A new froth pump for improved flotation concentration handling

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The apatite mineral containing the phosphate at the Foskor Phalaborwa operation is recovered via a flotation process. The phosphate concentrate is recovered in the flotation froth, which comprises a fine particle slurry containing entrained air. Depending on the percentage of contained air – the froth volume factor (FVF) – in the slurry, this tends to create unfavourable pumping conditions when using conventional slurry pumps. This presence of air within the froth poses specific problems for a typical centrifugal slurry pump, one being the effect of raising the apparent vapour pressure of the mixture.

This may create the expectation that cavitation could be a contributing factor to poor pumping performance. On the contrary, rather than the collapse of the vapour pockets (which is what cavitation implies), the entrained air bubbles actually expand rapidly in areas of low pressure within the pump to decrease both head and efficiency.

This dictates the need for a froth pump with good suction performance (low net positive suction head required – NPSHr) to prevent poor froth pumping performance (Bootle, 2009).

In high FVF conditions (typically known as medium to tenacious froth), there is the real possibility of air separation from the liquid, which can contribute to air binding within the eye of the impeller and the subsequent loss of efficient froth transfer. The typical consequence is that conventional sumps are prone to overflowing, leading to spillage and loss of valuable concentrate.

Based on the proven Warman® AH™ series horizontal slurry pumps, the technologically improved Warman® AHF™ froth pumps can be considered as a significant advancement in the efficient handling of air-entrained froth slurries.

By custom designing the unique AHF™ froth hopper specifically for the required froth transfer duty, a more stable operation can be achieved.

At the Foskor U-Bank Flotation Plant Upgrade Project, the Warman® AHF™ pumps complete with the compatible AHF™ froth hoppers have been installed as a means of ensuring optimum froth transfer efficiencies.

Introduction

Founded in 1951 and commissioned in 1953, Foskor's Mining Division in Phalaborwa, Limpopo Province of South Africa, mines phosphate rock (pyroxenite), from which Foskor's Acid Division in Richards Bay produces phosphoric acid and phosphate-based granular fertilizers for local and international markets.

Pumping mineral froths utilizing centrifugal pumps has typically presented major problems for users. Most of these problems have occurred due to incorrect pump application and selection of operating speeds. The new Warman® AHF™ horizontal froth pump design now offers opportunities to greatly improve the pumping of froths while maintaining high efficiencies.

This new froth pumping technology was presented to Foskor Phalaborwa, and a selected froth transfer application was identified to test the performance of the new Warman® AHF™ froth pump.

In selecting the correct size Warman® AHF™ froth pump, an understanding of the complexity of the chosen test application required a detailed review of the ore treatment process. This evaluation involved the following:

- Understanding the mineralogy of the ore stream mined from the Foskor open pits, including the load/haul processes and the ore blending philosophies
- Understanding the ore treatment process flows from primary/secondary/tertiary crushing to primary and secondary milling, conditioning, and finally on to flotation feed
- A thorough understanding of the mass balances feeding the flotation plant, with emphasis on the particle size distributions (PSDs).

- Understanding how and when reagents are introduced into the mineral processing system
- A clear understanding of the flotation water recovery system
- Detailed sampling study campaigns on measuring and determining the true FVF at the respective flotation plants
- Detailed reviews of the current froth sumps and slurry pumps for the rougher, scavenger, cleaner, and recleaner concentrate streams at the respective flotation plants, with emphasis on identifying possible reasons for periodic instability issues and spillage problems.

The results from the above exercises proved invaluable in both understanding Foskor's flotation process and identifying root causes of pumping instability.

This article draws attention to the methodology used to gain a clear understanding of the froth conditions, and discusses how the new Warman® 6F-AHF™ froth pump technology provided an overall improvement to the froth transfer system.

With the dual focus on increased flotation efficiencies and seeking efficient solutions for the Foskor flotation upgrade/expansion programmes, Weir Minerals Africa (Pty) Ltd was consulted in the conceptual design reviews for both the Ultimate Flotation Upgrade Project and the new Flotation Plant Project.

Geological background

The Foskor Phalaborwa mining operation is situated within the Phalaborwa Complex, which extends over an area of 1950 hectares, primarily consisting of a phlogopite and apatite-rich pyroxenite. This pyroxenite is intruded successively by a series of more differentiated rocks – foskorite, and olivine-magnetite-apatite-phlogophite rock, and finally a central intrusion of transgressive carbonatite. Currently only the pyroxenitic ore portion is mined for the extraction of phosphate (Botha, 2012).

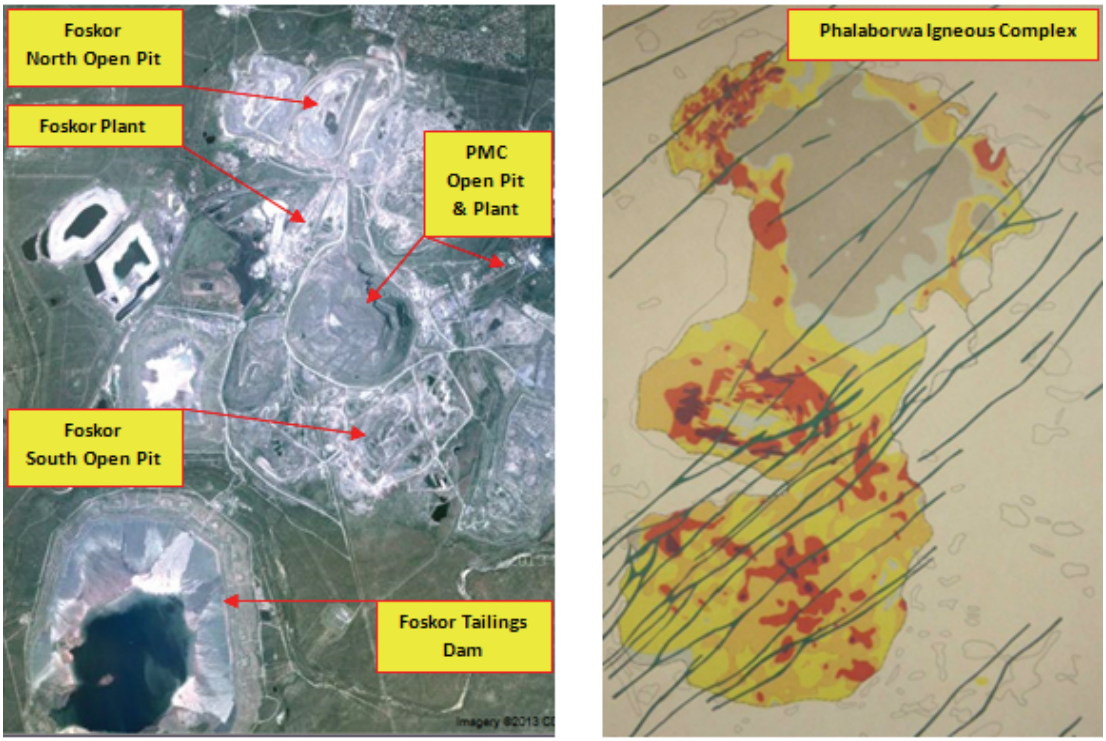

Figure 1. Aerial view of mining operations within the Phalaborwa Igneous Complex

The apatite occurring in the Phalaborwa igneous complex has the chemical formula $Ca_5F(PO_4)_3$, or $Ca_5Cl(PO_4)_3$, or $Ca_5OH(PO_4)_3$.

This mineral contains, for most intents and purposes, 42% P_2O_5 (Henkom, 1965).

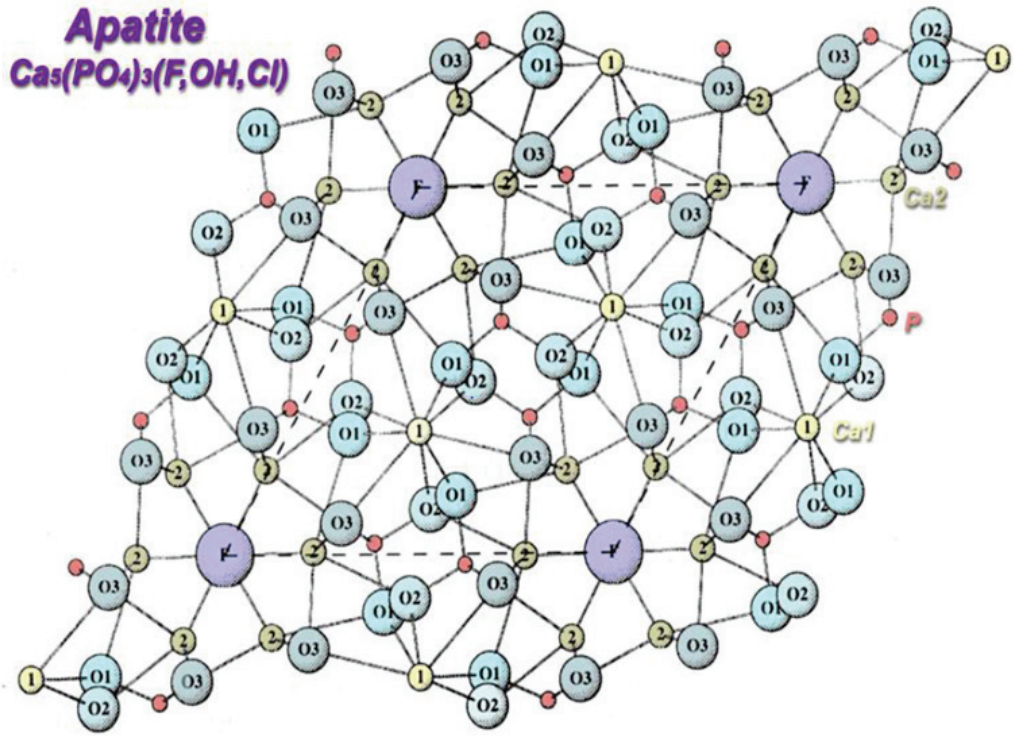

Figure 2. Mineral structure of apatite

Background to froth handling at Foskor

The Foskor Phalaborwa opencast mine has the capacity to yield 2.6 Mt/a of phosphate rock concentrate from processing 35 Mt of ore per annum. Once crushed, milled, concentrated, and dried, most of the phosphate rock concentrate is railed to Foskor's processing plant in Richards Bay (www.foskor.co.za).

