

Non-Newtonian Fluid Flow

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The shear stress and the shear rate of fluids can be described by the equation:

$$\tau = \mu\dot{\gamma}$$

where τ is the shear stress, $\dot{\gamma}$ is the shear rate, and μ is the viscosity.

For Newtonian Fluids, the shear stress and the applied shear rate are related linearly, i.e. viscosity is constant. Few real-life fluids are Newtonian, but a common one is water.

Most fluids are non-Newtonian, where viscosity varies with shear rate. In general how it varies cannot be easily described. Some fluids, including many used in oil-extraction applications, can be adequately described by the Bingham Model

$$\tau = \mu\dot{\gamma} + \tau_0$$

where τ_0 is some constant which is called Yield Stress.

In the experimental component of this summer, we worked with three non-Newtonian fluids: Laponite, Carbopol, and Xanthan, three very distinct types of non-Newtonian fluids. Two tests, displacement and start-up are done with these fluids in a horizontal circular pipe system.

In the displacement test, the non-Newtonian fluid is first pumped into the pipe. Then a Newtonian fluid, usually water or glycerin solution, is pumped into the pipe to displace the water. Realistically such situations occur in pipelines, and we would like to know how well non-Newtonian fluids can be cleared out from a pipe under different physical conditions. We can visually distinguish three types of flow regimes. Under high pressure, the fluid displaces cleanly, with obvious linear displacement boundaries. Under very low pressure, the displacement front stops completely after the transient, but a narrow line of fluid flows downstream along the walls of pipe, in what is called fingering in the industry. For medium pressure, while the displacement front moves along, it does not displace cleanly and leaves behind chunks of the non-Newtonian fluid. The Herschel Bulkley model ($\tau = K\dot{\gamma}^n + \tau_0$ for some constants K , n , τ_0) seem to work well with our data, especially if we add some correction terms at the high and low flow rates.

In the start-up test, the non-Newtonian fluid is allowed to remain inside the pipe under isobaric conditions for a set time before a pressure gradient is reapplied and the fluid would possibly resume flowing. We attempt to characterise

the transient and steady states by measuring the flow rate, velocity profile, and pressure. Analysis is still on-going.

In addition to carrying out the experiments, I have helped develop some code for data analysis. One was for automating the process of reading the pressure and flow data for different sets of experiments. In addition, we used cameras to record the geometry of the displacement. I developed an algorithm to filter the camera data to display only useful information along the pipe.

In the numerical component, we started off with simulation of the case of a Bingham flow through a symmetric periodic sinusoidal channel. The code is in C++ using the open-source Rheolef packages. The current Rheolef implementation can calculate the pressure and flow fields, as well as to find the unyielded and fouling regions of the Bingham fluid. The task, which is on-going, is to modify the current geometry to model a fracture. Possibilities for new geometry include sinusoids, square waves, saw tooth waves, or a superposition of these waves. For more information, refer to my USRA colleague Alexandre Gosselin's report.