ANALYSIS OF POLYMER DEGRADATION UNDER HIGH SHEARS IN MICROFLUIDIC CHIPS

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ABSTRACT
We report in this paper how we degrade polymers in solution and measure the consequent viscosity loss in a few minutes in a microfluidic device. This study is of importance for oil recovery processes where polymers are used as viscosifying agents. Thanks to a fabrication technology resistant to high pressures and a specific chip design integrating a constriction, a reservoir and a viscosimeter, we provide a tool for the rapid exploration of viscosity loss versus deformation rates imposed to the polymer solution, using small amounts of samples.

KEYWORDS: Polymer, viscosimetry, high pressure, oil recovery

INTRODUCTION
Because of the raise of oil prices, polymers are now seriously considered as candidates for enhancing oil recovery. In minute quantities, long chain polymers considerably increase the viscosity of the solution used to push oil out of the reservoir, reducing digitations and therefore enhancing oil recovery. However, the high deformation rates induced during the injection in the well lead to polymer chains breakup [1] and consequently to a serious viscosity loss for the solution. The dramatic financial impact of this reduced efficiency strongly motivates a better understanding of the degradation phenomenon. We report in this paper the first microfluidic device that degrades, under controlled conditions, polymers in solution and measure the consequent viscosity loss, both operations being made in a few minutes on the same chip. Compared to classical rheometry methods, the measurement time and sample volumes are reduced by more than one order of magnitude, and broader domains of deformation rates can be explored.

FABRICATION
The microfluidic device is made of two parts. The first part is a microchannel with a sudden constriction leading to elongational constrains on the polymer chains in solution (Fig. 1). The second part is a viscosimeter [2] relying on the principle that in laminar conditions, the position of the interface between two fluids driven at the same flow rate in a very flat channel gives quantitatively their viscosity ratio (Fig. 2). These two parts are linked by a microfluidic reservoir to collect the solution between these two steps (Fig. 1).

The system is microfabricated by a softlithography method [3] in a photocurable glue (NOA 81) that resists to the 20 bars that can be reached during the polymer
degradation step. To avoid relaxation times, connections to the syringe pumps are made via a very rigid tubing and a valve system.

![Diagram of the chip design](image)

*Figure 1. Design of the chip. The inlets are connected to precision syringe pumps (Nemesys, Cetoni). An external valve switches between two steps. Step 1: inlet 1 and 3 are closed; the polymer solution from inlet 2 is degraded in the constriction and collected in the reservoir. Step 2: inlet 2 is closed; the solution in the reservoir is pushed from inlet 1 into the viscosimeter and compared to a reference fluid from inlet 3.*

**EXPERIMENTAL**

We study the degradation of POE (polyoxyethylene) of several Mda semi-dilute solutions in a 60 microns height channel with a 500 to 20 microns constriction. Within this geometry we can impose deformation rates going from $10^4$ to $10^7$ s$^{-1}$ by changing the flow rate. We collect a sample of the degraded solution in a 50 μL serpentine reservoir and then compare the viscosity of this solution with the reference native solution in the microfluidic viscosimeter.

**RESULTS AND DISCUSSION**

These measurements agree with those made in a Couette rheometer (Low Shear 30) for different polymer solutions. The relative viscosity loss versus the maximum imposed shear rate in the constriction of several polymer mass and concentrations is obtained with a 5% accuracy. We can determine experimentally a critical shear rate for the beginning of the viscosity drop and the exponent for its power law decay (fig. 2).
Figure 2. Viscosity ratio before and after degradation in the constriction versus maximum imposed shear rate in the constriction, for a 4000 ppm 5 MDa POE solution. The values obtained with the microfluidic viscosimeter (squares) collapse with those obtained in the Couette rheometer (stars).

CONCLUSION
We have demonstrated that we can reach very high deformation rates leading to polymer degradation and measure in one minute the corresponding viscosity loss on a chip. These features make possible for the first time the screening of many different polymer solutions for a better understanding of the chain scission phenomenon in the semi-dilute regime. This device, consuming very small sample volumes, is also a necessary tool for the rapid design of appropriate polymer solutions formulations for the oil recovery industry.

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REFERENCES