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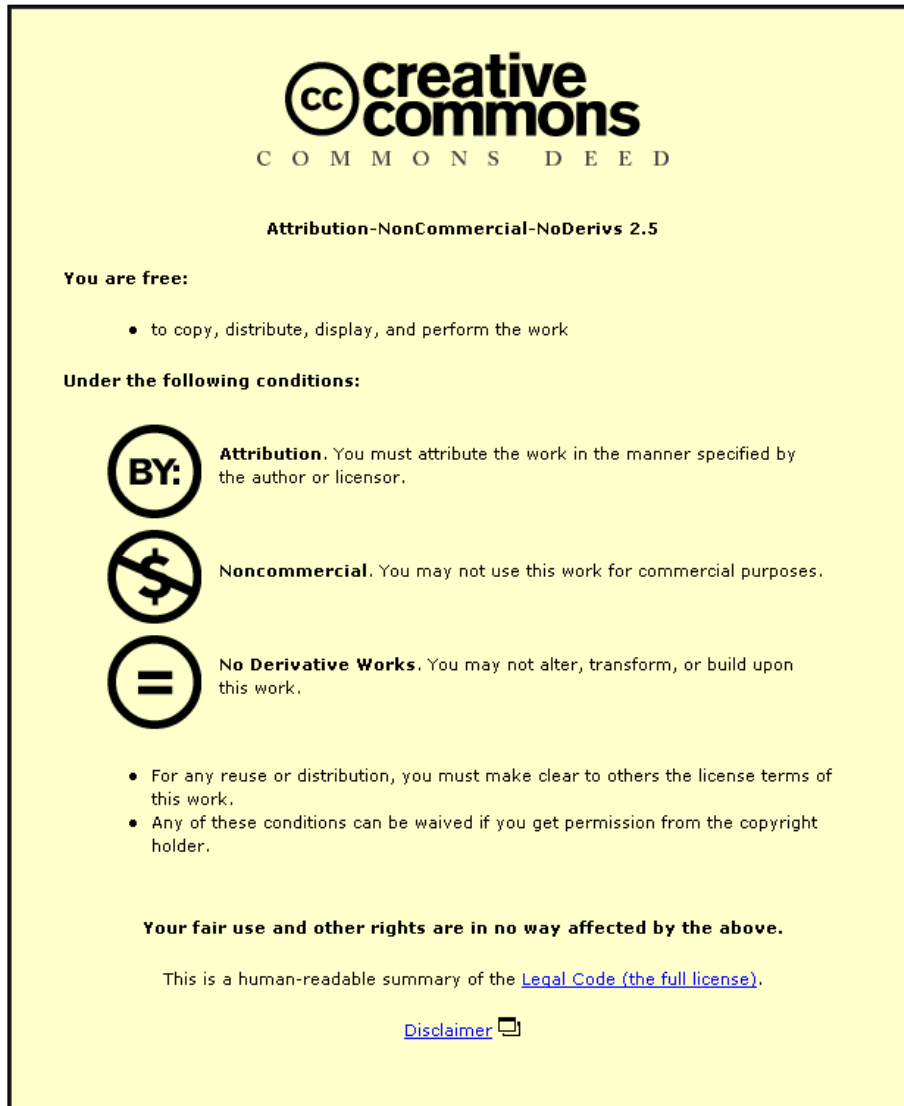
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
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COMPRESSIBLE CAKE FILTRATION

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ABSTRACT

The formation of a compressible kaolin filter cake has been examined using an electrical conductivity technique that continuously monitors the local solids concentration with height and time during filtration. The relative importance of liquid drag, solids weight and velocity inside a filter cake during the cake forming process were studied, and their effect on the modelling approach of Tiller and Shirato considered. It is concluded that a more accurate representation of the cake concentration profile would result from an incremental simulation of the solid deposition process.

INTRODUCTION

Compressible cakes are often formed when filtering chemical, biochemical, waste water and mineral slurries but equipment design and control is almost always based on the assumption that either the filter cake is incompressible or that an average cake concentration exists throughout the filtration cycle. Much of our present knowledge of the internal processes occurring during compressible cake filtration has come from an extensive set of publications from two researchers, Tiller and Shirato, who have provided a means of inferring concentration and velocity inside a cake from a limited set of experimental measurements. Their constitutive equations are not, however, normally applied in filter design or control, due in part to the lack of experimental evidence on compressible filter cake concentration profiles and uncertainty on how capable these theories are of predicting filter performance.

