Accurate Liquid Phase Density on Aerated Liquids

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Introduction

Density is one of the most widely used composition-based measurements in industrial process control. However, it is well recognized that the presence of small, but unknown levels of entrained gases can mask the density of the non-aerated component of a process mixture, resulting in an inaccurate determination of process fluid density. Recently, SONAR-based, clamp-on gas volume fraction meters have been introduced which provide an accurate, real time, measurement of entrained gases. Coupling entrained gas volume fraction monitor with most types of process density meters, enables accurate determination of liquid and the liquid-solid components of aerated mixtures.

Recognizing that entrained gases impair the ability of density meters to accurately determine the process density, most operators install density meters at points within the process where the entrained gases are intended to be minimal. In fact, with a few exceptions, most industrial processes are designed to minimize presence of entrained gases through the process. The large use of defoamers, gas /liquid separators, and deculators is evidence of the design practices used to minimize entrained gas levels. However, despite these efforts, entrained gases typically remain present in small, but variable and unknown, levels across a wide range of industries including pulp and paper, mining, chemical processing, and oil and gas production. As will discussed, the presence of this small, but unknown and variable, level of entrained gases impedes accurate determination of process fluid density, thus, impairs process optimization efforts in a large number of applications across a wide range of industries.

Density Measurement

The two most common types of density measurement are nuclear gamma densitometers and vibrating-tube based (including Coriolis meters) density meters. With some restrictions, both types of density measuring devices can continue to provide accurate measurement of the total mixture density in the presence of relatively small levels of entrained gases (0% to 10% by volume or higher depending on flow conditions). The problem with aeration is typically not that the measurement device fails to accurately report mixture density, but it is the interpretation that the measured density represents the density of the non-aerated liquid and/or liquid-solids mixture within the process lines.

Density is primarily used in two broad applications areas. The first is in conjunction with volumetric flow measurements to determine total process mass flow. The second use is as an on-line indicator of mixture composition. The density of the mixture is given by a volumetrically-weighted averaged of the component densities. For example, for a mixture of liquids, solids and gases, important in slurry type applications in mineral processing and pulp and paper, mixture density is given by:

$$\rho_{mixture} = \phi_{liquid}\rho_{liquid} + \phi_{solid}\rho_{solid} + \phi_{gas}\rho_{gas}$$

Where ρ_i is the density and ϕ_i is the volumetric phase fraction of the i^{th} component of the mixture. In this framework, the sum of the components occupy the full volume of the pipe such that:

$$\phi_{liquid} + \phi_{solid} + \phi_{gas} = 1$$

Similarly, for a mixture of oil, water, and gas, important in the measurement of produced fluids in the upstream oil and gas industry, mixture density related to mixture composition as follows:

$$\rho_{mixture} = \phi_{oil}\rho_{oil} + \phi_{water}\rho_{water} + \phi_{gas}\rho_{gas}$$

with

$$\phi_{oil} + \phi_{water} + \phi_{gas} = 1$$

Density with Volumetric Flow for Mass Flow

Since, typically, the gas density is much smaller than the other components, entrained gas can be treated as simply a void fraction. Thus, the measured density with entrained gas is lower than the density of the non-aerated mixture. In this simplified formulation, mixture is related the non-aerated mixture density, termed $\rho_{mixtureNA}$, through the following relationship.

$$\rho_{mixtureNA} \cong \frac{\rho_{mixture}}{1-\phi_{gas}}$$

For mass flow applications, the product of mixture density and mixture volumetric flow determines mass flow rate. Since aeration causes the volumetric flow to increase in the same proportion as it causes the density to decrease, the accuracy of mass flow rate is, to first order, unaffected by entrained gases.

$$\dot{m}_{mixtureNA} = \rho_{mixtureNA}Q_{mixtureNA} \cong \frac{\rho_{mixture}}{1-\phi_{gas}}Q_{mixture}(1-\phi_{gas}) = \rho_{mixture}Q_{mixture} = \dot{m}_{mixture}$$

Density for Compositional Information

However, compositional-based interpretation of measured density of aerated mixtures is directly affected by presence of entrained gases. In slurry-type applications, a small, but unknown, level of entrained gases results is an under-reporting of the amount of solids presence in a slurry. This can result, for example, when running a density-based control loop to maintain coating consistency in a coating application, in higher coating consistencies than required, causing increased material costs and lower product quality. In the measurement of water cut of produced fluids on the liquid leg of gas/liquid separators, the presence of entrained gases results in over-reporting produced oil rates, impacting well allocation and field optimization.

Experimental Results

It is generally well accepted that the nuclear densitometers function in presence on entrained air as described above. There is, however, less certainty within the process measurement community regarding the performance of vibrating tube densitometers in the presence of entrained air. An investigation was conducted to characterize the effect of aeration on the density measurement reported by Coriolis mass flow meters. While a complete discussion of the results is beyond the scope of this article, the general conclusion was that, provided the flow was well-mixed and the Coriolis was appropriately designed to address aerated fluids, Coriolis flow meters, similar to nuclear densitometers, can provide accurate measurement of aerated mixture densities.

