APPLICATION OF DENSITOMETERS TO LIQUID MEASUREMENT
Class # 2010.1

Joe Harris
National Sales Manager
Anton Paar USA
10215 Timber Ridge Drive
Ashland, VA 23005

Introduction

There are a variety of accurate process density meters available that are based on the principle that the natural frequency of an oscillating u-tube is related to density. This paper reviews the basic theory of operation of the oscillating u-tube and discusses two modes of oscillation – the x-mode and y-mode oscillation. In addition, this paper summarizes a few of the applications relevant to the oil and gas market.

Theory of operation

Most of the theory behind vibrating density meters is based on a simple mass-spring model (Figure 1). The start of the derivation is the well-known formula defining the period (P) of resonant oscillation of a mass-spring model with mass (m) and spring constant (c):

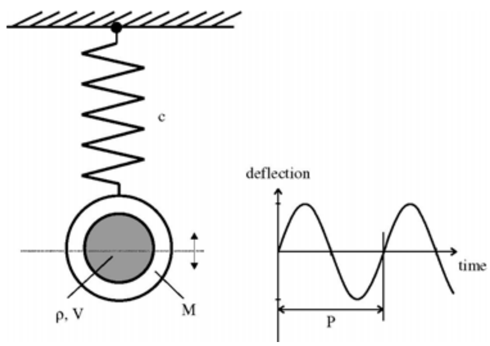

Figure 1
Mass-spring model of a vibrating densitometer

The basic equation that represents the mass-spring model is shown below:

$$P = 2\pi\sqrt{\frac{m}{c}}$$

The mass of the system consists of the mass of the vibrating element and the mass of the fluid in the oscillator. The mass of the fluid in the oscillator can be represented by the volume in the oscillator multiplied by the fluid's density (ρ). Using this information and rearranging the equation leads to the "fundamental" equation for density measurement using vibrating sensors which is shown below.

$$\rho = A \times P^2 - B$$

The constants A and B represent transducer constants, and are determined by calibration for each transducer.

Y and X mode oscillation

Y-mode oscillation

With the u-shaped tube in the horizontal (X) plane and the excitation in the vertical plane, the tube oscillates in the Y-mode, as long as the block is fixed rigidly onto a sufficiently heavy counter-mass (Figure 2). The heavier the counter-mass, the more independent the resulting oscillation will be.

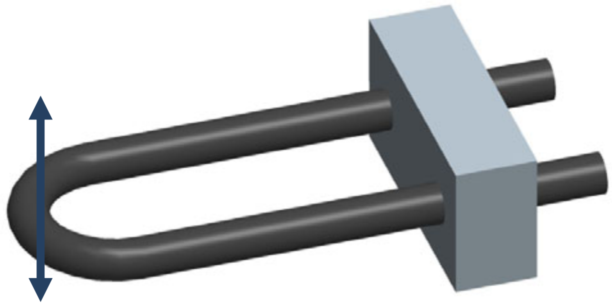

Figure 2
Y-mode oscillation

Figure 3 shows a typical design in which the sample fluid flows continuously through a u-shaped tube oscillating in the Y-mode and the frequency of oscillation is measured. Here, the oscillating u-tube is driven by a magnet and coil assembly and a feedback amplifier so as to maintain the oscillation at the resonant frequency of the system.

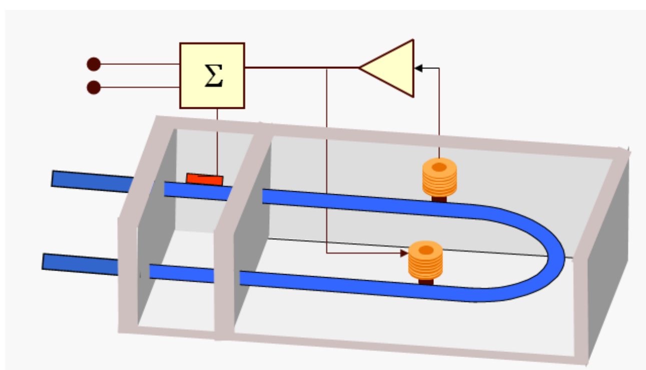

Figure 3
Typical y-mode u-tube density meter

X-mode oscillation

With the u-shaped tube in the horizontal (X) plane and an excitation approximately in the middle of the tube's legs' in the same plane, the tube oscillates in the X-mode (Figure 4). The system oscillates at its resonant frequency without the need for a counter-mass, provided that the system is sufficiently symmetrical. A high degree of stiffness in the block is required.

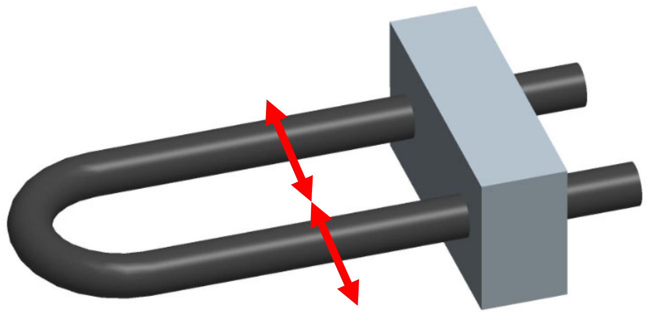

Figure 4
X-mode oscillation

Figure 5 shows a typical design in which the sample fluid flows continuously through a u-shaped tube oscillating in the X-mode and the frequency of oscillation is measured. Here, the oscillating u-tube is driven by a piezoelectric crystal assembly and a feedback amplifier so as to maintain the oscillation at the resonant frequency of the system. Without the need of a heavy counter-mass, the X-mode oscillation enables lighter and more compact systems, which are opening up new applications in the oil and gas industry.

