

Froth Pumping

using Warman® centrifugal slurry froth pumps.

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Abstract

Mineral froth pumping utilising centrifugal slurry pumps is a major engineering challenge for the end users and pump manufacturers due to the undesirable outcome of unstable pump performance. Most of these challenges occur due to incorrect pump selection and suction tank design. The traditional approach is to oversize the pump for pumping mineral froth. New horizontal slurry froth pump designs offer opportunities to improve the mineral froth with challenging (high) Froth Volume Factor while maintaining high efficiency, long wear life and stable pumping performance.

This paper examines the flotation process in detail and how froth pumps are designed to handle this arduous process.

Introduction

The following terms are used in this document:

Slurry: two-phase solid-liquid mixture (De-aerated mixture)

Mineral froth: three-phase solid-liquid-air mixture (Aerated mixture)

Froth Volume Factor (FVF): the ratio between initial mineral froth volume and final slurry volume after a 24 hour period of time, see figure 13.

Boyle's Law: $P \cdot V = \text{constant}$, where P is air pressure and V is air volume

To extract minerals from ores generally requires crushing and grinding the ore. For complex ores, and to maximise the recovery of minerals, it is ground to fine particle sizes. The flotation process is often utilised to liberate the minerals from rock. The fine particles in the form of slurry are introduced into agitated flotation cells with the addition of air and flotation agents. The fine particles of mineral ore attach themselves to the air bubbles and float to the surface as mineral froth, while the waste rock sinks. The mineral froth spills over the side of the flotation cells and is recirculated through other stages of the flotation process to achieve the maximum efficiency and mineral recovery.

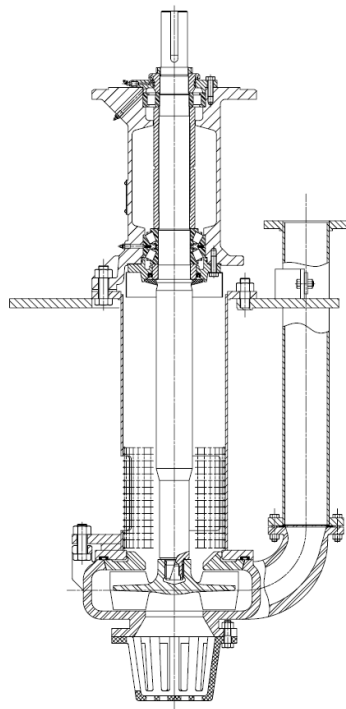
Mineral froth created from the flotation cells contains fine particles with a fine dispersion of air bubbles. To move the mineral froth from one flotation cell to another and then to the next process requires pumping. The characteristics of the mineral froth depend on the type of ore being treated, the fineness of the particles, the concentration, the amount of air in the mineral froth and the type of reagent used.

Mineral froth can vary from brittle (easily broken down with the bubbles generally being large) to tenacious (the air is tightly bound in the mineral froth and will remain a froth for many hours – these bubbles tend to be very fine). The characteristics of the mineral froth will change from day-to-day and even hour-to-hour depending on the varying parameters. Combinations of various ore material push the limits of the flotation process further, to recover more minerals and to improve flotation process efficiency. This means mineral froth with a higher Froth Volume Factor (FVF) in the flotation process is generated, resulting in arduous froth pumping conditions. The air in the mineral froth is equivalent to a fluid with a very high saturated vapour pressure close to atmospheric pressure. Consequently, the available Net Positive Suction Head (NPSHa) when pumping a mineral froth is usually very low.

