INSTALLATION AND OPERATION OF DENSITOMETERS
Class # 2205

Eric Estrada
Sr. Measurement Specialist
Targa Midstream Services, L.P.
P.O. Box 10
Mont Belvieu, TX USA

Don Sextro
Sr. Measurement Consultant
Targa Midstream Services, L.P.
1000 Louisiana, Suite 4700
Houston, TX USA

Introduction

A densitometer is an electromechanical device used to measure the density of a flowing stream. Because it measures density, a densitometer is often called a density meter. This paper uses densitometer and density meter interchangeable. The stream to be measured is usually a single-phase liquid, but instead could be a single-phase gas or vapor. In the oil and gas industry, a densitometer usually measures the density of liquid hydrocarbon finished products or liquid mixtures. Other industries use densitometers to measure the density of fluids like milk, vinegar and syrup.

As an electromechanical device, the densitometer uses electrical power and a mechanical arrangement of tubing, tuning fork or a float and chamber to measure the density of the fluid flowing through the device. The densitometer transmits an electrical signal representing the measured density.

Density can be measured either continuously or in discrete batches such as would be the case with a spot sample. Many of the density measurements taken in the oil and gas industry are determined by continuous densitometers. These densitometers are commonly installed on a meter skid and have a least a portion of the flowing stream flowing through them. Measuring density is discrete batches generally occurs in a pycnometer proving, a weigh tank or when using a hydrometer. If stream composition changes frequently or unpredictably, a continuous densitometer is appropriate.

Continuous densitometers fall into three general classes of devices; vibrating element, buoyant force and continuous weighing. A vibrating element densitometer uses a drive coil to excite a tube or tuning fork to vibrate at its natural or resonant frequency. As fluid flows through the tube, the resonant frequency changes because of the change in mass of the tube and its contents. This frequency change is non-linearly proportional to the flowing density of the fluid. A vibrating tube densitometer is often used in measuring natural gas liquid and liquefied petroleum gas streams but may also be used with refined products and crude oil. Vibrating tube densitometers may be mounted external to the main piping utilizing slipstream arrangements to measure the density of a representative sample of the fluid passing through the meter. A second option is to install a direct mount type of densitometer. A direct mount densitometer uses a sensing element, for instance a resonant frequency tuning fork, which is inserted into the meter run piping. Buoyant force densitometers measure fluid density by the change in electrical force required to balance a float in a chamber containing the fluid to be measured. The change in force is proportional to flowing density. Continuous weighting devices utilize fluid passing through a tube or vessel of known volume that is continuously weighed.

Density

Density is a measure of mass per unit volume, and may be expressed in grams per cubic centimeter, pounds per gallon, kilograms per meter cubed or another set of engineering units. A density reading in one set of units may be directly converted to another set by converting the mass and/or the volume units. Relative density is the ratio of the mass of a given volume of a substance to that of another equal volume of a reference standard substance. For applications in the oil and gas industry, liquids are referenced to water and gas is referenced to air with both at 60ºF and base atmospheric pressure or equilibrium vapor pressure. Relative density is synonymous with the historical term specific gravity. It is important to note that although the relative density of a liquid is close to the density in grams per cubic centimeter, it is not the same because the density of water is not exactly 1 gram per cubic centimeter.

Composition and temperature have a large effect on density. As an example, water is about twice as dense as propane. A mixture of butane and gasoline is more dense than a nearly-pure stream of isobutane. Temperature changes bring about a volume increase as the temperature increases and a volume decrease as the temperature drops. While the volume changes for a given mass of material, the mass does not change so the density decreases as temperature increases. Additionally, the rate of expansion of a hydrocarbon is about 10 times greater than water. Pressure also influences density, but to a lesser degree than composition or density. However, the effect of pressure on density is more pronounced in light hydrocarbons like ethane and high-ethane content raw mixes, in supercritical fluids like ethylene and carbon dioxide and of course in gases. For crude oil, water-based solutions and slurries, the affect of pressure on density is often ignored.

There are at least three reasons in the oil and gas industry to measure density. First, and probably the most widely used, is to determine the quantity of material passing through a meter. The quantity may be calculated either volumetrically or by mass measurement techniques. Inferred mass measurement techniques directly use measured density to determine the quantity passing through the meter, while volumetric measurement techniques use the measured density to apply the corrections necessary for the effect of temperature and pressure on the flowing stream.

The second use is for interface detection in a pipeline. An interface is the "plug" of liquid between two dissimilar products shipped in the same pipeline. Since a densitometer measures the density of the fluid passing through it, a pipeline operator can see the density change from one batch to the next and make the appropriate valve changes to properly send materials to the correct destination. Without a densitometer, the pipeline operator may have to rely solely on volume calculations to determine the time to switch valves. A small volume error can result in a significant amount of product contamination if the wrong material is transferred into a pipeline or tank.

