WHITE PAPER

Non-Invasive Density Measurement with Ultimo Percussion Technology

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ABSTRACT

This paper describes testing of the Ultimo percussion technology performed on various aqueous solutions of glycerin using the Ultimo Non-Invasive Density Meter, model DVM 4.0. This particular test unit had previously been subjected to a variety of other tests equivalent to approximately two years of service. The purpose of the test trials was to determine density measurement accuracy and precision of the Ultimo device.

Glycerin was selected as the test material because of the ability to create consistent, homogenous aqueous solutions of varying densities similar to target-industry process fluids, such as petroleum products and chemicals.

The vessel used for these test trials was a 200 gal. cylindrical tank with a 0.25" thick wall. The test trials began with pure glycerin with a specific gravity of 1.26. The glycerin was diluted with water to create test solutions with densities 2.5%, 5.0% and 10% less than pure glycerin. Each of the measured density readings was compared to actual density values obtained through the use of a standard industrial measurement instrument (Acculab Vicon precision scale).

The precision and accuracy of density measurements were determined to be 0.62% and 0.51% respectively. These values are well below the tolerance levels specified by all of the companies that have thus far shown an interest in the Ultimo Percussion technology.

This testing validates Ultimo Percussion technology as a viable approach to measure density with a high degree of accuracy and precision and shows that this technology is suitable for process control applications involving liquids such as gasoline, crude oil, various lubricants, and a variety of food and beverage products.

Introduction

Measurement of the density of a liquid solution is currently performed using invasive devices (direct contact with fluid, by laboratory sampling or by the use of nuclear radiation densitometers ("Nuclear"). Each of these methods has drawbacks.

Invasive devices can be a burden because of direct contact with the measured material. Further, the use of invasive devices necessarily requires the periodic shutting down of production to clean and re-calibrate the densitometer.

Laboratory sampling is labor intensive and, because it requires offline analysis, hundreds or even thousands of gallons/pounds of wasted process material may pass through production stages before a process error is observed and corrected.

Nuclear is generally considered to be the technology of last resort. The typical radiation source used by Nuclear is Cesium-137 which is classified by the Nuclear Radiation Commission as a Class I radiation source. Possession and use of this nuclear radiation source material is heavily regulated and used only where there are no other options.

Regardless of the nature of the measurement instrument used, accuracy and precision are critical characteristics. *Accuracy* describes the bias of measurement using a comparison between the mean value of the measured variable and the standard value of the measured variable [1]. *Precision* characterizes a dispersion of the measured values obtained by a measuring device under the condition that the parameters of the object of measurement, e.g. liquid in a vessel, are permanent [1].

The Ultimo Percussion technology is an online measurement instrument that is mounted to the outer wall of a vessel and measures density and viscosity of material inside the vessel. The device includes moving mechanical parts and micro-processor-based hardware electronics. Measurement is generated by executing certain real-time mathematical procedures using Ultimo proprietary software. None of the components of the Ultimo Percussion device come into contact with the measured material or invade the vessel/conduit area.

In-line density measurement applications of the Ultimo non-invasive percussion technology include both loose solid and liquid materials. In particular, process fluids found in petrochemical and food and beverage industries [2, 3] are good candidates for density measurement with Ultimo Percussion technology.

Test Materials

- Pure glycerin
- Water

The selection of glycerin for the performance evaluation test was based on the following reasons:

1. Glycerin is readily soluble in water with known density and viscosity at a given temperature. Thus, the glycerin-water solution is ideal as a standard material for calibration and accuracy evaluation.

2. Density of aqueous glycerin varies in the range of 1.26 units of specific gravity (SG) for pure glycerin to about 1.00 SG for its lowest concentration. This density range covers the majority of liquid products in petro-chemical and food and beverage industries – attractive markets for non-invasive density measurement.

