Application of microfluidic technology in oil industry----A new quick test method of fluid viscosity

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Abstract. In the process of oil and gas exploitation, various working fluids such as fracture fluid and flooding fluid are used. The rheological behaviours are key parameters for their application. In this work, we introduce a new method to make a quick rheological measurement for these work fluid on a microfluidic chip. The measurement is based on the volume flow rate ratio and interface location between two co-flowing streams in a micro-fabricated Y-channel in a rectangular channel. Using the microfluidic rheometer, it lets fast and precise analysis with just a few millilitres of sample consumption and visual control of the sample behaviour in the chip. Furthermore, it can also perform viscosity test at high temperatures and wide range of shear rate. This method makes it possible to measurement of almost all kinds of fluids and make viscosity analysis time and sample saving.

1. Introduction

Traditional viscometer for oil field working fluid are mechanical coaxial rotational viscometers (coquette) such as Fann35 viscometer, Brookfield DV viscometer and air bearing rheometer such as Haake rheometer and Anton Paar rheometer. These instruments are either of poor precision, large in sample consumption, or large in size and high in cost. As to the low viscosity fluid such like the gel breaking fluid (generally < 5mPa\(\cdot\)s.), the capillary viscometer (Ubbelohde or Cannon-Fenske viscometer) are usually chose to test the viscosity in terms of accuracy, even though it is very tedious and involves a series of long trials and tests. In this work, the microfluidic rheometer is used for the viscosity measuring. Use this technique will offer significant improvements over capillary viscometers devices and mechanical rotational viscometers.

There are two kinds of commercially microfluidic rheometers. One is the rheometer which needing a pressure sensor during the test. This system relies on the use of an external pressure transducer that measures the sum of the true microchannel pressure drop and thus leading to entrance and exit effects. To take these effects into account, both complex calibrations and corrections have to be applied [1]. To avoid this type of correction, Galambos and co-workers have proposed to use the optical tool to measure the features of specific microfluidic flows on a T junction chip [2]. Right after the T junction, two miscible fluids flowing side by side, the interface between the two fluids is still sharp because, under their experimental conditions, diffusion is slower than convection. In the channel, the position of the
interface is fixed by the ratio of the flow rates of the two fluids and by the ratio of their viscosities. By measuring the position of this interface using fluorescence microscopy they manage to compute the viscosity of one sample knowing the flow rates and the viscosity of the other fluid. Based on their work, Pierre Guillot and Annie Colin etc. did further research and make this technology more refined [3-6]. The second commercial microfluidic rheometer was produced base on Galambos and Pierre Guillot’s technology.

In the present work, the microfluidic rheometer we used was the second. In the following text, we present the viscosity measurement method. In the experimental part, viscosity versus shear rate, polymer concentration and temperature has been studied. Comparison of viscosity result with other methods has also discussed.

2. Experimental

2.1. Materials
Reference fluids Reference fluid is required during the test, as shown in Figure 1c. The reference fluids should be Newtonian fluids and have the viscosity similar to the studied sample. In this work, the reference fluids include deionized water, Formulation 5cp and 50cp standard samples, which were chose according to the viscosity of test fluids. In order to increase the contrast, the color of the reference and the studied fluid should be different. The Formulation 5cp and 50cp standard fluids is in dark color while the deionized water isn’t, if the latter is used as a reference fluid, the methylene blue should be added to it.

Polyacrylamide polymers various concentrations (up to 0.6wt %) of the polyacrylamide solutions were prepared. The solutions were prepared by adding carefully weighed amounts of the polymer to de-ionized water and mixing, and then stored for 24h at room temperature before testing.

