SOLVING SCALE PROBLEM IN PROCESS TANKS WITH SWIRL FLOW AGITATION

By

[1]Bon Nguyen, [1]Lachlan Graham, [1]Michael Hurley, [1]Greg Short, [1] Shen Long, [1]Dean Harris, [1]Yuqing Feng, [1]Jie Wu, [2]Andrew Nash

[1]CSIRO Mineral Resources
Building 121, Bayview Avenue/Research Way, Clayton, Victoria 3168, Australia

[2] Agnico Eagle Australia – Fosterville Mine
McCormicks Rd, Fosterville, VIC, 3557, Australia

Presenter and Corresponding Author

Bon Nguyen
Bon.Nguyen@csiro.au

ABSTRACT

Scale deposition is an on-going problem in many hydrometallurgical processes. Examples include neutralization processes for acidic tailings treatment in the gold, zinc and nickel industries, precipitation in the alumina Bayer process and crystallisation in the lithium carbonate process. Scaling leads to blockages in pipes, in slurry transfer launders and jamming of valves. Scale deposition on flow instruments can also lead to difficulties in monitoring and controlling the plant operation. Scale in tanks and on impellers can lead to loss of effective tank volume, inhibition of heat transfer, and more severely, can lead to tank stoppage due to bogging of the agitator. In some large-scale tanks, scale formation leads to deformation of the tank shells and bending of the agitator blades and shaft. Clean-up of scale lumps is not only time consuming, but it can also pose significant OH&S risk, for example, from the fall of large lumps of scale which can cause human injury and damage to equipment.

To address the challenges caused by the scale problem in the hydrometallurgical process, CSIRO Fluids laboratory has been undertaking research and development since early 2010 to solve this problem via design innovation, in close collaboration with the technical staff at alumina and gold processing plants. This research program has led to the successful application of CSIRO SWIRLFLOW® for solving scale problem in large-scale tanks. In this paper we will present two case studies demonstrating how to reduce the scale problem in the mixing tanks in a gold neutralisation tank and in alumina precipitation tanks. We will also present our latest laboratory scale modelling method involving a Gypsum scale system mimicking scale formation in plant scale tanks.

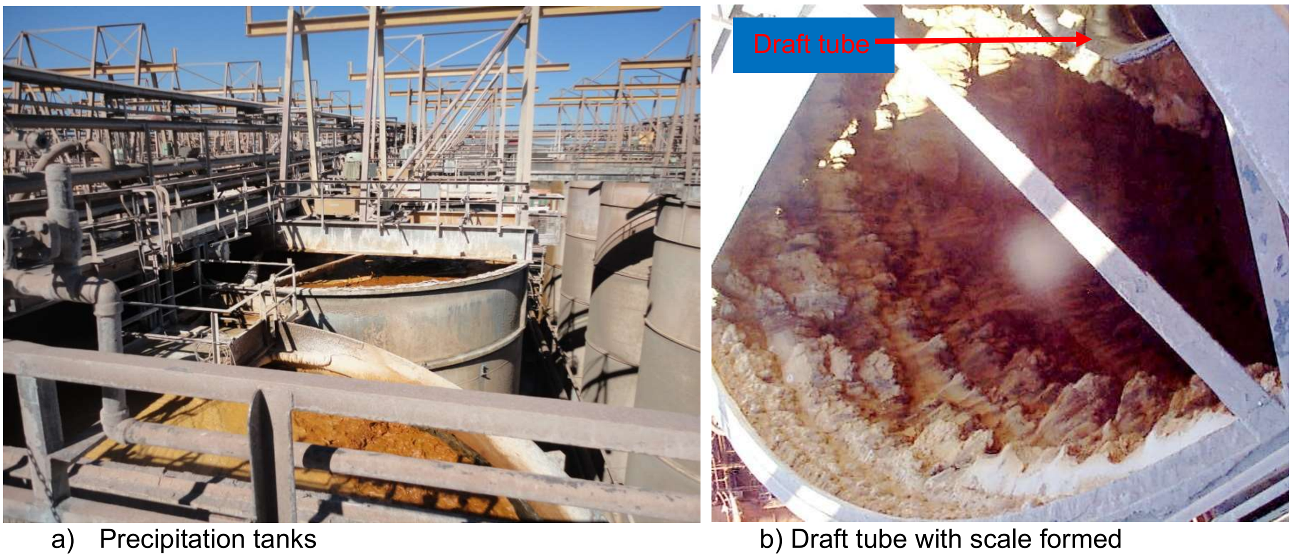
Keywords:
Scale, Tanks, Agitation, Swirl Flow/SWIRLFLOW ®. Crystallisation, Neutralisation.

INTRODUCTION

The unwanted deposition of solids on the tank wall or tank internal structure is normally referred as scale, and is an ongoing issue for hydrometallurgical processes distinct from settling solids. It has been well described by the operators at a number of refinery processes including gold and iron ore refineries that scale formed on their mixing tanks has caused many operational issues. Particularly, scale build-up on the walls of precipitation tanks has been noted to result in problems such as increased power consumption, tank deformation due to the additional weight, and sedimentation reducing the active working volume of the tanks[1]. If a significant amount of the active volume of the tank is occupied by scale, the residence time distribution (RTD) may also be compromised, which can affect the quality of the final product. These issues increase running costs, damage the structural integrity of the tank and often lead to increased down time, as the tanks need to be taken offline regularly for cleaning. Figure 1 shows precipitation tanks fitted with draft tube agitators. The volume of these tanks is typically in the range of 3500 – 5000 m^3.

