

Reflections on 25 years of SWIRLFLOW® Operation at QAL Alumina Refinery

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Abstract

In the early 1990's, QAL started looking for an alternate agitation technology for precipitation tanks that was high efficiency, low cost and scale growth inhibiting, seeking to replace the existing draft tube agitators. A partnership between QAL and CSIRO resulted in the joint development of SWIRLFLOW®, a slurry mixing technology that reduces sedimentation and scale formation in alumina precipitation tanks, thereby improving tank productivity.

QAL plant trials commenced in 1997 and were supported by modelling tasks undertaken by CSIRO. The initial version of SWIRLFLOW® was only suitable for precipitation tanks with conical bottoms. However, ongoing R&D that included numerous plant trials at QAL has established that running a backswept impeller is significantly more efficient than the original design. Furthermore, laboratory and plant trial results showed that a larger impeller-to-tank diameter ratio could reduce power consumption, allowing SWIRLFLOW® to operate in fillet-flat bottom tanks at QAL.

Compared to draft tubes, QAL has found that precipitator tanks utilizing SWIRLFLOW® technology typically have thinner scale deposits on tank walls, achieve increased operating factor, and are much easier to restart. All these factors lead to operational and maintenance cost savings. Based on laboratory studies and other plant implementations, it is possible to further optimize SWIRLFLOW® to consume lower power and to operate with higher solids concentrations than presently achievable.

At the time of writing, SWIRLFLOW® has been retrofitted to 30 of 106 precipitation tanks at the QAL refinery, with more conversions planned.

Keywords: SWIRLFLOW®, Precipitation, Impeller, Draft tube

1. Introduction

With a focus on improving precipitation tank efficiency, QAL initiated a partnership with CSIRO in the early 1990s to develop SWIRLFLOW®, an innovative slurry mixing technology. This paper explores the transformative journey of SWIRLFLOW® over the past 25 years, detailing its evolution, applications, and impact on QAL's alumina refining processes.

The primary aims of the SWIRLFLOW[®] design were to reduce scale growth over the tank wall by the cleansing effect of the swirling motion produced, while also increasing overall reliability by simplifying the mechanical structures in place.

The original SWIRLFLOW[®] was designed specifically for conical bottom tanks. It creates a tornado-like swirling flow pattern as shown Figure 1 (a), resembling that occurring in the natural environment. The flow is generated by an impeller located in the upper part of an unbaffled tank. The SWIRLFLOW[®] generates strong upward velocity in the centre of the tank, which then picks up solids from the bottom of the tank and carries them to the upper regions. Upon impact with the SWIRLFLOW[®] impeller, the slurry is dispersed to the outer region of tank where the solids continue to spiral downward along the tank wall en-route back to the base, to be lifted again. During this process, mixing and dispersion occurs. Figure 1 (b) shows a SWIRLFLOW[®] installation at QAL.

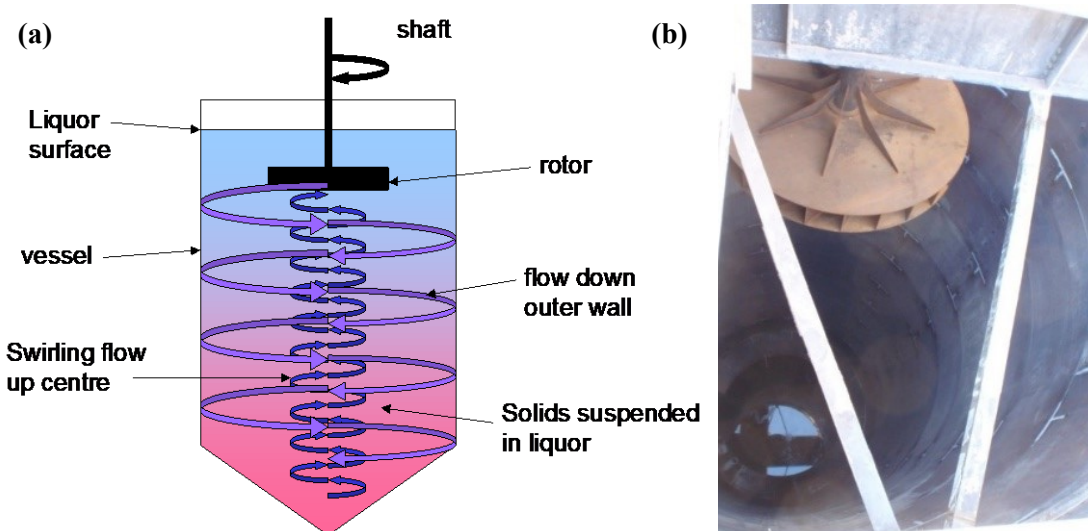


Figure 1. Swirl Flow, (a) concept, (b) in a QAL precipitation tank.

