PASTE THICKENING IRON ORE TAILINGS

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Summary: Paste thickening technology is rapidly emerging as an effective method for handling tailings for water recovery and as an alternative to conventional dams and ponds. This paper describes the principles of design and general operating characteristics of the paste thickener. A tailings paste is a non-settling suspension of relatively high solids content with a non-Newtonian rheology. These characteristics offer the advantages of increased water recovery and surface disposal of tailings. A pilot scale paste thickener thickened iron ore tailings to underflow solids ranging from 55 to 80 wt%. Deposition tests produced non-settling tailings with slopes ranging from 2 % to 8%. An integrated approach is to process design was used in the pilot testing to match the performance of the thickener, pumping system, and application on a common rheological basis.

Keywords: paste, tailings, stacking

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Introduction

The use of a thickener, without filtration, to produce a non-settling paste (also called thickened tailings) with non-Newtonian rheology has been practiced in Australia for many years for red mud disposal. The application of paste thickening technology outside of alumina is relatively new. Interest and installations in paste thickening are rapidly growing. Water shortages and environmental pressures make consideration of thickening tailings to solids concentrations within the paste range necessary in most new tailings projects. The paste thickeners at the DeBeers CTP plant in Kimberley, South Africa are an example of paste tailings disposal on the surface, also called "stacking" (Houman, 2003). This paper describes the principles of design and general operating characteristics of the paste thickener. The application and operating performance of paste thickeners in surface disposal is discussed using iron ore tailings, as produced in a one meter paste thickener pilot plant, as an example.

Nature of Paste Suspensions

The commonly used term "paste" is a suspension of solids characterized by relatively non-settling, non-segregating particles at high concentration as compared to settling slurries. Paste is generally described as a Bingham plastic, characterized by a yield stress, which is measured in units of pressure and is related to the force required to make a paste flow. The shape exhibited by a paste that is not flowing is a result of the presence of a yield stress. Yield stress can be measured directly with a laboratory viscometer. The yield stress curve is correlation of yield stress with solids concentration, as shown in Figure 1.

Slump, measured in units of distance, is an indirect measurement of yield stress. As shown in Figure 2, a cylinder is filled with sample, the cylinder is manually lifted, and the distance the paste sample "slumps" is measured. Slump and yield stress have an inverse relationship.

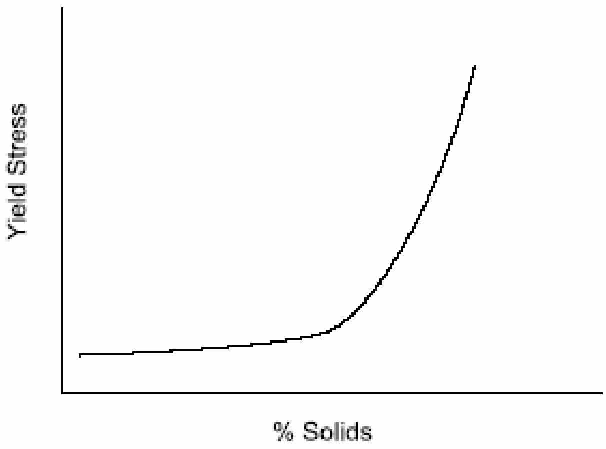

Figure 2 Yield Stress Curve

Figure 1 Cylinder Slump

The yield stress and non-settling nature of paste is produced from naturally occurring clays, silts, and fine sands. The solids content for a given yield stress is determined by the specific gravity and particle size distribution of the solids. Rheological and transport characteristics of paste are mainly dependent on the content of fine particles (less than 20 micron) as shown in Figure 3. The rheological character of paste is a result of the interaction of solid particles of different diameters and volumes making percent volume an appropriate way to characterize solid concentrations. However, industry convention is to use weight percent. In these terms paste concentrations can be as high as 75-85 wt% for base metal tailings depending on particle size and solids specific gravity.