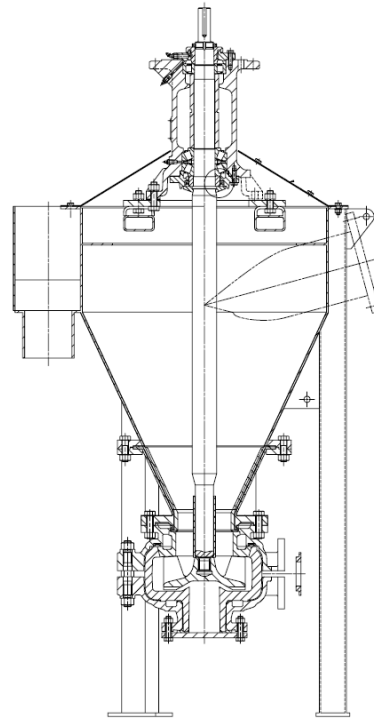
Vertical froth pumps

The Warman® SP, SPR and AF vertical heavy duty centrifugal slurry pump series SP (figures 1 and 2, have been traditionally used for pumping mineral froth. Due to the added bulk of the froth, the size of the conventional centrifugal slurry pumps used for mineral froth pumping must be larger than if selected for standard slurry.

Vertical pumps do not use submerged bearings and do not utilise shaft seals. Semi-open impeller designs with vanes located on both sides of the shroud, or only on the top side, are suitable for pumping froth. Mineral froth can escape around the shaft into the slurry level in the sump or the tank. With a vertical pump design using a cantilever shaft, the pump critical speed determines a lower pump Total Head (TH) of approximately 25 metres. Critical speed constraints can be overcome by special volute design and/or shaft materials. As flotation technology evolves, the volume of product processed increases. To attend to this new demand, there is a need to pump higher flow rates with an increased head. Vertical pumps used previously may become undersized and unsuitable to handle these new flow-head requirements. If such a pump is not upgraded and is taken to its limit during operation, its ongoing operational cost becomes an issue due to more frequent bearing failures and lower pump efficiency.



Vertical Sump pump SP
Figure 1

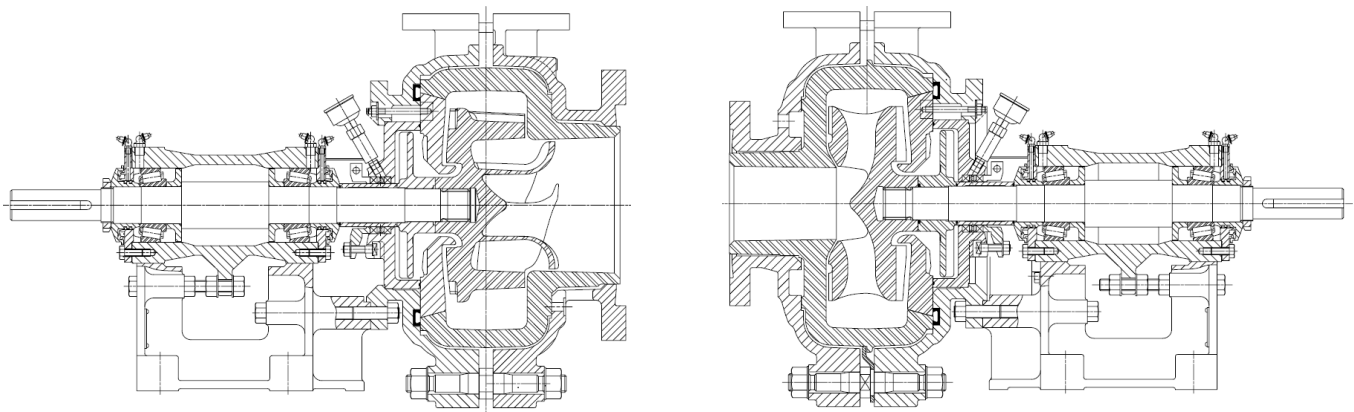


Vertical Tank Pump AF
Figure 2

Horizontal froth pumps of non-vented design

The Warman® AHF horizontal heavy duty centrifugal slurry pump series (figure 3), and the Warman® MF and LF series have a smaller footprint for their capacity, are easier to maintain and less sensitive to bearing and shaft failure due to very low vibration levels. Horizontal pumps are available in larger sizes than vertical pumps, so they can also handle larger flow rates of mineral froth.