Figure 1 shows a schematic of a test set-up used to evaluate the ability of the combination of a coriolis meter and a sonar-based gas volume fraction meter to accurately report the density of the liquid phase of a gas / liquid mixture. The coriolis meter was a 2 inch, u-tube design, mounted in the "flag" orientation. Air was injected ~20 diameters upstream of the inlet of the coriolis meter. A pressure gauge monitored pressure at the exit of the Coriolis meter. The SONAR-based gas volume fraction was clamped-on to a vertical section of 2 inch, schedule 5 piping immediately downstream of the exit of the Coriolis meter.

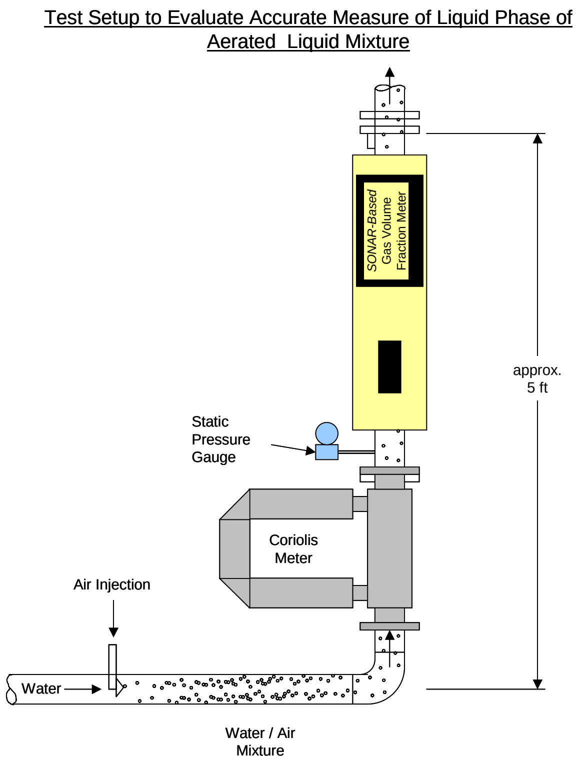

Figure 1

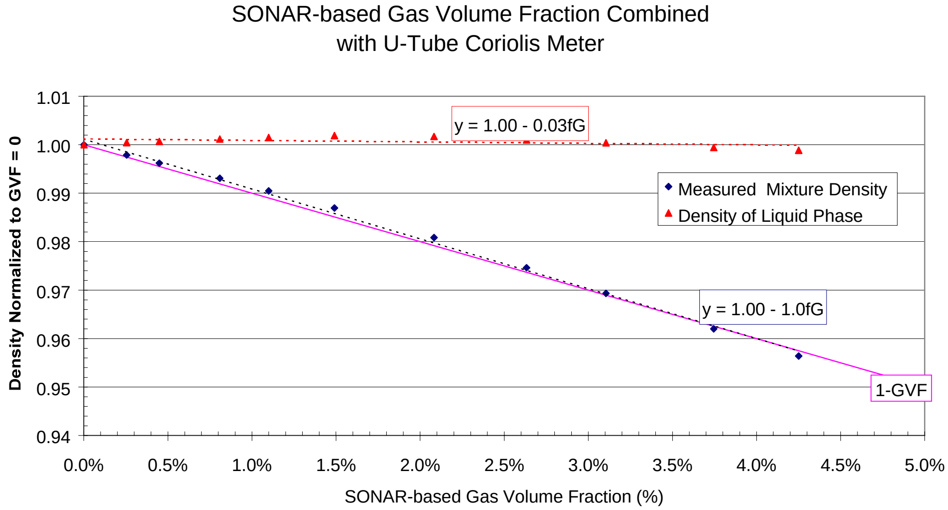

Figure 2

The results of the testing are summarized in Figure 2. The reported density, normalized to the non-aerated liquid density is shown versus the SONAR-based gas volume fraction measurement. The theoretical normalized density of $1-\phi_{gas}$ is also shown in addition to the reported density. As shown, the coriolis meter continued to accurately report the mixture density in the presence of entrained air. Figure 2 also shows the interpreted liquid phase density, interpreted from the simultaneous measurement of the mixture density and the gas volume fraction. As shown, the interpreted liquid phase density from this combination of measurements remains accurate in the presence of entrained gases.

Summary

Despite efforts to minimize levels of entrained gases, the presence of small, but unknown and variable amounts of entrained gases continue to confound accurate process fluid density measurement in a wide range of industrial applications. Most types of industrial processes, on-line density measurement devices can continue to accurately report mixture density. Mixture density, when combined with a SONAR-based gas volume fraction measurement provides a practical method to provide accurate measurement of the non-aerated component of aerated mixtures, eliminating the often-impractical requirement to completely eliminate entrained gases to extract compositional information from density measurements.

References

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