Paste 2024 – AB Fourie & D Reid (eds)
© 2024 Australian Centre for Geomechanics, Perth, ISBN 978-0-6450938-8-9
doi:10.36487/ACG_repo/2455_01

Lifecycle cost comparison: modern solid-bowl centrifuge technology outperforms filtration in tailings dewatering

AP Chinchankar *Alfa Laval, Sweden*

Abstract

Huge improvements have been made in the solid-bowl centrifuge (SBC) technology by Alfa Laval – a Swedish multinational company with global presence and over 60 years of centrifuge design and manufacturing experience. This has resulted in a highly robust centrifuge design with large tailings dewatering capacity that delivers consistent performance with minimal operator intervention.

Over the past 12 years, Alfa Laval's SBCs have been installed for dewatering tailings from a range of mineral processing plants all over the world. Some of the duties include dewatering of tailings from iron ore, borate, oil sands, platinum group metals, gemstones, coal and so on.

The modern SBC technology is deployed to produce dewatered solids suitable for either dry stacking or for co-disposal with coarse rejects. It can also be adapted to produce a thickened pumpable discharge if the mining customer desires, owing to site-specific requirements.

In this paper, we present a detailed lifecycle cost analysis for iron ore tailings dewatering using Alfa Laval's SBC versus filter press technology. Inputs have been collected from one of the SBC installations that has completed more than 20,000 hours of successful operation at an iron ore mine and the details regarding the filter press have been collected from a similar customer site.

This study shows more than 30% savings in capex and up to 21% savings in opex per annum resulting in up to 23% lower lifecycle cost for the modern SBC vis-à-vis the filter press considering a plant operating period of 20 years.

Key factors in favour of the modern SBC technology are lower installation cost, lower maintenance cost, less manpower and less wash water requirements which, together, more than make up for the costs on polymer addition (if needed) and power consumption.

Keywords*: tailings, dewatering, solid-bowl, centrifuge, water recovery*

1 Introduction

Needless to say, tailings dewatering is a challenge that needs to be addressed globally. According to available estimates the total number of active, inactive and closed tailings storage facilities worldwide is 8,500 with 217 km^3 of tailings or 282.5 billion tonnes of tailings stored in them (www.visualcapitalist.com). An estimated 14.4 billion tonnes of additional tailings will require storage per year over the coming five-year period (Global Tailings Review 2020). It is imperative that the tailings are dewatered efficiently to maximise the recovery and recycling of water as well as to facilitate its safe storage. In addition to the circularity benefits that mechanical dewatering of tailings brings, it improves the safety and sustainability of mining operations by enabling dry stacking or co-disposal of tailings as compared to the risk of storing ponded tailings.

The framework for tailings management considers key development pillars which are technological, economic, environmental, policy and social aspects. It incorporates tools for determining trade-offs inherent in different tailings management methods during operation and throughout the life of mine which include lifecycle assessment, net present value (NPV), decision analysis etc.

Today there is an increased awareness around tailings management than ever before. Independent non-profit organisations such as The Responsible Mining Foundation encourages responsible mining by transparently assessing the policies and practices of large mining companies on a range of economic, environmental, social and governance (EESG) issues, with the emphasis on leading practice and learning. The Global Tailings Review convened by the United Nations Environment Programme, the Principles for Responsible Investment and the International Council on Mining and Metals launched the Global Industry Standard on Tailings Management that sets a precedent for the safe management of tailings facilities with zero harm as the goal. The Initiative for Responsible Mining Assurance offers independent assessment of social and environment performance at mine sites globally and has released the draft standard for Responsible Mining and Mineral Processing V2.0 (Initiative for Responsible Mining Assurance 2023).

Within the financial and regulatory context, it would be interesting for stakeholders in the mining industry to find cost-effective ways to mechanically dewater mine tailings. This aspect is all the more critical for small- and medium-scale mining companies to adopt sustainable tailings dewatering practices owing to the limited resources at their disposal. While there is no single dewatering solution that can be applied universally on account of the technical and commercial factors that influence the selection of dewatering technology, significant advancements in the solid-bowl centrifuge (SBC) technology have contributed to make it reliable enough for meeting challenges associated with tailings dewatering applications. This paper goes on to explore the modern SBC design developed by Alfa Laval over the past several years and the benefits of this technology while presenting a detailed lifecycle cost comparison with chamber filter press installed in a similar tailings dewatering duty.