Instrumentation

- Ultimo DVM V4.0
- Test Tank
  - Volume: 200 gal.
  - Shape: Cylindrical
  - Material: Carbon steel
  - Wall Thickness: 0.25"
- Scale
  - Brand: Acculab VICON
  - Resolution: 0.1g
- PC-Based Data recording station
- Vacuum Pump
- Air Compressor, 20 HP

Procedure

1. Mount DVM V4.0 onto the test tank.

2. Pump 150 gal. volume of pure glycerin into the tank.

3. Record the DVM V4.0 output signal.

4. Pump a pre-calculated volume of glycerin out of the tank (refer to Appendices 1 and 2 for recipe).

5. Fill the tank with water until 150 gal. total volume is reached.

6. Obtain a known volume sample of the tank content and weigh the sample using the Acculab scale.

7. Calculate the resulting density of the solution by dividing the weight of the sample by the sample volume that corresponds with a 10% reduction in the density of pure glycerin.

8. Record the DVM V4.0 output signal.

9. Follow the steps described in Appendices 1 and 2 to obtain aqueous solutions corresponding to 5% and 2.5% reduction in pure glycerin density.

Precision Analysis

The Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results [4] were used for evaluating precision of the DVM V4.0 with the device's linear calibration curve accounted [5].

There were two precision evaluation trials performed: the first trial at the beginning of the evaluation period in July, 2010, and the second trial at the end of the evaluation period in November, 2010. In each trial, ten data samples of the DVM readings were collected. The length of each sample was limited to 30 records to eliminate the possibility of a thermal drift in the precision-related data.

Precision of density measurements made by the DVM V4.0 was calculated as

$$Precision_{\rho^o} = \frac{k\sigma_x}{\rho^o} \cdot 100\%$$

$$\sigma_x = 0.0002409$$

$$\rho = kx + b \rightarrow calibration\,curve$$

$$k = 32.426; b = 2.2031$$

$$Precision_{\rho^o} = \frac{32.426 \cdot 0.0002409}{1.26} 100 = 0.62\%$$

Where σ_x denotes the standard deviation of the DVM V4.0 estimator [4, 5] – an internal device-generated variable converted into the measured variable by calibration (in this case, density); ρ^o denotes the standard value of the pure glycerin density; k denotes the slope of the tested DVM V4.0 density calibration curve.

Accuracy Analysis

The DVM V4.0 uses 2-point calibration for measuring density. An experimental evaluation of the accuracy of the density measurement is based on the comparison of actual DVM V4.0 readings with the standard values of density of the aqueous glycerin solution prepared using recipes described in Appendices 1 and 2. The accuracy of the density measurements was evaluated using the procedure outlined in the NIST Guidelines [4].

The results of the tests are summarized in Table 1 below.

Table 1

Density range: 1.134-1.26 SG

DVM Estimator Reading $x10^{-3}$	Actual Density, SG Aqueous glycerin solution	Measured Density, SG Aqueous glycerin solution	Relative Density Change, % SG	Accuracy %
29.06	1.260	1.260908	0.0	0.072063
29.75	1.228	1.239200	2.5	0.912052
30.73	1.197	1.207448	5.0	0.872849
32.94	1.134	1.135844	10.0	0.162610
Device Accuracy,%				0.50489

Conclusion

- **Precision** of the non-invasive density measurement with the tested sample of DVM V4.0 on a 200 gal. steel tank with 0.25" thick wall was determined to be **0.62%** (2-point calibration model, aqueous glycerin solution).

- **Accuracy** of the non-invasive density measurement with the tested sample of DVM V4.0 on a 200 gal. steel tank with 0.25" thick wall was determined to be **0.51%**.

- This testing of the Ultimo-developed non-invasive density measuring device utilizing percussion technology demonstrated performance suitable for using DVM V4.0 in process control applications for liquids like gasoline, crude oil, various lubricants and a variety of food and beverage products.

Bibliography

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4. "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results." <http://physics.nist.gov>.

