Technical-Economical Feasibility of Using Centrifugal Pumps in High-Density Thickened Tailings Slurry Systems

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Abstract

Pumping a simulated tailings slurry at a high solids content has been investigated at the GIW Hydraulic Testing Laboratory in a 0.075 m diameter loop with a centrifugal pump with an auger-like inducer. The results and earlier experiences from the Laboratory and some reported data indicate that viscous slurries characterized by shear stresses in pipeline transportation of 100 to 200 Pa can be pumped effectively with centrifugal pumps. Stresses in this range were reported in pipeline, flume and viscometer experiments with typical base metal tailings slurries at concentrations by volume of 44% in pilot-scale thickening tests. The corresponding concentration by mass,70%, gave a non-segregating mixture which could be disposed at slopes of about 4%. With this type of slurry, an overall economical comparison indicate that centrifugal pumps can be a cost-effective alternative also in high pressure applications (4 MPa) corresponding to a pipeline length of 1000 m when pumping 300 tonnes of tailings per hour.

1. INTRODUCTION

Centrifugal pumps are used for pipeline transport of various mine tailings, silt, sand, gravel and waste rock, the latter for example together with tailings in co-disposal systems, Sellgren and Addie(1998). In large dredging systems the total pump efficiency including pump and motor has been found to exceed 70% with practically negligible effects of solids on the pump performance when pumping various sands at solids concentrations by mass of over 70% (Whitlock et al 2004). The pumps used had impeller diameters of about 2.5 m and the corresponding pipeline friction losses in 1 m diameter pipelines also showed a reduction when increasing concentrations by mass up to 70%. The economical effectiveness, in addition to energy savings, of using high solids concentrations can be related to an increased hourly capacity, a substantial reduction of the water requirement or the use of smaller pipeline diameters.

The general trend towards larger scale mining also leads to a demand of cost-effective high-capacity large diameter pipeline pumping systems for high solids concentrations. The capacity of the system above is enormous, about 100 Mtonnes of dry solids per year, when transporting sand with practically no particles smaller than 40 micron.

With tailings produced in minerals processing the amount of particles smaller than 20 mm normally exceeds 15 % and the average particle size may vary from 20 to 100 mm in the base metal industry. A tailings slurry that is produced and handled with an extremely high solids concentration is often called paste, a term initially associated with bauxite processing and backfilling in underground mines with use of binder to obtain high strength. Most experiences so far of surface deposition include clay minerals. For ground rock base metal mine tailings, the solids concentration by volume, C, must often exceed approximately 45% in order to obtain the required properties that give virtually no drainage of water and segregation of particles.

Increasing the solids content in a tailings slurry beyond a certain concentration means that the pumping pressure requirement and pumping costs increase substantially. However, in the same C-span the water content drops marginally. Therefore, the incremental cost for the last few percent in solids concentration can be dramatic. Paterson (2003) expressed the importance of determining the concentration and pumping system that maximises the benefits of paste without incurring the high costs.

Centrifugal pumps can be characterised as being cost-effective for large flow rates and low to moderate transportation distances or working pressures. Positive displacement pumps are generally cost-effective for small flow rates and high pressures. Limiting the amount of water means smaller flow rates and higher working pressures because of higher frictional resistance. Centrifugal pumps are used for high-density thickener circulation and feeding to positive displacement pumps in high pressure applications or to pump underflow slurry short distances. Therefore there is an intermediate area where both type of pumps are technically feasible.

The objective here is to show experimental centrifugal pump performance and pipeline friction loss results with a simulated high-density tailings slurry and to apply the data to base metal tailings pumping. The aim is also to discuss the cost-effectiveness of using centrifugal pumps in high pressure installations.

2. CHARACTERISATION AND EXPERIMENTS

Pastes and high-density tailing slurries behave in a highly non-Newtonian way and often exhibit a yield stress, meaning that they behave as a solid until sufficient force is applied. The yield stress is defined as the minimum stress required causing the solid-liquid mixture to flow.

The experimental work was carried out at the Hydraulic Testing Laboratory, GIW Industries Inc., U.S.A. Here, slurry pipeline hydraulics and pump performances can be investigated in loops with pipe diameters of up to 0.5 m and pipeline lengths of up to 200 m. The experiments in this case were carried out in a pipeline-loop system with pipe diameter of 0.075 m.

