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A COMPARATIVE STUDY ON TWO CEMENT SLURRY DENSITIES MEASUREMENT TECHNIQUES IN OIL WELL CEMENTING

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ABSTRACT
The density of the cement slurry used in oil well cementing is vital to the realization of the technical and economic goals of the well construction process. Also, the measurement technique used in the process can impact on the costs incurred both to the operators and the service providers. This study compares the measurement of cement slurry density using a radioactive density meter and a mass flowmeter. Cement slurries of predetermined densities - 1.501SG (specific gravity), 1.681SG and fluids of 1.0SG (water), 0.867SG (diesel) and 0.0SG (air) were used in both instruments. The measurements were analyzed using Z-Statistic. Whereas, the level of accuracy obtained from both instruments is similar, the Total Cost of Ownership (TCO) for using either instrument is not the same. Knowledge of TCO will help organizations make optimal instrument selection decisions when they are faced with contending technical options.

INTRODUCTION

Nelson (1990) states that the ability of an oil well to produce to its potential is influenced by the degree of zonal isolation which is in turn affected by the quality of the cement used in cementing the casing. The cement slurry density is one crucial parameter to be considered and the two common instruments for determining the density of cement slurry are radioactive density meters and mass flowmeters.

In a radioactive density meter, a radioactive source gives off gamma rays which pass through the process pipe and the slurry flowing through the pipe. The pipe and the slurry absorb some gamma rays. The amount of gamma rays energy that finally gets to the detector varies with each material and the density of the slurry through which the gamma rays pass. This variation is used to measure the fluid density.

Modeled as a spring and mass under vibration, mass flow meter density sensor is vibrated at its natural frequency. When the tube is filled with a fluid that increases in density, the mass of the tube increases and this in turn decreases the frequency of vibration. The measurement of the variation in frequency gives a direct indication of the change in mass from which density can be inferred.

Hingham and Boyes (2003) described several fluid density measurement techniques.

However, the two methods under investigation are most amenable to process automation used in oil well drilling and production. As explained by Sarah and others. (2011) instrumentation costs can be significant depending on the scope and complexity of the project or equipment used. Fraden (2010) stated the factors to be considered when selecting field instruments. According to Bathika (2010), field instrumentation contributes up to 15% of the cost of any industrial project. As explained by

Roodhooft (2005), in addition to technical factors users need to focus on the total cost of ownership rather than just the initial cost of acquiring or installing field instruments. This is because the installation and running costs over the life-cycle of the system or facility constitute a vital cost in the running of field instrumentation operations as explained in a paper by Endress and Hauser (2002).

Cartier (1977) explained that the costs of deploying field instruments come as direct and indirect costs. Thermo Scientific (2010) in a study explained that direct costs are easier to identify and track than indirect costs. Indirect costs are difficult to quantify because they are typically hidden and not included in the budget.

Therefore, the long term costs of acquiring and deploying a particular field data measurement system in the face of competing alternatives using the Total Cost of Ownership (TCO) concept must be considered. TCO analysis is used to find the lifetime costs of acquiring, operating and changing equipment, a device or operating an industrial facility, Schmidt (2011).

This study investigates these two fluid density measurement technologies in terms of technical and economic benefits derived from using one method instead of the other when applied on the same equipment. The insight drawn from this study will help to guide companies faced with making instrument and data measurement decisions so that they will avoid wasting unbudgeted amounts of money in terms of visible and invisible costs arising from using inappropriate data measurement technology.

MATERIALS AND METHODS

The setup used for carrying out the tests is as shown in Figure 1. The fluids and slurries of known density values were passed through the annulus of the radioactive density meter and the mass flowmeter, one slurry sample at a time. The corresponding density values as measured by each of these (previously calibrated) instruments were recorded. For each instrument, 30 set of readings were taken at 5 seconds intervals. The values obtained for each instrument are shown in Table 1. As shown in Table 1, different samples of fluids and slurry were used to carry out the tests on the radioactive density meter (RAD) and the mass flowmeter (MFM). Starting with air (specific gravity, SG = 0) in each of the devices, the density value measured were recorded sided by side under the predetermined density for air (0SG). This procedure was repeated for diesel (SG = 0.867), water (SG = 1.0) and cement slurries of 1.501SG and 1.681SG. It was not practically possible to use cement slurries of higher SG values because of the limitations imposed by the set up.