The focus of this paper is on gaining further understanding of scale formation using physical modelling techniques, as well as exploring alternatives for scale reduction, such as using SWIRLFLOW® technology instead of conventional mixing systems. The hypothesis is that SWIRLFLOW® generates a much higher tangential or 'swirl' velocity component near the wall, which is believed to be one of the key factors in reducing the scale growth. For the SWIRLFLOW® technology to function properly, all existing structure in the conventional mixing tank must be removed. This effectively eliminates all of the potential flow 'dead zone' regions, which have a low velocity, and therefore tend to have increased rates of scale formation. A common example of this low velocity region is behind the baffles in conventional agitated tanks.

Beyond the success in alumina precipitation tanks, SWIRLFLOW® offers a better alternative to the conventional agitator design used in tanks in the neutralisation circuit at the Agnico Eagle Australia, Fosterville Biox gold refinery plant. Fosterville Biox plant is located about 130 km North-Northwest from Melbourne, Australia. A conventional agitator design with an axial flow impeller and baffles was used in the neutralisation tanks at Fosterville. The scale formation in the neutralisation tank occurs when lime is added to adjust the pH to approximately 7, before the waste can be send to tailings storage. The issue with the conventional mixing tank design is that the mixing action in the upper section of the tank is gentle and low velocity. Therefore, when lime was added into the tank, it created a super saturated condition in the upper part of the tank. This caused the neutralisation reaction to take place quickly, which led to scale forming rapidly, creating a fillet in the top section of the tank.
Figure 2 shows an example of this typical scale formation in the upper section of tank, which grew over a period ranging from 6 weeks to 3 months. The scale also grew in other parts of the tank, such as the bottom fillet and behind the baffles, where the velocity is expected to be low, and eventually covered the tank wall. Among many concerns, during cleaning the safety concern is, the scale could fall from the top of the tank which may cause serious injury to the people who work below, e.g. driving the forklift in and out of the tank to remove the scale. Scale formed on the mixing tanks was observed at a number of different refineries however to further understand the scale behaviour and formation, this scale needs to be reproduced in the laboratory as described in the experimental set up.



a) Precipitation tanks

b) Draft tube with scale formed (Before caustic clean)

Figure 1: Precipitation tanks at an alumina refinery

a) Neutralisation tanks b) conventional mixing tank

Figure 2: Conventional mixing tank in the gold refinery neutralisation circuit

EXPERIMENTAL SET UP

CSIRO's approach was that in order to tackle the scale issue, it was essential to firstly understand the scale formation. Therefore, the important first step was to be able to reproduce the scale in the laboratory. A series of geometrically scaled down mixing tanks of 2 L capacity were set up in the CSIRO laboratory to include the draft-tube tank, conventional mixing tank and SWIRLFLOW® tank. Figure 3 (a) shows the modelling tank with a draft tube, which was included as part of the research program since CSIRO has extensive experience and data on the draft tube and the SWIRLFLOW® precipitation tanks from the alumina plant. It was important for the physical modelling to be able to reproduce the scale phenomena that was observed at the refinery.

