Technical Publication

Analyzing Natural Gas and Consumable Gas Flow Measurement Technologies

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As the costs of fuels and consumables (natural gas, hydrogen, oxygen, etc.) continue to rise, the ability to accurately measure the amount used in a process becomes significant in controlling costs and determining bottom line profits. It may have been acceptable in the past to absorb these expenses as necessary overhead to conduct business, but more companies are beginning to analyze consumables used in heat-treating processes to determine the profitability of each particular job. Therefore, it is important to implement a strategy of adding cost effective, accurate gas flow measuring devices to heaters, boilers and cogeneration equipment.

General Flow Meter Technologies

Once we've decided to add this level of measurement, it should be relatively easy to select a flow meter that will meet our needs. Differential Pressure with primary flow elements, Magnetic, Ultrasonic, Turbine, Venturi, Rotameter, Coriolis, Vortex Shedding, Thermal Dispersion and several other technologies exist. We can add the same type of metering being used in other parts of the facility since we are familiar with it, or we can search "flow meters" on the web and quickly find a couple of meters, something either inexpensive or hi-tech, that will do the job for us. How difficult can it be? Unfortunately, it does require more analysis than this to ensure that we get the correct flow meter solution for the application.

All of us should understand by now that there are advantages and disadvantages associated with any type of technology used in process measurement. Just the type of fluid that we are trying to measure can limit the options available. Fluids come in the form of liquids, slurries, gases and steam. There are fewer concerns associated with the flow measurement of a liquid or slurry given that they are considered incompressible and, if homogeneous, have a constant density. Gases require more consideration given that they are compressible, which results in a density that varies with changes in process pressures and temperatures. Steam presents its own set of complications since not only is it compressible, it has a high moisture content at relatively high temperatures. For the purposes of this article, we are going to look at the differences between liquids and gases. For reasons that will be explained, a proven method for measuring a liquid does not necessarily translate into a good solution for measuring a gas.

Consideration should be given, but not necessarily limited, to the following items when selecting a flow meter for gas measurements: accuracy, turndown ratios, pressure drops, process temperatures, additional sensor requirements, and process connections. To help develop a method that will allow us to effectively compare technologies, we are going to look specifically at how these factors are addressed by Differential Pressure and Thermal Dispersion technologies.

Differential Pressure Technology

The most common method of measuring liquid flow is to use a differential pressure (DP) transmitter with a sharp edged orifice plate. The square root extraction of the pressure drop across the orifice is directly proportional to the volumetric flow rate in the pipe *(Figure 1)*. Other primary flow elements used to take

Basic Flow Rate Formulas

Volumetric Flow Rate (Q)

Q = Velocity (avg) x Area (pipe)	V = Average Velocity of Gas (length/time)	ft/sec
Q = V x A	A = Cross Sectional Area of Pipe (area)	ft^2
	Q = Volumetric Flow Rate (volume/time)	ft^3/sec

Mass Flow Rate (M)

M = Density x Volumetric Flow Rate		
M = ρ x V x A	ρ = Density of Gas (mass/volume)	lb/ft^3
M = ρ x Q	M = Mass Flow Rate (mass/time)	lb/sec

Figure 1

similar measurements with DP transmitters are pitot tubes, averaging pitot tubes (e.g. Annubars), v-wedges, and v-cones (e.g. McCrometer).

These same instruments are often selected in gas flow measurement based upon maintaining commonality of instrumentation throughout a facility. While this makes sense from a maintenance and inventory standpoint, our real objective is to improve the gas flow measurement of the process. Since we are now trying to measure a compressible gas, we have to recognize that knowing the mass flow rate is more beneficial than the volumetric flow rate *(Figure 2)*. Without taking into account that the density of a gas will change with variations in process temperature and pressure, a volumetric flow reading will not be an accurate representation of actual gas consumption in a process.