1.1 SWIRLFLOW[®] Development Phase

During the development phase of SWIRLFLOW[®] for QAL's precipitation tanks in 1997, the CSIRO Thermal and Fluid Dynamics team utilised their physical modelling and computational fluid dynamics (CFD) capabilities to gain better understanding of the existing draft tube design for comparison with the SWIRLFLOW[®] option. Modelling accounted for QAL's operating conditions and slurry characteristics at that time. A geometrically scaled-down QAL precipitation test rig for physical modelling was set up in the laboratory in Highett, Melbourne, as shown in Figure 2, with (a) the existing design (draft tube) and (b) SWIRLFLOW[®]. The developed SWIRLFLOW[®] was then benchmarked against the draft tube performance, focusing on the wall velocity and solids suspension, both critical parameters towards minimising scale growth on the tank wall and keeping the tank bottom free from sedimentation. Simultaneously, CFD simulations were conducted using CFX software, as shown in Figure 2 (c).

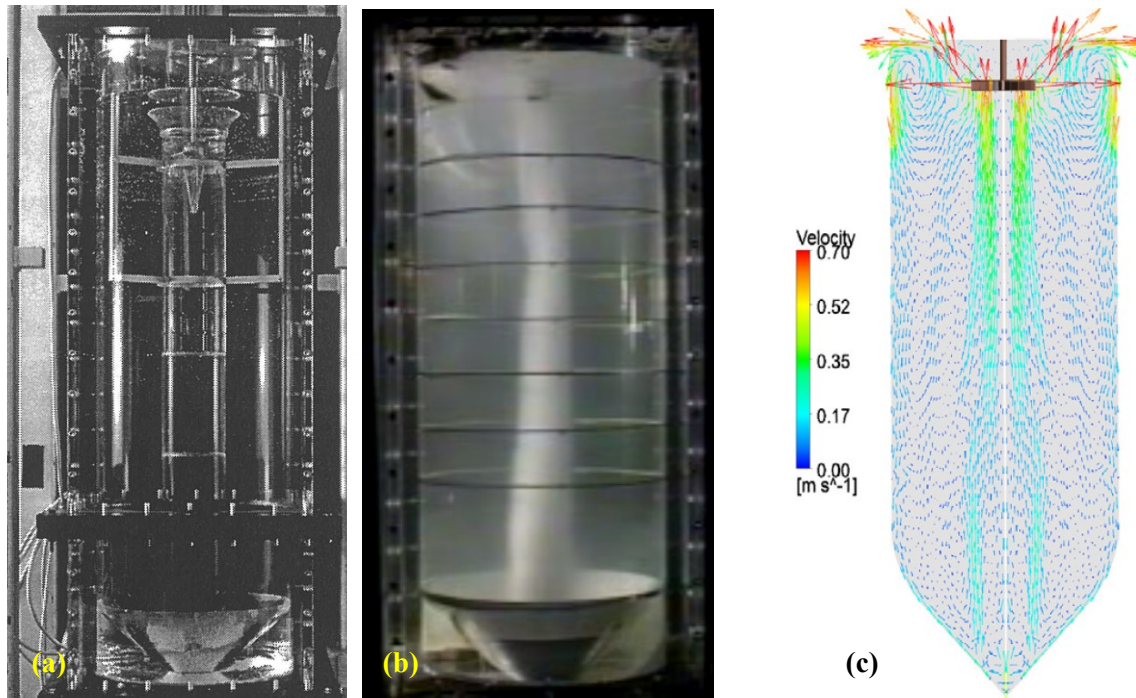


Figure 2. Modelling of QAL's precipitation with physical modelling of; a) draft tube (geometrically scaled down tank), b) SWIRLFLOW® applications; and with c) the CFD modelling. (The photos labelled a & b were taken in the 1990s)