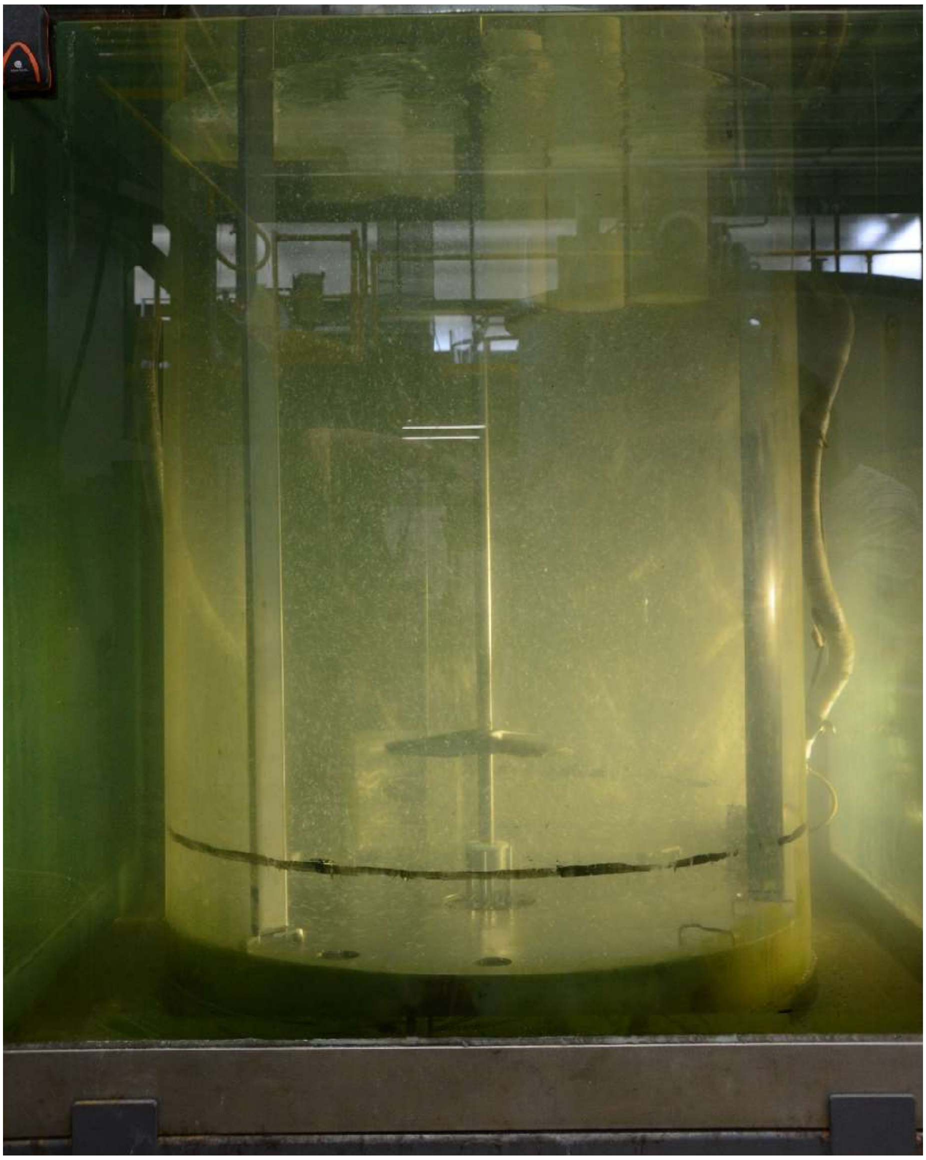
Similarly, a scaled down conventional mixing tank was set up, as shown in Figure 3 (b), to understand, and reproduce, the scale issue in the neutralisation tank at Fosterville gold refinery. A mixing tank was also set up with SWIRLFOW®, as shown in Figure 3 (c), so that the scale formation under different agitation conditions could be determined. All of the agitators were run at nominally the same power, so that a fair comparison could be made between the different designs. At the initial stage of the research, rather than quantifying the scale, the assessment of the scale growth in the laboratory was by visual observation and photos.

a) Draft-tube b) Conventional mixing tank c) SWIRLFLOW ®

Figure 3: Laboratory modelling mixing tanks, 2000 mL; a) draft tube (alumina precipitation), b) Conventional mixing tank (neutralisation at Biox gold refinery) and c) SWIRLFLOW ®

When Fosterville agreed to proceed with the SWIRLFLOW® implementation, the plant trial results of the scale thickness measured from a rod that was deliberately submerged into a fixed location of a mixing tank were also available for comparison. The ultimate objective was to reduce scale in the neutralisation tank; however, it was also important to carry out due diligence to assure that the SWIRLFLOW ® was not compromising the tank's suspension performance. A larger scaled down modelling tank was set up to include a conventional mixing design, which was then replaced by the SWIRLFLOW® configuration, so that their performance could be assessed under the same operating conditions. The modelling mixing tank consists of a 1 m diameter, 1.5 m high transparent acrylic tank installed in an outer square glass tank (for optical correction) as shown in Figure 4. The agitator shaft was equipped with an Ono Sokki SS101 torque transducer and speed detector. The motor was equipped with a Danfoss variable speed drive to allow the agitator speed to be varied.

The slurry used in the suspension tests was made up of water and sand particles of similar particle size distribution (PSD) and solids concentration (~100 g/L) as that used in the Fosterville neutralisation tank. The tests were conducted at ambient conditions. The torque and sedimentation bed height were recorded at a range of fixed speeds during the tests. The test rig, agitator speed and other operating parameters for the conventional mixing tank are detailed in Table 1.



a) Conventional mixing tank.

b) Swirl flow mixing tank.

Figure 4: Mixing tank diameter 1 m; a) convention mixing tank, b) SWIRLFLOW® mixing tank

Table 1: Operating conditions & geometry of scaled down from plant data

Parameter	Full-scale (Conventional)	Full-scale (SWIRLFLOW®)	Laboratory (Conventional)	Laboratory (SWIRLFLOW®)
Tank diameter, T [m]	5.1	5.1	1.00	1.00
Liquid level, H [m]	5.20	5.20	1.00	1.00
Tank volume, Vol [m^3]	106.60	106.60	0.80	0.80
No. of Baffles	4	0	4	0
Impeller diameter, [m]	1.91	1.39	0.38	0.291
Bottom clearance, [m]	1.55	3.18	0.30	0.62
Motor power capacity, [kW]	11.00	11.0	-	-
Speed, N [rpm]	56	56	270	270
Tip velocity, [m/s]	5.59	4.08	5.42	3.85
Solids concentration, [g/L]	106	106	106	106
Liquid density, [kg/m^3]	1000.00	1000.00	1000.00	
Solids density, [kg/m^3]	2400.00	2400.00	2400.00	1000.00
Slurry density, [kg/m^3]	1061.83	1061.83	1061.83	1061.83
Particle maximum size [mm]	0.40	0.40	1.40	1.40

Computational Fluid Dynamics (CFD) was also conducted on the neutralisation tank at full-scale, for both configurations, the conventional and SWIRLFLOW® tanks, to predict the wall velocities, as it is anticipated that a higher wall velocity will lead to lower scale deposition onto the tank wall.

