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Simulation of the cake formation and growth in cake filtration

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Abstract

A computer model was developed to simulate the cake formation and growth in cake filtration at an individual particle level. The model was shown to be able to generate structural information and quantify the cake thickness, average cake solidosity, filtrate volume, filtrate flowrate for constant pressure filtration or pressure drop across the filter unit for constant rate filtration as a function of filtration time. The effects of particle size distribution and key operational variables such as initial filtration flowrate, maximum pressure drop and initial solidosity were examined based on the simulated results. They are qualitatively comparable to those observed in physical experiments. The need for further development in simulation was also discussed.

Keywords: Cake filtration; Simulation; Packing structure; Particle mixtures

1. Introduction

Cake filtration is one of the solid–liquid separation processes. It can be found in many industries, including, for example, mineral, chemical, food, pharmaceuticals and petroleum industries. The principle of cake filtration is to remove solid particles from a liquid by using a filtering medium which is permeable to fluid flow but does not allow the passage of solid particles. When a solid–liquid suspension (slurry) moves towards a medium, solid particles retain at the medium surface and form a filter cake. The cake thickness will increase with time. Therefore, cake formation and growth are most important dynamic processes in cake filtration. However, this dynamic behavior and its associated cake microstructure are usually not considered in the mathematical models proposed in the literature.

Theoretical analysis of cake filtration began with the classical work of Ruth et al. (1933a,b) in 1930s. Since then, many researchers have dealt with this problem from different perspectives leading to a rich and diverse collection of filtration models (Wakeman, 1978, 1994; Bockstal et al., 1985; Stamatakis and Tien, 1991; Lu and Hwang, 1993; Tiller et al., 1995; Theliander and Fathi-Najafi, 1996; Tien et al., 1997). While useful to filtration theory and practice, most of the proposed models were formulated at a macroscopic level. For example, they consider solid particles retaining on the surface of a filtering medium to form a filter cake but do not discuss how the particles pack themselves at a microscopic level, or a microscopic model was so developed that it was not directly linked to process variables (for example, see Lu and Hwang, 1995).

In cake filtration, cake formation and growth process are essential in particle packing process. The packing is not ordered. Instead particles generally form random or loose packing structures. Computer simulation is useful to understand cake formation and growth, like the case in the study of particle packing. In this paper, we developed a computer model to describe the dynamic cake formation and growth at an individual particle level. It can be used for modeling a three-dimensional flirtation system. The cake thickness L, average cake solidosity ε_{sav}, filtrate volume V, filtration

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flowrate dv/dt or pressure drop across the filter unit ΔP can be simulated as a function of filtration time. The effects of variables such as particle size distribution, initial filtration flowrate, maximum pressure drop and initial solidosity will be studied in this work.

2. Simulation method

The problem can be stated as follows. A mixed slurry under pressure drop ΔP moves towards a medium in a vessel at the start; no feed is added; and no particles can enter the medium. The filter cross-section considered is rectangular. We define the length, x_l, and width, y_l, of the filtrate container, and then the initial height of the slurry, z_l, can be calculated as follows:

$$z_l = \frac{4}{3}\pi \sum_{i=1}^{n_{\text{total}}} r_i^3 / x_l y_l \varepsilon_{s0} \tag{1}$$

where r_i is the radius of particle i, n_{total} is the total number of particles in the system considered, and ε_{s0} is the initial volume fraction (solidosity) of solids in the slurry. The origin of the coordinates system is at the center of the medium.

When a particle just touches the cake surface, it will contact with the medium surface, or one and then more stable particles. Fig. 1 illustrates how a new particle attains its stable packing position by first impacting on one existing particle, rolling to contact the second particle, and finally reaching the position of the lowest height and energy among the three stationary particles. This process has been widely used in the simulation of particle packing (German, 1989). However, different from the event-driven simulation used there, time should be introduced to link the packing process to the sedimentation and filtration process. As a first step in our developing a comprehensive simulation model, in this work, the motion of particles in a cake formation process is traced as a function of time under the following assumptions:

(1) The process is operated with a two-stage scheme. At the initial stage, a constant rate filtration rate is used while the pressure drop ΔP increases with time. When the pressure drop reaches a pre-set maximum value ΔP_0, the process will be operated as a constant pressure filtration.
(2) The fluid flow is one-dimensional, normal to the horizontal medium surface. Particles involved are spherical and larger than 1 μm in diameter, so that the Brownian motion of particles can be neglected.
(3) A particle follows a one-dimensional path, and the influence of the sedimentation can be neglected, so that the particle velocity and the fluid velocity are same in the slurry layer. However, once the particle touches a particle at the cake surface, it may roll and/or fall further until a gravitationally stable position is found as described above. A stable particle is not in motion any more.
(4) The slurry is so dilute that the motion of a particle in sedimentation is not affected by other particles. So inter-particle forces as a result of particle collision can be fully neglected. In fact, the present model is better understood as a kinematic rather than dynamic model as no force is explicitly considered.
(5) The possible percolation of a small particle through pores among large particles is neglected. This is

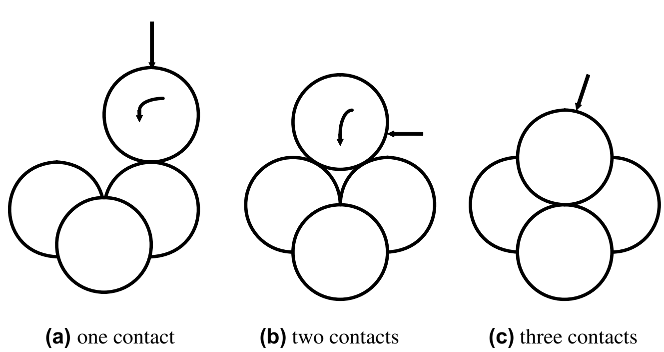

Fig. 1. Schematic illustration of a particle attaining its gravitationally stable position.

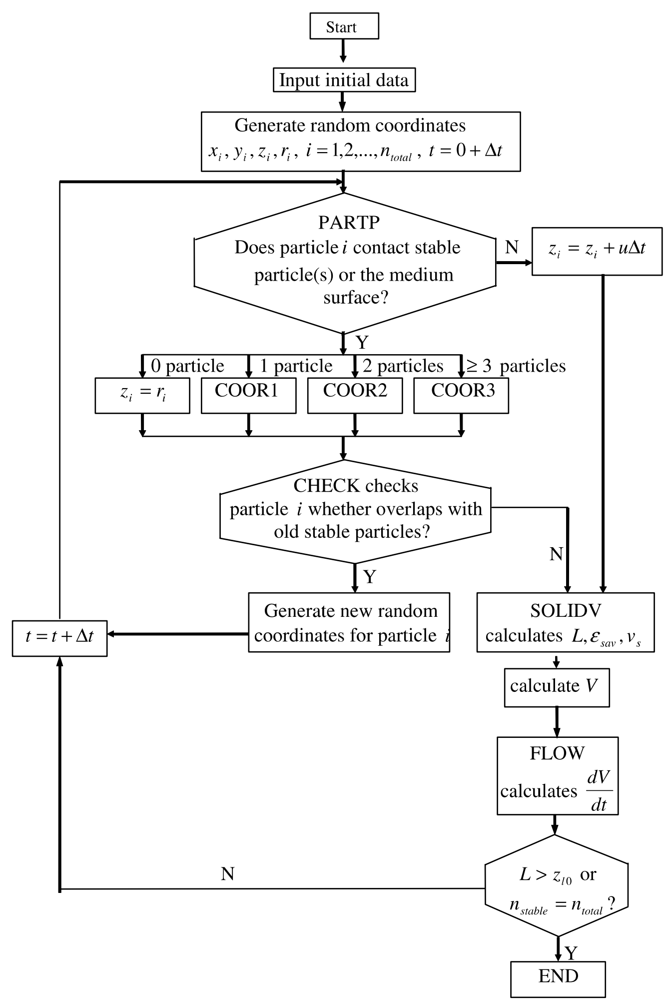

Fig. 2. Flowchart for cake filtration program.