Virtual testing-based Homogenization for Solid-Liquid Mixture

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ABSTRACT

We present a method of virtual testing for solid-liquid mixtures to evaluate the macroscopic viscosity of equivalent homogeneous liquids by applying a sort of homogenization procedure to the microscopic flow with suspended solid particles in a representative control volume (RCV). In this study, the classical theory with the Hagen-Poiseuille equation is regarded as a macroscopic formula to mutually relate the macroscopic state variables and physical properties. In analogy with an actual hydraulic measurement, a pipe channel filled with the mixture is employed as a RCV, in which microscopic flow simulations are conducted with the macroscopic pressure gradient being an external force. Due to the oscillation and rotation of the solid particles inside the RCV, the flow at microscale inherently involves transient states, and is not only non-stationary, but also non-uniform. To properly characterize the macroscopic fluid properties, we also discuss appropriate averaging or homogenization schemes and statistical treatments for both time and spatial variations of state variables.

The standard Navier-Stokes equations are used to analyse the liquid flow, which is assumed to be water, whereas suspended solid particles are assumed to be rigid bodies whose motions are determined by the distinct element method (DEM). The interaction between water and solid particles is evaluated with the help of the finite cover method (FCM) [1] with an unstructured mesh for the fluid phase. The motions of the solid particles and the water are assumed to be periodic so that the boundary conditions are imposed on both ends of the pipe. No-slip conditions are applied for the sidewall.

A series of microscopic flow simulations are carried out with different pressure gradients and different numbers of suspended solid particles to demonstrate the capability of the proposed virtual tests and to find out the relationships between the macroscopic strain rate and shear stress, which characterizes the dependency of the macroscopic viscosity on the macroscopic flow velocity. According to the results, the macroscopic flow might not be non-Newtonian, even though the microscopic liquid flow is assumed to be Newtonian. In fact, it is reported by Coussot and Piau[2] that liquefied sands have Bingham flow characteristics.

REFERENCES

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[2] P. Coussot and J.-M. Piau, "On the behavior of fine mud suspensions", *Rheological Acta*., Vol. **33**, pp. 175–184, (1994).