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Optimising thickener performance: non-nuclear underflow density control using multipoint calibration

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Abstract

Accurate measurement of thickener underflow density is essential for controlling water recovery, maintaining stable throughput, and ensuring downstream processing efficiency. Industrial practice has relied predominantly on nuclear density meters because of their robustness under abrasive, high-solids conditions. However, these instruments present challenges associated with the handling of radioactive materials, including regulatory compliance, safety management, and disposal. Recent developments in ultrasonic instrumentation provide a potential non-nuclear alternative, but their performance in thickener control is insufficiently documented.

This study investigates the application of an ultrasonic slurry density meter for continuous monitoring of thickener underflow. Comparative assessments were undertaken against a nuclear reference instrument across a range of operational conditions representative of thickener performance, including variations in solids concentration, flow velocity, and transient slurry behaviour. A particular focus of the investigation is the use of multipoint calibration (MPC). In contrast to single-point calibration, which assumes uniform slurry characteristics, MPC establishes a composite calibration function derived from multiple reference points. This approach enables the instrument to capture nonlinearities associated with stratification, transitional flow, and bed formation.

Experimental data show that the non-nuclear device, when configured with MPC, achieved measurement accuracy and dynamic response comparable to the nuclear reference across the tested operating envelope. The MPC methodology improved stability during transient events, reducing sensitivity to localised fluctuations in solids distribution. Extended field deployment confirmed that calibration drift was minimal and that the instrument remained stable during prolonged operation. Integration into existing control systems was achieved without modification to underlying logic.

The findings demonstrate that non-nuclear, ultrasonic density measurement, enhanced through multipoint calibration, provides a technically robust alternative to nuclear meters for thickener underflow monitoring. This work contributes to the broader understanding of non-nuclear instrumentation for slurry systems and highlights its potential for reliable process control under dynamic thickener conditions.

Keywords: *slurry density, density measurement, non-nuclear density measurement, calibration*

1 Introduction

Tailings thickening is nowadays monitored on basis of underflow density (Talmon et al. 2024). Accurate measurement of thickener underflow density is essential for controlling water recovery, maintaining stable throughput, and ensuring downstream processing efficiency.

Thickener control software relies on input data such as underflow density, settling band and clarity, as well flocculant addition to control existing measures such as rake torque, bed level and bed pressure (Weidenback

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et al. 2012). But mathematical models and software are useless if experimental parameters defining the constitutive equations are not available (Concha et al. 2014).

Reliable measurement techniques and practices are therefore paramount for efficient thickener control. Several technologies for the measuring of thickener underflow density are available. To date, in minerals processing, nuclear density meters are the most commonly used sensors because of their robustness under abrasive, high-solids conditions. However, these instruments present challenges associated with the handling of radioactive materials, including regulatory compliance, safety management, and disposal. Recent developments in ultrasonic instrumentation provide a potential non-nuclear alternative, but their performance in thickener control is insufficiently documented.

This study investigates the application of a non-nuclear, ultrasonic slurry density meter (SDM Eco) for continuous monitoring of thickener underflow. Comparative assessments were undertaken against a nuclear reference instrument and a Coriolis massflow meter across a range of operational conditions representative of thickener performance, including variations in solids concentration and flow velocity.

2 Methodology

In order to compare the accuracy of the non-nuclear density meter (SDM Eco) against other available measuring technology, a series of tests was carried out in a pipeloop fitted with 3 density meters: an acoustic density meter, a nuclear density meter and a Coriolis meter. All density meters were placed in a vertical position with the flow in an upward direction. The acoustic density meter was placed above the nuclear density meter with sufficient spacing to allow for undisturbed flow conditions. A schematic of the test arrangement is depicted in Figure 1.

