# Experimental Studies on Visco-plastic Lubrication of Visco-elastic Fluid: Interfacial Instability and Geometry Effect


## S.Hormozi[1], D. M.Martinez[2] & I.A. Frigaard[1,3]

[1] Department of Mechanical Engineering, University of British Columbia, Vancouver, Canada.

[2] Department of Chemical & Biological Engineering, University of British Columbia, Vancouver, Canada.

[3] Department of Mathematics, University of British Columbia, 1984 Mathematics Road, Vancouver, Canada



## ABSTRACT

**Multi-layer shear flows have broad range of application in industry, such as in co-extrusion processes and lubricated pipelining. In the case of a duct flow, it is known that use of a yield stress fluid as the lubricating fluid, coupled with maintaining a plug region at the interface can lead to flows that are hydrodynamically stable. In this area, previous studies have considered the stability of the established flow of inelastic fluids both theoretically [1], [2] and experimentally [3]. However, a common feature of the fluids used in co-extrusion processes is that the fluids may be visco-elastic, which has not been considered to date. Hence the motivation for this work is investigating two aspects of the initial part of the core annular flow experimentally. First, is it possible to establish the base multi-layer flows at all, using a visco-elastic fluid (Poly Ethylene Oxide solution) in the core region and visco-plastic fluid (Carbopol solution) as lubricant? Secondly, what is the effect of geometry on the stability of the flow?**

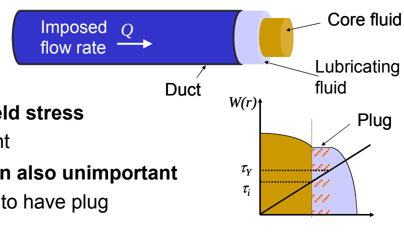


[1] I.Frigaard, J.Non-Newtonian Fluid Mech, 100,49 (2002).

[2] M. Moyers-Gonzalez, I.Frigaard and C.Nouar, J.Fluid Mech, 506, 117 (2005)

[3] C.Huen, I.Frigaard and M.Martinez, J.Non-Newtonian Fluid Mech, 142, 150 (2007).


## OBJECTIVE: ELIMINATE INTERFACIAL INSTABILITIES



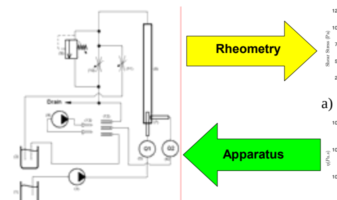

► **Outer fluid has yield stress**

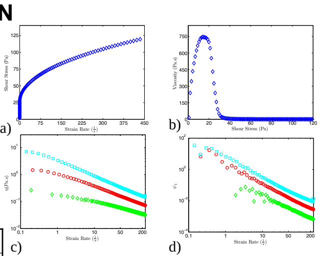
Inner fluid unimportant

► **Duct cross-section also unimportant**

Flow rates controlled to have plug at the interface

## EXPERIMENTAL DESCRIPTION

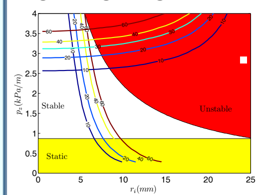


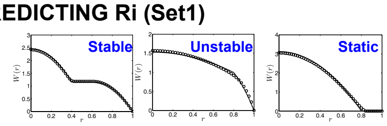
| Series | Inner Fluid (wt%) | Outer Fluid (wt%) | Inner flow rate (ml/s) | Outer flow rate (ml/s) | Inner pipe (ID: mm) |
|---|---|---|---|---|---|
| 1 | PEO (.5) | Carbopol(.15) | 5-40 | 5-60 | 3.17 |
| 2 | PEO (.75) | Carbopol(.15) | 5-40 | 5-60 | 3.17 |
| 3 | PEO (1) | Carbopol(.1) | 5-40 | 5-25 | 3.17 |
| 4 | PEO (.75) | Carbopol(.15) | 5-40 | 30 | 3.17-18.84 |

**Flow curve data:(a,b) 0.15% Carbopol 940 solution. (c,d) 0.5%(◊),0.75%(○) and 1%(□) Polyethylene Oxide solution**

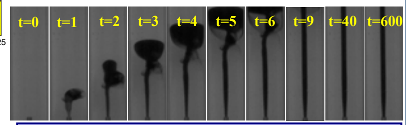
## CONTROLING AND PREDICTING Ri (Set1)




**Flow regime map: Inner and outer fluids are 0.5% PEO and 0.15% Carbopol solutions respectively.**

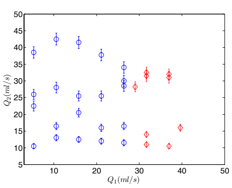



**Three possible velocity profile**

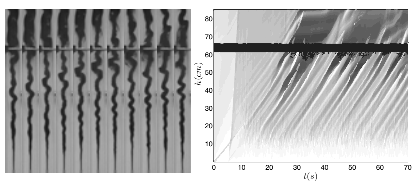



**Snapshots of a typical stable experiment, h=22 cm**

## EXPERIMENTAL OBSERVATIONS (Set 1)

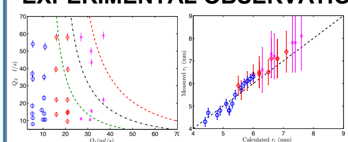


**Experimental observations plotted with respect to flow rates of two fluids (○) stable (◊) unstable Inner and outer fluids are 0.5% PEO and 0.15% Carbopol solution**

