

## Froth Pumping

### Introduction

Pumping mineral froths with centrifugal slurry pumps is a major engineering challenge for both the end users and the pump manufacturers. Incorrect pump selection and operation, and incorrect suction tank and suction piping design can cause unstable pump performance. New horizontal froth pump designs offer opportunities to improve froth pumping capabilities.

The Warman® froth pump designs can pump froths with Froth Volume Factors (FVF) of up to 2.5 while maintaining both high efficiency and stable pumping performance. This document provides a simple selection procedure, along with tips and techniques, for successful pump selection and operation in difficult froth pumping applications.

The following terms are used in this Technical Bulletin:

**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 of the aerated volume to the de-aerated volume. See Figure 13.

**Equation 1** - 
$$FVF = \frac{\text{Aerated Volume}}{\text{De-aerated Volume}}$$

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

**Subscripts Used:** s = suction, d = discharge, f = froth, sl = slurry, w = water, a = available

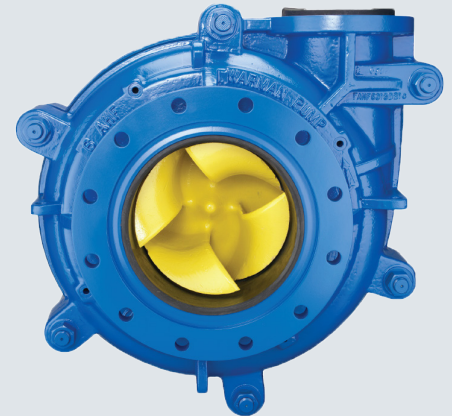
### Froth pumping background

Extracting minerals from ore generally requires crushing and grinding of the ore. In order to maximize the recovery of minerals, the ore is ground into fine particles. The flotation process liberates the minerals from the non-

valuable material. The fine particles, in the form of slurry, are introduced into agitated flotation cells. Air and flotation reagents are then added. In the forward flotation process, the fine mineral particles attach themselves to the air bubbles and float to the surface as mineral froth. 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 consists of 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, pumping is required. The characteristics of the mineral froth depend on the type of mineral, the particle size distribution, the solids concentration, the amount of air in the froth, and the type of flotation reagent used.

Mineral froths can range from brittle on one end of the spectrum, consisting of large bubbles that break easily, to tenacious on the other end of the spectrum, consisting of small bubbles that can remain in the liquid for many hours. The characteristics of the mineral froth can change frequently depending on the varying process parameters. Combinations of various flotation techniques push the limits of the flotation process in order to recover more of the valuable minerals and improve flotation process efficiency. This typically results in a mineral froth with a high FVF. The air contained in the mineral froth complicates suction conditions, often resulting in an air lock condition at the impeller eye.



Warman® horizontal froth pump

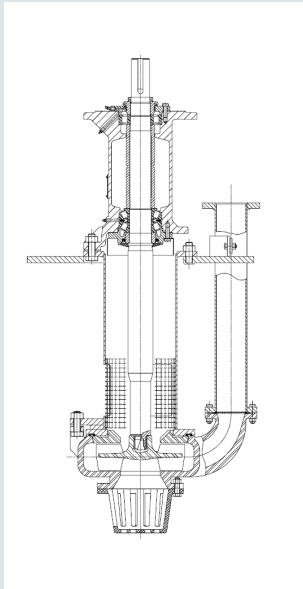


Figure 1. Vertical sump pump SP/SPR

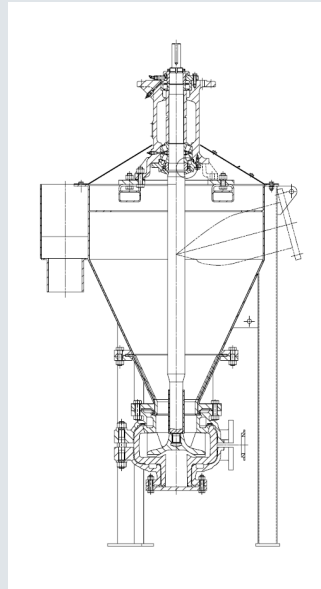


Figure 2. Vertical tank pump AF

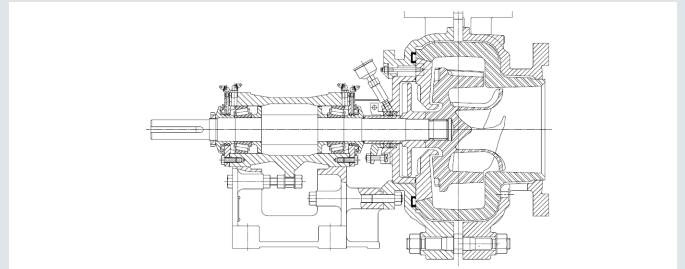


Figure 3. 3" AHF (Warman® standard froth pump)

