

# PUMPING OIL SAND FROTH

by

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## ABSTRACT

Froth is the basis to the extraction of bitumen from oil sand. Its components include sand, bitumen, water, and air. The technology of extraction and processing is evolving toward lower temperature of operation where the volumetric content of air and viscosity of bitumen challenge pumping.

To improve the efficiency of froth handling pumps it is important to adapt the technology from other industries. This may include degassing while pumping with secondary vacuum impellers (expellers), recirculating a part of the slurry to the suction, or injecting external hot water.

In an effort to reduce air locking problems and derating of performance, a special impeller for centrifugal pumps was developed. The impellers feature split vanes between the principal vanes. The design allows for adequate passageway for solids at the eye while reducing the formation of large pockets of air between the main vanes. Adequate vane thickness for principal and split vanes is maintained in this design to resist wear from sand.

## INTRODUCTION

Oil sand, also known as tar sand, is a major source of synthetic fuel. It is anticipated that within a few years 35 percent of the oil production in Canada will be derived from oil sand fields in Northern Alberta. In the process of separating bitumen from oil sand, hot water at 90°C (194°F) or warm water at 45°C (113°F) is added to form froth. The froth, which is a mixture of viscous bitumen, water, sand, clay, and air (up to 40 percent by volume), challenges the design of slurry pumps. To reduce the high head to pump froth, designs of piping should focus on the self-lubrication of froth by the water content and by pumping at high speed.

The conventional mineral froth pumps are typically vertical pumps or derated horizontal pumps that are used in much less

stringent conditions. A second generation of froth pumps is needed to meet the challenge of oil sand froth, particularly at the lower temperatures.

To maximize output from the plant and reduce inefficiencies associated with pumping froth, the centrifugal pumps must be improved. Concepts of pumping may include degassing the froth while pumping it by special secondary impellers, or using inducers that centrifuge the heavier water and bitumen from the air. The air pockets may also be collapsed by recirculating a percentage of the slurry from the discharge back to the eye of the impeller, or by injecting hot water at the suction.

The oil and gas industry has been at the forefront of multiphase pumping and the concept of impellers with tandem and slotted vanes has emerged to handle the accumulation of air in the impeller. In order to adapt the experience gained with such pumps to the design of a new generation of slurry froth pumps, a new impeller was developed under a grant from the National Research Council of Canada to Mazdak International Inc. The design features split vanes between the principal vanes. Such a design avoids choking at the eye for large solids, while the split vanes reduce air locking in the impeller. Adequate vane thickness of principal and split vanes is incorporated in the design to resist wear.

## THE OIL SAND MINERAL PROCESSING PLANT

There are two main types of oil sand process plants:

- Plants that use steam and very hot water to extract bitumen (such as the Clark's hot water extraction process).
- Plants that use warm water and solvents to extract bitumen

Plants with hot water extraction process have been built since the 1960s. Plants with warm and solvent extraction processes started in the 2000s. It is claimed that by maintaining lower temperatures, the cost of production per barrel of bitumen is reduced.

In order to appreciate the importance of froth in the extraction of bitumen from oil sand, a simplified flow sheet is presented in Figure A-1 (please refer to APPENDIX A for figure). This plant uses warm water and solvents.

The ore is excavated in bulky form and then crushed and stored as stockpile or in a dedicated silo, according to Odegaard, et al. (2001). In crushers, the size of the ore is typically reduced to minus 150 mm (6 inches). It is then transported by apron feeders and conveyors to breakers. In breakers, the size is reduced to minus 50 mm (2 inches) and water is added in the process to form slurry. The coarsest particles tend to deposit in the lower layers of the sump under the breakers and are recirculated to the breakers. The rest of the slurry is pumped to a slurry-conditioning pipeline. Since the solids of the slurry mixture consist of balls of sand, clay, and bitumen, it is possible to break them up further by pumping them over a distance of a few kilometers. In the slurry-conditioning pipeline, hot water and some chemicals are added to help the release of the bitumen. This slurry-conditioning pipeline is also called the hydrotransport pipeline.

The slurry from the conditioning pipeline is discharged into a 30 m (9.8 ft) tall conical vessel called the "primary separation vessel" or PSV. In this large vessel, separation occurs by gravity, with the

sand and coarse stones sinking to the bottom, middlings and clays at higher layers, and then froth at the top. Pipes at these three levels are installed to extract slurry for further processing.

From the bottom of the primary separation vessel, coarse tailings are extracted and pumped to hydrocyclones. The underflow from the cyclones is pumped to the tailings dam to build the dykes. The overflow of the cyclones is pumped to a set of flotation cells to remove any bitumen contained in the fines mixed with the coarse. This circuit is called secondary flotation froth. The overflow of the secondary flotation cells is directed back to the PSV.

From middle layers of the PSV, middlings are extracted to flotation banks. Bitumen in the middlings is extracted in the form of froth. This froth is essentially the overflow of the flotation cells flows in launders to the froth tanks. This is called primary flotation froth, and it is pumped back to the PSV. The underflow of the flotation cells flows in launders to a thickener. The underflow of the thickener is pumped as fine tailings to the tailings pond while the overflow consisting of water is pumped to the recycle pond as warm water.

Froth from the PSV is deaerated by steam and then stored in special bitumen froth tanks. In some cases, petrified wood is found in the ore. Due to its buoyancy, it floats with the froth at the top layers of the PSV. The circuit between the PSV, the froth deaerator, and the froth flotation plant must then be modified by installing special screens and screen froth pumps.

Froth from the froth tanks is pumped to the froth treatment plant where paraffin solvents are added to extract the bitumen. The longest froth pipeline ever built is the pipeline of a large crude oil producer in Fort McMurray with a length of 37 km (23 miles).

