



The effect of shear on gravity thickening: Pilot scale modelling

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ABSTRACT

Mathematical models are potentially a valuable tool for the prediction of continuous gravity thickener operation. However, experience shows that existing mathematical models underestimate dewatering in thickeners for flocculated feed materials when predictions are made of either the underflow solids concentration for a given solids feed flux density or the maximum solids feed flux density achievable for a minimum underflow solids concentration set point. One reason postulated for this discrepancy is shear enhancement of sedimentation and bed dewatering as a result of aggregate densification. This process is not taken into account in conventional 1-D thickener models. A pilot scale column, operated at low bed heights without the addition of mechanical shear, produced results that compared well with 1-D model predictions. The effect of mechanical shear and/or greater bed height was to significantly enhance thickener performance relative to model predictions (as measured by underflow density or maximum solids flux density achievable for a nominated underflow density). An experimental method was developed that enabled shear to be incorporated into the suspension dewatering characterisation. The results suggest an order of magnitude increase in solid flux density can be expected under controlled shear conditions with polymer flocculated aggregates. The results also indicate that mechanical shear is not the only factor that can enhance dewatering, since higher beds, and hence longer residence times, also improve the achievable solids flux density. This is despite the fact that the thickener is operating in a regime that is predicted to be limited by the sediment permeability and not its compressibility. This suggests an additional mechanism must be at play in full scale operation and points a direction for further experimentation.

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1. Introduction

Faced with a growing demand for potable water, industry faces a greater expectation to conserve, recover and reuse process water. Gravitational thickening is a widespread process, used to concentrate the solid phase and clarify the liquid phase of a particulate suspension. The recovered water can be recycled within the process or further treated for environmental release. The appeal of gravity thickening is its ability to treat highly variable feeds with low solids concentrations, both economically and efficiently. When operated appropriately, thickeners can produce a concentrated underflow stream that is substantially higher in solids than the feed. The use of gravity as the force driving separation ensures a relatively low operational and energy cost. Simplistically, a thickener can be envisaged as a cylindrical tank with a central feed-well in which solid particles are brought into contact with a polymeric flocculant, causing them to aggregate. As the solids settle from the feed-well, and if the

solids flux density permits, a networked bed of solid particles forms at the base of the tank. This base is usually sloped and a scraper or rake aids the transport of thickened solids to a central pump well (the underflow). Clarified liquor exits through a peripheral launder at the top of the tank.

In terms of water recovery, the formation of a bed is desirable as the compressive/consolidation forces transmitted in the bed aid sedimentation, increasing the solids concentration in the underflow and thus improved water recovery. Although there are other material properties that can be important in the thickened material (i.e. pumpability of the underflow, angle of repose of the tailings if sent to a Central Tailings Discharge), fast settling to achieve a given underflow solids concentration (i.e. highest throughput for a given water recovery) is usually the design factor that is considered important in conventional thickening.

Despite the prevalence of gravity thickeners, their design is usually empirical and their operation often based on a combination of experience and folklore. Kinematic thickener models based on Kynch (1952) theory predict area requirements for thickeners operated at their throughput limit, i.e. where the underflow solids concentration is not sufficient to form a networked bed of

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particles and consolidation is absent. However, they do not provide an accurate indication of the expected solids concentration or the rheology of material exiting the underflow for thickeners operated at lower solids fluxes. In mining operations, there are ongoing efforts to continually improve water recovery and to produce thickened tailings, often with a high yield stress (sometimes erroneously termed “viscosity”) to aid waste solids disposal. In these applications, the aim is to predict, design and operate thickeners close to the rheological limit; namely the point where the raking mechanism of the thickener is torque limited and a higher solids output would compromise the flow or pumping of solids from the thickener.

Phenomenological thickener models encompassing both sedimentation and consolidation are more practical than the classical kinematic models as they take into account compressive forces in the networked bed of particles. Thickeners operating with a networked bed of particles show underflow slurry behaviour that is non-Newtonian and characterised by a yield stress. The ability to predict dewatering is advantageous both in thickener design and operation. On a more fundamental level, modelling can provide a better understanding of dewatering at a microscopic scale and elucidate how flocculation and hydrodynamic conditions can be optimised for throughput, underflow density, etc.