A third common use, leak detection, also involves pipeline. Pipeline operators look for relatively small leaks by comparing pressures and flow rates at points along a pipeline. The pressure loss through a pipeline is a function of the flow rate and the Reynolds number which is in turn a function of the fluid density. The pipeline operator often knows the flow rate to low uncertainty because of meters in and out of the line, but must calculate the Reynolds number. Measuring flowing density can reduce the uncertainty of the pressure drop calculation.

This paper focuses on using densitometers to measure quantities of material passing through a meter. Principles detailed in this paper can also be applied to installing and operating densitometers for interface or leak detection service.

Measuring Quantities

In the oil and gas industry, the main reason to measure density is to determine the quantity of material passing through a meter. Density is an important variable in the calculation procedure, whether one uses a volumetric method or a mass measurement technique. In both methods the density is used to determine the volume at base conditions. Base conditions are usually specified in the contracts associated with each metering facility and typically are 60ºF or 15ºC for base temperature and atmospheric pressure or the equilibrium vapor pressure of the liquid for base pressure.

Inferred mass measurement involves multiplying the measured volume at flowing conditions by the flowing density at the same conditions as the volume over time to determine the pounds or kilograms or other mass unit of measure for the liquid that has passed through the meter. Using the weight percent analysis of a sample representative of the liquid that passed through the meter, one may calculate the mass and volume of each component that passed through the meter. Uncertainty in density measurement has an equal impact on mass measurement as does uncertainty in volume measurement since flowing density is a direct multiplier in determining the total mass. Mass measurement is commonly used where the liquid contains both small and relatively large molecules, such as in mixed natural gas liquid production from a gas plant. When the liquid contains a mix of these different sized molecules, there are solution mixing and intermolecular adhesion effects. Solution mixing and intermolecular adhesion is illustrated by imagining a mixture of 1,000 cubic feet of gravel and 1.000 cubic feet of sand. Because the sand fills the voids around and between the gravel, the total volume of the mixture is less than 2.000 cubic feet. Mass measurement effectively separates the molecules, represented by the gravel and sand, and provides the correct volume measurement for each.

Specification products, like propane, isobutane and gasoline, may rely on published tables and equations to correct for the effects of temperature (Ctl) and pressure (Cpl) as a function of measured density. Measuring the flowing density may result in a more accurate determination of Ctl and Cpl than assuming the density based on product specifications or an assumed composition. Since Ctl and Cpl are functions of density, the sensitivity of the volume calculation to density uncertainty is lower than in mass measurement. Generally this means the densitometer in a mass measurement station must have lower uncertainty than in a volumetric meter station.

Design

A successful densitometer installation measures flowing density at the accuracy level appropriate for the measurement technique, is easy to operate and maintain, and is installed at the lowest cost. Accuracy, operation, maintenance and cost objectives do not easily blend together. Careful attention to developing a complete design can achieve these objectives.

In all cases, the installation must meet codes, standards and company policies to protect people, property and the environment. Terms and conditions specified in the contract must also be followed. Many times, the contract references API Manual of Petroleum Measurement Standards (MPMS) Chapter 14, Section 6, *Continuous Density Measurement* for design, installation, operation and maintenance.

The designer must know the purpose of the density measurement. Will it be used to calculate the quantity of liquid changing custody through a fiscal meter or will it measure density for pipeline interface detection? What is the risk involved, in other words, what might be the cost of inaccurate density measurement? Is the density used for inferred mass measurement or for determining temperature and pressure corrections for volumetric measurement? What experience does the operating company have in measuring density? Answers to these questions lead to selecting a type of densitometer from the classes of continuous and discrete measurement. If a continuous densitometer is selected, a further choice must be made between vibrating element, buoyant force and continuous weighing designs.

A densitometer manufacturer needs to know the composition of the fluid to be measured, what normal, minimum and maximum temperatures and pressures to expect, whether the fluid is corrosive and the expected flowing density range. Without correct answers to these questions, the densitometer may not perform properly and could fail. Be aware that density uncertainty is different between models of densitometers, and that temperature effects can be different. Consult with the densitometer manufacturer to select the appropriate model.

Piping design and layout is critical to a successful installation. MPMS Chapter 14.6 shows a number of piping arrangements for installing density meters. The most important piping design consideration, after addressing all mechanical integrity and safety issues, is to ensure the densitometer measures a representative sample of the flowing stream. A representative sample exists when it has the same composition, pressure and temperature as exists at the volume meter. Careful attention to providing sufficient flow through the densitometer will prevent problems in the field.

If the selection is an externally mounted densitometer, slipstream piping must be designed. MPMS Chapter 14.6 shows piping arrangements for these slipstream systems. The piping arrangements are based on supplying a representative sample of the fluid to be measured to the densitometer. Many times the slipstream piping, densitometer, pycnometer piping and the volume meter and its piping must be insulated to maintain temperature stability through the system. It is common to install the densitometer downstream of the volume meter to avoid pressure losses through flow conditioners, valves and strainers that may exist if the densitometer was installed upstream. For best overall measurement, make sure the densitometer is operating at pressures and temperatures as close as possible to the conditions existing at the volume meter.