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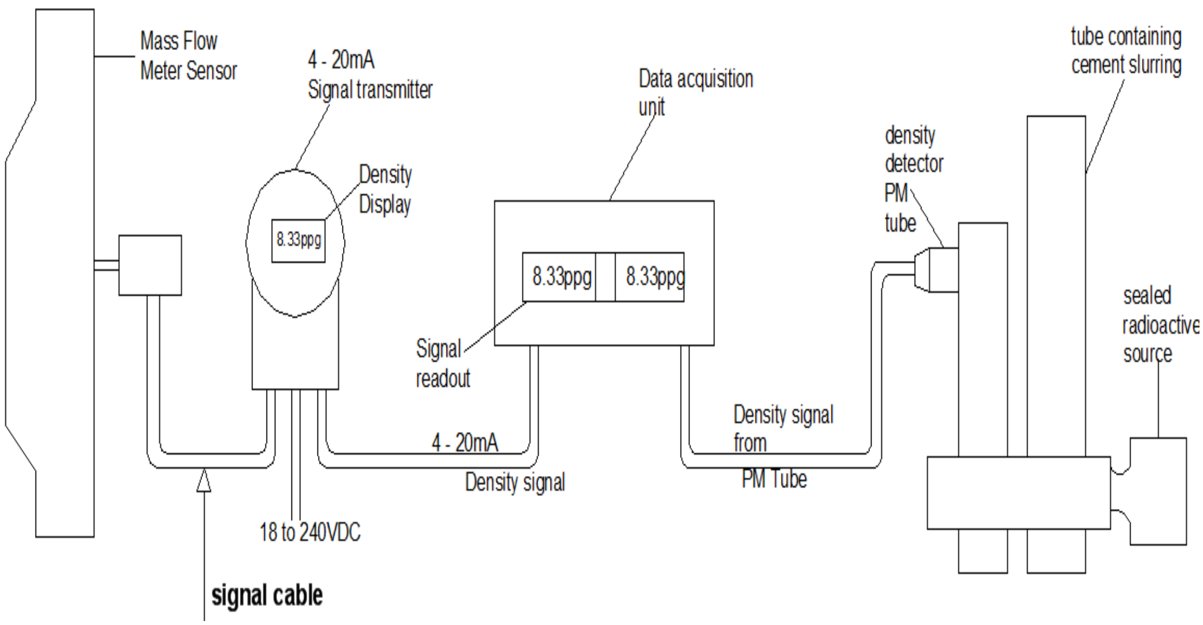

Figure 1: Laboratory setup for comparing Coriolis mass flowmeter and radioactive density meter density measurements.

Test of Significance

Tests were carried out using air, diesel, water and cement slurry samples of various densities. The results obtained are as shown in Table 1. To carry out tests of significance, the null and alternate hypotheses are stated as follows:

Null hypothesis H_o,

Both methods of measurement provide the same analytical results. The differences observed if any are purely due to random errors.

The **alternate hypothesis H_1,** is stated as follows:

The methods provide different analytical results, so, at least one method yields systematic analytical errors.

The null and alternate hypothesis was done by using the Z – statistic test. The Z-statistic is used for large sample with N ≥ 30. For the z-statistic, we have:

$$Z = \frac{Difference\ in\ mean\ of\ sample\ and\ population}{standard\ error\ of\ the\ sampled\ mean} \quad \ldots\ldots\ldots\ldots(1)$$

$$= \frac{(x' - \mu_0)}{\sigma/\sqrt{N}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

For Equation (2), the sample standard deviation is used as an estimate of σ if σ is unknown. For large sample sizes (N1, N2 ≥ 30), the sampling distribution of differences in means is approximately normally distributed with means and standard deviations given by:

$$\mu_{x'_1 - x'_2} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

and,

$$\sigma_{x'_1 - x'_2} = \sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

For the z test statistic, we have:

$$Z = \frac{x'_1 - x'_2}{\sigma_{x'_1 - x'_2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Equation 5 above is used for evaluating the value of the Z – statistic.

