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Semi-empirical full cycle optimisation of fill, squeeze and blow plate and frame pressure filters

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ABSTRACT

Investigation of the response of plate and frame filter performance to changes in design and operating variables is complicated by the large matrix of potential variables and the inter-dependent kinetics of the fill, press and air blow stages. However, through some key simplifying constraints an integrated optimisation framework has been developed. An example application is presented for an iron ore fines material from the North West of Australia, which indicates an optimum filling duration exists for all conditions investigated and illustrates the throughput benefits of higher feed solids and pressing pressures and larger cavity thicknesses. Significantly, the optimum filling duration is not constant and depends on the ratio of pressing to filling pressure and cavity thickness employed, largely due to the important role of the pressing stage not from the perspective of compression, but rather from that of an increased rate of secondary filtration of unfiltered suspension remaining at the end of the filling stage. Although simplistic in the form presented and limited to incompressible systems, with the integration of more rigorous theoretical treatments of the individual filter stages, the applicability of the approach could be broadened to all types of substrates.

1. Introduction

The process of filtration is widely used across the chemical, mineral and process industries. Consequently an incredibly diverse range of filter types and configurations have been developed, operating with vacuum or positive pressure, mechanical, fully saturated or gas-driven desaturated dewatering modes and cake washing steps.

A common feature of these filtration operations is that they are all governed by the same fundamental theory, using material properties describing the compressive response of the solid network to pressure, the permeability of the network as a function of solids concentration and the surface tension and capillary pressure behaviour of the porous cake (de Kretser and Scales, 2007; Tien, 2006; Wakeman and Tarleton, 1999). However, another common feature is that, through the inherent variability of industrial operations, these material properties can frequently change, making running filtration devices in an optimal state a constant challenge. Due to the non-linear inter-relationships between the process variables that dictate the performance of the different dewatering stages, the actions required to maintain optimum operation, most commonly the highest throughput whilst attaining target moisture, can be counter-intuitive.

Understanding and optimising these inter-relationships is best performed through the use of mathematical theories, of which a wide variety with varying complexity have been developed over the past century (de Kretser and Scales, 2007; Tien, 2006; Wakeman and Tarleton, 1999). However, even employing theoretical approaches, true optimisation of multi-stage filter operation is a challenge and is a subject of scant attention within the literature. Development of integrated models has been completed by a range of workers, in particular for operation of rotary drum (Nicolaou and Stahl, 1992, 1995) and belt vacuum filters (Wakeman and Tarleton, 1991) and plate and frame pressure filters (Tarleton, 1998, Wakeman and Tarleton, 1994), yet the use of these models to identify the optimum cycle design in terms of what ratio of filtration, pressing and desaturation times yields the maximum throughput, and how this is affected by process and equipment variables has not been reported.

Stickland et al. (Stickland et al., 2006, 2008) conducted a detailed optimisation study of both fill only and fill and squeeze plate and frame pressure filtration using a numerical filtration and expression model. These authors investigated the impact of operational and material variables on filter throughput, making the key observation that as more stages are brought into a pressure filter cycle, greater flexibility exists with respect to obtaining both target moisture and high throughput. However, this greater flexibility also increases the likelihood of sub-optimal operation due to the many degrees of freedom present in the cycle design.

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Introduction of an air blow stage to a filter press cycle adds another degree of freedom to the optimisation process, making the matrix of variables to investigate too large for simple analysis. However, through application of a number of key simplifying constraints based on fundamental considerations, the integrated optimisation approach for fill, squeeze and blow cycle pressure filters presented in this paper circumvents these complications.

This paper describes a first-pass optimisation framework for operation of a plate and frame pressure filter with fill, squeeze and air blow stages using the semi-empirical Darcian treatment of filtration and a treatment of desaturation during the air blow stage based on the semi-empirical approach of Nicolaou and Stahl (1992). This type of framework could have been implemented with a full numerical model for describing filtration and compression; however a common feature of most mineral processing substrates for which air blow steps are employed is that they exhibit at least moderately incompressible character. This renders the simpler Darcian filtration model suitable for application with these materials. To demonstrate the utility of the approach, the impact of a range of both operating and design variables (feed solids, pressing pressure and cavity thickness) on pressure filtration of a North-Western Australian iron ore fines was investigated.