A high-density thickened tailings slurry was here simulated by a phosphate clay slurry with a S.G. of 1.11 to which a fine sand with an average size of 135 microns was successively added to increase the consistency. The rheological properties and the pumping characteristics of the slurries were determined from differential pressure drop and flow rate measurements. The primary experimental results were presented by Sellgren and Whitlock (2002) and Sellgren et al. (2002).

The pump was a GIW LCC-type (3-vane, all-metal) centrifugal pump with an open shrouded impeller (diameter 0.3 m) with a simple auger-like inducer, see Figure 1.

Figure 1: Open shrouded centrifugal pump (impeller diameter 0.3 m) with a simple auger-like inducer.

The standard method for consistency measurements in the concrete industry has been modified and adopted for yield stress estimations in connection with disposal of mine tailings, simply by using a cylindrical tube, Pashias et al. (1996). Slump measurement with a cylinder of a height and diameter of 0.1 m each was carried out here for the highest solids concentration investigated, see Figure 2.

Figure 2: Slump test adapted in a 0.1 m-standing pipe for indicative measurement of the yield stress. Slurry S.G.=1.67.

The yield stress corresponding to the slump of about 25 mm in Figure 2 is 350 to 400 Pa following the procedure given by Pashias et al. (1996).

The viscous properties of the clay-sand mixtures were determined from the pipeline experiments, following the procedures described in, for example (Wilson et al. 1997). Calculated shear stresses versus the viscous scaling parameter 8V/D (V= velocity, D=diameter of pipe) are shown for a clay only slurry and a clay-sand mixture with slurry S.G., S, equal to 1.60, Figure 3.

Sand was then added at 8V/D=400 up to an S-value of 1.67-corresponding to a shear stress value of about 360 Pa. The slope of the curve for S=1.60 is about 0.2 in Figure 3. Rheograms were then constructed for S-values of 1.60 and 1.67, see (Wilson et al. 1997). It was assumed that the slope for S=1.67 remained the same (0.2) as for 1.60. The rheograms with the results represented by a Bingham model are shown in Figure 4, the slope or plastic viscosity is about 0.04 Pas.

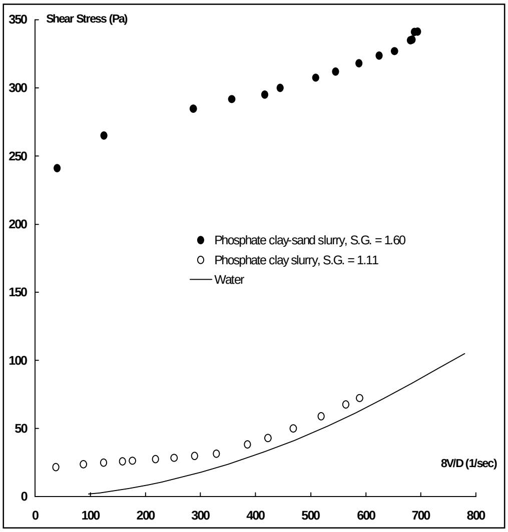


Figure 3: Shear stress versus the viscous scaling parameter.

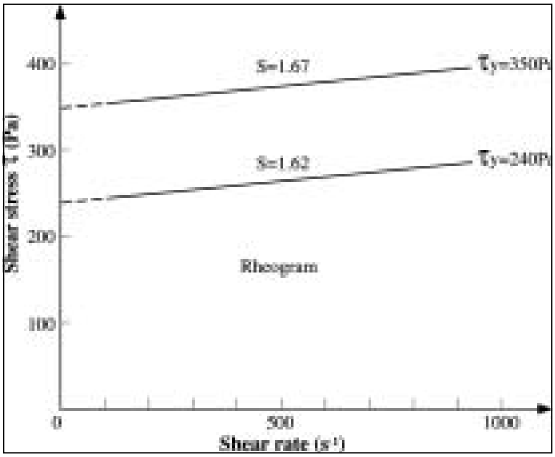
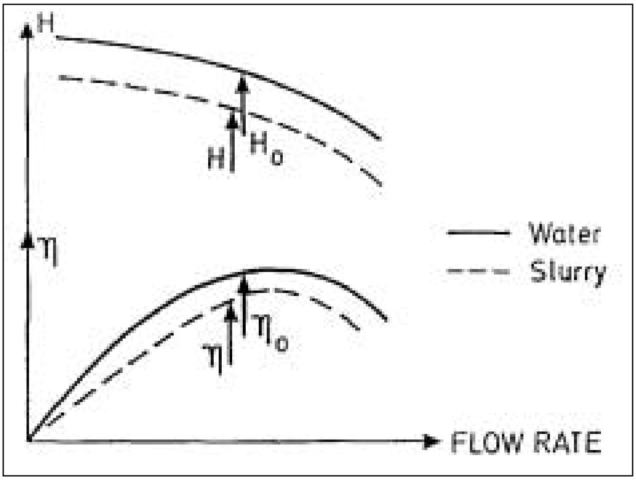


Figure 4: Rheogram with estimated yield stresses, τ_y.