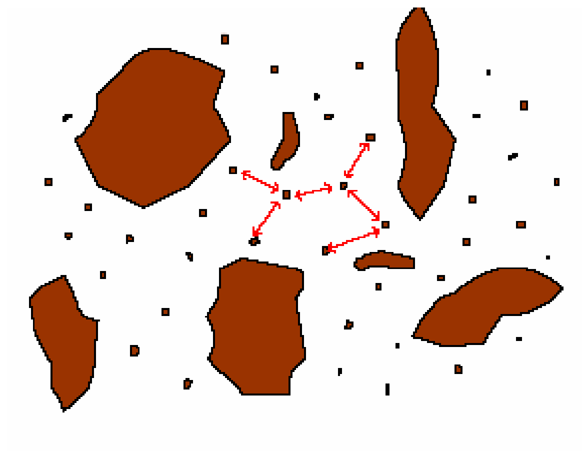

Figure 3 Fine Particles Interact Producing Paste Properties

The high viscosity of pastes makes pipeline design critical. Pastes are generally pseudoplastic where the viscosity decreases with shearing such as in pumping and pipe line flow. The yield stress of paste produced by a thickener, for example, may be higher than the yield stress at the end of the pipeline delivering the paste to the stack. More detailed descriptions of a paste can be found in sources such as Boger (1999) and Robinsky (1978) and for pipeline design, Paterson (2003).

Paste Thickener Design

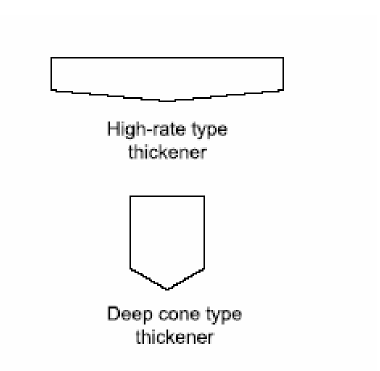

Figure 4 High-rate and Deep-cone Comparison

The concept of deep cone thickening was developed in the 1960 and 70s in the British coal industry (Abbott, 1973). Over the years the deep cone thickening idea has been combined with modern day flocculation techniques, feedwell design, and improvements on the design of the tank, rake and underflow discharge system to produce the modern deep cone type paste thickener. This thickener is characterized by a height to diameter ratio typically greater than one to one with unit areas (m^2/tph) several times smaller than for conventional and high-rate thickeners (Figure 4). The mud bed height in a deep bed thickener is much higher (several meters) than the level in a high rate thickener which more than compensates for the effect of smaller area on underflow solids concentration. The combination of the high aspect ratio and steep cone angle also facilitates the discharge of paste underflows.

Understanding yield stress is a key parameter in paste thickener design. Under gravity a tailings paste will flow to a point dictated by the yield stress and stop. The paste must move through the thickener and be delivered to the pumping system for transportation to the application point. With proper interpretation the operating range of a paste thickener can be located on the yield stress curve revealing the maximum underflow paste solids concentration and the minimum concentration below which the suspension will be settling slurry.

Bed depth distinguishes paste thickeners from other types of thickeners. Bed depths in a deep cone type paste thickener may be 10m or higher, creating compression forces which drive up the underflow solids concentration. Because of these depths, the concept of unit area, m^2/tph has little meaning for a deep cone style paste thickener. For a given diameter and tonnage throughput, a paste thickener may have a wide range of bed depths, producing a similarly wide range of underflow densities. Because of the understanding required for relating paste rheology, bed depth, and thickener design to paste production, the number of producers of this style of thickener is limited and currently includes GL&V, Outokumpu, and WesTech.

Advantages of Producing Paste as an Alternative to Conventional Disposal

Tailings slurries are most commonly disposed in an impoundment. The financial, environmental, safety and reclamation problems with tailings dams in general and coal tailings impoundments in particular are discussed in the literature in by several sources such as Hart (2004).

Surface stacking is the disposal of tailings as a paste (commonly referred to as "thickened tailings") on the surface of the ground, as a non-settling, non-segregating suspension of solids with minimal water release. There are various methods of accomplishing the stacking depending on the topography of the disposal site and the rheology of the paste. For slopes up to 5%, paste thickeners can be used.

Figure 5 shows how a paste thickener is used to produce the disposal stack. The paste thickener's underflow concentration must meet the requirements of the disposal site (stack slope) and still allow the paste to be pumped out of the thickener. Depending on the distance from the thickener to the disposal site, centrifugal or positive displacement pumps are used for transporting the tailings.

