

In-situ velocimetric measurements in flow assurance rheometry

Christopher Dimitriou^{a,*}, Gareth H. McKinley^a, Rama Venkatesan^b

^a Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139

^b Chevron Energy Technology Company, 1400 Smith St., Houston, TX 77002

(* corresponding author: chrisd@mit.edu)

Waxes are a commonly encountered precipitate that can result in gelation of crude oils and cessation of flow in pipelines. In this talk we study a model wax-oil system that exhibits rheological behavior similar to waxy crude oils encountered in production scenarios¹. To study the consequences of gelation on the rheology of the model system a combined approach of rheometry and PIV is used. This approach specifically allows for simultaneous measurement of bulk rheological behavior and velocity variations for a waxy oil undergoing shear. Bulk rheological measurements can then be correlated to deviations from a linear velocity profile for a sample undergoing simple shear – this provides new insight into the rheology of these wax-oil systems. In addition to this, different model wax-oil mixtures were synthesized to obtain a system that is representative of the wax precipitation behavior of a “typical” crude oil.

The model wax-oil system is first characterized using a number of experimental techniques. The thermo-rheological behavior of the model wax-oil system is probed by viscosity-temperature measurements, while the chemical composition is studied through the use of GC and DSC. Furthermore the microstructure of the wax precipitates below the wax appearance temperature (WAT) is imaged using birefringence imaging techniques.

The flow behavior of the model system is then studied under shear, using an experimental apparatus that allows for direct visualization of the velocity profile of a sample undergoing shear in the rheometer. The velocity profile in the molten wax is measured through the use of digital PIV. This in-situ approach allows for characteristic flow behavior of the model waxy oil to be observed under several scenarios. These scenarios include cessation of flow under a decreasing temperature (from above the WAT, to below the gelation temperature), as well as flow restart of a gelled waxy-oil. The restart behavior is observed under a steady imposed stress. This type of scenario is also called a “creep test” and involves monitoring the local and global strain of a sample over a given period of time (example data in Fig. 2). The evolution of the local kinematics during flow restart can be quantified and compared to the corresponding bulk rheological measurements. The evolving flow profiles are typically illustrated in the form of space-time diagrams², such as in Fig. 2. These diagrams show spatial variations of the

velocity (represented by a color scale) between the two shearing surfaces over a given period of time.

The image analysis technique used for these experiments is a cross correlation scheme³ that allows for an equally spaced grid of velocity vectors (typically 30x40) to be obtained for each frame of video. The high frame rate at which images are captured results in a large sample size of velocity measurements. As a result the flow profiles such as those shown in Fig. 1 can be resolved down to 0.02 seconds while the standard deviation of the velocity measurements is 0.02 mm/s.

In addition, the effect of varying surface roughness is investigated by comparing the evolution of these flow profiles for an initially gelled fluid in contact with both a roughened and smooth surface. The material response in each case (as shown in Fig. 2) indicates that some types of surfaces effectively act as “slip promoters” and prevent the gelled wax-oil system from sticking to them. These results are similar to observations made in other yield stress fluids² and have an immediate bearing on the design and construction of pipelines used to transport waxy crude oil. Thermal history dependence of the yielding behavior is also being investigated.

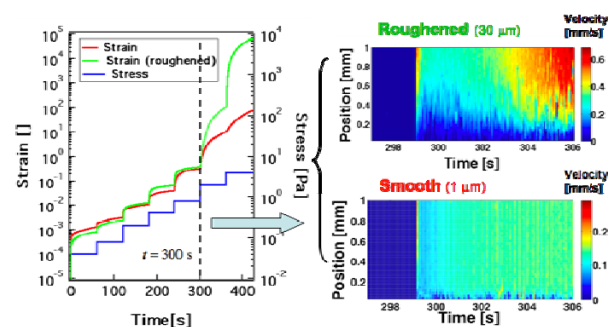


Fig. 2. Restart of a gelled wax-oil system through a sequence of creep tests. The system exhibits a yielding behavior at a stress of 2Pa. The space-time diagrams illustrate the change in velocity profiles resulting from the different surface types (30 μ m roughness (green) vs. 1 μ m roughness).

References

- [1] Visintin, R. F. G.; Lapasin, R.; Vignati, E.; D’Antona, P.; Lockhart, T. P. *Langmuir* **2005**, 21, 6240–6249.
- [2] Gibaud, T; Barentin, C; Manneville, S. *PRL* **2008**, 101, 258302
- [3] K. Breuer, *Microscale Diagnostic Techniques*, **2005**, pp 50