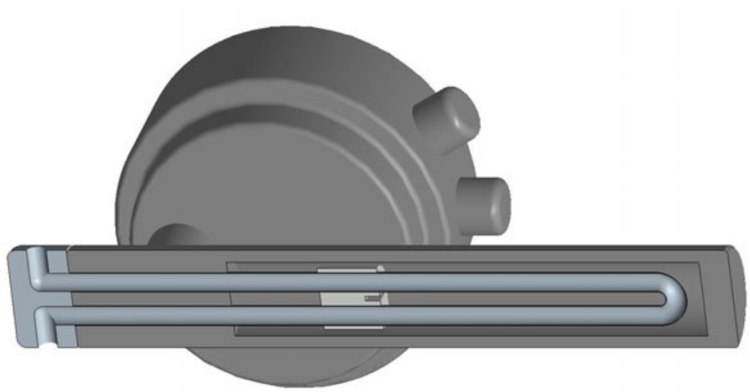

Figure 5
Typical x-mode u-tube density meter

Both designs can handle gases, homogeneous fluids, and light slurries with low to medium viscosities. Larger amounts of entrained gas cause the oscillation to stop due to excessive damping. Therefore, such liquids cannot be measured unless increased line pressure causes the gas bubble volume to be compressed to a suitable extent and / or causes the gas to become dissolved in the liquid

Applications of Density Measurement

Custody Transfer

One of the most common uses of density measurement is in custody transfer metering systems. While mass meters are common they are limited in size, and therefore flow rate. The density of a fluid changes with temperature and pressure so volumetric metering is not reliable when two stations are metering product at different temperatures / pressures. Density is an important measurement when converting from volumetric units to mass or standard volume units.

Interface / Product Detection

Density can easily be used to determine the transition point between two products flowing through the same pipeline. Using standard API / ASTM equations to convert measured density to known reference conditions allows the separation or "cut" of products in multi-product pipelines based on known density, SG, or API bands for the expected products. In many installations, a density system will be installed prior to a metering station to identify the change in product. It is then possible to calculate the expected arrival time of the cut which is confirmed with a second meter at the station. This allows accurate "cutting" of the interface and routing of the new product.

Blending / Binary Concentration

When two liquids are blended together, density can be very useful in determining proper blending ratios or concentrations. Consider the generic blending example shown in Figure 6.

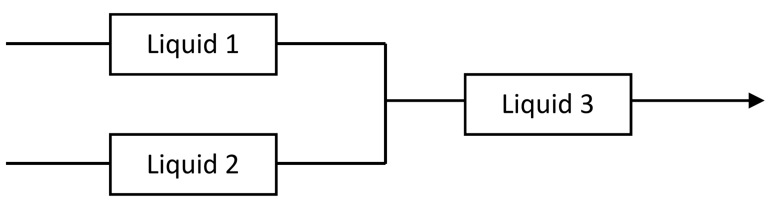

Figure 6
Generic blending example

There are three scenarios to consider in the example shown in Figure 6. First, if liquids 1 and 2 have similar densities, then a density measurement will not be useful in verifying blending rations. This is the case since the combinations of liquid 1 and 2 in any ratio will still result in approximately the same density of liquid 3.

Second, if liquids 1 and 2 have different densities that are stable and known, it is often possible to use one density meter for liquid 3 to determine the correct blending or concentration ratio. This is usually true for pure liquids. Many standard tables and calculations exist and are available in literature for the mixture of pure liquids. Density meters are extremely accurate and easy to use in this scenario.

However, the second scenario would not apply to a typical fuel, for example. The chemical makeup of the fuel varies, and as such, the density varies. In this case, it is useful to consider the third scenario where one or both liquids have densities that vary. In this case, density measurement can still be useful if a density meter is installed for each liquid to measure the density of all three liquids independently. Often, advanced calculations are then needed to determine the blending ratio or concentrations. However, modern evaluation units used in combination with density meters make this application possible.

The accuracy to which the concentration can be determined is dependent on the relative densities of the two liquids, the accuracy of the density meter, and the accuracy of the equations used to estimate the concentration.

Tertiary Concentration

It is common that more than two liquids are mixed or blending with a desired target concentration for each. Density measurement can also be useful in these applications. Density can sometimes be used in combination with additional measurement technology to determine concentrations. One example is to combine density with sound velocity measurement. Just as density alone is useful for concentration analysis of binary liquid mixtures, the combination of density with another measurement can be useful in determining concentrations of tertiary mixtures.

Quality Control

Many times a product has a defined density, Specific Gravity, or API range. These values are often defined for quality purposes, or are defined in a contract agreement between buyer and seller. Continuous density measurement can be important in determining when a product is either in or out of specification. When out of specification conditions are detected, corrective action can quickly be taken to reduce waste or reduce the amount of liquid which needs to be re-worked to bring it back into specification.

Liquefied Gases

Liquefied gases typically have non-linear density temperature / pressure relationships and are often not liquid at atmospheric conditions. Density meters are designed for a wide range of pressures and temperatures and can be used in measurement of liquefied gases. Some of the same applications mentioned earlier also apply to liquefied gases.

Conclusion

Process density meters that are based on oscillating u-tube technology are fast, rugged, and accurate systems that can be used for a variety of applications. The two principle modes of operation, the x-mode and y-mode, can each be used to accurately determine density. The x-mode oscillation does not require a heavy counter-mass, and as a result, leads to lighter and more cost efficient systems, which opens up new applications in the oil and gas market. Density measurement can be used for custody transfer, product detection, blending / concentration analysis, along with many more applications.