CFD-DEM MODELING OF PARTICLE-LADEN VISCOELASTIC FLOWS IN HYDRAULIC FRACTURING OPERATIONS

C. FERNANDES[1], S.A. FAROUGHI[2], R. RIBEIRO[1], G.H. MCKINLEY[3]

[1]*Institute for Polymers and Composites, University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal, cbpf@dep.uminho.pt, a58714@alunos.uminho.pt*

[2]*Petrolern LLC, 1048 Arbor Trace NE, Atlanta, GA 30319, USA, faroughisalah@gmail.com*

[3]*Hatsopoulos Microfluids Laboratory, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA, 02139, USA, gareth@mit.edu*

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The ability to simulate the behavior of dense suspensions, using computationally-efficient Eulerian-Lagrangian techniques, requires accurate particulate-phase drag models that are valid for a wide range of process fluids and material parameters. The currently available closed-form drag models – which enable rapid calculation of the momentum exchange between the continuous and dispersed phases – are only valid for dilute suspensions with inelastic base fluids. The present work aims at developing appropriate drag models for moderately-dense suspensions (particle volume fractions < 20%), in which the continuous phase has viscoelastic characteristics. To this end, we parametrize the suspension properties through the Deborah number and the particle volume fraction, and compute the evolution in the drag coefficient of spheres translating through a viscoelastic fluid that is described by the Oldroyd-B model. To calculate the drag coefficient, we resort to three-dimensional direct numerical simulations (DNS) of unconfined viscoelastic creeping flows ($Re < 0.1$) past random arrays of stationary spheres, over a wide range of Deborah numbers ($De < 5$), volume fractions ($\varphi < 20\%$) and particle configurations. From these calculations we obtain a closure law $F(De, \varphi)$ for the drag force in a fluid described by the quasi-linear Oldroyd-B viscoelastic fluid model (with fixed retardation ratio β=0.5), which is, on average, within 4.7% of the DNS results. Subsequently, this closure law was incorporated into a CFD-DEM Eulerian-Lagrangian solver to handle particle-laden viscoelastic flow calculations, and two case studies were simulated to assess the accuracy and robustness of our numerical approach. These tests consisted of simulating the settling process in Newtonian and viscoelastic fluids within eccentric annular pipes and rectangular channels; configurations commonly employed in hydraulic fracturing operations. The numerical results obtained were found to be in good agreement with experimental data available for suspensions in Newtonian matrix fluids. For the case of viscoelastic fluids, the resulting particle distribution is presented for different elasticity numbers (i.e., $El = De/Re$) and particle volume fractions, and the results provide additional insights into the pronounced effects of viscoelastic matrix fluids in hydraulic fracturing operations.

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