Analysis Techniques

The well known reciprocal rate equation for constant pressure filtration is

$$\frac{dt}{dV} = \frac{\mu c \alpha_{av}}{A^2 \Delta P} V + \frac{\mu R_m}{A \Delta P} \quad (1)$$

where t is the time, V the filtrate volume, μ the liquid viscosity, A the filter area, ΔP is pressure, R_m the medium resistance, α_{av} the average specific cake resistance and c the mass of dry solids deposited per unit volume of filtrate. It is possible to interpret experimental data according to equation (1), or its closely related integrated form, to provide values for the cake and medium resistances. If a series of cake forming pressures are investigated the effect of pressure on cake resistance and concentration results. These are often correlated by simple power law expressions such as

$$C_{av} = C_0 (1 - \beta) \Delta P^\beta \quad (2)$$

and

$$\alpha_{av} = \alpha_0 (1 - n) \Delta P^n \quad (3)$$

where C_{av} is the average cake concentration and C_0 , α_0 , β and n are empirical constants. It has been proposed (Tiller, 1975) that when these constants are known it is possible to predict the filter cake concentration profile from

$$C = C_0 \Delta P^\beta \left(\frac{y}{L} \right)^{\beta(1-\beta-n)} \quad (4)$$

where y is the fractional cake depth and y/L is the dimensionless distance into the cake. Cake depth can then be deduced from

$$L = \frac{\Delta P^{(1-\beta-n)} A}{\mu \alpha_0 C_0 \rho_s (1-\beta-n) Q} \quad (5)$$

where Q is the instantaneous filtrate rate.

The above approach follows from a consideration of a local force-momentum balance on a filtering layer, and equations (4) and (5) are considered valid when the contribution to the local solid stress gradient (dP_s/dx) from the local cake weight and the local solids velocity (v) can be neglected. Under these conditions equation (6) is valid

$$\frac{dP_s}{dx} = \mu \alpha C \rho_s \frac{Q}{A} \quad (6)$$

where C is the local cake concentration by volume fraction. If weight and solid velocity cannot be neglected equation (7) must be used

$$\frac{dP_s}{dx} = gC(\rho_s - \rho) + \mu \alpha C \rho_s \left(\frac{Q}{A} - v \right) \quad (7)$$

The remainder of this paper investigates these equations and the consequences of the simplifying assumptions on the calculated concentration profile during a compressible cake filtration.

EXPERIMENTAL PROCEDURE

Kaolin with a density of 2650 kg m⁻³ (ECC china clay, grade E) was used in all the tests. The size distribution of this material was measured by a Micromeritics Sedigraph which gave a median diameter of 3.4 μm.

The experimental equipment required for in-situ concentration analysis using electrical conductivity has been described previously (Holdich and Sinclair, 1992), and is shown schematically in Figure 1. In this study the 44 mm diameter filter cell was constructed from PVC with an inner cylinder of perspex. A small viewing window was cut in the PVC and pressures of up to 3 bar could be used. Four constant pressure filtrations were conducted at 0.55, 1.0, 2.0 and 2.8 bar starting with a slurry of 16.3% solids by volume (34% by weight) in 0.31 g l⁻¹, potassium chloride solution at a pH of 5.04. The filter surface faced upwards, but significant sedimentation in the filter cell was not observed during the test.

RESULTS

Figure 2 shows the cake solids concentration with height from the filtering medium at arbitrary times during filtration at the four cake forming pressures.

The compressible nature of the kaolin filter cake is evident from Figure 2 as cake concentration increases with pressure. At the times investigated some residual slurry at 16.3% solids remained

in the cell. Filtrate volume with time was monitored during the filtration and hence the constants in equations (2) and (3) could be evaluated in the conventional way using the gradient of a reciprocal rate with volume plot. Using this information it is possible to solve equations (4) and (5) at any instant in time for all the filtrations undertaken and an example profile calculated according to equations (4) and (5) is given in Figure 3.

The predicted profile yields an overestimate of the cake concentration at the medium, and a 10 mm error (17%) in the total cake height. A knowledge of the cake height is important in pressure filtration where clearances are often small and cakes are formed in visibly opaque chambers. The shape of the predicted concentration profile is considerably different from the measured, but it is more accurate than one given by assuming an average or incompressible cake concentration. Such a profile would be, in effect, a vertical line parallel to the height axis with a 90° corner at the cake surface.

Figure 4 shows the contribution to the stress gradient from the constituent terms of equation (7), and equation (6) which is represented as curve A. Curves B and C are the liquid drag term including solids velocity and the solid weight term, respectively. The solids velocity for each concentration in the cake was calculated from a material balance, giving

$$v = -\frac{1}{C} \int \frac{\partial C}{\partial t} \partial x \quad (8)$$

which can only be evaluated when the cake concentration profile is known. Curves B+C represent the accurate solids stress gradient during filtration under the chosen conditions, and curve A is a good approximation to this for concentrations above 30% solids. Hence predictions based on equations (4) and (5) are less reliable at the lower concentrations, such as when filtrations are performed at lower pressures. Equation (7) can be used in an incremental simulation of the filtration process (Wakeman, 1981), which is valid at all cake forming pressures so long as appropriate empirical constitutive equations are used.