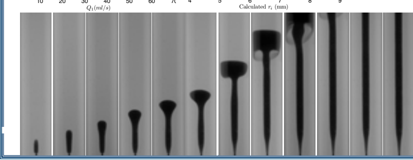


**Snapshots of an unstable experiment (39<t<51) and spatiotemporal plot**

## EXPERIMENTAL OBSERVATIONS (Set 2)

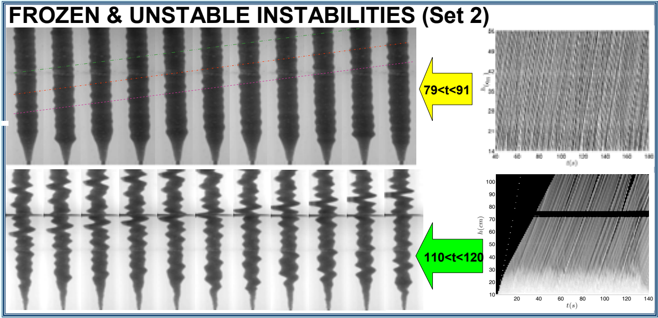


**►Experimental observations: Inner and outer fluids are 0.75% PEO and 0.15% Carbopol solution respectively. (○) stable,(◊) frozen &(x) unstable**

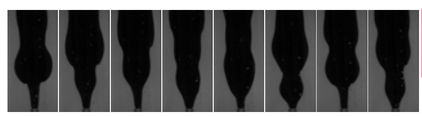


**►Snapshots of a typical stable experiment, h=30 cm and ($Q_1$,$Q_2$)=(11,30)ml/s. from left to right: t=2,3,4,5,6,7,10,13,16,22,32,90 sec**

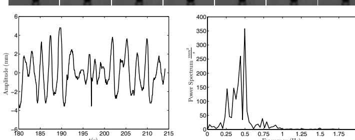
## FROZEN & UNSTABLE INSTABILITIES (Set 2)




## EXPERIMENTAL OBSERVATIONS (Set 3)



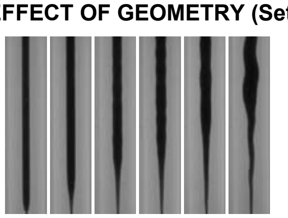
**Snapshots of unstable experiment (179<t<188), inner and outer fluids are 1% PEO and 0.1% Carbopol solutions respectively. h=22 cm**



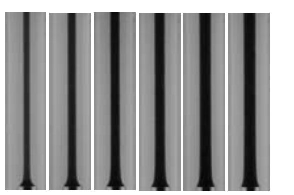
a) b)

**(a) Variation of amplitude vs time (b) Power spectrum vs frequency, for a point located at 5cm above the manifold on the left edge of core fluid. Inverse of dominant frequency is of order of relaxation time.**

## EFFECT OF GEOMETRY (Set 4)



a)



b)

**Snapshots of established experiment for (a) ID of inner pipe is 3.17mm (b) ID of inner pipe is 18.84mm . Inner and outer fluids are 0.5% PEO and 0.15% Carbopol solutions respectively at Q2=30 ml/s. From left to right Q1=5.5,11,16,21,28,37 ml/s.**

## SUMMARY OF RESULTS

- ► 4-meter (full tube) of stable interface was achieved during experiment.
- ► For stable experiment: Interfacial perturbation does not grow as flow travels downstream.
- ►Visco-elastic instabilities appear before passing the plasticity margin.
- ►Initially, interfacial instabilities are frozen in the plug region and advect upward with constant velocity of interface.
- ►The amplitude of perturbations grow by increasing the flow rate, Interfacial perturbation propagates. Two fluids mix together when the core fluid is less elastic, but presence of significant elasticity prevents mixing (set2).
- ► The inverse of dominant frequency of instabilities is of order of relaxation time.
- ► The core fluid has been highly pre-stressed in the inner pipe of small radius and it experiences discontinuity in shear stress and boundary condition at the entrance region which leads to interfacial instabilities as a result of relaxation.
- ► Inlet geometry has strong effect on the observed interfacial instabilities, they disappear with radius of inner pipe closer to radius of core fluid.


**IWNMNF 2010**
**XVIth International Workshop on Numerical Methods for Non-Newtonian flows, June 13-16**

**Research sponsors:** Pacific Institute for the Mathematical Sciences; National Sciences and Engineering Research Council of Canada (NSERC CRSNG); Canada Foundation for Innovation