In-Tank Measurement of Solution Density

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This paper presents the results of an experiment which established the feasibility of in-tank determination of the density of nuclear process solutions in the field with a precision competitive with the precision claimed for laboratory determinations of the density of samples taken from a tank. The in-tank determination is made by inferring the density from the differential pressure measured between two probes immersed at different heights in the tank. The differential pressure was measured using a null-operated quartz bourdon type electromanometer. The work provided a calibration factor, with a precision (estimate of the relative standard deviation of the mean) of 2.2 parts in 10,000, which can be used to infer density from differential pressure measurements in the particular accountability tank. The technique eliminates one error in the laboratory determination of density and minimizes another. It also can be used to indicate the homogeneity of the tank solution and thus determine when a sample should be taken for determination of the concentration of nuclear material in the solution.

Key words: Accountability tanks; differential pressure; in-tank density determination; nuclear process solutions; solution density.

1. Introduction

The density of a solution in a nuclear process tank is usually determined by laboratory measurement on a sample taken from the tank. Since the laboratory measurement is made at a temperature different from the temperature of the solution in the tank, a significant error is introduced if, as is generally the case, the relationship between the density of the particular solution and the temperature is not well known. Also, there is an error associated with the sampling. It is possible to eliminate the first of these errors and to minimize the second by making the density measurement in the tank. This is done by inferring the density from the differential pressure measured between two probes immersed at different heights in the solution. This is the conventional method for determining "specific gravity" in the process; however, the availability of electromanometers of excellent precision makes it possible to make in-tank density measurements precise to several parts in 10,000. This precision is comparable to the precision claimed for laboratory measurements and, as mentioned above, two sources of error are either eliminated or minimized.

The relationship between the differential pressure, ΔP, between two points separated in height by a distance, h, measured downward from the higher point, is

$$\Delta P = \varrho g h, \tag{1}$$

where ϱ is the density of the fluid and g is the acceleration due to gravity. The ratio of ΔP to ϱ is a measure of the product (gh). Therefore, a series of measurements of ΔP in a liquid of known density provides a determination of (gh) with an estimate of precision from the multiple measurements. The (gh) so determined then becomes a calibration factor relating ϱ to ΔP.

Since the relationship between density and temperature is very well known for water, it is the ideal liquid for making the determination of (gh) in a tank. The determination involves ΔP measured using an electromanometer of high precision, and the measurement of temperature from which the density of water is inferred. The (gh) determined using water can then be used in a rearrangement of eq (1) to infer ϱ of a process solution from measurements of ΔP in the solution:

$$\varrho = \frac{\Delta P}{(gh)} . \tag{2}$$

The determination of (gh) can be made in the course of volume calibration of a tank with little or no additional effort. Alternatively, an experimental determination can be made in preparation for a calibration by connecting an electromanometer across two probes (the "specific gravity" probe and the probe near the bottom of the tank). Calibration run data can then provide confirmation of the (gh) value and its precision.

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2. Experimental

An in-tank density experiment was performed in an accountability tank at the DuPont/DOE Savannah River Plant at Aiken, SC, the site of a previous very succesful tank volume calibration [1].[1] The tank is essentially a right circular cylinder 3.35 m (11 ft) high and 3.05 m (10 ft) in diameter. The vertical separation of the probes was approximately 25.4 cm (10 in).

A null-operated quartz bourdon-type differential pressure electromanometer was connected between the two probes and a flow of 8 mL s^{-1} (1 ft^3 h^{-1}) of dried instrument air was maintained through each of the two lines communicating the pressure from the probes to the electromanometer. The temperature of the calibrating fluid, water, was measured using the nickel resistance thermometer used in the operation of the tank. The output of the electromanometer was displayed on a digital voltmeter (DVM) with 5-place capability.

