19th International Conference on
TRANSPORT AND SEDIMENTATION OF SOLID PARTICLES
24-27 September 2019, Cape Town, South Africa

PIPE LOOP TESTING OF A MIXTURE CONTAINING FINE, DENSE SOLIDS WITH MAGNETIC PROPERTIES

J. Furlan[1], R. Visintainer[1] A. Sellgren[2] V. Matoušek[3] L. Pullum[4]

[1] GIW Industries, Inc., 5000 Wrightsboro Rd., Grovetown, GA, USA, john.furlan@ksb.com, robert.visintainer@ksb.com; 2Lulea University of Technology, anders.sellgren@telia.com; 3Czech Technical University in Prague, v.matousek@fsv.cvut.cz; [4] Consultant, lpullum@bigpond.net.au

Tests were performed in the GIW Hydraulic Laboratory on a milled copper slag tailings slurry in pipe loops with 75 and 100 mm diameter loss sections. Volumetric concentrations of 1 to 14% were tested in the 100 mm loop, and the initial results, derived using magnetic flow meter measurements, showed pressure losses approximately equal to that of water. Chemical Testing of the solid particles was performed, and they were found to be made up of 56% magnetite by weight. Magnetite has been found in the past (Sonar Trac paper) to effect magnetic flow meter measurements, which was the primary method being used in this test program. Secondary measurements using a Sonar Trac instrument indicated, in contrast, the more common and expected equivalent fluid behavior in the 4" loop at the lower concentrations, where the losses, when expressed in height of slurry, now landed on top of the carrier liquid curve, which was found to be equal to that of water. A comparison between the measurements from the magnetic flow meter, and those from the sonar trac, showed a linear dependency between the flow rate ratio (between the magnetic flow meter measurement and the sonar trac measurement) and the solids concentration. These tests illustrate the importance of having knowledge of the makeup of the solid particles in a slurry, and the utility of acoustic based flow rate measurement methods in cases where magnetite (or other solids particles with magnetic properties) particles are present within the slurry.

KEY WORDS: Slurry testing, magnetite particles, loop testing, equivalent fluid behavior, magnetic flow meter, acoustic flow meter

1. INTRODUCTION

Loop slurry testing is performed in order to determine key operational parameters such as friction losses and deposition velocity (Wilson et al., 2006) which can be scaled up to field pipe diameters. Magnetic flow meters are commonly used in such tests, as well as in field installations. Initial results using a magnetic flow meter indicated no increase in friction losses (when expressed in terms of pressure, or height of water). However, chemical testing via spectral analysis indicated the presence of magnetite particles, and a comparison between the SONARtrac acoustic flow rate measurements and those of the magnetic flow meter indicated a large discrepancy - the sonar trac-derived loss vs. velocity curves indicated the more typical equivalent fluid behavior, when the losses expressed in height of slurry landed on top of the water /carrier liquid curves.

ISSN 0867-7964 ISBN 978-83-7717-323-7 DOI 10.30825/4.12-02.2019

2. PROCEDURE AND TEST LOOP SETUP

Tests on a crushed copper slag tailings slurry were conducted in the 4-inch NPS (100 mm DN) slurry test loop (with 4.038 inch (102.6 mm) internal diameter loss measurement section) at the GIW Hydraulic Laboratory in Grovetown, Georgia, USA. The test loop employed an inverted U loop (Wilson et al., 2006) to measure slurry specific gravity, and pressure tappings (Yokogawa Model: EJA110A-DHS4B-92NA/FF1/D1) in the horizontal loss section in order to measure friction losses. Both a magnetic flow meter (Yokogawa 4" Magmeter: Model: AXFA14C-E1-21/FF1) and a CiDRA SONARtrac acoustic flow measurement device (Model: SH-E04-08-00-000-00) were installed in the loop. The water accuracies of the magnetic flow meter and acoustic flow meter are specified by the vendors to be 0.35% of the reading, and 1%, respectively. The vendors do not give accuracy specifications for slurries, but do acknowledge that the presence of solids in the flows can negatively affect the accuracy of the instruments in a variety of different ways. The acoustic meter monitors the acoustic emission from eddies that are attached, by definition, to the mean velocity profile. The roughness ratio (roughness divided by inner pipe diameter) in the 100 mm diameter loss section was found to be equal to 0.000015, corresponding to a hydraulic roughness of 1.5 μm. A drawing of the loop can be seen in Figure 1.