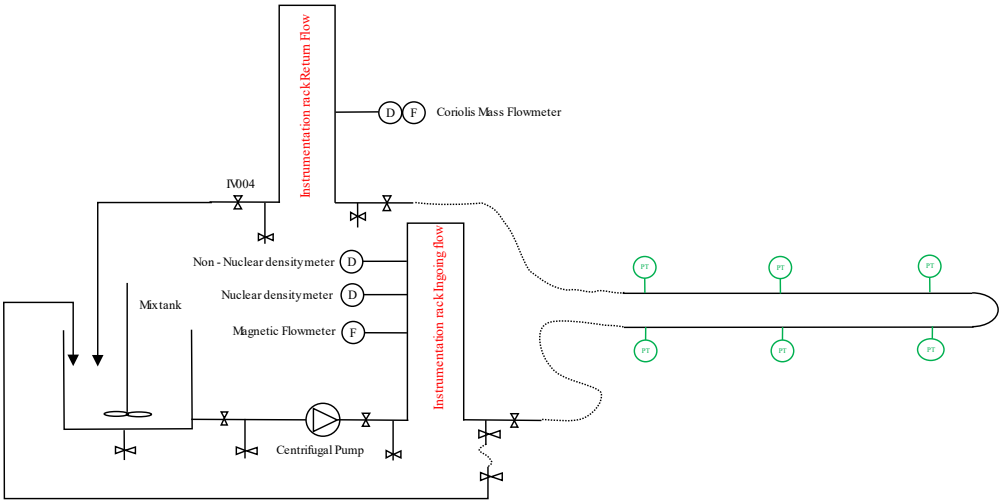

Figure 1 Process flow schematic for the test set-up. The instrumentation is installed in a vertical position, with flow in an upward direction. The nuclear density meter and slurry density meter are installed in the feed pipeline, and the Coriolis massflow meter is installed in the return pipeline

A laterite slurry was then prepared and pumped through the pipeloop at regular flow rate intervals. This process was repeated for several solids concentrations varying from 43–67% solids by weight, representing the expected range the thickeners could deliver. A minimum of 2 lab samples were taken for each solids concentration. These slurry samples were oven dried to create a baseline to compare the 3 meters against.

The Coriolis meter was located in the return pipe of the loop, and the acoustic and nuclear density meter were installed in the feed line. This set-up allowed for detection of settling while operating the pipeloop over a range of flow velocities. When operated at flow velocities in excess of the critical flow velocity, the solids are homogenously distributed through the loop and the solids concentration is equal throughout the entire system. Reduction of the flow velocity close to or below the critical flow velocity will see settling of particles

at the bottom of the horizontal section of the pipeloop. The outflowing slurry will have a lower solids concentration than the incoming flow, and material accumulates in the pipeloop.

When pumping under these conditions, the flow density meters installed in the feed line measure a higher density than the density meter (Coriolis) installed in the return line. When a settling flow regime is sustained for longer than a single pass through the pipeloop, both measured densities in the feed and return line will trend downward, indicating settling of particles in the loop. Density data obtained from the 3 measuring points deviates and cannot be compared to oven dried samples in the absence of multiple sampling locations. The data obtained at flow velocities lower than the critical flow velocity have therefore been rejected in the comparison.

Prior to introducing slurry in the system, the circuit is calibrated on water to assure obtaining valid data from the tests.

2.1 Sample preparation

The sample was received in intermediate bulk container (IBC) containers. After several weeks of storage, the sample was completely settled and the clear water was decanted off. The settled solids were loaded in a mixing tank and sufficient water was added to prepare the highest target solids concentration. After approximately 30 minutes of mixing, a slurry sample was obtained for oven drying. The slurry was then pumped through the pipeloop. After completing testing, the slurry sample was diluted to the next, lower solids concentration target. At each target solids concentration, a sample for oven drying was obtained. In total, 4 test series were executed.

3 Results

The test campaign was executed in 3 parts and was part of a larger study deriving the rheological properties of the tested slurry for pipeline design. For each test run, the slurry density was logged for the 3 installed measuring devices. For each target density, 3 samples were obtained for oven drying. The average solids concentration of the oven dried samples is taken as the baseline for comparison. An overview of the target and actual solids concentration is given in Table 1. In the table, the slurry density is calculated from the average oven dried solids concentration using the average specific dry solids density measured for the slurry sample. The calculated value of the slurry density (S_m) represents the baseline against which the measured data is compared.

$$S_m = \frac{1}{\left(\frac{C_w}{S_s}+\left(1-\frac{C_w}{S_l}\right)\right)} \quad (1)$$

where:

S_m = slurry density of the homogenous slurry

C_w = solids concentration by weight

S_s = specific gravity of the dry solids

S_l = specific density of the liquid.