2. Applications of SWIRLFLOW® in QAL's precipitation tanks

2.1 The early years (1990's)

While physical and CFD modelling were major steps in the conceptual development of SWIRLFLOW®, what was more important was the actual full-scale implementation of the technology. The first SWIRLFLOW® installation was in precipitator tank A3 in 1997. As a draft tube tank, it typically had online time of 720 days, indicating minimal issues with sedimentation or scale, making it a logical and low-risk choice to trial a new technology. The trial allowed a fair comparison between draft-tube and SWIRLFLOW® in terms of their ability to keep solids in suspension without being overly affected by other factors such as scaling. The A3 trial confirmed that the A3 tank's online time was extended from 720 to 1080 days with SWIRLFLOW®. Building on successful progress with that trial, SWIRLFLOW® technology was then implemented in tanks A1, A4, H5 and H11 in 1998. QAL has 9 trains of precipitation tanks labelled A to I. Therefore, the numbering system always starts with a letter, followed by a number which indicates the location of the tank within train.

The SWIRLFLOW® installations in 1998 were more strategic trials which can be explained as below:

- Tanks A1 and A4 had similar operating conditions to A3, which was a good demonstration of the repeatability of the SWIRLFLOW performance. However, tank A1 typically experienced slightly higher scale growth, online for 540 days before being taken offline for service.
- Both H5 and H11 were fillet flat bottom tanks (explained in Section 3.1), with H5 experiencing severe scale growth, being located immediately after the interstage cooling. With an online time 180 days, tank H11 had much lower scale formation compared to H5 but much higher than in A1. It was thought that if the H5 and H11 trials were successful, then QAL would have complete confidence in converting draft tubes to SWIRLFLOW® when they reached end-of-life.

2.2 The conversion continues through the millennial years (2000 – 2009)

Expansion continued with challenges and successes for installations that included precipitator tanks C8 (2000) and A4 (2001). As already explained, the A1, A3 and A4 tanks require online times of at least 1.5–2 years before trial results could be fully assessed, hence there were no installations from 1998 to 2000 as the original trials were monitored. Based on the results from A1, A3 and A4, QAL then decided to convert other precipitation tanks to SWIRLFLOW®. However, this decision was only made for tanks with conical bottoms.

Typical images from a draft tube precipitation tank conversion are given in Figure 3, showing (a) the original draft tube tank, (b) draft tube removal and (c) SWIRLFLOW® installation. From 2000 to 2009, a total of 13 SWIRLFLOW® conversions were made to the tanks in multiple rows (A, B and C). This was accelerated by a series of external power outages, where the swirl tanks clearly outperformed the draft tube tanks in rapidly returning to operation. SWIRLFLOW® was by then installed and operating at multiple locations within the circuit, other than immediately after the interstage cooling tank due to severe scale growth conditions. However, H5 and H11 were converted back to draft tube tanks in 2002, which was not surprising, given that QAL considered SWIRLFLOW® technology to still be in its early stages of development and not at that time suitable for fillet-flat bottom tanks.

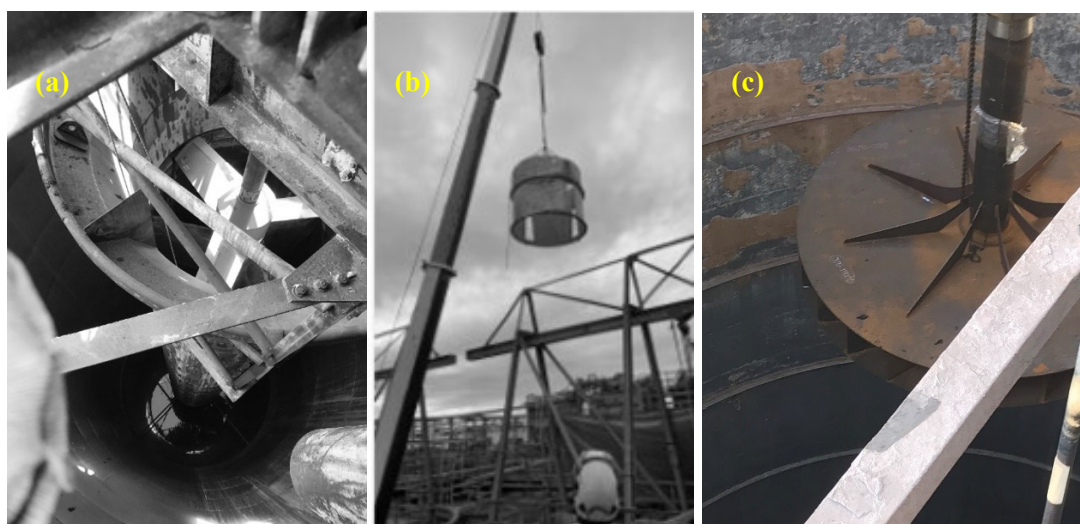


Figure 3. Conversion to SWIRLFLOW®, showing a) draft tube, b) removing draft tube section-by-section and c) SWIRLFLOW® installation completed. (note: to avoid revealing some sensitive information, image color and size have been modified)