During the processing of the phosphate rock, vast numbers of centrifugal pumping systems play a major role in sustaining Foskor's phosphate production, as for any flotation circuit for any mineral. Centrifugal slurry pumps are the most economical means of moving the high tonnages of material in slurry form. A major process utilized is that of flotation, where air and flotation reagents are added to the slurry to assist separation of the mineral (Wills, 2007).

While conventional centrifugal slurry pumps will pump light frothy slurries, operational problems normally occur when the air content is increased. A thorough understanding of the Foskor Phalaborwa complex flotation circuit lead to further recommendations regarding the froth handling during slurry transportation, while introducing the new Warman® AHF™ horizontal centrifugal slurry pump.

Froth volume factor (FVF) testing

From detailed plant surveys on all the Foskor flotation plants, it was noted that all froth transfer pumps were of the standard Envirotech® Alpha™ and Warman® AH™ centrifugal slurry pump designs. Prior to the introduction of any new froth pumping technology, this was the only available technology. In the cases of a few of the froth transfer pump applications (especially where there appeared to be high froth conditions), it was noted that the standard slurry pumps had specifically been oversized to cater for the apparently high percentages of air volumes (currently an outdated design procedure referred to as 'past approach', but often endorsed in previous years).

Prior to the development of the new Warman® AHF™ froth pump design, past approaches to pumping froth involved one of three methods:

- Integral tank-mounted, top suction vertical pumps. The tank was designed to liberate and vent as much air as possible from the slurry prior to it reaching the pump suction. In this design the flow capability was limited by the tank volume
- Double suction vertical pumps to increase the pump inlet area, lower the pump NPSH requirement, and provide additional area/volume to lower inlet velocities and minimize the chance of air binding. In this case the mounting of the pump within a tank was less than desirable from a pump maintenance standpoint

- The use of an oversized horizontal pump (as used at Foskor). Here a generous froth factor was applied to the desired volume flow to determine the appropriate size pump (Boolte, 2009).

The objective was to have a larger diameter impeller running at a lower speed of rotation to achieve a reduction of the NPSHr (Addie, 2007).

In most cases, the net effect was higher energy use/cost and high capital expenditure from the purchase of a large pump, large motor and associated floor space.

The unique Warman® AHF™ froth pump addresses the above maintenance, sizing and efficiency concerns. The key to this design is a significantly larger than normal inlet diameter and a unique patented flow inducer impeller. By utilizing a larger than normal inlet, with correspondingly larger inlet volume, the suction can handle significantly greater expanded air volume without air binding (Bootle, 2009).

For the selection of any Warman® AHF™ froth pump, it was recommended to undertake thorough FVF testing to establish the unique concentrate properties.

Figure 3 shows conventional Envirotech® and Warman® centrifugal slurry pumps on froth transfer applications, selected on the 'oversized horizontal pump option' basis.

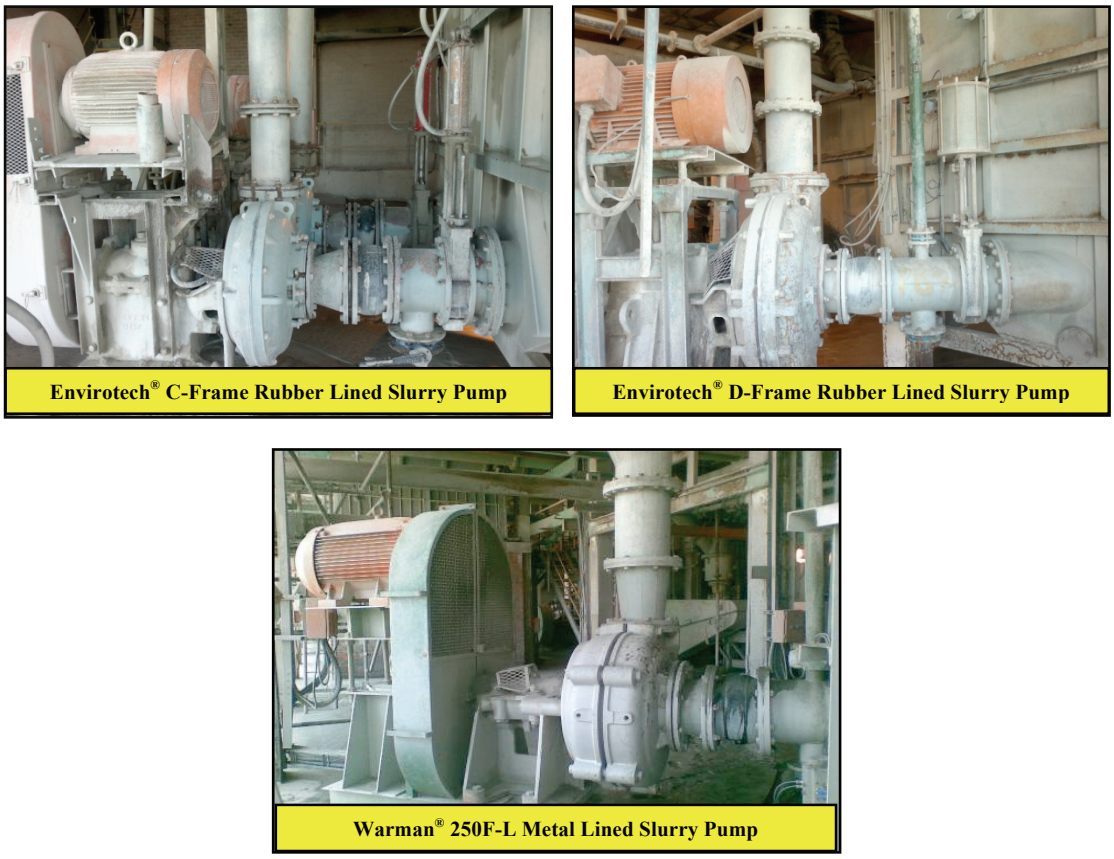

Figure 3. Three conventional slurry pumps installed in froth transfer applications

As depicted in Figure 4, it was further noted that in all froth transfer applications, large sumps had been designed and installed. Most of the current froth sump designs ranged from high-walled rectangular sumps with steep sloping sides, to low-walled rectangular sumps with very shallow sloping sides, to circular flat-bottomed sumps. In most cases, the sump feed pipeline(s) were perpendicular to the sumps, with varying drop heights. This perpendicular sump feed design allows for added froth generation inside the sump.

Figure 4. A variety of conventional froth sump designs

As the selection of a suitable froth factor was based on apatite flotation experience, it was clear that when the conventional centrifugal slurry pumps were initially selected for froth transfer duties, a somewhat unsubstantiated factor was invariably used. These typically ranged from 1.6 to as high as 4.0. As the FVF is always applied to the slurry flow rate (referred to as Q_s) to achieve the froth flow rate (referred to as Q_f), using a FVF of 4.0 would be emphasising a grossly oversized conventional slurry pump.

As the FVF plays a vital role in selecting the correctly sized froth pump and motor for the application, it was essential to verify and note that the correct FVF number(s) were used to ensure the success of the optimization programme.

To obtain the true FVF numbers, detailed froth volume tests on the different froth transfer applications were initiated. This typically involved taking numerous random froth samples to accurately understand the FVFs from the different flotation plants. For the purpose of capturing realistic froth samples, it was important that the sampling was extracted from the drain valves fitted on the underside of the spool pieces situated between the sump discharge port and the pump intake (the area closest to the impeller eye of the installed pump, as depicted in Figure 5).

Froth Sample Point: Spool Piece Drain Valve – Scavenger Concentrate Sump & Envirotech® D-Frame Pump

Figure 5.The ideal froth factor sampling point

As demonstrated in Figure 6, where access to the spool piece drain valves was not possible, the main sump drain valves on the sumps were used as the sampling point.

Froth Sample Point: Main Sump Drain Valve – Rougher Concentrate Sump

Figure 6. The sump drain valve, a substitute froth factor sampling point

It should be mentioned that froth sampling should never be undertaken from the top of a froth sump. As demonstrated in Figure 7, sampling from this area could provide misleading results, as aeration of froth bubbles rising to the surface will provide unrealistic or higher than normal FVFs, rather than what would normally be found entering into the eye of the impeller.

