Chemical Engineering Science 122 (2015) 585–595

Contents lists available at ScienceDirect

Chemical Engineering Science

journal homepage: www.elsevier.com/locate/ces

Aggregate densification in the thickening of flocculated suspensions in an un-networked bed

Rudolf Spehar[a], Anat Kiviti-Manor[a], Phillip Fawell[b], Shane P. Usher[a], Murray Rudman[c], Peter J. Scales[a,*]

[a] Particulate Fluids Processing Centre, Department of Chemical and Biomolecular Engineering, The University of Melbourne, VIC, Australia
[b] CSIRO, Minerals Resources Flagship, Waterford, WA, Australia
[c] Department of Mechanical & Aerospace Engineering, Faculty of Engineering, Monash University, Clayton, VIC, Australia

HIGHLIGHTS

- Aggregate densification is shown to be critical to understanding thickening.
- Aggregate densification is correlated at both a laboratory and pilot scale.
- A novel technique is demonstrated to characterise densification changes in shear.
- The concentration and shear dependencies of densification are demonstrated.

ARTICLE INFO

Article history:
Received 22 August 2014
Received in revised form
8 October 2014
Accepted 11 October 2014
Available online 28 October 2014

Keywords:
Batch settling
Aggregate densification
Gravity thickening
Shear
Sedimentation

ABSTRACT

Experimental data from batch settling tests on polymer flocculated suspensions was used to determine the material properties that quantify dewatering behaviour and relate settling rate to solids concentration. These material properties were subsequently used to predict the performance of a pilot-scale gravity thickener, including the expected solids concentration profile in the thickener. Analysis of data from a novel laboratory fluidisation rig, used to simulate the hindered settling zone of a thickener, and the pilot-scale thickener, indicates that relative to simple batch settling tests, the dewatering behaviour and related material properties of flocculated aggregates change over time, even at concentrations less than the gel point of the suspension and in the absence of mechanical shear. The change is primarily attributed to the phenomenon of aggregate densification as a result of aggregate-aggregate buffeting and manifests as enhanced settling and increased thickener throughput. A fluidisation case study using calcite with no added mechanical shear (only that due to fluidisation) found that the aggregates densified to 86% of their original diameter over a period of order 4000 s. This was enhanced with the addition of mechanical shear with a further decrease in aggregate size to 76% of their original diameter. Almost identical results were observed for the pilot thickener. Laboratory data typically underestimates thickener performance, even at the pilot scale, and the agreement between laboratory and pilot results represents a novel outcome for the characterisation of material dewatering properties. The observations herein are an important step towards full-scale thickener modelling incorporating aggregate densification effects due to shear.

1. Introduction

Thickeners are a simple continuous solid–liquid separation device widely used in the minerals, water and waste-water industries. The feed slurry enters through a pipe or launder into a central feedwell, in which flocculation is achieved and much of the momentum/energy of the feed is dissipated. On discharge from the feedwell, the solids are concentrated through sedimentation, hindered sedimentation and then consolidation in a solids bed, with thickened slurry then exiting through a discharge or underflow point at the base. The latter is often controlled to a fixed slurry rheology to allow predictable disposal in a tailings emplacement (Sofra and Boger, 2002). The released liquor rises and a low solids overflow exits via a weir at the top of the thickener.

---

[*] Corresponding author
E-mail address: peterjs@unimelb.edu.au (P.J. Scales).

http://dx.doi.org/10.1016/j.ces.2014.10.018

Enhancement of throughput whilst at the same time still achieving high overflow clarity and the desired underflow rheology or solids concentration is a key aim of many industrial thickening operations. Optimisation of the dosage of polymeric flocculants is one way to enhance throughput via improved sedimentation, although this is sometimes at the expense of the underflow solids concentration, since the addition of flocculants produces a stronger aggregate network. The result of high flocculant dosing is a lower output solids for a fixed underflow slurry rheology. The manipulation of shear processes is also known to be highly effective at improving the sedimentation rate of aggregates (Gladman et al., 2005, 2010a; Loan and Arbuthnot, 2010). Linking these effects to measureable parameters at a laboratory scale in a quantitative rather than qualitative manner has proven difficult and constitutes the focus of this work.

Dewatering theory along with one-dimensional phenomenological thickener dewatering models has been successful in describing dewatering trends in thickeners. This has led to the development of analytical laboratory based tools to generate dewatering parameters relevant to the modelling of thickening at an industrial scale (de Kretser et al., 2001; Landman et al., 1995; Lester et al., 2005; Usher et al., 2001). However, comparison of the predictions from these models with industrial scale data has shown discrepancies between the two and suggests flaws in the dewatering model (Usher and Scales, 2005). These discrepancies have been attributed to a number of factors, but for the sake of producing a correlation between laboratory and field studies, the difference was offset through use of an empirical parameter referred to as the “performance enhancement factor” (Gladman et al., 2010a).