3.1 Baseline testing: series 1

Although system calibration on water was successful, no valid density measurements were obtained in the first test on actual slurry. The nuclear density meter produced flat line profiles indicating it was operating outside of its calibrated range. The non-nuclear density meter data varied also considerable from the Coriolis data at high solids concentrations. It was therefore decided to recalibrate the nuclear density meter prior to restarting testing.

Table 1 Slurry solids concentration by weight and slurry density

Test series	Target C_w (%w/w)	Actual C_w (%w/w)	Slurry density (S_m) (t/m^3)
Baseline Series 1	60	59.6	1,519
	55	56.0	1,472
	50	51.3	1,416
Main test Series 2	60	61.1	1,538
	60	60.3	1,528
	55	54.4	1,453
	50	50.5	1,407
	45	43.9	1,335
	64	64.0	1,578
Confirmation Series 3	65	66.6	1,617
	55	54.2	1,450
	50	47.8	1,377
	45	43.4	1,330

3.2 Main test campaign: series 2

Based on the obtained baseline solids concentrations, a multipoint calibration model was derived for the non-nuclear density meter (Table 1). This profile is commonly referred to as a super profile and allows for accurate operation over a wider range of solids concentrations. In parallel, the nuclear density meter was calibrated at 3 points: 1.000, 1.200 and 1.700 t/m^3.

Data obtained during testing has been averaged over the time interval at which the test has been running. The results are presented in Table 2. In the table, the variation of the solids concentration against the true, overdried, dry solids concentration is given. On average, the Coriolis meter provided measurements closest to the true solids concentration. The Coriolis meter was within 1% accurate from target density. The nuclear density meter returned readings which were accurate for target 60% solids concentration (0.5%), but considerably less accurate for 65% target solids concentration. At this target, the nuclear density meter overshot by 4.8%. Overall, the accuracy of the nuclear density meter varied from 0.5 to 4.8%. The non-nuclear density meter was within 2% accurate. The accuracy was highest close to, or onto the calibration points (0.5%). The non-nuclear density meter was calibrated at 10% concentration intervals, starting from 40%.

The large variation in accuracy of the nuclear density meter led us to believe adding calibration points for the nuclear density meter would increase its accuracy. A third series of tests was conducted to confirm this hypothesis.

Table 2 Variation of measured solids concentration against true solids concentration

Series	C_w dry solids	Variation of C_w		
		Coriolis	Nuke	SDM
2	60%	0.2%	0.5%	
2	54%	0.8%	1.9%	
2	51%	−0.3%	1.5%	0.5%
2	44%	1.0%	3.7%	1.7%
2	64%	0.9%	4.8%	
	After recalibration of the nuclear density meter			
3	54%	1.2%	−0.5%	
3	48%	−0.6%	−1.1%	
3	43%	2.1%	1.7%	

3.3 Confirmation testing: series 3

The nuclear density meter was recalibrated for 5 points at 10% solids concentration intervals, identical to the non-nuclear density meter. With the new calibration settings the accuracy of the nuclear density meter improved significantly as can be seen in table 2.

4 Deviation from true density

In Figure 2 the averaged measured slurry density data is plotted against the slurry density calculated from the oven dried samples. The calculated slurry density is plotted on the x-axis. On the Y-axis the measured data is given. The 1:1 line represents the situation in which the measuring devices work 100% accurate. When the measured value is higher than the true solids concentration the measuring device is overshooting density. In the contrary, when the measured value is lower than the true solids concentration the measuring device is undershooting.

Overshooting solids concentration entails a miss representation of thickener performance. The actual underflow is more dilute than anticipated. Depending on the process control parameters and architecture it may result in further dilution and loss of rheology. Although the operational risk of settling due to the reduced yield and viscosity is in general mitigated by the increased flow, operating in these conditions may lead to unnecessary discharge of water.

Undershooting solids concentration leads to pumping of slurries which have a higher density than anticipated. This may result in increased pressure losses and hence increased power consumption (Möller et al. 2012). In extreme cases the pressure losses may exceed the pump capacity.