2.3 SWIRLFLOW® through its teenage years (2010-2019)

SWIRLFLOW® found its place in tanks such as C1 (2010), D2, D10, E4 (2011) and E3 (2014), with ongoing developments further shaping its effectiveness. Similar to the H5 and H11 tanks previously mentioned, E4 also had a fillet flat bottom. However, in 2011, QAL was willing to trial SWIRLFLOW® in E4, almost 10 years after the inconclusive trials in H5 and H11. This new attempt was largely due to CSIRO in-house research which concluded it was feasible for SWIRLFLOW® to be implemented in a fillet flat bottom tank. A similar tank (E3) was also subsequently converted to SWIRLFLOW®.

In 2013, QAL decided to release the exclusive rights to SWIRLFLOW® to CSIRO, allowing CSIRO to commercialise the technology to other alumina refineries and explore applications in other industries.

In 2014, CSIRO undertook development work on swirl agitators for GHI-row precipitators. GHI tanks are ~3 m taller than the 28.9 m high E tanks, with the same diameter (10.92 m) and bottom fillet dimensions as E-row. Due to the increased height, it was anticipated that larger SWIRLFLOW® impellers with increased agitation power would be required to ensure solids were adequately suspended from the tank bottom. The work found power requirements for GHI tanks could potentially increase by 15 % when compared to E4, due to the taller tank introducing a longer clearance distance between the historical impeller submergence depth of 2 m and the tank bottom.

Increasing the depth of the SWIRLFLOW® submergence would reduce the amount of power required to suspend solids from the bottom. If the shaft was extended by 3 m so the submergence depth increases to 5 m, the required power would then be equal to that of E4 as the distance from SWIRLFLOW® to tank bottom would be the same. However, it was theorised that a clarified layer may form at the top of the tank close to the launders; in this case, the potential benefits or risks were uncertain. A risk assessment suggested higher solids loadings of 600 g/L lower in the tank compared to 400 g/L in the launders may lead to increased sedimentation, however, it may also be a potential yield driver through increased clarification.

The installed motor power capacity for GHI tanks is 55 kW which is an issue for copying the SWIRLFLOW® design from E4 as A-F installed motor power is 90 kW. CSIRO proposed a revised SWIRLFLOW® design for GHI tanks to compensate for the reduced power availability, but it had not yet been tested in the laboratory or plant environment.

In 2019, ‘GHI SWIRLFLOW® Development’ was raised to address the lower power that was available to the GHI tanks and CSIRO modelled three designs - the existing draft tube, and two SWIRLFLOW® agitator designs (SF-B and SF-C). Test work showed both SF-B and SF-C designs were acceptable replacements, with SF-C also showing it could potentially produce stratification in the upper part of the tank, allowing higher solids concentrations approaching 800 g/L within the tank while keeping overflow at the existing solids loading of 300–400 g/L. This could provide a significant yield increase without affecting operation of the classifiers, as the flow entering classification will still have the same solids loading. The advantage comes from increased residence times of the particles within the precipitation tank (theoretically, the particle retention time should double). The findings from the modelling suggest the motor power would increase to 50 kW (80 amp) at 800 g/L which is feasible to apply the SWIRLFLOW® in the GHI tanks however, the plant trial is yet to be conducted.

A key message here is that the transition from laboratory to full plant implementation is crucial to the technology development process. QAL trialed both SF-B and SF-C and found that when the original SF-A (as shown Figure 4 (a)) runs in reverse, it was still better and more efficient than SF-B and SF-C. QAL was pleased to learn that CSIRO then further optimised SF-C (now known as SF-C1) and has successfully implemented it in storage, neutralization and other tanks for various processes, as shown in Figure 4 (b) and (c).



Figure 4. Different SWIRLFLOW[®] types; a) SF-A or mark 3 (similar to SF-B), b) SF-C and (c) SF-C1.

2.4 2020 Onwards

The section explores the most recent applications of SWIRLFLOW[®], providing insights into its adaptability and ongoing refinements.

