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INTERFERENCE OF COARSE PARTICLES WITH FINES OF DIFFERENT SHAPES IN CAKE MODEL

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Introduction

Mixtures of irregular and regular (close to spherical) particles are widely used in practice. Moreover, in solid-liquid separation we have often suspensions where solids can be clearly separated in two particle fractions of significantly different size (large – coarse, and small – fine).

Perlite and kieselguhr are used as filter media and filter aids for filtration of suspensions of different nature. Simultaneously, kieselguhr filter aids, represented by highly irregular particles, may represent an excellent experimental model for the investigation of the behaviour of mixtures of irregular particles with regular (granular) material. Filter cakes and sediments represent such type of binary mixtures. Binary mixtures of two particle types, irregular and granular, were investigated in this work. Depending on conditions, granular particles represent the fraction of large size D or of small size d particles, whereas irregular particles play role of second mixture's fraction. We made experimental measurements of packing porosity and permeability of mixtures of glass beads and irregular particles. Our experimental results, together with other published data, were then used to develop a generalised approach to explain the porous media properties.

Materials and experimental procedure

Three types of the kieselguhr and kieselgel, mixed with spherical glass beads of mean size D = $337.5{\cdot}10^{-6}$ m were investigated. Particle size ratio D/d in mixtures with glass beads was as follows: kieselgel – 23.3; kieselguhr-G – 27.4; kieselguhr middle sdize – 29; kieselguhr fine – 27.5. Middle and fine kieselguhr are samples of commercially used kieselguhr. Glass beads were the largest particles in the mixture and their volume fraction in the mixture was defined as x_D. Particle shape was defined after microphotograph image analysis. All samples contain plate and rod irregular particles, and disc-like particles were also observed in kieselguhr. Particle size distribution was measured by means of Particle Size Analysing system GALAI-CSI-100 with Computerised Inspection System.

Results and Discussion

The obtained results raise the hypotheses that a shape factor (sphericity) is more important than a defined geometrical form. It was found that the overall porosity ε has a minimum value in the range of x_D around 0.9. Dependency of ε on x_D for kieselgel and kieselguhr-G is concave, whereas for other kieselguhr samples the right part of the dependence is close to horizontal. The observed dependency of ε on x_D is shown in Fig. 1. A possible reason for the obtained difference in curve shape is

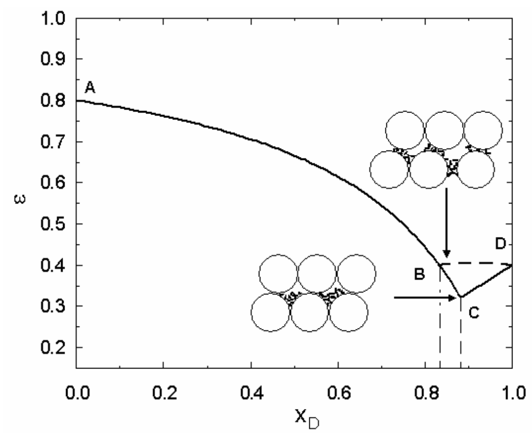

Fig. 1. Dependency of the overall mixture porosity ε vs. x_D. Curve of type *ABCD* was observed for kieselgel and kieselguhr-G; curve of type *ABD* – kieselguhr fine and middle.

presented. The curve *ABCD* may be due to the fact that kieselgel and kieselguhr-G fill the void between large particles; in turn the curve *ABD* may be explained by intrusion of fine particles in the skeleton of the large particles. Although a model of non-spherical particle mixture becomes complex when particle size distribution occurs, as in our case, for mixtures when components can be separated on two fractions (glass beads and kieselguhr), it is possible to apply a binary mixture model.

Overall porosity description

Let us represent the overall porosity ε as a function of fractional porosity $\varepsilon_D = \varepsilon_D(x_D)$ and $\varepsilon_d = \varepsilon_d(x_D)$, where ε_D is the void fraction of large particles in the total volume of the mixture, and ε_d is the specific void fraction of small particles in the remaining void volume of the mixture. Since the overall volume of solids in the mixture, $1-\varepsilon$, is a sum of volumes of large particles, $1-\varepsilon_D$, and small particles, $(1-\varepsilon_d)\cdot\varepsilon_D$, the porosity of the mixture becomes

$$\varepsilon = \varepsilon_D(x_D)\cdot\varepsilon_d(x_D) \qquad (1)$$

Dependencies ε_D and ε_d on x_D were calculated on experimental data and analysed.