2 Lifecycle cost evaluation of filtered versus centrifuged tailings

2.1 Solid-bowl centrifuge technology

SBCs have for many years been known for their separation efficiency based on the enhancement of sedimentation in a high centrifugal field of 1,000–3,000 times the Earth's gravity. Sedimentation velocities of particles in the suspension will increase with the same factor and area needed for a given sedimentation duty is greatly reduced. Dewatering of tailings using SBCs will, in most mining applications, involve both sedimentation and dewatering. In recent years, we have seen an increased focus on water recovery and a push for dry stacking/co-disposal instead of tailings disposed as slurry. This has increased the demand for highly dewatered solids, while maintaining high capacity and clean liquid. The SBCs used in the mining industry during the 1970s and 1980s relied on drainage of liquid from the solid particles to generate a high concentration of the discharged solids. Screen bowl centrifuges, where the solids are conveyed across a section with a perforated outer rotor wall were also introduced to improve the drainage capacity to reach a high solids concentration without any liquid runoff in dry stacking. Drainage is a relatively slow process when the solid fraction contains significant amounts of fine particles below about 50 microns. In many of these applications, other technologies including filter presses have been the preferred solution for a number of years presumably due to the low volumetric dewatering capacity of the drainage process in the earlier SBCs. In recent years, a new design of the SBC coupled with a change of operating mode, where solids are compacted by an overburden of solids in a thick layer while still located below the liquid surface in the centrifuge, have shown an impressive increase in solids handling capacity to the extent that SBCs are once again becoming an attractive alternative to other dewatering solutions (Madsen 2017). A schematic view of the SBC is shown in Figure 1.

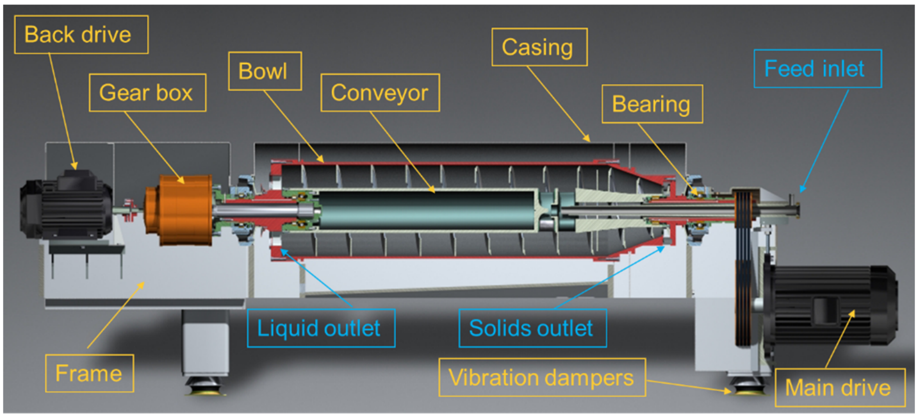


Figure 1 Schematic view of a solid-bowl centrifuge

The horizontal centrifuge rotor (bowl) with red cross-section is driven from the main motor on the right side to provide fast rotation where the feed suspension is accelerated to form a liquid ring inside the rotor after being pumped into the centrifuge through the stationary feed tube. The particles in the suspension will settle to the inside of the rotor while the liquid flows through the centrifuge and leaves by overflowing weir plates at end wall to the left. The SBC has an internal conveyor (inner rotor with a helical flight) which is connected to the outer rotor through a high torque gear box (shown in orange). The central shaft of the gearbox is connected to the motor to the left, where it is possible to establish and control a differential speed between the conveyor and the rotor. The differential speed of the conveyor will transport the separated solids towards the conical end, where it leaves the centrifuge at a radial position unreachable for the liquid (Madsen 2017).

2.2 Solids consolidation/dewatering

In the original configuration of SBCs, the solids were dewatered when the conveyor transported the solids out of the liquid pond on its way along the conical section towards the solids discharge openings and liquid could drain off and return to the pond. This situation is shown in the upper half of Figure 2 where the pond depth was very small (shallow pond) allowing for a long drain zone. For large particles with high permeability, the drainage is efficient but capacity will be reduced if we have fine particles in the cake.

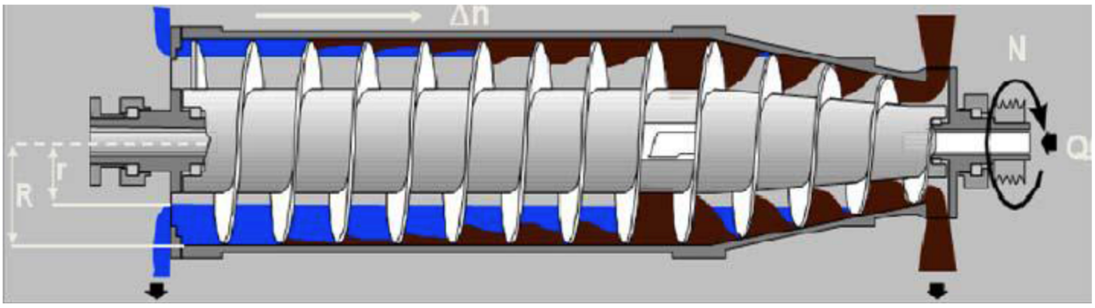


Figure 2 Upper half shows shallow pond and lower half shows a deep pond

For suspensions with a content of fine particles, it is better to operate with a deeper pond as shown in the lower half of Figure 2. With a deeper pond, the load from the overburden of solids can be used to compact or consolidate the solids before it is conveyed into the conical section and we no longer need the drainage to achieve the high solids concentration.