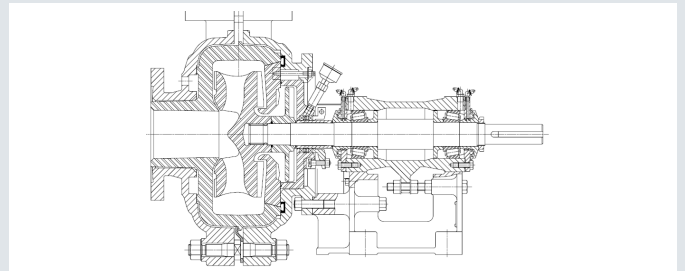


Figure 4. 4/3 AH® (Warman® slurry pump)

## Vertical froth pumps

The Warman® SP, SPR and AF vertical slurry pumps (Figure 1 and Figure 2) have been used for pumping mineral froths in the past. Vertical pumps do not have submerged bearings or shaft seals. Semi-open impeller designs with vanes located on both sides of the shroud are suitable for pumping froth. With a vertical cantilevered pump, the shaft critical speed limits the head that the pump can produce to about 25 meters. In some cases, shaft critical speed issues can be resolved by implementing a special volute design and/or shaft materials.

As flotation technology evolves, the volume of product will increase. To meet the demand, there will be a need to pump higher flow rates at a higher head. The vertical pumps used previously may become undersized and unsuitable to handle these tougher duty requirements.

### Standard Warman® froth pump design

The Warman® AHF, MF, and LF horizontal slurry pumps (Figure 3) are easier to maintain, and they are not as prone to bearing and shaft failures as their vertical counterparts. An enlarged intake diameter helps facilitate the froth flow into the pump. The inducer vanes of the impeller help draw the froth into the pump suction as well (Figure 5). The pump configuration in Figure 3 is a non-vented horizontal froth pump design. A large population of successfully operating pumps support the non-vented design concept. However, in certain mineral froth conditions where the froth is particularly tenacious and/or has a high FVF, the non-vented froth pump can still become air locked, causing surging and unstable pump performance. Measures can be taken to try to reduce the FVF in the suction tank before the froth gets to the pump, but these measures often times are cost prohibitive.

### Warman® froth pumps of vented (CARS) design

The solution to pumping mineral froths with high FVFs is to implement the concept of using the pump itself to separate and remove the entrained air from the froth slurry. The technique of separation and venting has been used in paper stock pumps since the 1980's. The initial concept consisted of a single stage pump equipped with a semi-open impeller with back expelling vanes and venting holes in the back shroud, and a gas collection

chamber behind the impeller. The primary means to assist gas evacuation found in these pumps was the use of an additional vacuum pump. The vacuum pump would be either mounted on the centrifugal pump shaft inside the gas collection chamber or connected to the venting pipe separately. However, typical vacuum pumps are not slurry pumps due to their reliance on tight running clearances. Once slurry is introduced, the tight clearances are either blocked or opened up via wear. In either case, the operational life of a vacuum pump is dramatically reduced.

Figure 7 shows the new Warman® horizontal froth pump Continuous Air Removal System (CARS) design. The impeller has back expelling vanes and back shroud vent holes (Figure 6). In addition to the impeller modifications, the venting system includes a gas collection chamber with a flow inducer behind the main impeller. The flow inducer facilitates the flow of separated air through the vent pipe and out of the pump. As the inducer vanes apply a swirl effect, the heavier (compressed) portion of the mixture centrifuges to the outer periphery of the suction piping which forces the free air towards the middle. The air passes through the vent holes in the back shroud of the impeller into the collection chamber where the flow inducer forces the air out through the vent pipe.

The CARS design has been developed and refined using Computational Fluid Dynamics (CFD) analysis and a significant amount of supplemental testing to confirm the CFD results. Testing was conducted on site in a flotation process where the high FVF (>1.4) mineral froth was causing major issues for the operator.