A quantity of water sufficient to fill the tank to a level approximately 25 cm above the upper probe was introduced into the tank. Prior to each of three sets of measurements of the electromanometer output, the water was stirred using the agitator in the tank and the water temperature was measured. The sample period (or integration time) for the DVM was set at 1 s and the sampling "rate" was set at 2 s; the DVM was read visually. The three sets of measurements provided 33, 42 and 40 consecutive measurements of the differential pressure. The DVM readings were converted to pascals and the water temperature, 28.7 °C, was used to infer the density of the water from a table [2]. The resulting set of 115 (ΔP, ϱ) pairs was used to determine (gh) and to assign a measure of precision to the determination. The water density values in the table correspond to air-free water. Bowman and Schoonover [3] have discussed the effects of isotopic abundance ratios, dissolved air and pressure on water density. These effects are negligible in the present work; however, it is advisable in general to have a laboratory determination of density made on water to be used in tank calibration or in-tank density calibration.

3. Results

The mean value of (gh) is 2.48525 m^2 s^{-2} with an estimate of the standard deviation of the mean of 0.00055 m^2 s^{-2}, which corresponds to a precision of 2.2 parts in 10,000. Using a value of g of 9.79558 m s^{-2}, the vertical separation of the probes is calculated to be 0.253711 m (9.98860 in). It is, of course, unnecessary to know either g or h since the product (gh) is determined from the experimental calibration of the probes and is used subsequently to infer the density of

the process solution from measurements of the differential pressure.

In the application of (gh) for a solution temperature, t_s, different from the calibration temperature, t, (gh) is multiplied by $[1 + \alpha(t_s - t)]$, where α is the coefficient of linear expansion of the probe material. In order to attain and maintain the precision and accuracy reported here, the vertical separation of the probes must remain sufficiently well fixed. The applicability of this method to highly viscous liquids has not been investigated.

After the data for the field experiment were analyzed, data from NBS laboratory work of Schoonover et al [4] in a right-circular cylindrical tank 1.22 m (4 ft) in diameter with a vertical separation of probes of approximately 20 cm were similarly analyzed. The differential pressure measurements were made by connecting an electromanometer, different from the one used in the field experiment, alternately between one of the probes and the atmosphere. The temperature of the water in the tank was measured using a quartz crystal thermometer. A set of 78 (ΔP, ϱ) pairs taken from 6 runs were used to determine (gh) and to assign a measure of precision to the determination. The mean value of (gh) is 2.03231 m^2 s^{-2} with an estimate of the standard deviation of the mean of 0.00021 m^2 s^{-2}, which corresponds to a precision of 1.0 part in 10,000.

4. Discussion and conclusions

The experimental work at the Savannah River Plant established the feasibility of determining nuclear process solution density in a tank in the field with a precision competitive with the precision claimed for laboratory determinations. The work provided a calibration factor which can be used to infer solution density from differential pressure measurements in the particular tank. The precision of the calibration factor confirms the feasibility of making accurate in-tank solution density determinations and is within a factor of 2.6 of the precision attained in NBS laboratory in-tank measurements, although the two results are not directly comparable. The precision of the field measurement would be improved by using a DVM with a longer integration time.

The calibration factor, (gh), could be determined during the volume calibration of a tank by recording the outputs of electromanometers connected to the two probes (and taking the differences); the density of the calibration fluid, water, is used in the volume calibration and does not therefore represent additional effort.

The 25.4 cm vertical separation of the probes in the tank delineates a section of the tank containing about 6 percent of the full volume of the tank and a larger percentage of the liquid if the tank were not completely full above the probes. The in-tank density determination, therefore, involves a

[1] Figures in brackets indicate literature references at the end of this paper.

sample which is very much larger than is conventionally taken for laboratory density measurements (approximately 1600 L compared to 0.015 L).

In the operation of a tank, the differential pressure between the probes could be monitored to determine the adequacy of stirring, as indicated by the constancy of ΔP for repeated stirrings, and to determine when the solution was sufficiently homogeneous that a sample might be taken for the measurement of the concentration of nuclear material in the solution.

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5. References

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