A further development of the deep pond operation is shown in Figure 3, where a baffle disc has been added to be able to operate with a liquid surface level radially inside of the solids discharge radius. In this way, we can stack the solids in an even thicker layer for more radial compaction and in addition we get a hydraulic pressure supporting the mechanical conveying of the solids towards the solids discharge. This solution is particularly useful for cakes with a low permeability and this is also the reason the liquid cannot pass through the cake and escape through the solids discharge openings.

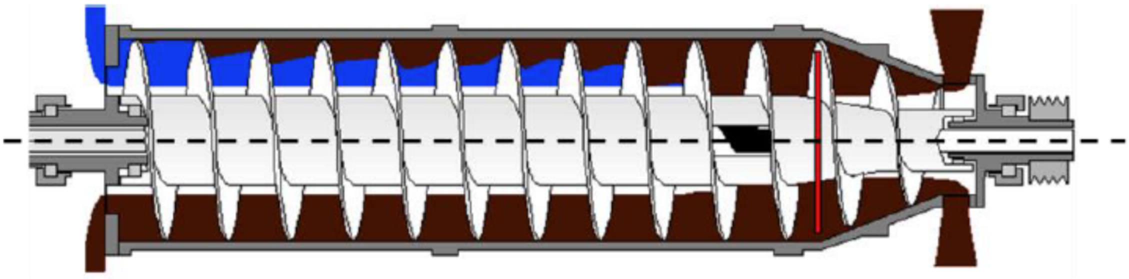


Figure 3 A baffle disc (shown in red) allows operation with very deep pond

2.3 Reliability and uptime of a solid-bowl centrifuge installation

Lynx Endurance is a modern design of SBCs that incorporates the deep pond technology and is built using highly wear-resistant materials. One such machine has been installed in slimes dewatering duty on an elevated structure. After undergoing separation in the centrifuge, the solids are dropped in the form of a cake into a screw conveyor located below the centrifuge. The conveyor pushes out the solids cake to form a stockpile which is then removed and transported to a nearby tailings disposal area by using earth moving equipment and dumper trucks. The SBC facilitates continuous dewatering and removal of slimes and the centrate is recycled back to the upstream thickener for recovery of water.

The installed centrifuge has completed more than 20,000 hours of operation without needing any major repair thereby contributing to the mine's lower opex. It is now perceived to be a robust and reliable technology in terms of equipment availability and plant uptime.

The robust design of the Lynx Endurance SBC is explained in Section 2.5.

2.4 Inspection of the rotating assembly

After about 8,000 hours of operation, the centrifuge was disassembled and its rotating assembly – which consists of the solid-bowl, scroll conveyor located inside it and the gearbox – was sent to Alfa Laval's workshop for inspection and servicing. Minimal wear was observed in the wetted parts that are exposed to the abrasive slurry and the rotating assembly looked almost new after cleaning. There were only 30 tungsten carbide tiles (out of 720) on the scroll conveyor that were found in chipped or cracked condition that needed to be replaced. Pictures of the rotating assembly and the scroll conveyor are shown in Figures 4a and 4b.

The bearings at both ends of the bowl, as well as the gearbox, were found to be in good mechanical condition. However, in line with Alfa Laval's policy for major service of the centrifuge, the bearings were replaced as those had completed 8,000 hours of operation.

(a) (b)

Figure 4 (a) Rotating assembly; (b) Scroll conveyor

2.5 Robust mechanical design of the Lynx Endurance

Mining slurries contain erosive solids and the centrifuge needs to operate reliably via suitable erosion protection. Although most SBCs incorporate a degree of erosion protection, Alfa Laval has taken this to the next level with customised features to meet the durability and reliability requirements in the mining industry as explained with the help of Figure 5.