In the froth treatment plant, the solvents, water, and remaining solids are then separated. Solids and water are pumped to tailings, and solvent is stored for further use. Bitumen from the froth plant is pumped to the upgrader to be converted into synthetic petroleum products.

## CHARACTERISTICS OF OIL SAND FROTH

Within the same mineral processing plant, there may be different forms of froth circuits.

- Primary flotation froth associated with flotation of middlings
- Secondary flotation froth associated with flotation of coarse tailings
- Bitumen froth from the PSV before deaeration
- Bitumen froth pumped to the froth treatment plant after deaeration

The characteristics of these three types of froth depend on a number of factors:

- Type of ore
- Temperature and viscosity of the froth
- Air, bitumen, clay, sand, and water content

It is important to review these factors to appreciate pumping problems.

### Types of Ores

There are four principal types of ores:

- Low-grade ore
- Average-grade ore
- High-grade ore
- Coarse-grade ore

Low-grade ores contain less than 8 percent bitumen. Average grade ores contain 8 to 12 percent bitumen. High-grade ores contain 12 to 20 percent bitumen. Coarse grade ores are very coarse sand and gravel with bitumen content.

### Temperature and Viscosity of Froth

In plants that use the hot water extraction process, the temperature of the froth mixture is on the order of 90°C (194°F). In plants that use warm and solvent processes, the bitumen froth is at a temperature on the order of 45°C (113°F).

This marked difference affects the viscosity of the bitumen, which in the former case is at 200 cP and in the latter at 20,000 cP. Depending on the bitumen content and composition, the viscosity of the froth may be as high as 1000 cP at 50°C (122°F) and 2000 cP at 40°C (104°F).

### Air, Bitumen, Clay, Sand, and Water Content of Froth

At temperatures of 90°C (194°F), it is possible to reduce the air volumetric content to 0.5 to 1 percent, but at 45°C (113°F), froth tends to retain air at 10 to 20 percent by volume. The air content changes from circuit to circuit.

- Primary flotation froth associated with flotation of middlings with air content as high as 40 percent
- Secondary flotation froth associated with flotation of coarse tailings with air content up to 15 percent
- Bitumen froth from the PSV before deaeration with air content as high as 40 percent
- Screen froth after passage through the deaerator and screens with air content as high as 15 percent
- Bitumen froth pumped to the froth treatment plant is essentially screen froth, but may be more deaerated by removal of air in the screens or more diluted by addition of water to the screen pumpbox.

Water content is matched to the grade between 28 percent to 35 percent by weight. Bitumen weight concentration in the froth varies with the ore from 55 percent to 65 percent. Solids have a weight concentration from 12 percent to 15 percent. However, difficult pumping conditions may force operators to dilute the froth by adding water. This is not a very popular solution, as the water must then be removed in the froth treatment plant at a cost.

## DETERMINING THE FRICTION LOSSES

Joseph, et al. (1999), conducted laboratory and pilot tests on deaerated bitumen froth for pipeline transport. They indicated that in the range of self-lubricated flow in straight pipes:

- Pressure losses were proportional to the velocity ratio to the power of 1.75.
- Pressure losses were proportional to the diameter ratio to the power of 1.25.
- Self-lubrication depends on the froth weakness and clay covering bitumen to allow water to coalesce and to prevent bitumen from sticking to the wall of the pipes.
- Self-lubrication is associated with the formation of water tiger waves at the wall of the pipes. This type of flow is also called core-flow.

From the data, Joseph, et al. (1999), proposed that the pressure drop per unit length be expressed as:

$$\frac{dP}{dz} = K \frac{U^{1.75}}{R^{1.25}} \quad (1)$$

where:

- K = 0.0405 for bitumen froth at a temperature of 38°C to 47°C (100°F to 116°F)
- K = 0.0281 for bitumen froth at a temperature of 49°C to 58°C (120°F to 136°F)
- U = Velocity of flow in m/s
- R = Pipe radius in meters
- dP/dz = Pressure gradient per unit length in kPa/m

Comparing Equation (1) with the Blasius equation for friction losses, which apply in the turbulent regime of Reynolds number between 5000 and 100,000, Joseph, et al. (1999), proposed that effectively the friction losses associated with bitumen froth in straight lines was 10 to 20 times as high as friction losses for water and were temperature-dependent. Joseph, et al. (1999), proposed to express a Fanning friction factor as a function of a modified Reynolds number  $Re_{mod}$ .

$$f_{N\ mod} = \frac{k}{Re_{mod}^{0.25}} \quad (2)$$

For bitumen froth,  $k \approx 6$ .

The modified Reynolds number is based on the kinematic viscosity of water  $\nu$  (not the froth mixture), the average speed of the flow  $U$ , and the inner diameter of the pipe  $D_I$ .

$$Re_{mod} = \frac{U D_I}{\nu} \quad (3)$$

Determining the critical speed at which self-lubrication starts is complex and depends on the composition of the froth.

Fouling of pipe walls is a principal impediment to successful application of self-lubricated flows. Fouling is more of a problem at certain fittings such as tees, short elbows, and near pumping stations. There is however no published data on pressure losses for bitumen froth in fittings. Certain field tests suggest pressure losses as high as 100 times. Johnson (1982) proposed a two-K method for non-Newtonian flows in fittings, but this method has not been extended yet to bitumen froth.

**PUMPS FOR OIL SANDS FROTH**

Modern oil sand froth pumps handle large quantities of froth. The range of air content, from 0.5 percent to 40 percent by volume, would certainly challenge most designers of centrifugal pumps.