RESULTS

Table 1: Specific Gravity of Fluids as measured by RAD and MFM instrument

	SPECIFIC GRAVITY OF FLUIDS AS MEASURED BY RAD AND MFM INSTRUMENTS									
S. GRAVITY	**0.000**		**0.867**		**1.000**		**1.501**		**1.681**	
INSTRUMENT	**RAD**	**MFM**	**RAD**	**MFM**	**RAD**	**MFM**	**RAD**	**MFM**	**RAD**	**MFM**
	0.006	0.002	0.876	0.858	0.996	0.993	1.513	1.505	1.681	1.672
	0.004	0.002	0.875	0.858	1.008	0.993	1.513	1.505	1.693	1.672
	0.006	0.002	0.872	0.858	1.020	0.993	1.513	1.505	1.693	1.672
	0.002	0.002	0.868	0.858	1.008	0.993	1.513	1.505	1.681	1.672
	0.008	0.002	0.872	0.858	1.020	0.993	1.513	1.505	1.681	1.672
	0.006	0.002	0.858	0.860	1.020	0.993	1.513	1.505	1.681	1.672
	0.004	0.002	0.866	0.860	1.032	0.993	1.513	1.505	1.693	1.672
	0.007	0.002	0.876	0.858	1.020	0.993	1.513	1.505	1.705	1.672
	0.007	0.002	0.868	0.860	1.008	0.993	1.513	1.505	1.693	1.672
	0.008	0.002	0.881	0.860	1.032	0.993	1.513	1.504	1.693	1.672
	0.002	0.002	0.862	0.860	1.008	0.993	1.513	1.504	1.693	1.672
	0.003	0.002	0.858	0.860	1.020	0.993	1.513	1.504	1.693	1.672
	0.007	0.002	0.867	0.860	1.020	0.993	1.513	1.504	1.681	1.672
	0.001	0.002	0.869	0.858	1.020	0.993	1.513	1.504	1.693	1.672
	0.017	0.002	0.875	0.860	1.008	0.993	1.513	1.504	1.693	1.672
	0.013	0.002	0.863	0.858	1.008	0.993	1.513	1.504	1.693	1.672
	0.013	0.002	0.864	0.858	1.008	0.993	1.513	1.503	1.693	1.672
	0.009	0.002	0.867	0.858	1.020	0.993	1.513	1.503	1.693	1.672
	0.012	0.002	0.868	0.860	1.008	0.993	1.525	1.503	1.693	1.671
	0.007	0.002	0.869	0.860	0.996	0.993	1.525	1.503	1.693	1.671
	0.007	0.002	0.864	0.860	1.008	0.993	1.525	1.503	1.693	1.672
	0.011	0.002	0.862	0.858	1.020	0.993	1.513	1.503	1.693	1.672
	0.008	0.002	0.866	0.858	1.008	0.993	1.525	1.503	1.693	1.671
	0.008	0.002	0.864	0.860	1.008	0.993	1.525	1.503	1.681	1.671
	0.005	0.002	0.866	0.860	1.008	0.993	1.525	1.502	1.681	1.672
	0.006	0.002	0.864	0.860	0.996	0.993	1.501	1.502	1.681	1.671
	0.007	0.002	0.866	0.858	1.020	0.993	1.513	1.502	1.693	1.672
	0.007	0.003	0.875	0.860	1.032	0.993	1.513	1.502	1.705	1.672
	0.004	0.003	0.875	0.858	1.008	0.993	1.513	1.502	1.717	1.672
	0.006	0.003	0.881	0.858	1.020	0.993	1.513	1.502	1.705	1.672
MEAN	**0.0071**	**0.0024**	**0.8686**	**0.8589**	**1.0140**	**0.9928**	**1.5146**	**1.5038**	**1.6915**	**1.6721**
ST. DEV	**0.0035**	**0.0001**	**0.0061**	**0.0006**	**0.0098**	**0.0000**	**0.0055**	**0.0014**	**0.0085**	**0.0005**
(ST. DEV)2/30	**4.06E-07**	**5.1E-10**	**1.2E-06**	**1.24E-08**	**3.22E-06**	**6.8E-33**	**1.02E-06**	**6.12E-08**	**2.44E-06**	**6.9E-09**
	0.0006		**0.0011**		**0.0018**		**0.0010**		**0.0016**	
Z-Statistic	**7.28**		**8.65**		**11.81**		**10.42**		**12.42**	

Using Microsoft Excel, the calculated values of the Z – statistic is shown in the last row of Table 1.

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DISCUSSION

Table 2 shows the critical values for a one tailed and two tailed test at specified levels of significance as cited in Nwaogazie (2005). The 5% and 10% levels of significance represent the approximate levels of difference in the readings obtained from the instrument and the expected value for the density measurement figures.

