readable while the thermometer is inserted into the reference temperature well. Erroneous measurements can occur when a thermometer (or an electronic temperature-sensing element) is removed from a test temperature well before the temperature reading is taken. This is especially true when the test thermometer becomes wet from immersion in a heat transfer fluid, especially when there is a wide difference between the ambient temperature and flowing gas temperature, or when wind causes cooling due to evaporation.

Some end-users have decided to use electronic temperature references while others insist the only acceptable reference is a glass thermometer meeting a specific traceable temperature tolerance. API MPMS Chapter 21.1 requires that the as found reading of the fluid's temperature to be checked against a certified thermometer to within 0.5°F of the certified thermometer's reading.⁵

SQUARE ROOT METERS

Orifice meters, flow nozzles, Venturi meters, and many other meter types fall under the general category of square root meters. Like most other meter types, square root meters require gas temperature to calculate flow in

adjusting for the effects of Charles' Law, calculate gas compressibility at flowing conditions, and correct for meter geometry changes caused by temperature.

Most square root meters rely on a single-point temperature measurement that is presumed to be identical to the temperature of the meter's primary element, consisting of:

- Meter tube (upstream and downstream) and flow restrictor holding device
- Flow conditioner (if used)
- Flow restrictor (e.g., orifice plate, Venturi throat, cone-type meter restrictor)

Orifice meter tubes and orifice plates are usually made of carbon steel and stainless steel respectively, though both are sometimes made of other metals (e.g., Monel®) that have special characteristics to help resist corrosive conditions in some gas streams.

The meter tube and orifice plate diameter correction calculations are referenced to a measured diameter (D_m for meter tubes and d_m for orifice plates) and referenced to a standard temperature (commonly 68° F); any temperature may be selected. As meter tube and orifice plate geometry changes due to changes in gas temperature, the beta ratio (β , orifice plate bore divided by meter tube diameter, d/D) also changes.

In turn, the calculations of other flow calculation factors are also affected, including:

- Coefficient of discharge — $C_d(FT)$
- Velocity of approach factor — E_v
- Gas expansion factor — Y_1 or Y_2

Some square root meter primary elements are made entirely of the same material. Flow nozzles, for example, are commonly machined from a single block of stainless steel. Regardless of the type of metal used, meter tubes and flow restrictors expand when heated and contract when cooled. For this reason, the coefficient of thermal expansion for the material used is considered.

LINEAR METERS

Turbine meters, ultrasonic meters, rotary meters, diaphragm meters and many other types of gas meters fall into a general classification called linear meters. As with square root meters, the reliable measurement of gas temperature is also required to calculate flow in order to correct for the effect of Charles' Law, calculate gas compressibility at flowing conditions, and correct for meter thermal expansion.

AGA-9, which addresses natural gas measurement using multi-path ultrasonic meters, includes gas flow and energy calculations that clearly show, once again, the importance of measuring gas temperature correctly.

However, temperature plays another special function where ultrasonic meters are used because it is also used to calculate speed of sound that is then compared to the ultrasonic meter indicated speed of sound as one means of checking correct meter performance. The calculated speed of sound is affected greatly by gas temperature.

If the measured gas temperature is incorrect, then the resulting speed of sound calculation will also be in error.

As can be seen in Fig. 5, a five degree Fahrenheit temperature error at 600 psia and at a gas temperature of approximately fifty degrees Fahrenheit would result in a calculated speed of sound difference of roughly ten feet per second (roughly 0.7%). When speed of sound comparisons do not agree with those provided by the ultrasonic meter, knowledgeable field technicians will check the temperature measurement first to ensure it is correct.

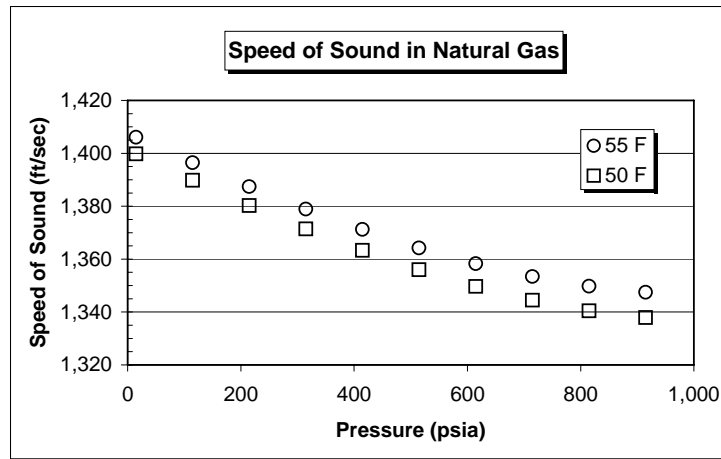


Fig. 5 – Gas temperature and speed of sound

CONCLUSION

Temperature measurement is fundamental yet crucial to overall measurement precision. Even relatively small bias errors in temperature can have a significant impact on the bottom line. Where reliable measurement is expected, care must be taken to design temperature measurement systems using methods and equipment that will get the job done right.

Gas measurement technology has improved significantly from the mid-1960s until today in 2011. The advent of flow computers, electronic flow measurement systems, and new metering technologies has drastically changed the way gaseous hydrocarbons are measured. The science of thermometry will continue to benefit from future studies and as the science of thermometry advances.

REFERENCES

The following references are among those used in the preparation of this paper. Please contact the author through his Web site at www.StarkAssoc.com for questions, additional technical clarification, or comments.

1. AGA Report No. 3, *Concentric, Square-Edged Orifice Meters*.
2. AGA Report No. 7, *Measurement of Natural Gas by Turbine Meters*.
3. AGA Report No. 8, *Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gases*.
4. AGA Report No. 9, *Measurement of Gas by Multipath Ultrasonic Meters*.
5. API MPMS Ch. 21.1, *Flow Measurement Using Electronic Metering Systems*.
6. United States Patent 5,674,009, Adjustable length temperature sensor (October 7, 1997).