Whilst conducting a trial on the plant, CSIRO also established a scale testing rig to closely monitor and make assessment on the scale formation by comparing the results from laboratory to the plant. Figure 5 shows a test rig consisting of a twin tanks system, which have a volume capacity of 50 L each. They are nominally identical and are configured as a geometrically scaled-down version of the full-scale neutralisation tank. The twin tanks set up allows the test program to better understand the scale behaviour between the test results from the plant trial and laboratory results. One tank was used as a benchmark of the SWIRLFLOW® implementation at Fosterville, whilst the other tank was used to test potential design improvements.

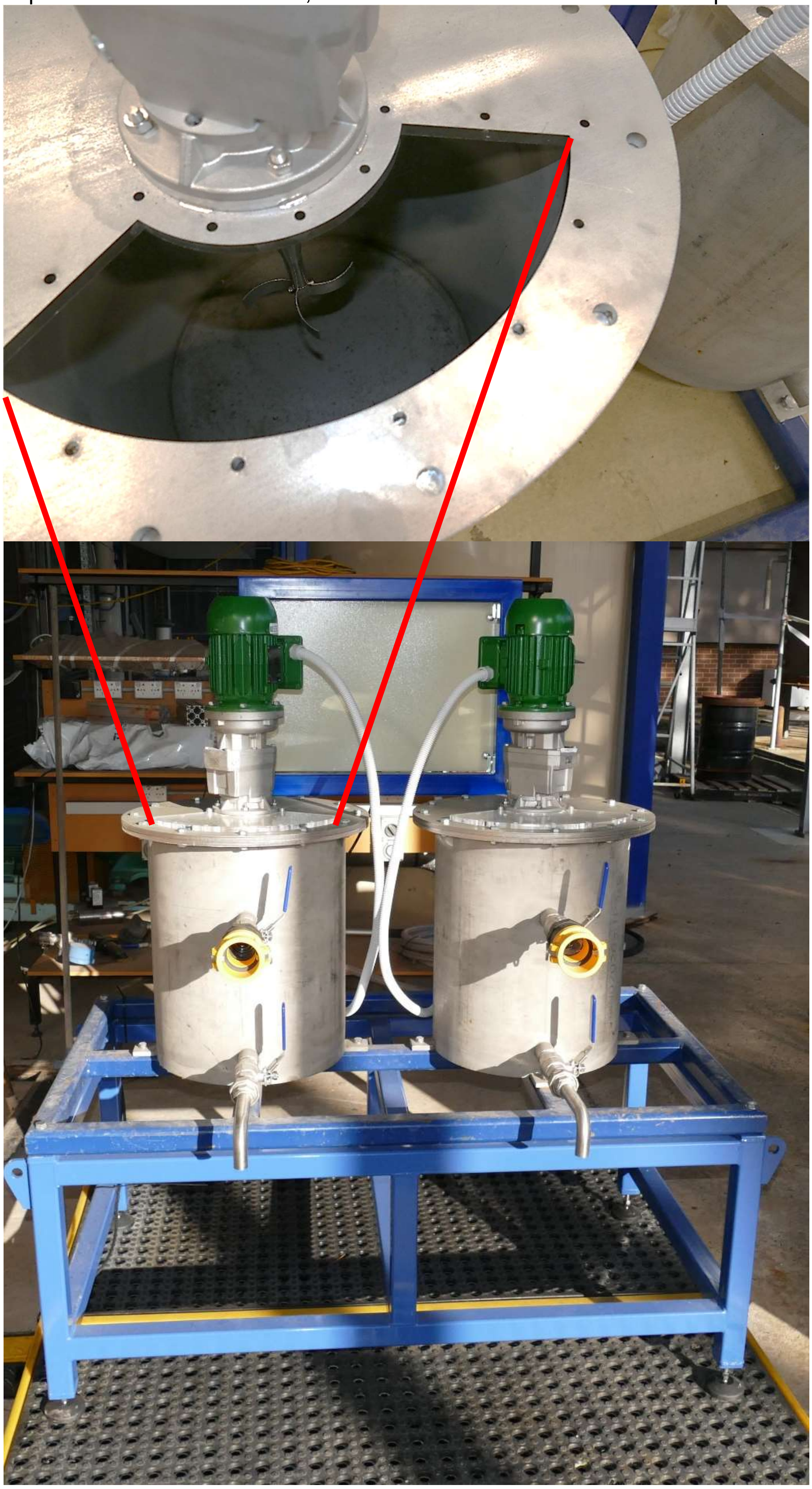


Figure 5: Mixing tank, 50 L, physical modelling to optimise the scale reduction with SWIRLFLOW ®

