FUNDAMENTALS OF GAS MEASUREMENT

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HISTORY

Samuel Clegg made the first practical gas meter in England in 1815. It was a water-sealed rotating drum meter that was improved in 1825; however, it was still very costly and very large. Thomas Glover developed the original diaphragm meter in England in 1843. It consisted of two diaphragms, sliding valves and linkage. T. S. Lacey patented the pre-payment meter in 1870. The most significant change to diaphragm meters over the years has been in the materials of construction. Brass parts have been replaced by plastic, and leather diaphragms have been replaced with synthetic rubber.

A rotary piston meter was invented in the late 1800's, but it was primarily used a blower. In the 1940's a Roots-Connersville dimensional rotary meter was used. The style of rotary meter in use today was first used in the 1960's in the cast iron version, the extruded aluminum style came out in the 1970's. The modern turbine meter was developed in the 1970's. It has had minor modifications over the years, but the basic operation is the same. Ultrasonic measurement was first developed in the 1980's and has been refined over the years.

MEASURING VOLUME

There are essentially two different ways to measure volume of a fluid (gas): by counting amounts of known volumes (displacement) or by calculating volumes based on observed data (inferential). The two primary displacement meters are the diaphragm meter and the rotary meter. There are several different types of inferential meters, but the most common are the orifice, the turbine and the ultrasonic meters. Every meter must have a way of translating its measurement information into a volume that can be used for billing. Methods vary from a simple mechanical index to a full-blown computer.

While meters register volumes in actual cubic feet, customer bills are based on standard cubic feet. For most homes that have a domestic meter and receive "low" pressure delivery, i.e. 7" w.c. or 0.25 psig or 4 ounces, the actual cubic feet registered is used as the standard cubic feet for billing. However, if a meter measures at elevated pressure, a correction must be made to account for this higher pressure. In addition, there is a supercompressibilty factor that accounts for the fact that natural gas is not truly an ideal gas. This factor is very small at lower pressures and many times is not used for pressures below 100 psig.

The use of standard cubic feet for billing volumes was a means to account for the heating values, or Btu value, of gas. With the advent of computer technology and the rising cost of gas, billing in units of energy has become more common, particularly with transmission measurement. Dekatherm measurement requires a measured or assumed Btu value of the gas. This is then used in conjunction with the volume measurement to calculate the energy used.

DIAPHRAGM METERS

The diaphragm meter is the most common type of meter in use today. It is very similar in operation to the original diaphragm meter invented over 150 years ago. While it is the standard for domestic use, it has been used for commercial and industrial customers for many years. While large diaphragm meters up to 10,000 cubic feet hour (cfh) capacity are still in use today, most companies only purchase diaphragm meters up to 1000 cfh capacity.

In the two diaphragm, four-compartment meter, each stroke of the diaphragm displaces a fixed volume of gas. The diaphragms operate 90 degrees out of phase, so when one is fully stroked, the other is at mid-stroke. This ensures the meter will always start to measure regardless of its position, and will provide a smooth flow of gas to the meter outlet. When there is a demand for gas on the downstream side of the meter, a pressure differential is created across the meter diaphragms. This differential pressure provides the force to drive the meter.

There is a sliding valve above each diaphragm on the meter. Under the valve are three port openings that direct the flow of gas in and out of the case and diaphragm compartments. As the diaphragm expands, it forces the gas in the case compartment up through the case port. The valve directs the flow of gas into the center port that leads to the meter outlet. When the diaphragm contracts, a similar process occurs.

The stroke of the diaphragm is controlled by a linkage in the upper part of the meter and a flag rod that extends down into the diaphragm compartment. An adjustable tangent at the top of the meter crank is used to adjust the diaphragm meter stroke, which in turn adjusts the meter's accuracy or proof.

Hundreds of thousands of diaphragm meters are sold each year and nearly all are accurate within 1% or less. Its accuracy at low flows, especially for pilot lights, is unmatched. Millions of diaphragm meters are in service, some for more than 40 years. There are no special piping requirements necessary. Diaphragm meters are usually grouped by "Class," which refers to the badged capacity of the meter in cubic feet per hour, 250 Class, 400 Class, etc.

The badged capacity if based on a ½" water column pressure drop across the meter. However, the meter can pass more than the badged capacity at higher pressure drops, and many utilities size diaphragm meters based on a 2.0" water column pressure drop across the meter, especially when measuring at elevated pressures.

The diaphragm meter requires no special piping or flow conditioning. It is sometimes manufactured with a built in service regulator for compact meter sets. Indexes come with traditional dials, or as a digital, odometer-type, which is easier for the customer to read.

