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Viscosity of multimodal suspensions predicted from solid fraction model for mixtures

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Objectives:

- PARIS-EST

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The model is able to predict the viscosity of a suspension of non colloidal rigid spherical particles in a Newtonian fluid. The theory is developed to highlight a new relation between relative viscosity and the solid volume fraction. A new version of the Compressible Packing Model (CPM), the 4-parameter CPM, is introduced to predict the solid fraction of maximally dense disordered packings of spherical particles. It is apt to account for the geometrical interactions between particles.

4-parameter Compressible Packing Model (CPM):

The 4-parameter CPM is apt to account for the loosening effect on big particles from interstitial small ones and for the wall effect within assemblies of small particles near a big one. The new theory is based on a specific treatment of configurations of one secondary class particle surrounded by dominant class neighbours. Four parameters are: wall effect and loosening effect coefficients, critical cavity size ratio and compaction index.



 β : compactness value, supposed to be constant, of each elementary class ; y_j : volume proportion of each elementary class, by reference of the total

Loosening effect:

Delimitation of the spherical reference cell:

 $\dot{d}_{hvp} = d_2 (1 + 2 k_{P_1}/x)^{1/2}$

compactness **B**"1 of large

spheres in the reference

ell. Deduction of the

compactness **\$**1 in a more global interference

zone by taking into

account the critical cavity

size ratio.

 $X = \frac{a_2}{2}$

PO 13

- solid volume;
- b_{ij}: wall effect coefficient;
- a_{ii}: loosening effect coefficient;

 $\beta''_1(\mathbf{x}) = -$

 γ_i : compactness value of the mixture when the class i is dominant.



η: suspension viscosity; $η_0$: viscosity of the newtonian suspending fluid;

Wall effect coefficient for a binary mixture:

 $b_{21}(x) = \frac{\beta - \beta'_{2}(x)}{1 - \beta} \left[\left(1 + 2k_{p2} x \right)^{\frac{3}{2}} - 1 \right]$

1000

 k_{p2} is determined by respecting the boundary condition: $b_{21}(1) = 1$

 $\left(2\left(1+2k_{P2}x\right)^{\frac{3}{2}}-3\left(1+2k_{P2}x\right)\left(1+\frac{k_{P2}x}{1+x}\right)+\left(1+\frac{k_{P2}x}{1+x}\right)^{3}-x^{3}+\frac{3k_{P2}x^{3}}{1+x}+x^{3}\left(1-\frac{k_{P2}}{1+x}\right)^{3}\right)$

 ϕ : volume fraction of the suspended spheres in a total volume unity;

 ψ_i : volume fraction of the class i considering the presence of finer class;

 ψ_i^{MAX} : maximal volume fraction of the class i considering the presence of finer class;

In agreement with a previous work of [BOUR05], the iterative approach advocated by Farris and a power-law relation (Krieger-Dougherty type) are used for the relative viscosity. The theory is developed to highlight a new relation between relative viscosity and the solid volume fraction, compatible with the Einstein relation. When the solid volume fraction reaches its critical value, the suspension is jammed and the mixture reaches the packing density of the solid skeleton. Compactness of large spheres in a more global interference zone by taking into account the critical cavity size ratio x_0 :

 $\left| 2\left(1 + \frac{2\,k_{_{P1}}}{x}\right)^{\frac{3}{2}} - 3\left(1 + \frac{2\,k_{_{P1}}}{x}\right)\left(1 + \frac{k_{_{P1}}}{1 + x}\right) + \left(1 + \frac{k_{_{P1}}}{1 + x}\right)^{3} - \frac{1}{x^{3}} + \frac{3\,k_{_{P1}}}{x^{2}\left(1 + x\right)} + \left(\frac{1}{x} - \frac{k_{_{P1}}}{1 + x}\right)^{3}\right) \right|$



Delimitation of the spherical reference cell: $d_{hyp} = d_2 \sqrt{1 + \frac{2k_{P1}}{x}}$

Compactness of large spheres in the reference cell:

 $= \frac{1}{4\left(1 + \frac{2k_{P1}}{x}\right)^{\frac{3}{2}}} \operatorname{arcsin}\left(\frac{1}{1 + x}\right)$

Volume proportion of small particles at the « eutectic » point: $\phi_{2}^{*}(x) = \beta + ((1 - \beta)(1 - b_{21}(x)) - 1)\beta'_{1}(x)$

Loosening effect coefficient for a binary mixture:



 k_{p1} is determined by respecting the boundary condition: $a_{12}(1) = 1$

Theoretical relative viscosity versus experimental one:

To infinity

•

Theoretical relative viscosity versus normalized total solid volume fraction:

	● x=0,2
•	• x=0,7



Bidisperse suspensions: comparison between relative predicted viscosities and relative experimental values from Stovall, Buil and Such [STOV87], with 3 different size ratios (x=0,2, x=0,4, x=0,7), for glass beads in silicone oil.



Bidisperse suspensions relative predicted viscosities as a function of the normalized total solid volume fraction for 3 different size ratios (x=0,2, x=0,4, x=0,7), for a volume proportion of the fine class $y_2=0,30$ and for $\beta=0,60$.

Conclusion:

The viscosity of a multimodal suspension is predicted by taking into account geometrical interactions and hydrodynamic interactions between particles. The model initially proposed by Farris is modified to include interactions used in the 4-parameter compressible packing model (CPM) to predict the compactness of a dry granular mixture. The wall effect and the loosening effect are the subject of a new theory. A spherical reference cell, concentric with a foreign sphere lost in a monodimensional mixture, can be used for both types of geometrical interactions. Its diameter is adjustable, depending on fine/coarse diameter ratio and on the specific packing density of the elementary dominant class.

References:

10000

1000

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