Understanding filter cake formation through electrical impedance measurements

UNDERSTANDING FILTER CAKE FORMATION THROUGH ELECTRICAL IMPEDANCE MEASUREMENTS

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ABSTRACT

An electrical impedance tomography technique for determining the solids concentration in solid/liquid mixtures has been used to analyse cake formation during the pressure leaf filtration of aqueous based mineral suspensions. The experimental data are interpreted through so-called 'modern filtration theory' which serves to highlight some of the difficulties that currently exist in the areas of both modelling and scale-up in solid/liquid separation.

THEORETICAL CONSIDERATIONS

Cake filtration is concerned with the separation of particles from fluid streams by forcing the liquid constituent through a semi-permeable medium under a pressure gradient. The filtered solids accumulate with time on the septum surface(s) and exhibit a compressibility and concentration profile dependent on the extent of particle re-arrangement induced by the flow of liquor through the interstices of the cake. Modern filtration theories[1,2], which purport to take account of compressibility, describe cake formation through an equation of continuity, an equation of momentum, Darcy's equation and constitutive equations relating the cake structure to the compressive stress gradient experienced by the solid particles (dP_s/dx) such that

$$\frac{dP_s}{dx} = gC\left(\rho_s - \rho\right) + \mu\alpha C\rho_s\left(\frac{Q}{A} - v\right) \qquad (1)$$

where g is the gravitational constant, C the local volume fraction concentration of solids in the filter cake, μ the liquid viscosity, α the local specific resistance, Q the filtrate flow rate, A the filter area, v the local solids velocity towards the filtering medium and ρ and ρ_s are the liquid and solids densities respectively. The apparent reluctance to employ eqn.(1) to model filtration processes stems from factors such as literature conveyed confusion, the lack of terms which account for the contributions from the body forces associated with the solid/liquid interface and the need to relate the solids compressive pressure to the cake properties through expressions such as

$$\alpha = \alpha_0 P_s^n \qquad (2)$$

$$C = C_0 P_s^m \qquad (3)$$

where α_0, C_0, n and m are empirically derived constants valid over a restricted pressure range[3]. When these relations can be established, however, it has been proposed that both cake solids concentration and cake height can be predicted *a priori*[1] such that the former is given by the expression

$$C = C_0 \Delta P_c^m \left(\frac{y}{L}\right)^{m/(1-m-n)} \qquad (4)$$

where ΔP_c is the pressure drop over the cake, y is the fractional cake depth and y/L is the dimensionless distance into the cake measured from the filtering surface.

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The experimental data presented in this paper were obtained with the aid of a novel electrical impedance measurement technique that allowed transient cake solids concentration profiles to be monitored. These data, accumulated during the initial period of a recently funded ESPRC project, show how existing theories can only be used to model real systems over a limited range of experimental conditions.

EXPERIMENTAL PROCEDURES

The experimental set-up employed during the tests has previously been described in detail[4,5] and essentially comprised a leaf filter cell constructed from plastics or stainless steel fitted with a suitable filter medium at its base and controlled through a series of valves and transducers linked to a dedicated personal computer. Suspension made to a known concentration from a mineral powder and distilled water was fed at a constant pressure between 0-0.8 MPa and the growth of the cake formed by the filtered solid particles was monitored in-situ via diametrically opposite pairs of electrode probes placed within a vertical plane of the filter cell. Table 1 shows a summary of the measured properties of the suspensions tested.

RESULTS AND DISCUSSION

Figure 1 shows a typical result from initial tests performed with a 10% w/w aqueous zinc sulphide suspension filtered at a constant pressure of 100 kPa through a 0.2 μm rated Gelman Versapor membrane. The data show the transient solids concentration in the cake as a function of time for the six electrode pairs nearest to the filtering surface. The solids concentrations, and hence specific cake resistances, of the particle layers adjacent to the septum are clearly appreciably larger than those some distance away; thus indicating that the cake is compressible. If the solids concentration data for the electrode pairs in the cake are plotted against electrode displacement from the septum at a filtration time approaching 12,000 s the concentration profile shown in Figure 2 is produced. On the same graph data are plotted which illustrate how eqn.(4) can be used to estimate the solids concentration profile. Here the values of the constitutive parameters C_0, n and m were obtained from sequences of experiments at pressures ranging from 0-0.6 MPa (see Table 1) and these parameters were then used to obtain the theoretical solids concentration profile at the calculated pressure drop across the cake. Although the theory fits the experimental data reasonably well at intermediate cake heights it is pertinent to note that the general shape of the theoretical profile is incorrect and that the largest discrepancies occur toward the profile extremities. Moreover, the error in predicted cake concentration near the filtering surface is of major significance as the cake properties in this region are thought to be crucial to the rate at which compressible materials can be filtered.

The example data shown in Figures 1 and 2 illustrate the extent of the difficulties which confront the separations technologist. Whilst the available theory can potentially predict filter performance, its use is restricted by significant errors in the region of greatest importance, namely that adjacent to the filter medium. Furthermore, closer examination of eqn.(4) shows that as the combined sum of the constitutive parameters m and n approaches one so predictions with the existing theories become impossible. Thus, for more compressible cakes the errors introduced by prediction increase significantly and it is therefore hardly surprising that difficulties are encountered when scaling up from laboratory to pilot and subsequently full size apparatus and reliance is frequently placed on non-representative experimental data. Such problems are further enhanced by the reluctance of practitioners to stop using ad-hoc ‘rules of thumb’ and filtration theories developed in the 1930’s and utilise, and hence develop, more advanced theories which can be used to predict filter performance from a knowledge of suspension properties.