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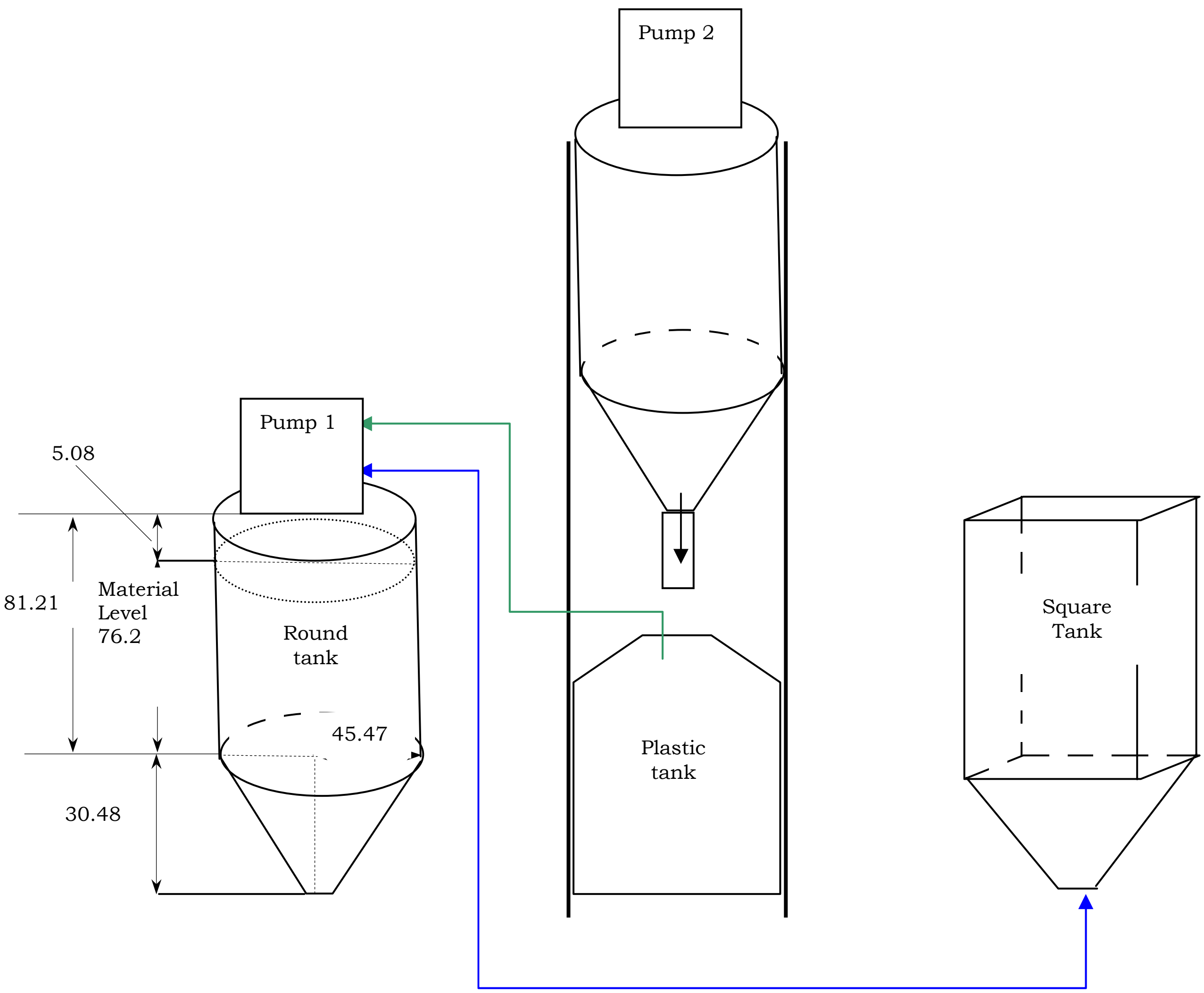
Appendix 1

Ultimo Test System

(All linear dimensions are in cm)