ROTARY METERS

The rotary positive displacement type meter has been in existence for over 75 years. The technology had been around since the 1880's in industrial blowers. Lobed-impeller rotary meters, made of extruded aluminum, have been in use since the 1970's. Enhancements have been made, particularly with temperature and pressure correction integrated within the meter, but the principle operation remains the same.

A lobe-impeller type rotary meter consists of two figure-eight shaped impellers, positioned 90 degrees from each other, which rotate in opposite directions inside a cylinder of fixed volume. Gas flowing through the meter causes the impellers to turn, creating a measurement chamber bounded by the impeller, cylinder and headplates. This known volume is then discharged and another identical volume of gas is trapped by the other impeller, cylinder and headplates. Gas is alternately trapped and discharged four times for each impeller revolution.

The displaced gas per revolution is multiplied by the number of impeller revolutions to determine the volume of gas passed by the meter. A gear reduction system is used to totalize the displaced volume for instrument drives and counter readouts. In many cases a temperature compensating index may be used to adjust the actual volume into a temperature corrected volume.

Since the rotary meter is a positive displacement meter, turbulence in the gas stream has little effect on measurement. However, the close tolerances built between the impellers means particles of dirt or debris (or plastic pipe shavings) can damage the impellers or even cause the meter to bind and stop. In many instances, some type of filter is installed upstream, particularly where there is dirty or wet gas present. In most cases a strainer or screen is installed to catch larger debris.

Today the primary application for rotary meters is for small commercial loads. It is also frequently used for production measurement, where it must be protected form fluids and from freezing. Rotary meters come as small as 500 cfh and are still made in sizes up to 102,000 cfh.

TURBINE METERS

Gas turbine meters are velocity sensing devices. The direction of flow through the turbine meter is parallel to a turbine rotor axis and the speed of the rotation of the turbine meter is nominally proportional to the rate of flow. A turbine meter introduces a restriction, a nose cone, of known cross-sectional area into the gas stream. The turbine meter determines the flow velocity through this restriction by counting rotations of the turbine rotor mounted in the open area of the restriction. The turbine blade rotations are transferred through a gear train to a readout device where totalized volume at line conditions is displayed.

As the flowing gas stream enters the turbine meter inlet, it is diverted to the periphery of the meter body by the nose cone, which is a symmetrical obstruction. The flowing gas passes through a machined annular channel defined by the outside diameter of the nose cone and the inside diameter of the meter body. Integral straightening vanes are usually located in this annular channel to ensure an even velocity of the gas as it impinges on the rotor.

The turbine rotor is fixed to a shaft that is suspended on ball bearings. Rotations of the turbine rotor are transmitted through a magnetic coupling from the pressurized are within the meter body to a non-pressurized are above the meter top plate. A gear train is located in this non-pressurized area to reduce the rotational speed to acceptable and definable limits, which then can drive a wide variety of readout devices.

The energy of the gas stream itself is the driving force of the turbine meter. Since the ball bearings and gear train has some friction, it will take some minimum amount of energy, or gas velocity, to turn the rotor. There will then be an even higher velocity at which the friction of the bearings and gears are negligible and the meter is measuring within acceptable accuracy limits. While it is possible for the turbine meter to not register any volume at extremely low flow rates, this volume is negligible compared to the total volumes when the meter is running at close to its' capacity.

Since the turbine meter is sensing velocity, it is critical that the flow in the meter be smooth and laminar. While the straightening vanes and nose cone smooth out the flow inside the meter, it is necessary to ensure that the gas entering the meter be a smooth as possible. Restrictions upstream of the meter, such as valves, fittings and taps, can cause turbulent flow and even jetting. To create laminar flow before the meter, long straight runs of pipe and straightening are usually employed. Industry standards have been established, namely AGA Report #7, to provide minimal design guidelines to ensure accurate measurement. Typically, the 10 pipe diameters of straight is required upstream of the meter and 5 pipe diameters downstream.

ORIFICE METERS

The basis of orifice measurement is that a calibrated restriction creates a resistance to flow and causes a pressure drop, which is indicative of the quantity of the gas flowing. The primary elements are the meter-piping run, straightening vanes, orifice fitting, orifice plate and pressure and temperature taps. In addition, a recording secondary element is necessary to record pressure differential, upstream pressure and gas temperature.