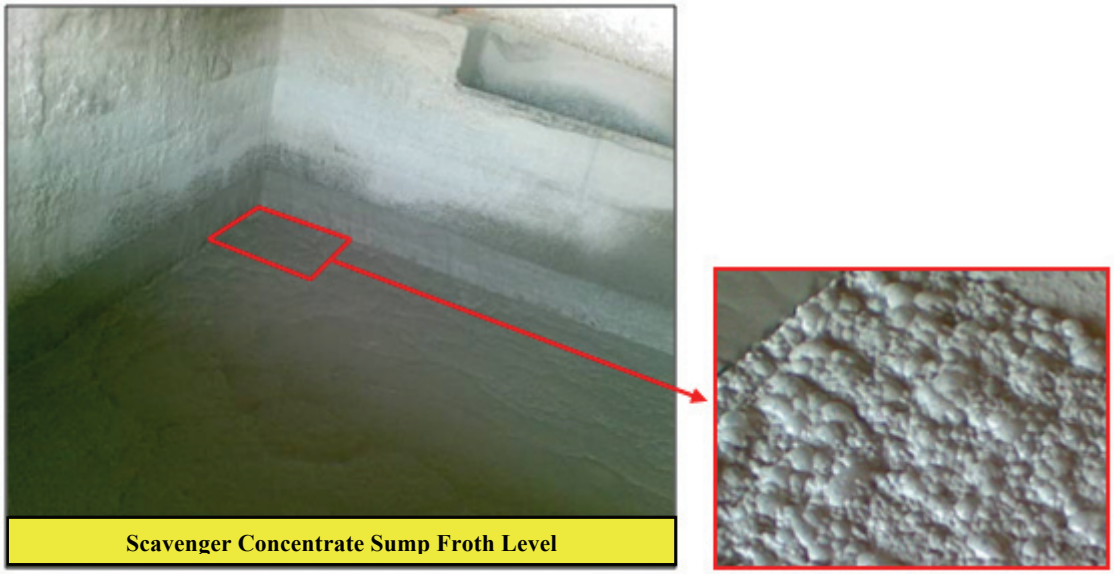

Figure 7. An example of the typical high FVFs that can be found at the surface of froth sumps

With access to the froth stream in the suction lines, froth samples were carefully collected in 1.0 litre and 2.0 litre measuring flasks, and then transported to the Foskor metallurgical laboratory, where they were weighed to determine a snapshot of the pulp density, then left for 24 hours to determine the FVF (the true air volume in the specific volume of froth slurry concentrate). For each froth application, approximately 40 individual FVF samples were taken. The pictures in Figure 8 indicate the typical four-step FVF testing process.

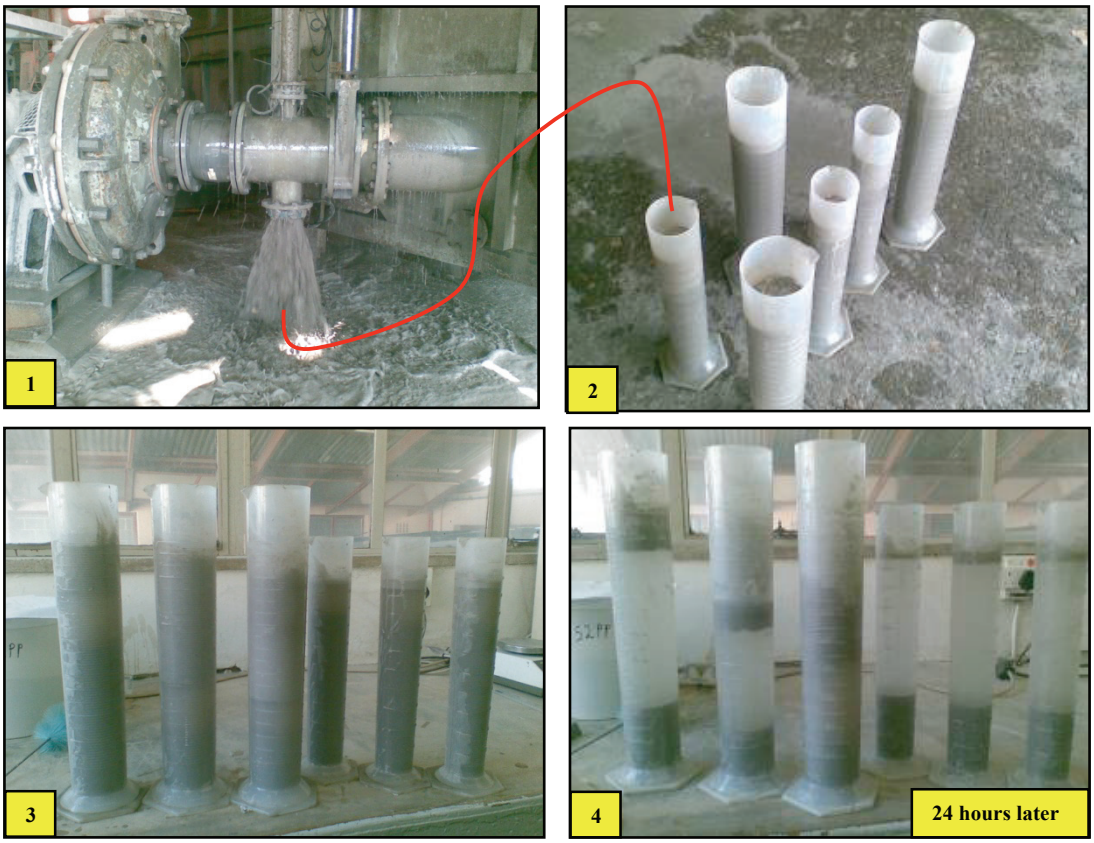

Figure 8. Four stages in the process of determining the FVF

The testing campaigns ran for approximately six weeks to ensure that the sampling was undertaken under different operational conditions. This included the roughers, scavengers, cleaners, cleaner tails, and final concentrate applications.

During the testing campaigns, adverse FVFs were measured in some of the samples. Figure 9 provides a unique example of one of the high FVF conditions measured.

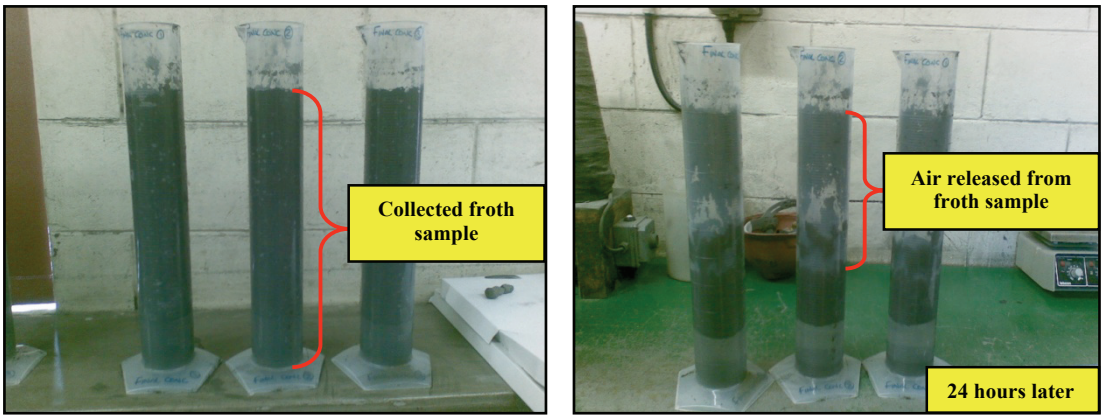

Figure 9. The volume of air released during a specific FVF test campaign

All froth sampling was conducted in a consistent manner. Each flask containing the froth sample was weighed for a snapshot reference of the pulp densities, and then compared against the weight of a clean, dry, and empty flask (as depicted in Figure 10).

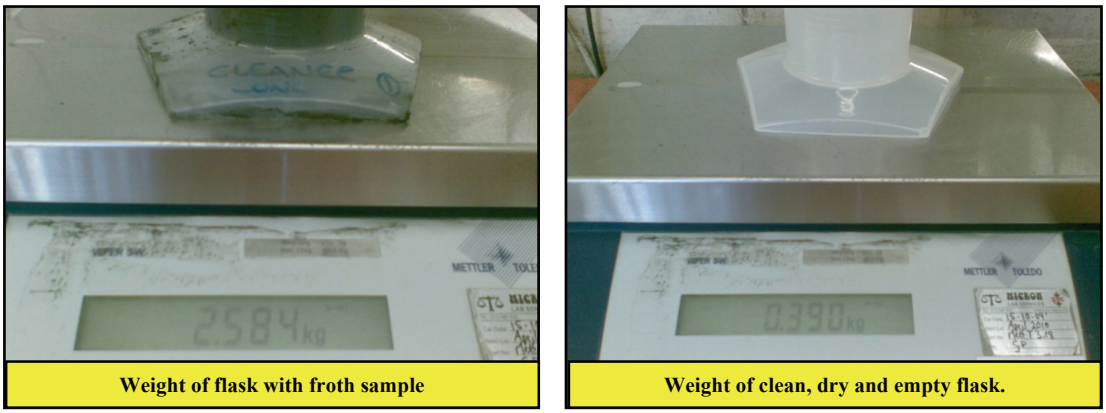

Figure 10. Calculation of the pulp densities

After capturing the data from each froth sampling campaign, both the FVFs and the percentage air volumes were calculated, as per the procedure illustrated in Figure 11 (Bootle, 2009).

