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Quantification of wastewater sludge dewatering

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ABSTRACT

Quantification and comparison of the dewatering characteristics of fifteen sewage sludges from a range of digestion scenarios are described. The method proposed uses laboratory dewatering measurements and integrity analysis of the extracted material properties. These properties were used as inputs into a model of filtration, the output of which provides the dewatering comparison. This method is shown to be necessary for quantification and comparison of dewaterability as the permeability and compressibility of the sludges varies by up to ten orders of magnitude in the range of solids concentration of interest to industry. This causes a high sensitivity of the dewaterability comparison to the starting concentration of laboratory tests, thus simple dewaterability comparison based on parameters such as the specific resistance to filtration is difficult. The new approach is demonstrated to be robust relative to traditional methods such as specific resistance to filtration analysis and has an in-built integrity check. Comparison of the quantified dewaterability of the fifteen sludges to the relative volatile solids content showed a very strong correlation in the volatile solids range from 40 to 80%. The data indicate that the volatile solids parameter is a strong indicator of the dewatering behaviour of sewage sludges.

1. Introduction

The processing of sewage sludge is made difficult by the fact that biomass-rich sludges are both slow to dewater and form a networked gel at low concentrations. This is termed the gel point, where the gel point is the solids concentration at which they first form a networked sludge. For example, simple sedimentation of an activated sludge biomass typically results in a settled or networked sludge layer with a solids content of only 1.5–4.0 wt%. If left to stand, this layer is resistant to further sedimentation as the network of sludge particles is able to support its own weight and as such, dewaters no further in time. Subsequent addition of flocculants and other dewatering aids followed by mechanical dewatering of the settled sludge using high speed centrifugation or a range of high pressure filtration processes often only achieves a sludge cake with a solids content of order 20–30 wt%. This is then

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highly limiting to re-use options since transport and drying costs per tonne of wet sludge are high.

There is a range of potential re-use options for sewage sludge including as a nutrient-rich fertiliser, as a supplement to composting or as a feedstock to energy production. The presence of pathogens, metals and unwanted chemicals are all important to re-use considerations. However, arguably the most prohibitive expenses for re-use are the costs associated with dewatering, drying and transport of water-rich sludges. The key problems of interest are:

- Why are these sludges hard to dewater?
- What changes the dewatering characteristics of sewage sludge? and
- Can dewaterability differences between sludges be truly quantified?

These questions have all received a lot of attention both industrially and academically. This work considers a systematic and quantitative comparison of the dewatering characteristics of sludges at a laboratory scale. Armed with a quantitative comparator of dewatering performance, it then considers the parameters that operationalise this data and as such, aims to provide a quantitative basis for decisions around choices of dewatering equipment, process selection, dewatering additives and sludge pre-treatments, although not all of these issues are covered in detail herein.

1.1. *Dewatering characterisation*

Classical testing of particulate suspension dewatering involves either or both simple sedimentation tests, to characterise low solids separation behaviour as might be consistent with continuous clarification or thickening processes and batch sedimentation tanks, and filter tests to characterise the rate and extent of dewatering to a fixed pressure, as might be consistent in filtration and centrifugation. In the sedimentation test, recording the fall of the interface over time allows fundamental parameters such as the free settling rate, hindered settling rate and gel point (ϕ_g) to be determined as well as empirical parameters such as the sludge volume index (SVI). All measure properties that are useful for monitoring operational performance (e.g. SVI) or for designing devices such as clarifiers (Koopman and Cadee, 1983; Usher and Scales, 2005). A range of literature is available to describe the parameter extraction process and its potential application (Dick and Vesilind, 1969; Garrido et al., 2003; Grassia et al., 2011; Lester et al., 2005; Parker and Collins, 1999; Sezgin, 1982).

In the case of mechanical dewatering, recording the volume of filtrate on a bench-scale or pilot-scale filter over time allows determination of the permeability (rate of dewatering) and the compressibility or compactibility of the suspension (extent of dewatering) as a function of applied pressure (Shirato et al., 1983, 1969). Analysis of the experimental data for constant pressure filtration indicates that the filtration time (t) usually varies quadratically with the specific filtrate volume (V) during what is termed the ‘filtration’ or ‘cake formation’ phase of filtration (i.e. a plot of t versus V^2 is linear). The rate of dewatering or permeability can then be determined from the slope of a t versus V^2 plot in the cake formation region. This is followed by a logarithmic region (to first order) in which the cake compresses or becomes uniform in solids concentration (the expression phase), allowing determination of the extent of dewatering. Using models of filtration, (Landman and White, 1997; Landman et al., 1995; Ruth, 1946; Terzaghi and Peck, 1967; Tiller and Shirato, 1964; Tiller and Yeh, 1987) parameters such as the specific cake resistance, permeability, hindered settling function, coefficient of consolidation, solids diffusivity and compressibility can be determined.

These dewatering parameters come from two theoretical approaches, those due to Tiller and Shirato (1964), who combined a modified Darcy's Law to model the cake filtration phase with the theory of Terzaghi and Peck (1967) for the consolidation, expression or cake compression phase and a filtration theory proposed by Landman and White (1997). The parameters from the two theoretical approaches are, perhaps not surprisingly, all related (de Kretser et al., 2003; Landman et al., 1994; Olivier et al., 2007; Stickland and Buscall, 2009; Stickland et al., 2005b) although there are instances where the assumptions behind their use breaks down (de Kretser and Scales, 2007). An example is the case of Terzaghi's consolidation theory, where it is assumed during dewatering that strains (deformations) are small (which is indeed the case in filtration of many coarse materials that have a high gel point) but if this is not the case, Casagrande's method (Casagrande and Fadum, 1940) for the determination of the coefficient of consolidation is no longer valid (Stickland et al., 2005b). As with sedimentation tests, a range of methods have been developed to determine these parameters (Casagrande and Fadum, 1940; de Kretser et al., 2001; Green et al., 1998; Usher et al., 2001). The use of these various characterisation methods is industrially widespread and along with phenomenological models of equipment, the prediction of dewatering for a range of particulate suspensions at both laboratory and full-scale is possible, albeit not widely used in the design of equipment in the absence of qualifying pilot tests (de Kretser et al., 2010; Eberl et al., 1995; Tarleton and Wakeman, 2007).

1.2. *Sewage sludge dewatering characterisation*

In the case of sewage sludges, the classical dewatering parameter extraction methods are not rigorous and as such, the application of these parameters to the prediction of the performance of mechanical dewatering equipment is also flawed. The failure comes from the reliance on extracting information from a linear plot of t versus V^2. Simple dead-end filtration experiments on sewage sludges and other biomass-rich materials such as algal cells and starches show the filtration phase of dewatering quickly becomes non-linear. The short filtration phase is followed by an extended expression phase of dewatering that may represent well in excess of 80% of the process time. In tracking this behaviour to equilibrium, a typical result shows that all but very thin cakes can take many hours and up to days to dewater at moderate pressures of a few hundred kPa.

The behaviour has led to the designation by some that these sludges are “highly compactible” or “super-compactible” (Cleveland et al., 1996; Tiller and Li, 2000; Wu et al., 2001). This is because at some point in standard filtration tests using