A number of workers have modelled the thickening process (Tiller et al., 1987; Landman et al., 1988; Garrido et al., 2003a,b; Usher and Scales, 2005) but very few have reported the output of their model against the output of full scale operational thickeners (Gladman et al., 2006). To achieve a useful comparison, the dewaterability of the feed slurry needs to be characterised via parametric rheological functions termed the compressive yield stress $P_y(\phi)$ and hindered settling function $R(\phi)$ (or an equivalent set of dewatering parameter descriptors). These functions are key inputs for a phenomenological dewatering model. A review of current thickener operations shows that the majority are predicted to operate in a regime in which the underflow rheology is close to Newtonian or perhaps exhibits a low yield stress, a direct consequence of the torque limitation of the raking mechanism in most cases. In this mode, the maximum operational flux is limited by the suspension permeability, not by its compressibility. Therefore, the bed height and the compressive forces imparted as a result of the bed are not predicted to be the rate-determining step. Both operationally and from a design perspective, it is advantageous to push the rheological limit, but a lack of correlation between models and thickener performance presently makes this an empirical exercise.

The lack of a quantitative design process for thickening results from the fact that when laboratory measured dewatering parameters are used as inputs, current phenomenological models consistently underestimate the actual solids flux density required to achieve a given underflow solids concentration by anywhere between 2 and 200 times (Usher et al., 2005). It should be noted at this point that this discrepancy is rarely if ever observed for solids that are not aggregated. It is common practice, however, for the solids fed to a thickener to be aggregated through the addition of polymer flocculant and as a consequence, most current dewatering practice does not correlate with best practice in the modelling field. The work described herein pertains to the case for a flocculated solids thickener feed.

The ratio between actual and predicted solids flux density for a given underflow solids concentration is termed the permeability enhancement (PE) factor of the thickener and is in general a function of the operating conditions (feed flux, flocculant dosage, bed height, residence time, etc.). Although factors up to 10 are typical, some level of permeability enhancement is common for

most thickeners. To a reader unfamiliar with gravity thickening, this might seem an extremely poor correlation, although it reflects the current state of the art (Usher et al., 2005). Worth noting is that the predicted underflow solids concentration for a given solids feed flux density is usually predicted to a much better degree with these models than the achievable flux. However, for operational reasons, a minimum underflow solids concentration and a solids feed rate (t h^{-1}) is usually specified and for design reasons the thickener size will be dependent on the settling flux density ($\text{t h}^{-1} \text{m}^{-2}$). Consequently, predicting the maximum achievable flux for a desired underflow density is a highly desirable feature of such models. Pilot scale studies have produced more encouraging results than those obtained from plant measurement. They provide far greater control over the measurement conditions, helping reduce the uncertainty associated with a full scale process. Good control also allows effects due to raking, sloped walls and poorly operated feed-wells to be isolated. In an earlier study by the same authors (Gladman et al., 2009), model validation was considered using a pilot scale dewatering column and flocculated calcite. The work showed that the predicted solids flux density through the column for a given underflow solids concentration was underestimated by factors between 1 (i.e. accurate) and 10 times.

The reason why full scale predictions show a greater deviation from the models is difficult to establish. One explanation is that the methods used to measure the dewatering parameters, namely laboratory batch sedimentation (Lester et al., 2005) and filtration tests (de Kretser et al., 2001) are not representative of the hydrodynamic conditions or timescales under which a suspension dewaterers in a thickener. Another is that the levels of shear stress on flocculated aggregates are higher in the full scale process and are imposed for longer periods due to the longer inherent solids residence times and finally, that channel formation and other in-homogeneities are not taken into account in the models.

Many thickeners employ rakes to transport material to a common discharge point. Several studies in the literature show a qualitative improvement in dewaterability as a result of raking the suspension (Vesilind and Jones, 1993; Farrow et al., 2000; Comings et al., 1954; Novak and Bandak, 1994; Johnson et al., 2000; Holdich and Butt, 1996) although the exact mechanisms by which rakes or pickets enhance dewatering are not well understood. Careful examination of the results revealed that the degree of improvement depends on the speed of the rake and the slope angle of the conical thickener base (Comings et al., 1954). Both higher rake speed and a steeper conical section were associated with higher underflow densities and since the thickener was generally permeability limited, this implies that rake speed and cone angle also improved the permeability (Usher et al., 2005). As material settles and flows in the region of the sloped surface or past a rake blade, the flocculated material is sheared, leading to the conclusion that shear enhances the permeability of networked, flocculated suspensions.

Investigations of the effect of shear on dewatering generally conclude that a low level of mechanical shear improves the rate and extent of dewatering in gravity settling (Gladman et al., 2005). Wall effects have been shown to be important; settling tests in a conical geometry revealed that settling in a sloped vessel was faster and achieved a lower equilibrium height than the equivalent test in a straight walled vessel (Usher et al., 2005). However, these conclusions are usually qualitative and do not provide a framework for incorporating shear into dewatering models.

To quantify the role of mechanical shear, shear rates were targeted to match those typically encountered in a raked thickener bed (Rudman et al., 2008) and $P_y(\phi)$ and $R(\phi)$ measured

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