*Vertical Froth Pumps*

The conventional approach to the pump froth has been focused on the use of vertical slurry pumps (Figure 1), tank pumps (Figure 2), or oversized horizontal pumps.

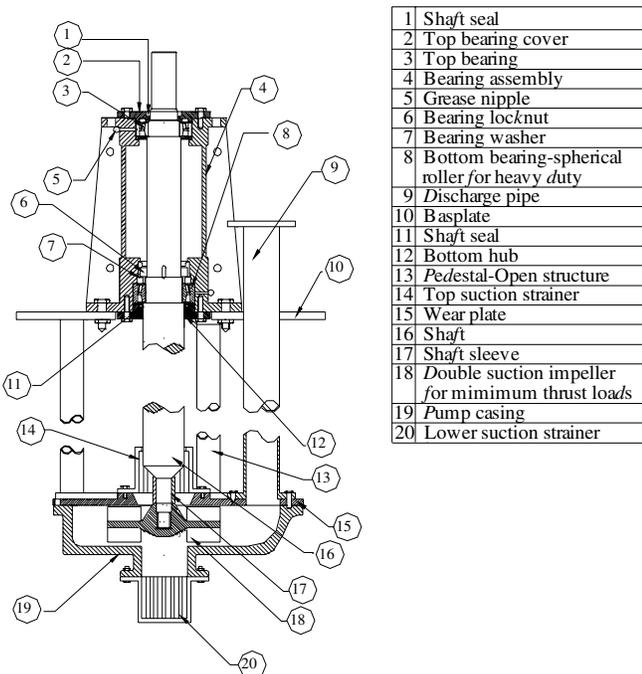


Figure 1. Cross-Section of Vertical Froth Pump with Double Suction Impeller.

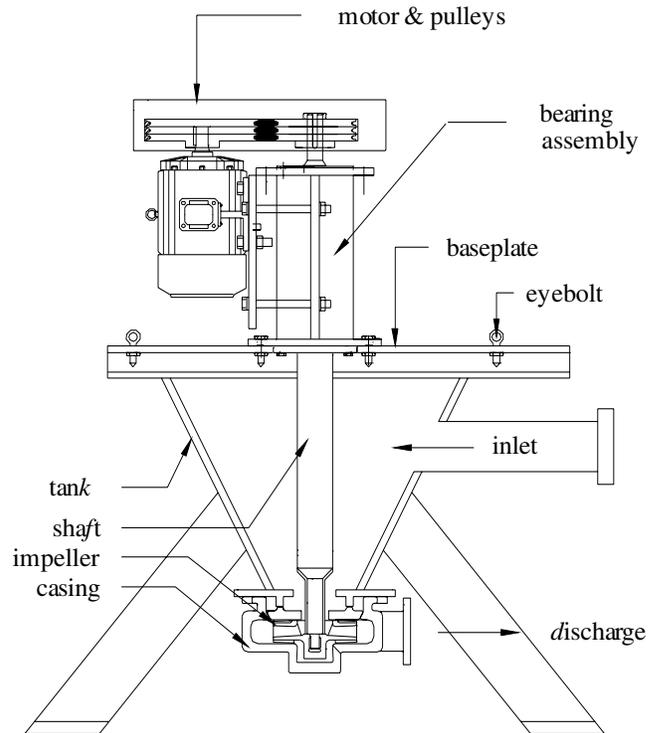


Figure 2. Vertical Tank Pump Designed to Handle Slurry and Frothy Mixtures. Impeller Is a Single Top Suction Design.

Vertical pumps do not use submerged bearings to avoid contamination by the solids in the slurry. The deeper the impeller, the lower is the critical speed. These pumps require large diameter and stiff shafts to maintain speed of operation for reasonable head.

The vertical froth pump is known to handle high air contents better than the horizontal pump. This is due to a number of reasons:

- Some of the air in the froth can escape to the top of the sump or tank
- Large air bubbles can collapse under the weight of slugs of slurry. This reduces the problem of air locking.

Because of their lower critical speed, vertical froth pumps are usually used for froth pumping for a total dynamic head smaller than 20 m, or 66 ft. This is generally acceptable in many mineral flotation circuits.

Bearing life is a function of the bending moment due to the impeller. In a horizontal pump, the load is a combination of the weight of the impeller and the hydraulic thrust load. In a vertical pump, the load is essentially due to the radial thrust and a combination of the weight of the impeller and a portion of the weight of the shaft.

To calculate critical speed, the distance between the load and the bearing near the wet end is used in the calculations. In horizontal pumps, the so-called  $L/D^3$  ratio is often quoted for reference, but this does not really apply to vertical pumps, as the length and diameter of the shaft between the bearings play a role too.

The radial load is a minimum at the best efficiency point (BEP). This load is essentially due to the uneven distribution of pressure in the volute. To reduce the load, and permit operation at higher speed for higher head, two designs are available:

- Single discharge-double volute pumps (Figure 3)
- Double-discharge pumps (Figure 4)

Wear of the dividing vane (or volute tongue) of the single discharge of the double volute pump is a concern. The performance of the pump is likely to deteriorate with time. The double discharge pump is more complex but can handle large flows and at total dynamic head in magnitude up to 150 ft.