The preferred method to improve pumping mineral froth is to enlarge the pump intake diameter to expose the maximum possible volume of fluid flow to the impeller blade action. The spinning impeller is also able to induce pre-rotation and shear to the froth in the intake pipe ahead of the pump, thereby assisting mineral froth handling. Semi-open impellers are very effective in inducing swirl motion to the mineral froth in the intake pipe. For very tenacious mineral froth, it is necessary to enlarge the pump inlet size as well as adding impeller inducer vanes (scoops) in the pump intake - see figure 5.



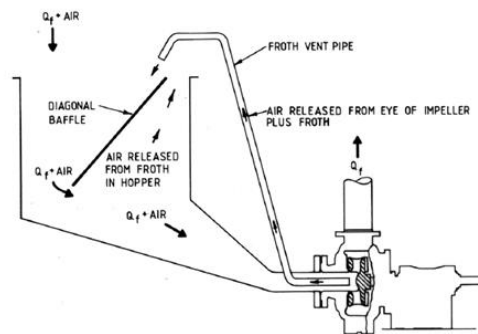
3 AHF Horizontal non-vented froth slurry pump
Figure 3

4/3 AH Horizontal slurry pump
Figure 4

This pump configuration is called a non-vented standard horizontal froth slurry pump design. A large population of pumps prove the non-vented design concept. However, in certain mineral froth conditions with high FVF and tenacious mineral froth, the non-vented pump application results in unstable pump performance due to air lock (air binding) in the impeller eye. Additional methods to reduce FVF in a suction sump can be used, but sometimes they turn out to be too costly and typically end users are not in favour of this type of solution.



Warman patented flow inducer impeller vanes (scoops)
Figure 5



Froth vent pipe in pump suction
Figure 6

A venting pipe fitted into the pump suction can be used to release air lock - see figure 6. The addition of a venting pipe has a minimal practical enhancing effect on pump performance and is very rarely fitted into the pump on site.

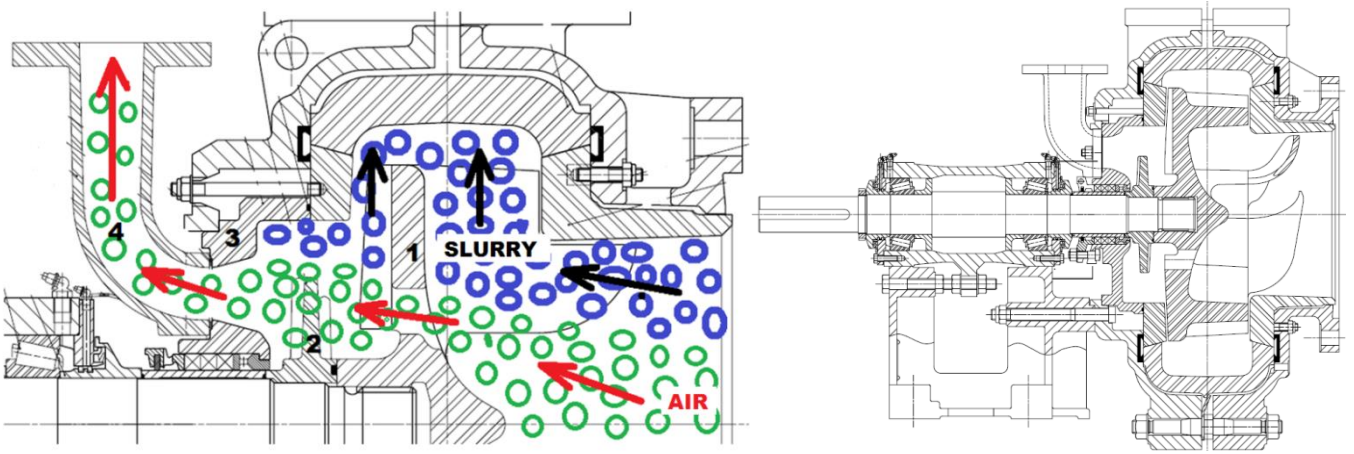
Horizontal froth pumps of vented design

The way forward for pumping mineral froth with high FVF is to explore the technique of separating gas from highly aerated mixtures and subsequently venting the separated gas through the impeller back shroud.