Appendix 2

Test Recipes

$$Vcn := \frac{\pi \cdot 45.47^2 \cdot 30.48}{3}$$ Volume of cone

$$Vc := \pi \cdot 45.47^2 \cdot (81.28 - 5.08)$$ Volume of cylinder

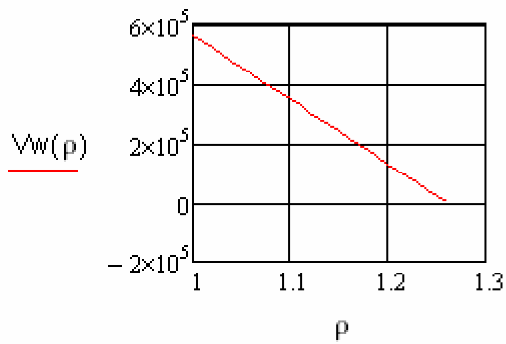
$$V := Vcn + Vc$$ Volume of tank $V = 5.609 \times 10^5$

$\rho w := 1 \qquad \rho g := 1.26$

$\rho := 1, 1.01 .. 1.26$

(1) $$w(\rho) := \frac{V \cdot (\rho - \rho g)}{\rho w - \rho g}$$

ρw - density of water
ρg - density of glycerin
ρ - density of the mix
V - tank working volume, cm^3
Vw - diluting volume of water, cm^3



index 0 = 1% reduction of pure glycerin density

index 1 = 2.5% reduction of pure glycerin density

index 2 = 5% reduction of pure glycerin density

index 3 = 10% reduction of pure glycerin density

Verification by Chemical Calculator from www.chembuddy.com a UK chemical calculation website

$$Vwtr := \begin{bmatrix} Vw[(1-0.01)\cdot\rho g] \\ Vw[(1-0.025)\cdot\rho g] \\ Vw[(1-0.05)\cdot\rho g] \\ Vw[(1-0.1)\cdot\rho g] \end{bmatrix} \qquad Vwtr = \begin{pmatrix} 2.718\times10^{4} \\ 6.796\times10^{4} \\ 1.359\times10^{5} \\ 2.718\times10^{5} \end{pmatrix}$$

Vwtr - Deluting Volume of water

$$Vg := \begin{pmatrix} V - Vwtr_0 \\ V - Vwtr_1 \\ V - Vwtr_2 \\ V - Vwtr_3 \end{pmatrix} \qquad Vg = \begin{pmatrix} 5.338\times10^{5} \\ 4.93\times10^{5} \\ 4.25\times10^{5} \\ 2.891\times10^{5} \end{pmatrix}$$

Vg - Remaining Volume of glycerine

Height of water column for glycerine substitution

$$r := 45.47$$

$$\Delta h(\Delta V) := \frac{\Delta V}{\pi\cdot r^2} \qquad \Delta V := Vwtr$$

$$\Delta h(\Delta V) = \begin{pmatrix} 4.185 \\ 10.463 \\ 20.926 \\ 41.851 \end{pmatrix}$$

Linear approximation

$$\Delta Vwtr\_casc := \begin{pmatrix} 35000 \\ 87000 \\ 169000 \\ 317000 \end{pmatrix}$$

(2)

$$\Delta h(\Delta Vwtr\_casc) = \begin{pmatrix} 5.389 \\ 13.394 \\ 26.019 \\ 48.804 \end{pmatrix}$$

CASC-based calculaation

The amount of water used for diluting the pure glycerin in the tests should stay within the limits defined in (1) and (2). To reduce pure glycerin density to numbers other then 10%, the following procedure must be followed:

1. Mark the initial content material (glycerin) level in the round tank.

2. Remove 48.804 cm of glycerin from the round tank (measured level difference) and store it in the square tank

3. Fill the round tank with water until the initial level is reached.

4. Thoroughly mix the tank content and wait 30 minutes.

5. Using the tank's content sample of known volume and the laboratory scale, measure the density of the mix by dividing the mass of the sample by the sample volume and record it in the lab journal.

6. Perform measurements with the DVM V4.0.

7. Drain a pre-calculated amount of the round tank content and fill the tank with pure glycerin up to the initial material level to obtain a glycerin-water solution corresponding to 5% and 2.5% density reduction, respectively, according to the schedule below:

Glycerin Density Additional Reduction Schedule

Glycerin Density Reduction, %	Height of Round Tank content material column to be filled with glycerin, cm
5	20.923
2.5	10.629

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