CONCLUSIONS

There is a pressing need for the development of both existing and new filtration theories to aid the process engineer in designing solid/liquid separation plant. Terms to account for factors such as surface charge must be included in any developments which may also incorporate novel interpretations of the empirically derived constitutive parameters highlighted in this paper. The models produced should be based on well founded, systematic research programmes which investigate all the parameters necessary to understand compressible cake filtration and maintain the essential elements of user-friendliness and rigorous analysis.

ACKNOWLEDGEMENT

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FIGURES AND TABLES

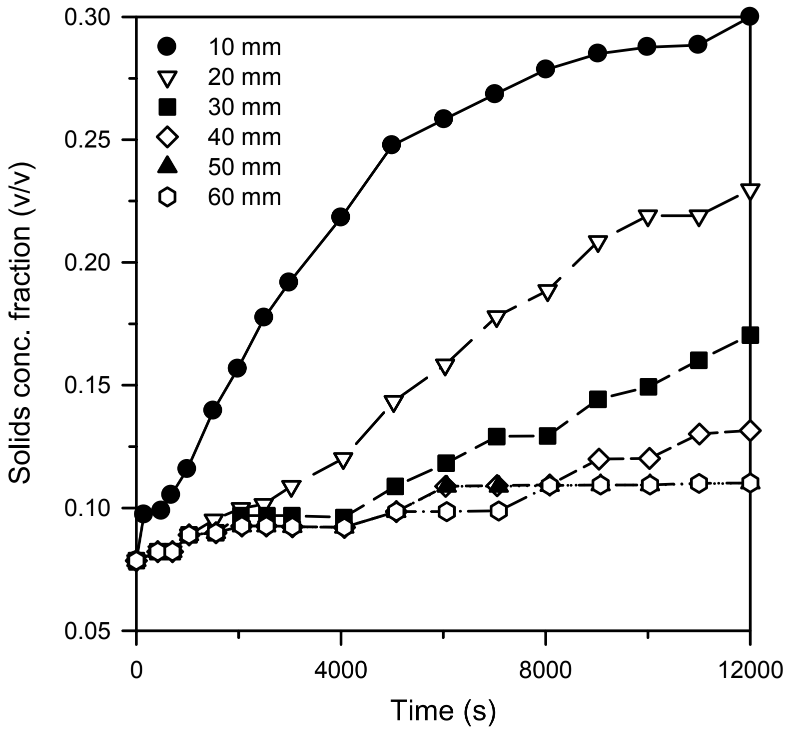

Figure 1: Solids concentration vs. time for a zinc sulphide suspension.

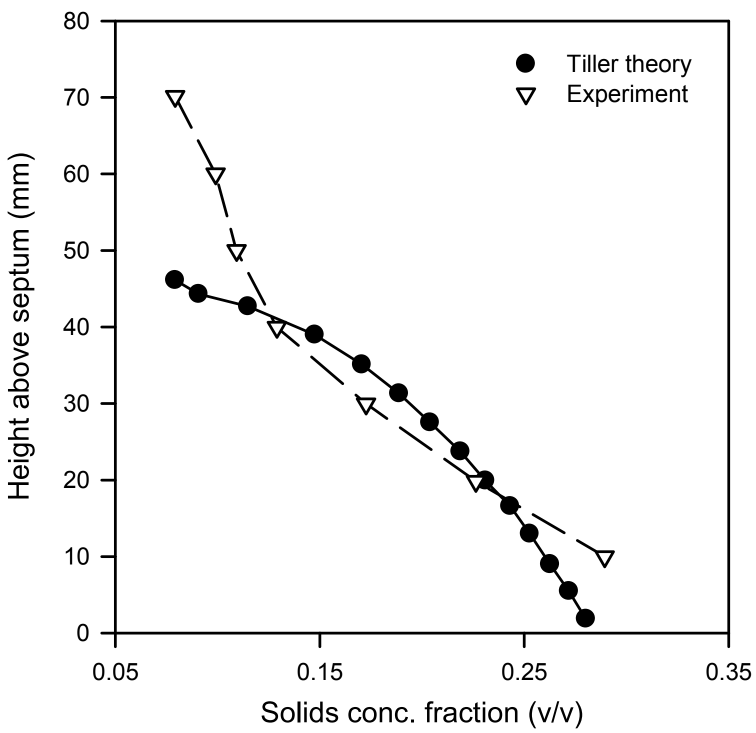

Figure 2: A typical cake concentration profile for filtered zinc sulphide.

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Property	Calcite	China clay	Zinc sulphide*
50% particle size (μm)	7.9	3.4	9.4
Variance (μm^2)	26.6	15	208
Particle shape	rhomboidal	platelet	spheroidal
ζ-potential (mV)	+4.7 → -13	0 → -55	+31 → -51
$\alpha_0 \Delta P_c^{\,n}$	-	$4.8\text{x}10^8 \Delta P_c^{\,0.55}$	$1.2\text{x}10^{10} \Delta P_c^{\,0.39}$
$C_0 \Delta P_c^{\,m}$	-	$0.12 \Delta P_c^{\,0.1}$	$0.05 \Delta P_c^{\,0.16}$

*50% size = 0.8 μm and variance = 4.2 μm^2 on addition of Dispex 40

Table 1: Measured properties and constitutive equations for the test suspensions.

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