The CARS design separates and removes gas from the froth in a two-stage process. In the first stage of the process, the flow inducer blades of the froth impeller help draw the froth slurry into the pump while, at the same time, inducing slurry pre-rotation in the suction piping. This is where the initial separation occurs.

In the second stage of the process, the flow inducer, which is located behind the impeller in the gas collection chamber, facilitates the movement of the collected air out of the collection chamber through the vent pipe (Figure 17). The rotating action of the flow inducer also centrifuges the mixture inside the chamber resulting in additional separation. Solids in the collection chamber are forced back into the process by the centrifugal action

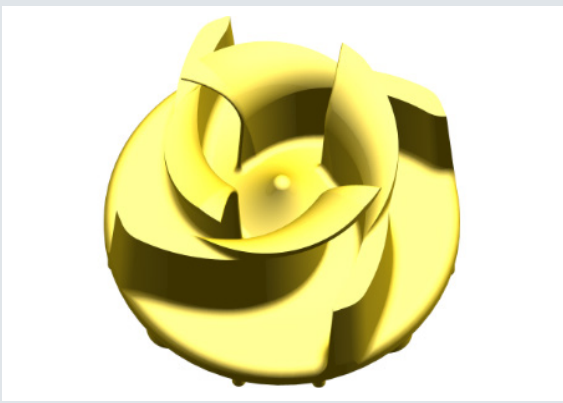


Figure 5. Warman® non-venting froth impeller, QU1

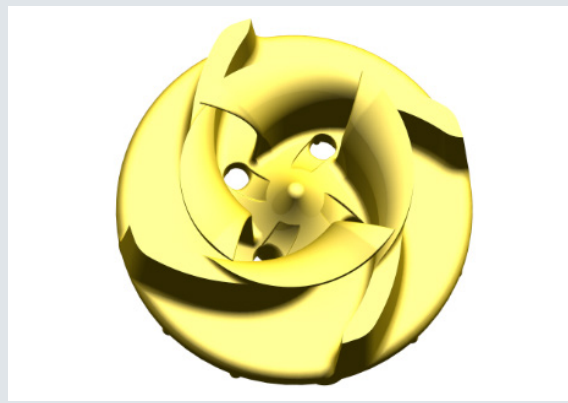


Figure 6. Warman venting (CARS) froth impeller, QUAR

of back expelling vanes of the main impeller. Unlike the vacuum pump, this arrangement has no dependency on tight running clearances, and all wetted parts are made of wear resistant materials specifically designed for handling abrasive slurries.

As FVF increases, air volume starts to build up in the impeller eye, and the pump performance suffers. This causes froth levels in the tank to rise which causes the control system to increase pump rpm which only serves to exacerbate the initial air locking problem. The CARS venting design effectively helps to relieve this air lock in the impeller eye. The CARS design starts to vent intermittently until it reaches a continuous air venting state. At this stage, the air is discharged through the venting pipe at almost fan like pressure levels. The air that would accumulate at the impeller eye is continuously released and the pump performance remains stable. Impeller design is very important for overall pump efficiency. Tests were conducted on various froth pump impeller designs including semi-open and closed impellers, both including flow inducer vanes. Tests were also conducted on pumps made by other manufacturers. A semi-open impeller with inducer vanes showed better pump efficiency relative to other impeller designs. Figure 9 is a comparison between the pump absorbed power of a Warman® froth pump with semi-open impeller with flow inducer vanes and the absorbed power of a froth pump of another manufacturer in the same high FVF application.

CFD was used to estimate froth pump performance and to understand air distribution and movement inside the pump. Fig. 10 shows air velocity across the pump internal channels, including the vent pipe. Based on the CFD results, the air venting and slurry compression in the pump are significant and both need to be considered in order to estimate pump performance. The volumetric flow rate at the pump discharge is significantly less than the volumetric flow rate into the pump suction. Boyle's Law, modified to accommodate the vented froth pump configuration, is used to evaluate air volume (**V**) and air pressure (**P**) inside the pump. The temperature is assumed to remain constant.

**Equation 2 -** 
$$P_s * V_s = P_d * V_d + P_v * V_v$$

Extensive testing with high FVF phosphate froth suggests that there is a minimum volume of air that needs to be vented in order to release the air lock in the impeller eye.

The FVF correction/conversion chart shown in Figure 11 is useful for the evaluation of the pump performance due to venting and air compression.  $FVF_d$  denotes froth volume factor of slurry in pump discharge and is lower than the

$FVF_s$ , froth volume factor of slurry in pump suction.