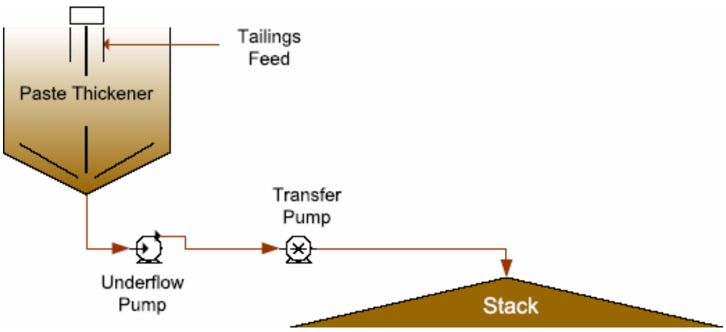

Figure 5 Paste Thickener Flowsheet for Stacking

Stacking as a method of tailings disposal, offers significant advantages over ponding. The most obvious benefit is the smaller impoundment area. In addition, there is less water in the pond, improved water or chemical recovery, a lower risk of containment breach, less groundwater contamination and easier final reclamation of the site.

Pilot-scale Paste Thickener Tests on Iron Ore Tailings

A pilot scale study for the thickening of iron ore tailings was conducted. The focus of the study was paste thickener sizing tests, generation of sample for pumping and deposition tests. The objectives of the pilot plant phase were selected and executed by the team of the customer, geotech, pipeline designer, and process designer

(PasteThick Associates). It is important to ensure the thickener, pump and pipeline and deposition are designed on a common set of rheological data (Johnson, 2004).

The Pilot Paste Thickener

A 1 m diameter, 4 m high pilot scale paste thickener (supplied by WesTech Engineering) was used, as shown in Figure 6. The feed stream was fed to the paste thickener by a peristaltic pump.

The pilot plant was operated under various conditions to evaluate design parameters of the paste thickener, including: feed characteristics (particle size distribution, ore-type, percent solids, etc.), mud residence time and depth, and flocculant dose. The test results were used to select operating conditions to produce the paste underflow for the deposition and pumping studies. Rheological analysis on the underflows was conducted using a VT550 Haake vane viscometer.

Figure 6 One Meter Pilot Paste Thickener

Pilot Plant Feed Characteristics

The particle size distributions tested were characterized by a D_{50} of 10 microns or less. The coarse fraction varied during the tests. Figure 7 shows the range of particle size distributions tested.

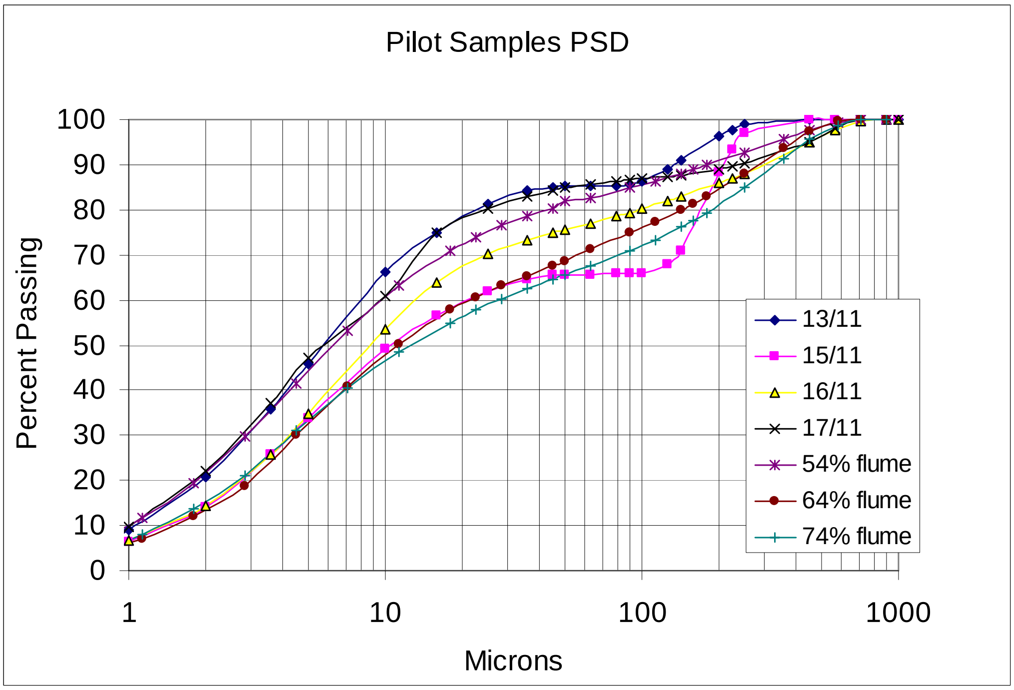

Figure 7 Pilot Plant Feed Particle Size

Test Results

Figure 8 Paste From Pilot Plant

The various test parameters (feed type, flocculant dose, etc) were evaluated under conditions designed to produce high and low and high yield stress paste. Figure 8 is an example of underflow (70% -20 µm, 10% +200 µm) of approximately 80 wt% solids with a yield stress is in excess of 400 Pa.