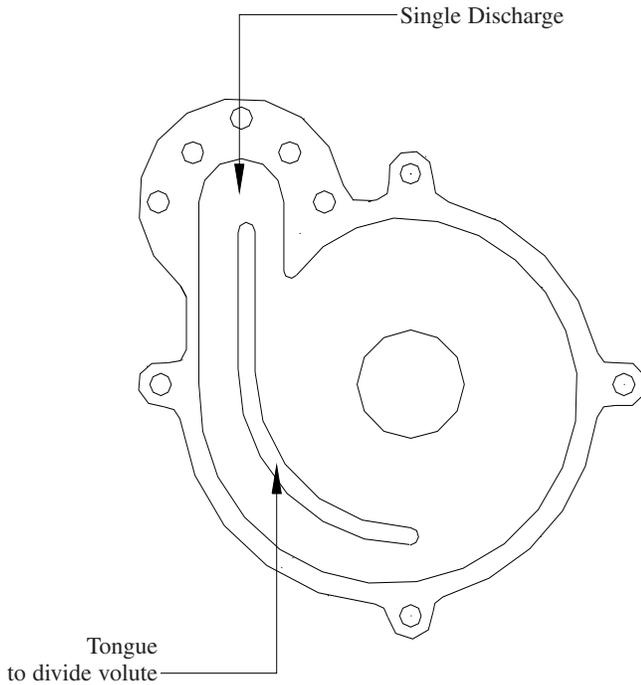


Figure 3. Method to Operate Vertical Slurry Pumps at Higher Speed by Reducing Hydraulic Radial Thrust—As Single Discharge-Double Volute.

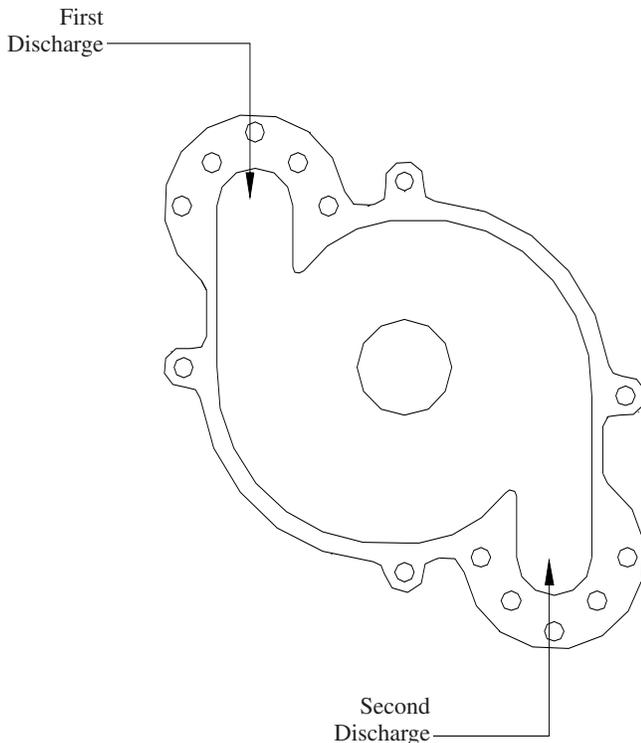


Figure 4. Method to Operate Vertical Slurry Pumps at Higher Speed by Reducing Hydraulic Radial Thrust—As Double Discharge.

#### Horizontal Froth Pumps

There are industries that handle large quantities of froth by horizontal pumps, such as the pulp and paper industry, sucrose industries, and molasses.

Two families of pumps may be considered:

- Pumps that would operate without removing the air

- Pumps that would operate while removing the air

In the first category, one would put conventional slurry pumps with and without inducers and centrifugal pumps with screw impellers.

Cappelino, et al. (1992), presented a very thorough study on the performance of centrifugal pumps with open impellers for pulp and paper flotation circuits and de-inking cells. High consistency stock (12 percent) can have as much as 20 to 28 percent entrained air.

Cappelino, et al. (1992), have therefore proposed to define appropriate head and power correction factors as:

$$HF = \frac{\text{Head measured with entrained gas}}{\text{Head measured without entrained gas}} \quad (4)$$

Or:

$$PF = \frac{\text{Power measured with entrained gas}}{\text{Power measured without entrained gas}} \quad (5)$$

Their test data indicate that the head and power factor are also a function of the ratio of the flow with respect to flow at best efficiency point. Tests on a pump with an open impeller pumping paper froth yielded interesting results. With 5 percent air the HF is as low as 0.66, but with 10 percent air it may be as low as 0.60. With 10 percent air, PF is as low as 0.95 and with 10 percent air it is around 0.85. Somehow, better results are obtained at 60 percent of BEP, with HF around 0.82 at 5 percent air and 0.66 at 10 percent air. This may be an indication that there are advantages to having oversized pumps handle the air. On the other hand oversized pumps tend to recirculate flow to the suction and develop high radial loads on the bearings. A compromise between the two would consist of having special froth pumps with enlarged suction.

No comparable data have been published for derating centrifugal pumps handling oil sand froth.

In primary flotation pumps with warm extraction when the air content may be as high as 40 percent, the performance of centrifugal pumps would be quite poor. Certain plants tend to inject large quantities of water in the launders from flotation cells to depress the air bubbles. They may also use tall feed sumps with further water injection. To cover all grades, these pumping systems are designed to have a turndown ratio of 1:12 with two or three pumps in parallel. At the higher dilution ratios, the viscosity is reduced, but the cost to pay is an important recycle of dilution water to the top of the PSV at high power.

Viscosity of the froth causes further derating of the pumps. The standards of the Hydraulic Institute suggest correcting for flow, head, and efficiency by using appropriate factors:

- For flow:

$$Q_v = f_Q * Q_w \quad (6)$$

Where  $Q_v$  is the flow that the pump would develop at the stated viscosity,  $f_Q$  is a correction factor for flow, and  $Q_w$  is the equivalent flow of water on the pump curve.

- For head:

$$H_v = f_H * H_w \quad (7)$$

Where  $H_v$  is the total dynamic head that the pump would develop at the stated viscosity,  $f_H$  is a correction factor for head, and  $H_w$  is the equivalent total dynamic head of water on the pump curve.