Volumetric v. Mass Flow Rate

- Assume a volumetric air flow rate of 3,000 acfm
  @ Standard conditions of 70°F (21.1°C) and 14.7 psia
- Actual process temperature = 100°F (37.8°C)
- Actual process pressure = 50 psig (64.7 psia)

To determine an equivalent flow rate at process conditions, we would calculate it as follows:

= Qacfm x Pact / Tact x Tstd / Pstd
= 3,000 acfm x 64.7 psia/310.8°K x 294.1°K/14.7 psia
= 12,494.6 scfm

Note: Temperatures & Pressures must be converted to absolute values; °Kelvin (273 + °C) and psia (14.7 + psig)

Since air is compressible, the mass flow rate can be represented as a volumetric flow rate of 12,494.6 scfm.

Figure 2

This limitation of volumetric flow meters in gas applications can be overcome. The addition of pressure and temperature transmitters can provide the data required to compensate for changes in gas density under process conditions. Sending the flow, temperature and pressure readings into the PLC or DCS will allow for the calculation of the mass flow rate. We have now added complexity, extra sensor expense, and extra installation expense to our gas flow measurement *(Figure 3)*. When working with flow elements like an orifice or averaging pitot tube, the use of a multivariable transmitter would definitely simplify our installation.

Several factors come into play when determining the actual accuracy of a DP transmitter being used with a primary flow element. We don't want to work from the incorrect belief that a DP transmitter will provide an accuracy of +/- 0.1% or greater depending upon the manufacturer. If you look closer at the specifications, the accuracy could vary with the span ratio (turndown), percentage of flow rate being measured, long-term drift, temperature effects and static pressure effects. Best-case conditions may provide accuracy better than +/- 1%, but the true accuracy can be +/- 5% or greater under actual process conditions. We have yet to take into account the additional inaccuracies associated with the additional pressure and temperature transmitters required because we are trying to determine the mass flow rate, not volumetric! We may further degrade the accuracy if the gas has particles that may build up around the edges of the orifice or plug the small openings in a pitot tube over time. A v-wedge flow element can be more forgiving in dirty gas applications.

When using a DP transmitter with an orifice, the turndown ratio would be more in the line of 10:1, maybe 20:1 depending upon the transmitter. This could become a significant issue when the required gas flow is high for one process and very low for another. Without adequate turndown, we may end up with a meter that is only capable of accurately measuring on the high end of the flow range. It is a common practice to "stack" meters of varying ranges to take readings from the same primary flow element in order to increase the measured flow range. This approach further increases the cost and complexity of our system.

The use of a sharp edged orifice or any other type of primary flow element is intended to create a measurable pressure difference. Although pressure drop is not critical in all gas applications, it does impact the efficiency of a process in the form of wasted energy. For an orifice plate, this loss could be significant over the life of our process. Averaging pitot tubes or v-wedges can limit those losses by reducing the size of the obstruction in the flow line. In the case of an orifice, this loss can be in the neighborhood of 50" w.c. in a 4" line for a flow rate of 3,000 SCFM. Given the same conditions, that value may be less than 20" w.c. for an averaging pitot tube and v-wedge. With low process pressures, these losses can limit our ability to maintain the required minimum flow rate of our system.

When performing mass flow measurements, we must take the actual process temperatures into consideration. Although there are many applications in which the gases are delivered at ambient conditions, there are applications in heating and cogeneration systems in which the temperatures can be quite high. Most DP transmitters are rated for temperatures up to 250 °F at the point of the measuring cell. For applications that will be significantly higher than this, say 500 °F or so, it will be necessary for us to use impulse tubing in order to dissipate the extra heat from the process. A general rule of thumb is about a foot of stainless steel tubing per 100 °F. For even higher temperatures, the use of a process (chemical) seal with a non-expanding fill fluid may be required. The use of impulse tubing or process seal is not a major concern, but we should be aware that it will slow the response time of the meter, add cost and complexity to our installation, and require adequate elevation if there is condensation in our lines.

