Non-Invasive Diagnostics to Measure Physical Properties in High-Level Wastes

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Research Objective

The viscosity of a Hanford waste stream is potentially an indicator of its composition, including solids load, and of how well it has been mixed. Viscosity could be a useful control variable that might indicate the need for heating or dilution, for example. However, traditional off-line measurements are slow and samples can be difficult to take. Pausing processing to take samples disrupts and slows down production schedules and so, if viscosity measurements are necessary, requires increased capacity in the whole process. An alternative viscosity measurement that does not require sampling, and that is fast would be more useful than traditional techniques.

In this work, rheological measurements of waste simulants were made without taking samples. A viscometric flow was created within the waste transport pipeline and shear stress and shear rate were recovered from relations valid for developed steady state laminar flow in a long horizontal pipe,

$$\tau = \frac{\Delta P}{2L} r \tag{1}$$

$$\dot{\gamma} = -\frac{d\mathrm{v}}{dr} \tag{2}$$

viscosity being the ratio of shear stress to shear rate, $\tau/\dot{\gamma}$. In equation (1) the local shear stress is shown to be a linear function of the distance from the centerline of the pipe r, the proportionality constant being half the pressure drop per unit length of pipe. A simple measurement of pressure drop was performed to determine the shear stress profile across the pipe. In equation (2) the local shear rate is given by the local velocity gradient. In this work we determined the velocity gradient from flow profiles measured non-invasively by pulsed Doppler ultrasonic velocimetry. The velocimeter determined the Doppler frequency shift of backscattered ultrasound as a function of the range from the ultrasonic transducer to scattering particles in the flow.

Research Progress and Implications

This report summarizes work after 24 months of a 3-year project.

The Ultrasonic Doppler Velocimeter (UDV) and rheometry software developed earlier in the project were applied to non-Newtonian waste simulants. In previous years' work the system was tested with a shear thinning waste simulant with a time independent, repeatable rheology. The fluid used in the early experiments was a 0.1-wt. percent solution of Carbopol EZ-1 (from B.F. Goodrich) in de-ionized water neutralized with sodium hydroxide to form a gel. The system was installed in a flow loop built to model a segment of a waste transport line. The velocity profiles that were measured at several flow rates are pictured on the left of Figure 1. The rheograms (plots of shear stress versus shear rate) derived from these data are pictured in the right of Figure 1. The UDV-based rheograms (solid lines) are comparable to off-line measurements taken on grab samples by a conventional rotational rheometer (dashed red lines). These results validated the UDV-based instrument.

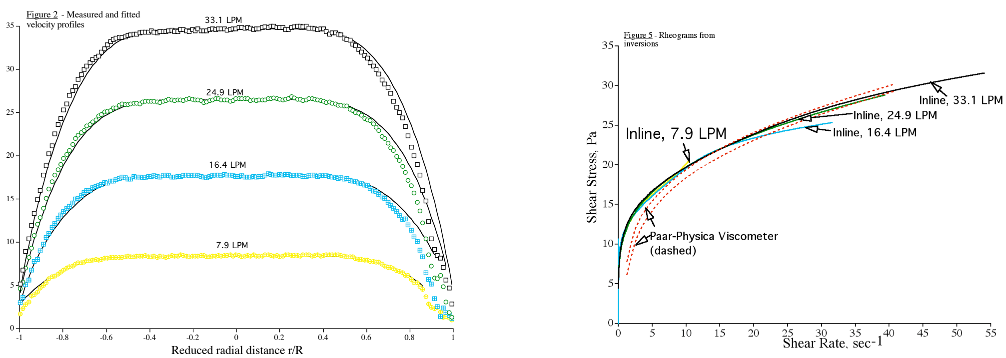

Figure 1

It is thought that many Hanford liquid wastes have time-dependent rheology (thixotropy). In this year's work the UDV-based rheometer was applied to a thixotropic waste simulant. The waste simulant used was a 1.8 weight percent mixture of RD Laponite (Rockwood Specialties Inc.) in tap water.