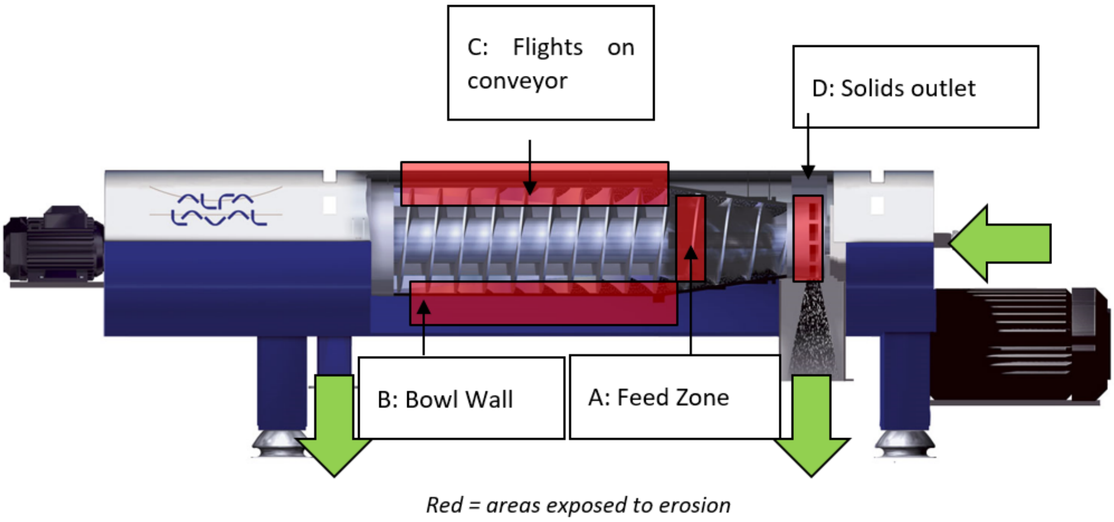


Figure 5 Schematic view showing wear-prone areas inside a solid-bowl centrifuge

2.5.1 Feed zone advanced wear protection

Feed slurry accelerates inside the feed zone of the centrifuge owing to high bowl speed. Therefore, it is important that the entire feed zone area is covered with erosion resistant material especially when erosive solids are present in the feed slurry.

Alfa Laval's Lynx Endurance range of SBCs include a fully covered tungsten carbide feed zone. The Esbjerg inlet system consists of yin-yang shaped profiles as shown in Figure 6. Feed is accelerated over the surface of the profiles and ejected through the inlet gap into the bowl. This gives an effective acceleration of the feed, but is still gentle enough to minimise shear forces that could potentially break agglomerated particles/flocs (which would lead to a poorer separation in the centrifuge).

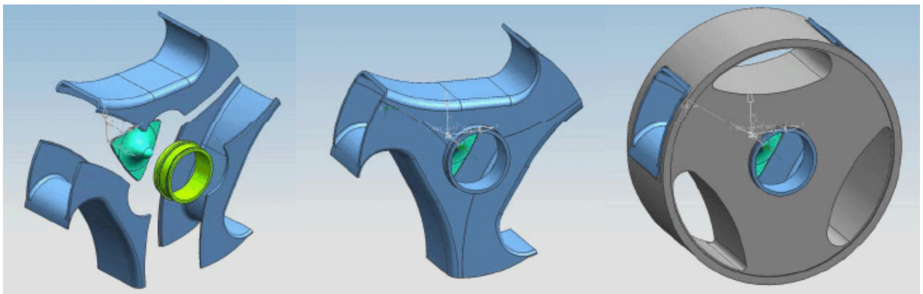


Figure 6 Fully covered tungsten carbide feed zone (patented by Alfa Laval)

2.5.2 Bowl wall wear protection

Stellite and/or tungsten carbide strips on the bowl wall as shown in Figure 7 protect the bowl wall from erosion. These strips also assist with efficient conveying of solids. In the Lynx Endurance SBC, 50% additional strips are added compared to conventional SBCs made by Alfa Laval. In addition, the conical area towards solids discharge has a unique combination of angles designed especially for mining slurries to optimise capacity.

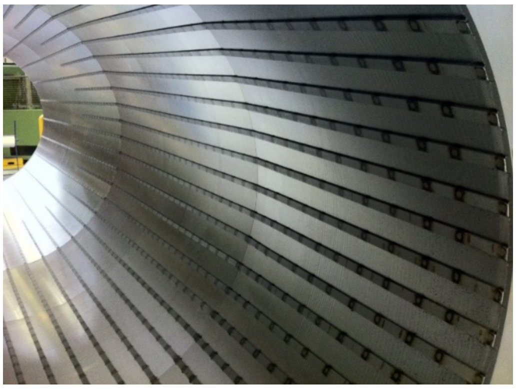


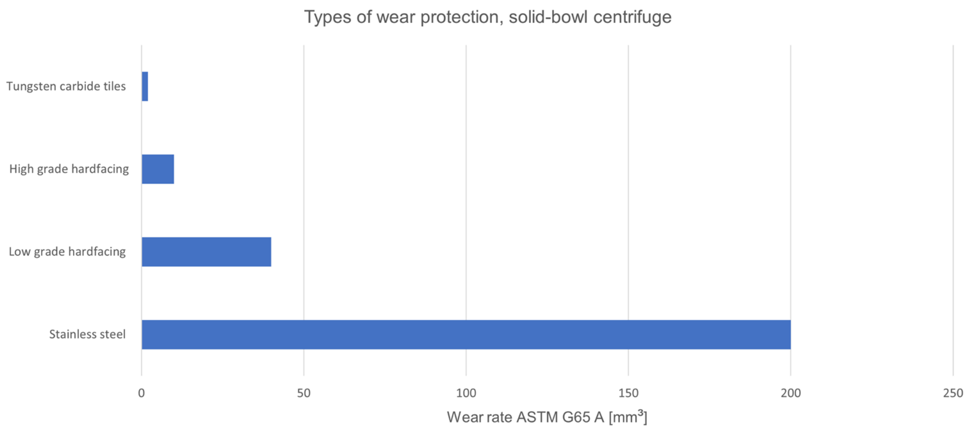
Figure 7 Bowl wall protection via stellite/tungsten carbide strips

2.5.3 Conveyor flight wear protection

Many different levels of conveyor flight protection are used in various SBC designs. These range from bare metal to flame sprayed tungsten carbide, up to the high wear protection of tungsten carbide tiles. Each is suitable in different applications, depending on the erosion potential.