The vented CARS design is successfully operating worldwide with various mineral froths such as Copper, Gold, Zinc, Bitumen, Talc, Molybdenum and Potash. It has been proven that the conversion chart shown in Fig. 11 can be used for the majority of typical froth pumping applications as a first approximation. Once a new installation of the CARS design is in operation, specific conversion charts can be developed based on actual pump performance.

The CARS design departs from the traditional froth pumping approach where froth pumps should be used in applications where the total head requirement is less than 35 meters. The CARS design works very well with high head froth pumping duties where the head requirements exceed 50 meters. CARS can be used in slurries with froth volume factors of up to 2.5. Unlike the standard, non-vented froth pump design, higher pump operating RPM improves the effectivity of CARS. The nominal operating flow rate should be located to the left of, but close to the best efficiency point (BEP). The maximum (design or rated) flow rate can be located to the right of the BEP, as shown in Figure 15. Based on empirical data, operating to the right of BEP with a non-vented design results in diminished performance. In the case of a standard AHF, the pump must be sized such that both the nominal and the maximum flow rates are located to the left of BEP.

### Suction sump design

Suction sump (Hopper) design is an integral part of mineral froth pumping system evaluation. Suction sump design should reduce FVF, or at least maintain the FVF of the mineral froth feeding into hopper. Incorrect hopper design can increase FVF and make already arduous froth pumping conditions even more difficult. It can also result in pump performance failures. Guidance for suction sump dimensions can be found in Figure 16. Basic suction sump design features should include retention time of 60 seconds (no less than 30 seconds), tangential feed, and cylindrical tank shape.

### Sealing and drive options

Froth pumps with CARS and standard froth pump designs have different shaft sealing and drive configuration options.

The non-vented AHF design can be equipped with any of the standard seal types including gland, centrifugal (expeller), or mechanical seal. A belted configuration and a direct connect configuration are both suitable drive arrangements. It is also preferable to use a variable

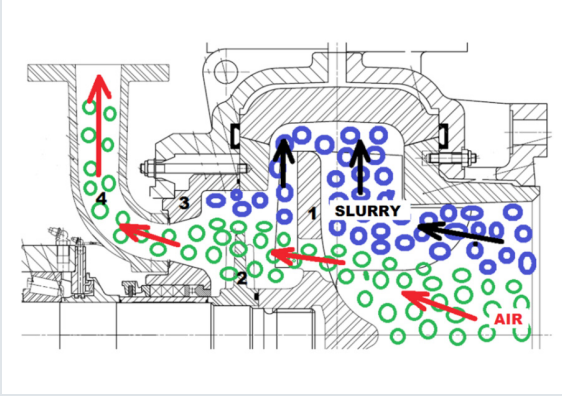


Figure 7. Warman® AHF froth pump with CARS

1 - QUAR Impeller, 2 - Flow Inducer, 3 - Collection Chamber, 4 - Vent Pipe

frequency drive in order to provide the necessary speed flexibility needed to accommodate changes in froth process characteristics that are caused by variable output of the flotation cells, duties changes, and variations in ore performance.

The vented “CARS” design has some restrictions for shaft sealing and drive configuration options. The vent pipe location limits this design to a gland style shaft sealing option only. A CV overhead motor mounting arrangement would interfere with the vent pipe, so a reverse overhead motor mount (ZV), or a side by side (CL/CR), would be required.

### Froth Volume Factor

The most important pieces of information to have for successful froth pump selection are both an accurate FVF value and a full understanding of FVF variation in the flotation process. The end user or the Engineering, Procurement, and Construction Firm should be able to provide the FVF. In the case of an existing process, a froth sample can be taken at site from which an accurate FVF can be determined. The sample should be taken from the suction piping, as close to the pump inlet as possible. This will be most representative of what is actually going into the pump. It is good practice to take several samples so that the FVF results can be averaged. For the majority of froth samples, 24 hours should be enough time for the sample to naturally deaerate. If, after 24 hours, the slurry still contains air, then the sample should be kept for another 24 hours, or until contained air disappears, see Figure 12. Note that if the froth volume factor is determined to truly be greater than 2.5, the application should be evaluated in more detail.