One common way to provide a sufficient flow to the densitometer is to create a differential pressure to drive the slipstream. This can be done with a control valve, slipstream flow meter and flow controller, with an orifice restriction or with a pump. If a pump is used, it must be installed downstream of the densitometer such that it does not add heat or pressure to the stream measured in the densitometer. Velocity head devices, like sample scoops, can in some cases provide sufficient flow through the densitometer. Some meter designs include both a differential pressure-producing device, like an orifice plate, together with a sample scoop to pull the densitometer sample from the center one-third of the pipe. If an orifice restriction is selected, consider using a dual chamber or a single chamber orifice fitting to eliminate or at least reduce downtime for when the orifice plate must be changed as flow rates change.

If an insertion type density meter is selected, and installed directly in the flowing stream, the designer must be sure there will be no stratification in the piping and that the fluid being measured is relatively clean. Consider whether the fluid velocity in the piping is fast enough but not too fast for the density meter.

Specify, buy and install a density meter designed for the appropriate electrical area classification. Consider power sources in the design and the type of electrical output signal required. Usually, the density output is a frequency fed to a flow computer.

Installation

Consider the needs of the individuals operating and maintaining the density meter when arranging and installing the densitometer, piping, conduit and wiring. A technician will periodically test and calibrate the densitometer, and may have to clean, inspect and maintain it.

Piping must be arranged such that low points can be drained and high points can be vented. Test temperature, pressure and pycnometer locations must be included in the design including across the densitometer and pycnometer combination as well as at the volume meter. Refer to MPMS Chapter 14.6 for guidance. Keep in mind that the technician reading temperatures and pressures, and catching the pycnometer samples, must be able to safely reach all of these locations. Piping arranged with the technician and operator in mind helps to improve density measurement quality and accuracy. Avoid installing densitometer and pycnometer piping that bypasses the volume meter or the volume meter proving connections.

Densitometer manufactures will specify how their device must be installed. For instance, a vibrating element densitometer may have to be installed such that flow is vertically up through the densitometer which often results in it being the highest point on the meter skid. Be aware of the possibility of lightening strikes and properly ground and isolate the equipment. A buoyant force meter likely will have to be level horizontally. Consult with the densitometer manufacturer for applicable constraints.

Excessive vibration causes inaccurate density measurement. Piping must be adequately supported and anchored, allowing sufficient room for expansion and contraction, to minimize or eliminate vibrations caused by pumps, control valves and other devices.

Operation

The densitometer will provide a signal proportional to the density of the fluid flowing through it as long as the fluid remains single-phase and at a sufficient flow rate to provide a stable signal. Refer to MPMS Chapter 14.6 for further operational details.

Periodic testing and calibration are also part of routine operation. Generally densitometers are tested and calibrated each month. Testing usually involves filling and weighing a pycnometer to determine the test density, comparing the test density to the densitometer flowing density reading at least twice, and calculating a density correction factor. The density correction factor causes the measured density to match the test density as measured by the pycnometer. A pycnometer is a sphere normally made of stainless steel, for which its weight, volume and expansion characteristics due to temperature and pressure are accurately known. Use a double-walled pycnometer in LPG, natural gas liquids and services where pressures are high and pressure increases due to fluid thermal expansion is expected.

Troubleshooting

Densitometers can provide long, trouble-free service. Problems however may arise from several areas. Normally these problems are seen in erratic readings or in density proving factors for which the difference between consecutive provings exceeds some tolerance, often plus or minus 0.25%.

These problems may be caused by two-phase flow in the densitometer or by excessive vibration. Further problems in vibrating element densitometers may result from entering incorrect calibration coefficients in the flow computer. These coefficients are used to convert the densitometer tube vibration frequency to a density reading in engineering units like grams per cubic centimeter. Consult the manufacturer for calibration coefficients for each densitometer.

A restriction in the densitometer piping will also cause errors if the stream flowing through the densitometer is no longer a representative sample. A flow meter on the densitometer slipstream piping or a differential pressure gauge across the orifice plate or control valve can help to diagnose this problem. No signal at all may result from a blown fuse on the densitometer power supply, a broken signal wire or a failed safety barrier.

Summary

Density is an important variable in determining quantities of material passing a meter. Careful consideration to the following issues should result in a successful installation.

- Understand what and why you want to measure
- Know how density meters work
- Select a densitometer for the intended service
- Utilize manufacturer expertise
- Rely on industry standards for minimum requirements
- Properly design the piping for sufficient flow
- Design the system for pressures and temperatures at the densitometer equal to volume meter conditions
- Eliminate vibration
- Install the densitometer according to manufacturers recommendations
- Arrange the densitometer piping system for operator and maintenance technician access
- Safely design, build, operate and maintain the system

Glossary

Density - mass per unit volume with the volume specified at some temperature and pressure

Mass - a measurement of the quantity of material, which is constant from one location to another

Pycnometer - a vessel whose volume and evacuated weight are known within 0.02 percent.

References

1. American Petroleum Institute, Manual of Petroleum Measurement Standards, Chapter 14, Section 6, Continuous Density Measurement.
2. Gas Processors Suppliers Association / Gas Processors Association, Engineering Data Book.