# Flow of a Polymeric Solution Through a Constricted Microchannel

José Angel Florián Gutiérrez, M. J. B. Moura, M. S. Carvalho

joseangel@lmmp.mec.puc-rio.br; maria@lmmp.mec.puc-rio.br; msc@lmmp.mec.puc-rio.br

**Abstract:** *An experimental study was conducted on the flow behavior of a Polyethylene Oxide (PEO) solution through a constricted glass microchannel, used as model for a pore-throat geometry of a porous media. The PEO concentration used in the experiments was of 0.1% by weight. Pressure drop and velocity field measurements were obtained. The velocity fields were measured using the micro-particle image velocimetry (Micro-PIV) technique. The velocity fields showed the presence of vortices (upstream of the contraction) and changes in the flow pattern (fluctuations). The pressure drop measurements exhibited a non-linear behavior (non-Newtonian fluid). This study provides important information on how viscoelastic polymer solutions behave in a porous media and can impact their use in Enhanced Oil Recovery.*

**Key-Words***: Microfluidics ;PEO Polymeric solution ; Viscoelasticity ; Elastic turbulence ; Micro-PIV*

**Introduction:** The sweep efficiency of water injection (oil recovery method) into an oil reservoir is limited. Polymeric solutions are used to improve the oil recovery due to their higher viscosity when compared to water. However, viscoelastic properties of polymeric solutions may also, change the pore-scale flow behavior and reduce the residual oil saturation. These phenomena are still not well understood. Microfluidic devices are used to represent porous media and study the effects of viscoelasticity at the micro-scale. Recent studies performed by Clarke et al. [1] observed velocity fluctuations when HPAM viscoelastic polymer solutions were injected into a microfluidic device (pore network and channels) using the PTV technique. Boek et al. [2] observed velocity fluctuations when EHAC polymeric solutions flowed through a constricted channel (expansion-contraction geometry) using the Micro-PIV technique. These velocity fluctuations were related to the phenomenon called elastic turbulence (transition from steady laminar flow to a strongly fluctuating flow). This work presents a study of a PEO solution flow through a constricted microchannel, measuring pressure drop and velocity fields.

**Experimental procedure:** The experimental set-up is shown in Figure 1a. It is composed of a micro-PIV (TSI Inc.) system and a pressure measurement system (Validyne pressure transducer sensor, model DP-15, range: 0-1.25 psi). Figure 1b shows the glass micromodel (Dolomite Center Ltd.) used as pore space model at the micrometric scale. Figure 1c shows the geometry of the elliptical cross section and details of the constriction.

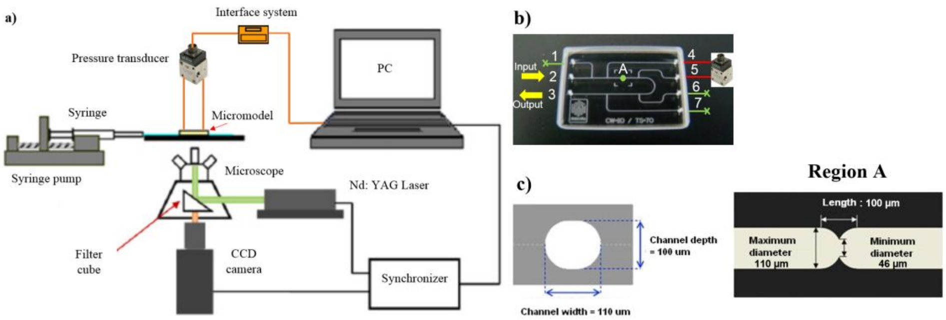


Figure 1: a) Experimental set-up; b) Micromodel; c) Cross-section and constricted geometries.

The polymer used was polyethylene oxide (PEO, $M_w$=8x10$^6$ g/mol) at concentration of 0.1% by weight. The polymeric solution (PEO in deionized water) was mixed using a digital mechanical stirrer and characterized rheologically using a rotational rheometer. This solution was injected in the microchannel using a syringe pump. The polymeric solution enters in the opening 2 and exits through 3 of the glass device (see Figure 1b). The openings 1, 6, and 7 are closed during the experiments. The openings 4 and 5 are used to measure the pressure drop in the microchannel with the constriction. The velocity fields were measured near the constriction using the micro-PIV technique. The polymeric solution was seeded with polystyrene microspheres (1.0 µm, orange fluorescent, Thermo Fisher Scientific) to follow the flow, without interfering with it. The software Insight 4G$^{TM}$was used to analyze and process the image pairs taken of the flow and then obtain the velocity vectors. The velocity fields were obtained from approximately 100 pairs of consecutive images (ensemble average).

**Results and discussion:**

a) **Measurements of pressure drop:** Figure 2 shows the pressure drop as a function of flow rate for (a) water and (b) the polymeric solution. The water shows a linear behavior (Newtonian fluid). While, the polymeric solution exhibits a non-linear behavior, due to the elastic behavior of the polymer through the contraction, increasing the pressure drop in the flow.