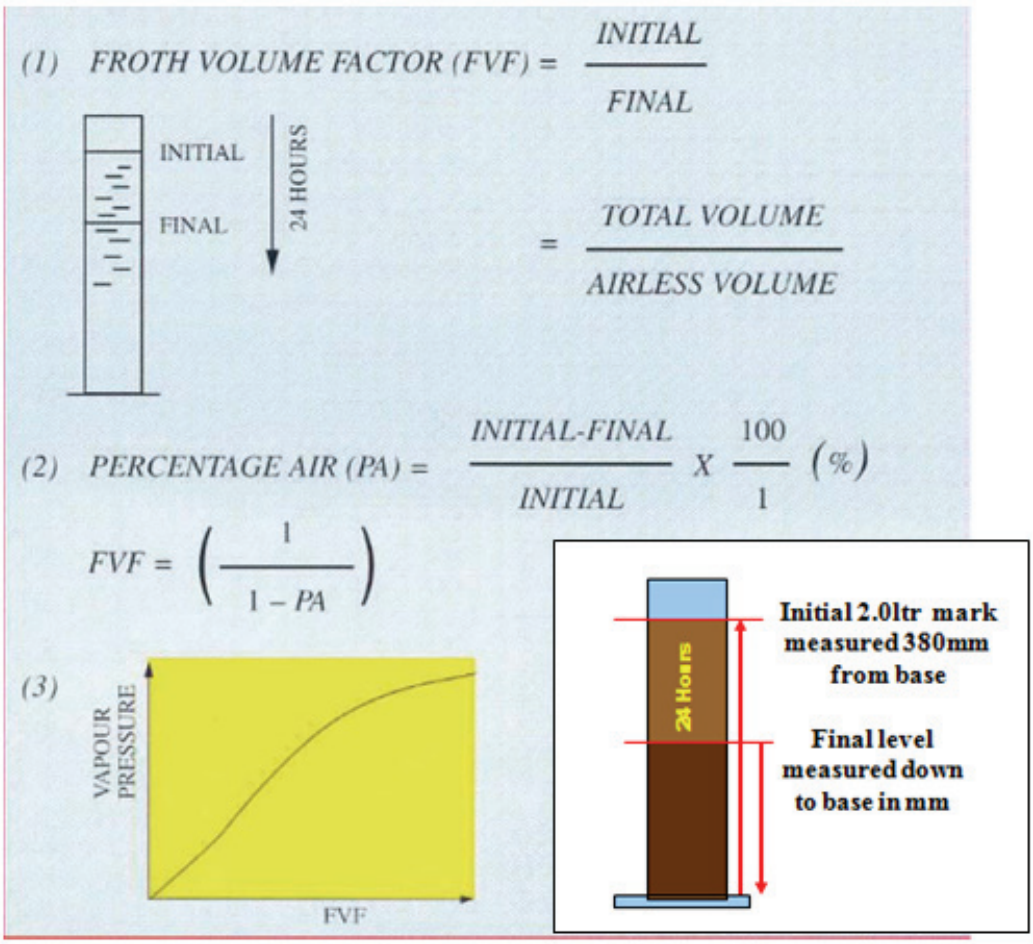

Figure 11. Methods used to determine the froth characteristics (Bootle, 2009).

According to Burgess (2004), the definitions of the different FVFs are:

Brittle froths: **FVF = 1.10 to 1.25**
Medium froths: **FVF = 1.25 to 1.50**
Tenacious froths: **FVF = 1.50 to 1.80**

Tables I–III present typical FVF results measured in 2010, as extracted from the original froth testing data sheets.

Table I. Extracts from a Foskor flotation scavenger concentrate FVF test (Plant A)

Index:	Yellow = Brittle Froth	Green = Medium Froth	Turquoise = Tenacious Froth

Test 4.	=	1.36 (FVF)	=	26.32 % (air vol.)
Test 13.	=	1.51	=	33.68 %
Test 20.	=	1.84	=	45.53 %
Test 25.	=	1.79	=	44.21 %
Test 31.	=	1.23	=	18.42 %
Test 34.	=	1.45	=	31.05 %

Table II. Extracts from a Foskor flotation rougher concentrate FVF test (Plant B)

Test 1.	=	1.21 (FVF)	=	17.11 % (air vol.)
Test 8.	=	1.60	=	37.63 %
Test 14.	=	1.12	=	10.79 %
Test 25.	=	1.35	=	26.05 %
Test 29.	=	1.51	=	33.68 %
Test 39.	=	1.27	=	21.05 %

Table III. Extracts from a Foskor flotation scavenger concentrate FVF test (Plant B)

Test 1.	=	1.09 (FVF)	=	8.16 % (air vol.)
Test 7.	=	1.48	=	32.63 %
Test 15.	=	1.20	=	16.84 %
Test 20.	=	1.37	=	27.11 %
Test 31.	=	1.91	=	47.63 %
Test 32.	=	1.86	=	46.32 %

With the understanding that brittle, medium, and tenacious froth conditions existed in certain flotation froth transfer applications, the next important step was to try and ascertain what was contributing to the vast fluctuations in the FVFs.

With mining from different open pits, the ore quality and metallurgical performance of the ore had much to do with periodic fluctuations. Mainly as a result of this, the distinct fluctuations in the FVFs were noted and recorded. As the characteristics of froth can vary from day to day, a thorough understanding of the froth transfer application is thus critical when designing and selecting the froth pump.

As froths can vary from brittle froth (generally large bubbles that are easily broken down) to tenacious froth (very fine air bubbles that are tightly bound and remain in a froth state for many hours, and difficult to break down), lack of insufficient process knowledge can easily contribute to the selection of the wrong pump for the froth duty. This can significantly impact on the efficient transfer of froth slurries, due to a host of unfavourable pumping conditions.

During times when there are high percentages of air volumes in froth slurries, it is quite common to find the froth slurry density dropping below 1000 kg/m^3.

The froth slurry density (S_f) is calculated by dividing the slurry specific gravity (S_m) by the froth volume factor $S_f = S_m$ / FVF.

The air in the slurry is equivalent to a fluid with a very high vapour pressure. Consequently, the available NPSH (net positive suction head) for frothy slurry concentration is very low, as the vapour pressure is close to atmospheric pressure. Pumping froth requires extra energy to be added to the froth so that it can easily enter the pump impeller eye.

One method might be to use conventional slurry pumps that offer relatively low NPSHr characteristics. However this does not always work efficiently during high FVF conditions, and froth feed sumps that continuously overflow are an indicator that the conventional installed slurry pumps are not coping.

The new preferred method is to widen the suction lines and open the pump suction intake so that maximum froth is delivered into the impeller eye. Depending on the impeller design, the spinning impeller will also be able to induce pre-rotation and shear to the froth in the intake pipe ahead of the pump, thereby assisting the froth handling. In the quest for innovative technology, the new Warman® AHF™ open impeller froth pump design is best for inducing the swirling of medium to tenacious frothy concentrate slurries in the pump intake chamber (Burgess, 2004).

To improve froth handling efficiencies and curb spillage problems during the transfer of medium to very tenacious froths, it would be necessary to utilize the Warman® AHF™ flow inducer froth pump impeller design with its enlarged pump inlet.

Conventional vs new froth pump technology

When physically comparing the conventional Warman® AH™ slurry pumps (as currently installed in many froth transfer applications in most flotation plants) to that of the new Warman® AHF™ technology, the differences are immediately noticeable. The large Warman® AHF™ open vane flow inducer froth pump impeller, with its greatly enlarged cover plate pump inlet and matching throat bush liner, is the result of technological improvements.

However, the volute, frame plate, gland assembly, bearing assembly, and the pump base all remain unchanged in both the Warman® AH™ and the Warman® AHF™ pump designs. Figures 12–14 provide a clear depiction of the unique design changes between the Warman® 8/6F-AH™ slurry pump and the new Warman® 6F-AHF™ froth pump.

For clarity, the new Warman® 6F-AHF™ froth pump has a large 371 mm suction diameter compared with the smaller 203 mm suction diameter of the Warman® 8/6F-AH™ slurry pump.