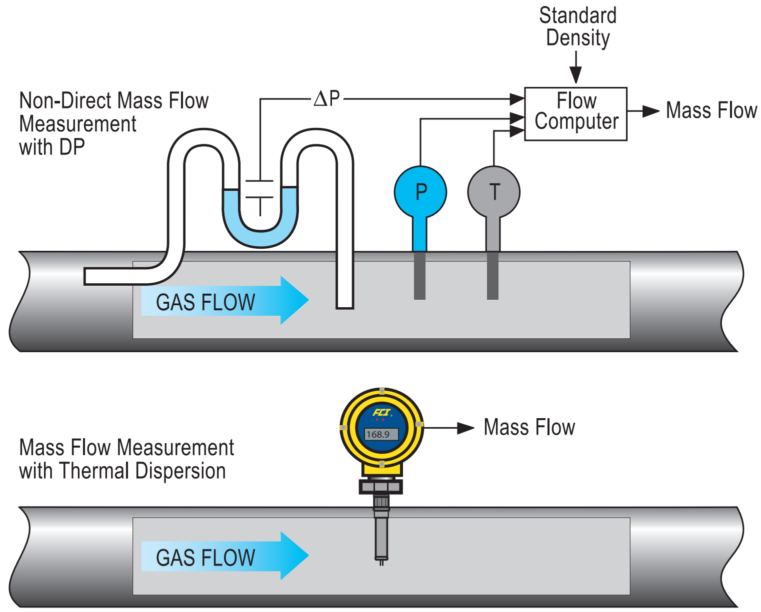

Figure 3: Mass Flow Measurement

Proper installation of a DP transmitter to a primary flow element adds to the complexity of our installation. In order to ensure accuracy, DP transmitters do require periodic calibration checks. In order to perform these checks with the system operating, installation of a 5-way manifold between the flow element and transmitter is common. This manifold allows for both isolation from the process and the ability to apply a known pressure source for calibration checks of the zero and span. A 3-way manifold may also be used, but it will only allow for isolation from the process. It would then have to be removed from the manifold to perform calibrations. Either way, it is another item that will add to our installed costs.

Thermal Dispersion Technology

Another technology often utilized in gas flow applications is the Thermal Dispersion flow meter. It may also be referred to as thermal differential (Delta-T) or simply thermal. This particular instrument makes use of two high precision RTDs. A reference RTD measures the process temperature and an active RTD is heated to a known value to create a differential temperature between the two sensors. When there is no flow, the differential will be at its greatest. As the gas begins to flow, the active RTD begins to cool and decreases the differential between the two sensors *(Figure 4)*. This is an oversimplification of the operating principle, but provides us a basic understanding. Thermal technology is advantageous because it also takes into account the density, absolute viscosity, thermal conductivity and specific heat of the gas being measured. The end result is a very accurate mass flow reading that requires no additional instrumentation or calculations.

The accuracy of a thermal mass flow meter is very straightforward. It is commonly broken into two components: a percentage of reading and a percentage of full scale. These instruments are immune to long-term drift, are commonly compensated for broad temperature ranges and the effects of pressure changes are negligible. So, to really understand how technologies compare, we have to look at our worse case process conditions and run the calculations.

For most applications, we can expect to achieve a turndown ratio of 100:1 with a thermal meter. This allows us to maintain a high level of accuracy over the entire flow range without having to “stack” multiple instruments.

The pressure drop across a sharp edged orifice vs. the drop across a single-point thermal flow element can be in the magnitude of 5 to 10 times greater. The most significant difference can be observed when we are operating 70% to 100% of the maximum flow range. Using our example of a flow rate of 3,000 SCFM in a 4” line, the pressure drop is in the neighborhood of 15” w.c. for a thermal meter vs. 50” w.c. for a DP meter and orifice.

Thermal meters are inherently suited to high temperature applications. Since we are literally dealing with RTDs in thermowells, standard temperature capabilities of these meters