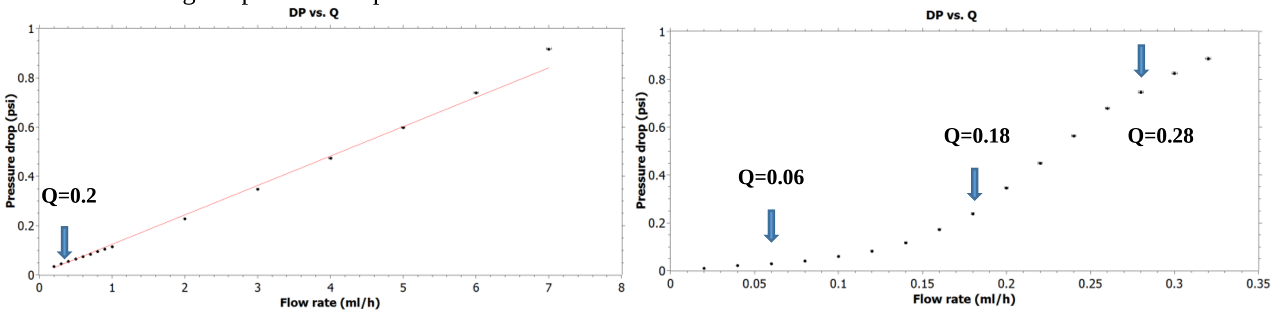


Figure 2: Pressure drop vs. flow rate. a) Water; b) PEO polymeric solution of 0.1% by weight.

b) **Measurements of velocity field:** Figure 3 shows the velocity fields for (a) water and (b-d) the polymeric solution in Region A of the micromodel (see Figure 1c). The flow rate range explored for the polymeric solution flow expands from the linear part to the non-linear part of the flow rate – pressure drop plot. As the flow rate was increased, the presence and growth of vortices were observed. In addition, the flow pattern showed changes of direction and velocity fluctuations over time.

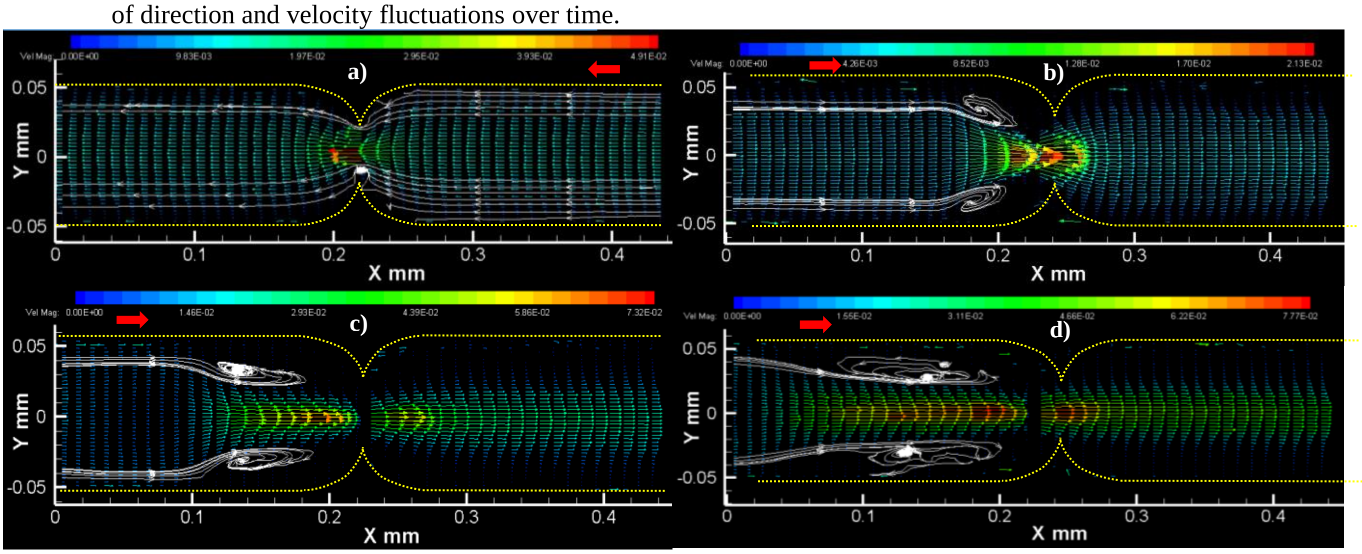


Figure 3: Velocity field. a) Water (Q=0.2 ml/h); b) PEO (Q=0.06 ml/h); c) PEO Q=(0.18 ml/h); d) PEO (Q=0.28 ml/h).

**Conclusion:** The flow of a PEO polymeric solution (of 0.1 wt%) through a constricted microchannel was studied by means of pressure drop and velocity fields measurements using the micro-PIV technique. A non-linear behavior was observed for the PEO solution. Instabilities in the flow pattern of the polymeric solution were detected in the velocity fields. This work helps the fundamental understanding of the behavior of PEO polymeric solution flowing through pore-throat geometries and can be used to improve oil recovery.

**Acknowledgments:**

The authors acknowledges the support from CNPq by granting a PhD fellowship.

**References:**

[1] A. Clarke, A. M. Howe, J. Mitchell, Mechanism of anomalously increased oil displacement with aqueous viscoelastic polymer solution, Journal The Royal Society of Chemistry, UK, 2015.

[2] E. S. Boek, J. T. Padding, V. J. Anderson, Flow of entangled wormlike micellar fluids: Mesoscopic simulations rheology and μ-PIV experiments, Journal of Non-Newtonian Fluid Mechanics, UK, 2006.