The 4-inch NPS (100 mm DN) slurry test loop had the following features:

- Sump designed to deliver solids to the pipeline as quickly as possible.
- GIW 3x4 LCC-9 2004X pump on a variable speed drive to produce a wide range of slurry velocities.
- Magnetic flow meter (as the primary flow measurement device).
- acoustic flow meter (as the secondary flow measurement device).
- Elbow flow meter (as the tertiary flow measurement device).
- Inverted U-loop for measuring specific gravity (Wilson et al., 2006).
- 6.1 m friction loss section.
- Slurry sample collection valve.
- Transparent pipe observation section to determine deposition velocity.

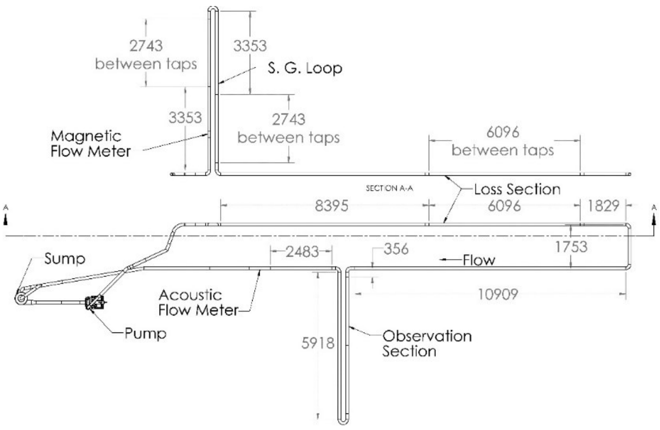

Figure 1. 100 mm Diameter Loop Drawing, units in mm.

Slurry tests were carried out at the solids volumetric concentrations of 1%, 2.5%, 5%, 7%, and 14% by volume in the 4” diameter loop, while much higher concentrations, of up to more than 50% by volume, were carried out in a 3” loop, although no acoustic measurements were taken in the 3” loop. Although a correlation between the acoustic and magnetic flow meters were obtained at low to moderate concentration in the 4” loop, as described below, use of this correlation would require unwarranted extrapolation in the 3” loop, where much higher concentrations were tested, and so was not used. . For reasons given below, only qualitative mention of the tests performed in the 3” loop, at the higher concentrations will be given herewith; namely, that at volumetric concentrations in excess of 30% by volume, the slurry behavior changed from equivalent fluid, settling slurry behavior, to non-settling, shear-thinning, with a yield stress, non-Newtonian behavior.

3. SLURRY CHARACTERIZATION

Solids specific gravities were measured using a Nitrogen pycnometer (AccuPyc II 1340 Foam pyc V2.00), and were found to vary from 3.0 to 4.0, with an average of 3.8. The particles were observed to be magnetic, and a spectral analysis by ICP atomic emission techniques was performed in order to determine the makeup of the solids. These analyses indicated that a significant portion of the particles (56% by weight) were composed of magnetite. Horizontal pipe friction measurements were performed on the pure carrier liquid, both before and after the testing, and indicated negligible change in the roughness or pipe diameter during the test program, and a carrier liquid density and viscosity equal to that of water. Slurry pH was measured to be neutral.

The particle size distribution (PSD) was measured using Laser Diffraction Analysis, and the mass median particle diameter (D50) was found to be equal to 30 μm for the virgin solids, and 23 μm for the particles following loop testing, indicating a moderate degree of degradation of the particles during the loop testing. The maximum particle size was found to be approximately 400 μm. Plots of the PSDs of all of the slurries tested can be seen in Figure 2 below.