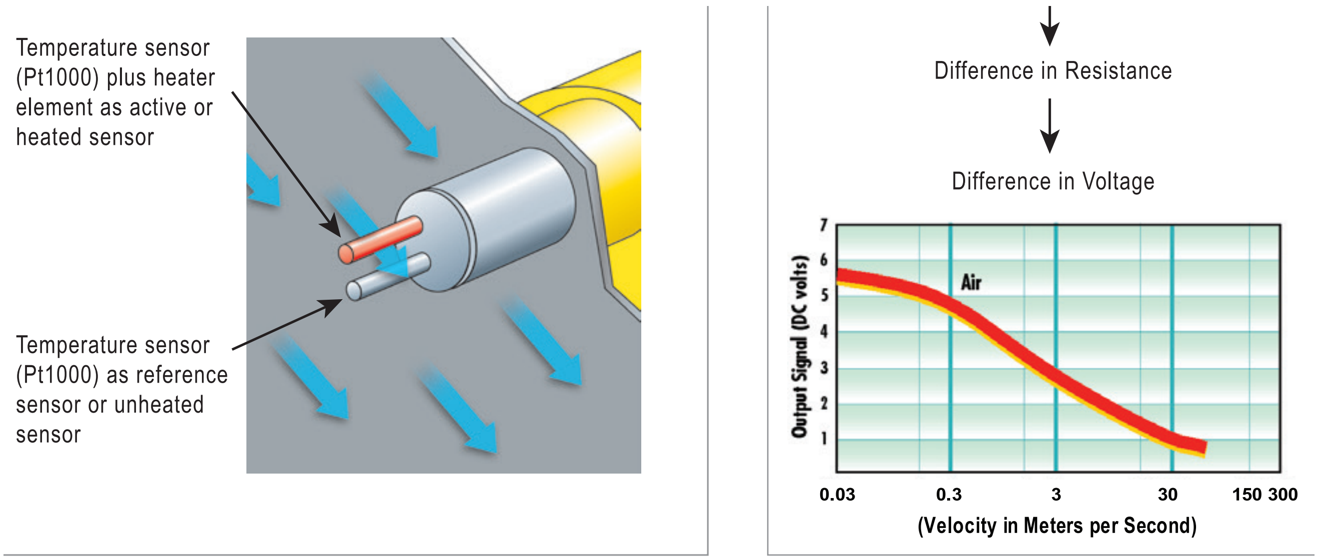

Figure 4: Operating Principle of Thermal Dispersion

run to about 350°F. With modifications to the design of the flow element, some manufacturers offer variations suited to process temperatures as high as 500 °F to 850 °F that require no added installation considerations.

The installation of a thermal flow element is simple. In the case of an in-line meter, the elements can be provided with either threads or flanges. With insertion type elements, it is common to install the units with a threaded compression fitting. Unlike a DP transmitter, periodic calibration of a thermal meter is not required. Manufacturers may recommend that a calibration check be performed every 12 to 18 months. In the case of processes that run continually or involve dirty gases, the use of a packing gland and ball-valve assembly is recommended with an insertion meter for extraction of the flow element for either calibration or inspection and cleaning.

Like any other instrument, thermal dispersion technology does have limitations and is not ideal for certain applications. First and foremost is that these instruments are not suitable for measuring the flow of liquids, slurries or saturated steam. Thermal technology is best suited for the measurement of dry gases, gases with limited moisture, or superheated steam (no water vapor).

We must also keep in mind that thermal meters are normally calibrated for a specific gas composition. For instance, this can be a single gas such as air, hydrogen, oxygen, etc. or a composition like Natural Gas (Methane and Ethane). If the composition changes, the mass flow reading will remain repeatable but it will no longer be as accurate. The use of a correction factor may improve the accuracy to acceptable limits for some processes.

If our process has condensation in the lines, a thermal meter may provide false readings due to the cooling of the active RTD that is not directly related to the flow rate. In some cases, appropriate positioning of the flow element in the pipe can reduce or eliminate this effect. Other cases might require the use of condensation (knock-out) pots or filters to reduce the moisture content to acceptable levels.

Ideal vs. Actual Flow Conditions

Another factor that impacts accurate gas flow measurement is the upstream and downstream (straight-run) piping conditions. For line sizes up to 6”, it is normally accepted that a straight run of 20 pipe diameters (i.e. 20D) upstream and 10 pipe diameters (i.e. 10D) downstream from the metering point is required for a fully developed flow profile. The acceptable requirements for lines over 6” are 15D upstream and 7.5D downstream. Although it is realistic to be able to find a 7.5 ft. straight run of 3” pipe, it is more difficult to locate an appropriate 22.5 ft. run for a 12” pipe. When straight-run conditions are inadequate, obstructions (e.g. elbows, valves, etc.) can disrupt the flow profile and reduce the accuracy of any flow meter technology being used.