This technique has been used in paper stock pumps since the 1980's. For this purpose a single stage pump equipped with a semi-open impeller was utilised; this impeller incorporated back expelling vanes and back shroud vent holes. Additionally, a vented gas collection chamber was installed behind the impeller with supplementary accessories to assist in removing the lighter aerated fraction.

The primary accessory for gas evacuation assistance found in other pumps for handling gaseous mixture is a vacuum pump; either being incorporated on the same pump shaft and placed in the gas collecting chamber or connected to a venting pipe separately. However, once abrasive solid particles are present, vacuum pumps do not work due to their tight internal clearances.

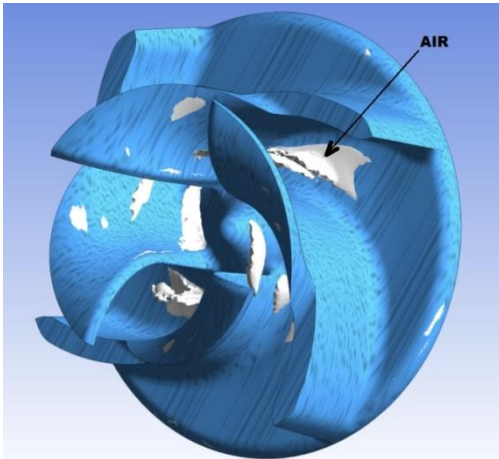
Figure 7 shows a Warman® horizontal heavy duty froth centrifugal slurry pump incorporating the new vented design - Continuous Air Removal System (CARS).



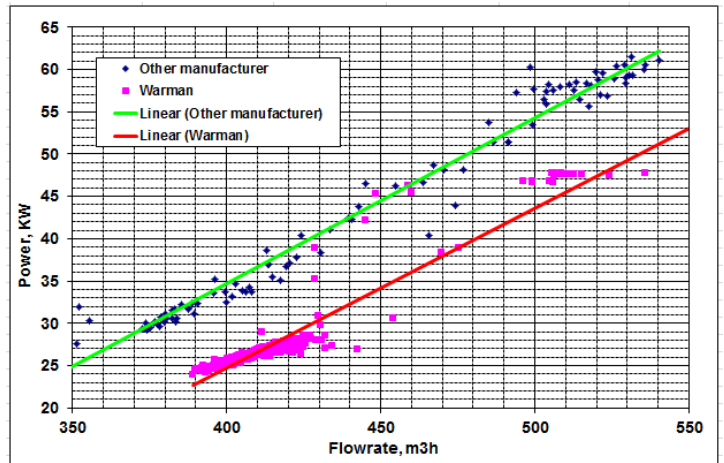
Legend: 1-Slurry Impeller, 2-Propeller, 3-Collection Chamber, 4-Venting Pipe

Horizontal froth pumps vented design - CARS
Figure 7

The CARS design has been developed and refined with the extensive assistance of Computational Fluid Dynamics (CFD) analysis (see figure 8), and a significant amount of testing which took place in real flotation processes with high FVF mineral froth (FVF > 1.4).