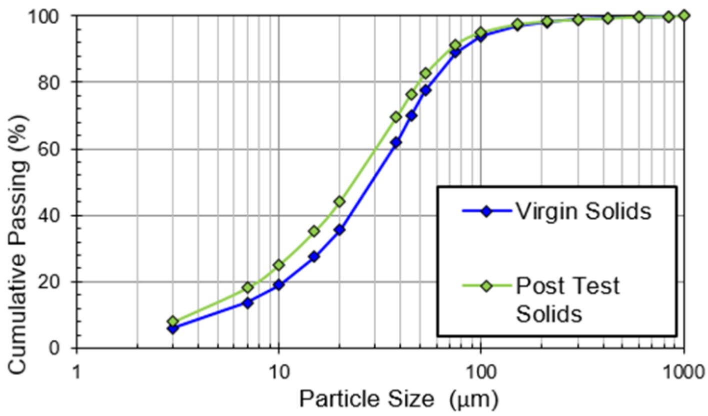

Figure 2. Particle Size Distributions of each of the slurries tested, measured using Laser Diffraction Analysis.

No difference in the particle shape factor was observed in micrograph images taken before and after the testing, which showed the particles to be angular. Loop temperatures were in the range of 30-40 °C during the test program.

The magnetic properties of the solid particles were measured using a vibrating sample magnetometer in order to generate a hysteresis loop. The measurements indicated that the solids contain ferromagnetic material that has been totally demagnetized. The measurements also showed that the material only becomes magnetic at about 2000 oe which is typical of iron-oxides. The magnetometer measurements showed that the material is paramagnetic, meaning it does not retain its magnetism when the magnetizing field is removed (Personal communication, 2019).

4. RESULTS – LOSSES AND DEPOSTION VELOCITY

The carrier density and viscosity were measured and found to be equal to that of water. Stationary deposition velocity was visually observed to occur in the range of 0.68-0.83 m/s in the 100 mm pipe, as can be seen in Table 1. The deposition velocity measurements obtained using the acoustic flow meter should be taken as the most accurate as it is unaffected by the magnetic properties of the particles. The deposition velocity measurements for these fine particles align relatively closely with the maximum deposition velocity (at worst case concentration) prediction of Thomas (1979) for particles of this size in a 100 mm pipe, which is equal to 0.6 m/s.

Table 1

Deposition Velocity, and flow rate ratio between magnetic and acoustic flow meters, for varying solids concentrations in 100 mm pipe.

Specific Gravity (SG_m) (-)	C_v (% v/v)	Dep. Vel magnetic flow meter (m/s)	Dep Vel. Acoustic flow meter (m/s)	Ratio of acoustic to magnetic flow meter values (-)
1.024	0.77	0.7	0.68	0.98
1.069	2.5	0.73	0.7	0.96
1.148	5.4	0.76	0.71	0.931
1.208	7.1	0.91	0.83	0.908
1.389	13.8	0.846	0.77	0.846

As can be seen in Table 1, the ratio of the acoustic flow meter flow rates to the magnetic flow meter flow rates decreases, dependent upon the solids volumetric concentration. The loss curves measured using the magnetic flow meter can be seen in Figure 3. These loss curves matched those of water when expressed in height of water, im (mwater/m), but when expressed in height of slurry, jm (mslurry/m), showed significantly lower losses than the carrier liquid, as can be seen in Figure 3.

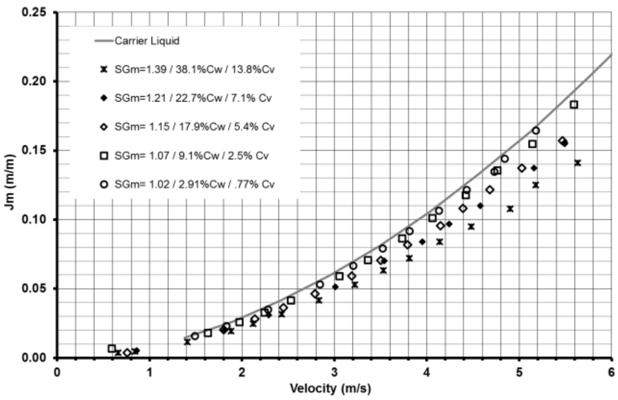

Figure 3. Loss curves (j_m vs. V) measured using *magnetic* flow meter, expressed in height of *slurry* per length of pipe, 100 mm loop.

