Order of Phase Transitions in Couette-Taylor Flow

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This project aimed to investigate the order of phase transitions from various stable patterns to the unstable regime in a Couette-Taylor flow. This is to be investigated with point velocity measurements obtained with Laser Doppler Velocimetry.

It has been shown previously that a small addition of high molecular weight polymers can drastically change the characteristics of instabilities in Couette-Taylor (CT) Flow. Groisman and Steinberg [1] observed two novel oscillatory flow patterns given rise to by the elastic properties of the test solution. The original observation of these new flow patterns prompted interest in the order of the phase transition from one state to another. Whether it be first order (almost instant transition) or second order (slow transition) is important for theoretical model considerations.

The experiments were conducted in a CT column which consists of an outer cylinder and a rotating inner cylinder with an annular gap where the test fluid resides. In the case of a Newtonian fluid, as the rotation velocity of the inner cylinder increases, the azimuthal laminar Couette flow bifurcates to a new stationary Taylor Vortex Flow (TVF) at a well defined Reynolds number Re_c. Further increasing the rotation speed leads to a flow that is increasingly chaotic. The addition of polymers to the solution introduces new characteristics and the flow is now hysteretic due the the stretching of polymer chains. The relaxation of these chains, characterised by the relaxation time λ, results in a new force in the flow. Dependent on elasticity, this can result in different stable patterns being observed and also the ability to go straight to a disordered turbulent flow from a laminar flow at very low velocities.

A convenient parameter which reflects the relative importance of inertial effects to elastic, is the ratio between the Deborah number and the Reynolds number $\kappa = De/Re$ where $Re = \Omega R_1 d\rho/\eta$ where here, Ω is the rotational velocity, R_1 is the outer cylinder size, d is the annular gap size, ρ is the fluid density and η is the viscosity.

In dilute polymer solutions the relaxation time λ and the polymer contribution to viscosity η_p are proportional to the viscosity of the solvent η_s so that $\kappa \approx \eta_s^2$. Therefore by varying η_s we can explore regions of different κ and thus various ratios of elasticity to inertia.

My contribution to this project was the building and setup of the Couette-Taylor column (including temperature variation to control κ), the building and testing of a Laser Doppler Velocimetry system and the characterisation of solution parameters to match the previously used solvent. Then reproduce previous patterns and instabilities.

My contribution to the project was a success and met the specified goals. The experimental system and the prepared solution are now being used to take velocity data at various κ. This will lead to the characterisation of the order of the phase transitions between states in the flow and thus provide experimental data to guide the development of theory for visco-elastic flows and turbulence.

I. HOSTING INSTITUTION

This research was conducted under the supervision of Prof. Victor Steinberg in the Physics of Complex Systems Laboratory located at the Weizmann Institute of Science, Rehovot, Israel.

II. LIST OF OTHER INSTITUTIONS VISITED

- Technion - Israel institute of Technology, Haifa, Israel

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[1] Alexander Groisman and Victor Steinberg. Couette-taylor flow in a dilute polymer solution. *Phys. Rev. Lett.*, 77(8): 1480–1483, Aug 1996. doi: 10.1103/PhysRevLett.77.1480.