- For efficiency:

$$\eta_v = f_\eta * \eta_w \quad (8)$$

Where  $\eta_v$  is the total hydraulic efficiency that the pump would develop at the stated viscosity,  $f_\eta$  is a correction factor for

efficiency, and  $\eta_w$  is the equivalent efficiency of the pump while pumping water.

- For power:

$$P = \frac{\rho_v * Q_v * H_v * g}{\eta_k} \quad (9)$$

The empirical coefficients published by the Hydraulic Institute were not developed for oil sand and emulsions. Water may separate in areas of high shear and cause self-lubrication. By comparison with bitumen froth, Orimulsion® is an emulsion as a mixture of bitumen at 70 percent by volume with water at 30 percent by volume. If surfactants are used, the bitumen remains well mixed with water in a certain temperature range. Emulsions can become unstable under certain high shear rates or through very tight clearances of pumps according to Nunez, et al. (1996). Slurry pumps do not rely on tight clearances.

There is still not a well-established method to derate froth pumps for air content and viscosity. It is most likely to remain an empirical science.

McElvain (1974) published data on the effects of solids on pump performance. He worked on the concept of the head and efficiency reduction factors defined as:

$$R_H = 1 - H_R \quad (10)$$

$$R_\eta = 1 - E_R \quad (11)$$

He tested on impellers up to a diameter of 35 cm (13.78 inches) and on various concentrations of silica and one grade of heavy mineral. He developed a set of curves and established a relationship between volumetric concentration and the head and efficiency reduction factors as:

$$R_H = R_\eta = 5 * K_v * C_v \quad (12)$$

The  $K_v$  factor was then plotted against the  $d_{50}$  and for various solid specific gravity. Its magnitude is between 0.05 for the solids as fine as  $d_{50}$  of 10  $\mu\text{m}$  and as high as 0.45 for coarse particles with  $d_{50}$  of 10 mm (.394 inches).

### FROTH PUMPS WITH AIR REMOVAL SYSTEMS

The mineral industry usually relies on froth factors to oversize pumps. Abulnaga (2002) discussed the concept of froth factors and advised against using them as they are not scientifically proven. Rubsam (2000) indicated that the rising velocity of air bubbles is relatively high in viscous fluids. The bubbles in these conditions are not released in the suction tank but tend to separate from the fluid to form bigger bubbles that plug the flow into the pump.

Air locking of horizontal froth pumps is a problem that may be reduced by a number of methods such as:

- Integral air removal design (Figure 5)
- Water injection at the suction to collapse the air bubbles (Figure 6)
- Slurry recirculation from the discharge (Figure 7)

Pumps with an integral deaeration system such as those described by Rubsam (2000) are a promising solution. These pumps use an impeller with holes through the hub of the impeller. The holes allow the air to be pulled by a special second smaller impeller in the back of the main impeller (Figure 4). This second and smaller impeller, with its own housing, form an integral vacuum pump with its own discharge for release of air.

The limitations of the pump with an integral air removal system are not well known. The work of Rubsam (2000) indicates that these pumps handle well viscous mixtures up to 10 percent air content. The second impeller works on the principle of centrifugal forces and there may be a range of speeds where the performance deteriorates. For froth with air content larger than 20 percent,

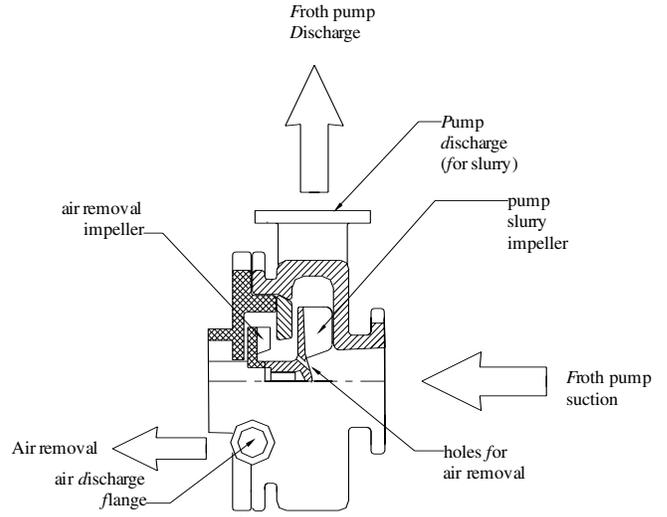


Figure 5. Concept of Horizontal Froth Pump with an Integral Air Removal System. Holes Through the Holes of Impeller Allow Escape of Air to Second Smaller Impeller and Housing from Which it Is Removed.

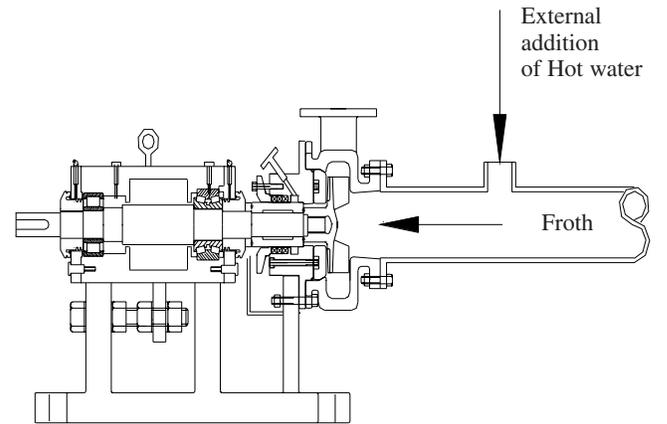


Figure 6. Air Locking Can Be Reduced in Horizontal Froth Pump by External Injection of Hot Water on the Suction.