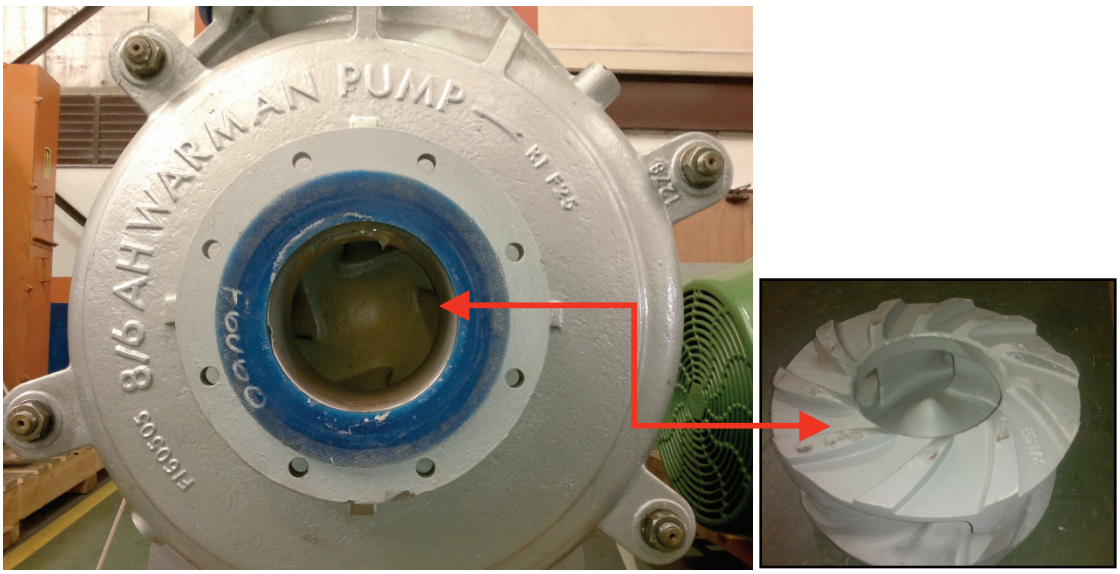

Figure 12. Standard Warman® 8/6F- AH™ slurry pump with standard impeller

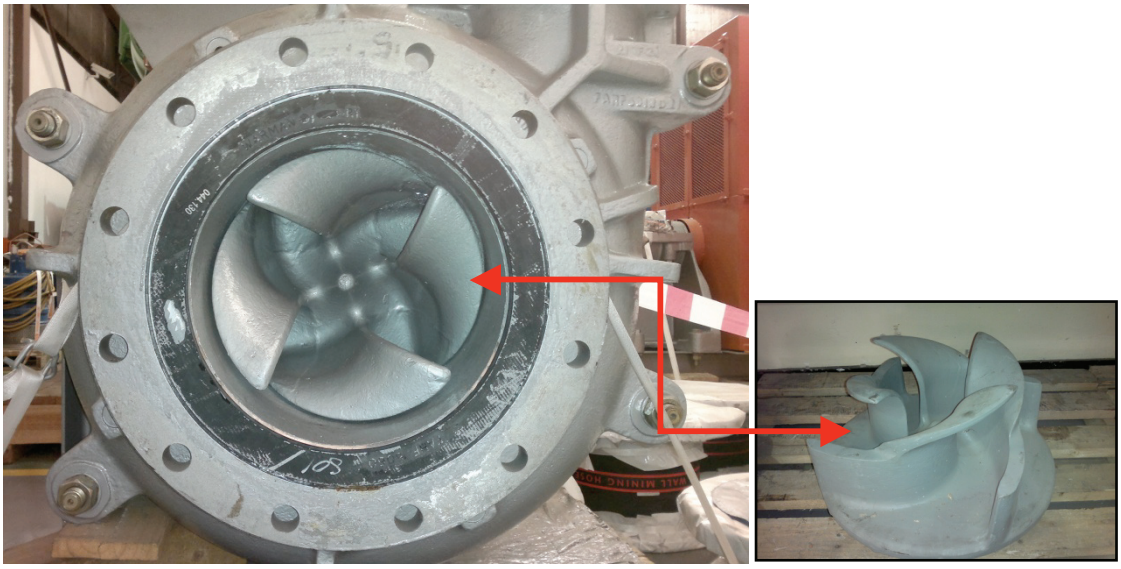

Figure 13. Warman® 6F- AHF™ froth pump with inducer vane impeller

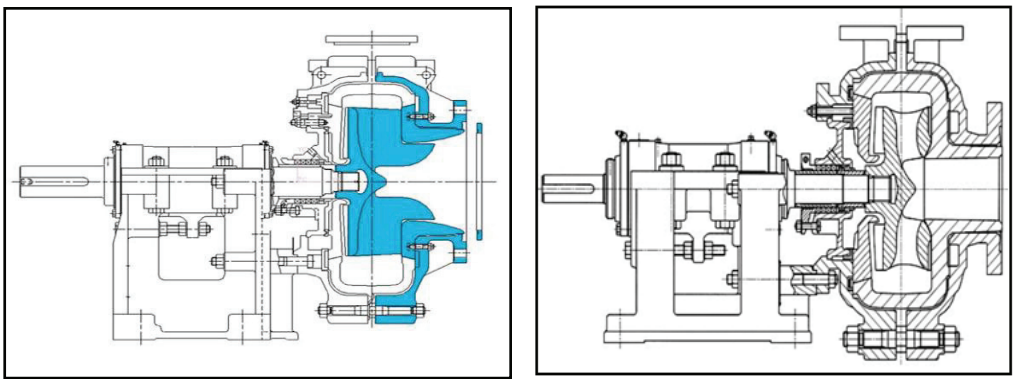

Figure 14. Warman® AHF™ froth pump and the standard Warman® AH™ slurry pump

Noticeably, the unique froth impeller has open inducer vanes that protrude into the large intake throat area. This extends the vane leading edges and serves to draw the difficult air-entrained froth slurries into the eye of the impeller. Consequently, the impeller vanes are able to swirl the slurry in the intake pipe, thereby adding kinetic energy and affording smoother entry of the frothy slurry to the impeller passageway.

The impeller vanes extending into the intake act mainly on the flow on the outside diameter of the inlet pipe, thereby assisting to draw in the central core plug flow of air. This action reduces the potential for air binding at the impeller eye. The larger Warman® AHF™ pump inlet also has the effect of reducing the inlet velocities and reducing the NPSHr. Conversely, the larger inlet increases the pump flow rate capacity, giving rise to improved efficiencies compared to a conventional pump (Burgess, 2004).

A further advantage of the improved froth pump design is that during operational froth transfer duties where there are brittle to medium froth factor conditions (>1.30 FVF), the pumping efficiencies for the standard Warman® AH™ slurry pump design start to reduce appreciably. However, when the extremely tenacious froth conditions (1.60 - 1.70 FVF) are encountered, there will be intervals when the standard Warman® AH™ slurry pump design will simply not cope, and will be incapable of adequately pumping or transferring the high frothy concentrate. It is during these very unfavourable pumping conditions that pump strain and cycles of severe sump instability lead to abnormal sump conditions, sump overflows, and the loss of valuable concentrate due to spillages.

The presence of solids, air, and viscosity in slurries all have the same basic effect of reducing the pump head and efficiency. These effects can be expressed as ratios of a pump's water performance as follows:

- Head ratio (HR) - ratio of head of slurry to the head of water at the same flow rate
- Efficiency ratio (ER) - ratio of efficiency of slurry to the efficiency of water at the same flow rate.

Ratios near to 1.0 indicate a small effect (low FVF), while ratios of 0.5 or lower indicate a large and very concerning effect (high FVF). HR and ER are normally constant over the pump's flow rate apart from the variations as shown in Figure 15 (Burgess, 2004). Figure 16 further indicates the mineral froth head correction, which is based on determining the HRf (head ratio froth) from the following:

- HRf = Head on froth slurry ÷ Head on water

Note that the dotted STD curves on the graphs represent the typical standard Warman® AH™ slurry pump impeller, and the QU1 curves represent the new Warman® AHF™ froth pump impeller technology.

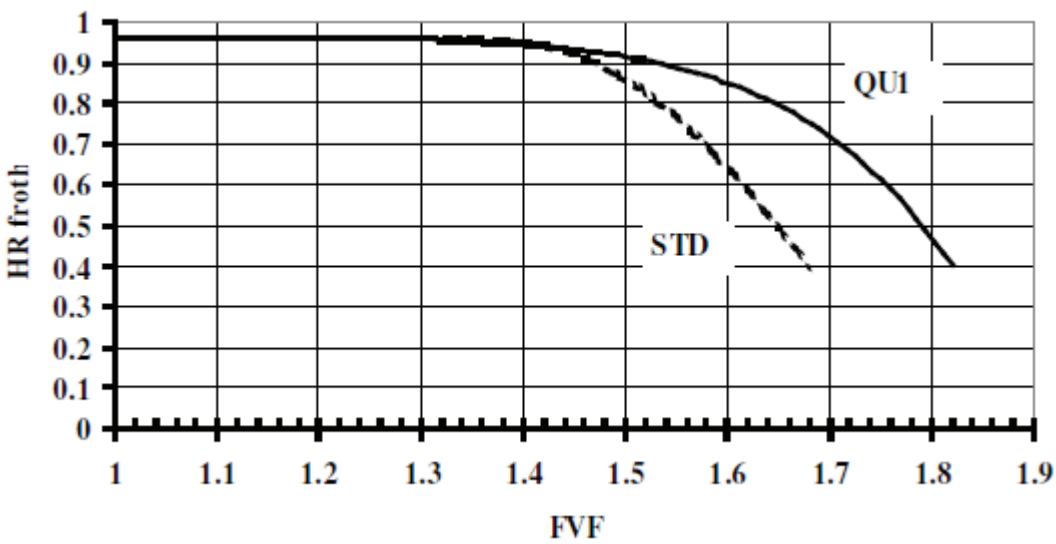

Figure 15. Head ratio chart for froth

To demonstrate this theoretically, Figure 16 has superimposed coloured lines depicting the respective FVFs and should typically be used as a first guideline (in the absence of any specific test data) to determine what the estimated HRf would be for a given froth condition. One can clearly see that at higher FVFs, the STD Warman® AH™ slurry impeller design becomes less effective in comparison to the new Warman® AHF™ impeller design. This is the first indicator that the standard Warman® AH™ slurry pump impeller will have significant difficulty in transferring flotation concentrate with high FVFs.

For the purpose of this discussion, Figure 16 provides confidence that the new Warman® AHF™ design (referenced as the 'QU1') can certainly handle higher FVF conditions compared with the conventional Warman® AH™ pump design (referenced as the 'STD').

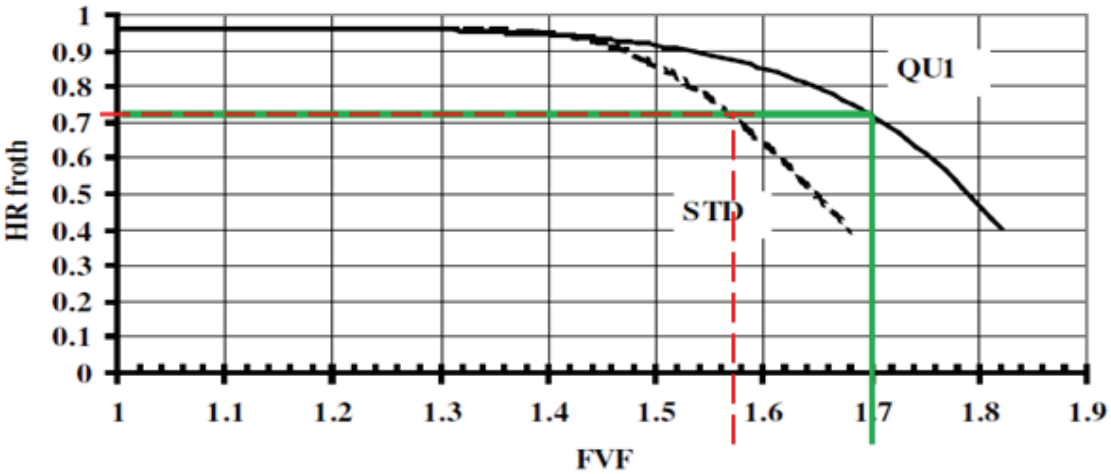

Figure 16 – Head ratio chart for froth. Green solid line: HRf to FVF capable of being pumped with the new Warman® AHF™ froth pump. Red dashed line: HRf to FVF capable of being pumped with the conventional Warman® AH™ pump

From Figures 15 and 16, it is clear that froth slurries with a FVF above 1.70 (40% air volume) would be considered as representing 'ultra-extreme froth conditions' and virtually impossible for the standard Warman® AH™ slurry pump to handle. Any FVF above 1.80 (44% air volume) may be too tenacious to efficiently transfer with the Warman® AHF™ froth pump.