RESULTS

The scale growth in the lab-scale mixing tank was successfully reproduced in the laboratory to be identical profile as that observed at the plant. Figure 6 shows the results of scale growth in mixing tanks with different agitation configurations; a) conventional mixing tank, b) draft-tube tank and c) SWIRLFLOW® tank. The conditions such as the volume, type of chemical, concentration of chemical and procedures such as when and how the chemical were added to these tanks to grow scale were kept the same. This was carefully controlled to establish the scale growth from the laboratory to be similar to what was observed on the plant. From the scale growth modelling, it was found that the SWIRLFLOW ® tank has a much lower scale growth rate compared to the conventional and the draft tube tanks.

a) Conventional mixing tank

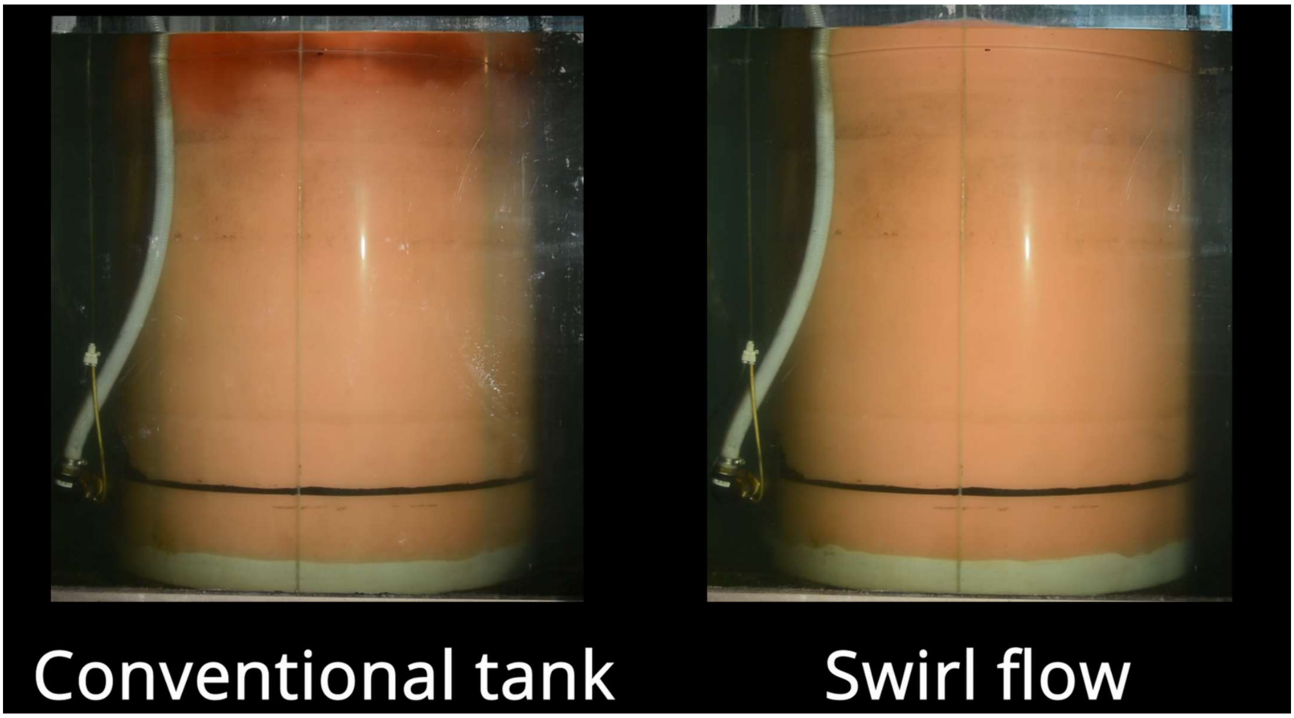
b) Draft tube tank

c) Swirl flow mixing tank

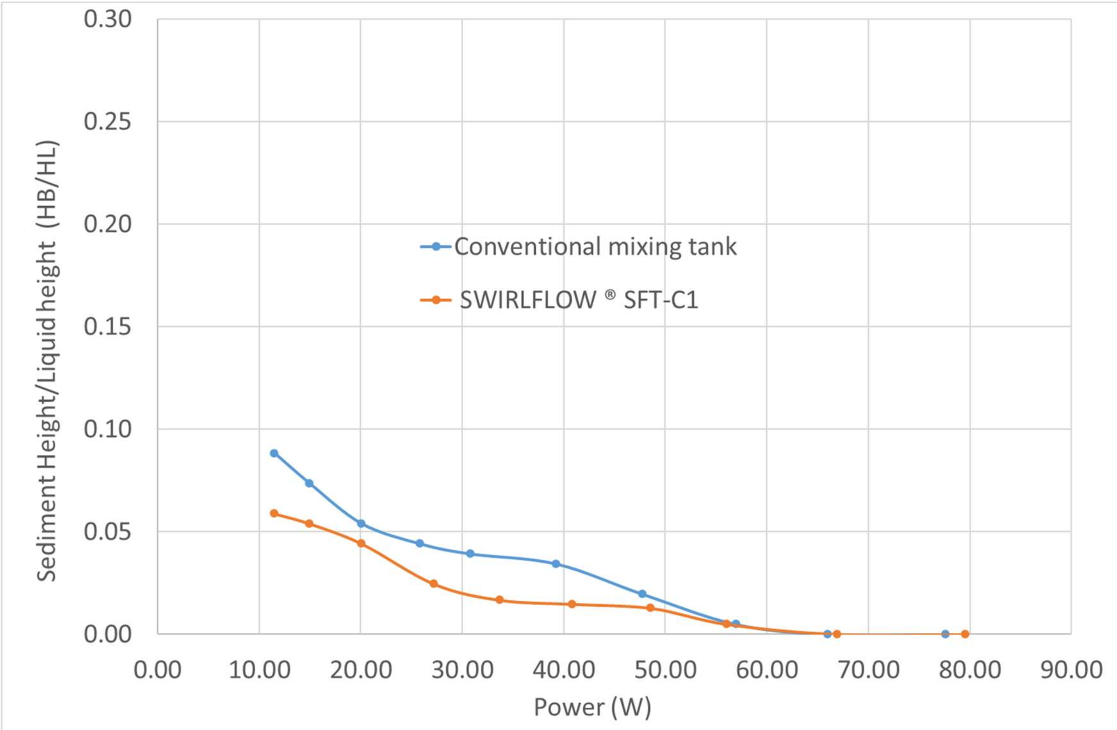
Figure 6: Scale reproduced in the laboratory