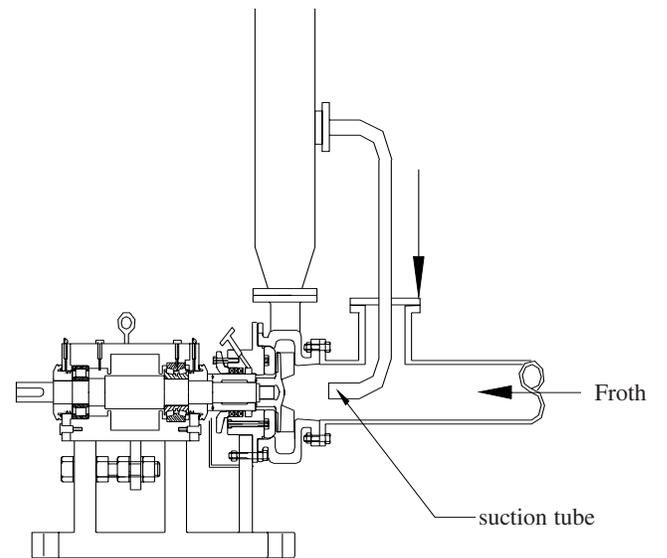


Figure 7. Air Locking Can Be Reduced in Horizontal Froth Pump by Recirculating Slurry from Discharge of the Pump by Using Special Tube.

Cappellino, et al. (1992), and Rubsam (2000) have also suggested that vacuum pumps be installed with a connection at the back of the impeller. This would be difficult in a slurry application where solids may damage the external vacuum pump.

Another approach would consist of removing the air at the suction of the pump. This would need a separate electric diaphragm pump or other positive displacement pump. This pump must be kept warm to avoid solidification of the bitumen that is associated with the removal of air. Herbich (1991) explored the concepts of attaching a vacuum pump and a venturi system on the suction pipe to remove gases from dredging pumps. These gases such as methane are generated by disturbing the bottom layers in the sea when dredging. These gases tend to deposit due to the fermentation of organic materials. The work of Herbich indicated that the venturi system on the suction of the dredge might be more promising than a vacuum pump.

Removing air at the suction may be done by extending the shaft and adding an inducer and a liquid ring vacuum pump (Yokota, 2003). The inducer helps to separate gas from liquid by centrifugal forces, as the liquid phase is heavier than the gas. The liquid is then expelled to the wall of the suction, while a core of gas forms in the center to be removed by the opposing vacuum impeller. This concept would be difficult to adapt to the design of slurry pumps. The shaft extension would have to be covered with a wear resistant sleeve. The bending and weight loads of the shaft extension, inducer, and vacuum impeller would require a stiff bearing assembly.

Air locking problems in horizontal froth pumps can be reduced by two methods:

- External water injection at the suction (Figure 6)
- Recirculating slurry from the discharge of the pump (Figure 7)

In the case of oil sand froth, the water injection must be hot to avoid solidification of the bitumen or increasing the viscosity of the mixture. This method, while effective to collapse bubbles, increases the water content of froth that must be removed in the froth treatment plant.

The slurry on the discharge of the pump is pressurized. It can be recirculated at a small percentage back to the suction to collapse the air bubbles at the eye of the impeller and resolve net positive suction head (NPSH) problems. This method has been successfully developed for self-priming water pumps by incorporating a built-in weir, a separator and a return pipe, as described by Turton (1994). In the case of a slurry pump, attention must be paid to the number of wear items, and a weir inside the casing complicates the design.

## IMPELLERS WITH TANDEM VANES AND SPLIT VANES

The concept of an impeller that can handle large quantities of gas mixed with liquid has challenged the oil industry. Furukuwa (1988, 1991) indicated that better gas handling is achieved by using blades with a very long passageway. These vanes should be slotted or tandem (Figure 8). Further contribution to the concept of gas/liquid pumping have been developed by Komowski (1983), Murakami and Minemura (1974, 1980, 1983, 1991), Sato, et al. (1996), and Tillack and Hellmann (1997). Zaher (2004) offers a comprehensive review of this topic and proposed installing bleeding systems in two-phase pumps.

These studies tend to show that total breakdown of pumping occurs when air tends to separate from the liquid at the suction and to coalesce as large pockets at the blade entry throat.

Shippen and Scott (2002) indicate that the use of multiphase pumps has grown rapidly since the mid 1990s. However, the majority of these pumps are twin-screws. Little indicates that these would be adapted to slurry pumping on the large scale required by oil sand projects.

In 1994, the author's company was awarded a grant from the Canadian government's research and development organization to develop a suitable impeller for slurry froth pumping. This was

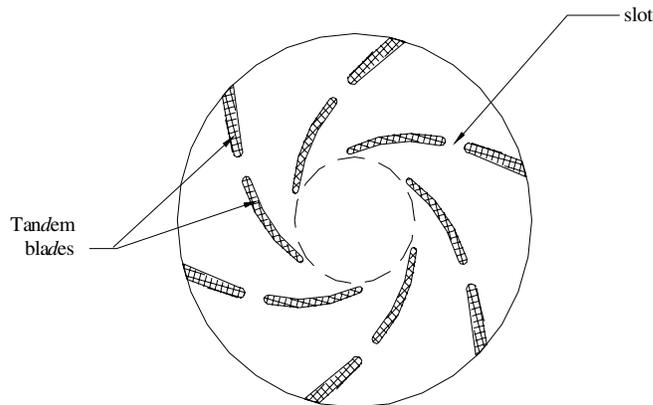


Figure 8. Concept of an Impeller with Tandem or Slotted Vanes for Better Handling of Air/Liquid Mixtures in Two-Phase Pumps.

followed by a second research grant from a large association representing the province of British Columbia in 1994-1995. Further funding was not made available due to the recession in mining in the late 1990s.