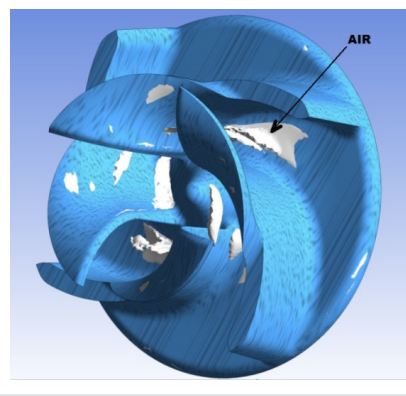


Figure 8. Air concentration areas from CFD

The amount of air entrainment in slurry can be expressed by the following equations:

#### Equation 3 -

$$\text{Percentage Air (or PA)} = 100 * \frac{(\text{Aerated Volume} - \text{DeAerated Volume})}{(\text{Aerated Volume})}$$

#### Equation 4 -

$$\text{Froth Volume Factor (or FVF)} = \frac{1}{(1 - (\text{PA}/100))}$$

### Froth pump selection procedure

Based on the measured FVF value, and the type of mineral froth, either the vented or the non-vented froth pump design will be more suitable. Each has its own selection procedure. The standard AHF, non-vented design is recommended for mineral froth with  $\text{FVF} < 1.8$ . The vented CARS configuration is recommended for any slurry with a FVF of greater than 1.8. However, in some cases, the CARS design can be used even if the FVF is less than 1.8 where the froth has proven difficult to pump with a standard AHF. Bitumen froth is one example of where CARS may be better suited even though the FVF is less than 1.8. The QU1 froth impeller with inducer vanes is the standard froth pumping impeller and is used in most cases. There are situations, such as high head applications, where an alternative impeller design may perform better. In either case, the piping should be such that the slurry velocity through the piping is in the range of 2 – 2.5 m/s. If a standard AHF is being used, the maximum flow condition should be used in this calculation. If the CARS AHF is being used, the nominal flow condition should be used in this calculation.