While was also found that the SWIRLFLOW® had a lower scale deposition rate compared to the conventional mixing tank, it was also essential to compare the mixing and suspension performance between the two cases to establish if the process performance would be detrimentally affected by the change in agitator design.

Figure 7 (a) shows the contrast of the mixing performance between the two designs. The conventional mixing tank (on LHS) appears to have slightly less homogenous mixture compared to the SWIRLFLOW® mixing tank. This can be seen by the unmixed dye beneath the liquid surface for the conventional design, whereas the SWIRLFLOW® distributes solids all the way up to the liquid surface. Figure 7 (b) shows that the power required by the SWIRLFLOW® to keep the solids in suspension was slightly lower than the conventional mixing tank. The SWIRLFLOW® consumes less power to achieve the same level of solids suspension and mixing, which means that it is more efficient.



a) Mixing performance based on visual observation



b) Suspension performance (sedimentation bed height versus the power consumption)

Figure 7: The mixing and suspension performance between the conventional mixing tank and the SWIRLFLOW ® mixing tank.

The results from laboratory tests all indicated that the SWIRLFLOW® was able to maintain or offer better performance in terms of mixing and suspension, while also significantly reducing the formation of scale. This effectively means the tank can be kept in operation for a much longer period of time before cleaning is required.

CFD simulations were conducted on the full-scale neutralisation tank, on both the conventional and the SWIRLFLOW® mixing configurations. Figure 8 shows a comparison between the velocities of the SWIRLFLOW® and the conventional mixing tank at the same power consumption. As the SWIRLFLOW® has all internal structures removed to eliminate the dead zones, it is unsurprising that CFD demonstrated it to have much higher tangential velocities near the tank wall. This is believed to be a key parameter in reducing the scale growth rate.

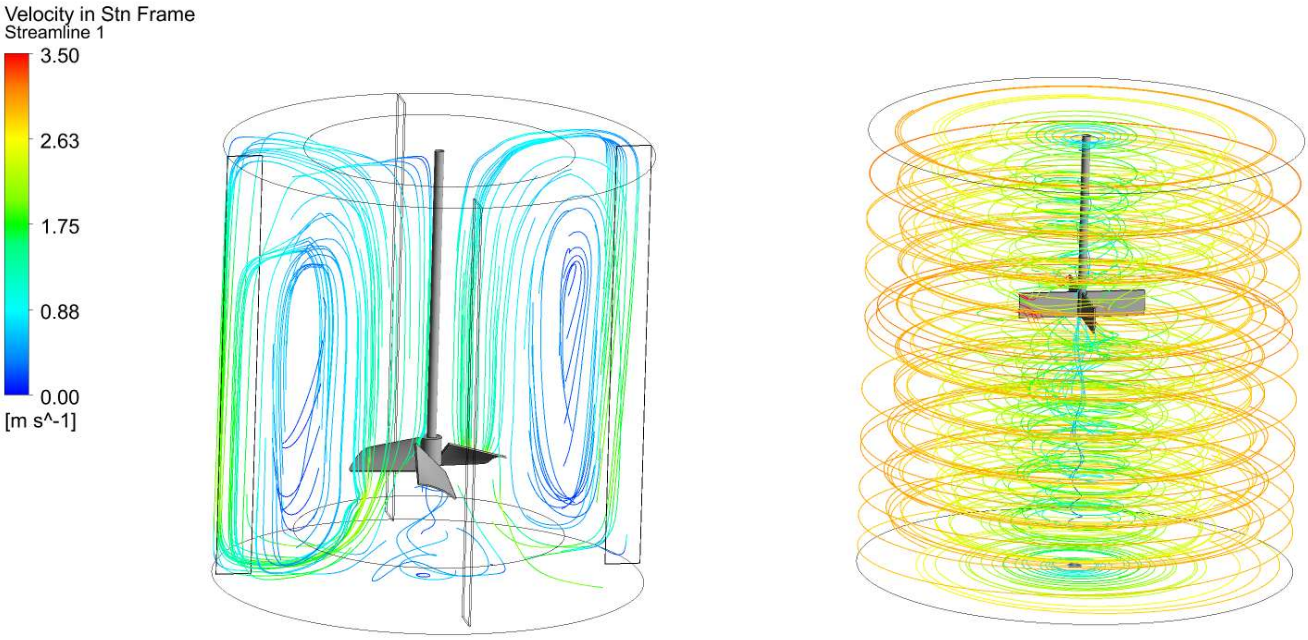


Figure 8: CFD results. Conventional mixing tank (Left) vs SWIRLFLOW® mixing tank (Right)

