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Ask Tom! Column

In Control: Density Measurement, Theory and Practice

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What is Density?

The density of a sample of a material is defined as the quantity of mass of the material to a given volume of the sample. The material becomes denser as the amount of material per unit volume rises. It can be said that the molecules of a dense material are “packed” more tightly together than the equivalent weight of a lighter material. Recall the question “which weighs more, a ton of feathers or a ton of steel?” While these items obviously weigh the same, their mass to volume ratio differs greatly. The steel is denser, of course, than the feathers because of a drastically higher quantity of mass to unit volume.

The measurement of the density of a process material is a common requirement of many processes. The control of the density of primary sludge in a wastewater treatment plant is a common example; controlling pulp density is essential in the pulp & paper industry; the production of ice cream also relies upon accurate measurement and control of density.

Density & Specific Gravity

Density and Specific Gravity are often used interchangeably. While Density is a straight Mass to volume relationship:

$$\text{Density} = \text{Mass}/\text{Volume}$$

The density of a material is measured in g/cc (grams per cubic centimeter) or lbs./ft3 . While ordinary paper has a range of density between .7 - 1.15 g/cc (44-72 lbs/ft3), Lead has a density of about 11 g/cc (687 lbs/ft3).

Specific Gravity (SG) is defined as the ratio between the density of a given volume of a material to the density of the same volume of water; the specific gravity of a gas is the ratio of the molecular weight of a given sample to an equivalent volume of standard air:

$$SG = D1/D2$$

Specific Gravity is used to describe the density of a liquid. Several different scales are used to measure specific gravity, depending upon the application and range of SG of the process liquids being measured. Specific Gravity is used to control the batching of liquid components of a product. For a given ingredient, the relationship between specific gravity and the quantity of the material to be added is predictable and can be controlled. This allows accurate mixing and minimized waste.

Density of a material is affected by temperature and pressure. For most applications, though, the effects of pressure are negligible and will not be considered. Temperature, however, does introduce measurable variations in density, particularly in liquids and gases. Measurements of Density and specific gravity must be corrected for variations in temperature.

Instrument Selection

Several methods are used to measure density. As with any instrument, all factors must be considered before deciding upon the method most suited for the application. Among these factors are:

- Environment
- Display and Transmitter options
- Pipeline or Vessel application
- Process material characteristics
- Cost

Most vendors offer instruments that are compliant with requirements for installation in hazardous environments. This item will have a significant impact on the cost of the unit, read the specifications carefully for required enclosure. Displays and transmitters will also have an impact on cost; Displays can be locally or remotely mounted. Transmitters can be integral or remote. All offer standard electrical connections for power and signal; data interfaces are also available. Pipeline mounts require either in-line or “strap-on” installations.

Certain instruments lend themselves to specific types of physical installation in order to effect that particular method of measurement. Vessel mounting can be accomplished utilizing standard fittings. Instrument vendors are a wealth of information on these items and will be happy to discuss the particulars.

Process material characteristics is most important to consider when deciding upon a densitometer. Slurries and aggressive fluids or solids will tend to degrade the relatively sensitive measurement apparatus. For light slurries and liquids, insertion types may be used. In certain applications, it may not be possible to pull the instrument for calibration or repair because of lost production, contamination or hazardous material. In this case, a “non-contact” type of densitometer is used.

The use of a densitometer eliminates the need for separate flow, temperature and pressure measurements in order to derive density. The proper application of a densitometer offers accurate and complete control of the process, virtually eliminating delays and lost production. Following is a general description of the common methods of density measurement.

Measurement Principles

Mass Flowmeters

Theoretically, all mass flowmeters can be used as densitometer, if the volumetric flow rate is kept constant. In all mass flowmeters, it is the mass of the process material that exerts a physical force upon the measuring apparatus, causing a measurable change . Most types of mass flowmeter are not suited to this type of duty, however. Thermal mass flowmeters may be used to measure the density of a gas and possibly some liquids. It would be inadvisable to use this type of device in a slurry. The Coriolis mass flowmeter is widely used as a densitometer on clean liquids and light slurries.

Coriolis densitometers operate by measuring the vibration and twist of a U-shaped tube. This is essentially the same principle used in measuring mass flow; a true mass flow meter measures mass flow over time. As the density of the material changes, it affects the frequency of vibration of the tube. This is a measurable quantity. The change in frequency is proportional to the density of the material. The effects of pressure are negligible; temperature compensation must be used however. Coriolis densitometers are relatively expensive and cannot be used for viscous fluids or heavy slurries. These units are typically used in the chemical, food and beverage industries on clean fluids with little solids content.