The variability of the tailings feed for this application is illustrated in Figure 9 where the yield stress curves for three underflow samples are compared. These samples were collected on different days and process plant operations. For these tests the differences are attributed to thickener feed variations in particle size distribution, although tailings mineralization can also be a factor.

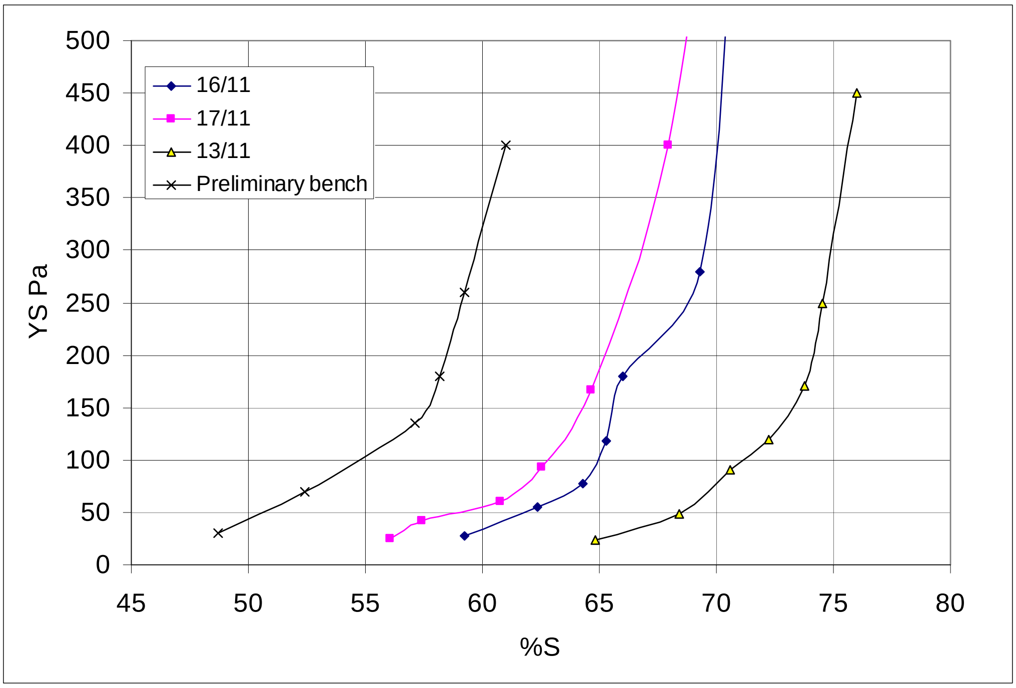

Figure 9 Yield Stress vs. Weight Percent Solids for Pilot Plant Underflow

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Deposition and Pumping Studies

Pilot plant operating conditions were selected to consistently produce underflow for each of three deposition tests. The deposition tests were designed to evaluate surface stacking as well as backfilling abandoned pits. A wide range of underflow rheology was tested to provide the data base to consider several deposition methods and sites.

Three troughs, approximately 2 m wide, 0.75 m deep and about 4 m long, were dug in the ground near the paste pilot plant. Three underflow densities were selected over a wide range of rheological properties;

1. A low yield stress paste (approx. 1.6 kg/l or 50 % solids),
2. A mid-range yield stress paste (approx. 1.85 kg/l or 60% solids), and
3. A high yield stress paste (approx. 2.13 kg/l or 70 % solids).

Once the pilot plant was consistently producing paste at the desired density a trough was filled. The height of the paste was measured using with graduated rods placed in the trough at about one meter intervals along the centerline. Heights were measured at deposition and after 24 hours of drying. Figure 10 shows the 24-hour deposition data for the three underflow densities. The yield stress was measured in the field using the cylinder slumps.