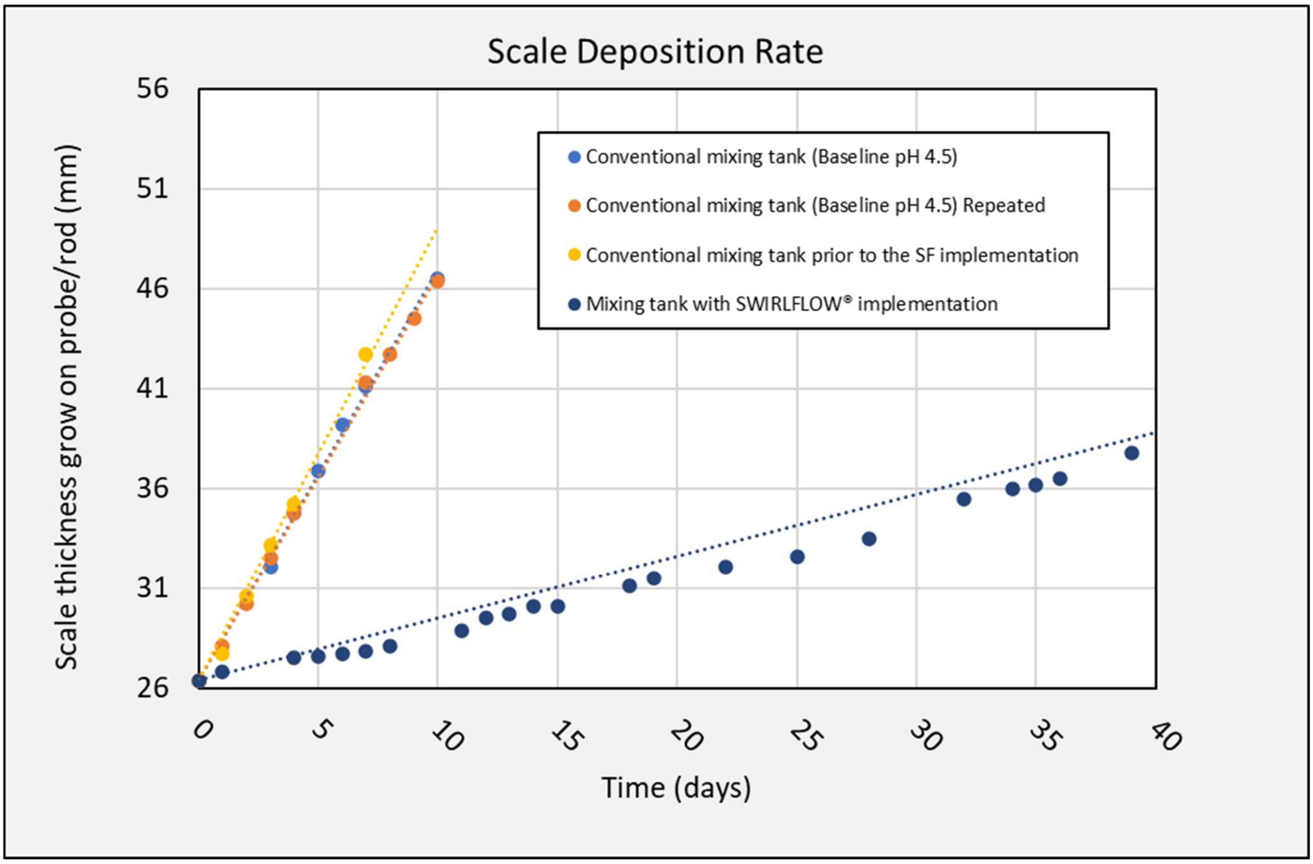
TRIAL RESULTS FROM PLANT

After the retrofitting of the SWIRLFLOW® agitator in the Fosterville Neutralisation tank, measurements of the scale thickness were made. There were compared with similar measurements made with the conventional mixing system in the same tank, prior to the SWIRLFLOW® implementation. Figure 9 shows the scale in conventional neutralisation tank in comparing to SWIRLFLOW® tank with a similar length of online time. For both agitation configurations, a probe/rod as shown in Figure 10 (a) was set up so that it was carefully submerged at the same location and periodically taken out the tank for the scale thickness measurement over time. Figure 10 shows the comparison of scale growth in the neutralisation tank on plant for both the conventional and SWIRLFLOW ® mixing tank. The results show the SWIRLFLOW ® takes approximately ~7-9 times longer than the conventional neutralisation tank to grow to a similar scale thickness compared to the conventional agitator.

a) Typical scale in conventional tank   b) Small scale in SWIRLFLOW® tank

Figure 9 Contrast of the scale in a) convention mixing tank and b) SWIRLFLOW®

a) Probe/rod that scale grows on



b) Scale thickness measured from the probe coupon

Figure 10: Scale thickness comparison between the conventional mixing tank versus SWIRLFLOW®