Vibration

These types of instruments have found widespread use because of the range of application conditions on which they may be used. All instruments in this category work similarly to the Coriolis described above. A

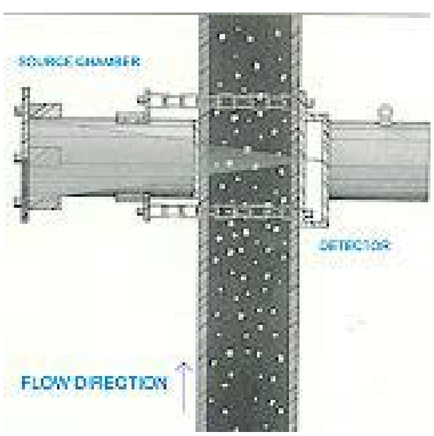
vibrating element is introduced into the process material; the damping of the vibration is proportional to the density of the measured material. This measurement is referenced to the element's natural frequency. Several types of instruments based upon vibration are in common use:

- Vibrating Tube: A tube of known mass is vibrated at its natural frequency. As the tube is filled with the process fluid, the frequency will be damped proportionate to the density of the material. Other variables, such as specific gravity, molecular weight, Brix (see below) and concentration can be derived from this measurement if required.
- Vibrating Spool: Similar to the Vibrating tube, but utilizing a vibrating spool piece inserted into a pipeline. These instruments are useful for interface detection in pipelines.
- Tuning Fork: Typically inserted into a process vessel. Consists of a vibrating element immersed in the process material. The figure below shows this type of unit, suitable for insertion into a tank or pipeline.

Gas density may also be measured using this method. A vibrating chamber filled with a reference gas is driven at it's natural frequency. As gas flows past the chamber, the change in gas density will cause damping of the chamber vibrations, which are proportional to the density of the gas.

Nuclear

Nuclear non-contact densitometers are used in application where it is impossible or undesirable to break a pipeline or containment in order to install an instrument. This approach allows for continuous containment of the process material. This is required when the system is sanitary or the material is hazardous, or when discharging the pipeline would result in lost production or a hazardous condition.



Nuclear densitometers measure density by measuring the strength of emitted Gamma radiation as it passes through the process material. Absorption of the radiation is directly proportional to the material density. The unit uses a Cesium or Cobalt source on one side of the pipe, and a scintillation counter on the other. The unit is strapped on to the pipe as a unit. Other units are available for use with open conveyors; the source is place above the belt with the detector mounted below. This type of application is useful in such industries as cement production and bulk loading or batching.

Nuclear densitometers are extremely accurate and stable, but can be costly. The use of a radioactive source requires permitting and regular monitoring and emergency procedures. This type of densitometer is well suited to use in applications dealing with hazardous or aggressive liquids or slurries. With no part of the instrument exposed to the process material, and no other wearing parts, there is little chance for a lost time failure.

Other Methods

Capacitance

It is possible to measure the density of a liquid by using a large capacitor. To do so, the capacitor must be inserted into the process liquid. The capacitor is usually some arrangement of concentric tubes made of conducting material. As the liquid fills the annular space, the dielectric constant of the capacitor changes, causing a change in the capacitance of the sensor. The capacitance is proportional to the dielectric constant, which is proportional to the density. This capacitor is connected to an external bridge, which measures the change. This type of sensor is used only with non-conductive fluids such as petroleum products. The cost of these units varies; instruments can be ordered in a wide variety of configurations to suit different applications.

Displacement

This type of instrument relies upon the application of calibrated floats. Float buoyancy is a function of liquid density; a rise or drop in liquid density will cause the float ot rise or drop accordingly. The position of the float relative to the instrument scale is an indication of fluid density. Floats may be attached to calibrated weights, these are referred to as chain-loaded, or chain-balanced, densitometers. Other types use sophisticated electromagnetic suspension techniques to eliminate skin-effect errors. Pickup coils embedded in the walls of the instrument sense the position of the float.

The most basic type of displacer system is a series of calibrated plastic or ceramic weights that become buoyant at certain densities. A cable attached to a torque arm or lever suspends the weights. As the weights become buoyant, less weight is exerted on the lever, which moves in the opposite direction. This arm activates a switch or series of switches, which in turn initiate the appropriate actions.

Other type of units use calibrated floats to obscure light from a series of discrete optical sensors. This unit operates similarly to the unit described above. Displacement units require a clean process fluid, though the suspended weight variety may be used in certain dirty, but non-coating applications.

Hydrometers

Hydrometers represent the simplest and most economical method of measuring density. A hydrometer is a calibrated glass float, which incorporates a scale for direct reading. Typically, a hydrometer is “spun” into a sample and eventually stabilizes at a certain height relative to the liquid surface. The SG is read directly forma the scale on the tube. Hydrometers may be calibrated in one of several specialized scales:

- Alcoholometer: This hydrometer is used for testing alcoholic solutions. The scale is calibrated is percent of alcohol by volume
- Ammoniameter: For testing Ammonia solutions. The scale is calibrated in 0°-40°.
- Barkometer: Used in the tanning industry. The scale is 0°-80°
- Baume’: Two types are in use- Heavy Baume’, for liquids heavier than water; and Light Baume’, for liquids lighter than water. Scales are available to 90°
- Brix: Used in the sugar industry for determining the percentage of sugar in solution. Degrees Brix is percent sugar.

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Welcome to Ask Tom!, a monthly column by our resident water treatment guru, Tom Keenan of National Environmental Services Agency (NESA). Tom addresses the issues that bug you the most. And Tom knows!! With 35 years experience in providing environmental support services to public and private sector clients on a wide range of environmental issues.

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