CONCLUSIONS

The modelling approaches suggested by Tiller and Shirato to predict the solids concentration profile during compressible cake filtration of materials such as kaolin give the required gradual increase in concentration towards the filtering medium, though the concentration profile predicted can be considerably in error. It is notable that the measured profiles, such as Figures 2 and 3, showed a more rapid increase in concentration near the cake surface and a substantial amount of cake at a nearly uniform concentration.

Detailed modelling of compressible cakes can only be made with the assistance of an experimental technique capable of measuring the local cake concentration, such as the electrical conductivity system. This enables an accurate analysis of the solid stress gradient within the cake and the technique will be used to develop an incremental computer simulation of the filtration process.

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TABLES AND FIGURES

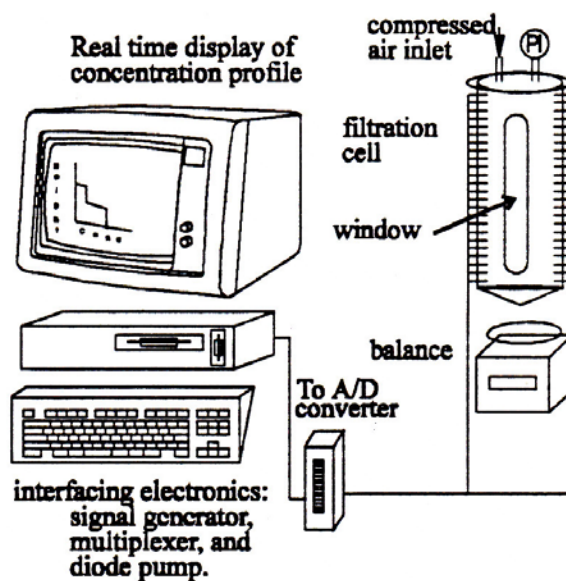


Figure 1: Experimental equipment.

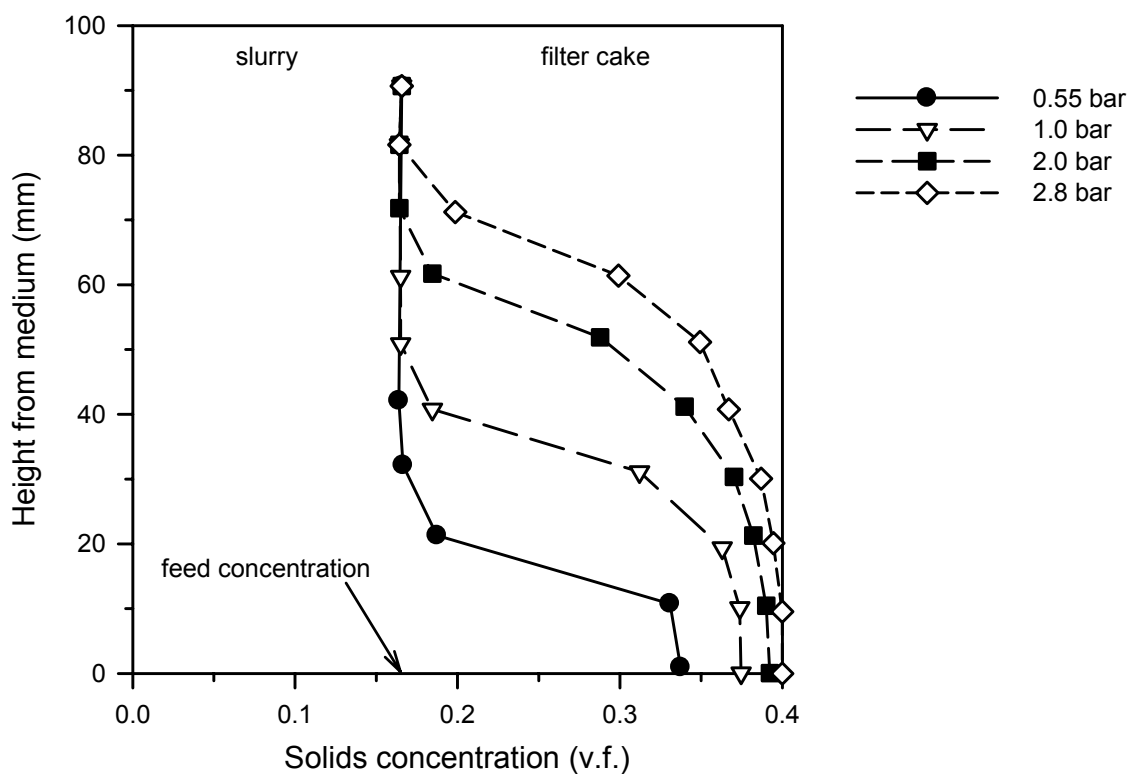


Figure 2: Measured concentration profiles.