DISCUSSIONS

Through many years of experience from working with alumina refineries, CSIRO has gained good understanding about the scale deposition in draft-tube precipitation and conventional mixing tanks in the full-scale plant and appreciates that scale is an ongoing issue for the Bayer process. The scale is not just limited to the alumina industry, it's a generic problem across other industries. In seeking further understanding, the CSIRO team decided to grow scale in the lab-scale mixing tank, effectively to reproduce the scale behaviour that is observed in the plant. Obviously, the time taken to grow the scale in the laboratory was on the order of days, which is much shorter than the time in which significant scale growth occurs on the plant, which normally could take weeks, months or even longer. Due to this reason, the scale characteristics from the laboratory may not be the same to those on the plant, however, an important feature of the scale grown in the laboratory was that it was similar in profile to what is observed on plant.

In particular, a visual assessment was made, which concluded that the scale profile in the laboratory was similar to the scale observed in the draft tube tank and the SWIRLFLOW® tank in the precipitation circuit at the alumina refinery. It was also established that the scale growth in the laboratory for both the conventional mixing tank and the tank with the SWIRLFLOW® was similar to what was observed in the neutralisation circuit at the Fosterville gold refinery. The scale growth was successfully reproduced in the laboratory and matched with scale patterns that observed on the plant means the technique, chemicals and procedures used are qualitatively able to reproduce the plant scale behaviour. This technique could therefore potentially be used to model and to solve scale issues in other mixing tanks, regardless of the industry, or application that the mixing tank is being used for.

The scale growth rate in the SWIRLFLOW® was significantly lower than in the conventional mixing tank. The plant trial demonstrated that the scale formed in the SWIRLFLOW® tank over a similar period to the conventional mixing tank was not only much thinner, but it was also more uniform. This reduces lumpy and overhanging scale formations at the top of the tank, which could fall and become a safety hazard during the cleaning progress.

The results from experimental tests, CFD and full-scale trial aligned with each other. This means that the potential of the current CSIRO modelling techniques are not just limited to utilising the SWIRFLOW® as a practical solution to scale issue in mixing tanks, but it also opens a new opportunity for future technology development to solve scale issues in other processes and equipment.

CONCLUSIONS

The SWIRLFLOW® technology developed by CSIRO was proven in both laboratory testing and plant trial results to successfully reduce the scale formation on the tank wall for tanks in the precipitation circuit in an

alumina refinery, as well as in a gold neutralisation tank. This resulted in keeping the tank online for much longer, which helps in reducing maintenance costs.
The laboratory test results, CFD and full-scale trial results support the hypothesis that the removal of baffles and other flow dead zones, along with increased wall velocity led to significant scale reduction.

The scale growth patterns observed on the plant were successfully and accurately reproduced in the CSIRO facility for the draft tube tank, conventional mixing tank and tank with SWIRLFLOW® agitation.
Therefore, regardless of which industry a mixing tank is from, as long as the problem is related to scale formation, the SWIRLFLOW ® technology offers a better alternative to conventional mixing systems.

The plant implementations demonstrated a significant reduction of the scale in the neutralisation tank at Fosterville with SWIRLFLOW®. This means the scale modelling technique described here can be utilised to model the scale growth in the existing mixing tanks however more work is needed to achieve the objective of the scale reduction.

ACKNOWLEDGEMENTS

The authors would like to thank QAL and Agnico Eagle Australia – Fosterville Mine for their ongoing support, sharing trial results and collaborations in help to model and solve this complex issue. We also acknowledge the contribution of CEM for supplying full scale SWIRLFLOW® impellers.

REFERENCES

1. B. Nguyen, S. Mills, A. Nash, M. Davood, D. Harris, K. Mohanarangam, W. Bruckard, L. Graham and J. Wu, Swirl Flow Agitation for a BIOX Neutralization Process, World Gold conference

2. Nyombolo, B M, Neale, J W, and van Staden, P J, 2000. Neutralization of bioleach liquors, *The Journal of The South African Institute of Mining and Metallurgy*, 100(7):403-408.

3. Wu, J, Wang, S, Nguyen, B, Marjavaara, D, Eriksson, O, 2016. Improved Mixing in a Magnetite Iron Ore Tank via Swirl Flow: Lab-Scale and Full-Scale Studies, Chemical Engineering & Technology, 39(3):505-514.

4. Wu, J, Nguyen, B, Graham, L, Connor, T, Marjavaara, D, Eriksson, O, Jia, F, and Coleman, C, 2018. Slurry Tank Swirl Flow Agitation, Alumina 2018, in Proceedings The 11th AQW International Conference, pp175-179 (AQW (Inc.)).

5. Wu, J, Nguyen, B, Graham, L, 2010. Energy Efficient High Solids Loading Agitation for Mineral Industry, Canadian Journal of Chemical Engineering, 88(2):287-294

6. Wu, J, G. Lane, G, Livk, I, Nguyen, B, Graham, L, Stegink, D, Davis, T, 2012. Swirl flow agitation for scale suppression International Journal of Mineral Processing, 112–113 (Special Issue Communition 2009):19–29