Air concentration close to impeller back shroud
Figure 8



CARS efficiency comparison
Figure 9

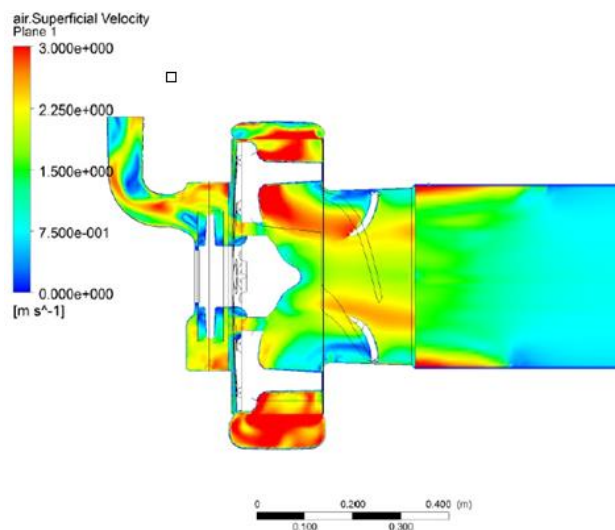
The CARS design performs by separating and removing gas from the froth inside the pump in a two-stage process. In the first stage of the CARS process, the flow inducer blades of the froth impeller promote the motion of the froth slurry into the impeller's eye, while inducing pre-rotation for initial separation of the high gas volume fraction towards the centre of the impeller and towards the venting holes located on the impeller back shroud.

In the second stage of the CARS process, the propeller, which is located behind the impeller in the gas collection chamber, promotes the axial movement of the gas contained in the mixture and out of the collection chamber through the venting pipe. At the same time it rotates the mixture inside the chamber for additional separation of solids back to the process by the centrifugal action of main impeller back vanes. This arrangement has no reliance on tight running clearances. All wetted parts are made of wear resistant materials for problem free handling of abrasive solid particles.

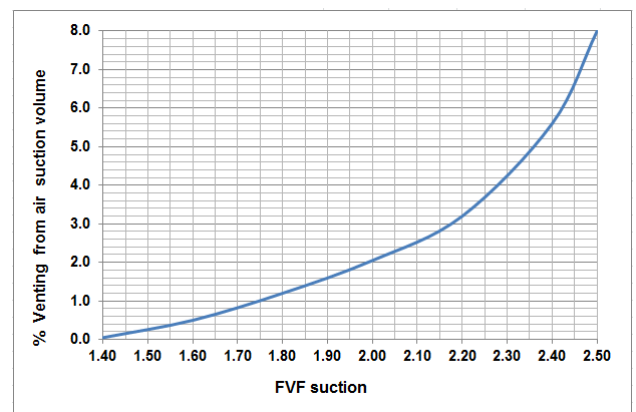
The CARS venting feature helps to relieve the air lock in the impeller eye in a very effective way. When the FVF increases, air volume starts to build up in the impeller eye. At the same time, froth levels in the tank rise and the pump speed is increased by the control system in order to handle additional flow. The CARS starts to vent intermittently until it reaches continuous air venting. At this stage, the air is discharged through the venting pipe at almost fan pressure levels. The impeller eye air lock is continuously released and the pump reaches a stable performance.

Pump efficiency drops when the pump is handling mineral froth with high FVF values and the CARS is venting. This is due to a high volume of air passing through the impeller. Impeller design is very important for overall pump efficiency. Tests were conducted on various froth pump impeller designs including semi-open impellers with flow inducer vanes in the eye and closed design impellers with flow inducer vanes. Tests were also conducted on pumps made by various manufacturers. A semi-open impeller with scoop vanes in the suction provided superior pump efficiency compared to other impeller designs. As an example, figure 9 shows a comparison between the pump efficiency of a Warman® froth pump with semi-open impeller and flow inducer vanes, and a froth pump of another manufacturer.

CFD was used to estimate froth pump performance, to understand air movement and its distribution inside the pump. Figure 10 shows air velocity across the pump internal channels including venting.



**Air velocity in pump body
Figure 10**



**Air Volume Vented
Figure 11**

Based on the CFD results to estimate froth pump performance when using a vented froth pump design, the air venting and air compression in the pump should be taken into account. This means

that the volume flow rate in the pump discharge has a lower value than at the pump suction inlet due to air venting and air compression across the pump.