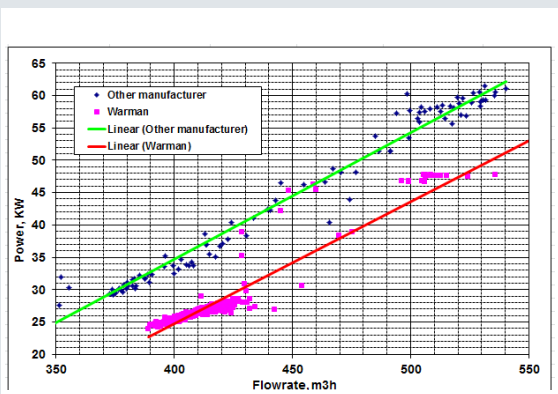


Figure 9. CARS absorbed power comparison

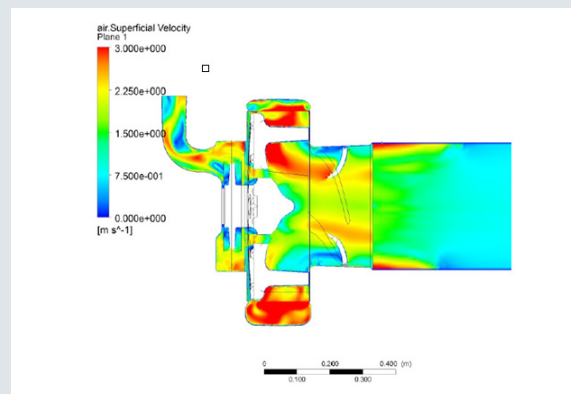


Figure 10. Air velocity in pump body

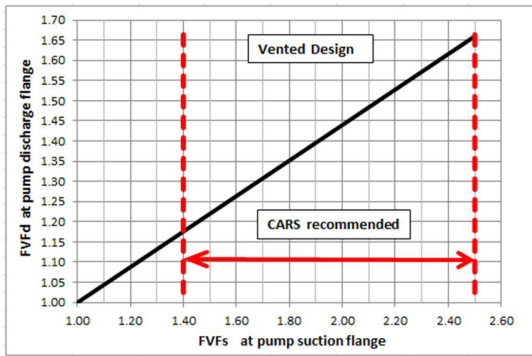


Figure 11. FVF conversion

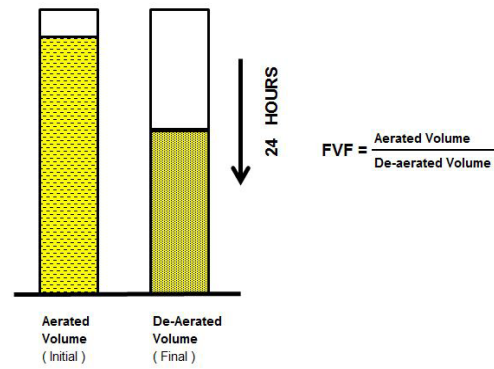


Figure 12. Froth Volume Factor

### Warman® non-vented horizontal froth pump selection procedure

**Note:** Air compression inside the pump is **not** taken into consideration.

- Determine the de-aerated slurry flow,  $Q_{sl}$ .  
**Note:** If a nominal condition and a maximum condition are given, use the maximum condition for pump selection.
- Either obtain from customer, or determine the froth volume factor, **FVF**, using samples taken from the pump suction.
- $Q_f$  denotes the aerated, uncompressed froth flow. Calculate  $Q_f$  using  $Q_f = Q_{sl} \times FVF$ .

Equation 5 -  $Q_f = Q_{sl} * FVF$

- Determine the required duty head.
- Select froth pump such that both the normal flow and design flow rates are between 50% and 100% BEP flow as shown in Figure 15. Required total head should be kept to a minimum, 35 m or less.  
**Note:** NPSHr should be minimised as much as possible.
- Determine Head Ratio (HR) and Efficiency Ratio (ER) correction factors from Figures 13 and 14.
- Determine pump operating RPM for froth head,  $H_f$ .  
**Note:**  $H_w$  = pump total head on clear water.

Equation 6 -  $H_f = H_w * HR$

- Determine froth specific gravity,  $S_f$ .

**Note:**  $S_{sl}$  is de-aerated slurry specific gravity.  $S_f$  can be less than 1.

Equation 7 -  $S_f = \frac{S_{sl}}{FVF}$

- Determine pump efficiency for froth,  $E_f$ .  
**Note:**  $E_w$  = pump efficiency on clear water.

Equation 8 -  $E_f = E_w * ER$

- Calculate the froth absorbed power.

Equation 9 - Absorbed Power on Froth =  $\frac{(Q_f * H_f * S_f)}{(E_f)}$

- Motor size should be chosen such that there is a minimum of 20% safety margin to account for drive losses, shaft losses, and variations in duty conditions.  
**Note:** The use of a Variable Frequency Drive is highly recommended.

### Warman® vented horizontal froth pump (CARS) selection procedure

**Note:** Air compression and venting inside the pump **are** taken into consideration.

$FVF_d$  (FVF at pump discharge) is numerically lower than  $FVF_s$  (FVF at pump suction).

- Determine the de-aerated slurry flow,  $Q_{sl}$ .  
**Note:** If a nominal condition and a maximum condition are given, use the nominal condition for pump selection.
- Either obtain from customer, or determine the froth volume factor, **FVF**, using samples taken from the pump suction.
- $FVF_s$  denotes the FVF of slurry at the pump suction. This is representative of the air content of the slurry entering the pump suction.  
**Note:** Do not use  $FVF_s$  greater than 2.5.
- $FVF_d$  denotes the FVF of slurry at the pump discharge. Estimate  $FVF_d$  using Figure 11.
- $Q_{fs}$  denotes the aerated, uncompressed froth flow rate.

Equation 10 -  $Q_{fs} = Q_{sl} * FVF_s$

- $Q_{fd}$  denotes the vented, compressed, partially aerated flow at the pump discharge.

Equation 11 -  $Q_{fd} = Q_{sl} * FVF_d$

- Determine the required duty head.
- Select froth pump such that both the nominal flow and maximum flow rates are as close to 100% BEP flow as possible as shown in Figure 15.  
**Notes:** NPSHr should be minimised as much as possible. For applications exceeding 35 m total head, impellers without inducer vanes may be required.

- Determine Head Ratio (HR) and Efficiency Ratio (ER) correction factors from Figures 13 and 14.

- Determine pump operating RPM for froth head.  
**Note:**  $H_w$  = total head on clear water.

Equation 12 -  $H_f = H_w * HR$

- Determine froth specific gravity,  $S_{fd}$ .  
**Note:**  $S_{sl}$  is de-aerated slurry specific gravity.  $S_{fd}$  can be less than 1.