As previously mentioned, some of the first SWIRLFLOW[®] installations at QAL were in H5 and H11. They used an early design of the SF-A impeller (previously known as mark 3) which had a smaller diameter and high-power requirements. Because of this, the trial found the smaller SF-A was inadequate for fully suspending solids and they were removed in 2002. Later developments concluded that when the SF-A (mark 3) was operated in reverse (backwards swept direction), the power consumption was reduced by 30–40 % while still achieving the same solid suspension performance and maintaining similar scale reduction.

CSIRO has reported that SF-A in a fillet-flat bottom tank has now been successfully implemented and is currently operating at a Hindalco refinery in India¹. The tank volume at Hindalco is ~ 5 000 m³ with a motor operating at 63 kW. In comparison, QAL's tanks are 3 000 m³, so the motor capacity proposed in the methodology should be successful.

While QAL refers to GHI precipitators as flat bottom tanks, their official title is a fillet-flat bottom tank due to the bevelled edge inside the tank bottom (Figure 5). The tanks in other refineries can be true flat bottom tanks, and modelling suggests that the internal bevelled edge/fillet flat bottom will assist with SWIRLFLOW[®] usage, but it is unknown how much in a practical sense.

3. Modelling and Plant Results

3.1 Laboratory modelling results

The physical modelling test rig was carefully scaled down and set up for a thorough investigation. The scaled down tanks were set up in the laboratory are shown in Figure 5, (a) features the conical bottom tanks of 60 and 90° while (b) shows the fillet-flat bottom tanks.

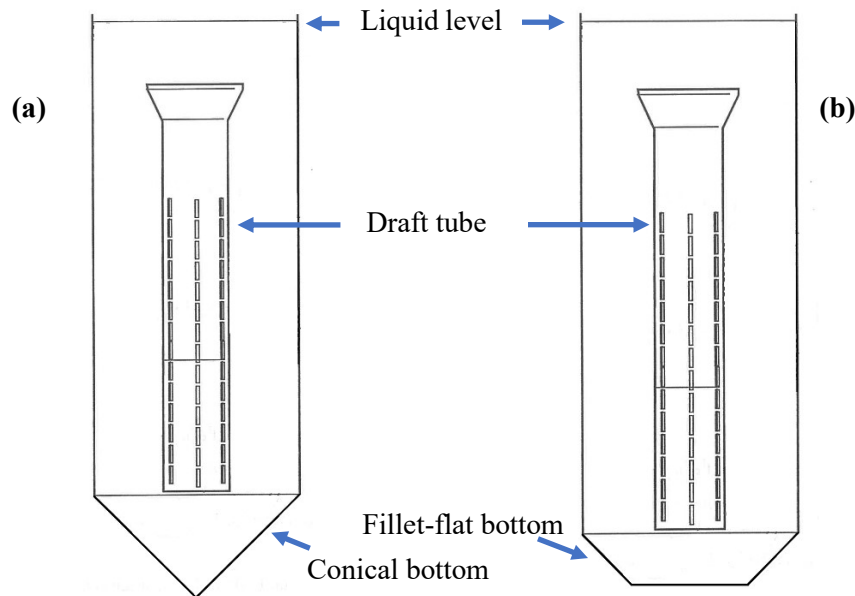


Figure 5. Schematic drawing of the draft tube tank in a) conical bottom tank and b) fillet-flat bottom tank.

The solids suspension tests in both tanks with conical and fillet-flat bottom were conducted in the laboratory with the draft tube and SWIRLFLOW[®] as shown in Figure 6. Due to the successful plant implementation in A1, A3 and A5, subsequent modelling work was typically conducted and benchmarked against the SWIRLFLOW[®] in the A tanks.

