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Particulate clusters and permeability in porous media

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A B S T R A C T

The permeability of particulate colloidal titanium dioxide, P25, was investigated during sedimentation, permeation and filtration when suspended in water at a consistent ionic strength similar to tap water. Happel's cell model of permeability was used to determine the apparent particle size during these processes, and compared with the size of particle clusters measured using laser diffraction under identical ionic conditions and varying degree of shear. The primary particle size of the P25 was determined to be 28 nm, from consideration of the surface area and density of the particles, and the cluster size during permeation and filtration was close to 100 nm. During sedimentation the cluster size was determined to be close to 10 μm, which is the same size obtained by laser diffraction when measuring under conditions of low shear. Using the above two sizes (28 nm and 10 μm) as limits in Happel's permeability model it was possible to determine an 'operating envelope' of permeability that matched the experimentally measured values for the sedimentation, permeation and filtration processes.

Keywords: Permeation; Cluster size; Porous media; Sedimentation; Filtration

1. Introduction

In any process where a fluid flows through a porous media, such as sedimentation, permeation and filtration, the permeability of the solids forming the porous medium governs the frictional loss. Hence, the observed rates of filtration, permeation and sedimentation are determined by that permeability, and process design and understanding would benefit from a method to reliably predict the permeability from a knowledge of the particle size distribution. This has been the desire of research workers over many years of study. Furthermore, the nature of the solids and how their particle size analysis is determined is also of great importance when dealing with finely sized particles, as they often form clusters containing many primary particles, and thereby influencing the predicted permeability. Clustering may be desirable in certain circumstances, such as to enhance sedimentation rate, but it will interfere with the particle size analysis, or characterisation, as the result will be dependent on the prevailing conditions during the analysis, which are likely to be very different to the conditions to be found in the process being designed.

There are a number of well-known permeability expressions (Carman, 1937; Brinkman, 1947) and most of them are derivatives of the Kozeny Carman equation (Xu and Yu, 2008). However, these expressions contain an empirically determined parameter, e.g. the Kozeny 'constant' based on a model of the porous medium as a collection of tortuous channels. A better description of the microscopic flow field through a structure of interacting, but single and monosized spheres, has been presented by the Happel solution to the Navier–Stokes equation (Happel and Brenner, 1965). Happel's cell model takes into consideration the drag forces acting on the individual spheres. Each sphere is assumed to be surrounded by an imaginary fluid region and the thickness of the outer fluid is chosen in order to have a voidage value of the cell (sphere + outer fluid) equal to the overall voidage in the medium.

The basic equation relating pressure drop (ΔP) and superficial velocity (U_0) is Darcy's law, which for a single dimension is:

$$\frac{\Delta P}{L} = -\frac{\mu}{kA} U_0 \qquad (1)$$

where k is the hydraulic permeability, A is the cross-sectional area to flow, μ is the coefficient of dynamic viscosity and L is the bed height.

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