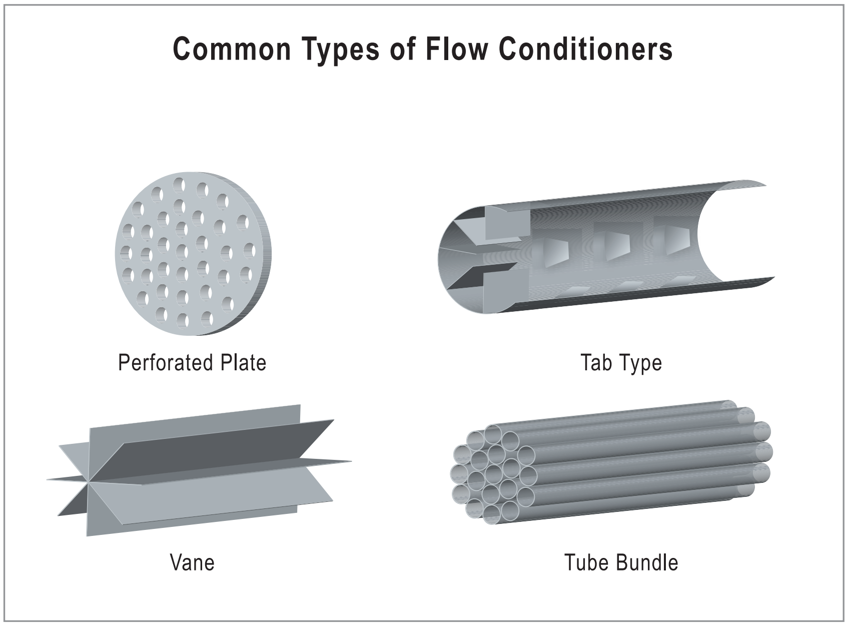

Figure 5: Solutions for Inadequate Straight Run

Figure 6: ST75V Flow Conditioner

Since our objective is to improve the flow measurement we should not accept these additional errors. The next step is to understand the flow disturbance created by our actual piping conditions. Many in-line obstructions can generate distorted velocity profiles. This will affect the readings of meters that are based on the average or maximum velocity of a fully developed flow profile. In the case of elbows out of plane, we will also see a swirling effect take place. Knowing this fact will help in selecting a conditioning device that will properly address our needs.

Common types of flow conditioners are perforated plates, screens, vanes, tube bundles and tabs *(Figure 5)*. These are all simple, mechanical devices that are installed in the process piping before the metering point. Perforated plates and screens do an adequate job of generating a measurable velocity profile, but have limitations when it comes to swirl. Tube bundles and vanes provide better conditioning for swirl, but allow a good portion of a distorted velocity profile to move on to the metering point. Only the tab design has been shown to eliminate the effects of both a distorted velocity profile and swirl by generating a very repeatable and measurable velocity profile. Like primary flow elements, the design of the flow conditioner can introduce pressure losses that equate to wasted energy. The greatest losses are observed with perforated plates and the least amount is associated with the tab design.

In the case of thermal flow meters, some manufacturers have integrated flow conditioning devices into their flow element *(Figure 6)*. This is a great benefit to us since not only have we reduced the amount of straight-run required for our installation, we now have an instrument that has been fully calibrated to our process conditions and will provide us with a very high level of accuracy in our measurement.

Conclusion

The proper selection of a flow meter for measuring the amount of gas consumed in a process can be challenging. Until we have determined what types of technology will properly address our actual process conditions, we should not jump ahead to evaluating costs associated with purchase price and installation. Getting one or two experienced gas flow meter manufacturers involved in the initial evaluation stage can add value by allowing them to make recommendations up front with regards to improving our flow measurements. You will then have peace of mind that the flow meters that you have selected are right for the application and will provide your organization with accurate measurements to optimize the process and achieve cost reduction goals. ■