Experimental report

13/02/2017

Proposal: 9-11-1787 **Council:** 4/2016

Title: Polymer Structure in Elastic turbulence

Research area: Materials

This proposal is a new proposal

Main proposer: Stuart M. CLARKE

Experimental team: Leonardo CHIAPPISI
Andrew HOWE
Stuart M. CLARKE

Local contacts: Philipp GUTFREUND

Samples: D2O
partially hydrolysed polyacrylamide

Instrument	Requested days	Allocated days	From	To
FIGARO	3	3	11/11/2016	14/11/2016
D11	2	2	28/11/2016	30/11/2016

Abstract:

The aim of this study is to investigate directly the conformation and structure of polymer molecules under flow: specifically the changes of a high MW viscoelastic polymer in the semi-dilute entangled concentration regime as the solution passes from Newtonian, through shear-thinning and into the elastic-turbulence regimes.

Report 9-11-1787 Figaro and D11:

This experiment aimed to characterise the conformation and structure of a very high molecular weight polymer in aqueous solution under static and under shear conditions. This material undergoes elastic turbulence (i.e. an unusual form of turbulent flow at low Reynolds numbers) for which the underlying polymer structure is not known.

This initial experiment was very successful in that we were able to obtain data under static and shear conditions and the data we obtained completely changed how we visualise the polymer conformation in these interesting materials.

However this unexpected behaviour requires further characterisation and a revision of the experimental arrangement which will require a further experiment (on D11 to be proposed)

Introduction

Polymer solutions have a wide range of interesting flow properties often with many uses. This proposal centres on a very particular behaviour of highly entangled polymer solutions known as 'elastic turbulence' (ET). ET is a flow field that varies randomly in space and time showing typical signatures of turbulence while the imposed shear corresponds to very low Reynolds numbers. Although this phenomenon has been known for some time[i] it only recently gained attention due to its important academic and commercial applications such as liquid mixing at low shear[ii] or promoting breakup and mobilization of otherwise-trapped oil in a reservoir[iii,iv].

In an extensive series of laboratory based measurements we have explored the rheological behaviour[v] of high molecular weight (approx. 20 MDa) partially hydrolysed polyacrylamide (HPAM - illustrated in Figure 1) in combination with other studies, such as NMR[vi]. The data has an interesting behaviour as illustrated in Figure 2 which has been interpreted to indicate viscoelastic fluctuations and provides direct evidence of elastic turbulence. These fluctuations have been visualised in microchannel model experiments with coloured flow lines, which are observed to fluctuate dramatically.[iii]

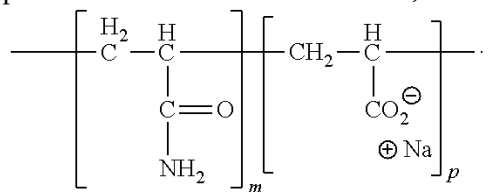

Fig.1: The repeating motifs of partially hydrolysed polyacrylamide. Some of the initial amide repeat units are hydrolysed to the carboxylate ions/salts to improve the water solubility.

Experimental results

We are pleased to report that we were able to successfully collect data from this high molecular weight polymer system under both static and shear conditions. Importantly the results were somewhat unexpected. We had expected to see scattering typical of concentrated polymers, for example with a $I \sim Q^{-1}$ or Q^{-2} dependence and possibly a weak peak arising from correlations in the number density of polymer segments at high Q. However, the scattering was dominated by a completely unexpected $I \sim Q^{-4}$ typical of a well-defined boundary, even for solutions that were optically clear. Higher concentrated solutions showed a reasonably high turbidity; and we suggest that the Q^{-4} scattering behaviour may be related to the inhomogeneities that cause the turbidity. Interestingly this turbidity disappears at higher temperatures (40°C) suggesting that inhomogeneities which give rise to turbidity at room temperature (~ 21°C) disappear on heating.

Hence this initial data highlights that it would be of great interest to address the static SANS from these polymers over a range of temperature crossing this 'phase separation' boundary.

Similarly we were able to observe SANS from the polymers in the shear cell and could identify changes. However, the scattering S/N ratio was lower than ideal, partly due to the background scattering from the rheometer.

We propose to improve the design of this equipment in an improved experiment, where we will use cones made of quartz instead of aluminium to significantly reduce this background and also enable us to access a wider range of Q.

In summary a very successful and insightful experiment that has changed how we view these important systems and has identified additional measurements that are required to understand these systems.

---

[i] G.V. Vinogradov & V.N. Manin, *Kolloid Z.* 201 (1965) 93.
[ii] A. Groisman & V. Steinberg, *Nature* 410 (2001) 905
[iii] **Mechanism of anomalously increased oil displacement with aqueous viscoelastic polymer solutions, Clarke et al Soft Matter, 2015, 11, 3536 – 3541.**
[iv] Clarke, et al 2016. How Viscoelastic-Polymer Flooding Enhances Displacement Efficiency. Society of Petroleum Engineers. doi:10.2118/174654-PA
[v] **Flow of concentrated viscoelastic polymer solutions in porous media. Effect of MW molecular weight and concentration on elastic turbulence onset in various geometries. Howe et al, Soft Matter, (2015) 11 6419 - 6431.**
[vi] **Viscoelastic Polymer Flows and Elastic Turbulence in Three-Dimensional Porous Structures, Mitchell et al, Soft Matter,** 2016,**12**, 460-468.