The head and efficiency of centrifugal pumps are generally lowered by the solids in the slurry. The relative reduction of the water head and efficiency for a constant flow rate and rotary speed may be defined by the ratios and factors shown in Figure 5.



Head ratio: $HR = H/H_0$
Efficiency ratio: $ER = h/h_0$
Head reduction factor: $R_H = 1 - HR$
Efficiency reduction factor: $R_\eta = 1 - ER$

Figure 5: Sketch defining the reduction in head and efficiency of a centrifugal pump.

Figure 6 shows how the pump head and efficiency were lowered by the highly viscous clay-sand mixture. When the pump was operating in the best efficiency region (0.015–0.020 m^3/s), the reduction in head was about 10% and about 15% for efficiency. However, the performance became very sensitive to small variations in the mixture S.G. for lower flow rates. It can be seen in Figure 6 that the pump can produce head fairly well for S-values of 1.62 to 1.65 corresponding to yield stress values larger than 200 Pa. However, it cannot maintain the head at a S.G. of 1.67, when an unstable head curve is created, i.e. this is here an upper value for reliable operation.

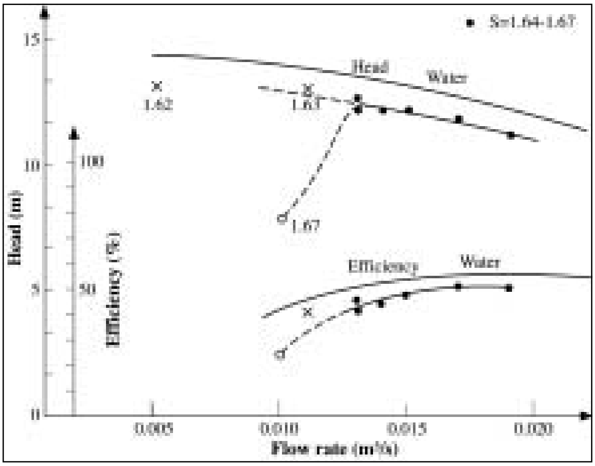


Figure 6: The effect of slurry on the pump head and efficiency at different S.G.-values. Pump rotary speed 1000 rpm.

3. Discussion and conclusion

The results in Figure 6 and earlier experiences from the Laboratory (Sellgren et al. 1999a,1999b) and reported kaolin data (Sery and Slatter 2002, Xu et al. 2002), indicate that viscous slurries characterized by shear stresses in pipeline transportation of 100 to 200 Pa can be pumped effectively with centrifugal pumps. Stresses in this range were reported in pipeline, flume and viscometer experiments with typical base metal tailings slurries at concentrations by volume of 44% in pilot-scale thickening tests, Engman et al. (2004). The corresponding concentration by mass, 70%, gave a non-segregating mixture which could be disposed at slopes of about 4%. The resulting shear stress versus the viscous scaling parameter 8V/D in Figure 7 indicates an overall maximum design shear stress of about 200 Pa. The yield stress was evaluated from measurements with a vane-type viscometer to be about 110 Pa (Engman et al. 2004)

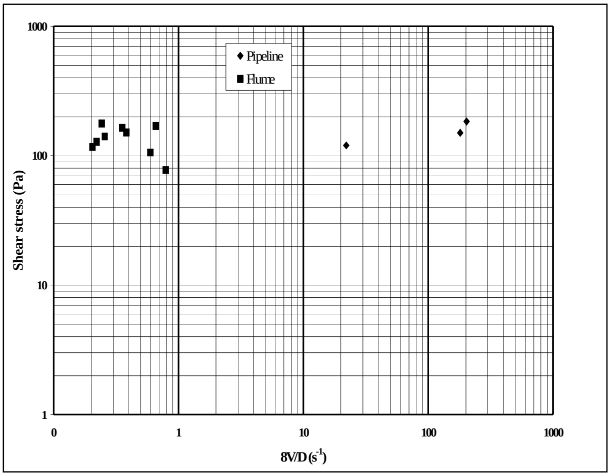


Figure 7: Shear stresses versus the scaling parameter 8V/D from pipeline and flume evaluation. From Engman et al. (2004).