Friction loss curves measured using the acoustic unit can be seen in Figure 4, along with the corresponding Four Component model (4CM) (Visintainer et al., 2016) predictions. As can be seen in Figure 4, the losses when expressed in height of slurry all collapse onto carrier fluid curve, indicating equivalent fluid behavior (Wilson et al, 2006). It should be noted that for fine particles smaller than 40 μm, the 4CM devolves into an equivalent fluid treatment, which as can be seen in the figure, gives a good match for this slurry at all concentrations shown.

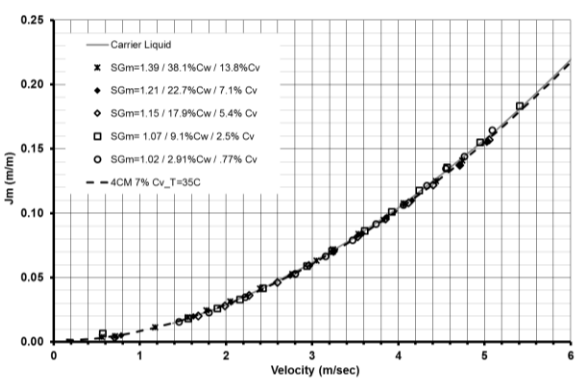

Figure 4. Loss curves (j_m vs. V), expressed in height of *slurry* per length of pipe, measured using the acoustic flow meter, and Four Component model (4CM) predictions at 7% volumetric solids concentration, 35 C, 100 mm loop.

The ratio between the flow rates measured with the acoustic flow meter and the magnetic flow meter, respectively, can be seen in Figure 5, which shows a plot of the ratio vs. volumetric concentration. The multiplier was found to be constant for a given slurry concentration, and did not exhibit any change for changing velocities/flow rates.

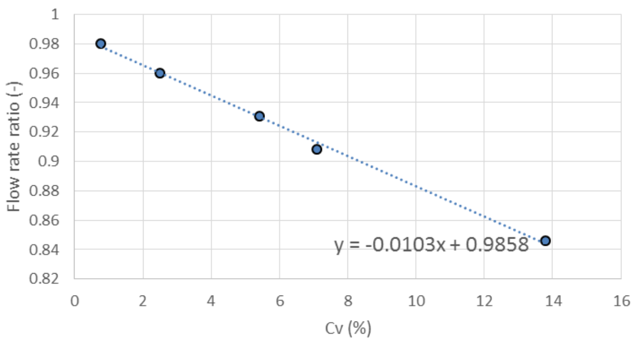

Figure 5. Flow rate ratio (acoustic flow meter values divided by that measured by the magnetic flow meter) vs. solids volumetric concentration, 100 mm loop.

Figure 5 shows that the flow rate correction ratio varies linearly with solids concentration, and one can surmise that the slope of this line would likely be proportional to the % magnetite present within the slurry (i.e. adding more magnetite would presumably increase the slope of the curve, and vice versa). Figure 5 also shows that the magnetic flow meter likely exhibited an error of up to nearly 20% on the highest concentration slurry (14% by volume).

Tests in the 75 mm loop, using only a magnetic flow meter for flow rate measurements, were then performed from 12% to 54% concentration by volume, and the pressure loss vs. velocity curves appeared to be nearly equal to those of water (assuming the same correction factor for flow rate as found in the 4" loop), for concentrations up to approximately 22% by volume. At concentrations between 22% and 40% by volume, the loss curves resembled the shape of equivalent fluid curves, although the pressure losses were higher than those of water, and were increasing with increases in solids concentration. As the solids concentration approached 40-46% by volume, the behavior deviated from the parabolic type of equivalent fluid behavior seen at lower concentrations, with a flatter laminar-like loss curve observed at the lower velocities and a curve resembling turbulent flow at the higher velocities. At the highest tested concentration of 54% by volume, the slurry looked and behaved as a non-settling, non-Newtonian slurry, with a yield stress of 12 Pa.