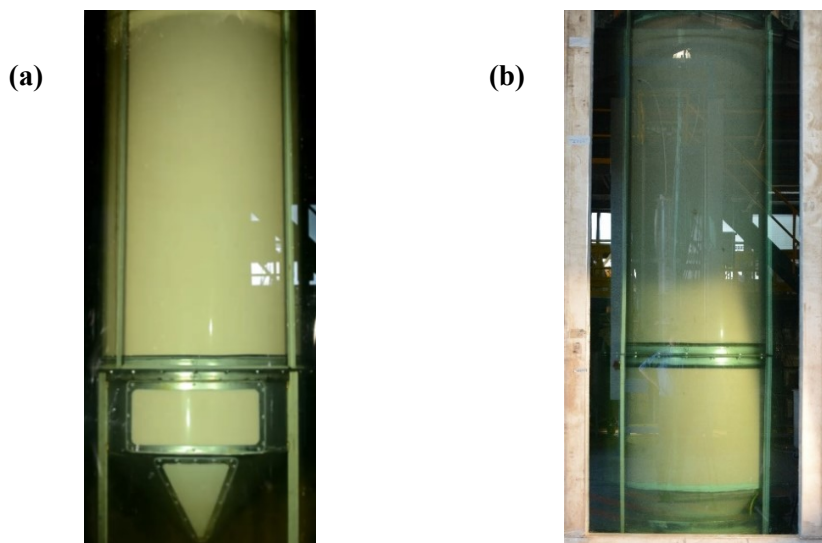


Figure 6. Modelling tank in the laboratory, solids suspension test in: a) 60° conical bottom tank and b) fillet-flat bottom.

Suspension performance tests were conducted by running the impeller at such a speed where all solids were suspended, with the speed then gradually reduced in steps. The torque was recorded and bed height of settled solids measured at the side of the tank at each impeller speed step. The typical solids suspension results shown in Figure 7 (a) conclusively demonstrate that SWIRLFLOW performed much better than the draft tube¹. Figure 7 (b) shows convincing solids suspension performance when SF-A ran in reverse, in terms of the power required for suspension being significantly less for the backswept version.