Although from time to time these 'ultra-extreme' FVF conditions do exist in flotation froth transfer circuits, the desired optimization outcome when upgrading a froth pumping system should always be to ensure that the selected froth pump application is given every possible opportunity to safely handle the froth duty.

This would specifically address the following:

- Ensure that correct Warman® AHF™ pump design and selection is done (standard slurry pumps should not be considered for any high FVF concentrate applications)
- Correct motor selection for maximum design duty (with reference to the relative pulp density, FVF, flow rate and TSDH (total static dynamic head)
- Calculate froth power* $P_f = Q_f \times (H_f \times S_f \times g)/(E_f/100)/1000$
- To compensate for marginal fluctuations in both the mass balance and FVF conditions, a variable speed drive (VSD) could be installed on the froth pump motor
- A recommended 35% motor safety factor (above the absorbed kW value) should be considered when using a VSD
- Ensure that the Warman® AHF™ froth pump system curve duty does not exceed 35 m TSDH with an NPSHr not exceeding 3 m
- A correctly designed AHF™ compatible froth hopper is highly desirable
- Ensure for correct AHF™ hopper retention times, which should not be less than 60 seconds and typically not exceed 90 to 120 seconds (maximum).

*Units: Q in litres per second, H in metres, E in per cent, P in kilowatts , S_f is dimensionless
Subscripts: f = froth, s or m = slurry or mixture (de-aerated)

Results from new froth pumping technology

From the above FVF test results linked to the comprehensive froth transfer reviews aimed at optimization possibilities, a Warman® 6F AHF™ froth pump was supplied on a trial basis to test the technology on a Foskor rougher concentrate froth transfer circuit. This selected application was identified by Foskor due to its cyclic instabilities and periodic overflows (an example of this condition is seen in Figure 17).

Figure 17. Typical indication of undesirable sump overflow condition

A conventional Warman® 8/6F-AH™ was replaced with a Warman® 6F-AHF™ centrifugal froth pump. From the original flotation plant design specifications, the application required the suitably sized Warman® AHF™ froth pump to handle a slurry flow rate (Q_s) of 387.72 m^3/h, excluding any FVF, at a slurry pulp density of 1400 kg/m^3. A dry tonnage throughput of 241 t/h was calculated from a given dry density of 2800 kg/m^3.

As the average FVF (determined from some 40 samples) was 1.3 (23% air volume), the new design froth flow rate (Q_f) including the FVF was calculated at 504.04 m^3/h. The TSDH was calculated at 25.5 m of slurry. The maximum NPSHr was 2.74 m at the final pump speed of 742 r/min.

For clarity, the respective FVF is always applied to the slurry flow rate to achieve the froth flow rate ($Q_s \times \text{FVF} = Q_f$).

The Warman® 6F-AHF™ froth pump Q/H and system curve in Figure 18 provides a clearer understanding of the 140.01 ℓ/s design flow rate duty point (with 1.3 FVF) and a secondary 'minimum' duty point for the system with no froth factor included (107.7 ℓ/s). Table IV compare the different pump technologies.

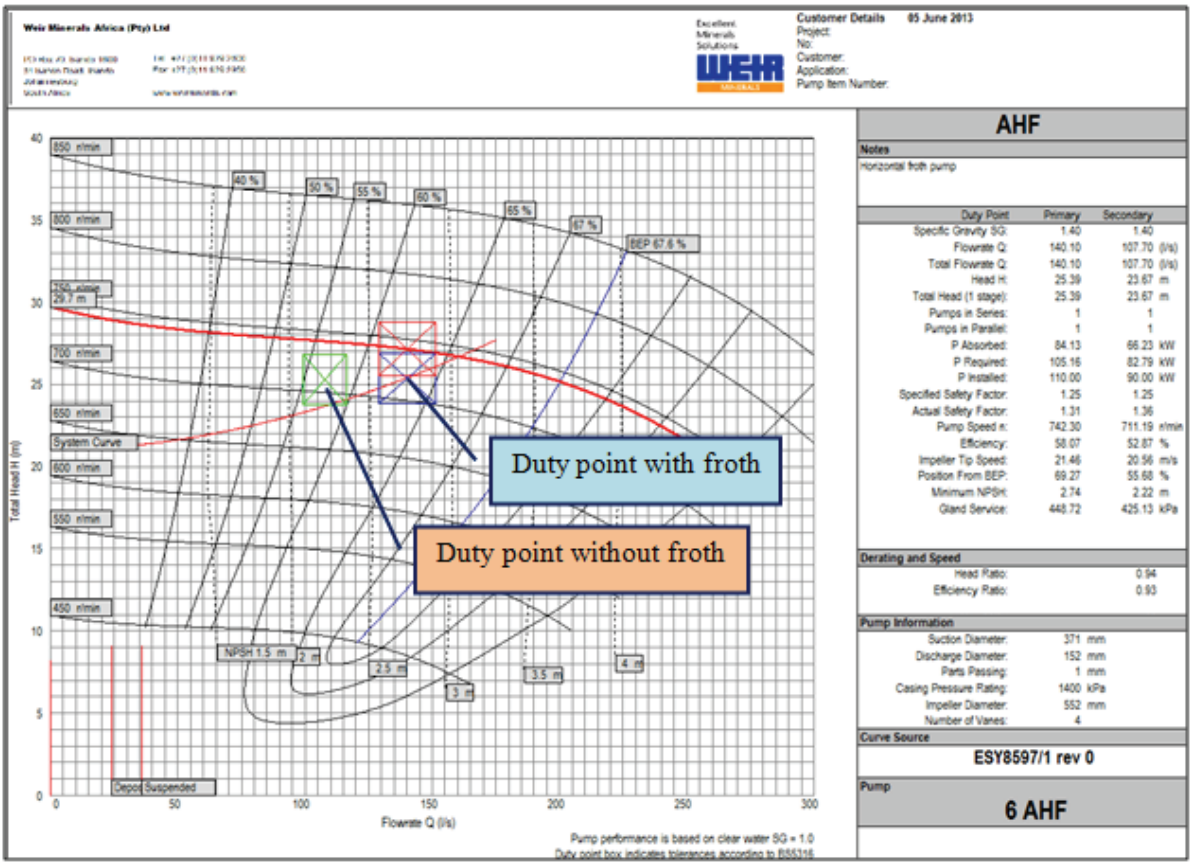

Figure 18. System curve for the new Warman® 6F-AHF™ froth pump

Table IV. Comparison between Warman® 6F-AHF™ and Warman® 8/6F-AH™ for duty

	Warman® 6F-AHF™	Warman® 8/6F-AH™
Number of vanes	4	5
Suction diameter (mm)	371	203
Discharge diameter (mm)	152	152
Pump speed (r/min)	741	812
NPSHr (m)	2.74	4

On acceptance of the Warman® 6F-AHF™ froth pump trial offer, Foskor carried out modifications to the current sump suction line, increasing the line from a 300NB to 400NB to accommodate the larger Warman® 6F-AHF™ froth pump inlet dimension.

The Warman® 6F-AHF™ froth pump, shown in Figure 19, was commissioned during the August 2011 shutdown, and has been in operation since.

Figure 19. The newly installed Warman® 6F-AHF™ trial froth pump

Figure 20 depicts a snapshot of one of the SCADA recordings of the motor amperes. It was noted that the Warman® 6F-AHF™ froth pump absorbed a higher amperage than the Warman® 8/6F-AH™ slurry pump (van Rhyn, 2012).

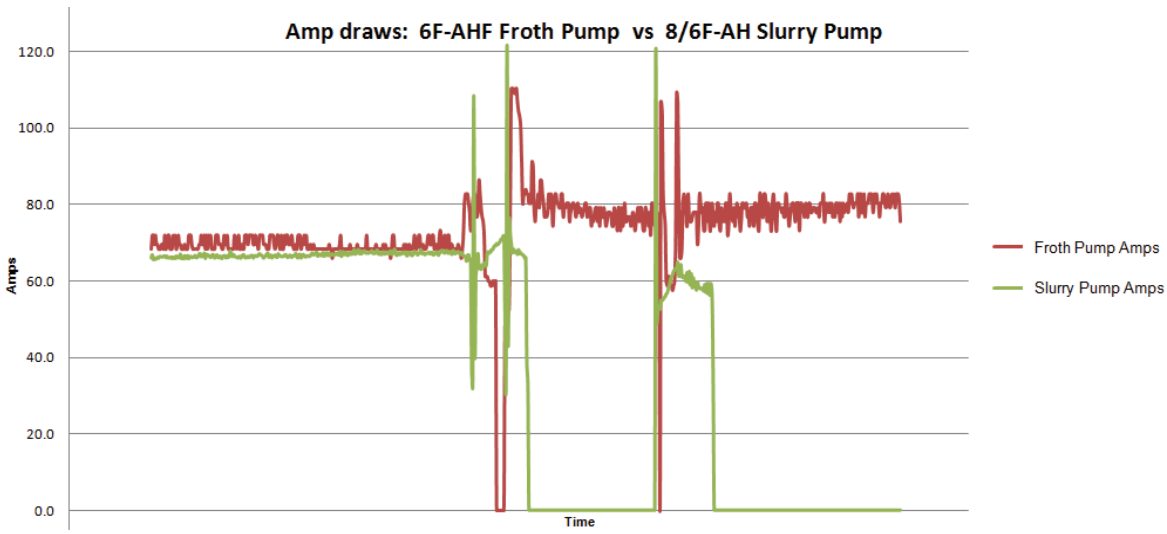

Figure 20. SCADA readings of the Warman® 6F-AHF™ froth pump vs the Warman® 8/6F-AH™ slurry pump

From a total of 410 independent amperage draw readings, it was calculated that the average absorbed power of the Warman® 6F-AHF™ froth pump motor was 54.35 kW, 11.56% higher than the 48.71 kW of the Warman® 8/6F-AH™ slurry pump motor .