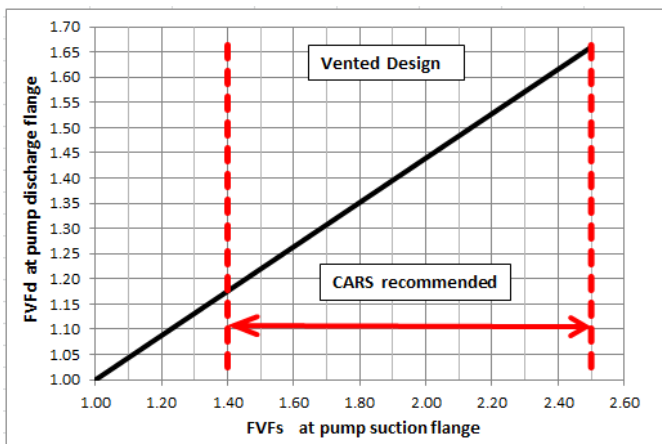
Boyle's Law modified to accommodate the vented froth pump configuration used to evaluate air volume (V) and air pressure (P) inside the pump on the assumption that the temperature of air remains constant.

$$P_s * V_s = P_d * V_d + P_v * V_v$$

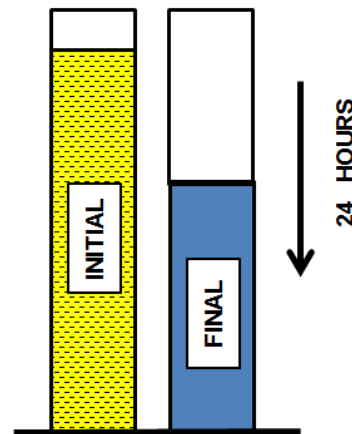
Where the subscripts are: **s** for suction, **d** for discharge and **v** for venting.

Based on significant testing with high FVF phosphate froth, it became possible to determine the percentage of air venting from the air volume in the pump suction. Figure 11 illustrates the minimum volume of air venting required to release the air lock in the impeller eye.

The FVF correction/conversion is valuable for the evaluation of the pump performance due to venting and air compression (see figure 12). FVF denotes FVF in pump discharge and is numerically lower value than the FVFs in pump suction.



FVF conversion
Figure 12



Froth Volume Factor
Figure 13

The vented CARS design is successfully operating with various typical mineral froths such as Copper, Gold, Zinc, Bitumen, Talc, Molybdenum and Potash. It has been proven that the conversion chart shown in figure 12 can be used for the majority of typical froth pumping applications as a first approximation. Once a new installation of the vented froth pump design is in operation, further specific conversion charts can be developed based on actual pump performance.

The CARS design breaks the traditional froth pumping approach, where froth pumps should be used for low total head applications only, typically less than 35m. Froth vented pump designs with CARS work very well for mineral froth high head tailings duty, with pump total head > 55m and with FVF > 2.0. With the assisted venting, higher pump speed improves the effectivity of CARS.