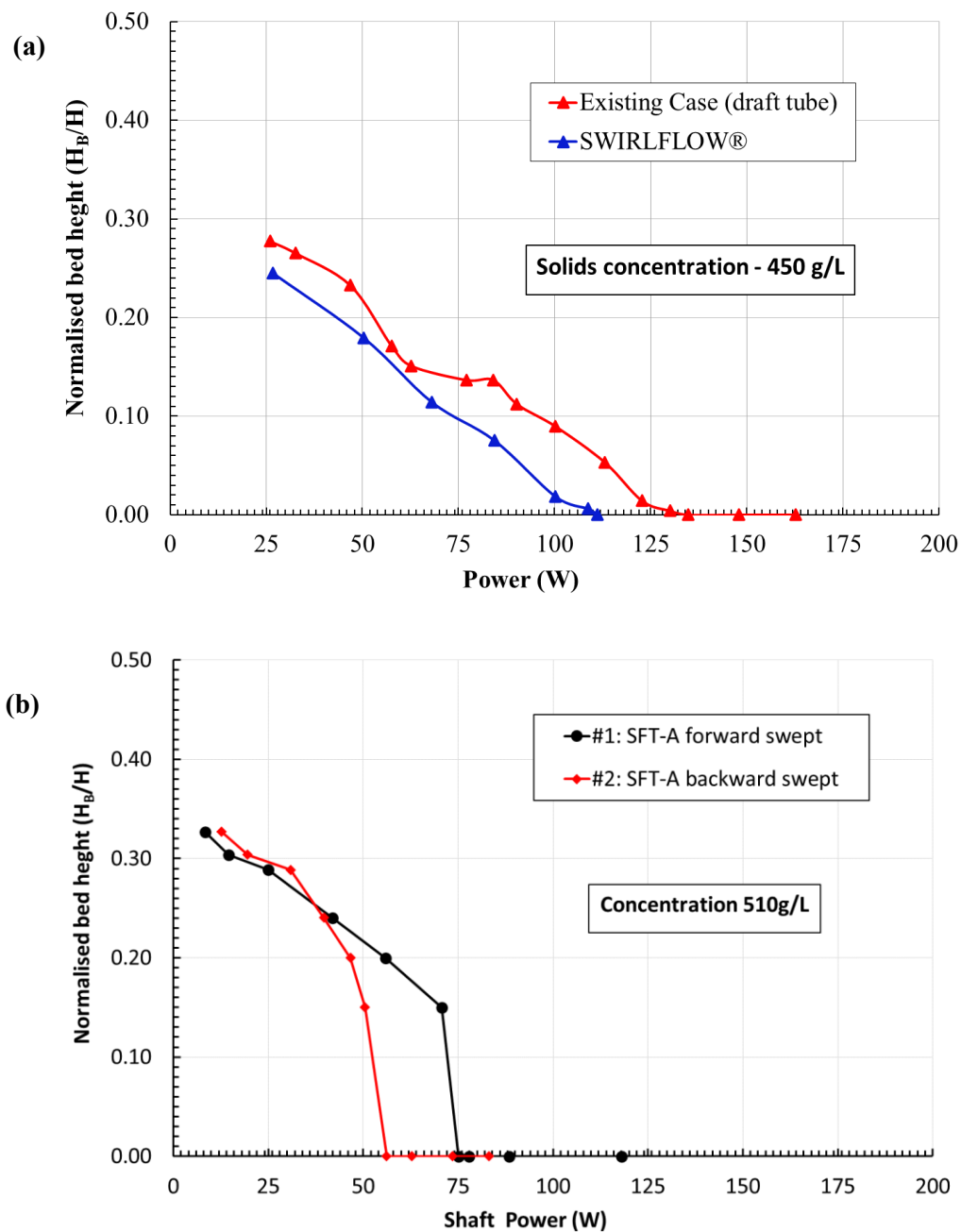


Figure 7. Solids suspension performance: a) draft tube vs SF and b) SF run in reverse vs normal rotational direction.

3.2 Computational Fluid Dynamics (CFD) Results

The CFD modelling results presented in Figure 8 show that SWIRLFLOW® maintains a strong upward velocity, which is necessary for solids suspension. The strong swirl velocity at the tank wall is the key in mitigating scale growth. The draft tube shows strong downward velocity, crucial for keeping the solids in suspension in that type of tank. However, when the flow then impacts on the tank bottom, it turns into an upward velocity that remains strong towards the tank wall in the lower section of the tank, which can result in erosion of the tank wall in the bottom section. Outside of the draft tube in the top section of the tank, very low velocities are predicted. This helps to explain why there was no scale inside the draft tube, while the outside of the draft tube

and tank walls (particularly in the upper region) always experienced severe scale formation. The scale from the tank wall can sometimes exceed 500 mm. The weight of the scale may cause the draft tube to collapse.

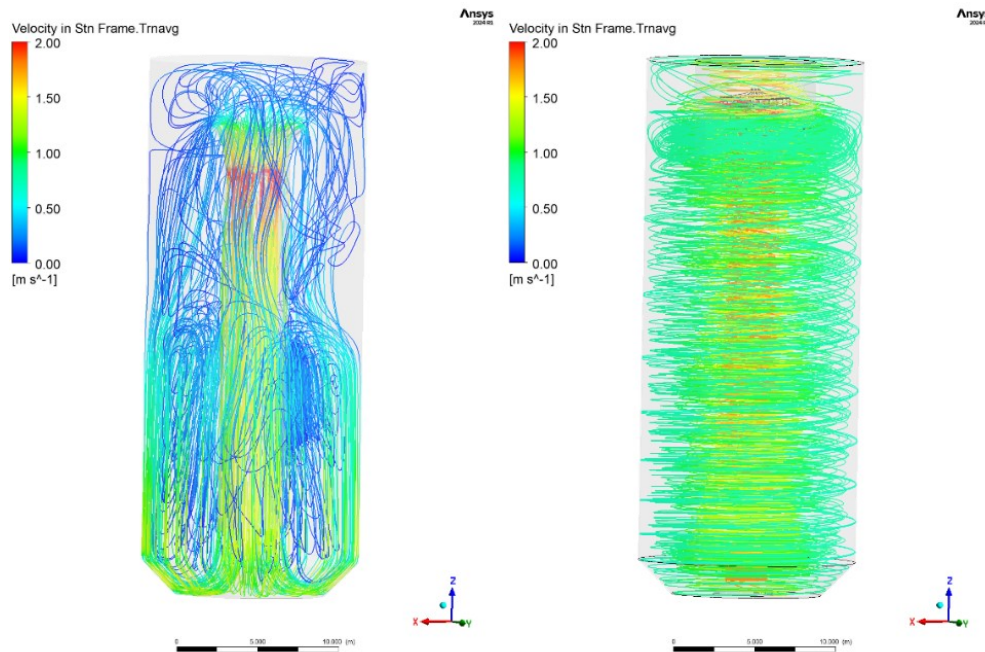


Figure 8. CFD simulations to compare the velocities between the draft tube and SWIRLFLOW®.

3.3 Plant Results

Figure 9 shows that when these tanks were taken offline for caustic cleaning and maintenance, the draft tube tank had heavy scale growth compared to a thin and uniform scale formed in a SWIRLFLOW® case. The draft tube had a much shorter online time.



Figure 9. Photos of scale formed in a) draft tube and b) SWIRLFLOW® after the precipitation tanks taken offline for service.

Table 1 shows a comparison between the online time between draft tube and SWIRLFLOW® for each position in a typical tank row.