The design shear stress, 200 Pa, is now used in an example for thickening of 300 tonnes of dry tailings per hour, corresponding to 227 m^3/h of slurry when pumped at a solids concentration by mass of 70%.The scaling relationship for viscous non-settling slurries between pressure, diameter and shear stress (see for example Wilson et al. 1997), gives a pumping pressure requirement of 4 MPa in a 0.2 m diameter pipeline with a length of 1000 m. The rheology-oriented pipeline friction loss evaluations are approximate, slurries of the type considered here may not behave in a completely non-settling way, see for example Pullum (2003).

Five units in series of a larger version of the pump used in the test (Figures 1 and 6) with an impeller diameter of 0.4 m were found to be suitable here, each giving a head of 43 m slurry when operating at nearly 1500 rpm. The observed ratios HR and ER of 0.9 and 0.85, respectively, should be lower in the larger pump, according to a pump Reynolds number criterion for Bingham type of slurries (Walker and Goulas,1984). Application of this criterion indicates that HR=0.95 and ER= 0.92 are reasonable values. In a comparison of different types of pumps, Paterson (2003) used an additional reduction factor for the effect of successive wear in the pump. Use of a 5% wear related reduction factor here (Addie and Sellgren, 1998) and 10% losses in the drive and motor and a water efficiency of 73%, then the total efficiency will be about 57%, corresponding to a power requirement of about 442 kW.

The total efficiency for a positive displacement pump may be about 80% corresponding to 315 kW. With 6000h of operation per year and a electric energy cost of 0.05 US$ per kWh, then the difference in total efficiency corresponds to about 38,000 US$ for a capacity of 1.8 Mtonnes per year. The investment cost for five centrifugal pumps including drives, motors and instrumentation will be about 100,000 US$.

Even if the comparison here is limited to capital and energy, it is indicated that the total annual cost is dominated by capital in a system with high-efficiency positive displacement pumps. Provided both systems are technically feasible, using a positive displacement pump instead of centrifugal pumps in series generally implies capital costs that are ten times greater, Cowper (1999).

The required capacity and slope of deposited tailings, i.e. the degree of thickening, are examples of factors that influence the choice of pumping system together with the location of the thickener. The location is a balance of the cost of high pressure pumping and the disadvantage of having the thickening facility remote from the rest of the processing, see Figure 8.

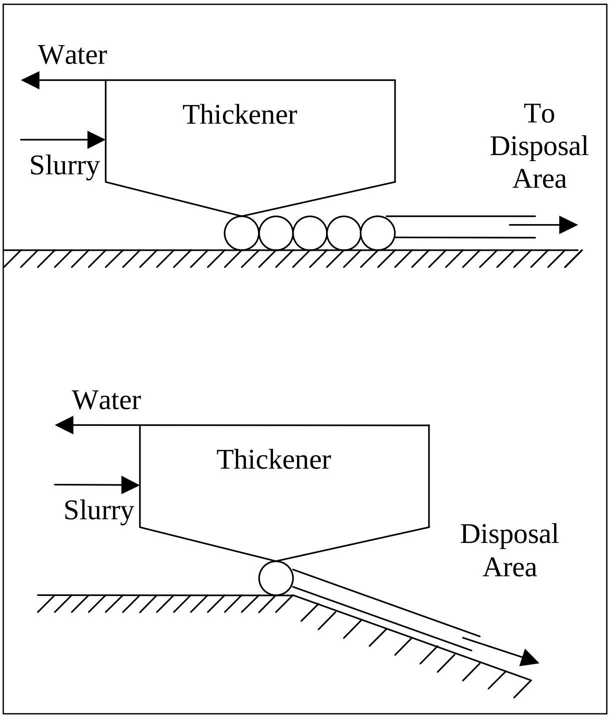


Figure 8: Location of the thickener related to the pumping requirement of high-density slurry.

The influence on the overall system economics of the choice of pump type and the location of the high-density thickening at an existing base metal tailings operation will be discussed in a subsequent paper, Wennberg et al. (2005).

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