Equation 13 -  $S_{fd} = \frac{S_{sl}}{FVF_d}$

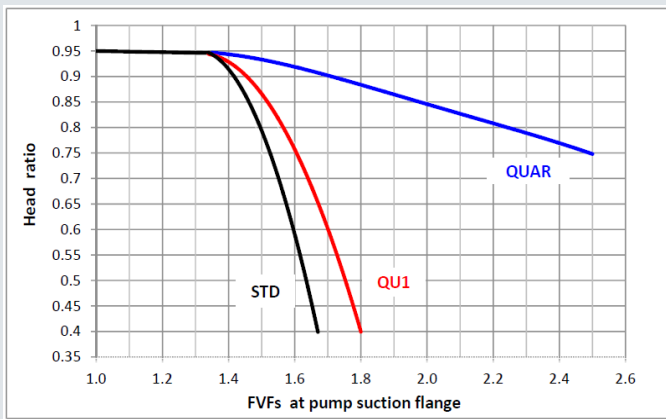


Figure 13. Head ratio

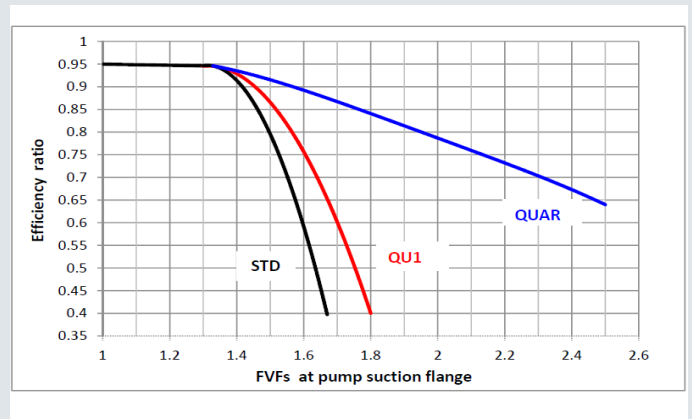


Figure 14. Efficiency ratio

12. Determine pump efficiency for froth.

**Note:**  $E_w$  = pump efficiency on clear water.

Equation 8 -  $E_f = E_w * ER$

13. Calculate the froth absorbed power.

Equation 14 - Absorbed Power on Froth =  $\frac{(Q_{fd} * H_f * S_{fd})}{(E_f)}$

14. Motor size should be chosen such that there is a minimum of 20% safety margin to account for drive losses, shaft losses, and variations in duty conditions.

**Notes:** The use of a Variable Frequency Drive is highly recommended. A "CV" motor mounting arrangement cannot be used with the CARS design.

### Other froth pump applications

Froth pumping exposes some of the problems that can occur at the inlet of a centrifugal pump. If there is nothing preventing the process fluid from entering the impeller eye, then the pump will perform as indicated on its performance curve. Some other types of applications that can present suction problems and ultimately cause pump performance problems are applications involving high yield stress slurries, non-Newtonian slurries, and paste slurries. One would encounter these types of slurries on thickener underflow, thickened tailings, or viscous froth applications such as oil sand bitumen froth. These particular slurries may require more severe corrections than those provided for mineral froths. The larger suction, the flow inducing vanes on the impeller, and larger passageways of the semi-open are features that have proven their capabilities in handling these difficult slurry conditions better than conventional centrifugal slurry pumps. For more engineering information refer to Technical Bulletin No# 14.

### Conclusion

Pumping mineral froths still remains a major engineering challenge. Both the standard AHF and CARS fitted froth pump designs have repeatedly demonstrated their capabilities in improving froth pumping performance stability in many installations around the world.