The scroll conveyor in a Lynx Endurance SBC includes sintered tungsten carbide tiles as shown in Figure 8a. The conveyor is tiled the entire length of the flights to provide the high level of protection necessary in mining slurry dewatering applications. Fully tiled conveyors have been proven to have more than five-times higher resistance to erosion compared to flame sprayed hard facing erosion protection. Wear rates of different types of wear protection is shown in Figure 8b.

(a)



(b)

Figure 8 (a) Lynx Endurance conveyor flights protected with tungsten carbide tiles; (b) Tungsten carbide tiled conveyor has much higher erosion resistance

2.5.4 360° solids discharge

The Lynx Endurance design incorporates 360° solids discharge where a number of spokes protrude from the small end hub. The spokes are protected against wear by use of 'saddles' made in tungsten carbide. The edge of the bowl is protected by use of a wear liner which also comprises the overflow rim (solids discharge radius) in the entire tangential direction.

With the 360° discharge there are no restrictions on scrolling the cake out of the bowl once it has been conveyed to the outlet. This is essential due to the desirable high density, firm cake produced during mining slurry dewatering that otherwise might block if the solids discharge is not maximised.

2.6 Background information

Through interactions with the mining industry stakeholders, the author realised that there is little literature available on lifecycle cost comparisons between various technologies applicable to tailings dewatering duty. This paper is an attempt to fulfill this gap and for the purpose of this paper inputs have been collected from one of the SBC installations that has completed more than 20,000 hours of successful operation in slimes dewatering and the details regarding the chamber filter press have been collected from an installation on the same application.

In order to arrive at a meaningful comparison, we have assumed the same tailings production rate of 300 dry tonnes per hour for each of the two types of dewatering technologies referred to above. On an annual basis, the tailings production rate works out to 1.6 million tonnes based on 80% plant utilisation. In each case, the plant life is considered to be 20 years which would result in disposal of 32 million tonnes of dry tailings solids over the period.

Based on the existing SBC installation with a bowl diameter of 1,000 mm, our sizing calculation shows that six units of the same type (Lynx 100 Endurance) will be required for dewatering tailings throughput of 300 dry tonnes per hour. For the same duty, four units of overhead filter presses are considered with each unit consisting of 2 × 2 m, 200 chambers. Upstream thickener consistency is considered to be 35 wt% in both cases. While the filters produce a dryer cake consisting of 81 to 85 wt% dry solids, the cake from the centrifuges has dryness in the range of 78 to 82 wt%.

Footprint requirement for the six centrifuges referred to above is approx. 400 sqm whereas for the four filter presses it is approx. 750 sqm. While the centrifuges are designed to give up to 96% utilisation, for the purpose of this paper 80% utilisation is considered for both cases.

2.6.1 Tailings characteristics

The tailings are a mix of 80% slimes and 20% coarse tails. Mineralogy showed the presence of approximately 57–59% Fe as hematite with small quantities of silica, alumina, kaolinite and other minerals. Particle size distribution analysis showed an average d50 of 5 micron, d10 of 2 micron and d90 of about 20 micron. Particle size distribution curves for both feed streams are shown in Figure 9.

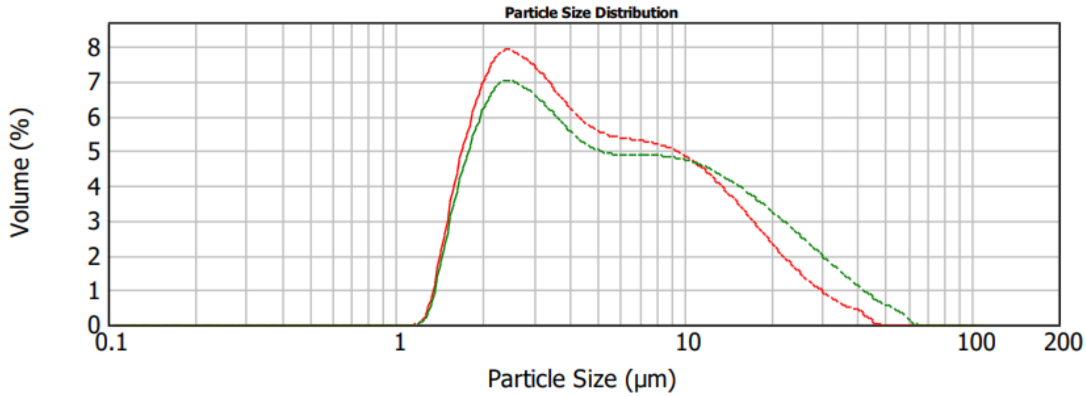


Figure 9 Particle size distribution curves for solid-bowl centrifuge feed (green) and filter press feed (red)

In order to assess the abrasive characteristics of the tailings, a hybrid Miller test developed by Alfa Laval was carried out which yielded an average Miller number of 450 indicating that the tailings were abrasive. From previous experience, Miller number below 20 is regarded as non-abrasive and a number exceeding 40 units is regarded as being abrasive. Miller number between 20 and 40 indicates slightly abrasive tailings.