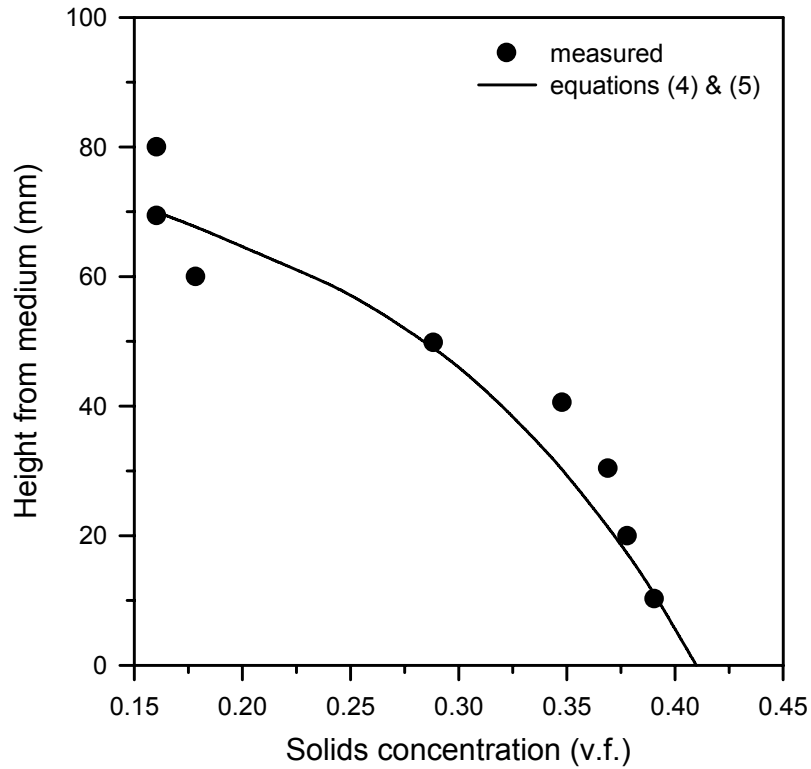


Figure 3: Solids concentration profiles inside the filter.

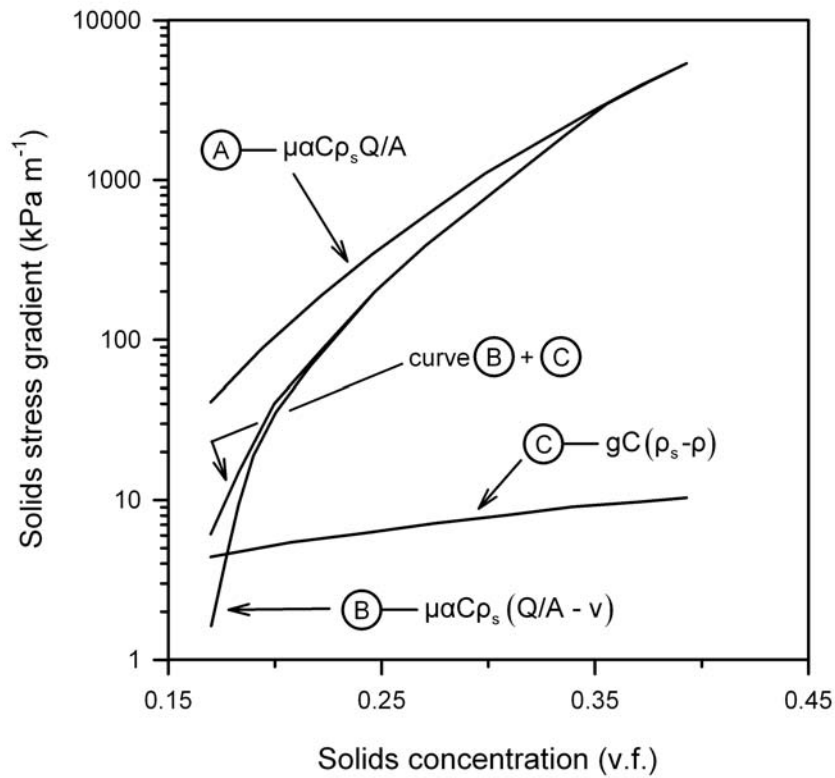


Figure 4: Constituent terms of the stress gradient.