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Particle Migration in Viscoelastic Liquids for Geometries that Model Fracturing Pump Valves

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We have recently started a program of experiments to study the migration of solid particles in viscoelastic liquids in simple channel and tube flows. Our objective is to understand the movement of particles in simple geometries that model those encountered in hydraulic fracturing. Our experiments are directly applicable to some features of flows in the vicinity of the valve seat in pumps used for injecting particle-ladened gel, and the geometry is easily adapted to provide a realistic model of the valve closing process. We want to determine the dependence of proppant migrations on the fluid rheology.

The modeling of the closure of the inlet valves in a pump used for injecting fracturing fluids may be divided into two parts: (i) the approach of the valve to the valve seat, which results in a gap of rapidly diminishing area through which the liquid and the proppant particles must pass, and (ii) the deformation of the urethane surface on the outer perimeter of the valve as it adjusts to the contour of the valve seat, resulting in a wedge-shaped volume of decreasing size from which the liquid and particles must be expelled. Both phases involve the motion of a particle-ladened viscoelastic liquid through narrow channels.

We have also constructed a motor-driven "syringe" device that allows us to examine particle motions near the entrance to a constant diameter tube as fluid is drawn at a constant rate into the tube from a reservoir of particle-ladened fluid. We are also constructing a two-dimensional piston device that provides a simple planar model of the valve closing process.

"Syringe" Device

This system is essentially a large syringe with a piston that is driven by a stepper motor running in a constant speed mode. The body of the syringe is a cylindrical tube, 4.45 cm in diameter, and the "needles" are constant-diameter tubes which, together with the particles, are the focus of the experiments. These tubes are 8.89 cm long and cover a range of diameters between 0.235 cm and 0.945 cm.

In order to describe the geometry of the particles in a simple way we are using sets of uniform-diameter nylon spheres. At present we have nine such sets available, with diameters from 0.1588 cm to 0.953 cm. A systematic program of experiments will be conducted for all particle and tube combinations for which the tube diameter is greater than the sphere diameter, using a variety of viscoelastic liquids and polymer concentrations and covering a wide range of fluid flow rates in the the tube. Preliminary results from a small number of combinations of sphere diameter and tube diameter using a 2% solution indicate that for each particle-tube combination there is a critical value of the mean flow speed in the tube above which no particles will enter the tube. For mean flow speeds below this critical value some particles will pass along the tube, with more and more particles entering the tube for progressively lower speeds. For a fixed sphere diameter the critical speed increases as the tube diameter is increased.

We plan to map the dependence of critical speeds on geometric parameters and fluid parameters. It is anticipated that the shear wave speed is an important fluid characteristic that will influence the migratory behavior of the particles. For this reason it is crucial that we achieve mean flow speeds in the tubes as large as the shear wave speed for each fluid. Unfortunately the present geometry of our system imposes a severe limitation on the maximum mean flow speed that can be achieved with each tube. Thus so far we have not been able to look at particle migrations at high mean flow speeds with 2% polyox. We are now designing a new "syringe" body of much larger cross-section to provide a larger and more flexible speed range and also to accommodate slits as well as circular tubes.

Valve Model

We have built a simple two-dimensional planar piston device in order to get a preliminary qualitative idea of the flow field and particle migration in the vicinity of a decreasing slit, which is a very simplified model of the valve closing process. The face of the piston, which closes on to a plane wall, will be made in a variety of shapes (e.g. planar, curved, wedge, flexible wedge), and a range of approach speeds will be used, although with this first simple model it is unlikely that we will be able to model the actual valve closing speed accurately. The intent of this preliminary experiment is to provide guidance for the development of a more sophisticated and realistic two-dimensional model. The early experiments will be carried out using spherical particles and liquids such as polyox and polyacrylamide in various polymer concentrations prior to using actual proppant particles and more realistic fluids. We anticipate extensive use of our high-speed video system in these experiments.