The deposition slopes were: “20 Pa yield stress”, 2% to 3 %; “55 Pa yield stress” 5% to 6 %, “280 Pa yield stress”, 8 % (over the last half of the deposit). Table 1 characterizes the paste used in each of the depositions.

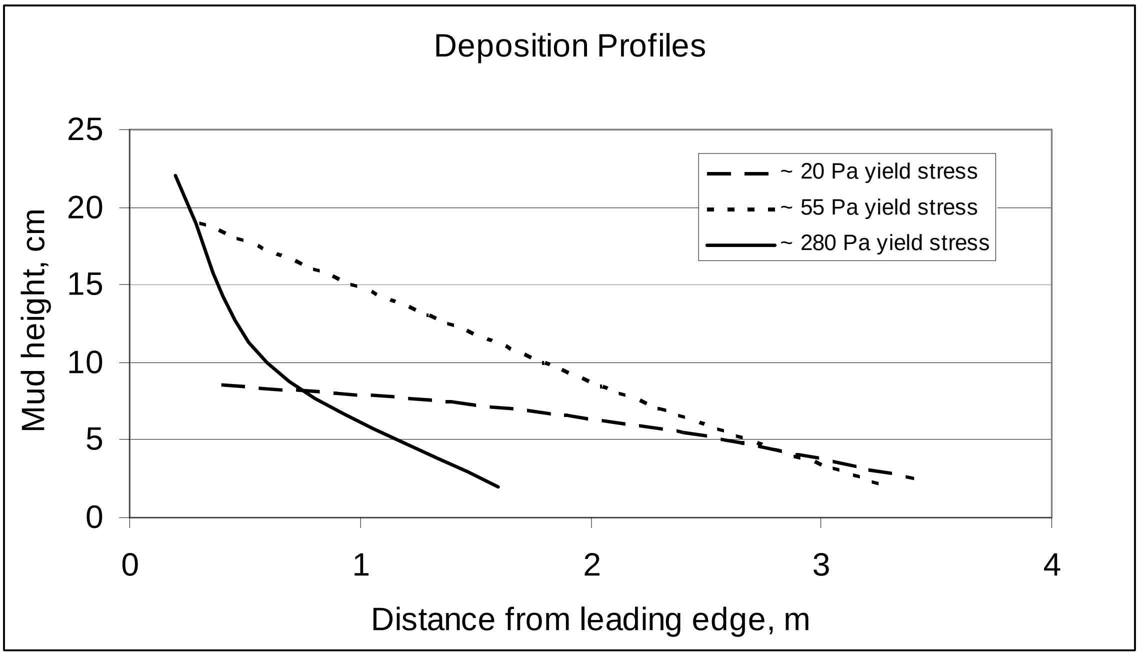

Figure 10 24-hour Deposition Height Profiles

Yield Stress (approximate)		20 Pa	55 Pa	280 Pa
Slope % (last half of deposit)		2-3 %	5-6 %	8 %
Density, kg/l		1.68	1.90	2.26
Solids Content, wt%		54.0	63.3	73.7
Particle Size, microns	D_{50}	6	10	10.2
	D_{80}	40	150	195

Table 1 Characterization of Paste Used for Deposition Tests

Particle size distributions differed (a result of changing pilot plant feed conditions) which does not allow direct comparison between the deposition tests based on underflow density. Each test must be viewed as a single point for the given particle size distribution and yield stress. Variations feed characteristics in pilot testing are a common problem and it is important to reference test results to particle size distribution, in particular.

As part of the deposition test series underflow samples were collected and tested by a consultant for pipeline design and pump specification. A "systems" approach, which associates the thickener, deposition, and pumping tests to the same sample (and sample rheology) is important to the efficient and accurate design of paste systems.

Conclusions

Paste thickening technology is rapidly emerging as an effective method for handling tailings for water recovery and an alternative to conventional dams and ponds.

Pilot scale paste thickener tests on iron ore tailings produced underflow solids ranging from 55 to 80 wt% depending on the particle size distribution of the solids and thickener operating conditions. Deposition tests produced non-settling tailings with slopes ranging from 2 % to 8%.

An integrated approach is to process design was used in the pilot testing to match the performance of the thickener, pumping system, and application on a common rheological basis. This approach is important to ensure that none of these steps prevents achieving process performance targets.

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