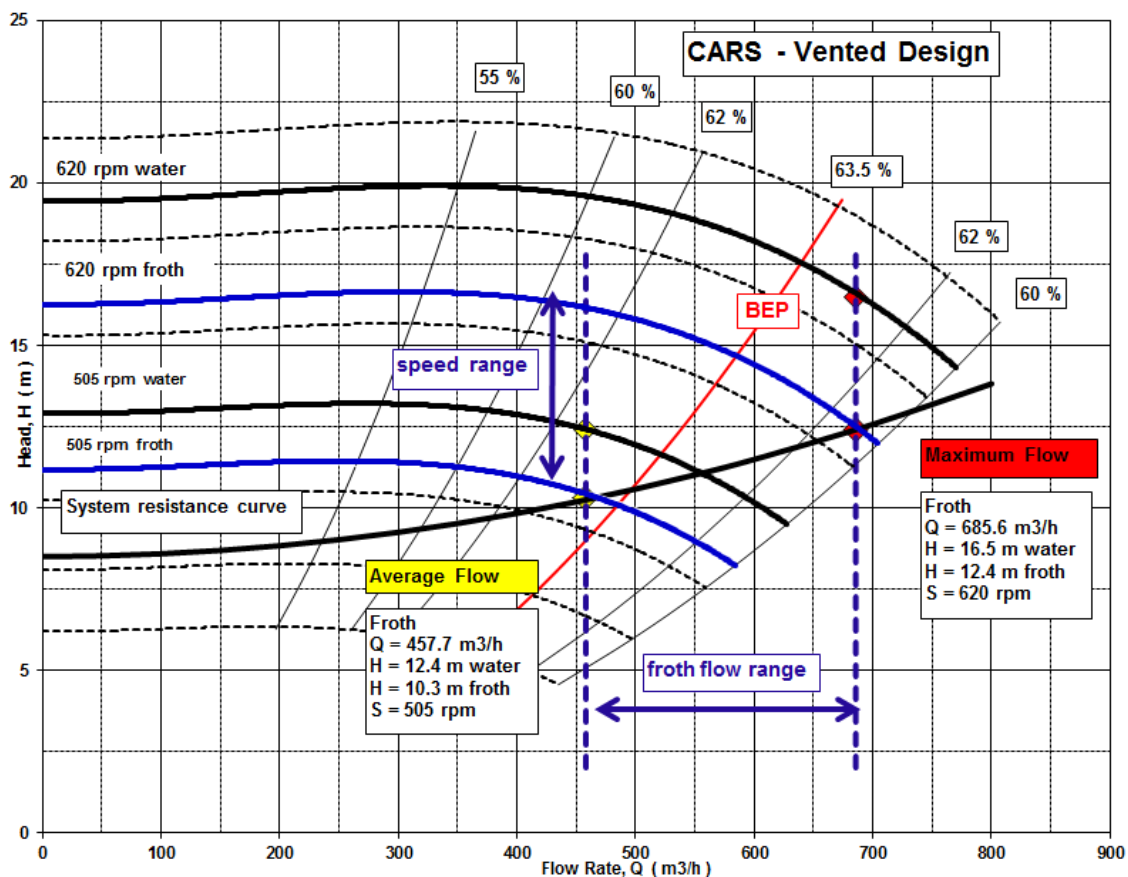
CARS also breaks the traditional froth pumping approach where a froth pump should be oversized with respect to flow rate. Froth vented pump design with CARS does not need to be oversized, see Figure 14. Normal (average) operating flow rate should be located to the left of, but close to the best efficiency flow line. Design (maximum or rated) flow rate can be located to the right of the best efficiency flow line.

For the full evaluation of the froth pump's performance, the suction sump and suction pipe design should be taken into account. This subject is not covered in the paper because in many cases

suction sump and pipe designs already exist on site and the end user has a preference to retain them without any design change.

Froth Volume Factor

The most important information to possess for froth pump selection is the correct FVF value and a full understanding of FVF variation in the flotation process. The end user or Engineering project company should provide the value of FVF. In case of an existing process, it is recommended to take mineral froth samples on site to determine the FVF. The sample should be taken from the feed into the suction sump, and pump suction pipe. It is especially difficult to take a representative sample from the pump suction pipe due to the high pressure of tall suction sumps (flooded suction) and location of tapping connection in the pipe. Mineral froth or air bubbles are mostly located at the top of the pipe cross section. Tapping point is typically located on the bottom of suction pipe as it is also used as a drainage point. If the tapping valve is fully open, it can blow mineral froth out from the sample container. If the tapping valve is only slightly open, not all mineral froth or air bubbles will be collected in the sample container. It is good practice to measure several mineral froth samples to obtain an average FVF value. For the majority of mineral froth samples, 24 hours should be enough time to determine the FVF. If after 24 hours the slurry still contains air, a sample should be kept until air essentially disappears, see figure 13.



CARS Froth Pump typical duty points position
Figure 14

Conclusion

Pumping mineral froth in flotation processes and froth tailing duties still remains a major engineering challenge for pump manufacturers and end users. The CARS vented froth pump design has shown the ability to significantly improve froth pump performance stability and pumping efficiency without the additional requirements of froth volume factor (FVF) reduction.

ACKNOWLEDGEMENTS

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REFERENCES

- [1] Weir Minerals Technical Bulletin #28 Version 2 , 08/2009 - Pumping Froth

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