The concept of a slurry pump with tandem vanes was not found to be practical. Vanes of slurry pumps must be made thicker than water pumps to handle wear from coarse solids. Furthermore the number of vanes at the eye of the impeller is limited to allow passage of solids from 1/4 inch on the smaller pumps to 4 inches on the larger units. To accommodate these two principles of design, it was decided to develop a slurry pump impeller with split vanes rather than tandem vanes (Figures 9, 10, and 11).

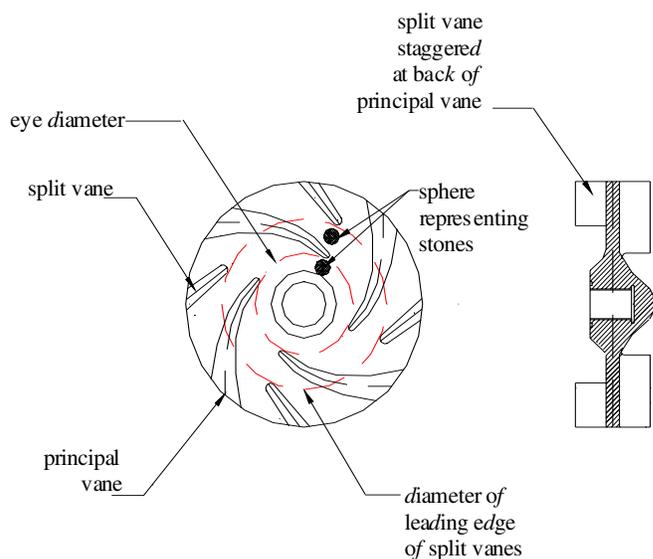


Figure 9. Impeller for Slurry Froth Handling with Split Vanes.

An impeller with four principal vanes allows adequate passage of stones and coarse solids. The diameter at which the split vanes are started has to match the ability to pass coarse solids or spheres as shown in Figure 9. This would be typically in the range of 60 percent to 65 percent. Air bubbles coalescing at the eye are then broken by four additional vanes midway to the tip of the impeller.

Tests conducted on a vertical pump with such an impeller indicate a smoother operation with slugs of air and slurry. Further tests in a pilot plant will be organized.

## CONCLUSION

The design of new oil sand mineral process plants leads to important economy of cost of extraction and treatment of bitumen froth by lowering the operating temperature of froth. This means

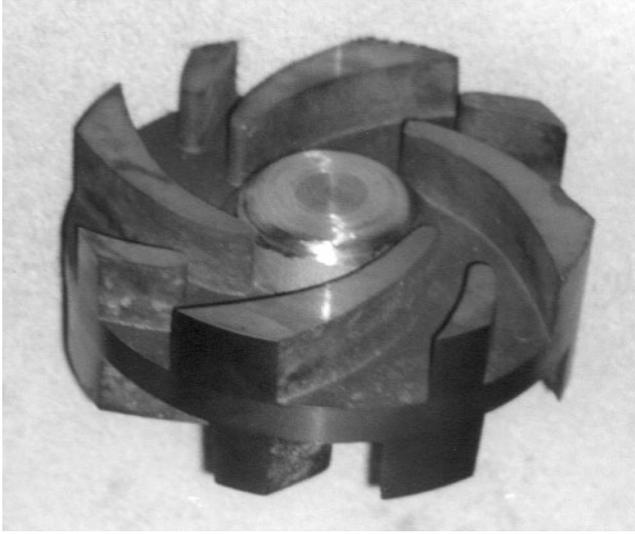


Figure 10. Top View of Double Suction Impeller with Split Vanes for Vertical Froth Pumps.

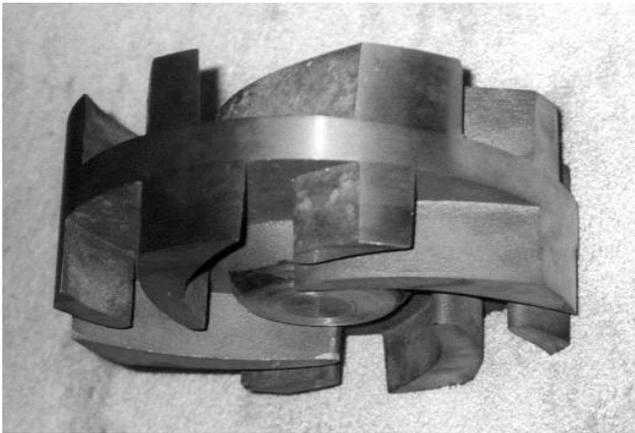


Figure 11. Side View of Slurry Pump Impeller for Vertical Froth Pumps. Split Vanes Are Staggered to Back of Principal Vanes for Smoother Passage at Cut-Water and to Reduce Pulsations.

that the froth contains much higher levels of air than conventional plants and is more viscous.

Various methods are available to improve the performance of froth pumps, such as air removal at the back of the main impeller by a second impeller integral to the pump, and slurry recirculation to the suction from the discharge.

The concept of the open impeller with split vanes is a good compromise between the need to allow large particle sizes to pass while reducing the size of air bubbles between vanes. Further research in this field is needed.