It is worth noting that application of the interpolated flow rate ratio from the 100 mm diameter loop, to the 12% concentration by volume data from the 75 mm diameter loop, resulted in an equivalent fluid loss curve. This may perhaps indicate that the flow rate correction factor found in the one pipe size is applicable to other pipe sizes. However, this does not necessarily indicate that linear extrapolation of the flow rate correction factor to much higher slurry specific gravities is valid- more testing would be required to confirm this. Consequently, the authors felt that the 3" data, obtained at much higher concentrations and without the use of an acoustic meter, could not be corrected in the same way as the 4" data was corrected, requiring more detailed research.

5. CONCLUSIONS

The primary conclusion drawn here is that caution must be exercised when using any type of device to measure flow rate (or other quantities of interest) during slurry testing. Depending on the type of slurry, and its properties, one device may yield more accurate results than another. The SONARtrac device, while shown to be the better measurement device for this particular slurry, is incapable of measuring flow in laminar flow, for example. Similarly, with a magnetic flow meters, there can be effects of the flow profile on the measurement accuracy, although most studies indicate that the effects are minimal in a well -designed flow meter system (Rosemount, 1995), especially when mounted in vertical lines. For yield stress slurries, the flow profile in laminar flow closely resembles that seen in turbulent flow of Newtonian liquids (Chhabra & Richardson, 2008), a feature exploited when calibrating such devices, presumably further reducing the error in measurements on these types of slurries which are typical in tailings thickener underflows, for example (Heywood & Mehta 1999, Heywood et al 1993)

It is therefore recommended to thoroughly test the chemical composition and magnetic properties of the slurry prior to loop testing, in order to make decisions related to instrumentation selection for loop testing.

The test results for this relatively high solids SG slurry, with a rather complex makeup (in terms of variability in solids SG, and magnetic properties) indicated equivalent fluid behavior often seen for slurries with this type of PSD, for the moderate volumetric concentrations tested (1-14%), and exhibited non-settling, non-Newtonian behavior at the higher concentrations tested (32-54%).

REFERENCES

1. Chhabra, R.P., Richardson, J.F. Non-Newtonian Flow and Applied Rheology, 2nd Ed., 2008, Elsevier Publishing, New York, USA.
2. Felix, J., O'Keefe, C., and Maron, R. Non-intrusive array-based technology and its application to iron ore processing flow measurements. Iron Ore and Manganese Ore Metallurgy Conference, The Southern African Institute of Mining and Metallurgy, 2011.
3. Heywood NI, Mehta KB. 1999. Performance Evaluation of Eight Electromagnetic Flowmeters with Fine Sand Slurries. Presented at 14th International Conference on Hydrotransport of Solids in Pipes: Hydrotransport 12, Maastricht, The Netherlands
4. Heywood NI, Mehta KB, Poplar D. 1993. Evaluation of Seven Commercially Available Electromagnetic Flowmeters in Solid/Liquid Mixtures. Presented at 12th International Conference on Hydrotransport of Solids in Pipes: Hydrotransport 12, Bruges, Belgium.
5. Personal Communication, Ron Weis, ARkival Technology Corp, May, 2019.
6. Rosemount Measurement. Magnetic Flow Meter Fundamentals. TDS 3032A00, September, 1995.
7. Rothman, P. Sonar Flow meter versus Magnetic Flow Meter Application: Large Diameter Hydro cyclone feed in a minerals processing concentrator plant. A cost and performance Comparison when measuring volumetric Flow. Cidra, BI0323 Rev. D.
8. Thomas, A.D., Predicting the deposit velocity for horizontal turbulent pipe flow of slurries. Int. J. Multiphase Flows, 5, 113-129, 1979.
9. Visintainer et al., 2016, Comprehensive Loop testing of a broadly graded (4-Compoent) slurry. Hydrotransport 20, BHR Group, Melbourne Australia, 2016.
10. Wilson, K. C., Addie, G.R., Sellgren, A., Clift, R. Slurry Transport Using Centrifugal Pumps, 3nd Ed., Springer, New York, U.S.A., 2006.