From Figure 2 it can be seen that the nuclear density meter when calibrated at 2 to 3 point can overshoot solids concentration by up to 4.8%. The Coriolis meter returns overall the most accurate data. The non-nuclear density meter demonstrated a slight overshoot of the solids concentration. The nuclear density meter returned better results after recalibration, with a slight tendency to undershoot solids concentration.

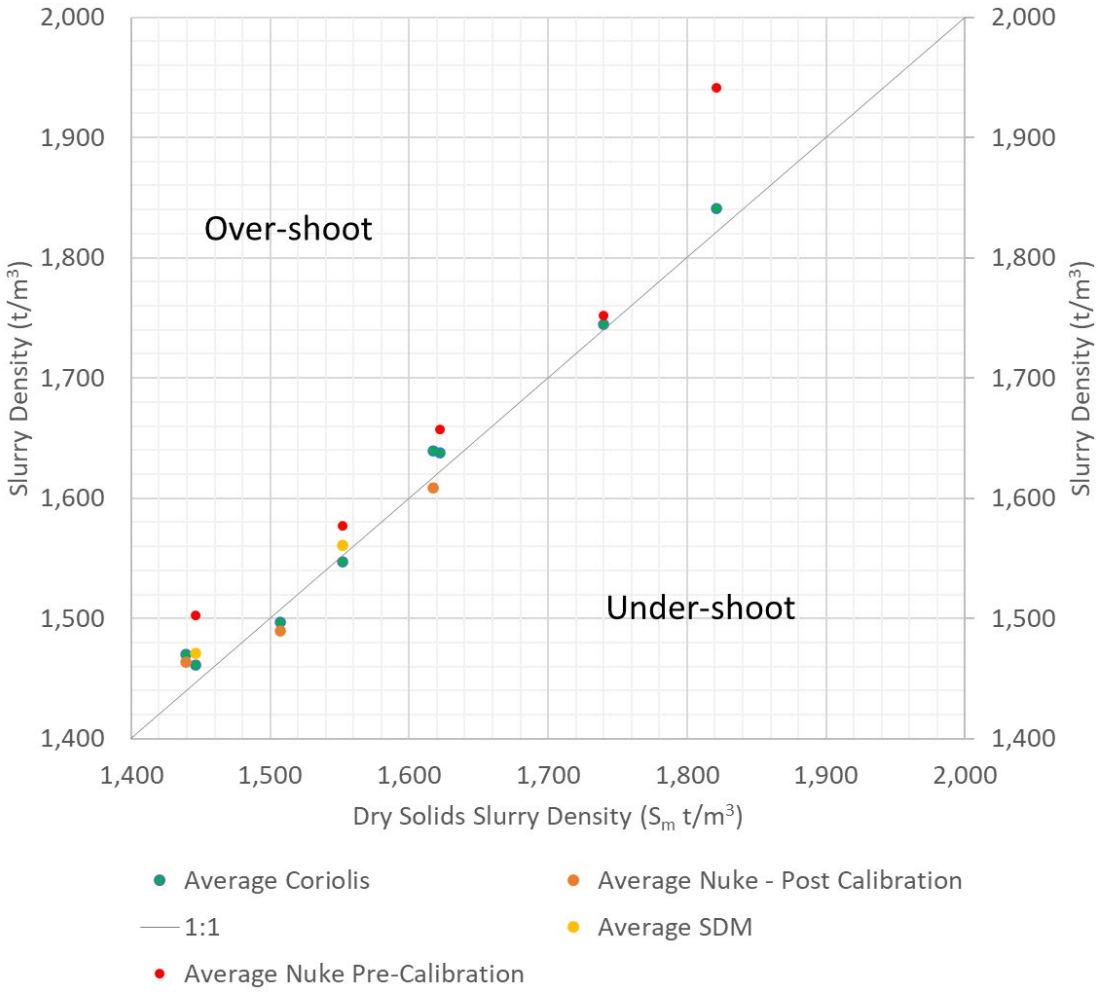

Figure 2 Measured slurry density plotted against the slurry density calculated from the oven dried slurry sample

4.1 Multipoint calibration

The results from the tests demonstrate the necessity of multi point calibration (MPC). Both the nuclear and non-nuclear density meter required 5 point calibration to return accurate density data during the tests. The Coriolis meter proved to be the most accurate measuring device. It is unfortunate that the working principle of the device does invoke unacceptable wear rates in industrial scale (abrasive) slurry applications. It is therefore recommended to use multipoint calibration for any density measuring device. The test data suggest that the maximum interval between calibration points should be 10%. Increasing the interval may return measured data varying more than 2% from the dry solids density.