Table 2: Critical Values of Z for Selected Levels of Significance for One-Tailed and Two-Tailed Tests

Levels of Significance	**10%**	**5%**	**1%**	**0.5%**	**0.3%**
Critical values of Z for One-Tailed Test	±1.28	±1.645	±2.33	±2.58	±2.88
Critical values of Z for Two Tailed Test	±1.645	±1.96	±2.58	±2.81	±3.08

The Z-statistic for 5 sets of density measurements obtained by using the two instruments to measure the density of the slurry samples side by side are as shown in Table 3.

Table 3: Calculated values of Z-statistic for 5 density samples

Specific Gravity	Calculated Z - Statistic
00.00	7.26
0.87	8.65
1.00	11.81
1.50	10.42
1.68	12.42

Table 4: Mean Density Measured values: Radioactive (RAD), Mass Flow Meter (MFM) and Expected Density measurement values in specific gravity (SG)

RAD	**MFM**	**EXPECTED**	**RAD OFFSET**	**MFM OFFSET**	**RAD % OFFSET**	**MFM % OFFSET**
0.007	0.002	0.000	0.007	0.002	-	
0.869	0.858	0.864	0.005	-0.006	0.6	-0.7
1.014	0.993	1.000	0.014	-0.007	-1.4	-0.7
1.515	1.504	1.501	0.014	0.003	0.9	0.2
1.691	1.672	1.681	0.019	-0.009	-1.1	-0.5

Comparing the calculated values of the Z-statistic in Table 3 with the critical values in Table 2, it was observed that the calculated values for the Z-statistic are higher than the critical values shown in Table 3. Therefore, the null hypothesis H_o is rejected and the alternate hypothesis, H1 is accepted – implying that the methods provide different analytical results, so, at least one method yields systematic analytical errors. From Table 3, the values obtained for the Z-statistic for each density value under consideration seems to indicate that there is a significant difference in the accuracy readings of the two density measurement techniques. However, the readings that is of most practical significance in real time applications are the average values. Also, from Table 4, all the values obtained for the measured density fall within acceptable offset values. With this, one can ascertain that the measurement techniques give similar levels of accuracy.

Table 4 shows how the measured density values compare with the expected density values. The % offset values obtained for the density measurements are within acceptable limits for oil well cementing applications where offset values of 2, 3 or 4% are acceptable.

Total Cost of Ownership

The various direct and indirect costs along with the Total Cost of Ownership associated with using either of these two density measurement instruments are as shown in Table 5.

Table 5: Cost Categories for Density Measurement Instrument

	Cost Component	Radioactive Density Meter	Mass Flow Meter
Acquisition Costs	Cost of purchase from vendor	N2,201,465	N2,090,795
	Shipping cost	N235,000	N100,000
	Calibration Equipment	N350,000	N1,050,000
	Electronic data acquisition unit	N566,960	N566,960
Running Costs	Personnel Training/Certification	N1,500,000	0
	Field installation Cost	N47,500	N157,636
	Calibration costs	N83,864	N25,500
	Maintenance	0	0
	Annual Regulatory Compliance Licensing fees	N150,000	0
	Annual Custody and Security Costs	N250,000	0
	Cost for keeping ready-to-go spares	0	N2,050,328
	Decommissioning Costs	N355,000	0
	Total Cost Of Ownership (TCO)	**N5,739,789**	**N6,000,252**

Table 5 shows the various cost components associated with using these instruments in the field. The cost for acquiring a mass flow density meter is lower than the cost of a radioactive density meter. However, it was observed that the total cost of ownership (TCO) for using a mass flowmeter is higher than that of a radioactive density meter even though it costs less to acquire initially. All other factors remaining unchanged, the results indicate that the radioactive density meter is less expensive to use compared to a mass flowmeter.

CONCLUSION

The findings of this study reveal that the measurement of cement slurry density using a

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radioactive density meter give the same level of accuracy as a mass flowmeter. However, the Total Cost of Ownership (TCO) incurred from using a mass flowmeter for cement slurry density measurement is higher over the lifetime of the field equipment even though it is cheaper to acquire initially. The use of radioactive density meters come with several hidden costs in the form of logistics and regulatory compliance costs that quickly adds up to the overall cost of using it in the field. This demonstrates that the selection and use of the wrong measuring instruments can lead to huge financial losses for the company. Consequently, comparative studies of various data measurement technologies are needed in order to determine the most optimal solution for a particular field need. This will help field operators to avoid wasteful financial cost over-runs in these days of slim operating margins.

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