Table 1. The online time comparison for draft tube vs SWIRLFLOW®.

Tank	Online time (days)		Number of brews to caustic clean	
	Draft tube	SWIRLFLOW®	Draft tube	SWIRLFLOW®
Tank 1	540	720	1 – 2	1 – 2
Tank 2	720	1080	1 – 2	1 – 2
Tank 3	720	1080	1 – 2	1 – 2
Tank 4	720	1080	1 - 2	1 – 2
<i>interstage cooling</i>				
Tank 5	100	100	2 – 3	1 – 2
Tank 6	100	120	2 - 3	1 – 2
Tank 7	130	150	1 – 3	1 – 2
Tank 8	130	150	1 - 3	1 – 2
Tank 9	180	200	1 – 3	1 – 2
Tank 10	180	200	1 - 3	1 – 2
Tank 11	180	200	1 – 3	1 – 2
Tank 12	180	No tanks converted	1 - 3	N/A

3.4 Extra benefits SWIRLFLOW® provides

QAL identified that having a precipitation tank with SWIRLFLOW® adds significant benefits to the process, such as increased productivity in terms of yield, cost savings in maintenance and reduced safety risks.

It is well established at QAL that increasing the tank online time, delivers an increase in precipitation yield. Tank online cycles have been extended and the offline time for cleaning has been reduced following conversion to SWIRLFLOW® with caustic cleaning completed in fewer brews and the brew length shorter compared to draft tube tanks. Entry into the tank as required for those with draft tubes is no longer needed in the SWIRLFLOW® tanks, which is a significant safety consideration. SWIRLFLOW® conversion is also cheaper and faster compared to the cost of replacing or repairing the draft tube.

It has been found that it is much easier to recover SWIRLFLOW® tanks than draft tube tanks after a loss of agitator due to power failure. Following a shutdown in 2003, works were conducted to compare the recovery performance between the draft tube and SWIRLFLOW® tanks, which concluded it was easier to re-suspend solids in the latter. The SWIRLFLOW® tanks were less likely to fail even when left without agitation for a significant period of time. It was also found that after restarting the agitator, the agitation system was sufficient to fully resuspend the hydrate without further operator intervention.

Natural cooling is increased, as the flow generated by SWIRLFLOW® agitation not only increases wall velocity and keeps the scale low, but also pushes the slurry towards the tank wall where the natural environment can reduce the slurry temperature. The reduction of scale also means the tank is not as insulated by scale as seen in the draft tube tanks.

Additionally, SWIRLFLOW® increases surface movement, eliminating the formation of stagnant zones. SWIRLFLOW® always generates a gentle vortex on the surface of the tank, pulling foams towards the centre and forcing them to coalesce, reducing the foam layer. This results in the liquor

being exposed to the air at a higher turnover rate, assisting evaporation, radiation and convection from the top of the tank.

4. Discussion

Results from physical and CFD modelling show that SWIRLFLOW[®] mixing performance is more efficient compared to the draft tube arrangement. However, power savings have not been a factor in considering the design, as it was always intended to keep the motor used with the existing draft tube. This suggests that there is potential to further optimise power consumption.

While the modelling work was conducted thoroughly, the implementation stage is the most crucial aspect of any technology rollout. There have been instances where the trial results did not align with the modelling results, or where a second trial failed to replicate the results of a first. This discrepancy may have been due to the conditions of the tank that QAL was operating at the time. QAL believes it vital to regularly update and align the modelling team with the plant results. That SWIRLFLOW[®] technology has been successfully implemented in many QAL precipitation tanks was thanks to the hard work and close collaboration between the technical team at the plant and the technical modelling team at CSIRO.

5. Conclusion

In less than three decades, SWIRLFLOW[®] has transformed alumina precipitation tank operation at QAL, reducing maintenance costs, reducing scale deposits, increasing online cycle times, and facilitating easier restarts. Continuous R&D efforts, coupled with plant trials, have led to advances in impeller design and increased efficiency. As of the paper's writing, SWIRLFLOW[®] has been retrofitted to 30 of 106 precipitation tanks at the QAL refinery, with positive results. The technology's impact on productivity, cost savings, and safety underscores its significance in the alumina refining industry.

6. Acknowledgements

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- The CSIRO workshop for making the scaled down test models.
- Dr Yuqing Feng from CSIRO for the CFD results.
- Mr Dean Harris for setting up the physical modelling precipitation tank.

7. References

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