2.6.2 Mass balance calculations for solid-bowl centrifuge

The 'Lynx 100 Endurance' SBC has a design capacity of up to 250 m^3/h tailings slurry containing up to 70–72 dry tonnes of solids. The capacity varies depending upon the tailings characteristics in terms of slurry density, viscosity, density difference, particle size distribution, mineralogy etc. For this particular duty, the feed flow rate to each centrifuge is considered to be 105 m^3/h with the addition of a suitable anionic flocculant at a dosing rate of 70 g/tonne of dry solids resulting in an average cake dryness of 80 wt% with less than 0.3 wt% solids in the centrate (separated liquid). A typical mass balance for slimes dewatering is shown in Figure 10. Note that flocculant consumption and cake dryness can vary depending on the feed slurry characteristics. A stackable solids cake as shown in Figure 11 can be produced using the SBC.

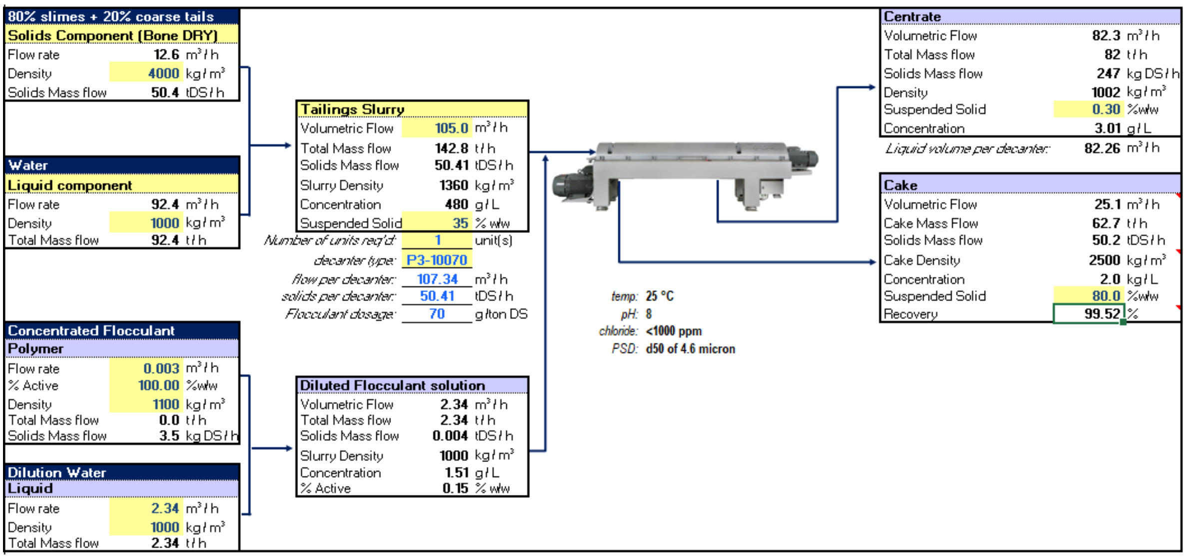


Figure 10 Expected mass balance in slimes dewatering duty

Figure 11 Stackable solids cake discharged from the solid-bowl centrifuge

2.6.3 Operating philosophy

Filter presses are operated in batches and at the referenced installation the filters need to be washed after every few filtration cycles to ensure cloth and plate sealing surfaces are free of solids. On the other hand, SBCs are operated continuously 24 × 7 and are normally given a run-down flush while stopping the machines. A centrifuge can also be given a quick high-speed flush simply by stopping the feed for a short time without stopping the centrifuge operation.

A detailed description of the chamber filter press is not included in this paper as the technology is being used in the mining industry since a long time and for the purpose of this paper it is presumed that industry stakeholders are familiar with it.

2.6.4 Scope considered for evaluation

Regarding bowl centrifuge station, the scope of equipment considered includes six tailings slurry feed pumps, two centrate pumps, two flush water pumps, six centrifuges, one flocculant preparation and dosing system, respective control systems as well as the piping, valves, fittings etc.

For the filter station equipment considered includes four tailings slurry feed pumps, four filtrate pumps, two manifold flush pumps, three cloth wash pumps, four hydraulic units, one high-pressure jet cleaning system, one compressor for cake pressing, four dry air compressors, respective control systems as well as the piping, valves, fittings etc.

Conveyors for transporting and depositing the discharged solids cake into piles are not included in the scope of supply. Typically there will be one or two belt conveyors located below the six centrifuges depending on their layout whereas there will be four conveyors for the four filters. Cake from the piles is considered to be transported by dumper trucks to the tailings disposal area.

The cost estimates have been mostly collected through customer interactions and are limited to the main capex and opex costs towards installing and operating a tailings dewatering station and do not include upstream or downstream equipment/operation.

3 Results and discussion

3.1 Cost factors taken into account

In each case, the capex takes into account cost estimates towards the following items:

- Dewatering equipment.
- Ancillary equipment such as pumps, compressors, flocculant dosing system etc.
- Plant and building.
- EPC management fee.