This was attributed to an improved pumping performance coupled to a significant reduction in air binding (the known effect that reduced the pumping performance for the Warman® 8/6F-AH™ slurry pump).

However, during very unstable conditions the highest (spike) kilowatts absorbed reading for the Warman® 6F-AHF™ froth pump motor was 80.11kW, as opposed to 88.85 kW of the Warman® 8/6F-AH™.

Although the current sump is not of an optimum design, the main objective of the trial study was to ascertain whether the Warman® 6F-AHF™ froth pump had the ability handle medium to tenacious froth (froth volume factors >1.25). Results from further test work during December 2011 revealed the following.

A snapshot test result (Figure 21) showed a stable sump level for the Warman® 6F-AHF™ froth pump compared with the Warman® 8/6F-AH™ slurry pump.

With periodic stopping of the Warman® 6F-AHF™ froth pump, the standard Warman® 8/6-AH™ slurry pump showed erratic current draws with a rapid increase in the level of the sump (van Rhyn, 2012).

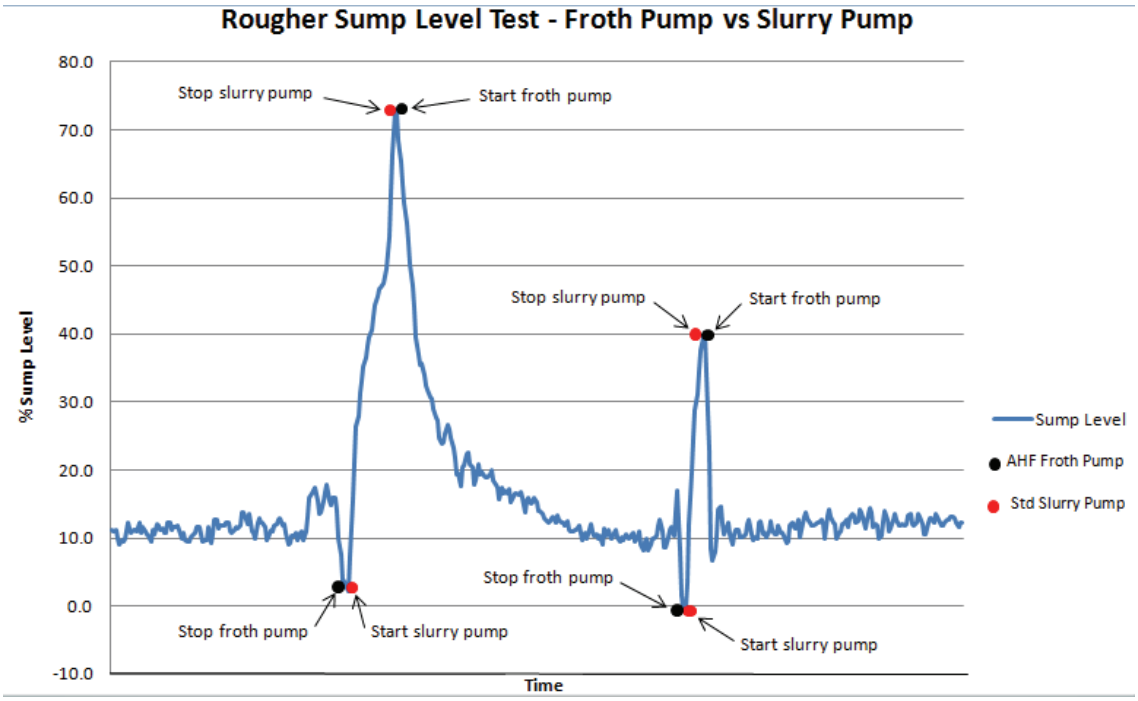

Figure 21. SCADA readings of the rougher concentrate sump level test

In further tests, the Warman® 6F-AHF™ froth pump continued to demonstrate better sump level control even though the pump was driven at a fixed speed (with no controlling VSD installed).

Furthermore, SCADA sump level recordings confirmed that the Warman® 6F-AHF™ froth pump sustained better stable sump level control over the conventional Warman® 8/6F-AH™ slurry pump (Figures 22 and 23) (van Rhyn, 2012).

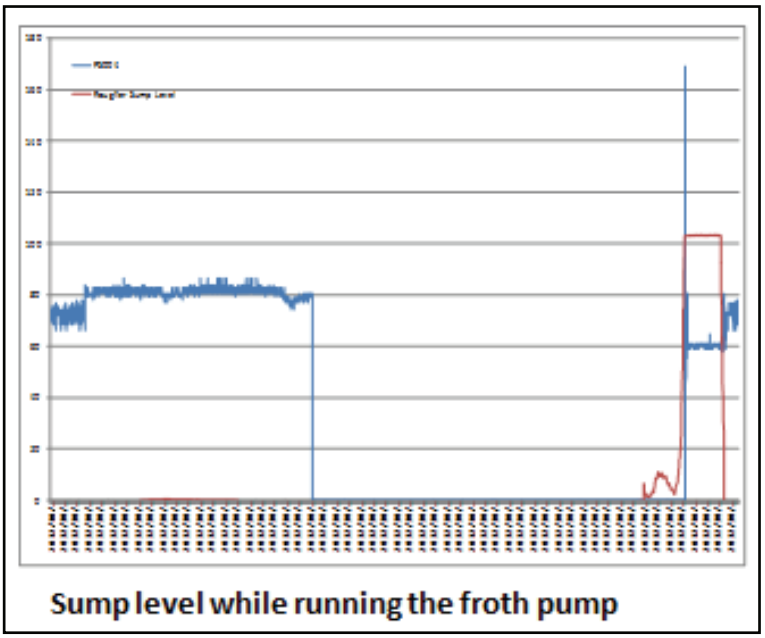

Figure 22. SCADA sump reading for Warman® 6F-AHF™ froth pump

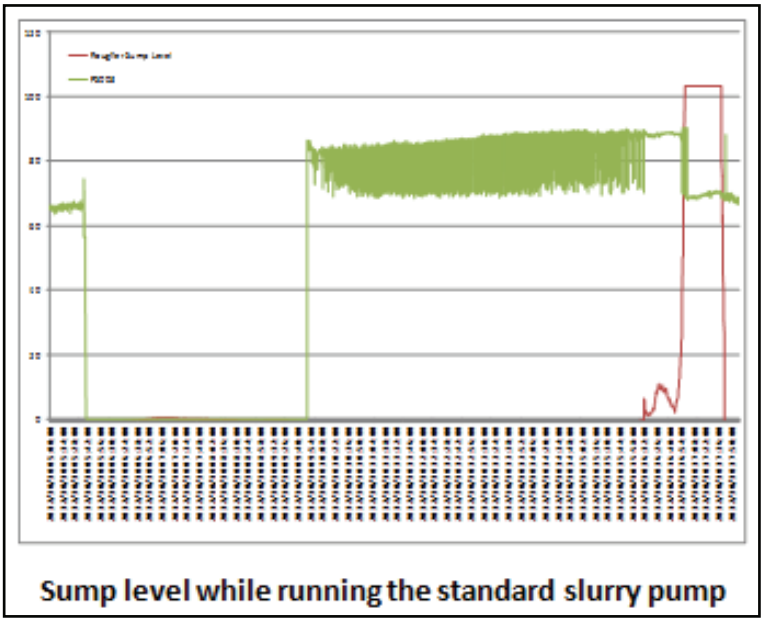

Figure 23. SCADA sump level readings for Warman® 8/6F-AH™ slurry pump

It was, however, noted that during excessively high FVF conditions (estimated >1.60 FVF), the Warman® 6F-AHF™ froth pump did not manage to hold a stable sump level.

In a specific test during unaccountably high FVF conditions (estimated ≥1.95 FVF), it was revealed that even with both the Warman® 6F-AHF™ froth pump and the standard Warman® 8/6F-AH™ slurry pump running simultaneously, the sump level could not be held stable.

From a closer review of the rougher concentrate sump design (Figure 24), it was noted that the following points were adversely influencing froth pumping performance:

- The current sump has a flat bottom section, which allows particles to rapidly settle out in the flat section of the sump, contributing to slumping and erratic flow regimes into the impeller eye
- The sump feed pipes allow for the frothy concentrate to drop into the sump. This enhances the generation of turbulence and new froth, and substantially increases the potential of air binding

- The current 300NB rubber-lined sump discharge pipe feeding the standby pump is too narrow and not suitable for froth slurry concentrate containing high air volumes. This contributes to poor pumping performance and air binding complications
- The current sump is of a high-walled rectangular design and has a 3 minute retention time, which contributes to product deposition/settling issues.