#### NOMENCLATURE

$C_V$	= Volumetric concentration of solids
$D_I$	= Inner diameter of pipe (in meters)
$E_R$	= Efficiency ratio due to solids
$f_H$	= Correction factor for head from a pump due to viscosity
$f_{N_{mod}}$	= Fanning friction factor for self-lubricated froth
$f_Q$	= Correction factor for flow in a pump due to viscosity
$f_\eta$	= Correction factor for the hydraulic efficiency of a pump due to viscosity
$H$	= Head (m)
$HF$	= Head correction factor due to entrained air in froth
$H_R$	= Head ratio due to solids

$H_v$	= Corrected head due to viscosity
$H_w$	= Magnitude of head that a pump would produce by pumping plain water
$k$	= Experimental coefficient for friction loss calculations. For bitumen froth, $k \approx 6$
$K$	= Experimental coefficient for pressure gradient calculations $K = 0.0405$ for bitumen froth at a temperature of 38°C to 47°C (100°F to 116°F) $K = 0.0281$ for bitumen froth at a temperature of 49°C to 58°C (120°F to 136°F)
$K_V$	= Correction factor due to particle size
$Q_v$	= Corrected flow in a pump due to viscosity
$Q_w$	= Magnitude of flow that a pump would pump with plain water
$\frac{dP}{dz}$	= Pressure gradient or required pressure per unit of length (Pa/m)
$P$	= Consumed power (Watts)
$PF$	= Power correction factor due to entrained air in froth
$R$	= Pipe radius in meters
$Re_{mod}$	= Modified Reynolds number for self-lubricated froth
$U$	= Speed of pumping the froth (m/s)
$\eta_v$	= Corrected efficiency due to viscosity
$\eta_w$	= Efficiency while pumping plain water
$\nu$	= Kinematic viscosity of water
$\rho_v$	= Density of viscous mixture

## APPENDIX A

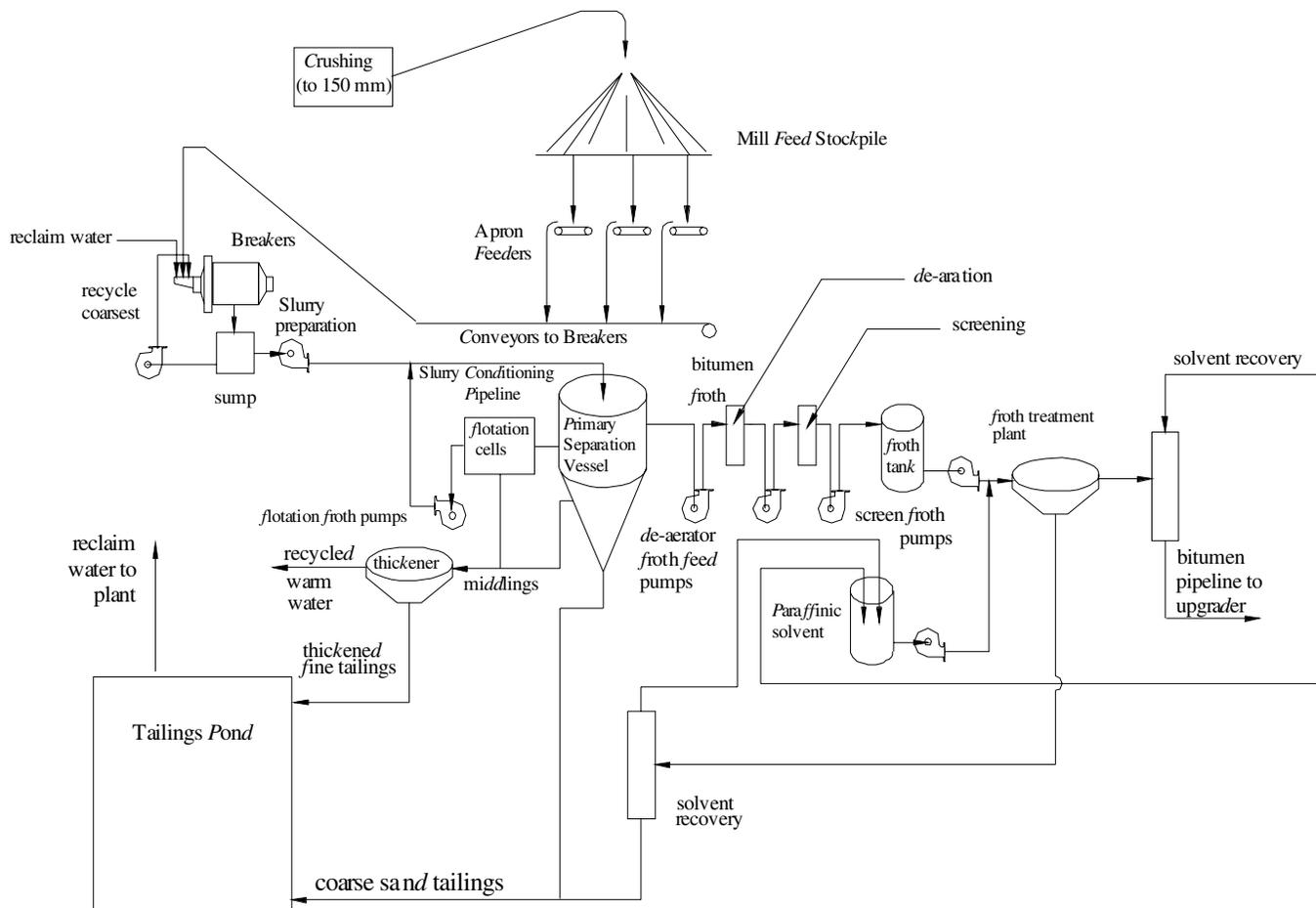


Figure A-1. Simplified Flowsheet for an Oil Sand Processing Plant.

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