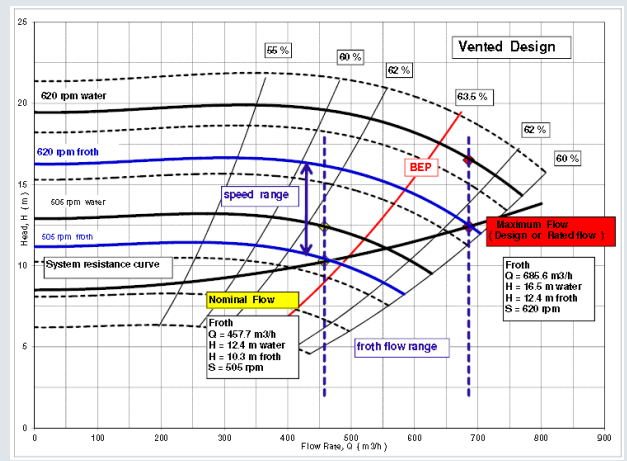
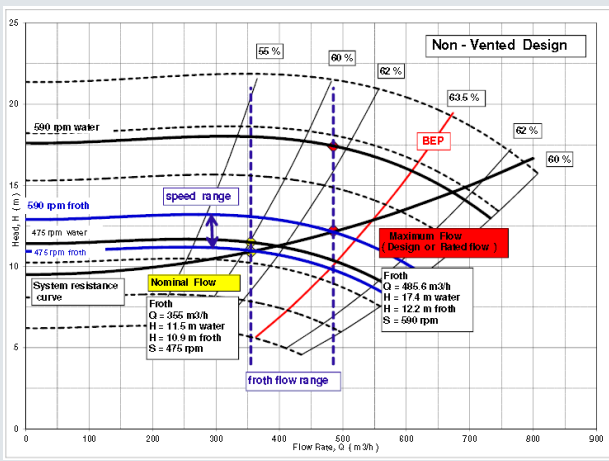
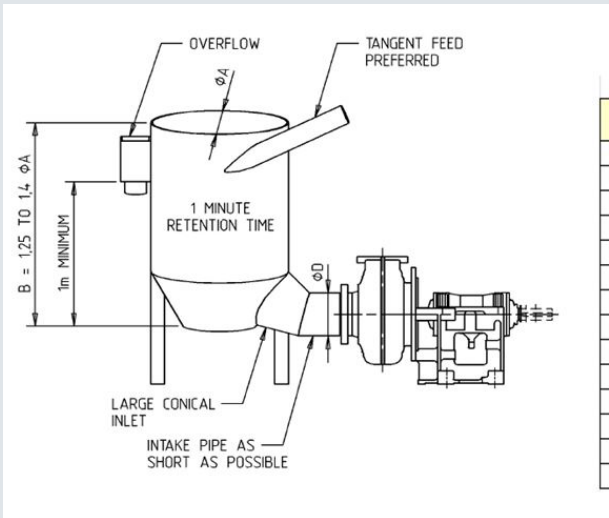


Figure 15. Typical duty points position for a standard (non-vented) front pump and the one equipped with CARS.



HOPPER DIMENSIONS FOR WARMAN HORIZONTAL FROTH PUMPS

PUMP SIZE	INTAKE DIAMETER 'D' (mm)	MAXIMUM FROTH FLOW (m <sup>3</sup> / h)	HOPPER VOLUME (m <sup>3</sup> )	HOPPER DIAMETER 'A' (mm)	HOPPER HEIGHT 'B' (mm)
2 AHF	140	50	1	1000	1250
3 AHF	185	90	2	1200	1500
4 AHF	290	270	5	1700	2150
6 AHF	370	630	11	2250	2850
8 AHF	455	1170	20	2700	3400
10 AHF	512	1620	27	3050	3700
12 AHF	575	2250	38	3500	3950
14 AHF	640	2970	50	3850	4250
10 MF	370	666	11	2250	2850
12 MF	422	936	16	2500	3200
300 LF	525	1404	24	2900	3650
350 LF	575	1440	25	2950	3700
450 LF	600	3600	63	4200	4500
550 LF	700	5400	91	4800	5000

Figure 16. Suction sump design guidelines

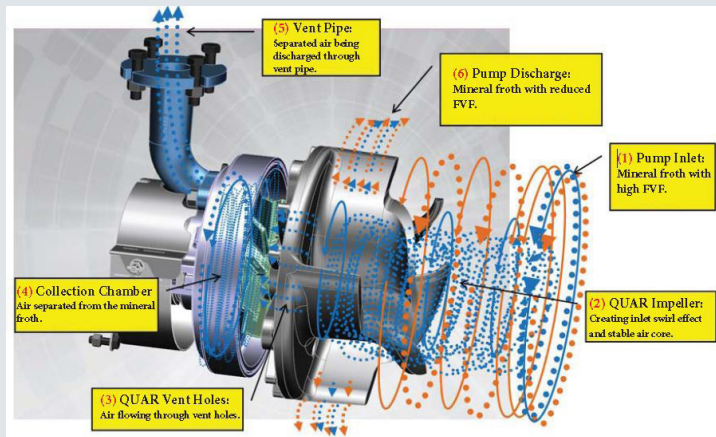


Figure 17. CARS Illustration

Weir Minerals

warman@mail.weir  
www.warman.weir