2. Model development

The core of the approach outlined in this work is that through some key constraints, the matrix of possible filter cycle times through which to search for an optimum case for a given set of feed solids and pressure conditions can be simplified. These key premises are:

(a) Given the low-compressibility of the material, little benefit in terms of moisture levels would be gained from spending time in actual cake compression and throughput would decrease (Stickland et al., 2008). Thus, as soon as cake growth completely spans the filter cavity, whether during the fill or press stage, for optimum throughput, advancement of the cycle directly to the air blow stage should occur.
(b) Efficient air blowing generally dictates that the cake is fully formed within the cavity before the start of air blowing, therefore either the fill or press stage should be run at least to the point where cake growth completely spans the cavity.
(c) Most mineral processing pressure filtration operations using an air blow step have a target solids concentration which can only be achieved via air blowing. Therefore from the perspective of optimisation, there will be only one characteristic air blow duration for each cake thickness that achieves the target moisture at optimum throughput.

These constraints effectively state that operation with any fill stage duration is feasible, up to the point where the cavity is completely filled with cake during the fill stage. However for each fill time, there is only one optimum press time, which is the time required to just filter the remaining suspension in the cavity into the cake. At this point, air blowing should commence, with the air blowing time required being that to just dewater the cake present to the target moisture level.

Whilst strictly limited to incompressible materials, the framework is set up to accommodate compressibility if needed. In the case of compressibility, the model can be treated only as an approximation to true behaviour however, and as the level of material compressibility increases, the model will become progressively less accurate and numerical modelling would be preferable.

2.1. Model assumptions

The model is based on the fundamental Darcian filtration equations incorporating membrane resistance to describe the filtration occurring in the fill and pressing stages (recalling the premise *a* above, that for optimum throughput the pressing stage will *ONLY* incorporate filtration). The desaturation process is modelled based on the approach of Nicolaou and Stahl (1992).

In addition to the simplifying constraints mentioned above, a number of key assumptions were also made, many of which were for the sake of simplicity in this first-pass approach. A more sophisticated model could provide a more thorough treatment. The key assumptions are:

- The filling or filtration stage refers only to the period where cake builds up after all cavities have actually been filled, i.e. the time spent actually filling the press is treated as technical time.
- The effect of membrane resistance on cake pressure drop (and hence average cake solids) over time during a cycle is negligible—a full numerical treatment would not make this assumption.
- Membrane resistance does not change with pressure—this variability could be integrated.
- Changes in the pressure of desaturation do not affect the actual porosity of the cake during this stage—it is possible to integrate this dependency.
- Changes in cake structure during desaturation are negligible.
- Technical time is constant with the parameters varied—this may not always be the case and would be equipment specific.

2.2. Fill stage modelling

During the fill stage, material is being continually pumped into the press to replace filtrate removed as cake builds up on the filter cloth. The basic Darcian filtration equation yields:

$$t=\frac{\eta\rho_s\alpha_{av1}\phi_{c1}}{2\Delta P_1}\frac{\phi_0}{(\phi_{c1}-\phi_0)}V^2+\frac{\eta R_m}{\Delta P_1}V=K_{01}V^2+\frac{\eta R_m}{\Delta P_1}V \tag{1}$$

where ϕ_{c1} is the average cake solids volume fraction during the fill stage, ϕ_0 the initial suspension solids volume fraction, t the time, V the cumulative volume of filtrate/unit area of filter, α_{av1} the mass-based specific cake resistance for the fill stage cake solids concentration, ΔP_1 the pressure drop across the filtration cavity, η the filtrate viscosity and R_m the filter medium resistance. For fixed pressure and feed solids conditions, all variables in the first term of Eq. (1) are constant and the lumped kinetic parameter K_{01} quantifies the rate of filtration of initial solids material into the cake.

To calculate the amount of cake deposited at the end of the fill stage, a volume solids balance to relate V to cake height data, h yields:

$$V_1=\frac{(\phi_{c1}-\phi_0)}{\phi_0}h_{c1} \tag{2}$$

Assuming a filter cavity thickness to be simulated (or half thickness in the case of two-sided filter cavities), fill stage model calculations involve splitting the cavity thickness into an arbitrary number of height increments and calculating the required fill time to build up a cake equivalent to each increment. The result is a range of fill times from zero up to the one that completely fills the cavity with cake. At this point the press stage can then be calculated.