For calculating the opex, the costs considered are shown in Table 1.

Table 1 Costs of main items

Consumable	Cost/unit	Filter press	Solid-bowl centrifuge
Cake transport cost	USD/t	1.05	1.05
Power cost	USD/kWh	0.10	0.10
Process water cost	USD/m^3	2.00	2.00
Flocculant cost	USD/kg	NA	3.50
Wage rate	USD/h	10.00	10.00

3.2 Comparison of capex estimation

Based on the capex estimates for both the options, total capex for the filter station was found to be higher than that for the solid-bowl centrifuge installation by 30%. There can be a variation in this cost difference depending on number of equipment used, it's footprint, design of the building etc. Solid-bowl centrifuge installations involve lower capital costs as shown in the estimates in Figure 12.

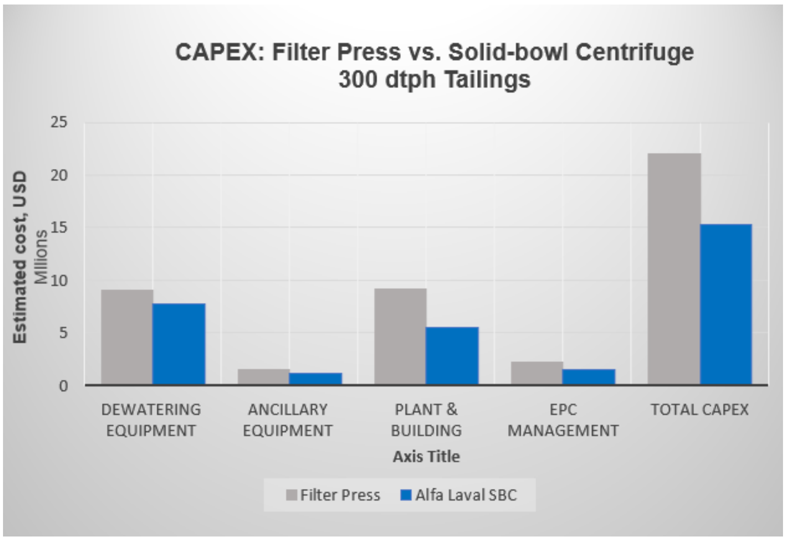


Figure 12 Estimated capex comparison

3.3 Comparison of opex estimation

Based on the operating parameters and the utility costs mentioned in Section 3.2, the specific consumption figures in terms of dry solids (DS) throughput were as shown in Table 2.

Table 2 Estimated specific consumption per dry tonne of tailings

Estimated consumption	Unit	Filter press	Solid-bowl centrifuge
Power consumption	kWh/t DS	2.70	3.23
Wash water consumption	m^3/t DS	0.35	0.05
Flocculant consumption	g/t DS	0	70
Maintenance cost	USD/t DS	0.39	0.17

Wash water consumption stated in Table 2 is the total of:

- Filter cloth washing as per the routine stated under operating philosophy
- The cost of USD 6/m^2 towards high-pressure jet cleaning (Fränkle et al. 2023) carried out at least once a week.

Figure 13 shows the estimated OPEX comparison between the filter press and SBC technologies.