The meter piping run is a specific length of pipe that is finely machined to have a precise inside diameter. The straightening vanes ensure a laminar gas flow, which is critical for accurate measurement. The orifice fitting holds and positions the orifice plate in a perpendicular position concentric to the meter piping run. The orifice plate is a flat, polished, circular, stainless steel plate with a predetermined dimension forming a calibrated restriction. The pressure taps are drilled in a precise location on the orifice fitting, upstream and downstream of the orifice plate. The temperature tap is located downstream of the orifice plate.

The secondary recording element is usually either a mechanical pressure and temperature recorder or an electronic recorder that receives signals from pressure and temperature transducers. The static pressure, differential pressure and a coefficient related to the physical characteristics of the orifice meter run. In addition, the gas temperature is necessary to adjust the volume for standard cubic feet.

The volume calculations for orifice meters can be quite complex and are usually accomplished by means of a flow computer. The dimensions and tolerances for the meter and meter piping run are critical to the accuracy of the meter. Industry standards such as AGA No. 3 and No. 8 have been developed toset standards on piping and machine tolerances.

ULTRASONIC METERS

Ultrasonic meters are velocity meters, like turbine meters, that infer a gas flow rate based on the velocity of the gas stream. An ultrasonic pulse, or pulses, is transmitted from one side of the pipe to the other and the velocity of the pulse is measured. The time for the pulse to travel through the gas stream is proportional to the velocity of the gas. Highly precise timing is necessary to measure these very small time increments. Multiple transmitters enable the ultrasonic meter to calculate a more fair representation of the average velocity of the gas stream.

While the ultrasonic meter requires sophisticated electronics to calculate flow, it offers much higher flow rates than orifice and turbine meters for the same size piping and has the added benefit of no moving parts and very little maintenance. The gas flow must be conditioned similar as that done for orifice and turbine meters. The more sensors or “paths” used increase the accuracy and reliability of the meter.

TEMPERATURE CORRECTION

The standard gas temperature used in almost all companies is 60 degrees Fahrenheit. However, the actual gas temperature in the meter can vary from near freezing to in excess of 100 deg F. Failure to properly account for the actual gas temperature can result in billings errors of 5% or more. For residential diaphragm meters in the Appalachian area, the effect of temperature is approximately 3% on a weighted annual basis. Diaphragm and rotary meters generally can be purchased as temperature compensating (TC) or non-TC. Turbine, orifice and ultrasonic meters usually employ temperature transducers to correct for temperature.

To calculate the temperature effect on volume, a comparison must be made between the actual and standard gas temperatures. This calculation must be done in absolute temperatures, or degrees Rankin (deg R). A gas temperature of 60 deg F is equivalent of 520 deg R. The ratio of the actual gas temperature to that of the standard gas temperature in deg R determines the percent correction. As a rule of thumb, there is 1% correction required for every 5 degrees variance from the standard.

PRESSURE CORRECTION

The effect of pressure on volume measurement can be significant. The standard pressure used for billing varies from company, however, most companies use a pressure of 14.73 pounds per square inch absolute (psia), or something close to it. Most meters in the United States measure at a pressure of approximately 7" water column or 0.25 pounds per square inch gauge (psig). In this case, the effect on measured volume is minimal and usually no correction is made. However, much commercial and industrial measurement is done at elevated pressures from 2 psig up to hundreds of psig.

To determine the effect of pressure on the gas volume, a pressure factor, or multiplier is calculated. The measured pressure must be converted from gauge pressure to absolute pressure. Absolute pressure is the observed pressure relative to a vacuum, or zero pressure. Usually, the pressure is measured in gauge pressure and the atmospheric pressure must be added to this to calculate the absolute pressure. In many cases the atmospheric pressure is assumed to be a certain value. In the Appalachian area a common assumed value used is 14.4 psia. The atmospheric pressure at sea level is assumed to be 14.7 psia, and it decreases as elevation increases. The pressure multiplier is then calculated by dividing the absolute pressure in the meter by the standard pressure.

BIOGRAPHY

Pat Donnelly

Pat Donnelly has over 23 years of experience in the natural gas industry, with the majority of that in measurement and regulation. Currently, he is Project Engineer - Meter Operations for NiSource Energy Distribution that has over 2.5 million meters in 8 states from Maine to Kentucky. He has a B.S. in Physics from Marietta College and a B.S. in Mechanical Engineering from Columbia University in the Coty of New York. He has been involved with the Appalachian Gas Measurement Short Course for over 20 years and is currently on the General Committee, serves as Treasurer and also the Deputy Program Chairperson for the Fundamentals Section. He lives in Columbus (but still roots for the Steelers!) with his wife, 2 dogs and from time to time one or more of his 3 grown children.