To have a better correlation in the range of minimum porosity, we applied an approach similar to the developed in a previous work (Mota *et al*, 2001)

$$\varepsilon_d(x_D) = \varepsilon_d^0 + (1-\varepsilon_d^0)x_D^{f(\delta)} \qquad (2)$$

$$\varepsilon_D(x_D) = 1-(1-\varepsilon_D^0)x_D^{\Im} \qquad (3)$$

where power indexes $f(\delta)$ and $\Im$ are correction functions depending on the ratio $\delta = d/D$. Using equations (2) and (3), correlation functions for mixtures of kieselguhr – glass beads were evaluated. Because of narrow dispersion of δ variation in the investigated mixtures, we may assume in equation (2) $f(\delta) = const$ and, from fitting analysis, to be equal to 10.

Due to significant deviation from spherical of small particles shape it was not possible to adopt equation (3) directly for non-spherical particles in all range of x_D and a fitting procedure was applied. The mixture permeability increases in the direction $x_D \rightarrow$ 1.0 and also was modelled by using equation 1.

Finally, we must check whether the fractional porosity approach gives a prediction of the mixture porosity sufficiently close to those obtained experimentally by other authors.

Comparison with published data

Binary systems quoted from publications were analysed: Bentonite + barite (Meeten and Sherwood; 1994); TiO_2 + perlite, $CaCO_3$ + talc, liquefied coal residue + Celite (Okoh, 1989). Binary mixtures of cubes or spheres, mixtures of disks, binary mixtures of short and long cylinders, binary mixtures of sphere and cylinders were also analysed (Yu *et al*, 1993 and 1996).

When granules correspond to the small size fraction then, for the same size ratio D/d , the dependency curve of ε vs. x_D is a mirror-like image of Fig. 1 (see Fig. 2). However, the permeability vs. x_D behaves in the same way in both cases.

Observed relationships give an opportunity to generalise behaviours of binary mixtures of irregular and granular particles when particle size ratio D/d is large: Less irregular (granular-like) particles define the minimum porosity range which is around of their volume fraction 0.9 – 0.8 in a binary mixture, whereas irregular particles controls the binary bed permeability when their volume fraction in a mixture larger than 0.1 – 0.2.

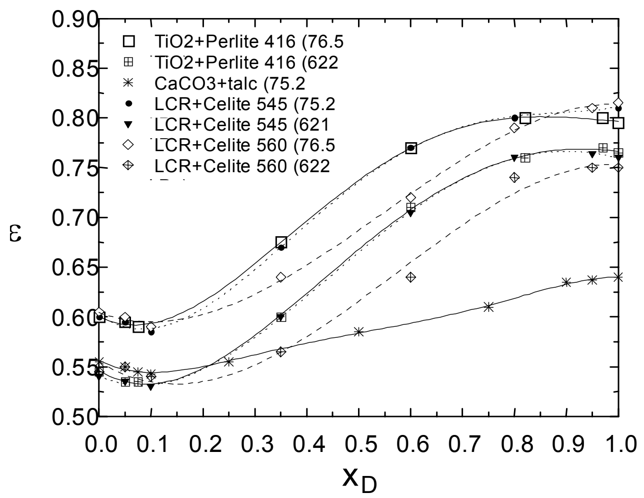

Fig. 2. . Dependency of binary system (Okoh, 1989) porosity on volume fraction of large particles (filter aid). LCR = Liquefied coal residue.

Conclusion

It was found that the presence of more than 10% of fines in the coarse granular bed significantly reduces the cake porosity and hence the permeability. To improve cake permeability the volume fraction of filter aid in a suspension must be at least 50 – 60 % of total solid volume.

The porosity behaviour can be analysed and predicted by means of the fractional porosity diagram. The minimal porosity of the mixture is a function of the size ratio between coarse and fine particles and can be estimated as a product of small and large size particles bed porosities when small particles fill the void space left by the large particles skeleton. When we have Kieselguhr particles as the small size particles fraction porosity the overall porosity is constant from $x_D \sim 0.85$ up to $x_D = 1$. This means that a build up of a filter layer from a binary mixture is possible with a reduced consumption of kieselguhr.

Application of fractional porosities for binary mixture analysis (filter cake, sediments, column and catalyse pellet packing, etc.) may also be a powerful tool to control the overall porosity and permeability by means of controlled changes in the properties of each particle fraction (particle shape, packing density, size ratio between and inside fractions, fractional content of the mixture).

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