2.2. Apparatus
Fludiciam Rheo works with a visual acquisition system allowing observing the product directly during the measurement. A Y-type microfluidic chip (Figure 1b) and charge coupled device (CCD) camera was used to collect the video image data. Figure 1c is the image of the flow channel with the dark water stream shown above the light sample solution stream. Flow is from left to right, and the dividing streamline separating the two streams is clearly evident. The location of the dividing streamline was determined using image analysis techniques. The viscosity of the sample is automatically extracted as a function of shear rate and plotted directly in the software giving a resulting rheological curve from the image data of the integrated camera. All measurements were performed at 30°C unless otherwise indicated. During viscosity testing, samples were simply introduced into 10mL syringes which later were clipped to the syringe holders and images were acquired at each shear rate in one protocol (Figure 1c).
3. Result and Discussion

3.1. Viscosity Versus shear rate

The viscosity values as a function of shear rate of the aqueous polymer solution at a variety of concentrations were measured at 30°C. It shows that with the increasing of the concentration, the sample viscosity property change from Newtonian to shear thinning. The sample was tested at the shear rate from 50 to $10^4$ s$^{-1}$ and in 2 replicas procedure. It is worth noting that the viscosity measurement provides the precise with good repeatability. The test requires less than 4mL of sample and less than 5min for each flow curve (with 8 points). Fludicam Rheo offers high precision even at low viscosities, which is very appropriate to test the low viscosity gel breaking fluid.

![Figure 1.](image)

**Figure 1.** (a) Sketch of the flow to perform rheological measurement (where Q is sample flow rate, $Q_R$ is reference flow rate, $\eta$ is Sample viscosity, and $\eta_R$ is reference viscosity). (b) the Y-type microfluidic chip, (c) The photogragh of interface of the two fluids.

3.2. Viscosity Versus temperature

Fludicam Rheo allows to measure viscosity at different temperature in a single experimental setup. The range of test temperature is 4 – 80°C with regulation at 0.1°C. The analysis time for the flow curve (with 5 points) of each temperature was about 4 min. Figure 3 presents flow curves for a 0.5% concentration of polymer solution for temperature from 10°C to 80°C and the shear rate from 200 to 10000 s$^{-1}$.

![Figure 2.](image)

**Figure 2.** The viscosity of different concentration polymer solution as a function of shear rate
2500 s\(^{-1}\). It shows that in the range of temperature the sample keeps a shear thinning behavior, and the viscosity decrease with the increase of the temperature.

3.3. Comparison of viscosity test methods

In this part, the viscosity of the same sample was tested using different viscometers. They are air bearing rheometer MCR302, Fluidicam Rheo and mechanical bearing rotary viscometer Brookfield DV. From figure 4, we can see the MCR302 and Brookfield DV rheometers are suitable for testing at the shear rates below 1000 s\(^{-1}\). While for Fluidicam Rheo, the range of shear rate to test is 100–20000 s\(^{-1}\). In addition, we can see that the viscosity curves of the three viscometers coincidence good over the 100–1000s\(^{-1}\) shear rate range. This verify the accuracy of the Fluidicam Rheo. We can conclude that this method makes it possible to measurement the working fluids of the oil filed. Furthermore, because the test was done on the micro-fabricated Y-channel chip, thus make the viscosity analysis time and sample saving.

**Figure 3.** Viscosity of a polymer solution as a function of shear rate at different temperatures

**Figure 4.** Viscosity of the same sample test with different viscometers. Inset photo is an enlarged view of the curve between the shear rate of 100–1000s\(^{-1}\).
4. Conclusion
In this paper, a new method of the viscosity measurement for the oil field working fluid was introduced for the first time on Fluidicam rheometer. The measurement is based on the volume flow rate ratio and interface location between two co-flowing streams in a micro-fabricated Y-channel in a rectangular channel. Using the microfluidic rheometer, it lets fast and precise analysis with just a few millilitres of sample consumption and visual control of the sample behavior in the chip. Furthermore, it can also perform viscosity tests at high temperatures and wide range of shear rate. This method makes it possible to measurement of almost all kinds of fluids and make viscosity analysis time and sample saving.

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