5 Flow rate Effect

The use of MPC in the field returns good results, however when installed in a horizontal position sudden increase or drop in measured density was observed. An example of this phenomena is presented in Figure 3. The Figure shows flow rate, nuclear density and SDM density. A sustained reduction of the flow rate is followed by a distinct increase in the SDM density reading. This phenomena is the result of the formation of heterogenous flow conditions in the pipe. When the flow velocity is sufficiently high, all solid particles are suspended, with the particle distribution being homogeneous. As the velocity decreases, all of the solids are still suspended, but their distribution becomes heterogeneous (Tanaji et al. 2014).

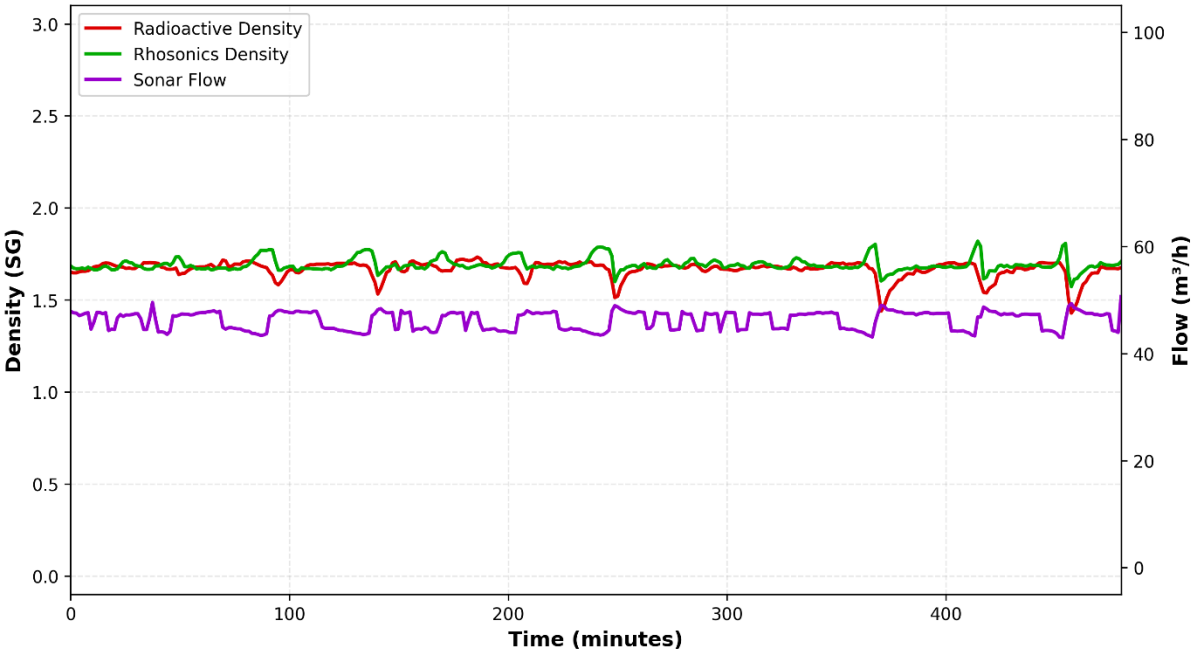

Figure 3 Flow rate effect: after running at reduced flow, an increase in solids concentration is measured by the non-nuclear density meter. SG = specific gravity

The non-nuclear sensor used (SDM Eco) measures acoustic impedance – it is highly sensitive to local changes in particle distribution. Positioning it low in the pipe makes it more susceptible at times to detecting temporary dense fronts or layers that do not reflect the actual bulk slurry conditions. To improve reliability, it is typically advisable to install the sensor higher up in the vertical pipe, ideally in a location where the slurry has reached a more stabilised, pseudo-homogeneous state. At this point, the effects of gravity-induced settling are more balanced by the turbulent mixing of the upward flow, and the sensor is less likely to encounter temporary interfaces or poorly mixed regions. The nuclear sensor, however, remains more stable as it averages solids concentration over the pipe cross-section and is less sensitive to interface dynamics.