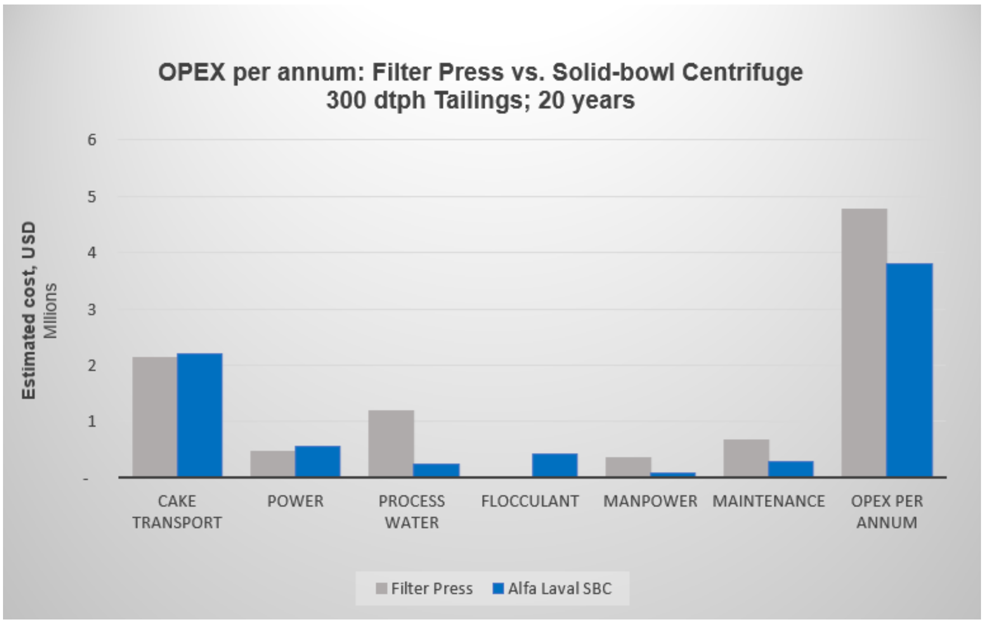


Figure 13 Estimated opex comparison

While the operating expenses can vary on a case-to-case basis depending upon the operating conditions and the utility as well as other costs prevailing at different mine sites, in this particular case, we found that the estimated opex is lower by 21% with Alfa Laval's solid-bowl centrifuge as compared to the filter press. The main factors that contributed to this were the lower maintenance cost due to the robust design of the solid-bowl centrifuge technology, lower wash water consumption as well as lower manpower cost as the operation of centrifuges is less labour intensive. Whereas the filter press station consumed less power and it did not require the use of a suitable flocculant in the feed tailings slurry.

3.4 Comparison of lifecycle cost estimates

Estimated lifecycle cost comparison considering NPV at 10% as per Figure 14 shows that the cost economics works in favour of Alfa Laval's solid-bowl centrifuge technology vis-à-vis the filter press technology. Estimated cost per tonne of dry solids works out to USD 1.83 for the solid-bowl centrifuge versus USD 2.38 for the filter press.

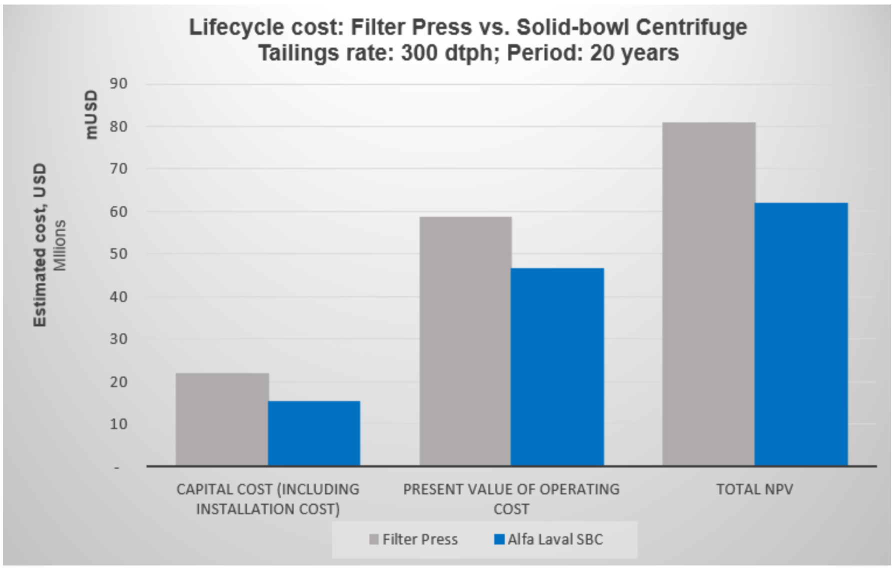


Figure 14 Estimated lifecycle cost comparison

4 Conclusion

This study shows that Alfa Laval's solid-bowl centrifuge technology has evolved to the extent where it can be considered as a viable option in the mining industry's quest for tailings dewatering technologies that not only support its EESG goals but are also cost-effective in terms of capex as well as opex.

Depending on the properties of the cake discharged by the centrifuge, it can be disposed of by dry stacking or by co-disposal with coarse rejects. The solid-bowl centrifuge can also produce a thick pumpable discharge in case a mining site needs to store the tailings with paste-like consistency.

The technology is being used or tested in a number of different tailings dewatering applications such as alumina, coal, copper, clay, iron ore, oil sands, phosphate, rare earths and others. This paper is an attempt to quantify the benefits of the solid-bowl centrifuge technology so that it serves as a tool for decision-makers to evaluate tailings dewatering solutions that are environmentally, socially and financially sustainable.

Acknowledgements

The author acknowledges the assistance and cooperation of all those who contributed with relevant inputs to this paper. Owing to non-disclosure agreements names cannot be disclosed. No warranties are given nor implied.

References

Fränkle, B, Stockert, M, Sok, T, Gleiß, M & Nirschl, H 2023, 'Tailings Filtration: water jet spray cleaning of a blinded iron ore filter cloth', *Water within Minerals Processing*, vol. II.

Global Tailings Review 2020, 'Chapter VII – lessons from tailings facility data disclosures', *Towards Zero Harm: A Compendium of Papers*.

Initiative for Responsible Mining Assurance 2023, *DRAFT Standard for Responsible Mining and Mineral Processing 2.0*, https://responsiblemining.net/wp-content/uploads/2023/10/IRMA-Standard-for-Responsible-Mining-and-Mineral-Processing-2.0-DRAFT-20231026.pdf

Madsen, B 2017, 'Re-introducing solid bowl decanter centrifuges for dewatering in the mining industry', *Proceedings of the 4th International Symposium on Innovation and Technology in the Phosphate Industry*, Elsevier, Amsterdam.