The performance enhancement factor (PEF) relates to a relative increase in observed solids flux through a device versus the predicted flux to achieve a given underflow solids concentration. The observation for flocculated suspensions is that field based devices consistently outperform model predictions based on dewatering parameters extracted from un-sheared laboratory batch settling tests (i.e. the PEF is >1). These flocculated suspensions are typical of the minerals industry (exemplified here) although nearly all thickening processes involve the addition of polymer flocculant to increase aggregate size and simultaneously aid overflow clarity and improve aggregate sedimentation rates (which as noted, also results in improved throughput). Values for the PEF are observed to cover the range of 1–100, although more typically lie between 5 and 20 (Usher and Scales, 2005). The use of an empirical factor to describe an un-quantified parameter is highly unsatisfactory as it clearly does not aid the predictive capacity that theoreticians and practitioners alike may wish to achieve through modelling of such devices.

Shear processes in full-scale thickeners are ubiquitous, since nearly all thickeners have a raking mechanism. Traditionally, rakes were designed to transport material to the discharge point, as it is important that a continuous supply of sediment makes its way to the underflow in order to prevent both caking (locally high solids concentrations) and channel formation. However, it is known that raking also plays a role in enhancing dewatering by applying shear (Rudman et al., 2008). Many thickeners also employ dewatering rods that penetrate to the top of the thickener to aid the process although the design basis for these devices is more empirical than predictive. The expectation when shear is applied through a mechanical force such as a rake or through buffeting of aggregates in sedimentation is that the local pressure gradients produced will result in the expulsion of water from the flocculated aggregates and subsequent aggregate densification. Furthermore, as the aggregates decrease in size, the tortuosities around the aggregates also decrease (at fixed solids), leading to a decrease in the resistance to fluid flow around and an increase in the resistance to fluid flow within or through the aggregates. A significant amount of such dewatering is believed to occur, and given that particle buffeting as a result of flow and not just mechanical shear is important, it is possible that the enhanced dewatering can be achieved before the aggregates even reach the raking zone of the thickener.

Experiments that look to characterise enhanced dewatering behaviour as a result of shear have shown that there is an optimum shear rate beyond which any further increase is detrimental to aggregate densification (Gladman et al., 2005). This is envisaged as a trade off between densification and breakage of aggregates, the latter being contrary to achieving enhanced sedimentation rates. It is also possible that aggregate buffeting could lead to further aggregation although this is not considered likely herein since studies on polymer bridging show that contact driven aggregation stops very quickly once free polymer is no longer available in the system (Owen et al., 2008).

An aggregate densification model was developed by Usher et al. (2009) to provide a model framework for the development of analysis methodologies that will close the gap between laboratory predictions and industrial observations due to shear effects. The model provides an estimate of the expected performance enhancement for a given state of aggregate densification but does not consider the role of the rate of densification (i.e. it is a steady state and not transient model). Zhang et al. (2013) have since presented a transient densification model at steady state flux. Given that full-scale thickeners are permeability limited (there is not enough residence time to achieve significant compressional dewatering), the performance enhancement could be thought of as resulting from permeability enhancement. This work presents techniques developed to infer shear-induced permeability enhancement data from laboratory and pilot thickening studies. They are then applied to case studies where they are used to more accurately predict thickener performance. The work provides a quantitative background to the dewatering parameter extraction techniques, observations and modelling that aim to fill the gap between laboratory and full-scale work in the thickening arena (Grassia et al., 2014; Loan and Arbuthnot, 2010; Usher et al., 2009; van Deventer et al., 2011; Zhang et al., 2013).

2. Theory

2.1. Background dewatering theory

The origin of gravity thickening theory can be traced back to Coe and Clevenger (1916), who took into account the operations of settling tanks, where it was observed that the settling rate was dependent on the solids concentration. Thus, it was recognised that with increasing solids concentration, Stokes' Law for settling of a single particle in a continuum was unable to describe the settling behaviour of mineral suspensions. Furthermore, the existence of distinct sedimentation and consolidation zones were postulated. Although Coe and Clevenger were unable to correctly model the physics of consolidation, their work did provide a classical framework from which the sedimentation zone could be described. The method developed by Coe and Clevenger provides a thickener flux plot over a range of solids concentrations by observing the initial sediment—liquid interface settling rate from a large number of batch settling tests, all at different initial solids concentrations. Whilst comprehensive, such a technique is impractical for the characterisation of mineral suspensions aggregated with a high molecular weight polymer since it is not possible to obtain identical and reproducible flocculation across a range of solids concentrations.