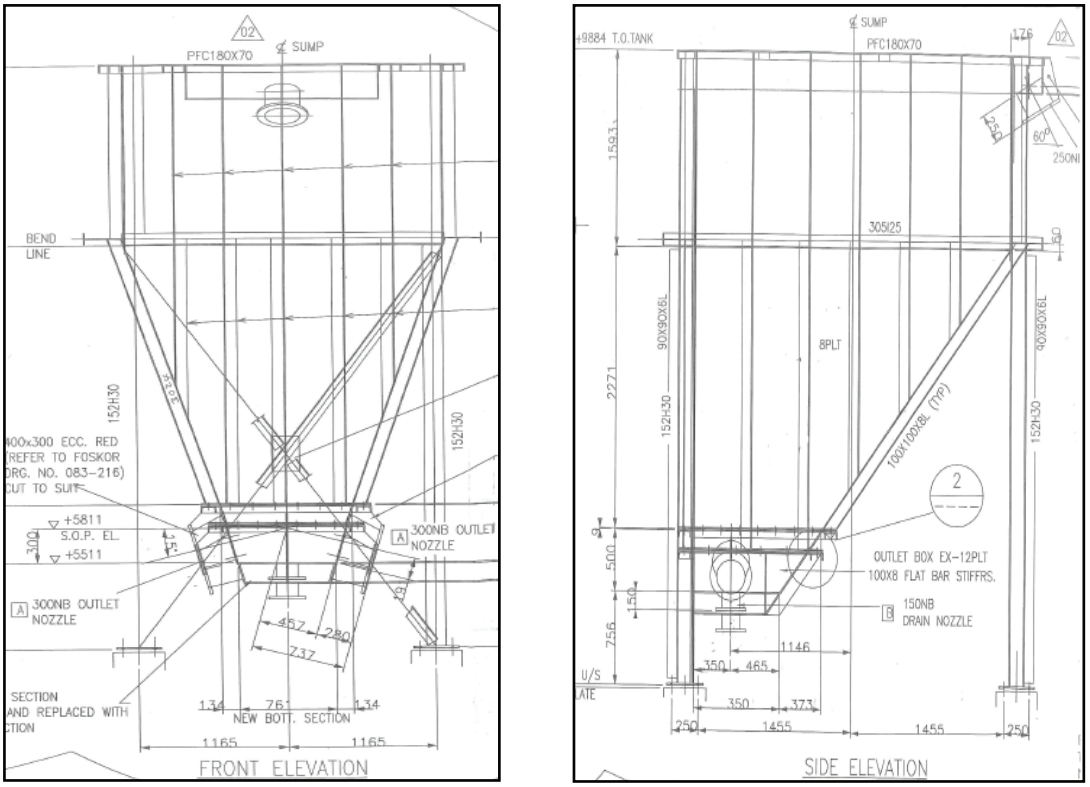

Figure 24. The conventional rougher concentrate sump where the trial pump was tested

Due to the abovementioned limiting sump efficiencies, a new AHF™ compatible froth hopper design has been recommended, as depicted in Figure 25. This hopper is especially designed to enhance the efficiency of the froth transfer system by (1) reducing 'froth generation' turbulence inside the hopper, (2) ensuring that the froth slurry concentrate is effortlessly induced into the impeller eye of the Warman® 6F-AHF™ froth pump. Every Warman® AHF™ froth hopper is thus uniquely match-mated to suit both the application and the chosen Warman® AHF™ froth pump.

Typically each hopper design requires a clear understanding of the following:

- Plant layout, space constraints, overflow launders and piping layout
- The selected Warman® AHF™ froth pump
- The froth volume factor(s)
- The required mass balance(s) and PSD.

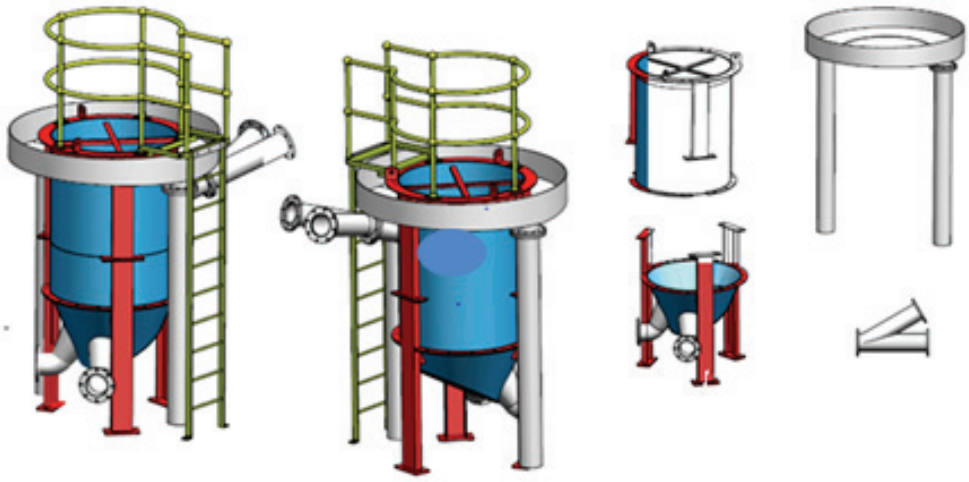

Figure 25. Custom designed Warman® AHF™ froth hopper.

Concluding the froth pump trial and the way forward

In a ramp-down phase to concluding the Foskor (Plant B) trial and testing campaign, the Warman® 6F-AHF™ froth pump was stopped and disassembled for a visual wear rate inspection of the AHF™ froth inducer vane impeller, the Hi-Seal™ expeller assembly, and other wet-end components (Hi-Seal™ relates to the upgraded expeller gland system).

After approximately 12 months of operation the froth impeller was still in excellent condition as compared to a conventional centrifugal impeller after the same operating period. In addition, the froth pump impeller displayed very little sign of any impact, sliding, or erosion damage to any of the wet-end components, as shown in Figure 26.

Figure 26. The Warman® 6F-AHF™ froth pump impeller after 12 months' service

Currently, this Warman® 6F-AHF™ froth pump impeller is still in operation after 98 weeks, and the projected wear life of the impeller is estimated to exceed a further 26 weeks (6 months).

During a planned stoppage, the Warman® 8/6F-AH™ slurry pump was opened to replace the worn impeller. Figure 27 shows the worn out impeller after 101 weeks of operation. Significant wear was noted to the inlet and leading edge of the pumping vanes, the vane trailing edges, and the back shroud. This wear pattern was the result of localized turbulent flows, recirculating flows, and fine particles trapped in localized vortices within the pump.

Figure 27. The Warman® 8/6F-AH™ slurry pump impeller after 101 weeks' service

Based on the superior pumping performance and improved wear life of the Warman® 6F-AHF™ froth pump, Foskor is considering installing similar pumps in other applications.

Furthermore, the proven benefits of the Warman® AHF™ froth pump range resulted in Weir Minerals Africa participating in the optimization/upgrading project for the Ultimate flotation plant, which resulted in Weir Minerals obtaining the purchase order for the AHF™ froth hopper design and supply of AHF™ pumps for the Ultimate flotation plant. The scope of supply included:

Froth transfer pump sets

Rougher concentrate: Warman® 4D-AHF™ froth pump with compatible AHF™ hopper.
Scavenger concentrate: Warman® 4D-AHF™ froth pump with compatible AHF™ hopper.
Cleaner concentrate: Warman® 3CC-AHF™ froth pump with compatible AHF™ hopper.
Final concentrate: Warman® 3CC-AHF™ froth pump with compatible AHF™ hopper.

Tails transfer pump sets (no froth hoppers required)

Cleaner tails: Warman® 4/3D-AH™ (HiSeal™) slurry pump - no FVF.
Final tails: Warman® 8/6E-WRT™ (HiSeal™) slurry pump - no FVF.

All system curve duty points for the Warman® AHF™ froth pumps were designed to include a medium-type froth condition (1.5 FVF or 33% air volume). All AHF™ froth hoppers were specifically designed for the respective froth transfer mass balances, and unlike the high retention times designed into the conventional sumps, the AHF™ froth hoppers were designed around 90 to 100 seconds retention times.

Detailed engineering drawings for the AHF™ froth hopper were completed in-house by Weir Minerals Africa's engineering office.

Conclusion

For many years the standard Warman® and Envirotech® centrifugal slurry pumps have been used in froth pumping systems. Detailed FVF test results have indicated that FVFs are susceptible to changes in a flotation plant, ranging from below 1.1 (brittle froth) to above 1.90 (very tenacious froth). In most cases the standard centrifugal slurry pump will struggle to transfer froth concentrates that fall within the medium to tenacious FVF conditions (1.25–1.80), which may create very unfavourable pumping conditions. Unstable froth sump levels and sump overflows, in conjunction with air binding problems, are indications that high FVFs are creating inefficiencies within the froth transfer system.

From the development of the new Warman® AHF™ froth pump, flotation plants can now enjoy improved froth transfer efficiencies with reduced concentrate spillages. The unique Warman® AHF™ froth pump design allows for greater froth handling operational windows. When faced with difficult froth transfer applications, the Warman® AHF™ froth pump complete with the custom-designed Warman® AHF™ froth hopper will handle high FVFs, offering improved system stability.

Acknowledgements

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Since 1993, I have been involved in supplying mining and mineral processing equipment to the heavy industrial and mining sectors.

Between 2001 and 2005, I managed a branch for a fan company, and was involved with designing and supplying air purification and materials handling equipment to processing plants.

Between 2005 and 2007, I headed up a branch specializing in bearing reclamation work and analysing bearing failures on mineral processing equipment.

In 2007, I joined Weir Minerals Africa, and since then have been extensively involved in supplying mineral processing solutions and optimization programmes to beneficiation plants.