5.1 Advanced multipoint calibration

To address this a piecewise calibration strategy has been developed. This approach applies different calibration models for specific density ranges or flow regimes, thereby capturing both the steady-state linearity and the nonlinear dynamic behaviour during transient conditions. This evolving calibration technique is intended to maintain high accuracy while improving the sensor's responsiveness across diverse operational scenarios.

With the implementation of the advanced MPC profile, the SDM was returning stable density measurements, as can be seen in Figure 4. In the figure, the flow rate Is plotted in purple (sonar flow = Sonartrac flow), nuclear density measurement plotted in red and the non-nuclear density plotted in green. From the graph, it can be seen that the 2 measurements track similarly.

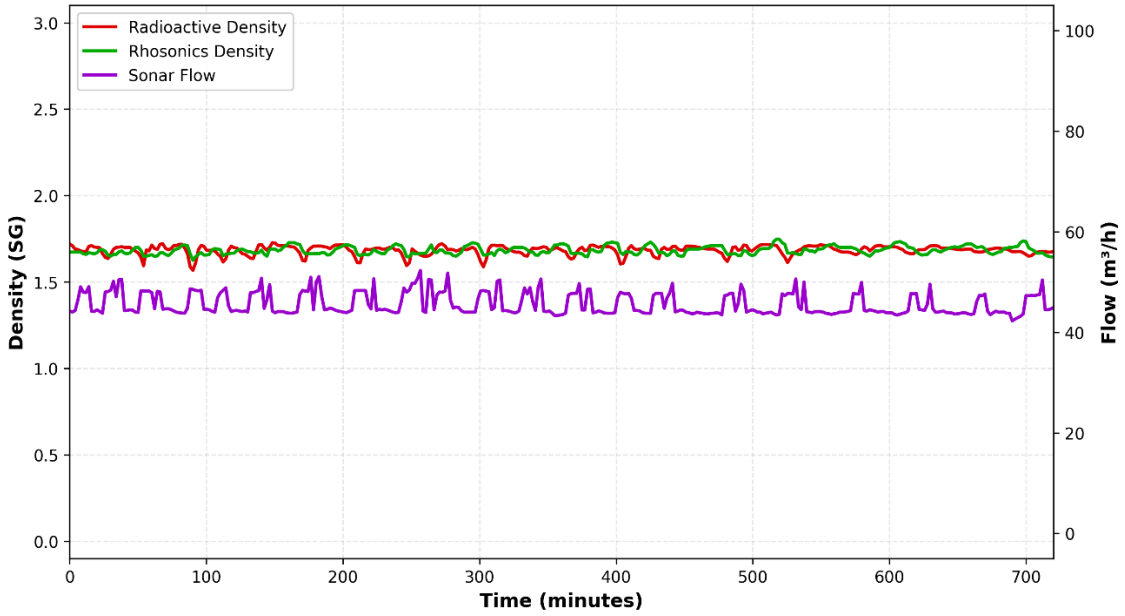

Figure 4 Density response to change in flow rate after implementation of advanced multipoint calibration. SG = specific gravity

6 Conclusion

Measuring of thickener underflow density plays a vital part in thickener control. Nuclear density meters are commonly used in this application. Due to operational or regulatory restrictions, safety management, or for administrative costs, the use of non-nuclear density meters is preferred. The direct comparison of nuclear, non-nuclear (acoustic) density measurement and a Coriolis meter leads to the conclusion that a Coriolis meter returns the most accurate density measuring without the need for calibration. Both the non-nuclear and nuclear density meter required multipoint calibration for accurate operation.

In the field, it was observed that flow rate variations did effect the non-nuclear density meter. The root cause of this fluctuation was found to be stratification in the slurry in conjunction with a horizontal installation of the meter. This deviation was addressed by implementation of a piecewise calibration strategy of the MPC. This advanced MPC approach resulted in accurate data generation over the full flow range.

Based on the provided data, it can be concluded that:

- Non-nuclear density measurement can be reliably applied in thickener underflow.
- Multipoint calibration is essential for reliable data generation.
- Vertical positioning of the sensor is preferred.

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