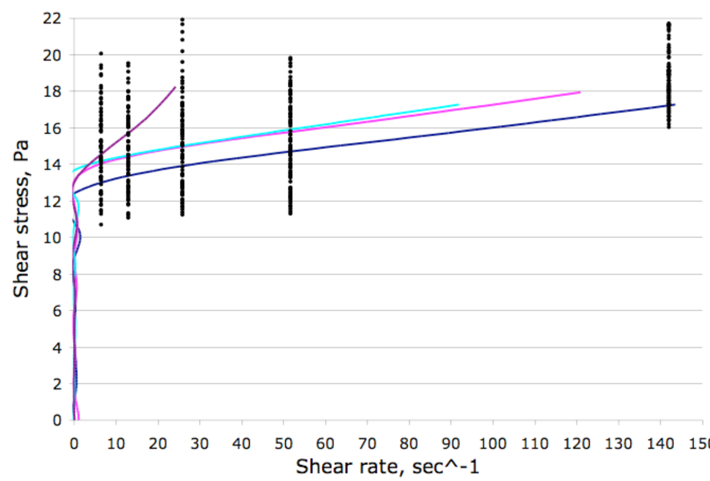

Figure 2

The solid curves in Figure 2 are rheograms obtained at different volumetric flow rates in the pipe. They do not overlap because the rheology of the fluid changed with time. The dots are measurements made with a conventional rheometer on a grab sample. The measured shear stress decreased with time at a given shear rate. The Figure illustrates two important advantages of the UDV-based in-line rheometer over conventional rheometers:

1. The UDV-based instrument captures the relationship between shear stress and shear rate over a broad range of shear rates in one quick measurement. The conventional

rheometer can measure the stress over only a finite set of shear rates, and the rheology of the fluid can change during the time the shear rate is adjusted to a desired measurement point.
2. The UDV-based rheometer determines the rheogram for the fluid with the actual shear history it has in the transport pipeline. It can monitor, in real time, changes in the rheology of the fluid such as gel formation (which can result in a plugged pipeline).

Planned Activities

We are seeking funding from other clients to continue the development of the UDV-based rheometer system. We will be trying to improve the system in the following areas.

The UDV system uses an immersion transducer that sits in a port in the pipe wall. The port introduces a free-slip surface that can distort the flow. The port is also a trap for contaminants. The constant exposure of the transducer to the fluid and to pressure leads to leakage and failure. Eliminating the port is desirable. We have tried mounting transducers on exterior wedges, but such mounts introduce large uncertainties in the range and in the ultrasonic beam angle and thereby limit accuracy. Also the wedge system requires a difficult acoustic impedance matching with plastic materials that seem not to be mechanically robust. Better alternatives would be to somehow fill the port or to build the transducer into the pipewall very close to the inner diameter and at a very precise angle.

The UDV is a pulsed Doppler system. The transducer fires a long sequence of very short tone pulses. The maximum flow velocity that can be measured by the UDV system is limited by the round trip time of a pulse to the rear wall of the pipe and back. This round trip time determines our maximum pulse repetition rate, which is the maximum rate at which the Doppler frequency can be sampled. Higher velocities than the system can measure are often present in pipelines. We have discussed extending the velocity range by "unwrapping" aliased velocity profiles. Another approach would be to bypass the round trip time limitation and increase the repetition rate, perhaps by transmitting distinctive coded pulses. Whether this could be done or not, and the effect of high repetition rates in general, can be determined with simulations.

We would like to apply the UDV technique to smaller pipes. Currently it seems that we cannot achieve the necessary spatial resolution. The beam profile determines the volume of fluid probed by the beam, the extent of which influences the width of the Doppler spectrum that is measured at each range. We need to have a better understanding of how transducer design and frequency influence the beam pattern. We need to be able to either select or build transducers that are smaller, have a smaller beam diameter and still produce a collimated beam.

Doppler power spectra become very wide when there are large velocity gradients within the probed volume of fluid. This occurs in small pipes and can also occur near the wall of large pipes. The mean energy frequency of the spectrum then becomes a poor, biased estimator of the Doppler frequency on the beam axis. We need to be able to better relate the flow profile, the beam profile and the measurement geometry to the broadened spectrum.

Information Access

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