Assignment 6, Team Project 3 – "Blackstock Fluid"

Brian A. Larsen, 12/14/2007

1 Objective

The objective of this project was to visualize highly controlled fluid dynamics using Blackstock fluid, a liquid capable of streaming birefringence, to develop quantitative relationships between the observed phenomena and measurable quantities of the fluid.

2 Setup and methods

Several experiments were attempted utilizing the Blackstock fluid as follows. Prior to using the fluid, the bottle was mixed using several pulses with a vortexer, a common technique used to resuspend colloidal solutions. All setups used two linear polarizing sheets in series with the light source and camera. Light was polarized before and after transmission through the fluid.

2.1 Square channel flow

.125" X .125" channels were machined in .25" thick polycarbonate sheet stock as shown in Figure 1. Threaded .125" I.D. (inner diameter) brass fittings were used to run liquid into the channels from .125" I.D. vinyl tubing. Volumetrically controlled flow was provided using a syringe pump setup consisting of 3 syringes in parallel compressed in an Instron Universal Testing System, as shown in Figure 2. Lighting for the setup was positioned underneath the channels and passed through linear polarizing film. The camera was positioned over the setup with a second polarizing film in series.

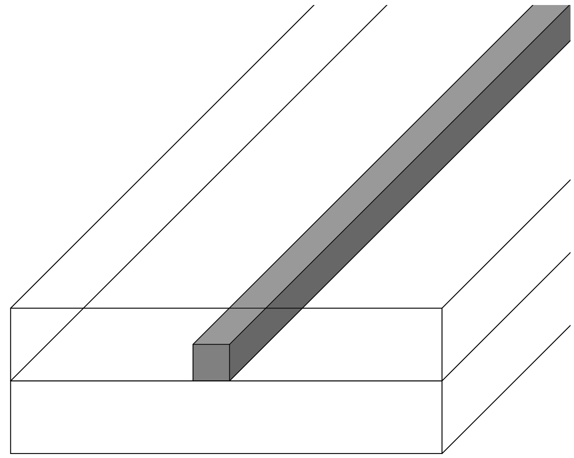

Figure 1 - Square channel setup

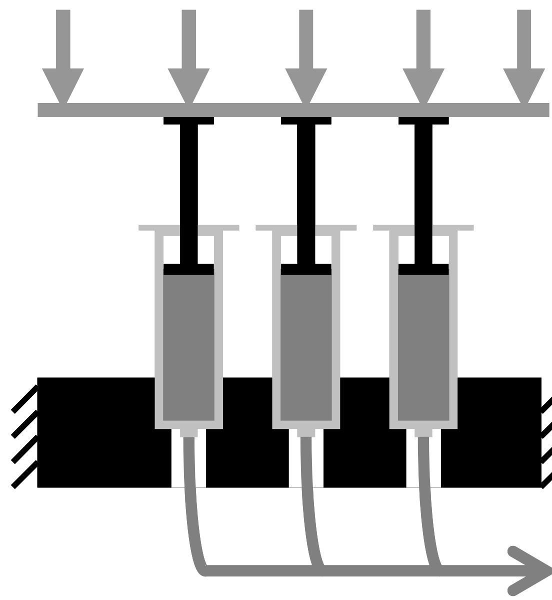

Figure 2 – Syringe pump using constant displacement rate for volumetric flow

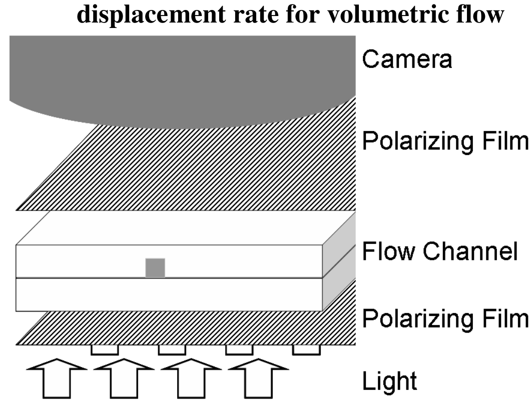

Figure 3 – Square channel lighting and polarization setup

Refer to Figure 3 for a schematic of the lighting and camera setup.

2.2 Vortex flow

A setup for vortex flow was constructed utilizing a magnetic stir plate, magnetic stir bar, and a 750 mL cylindrical dish, roughly 5" in diameter (Figure 4). The dish, liquid, and stir bar was held 1" above the stir plate and polarized light was reflected under the dish and through the liquid. The liquid was photographed through a second filter between the liquid and the camera lens.

2.3 Circular Channel Flow

Channel flow was attempted again at a smaller scale using a Pasteur pipette, which is a 1 cm diameter glass tube that converges to 1 mm and a length of approximately 10 cm. Prior to the experiment, the Blackstock liquid was transferred to a glass beaker and immersed in an ultrasonic bath to fully disperse the colloid. Volumetrically controlled flow was provided by a standard syringe pump connected to the pipette with ¼ ID vinyl tubing. Polarizing film was positioned above and the pipette to polarize incoming light and polarizing film was positioned below the pipette to polarize light transmitted through the liquid into the microscope objective. Refer to Figure 5 for a diagram of the setup.

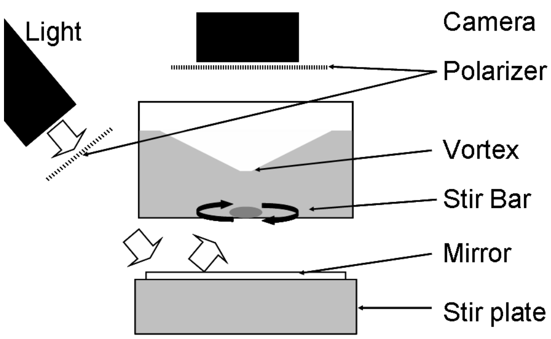

Figure 4 - Vortex setup

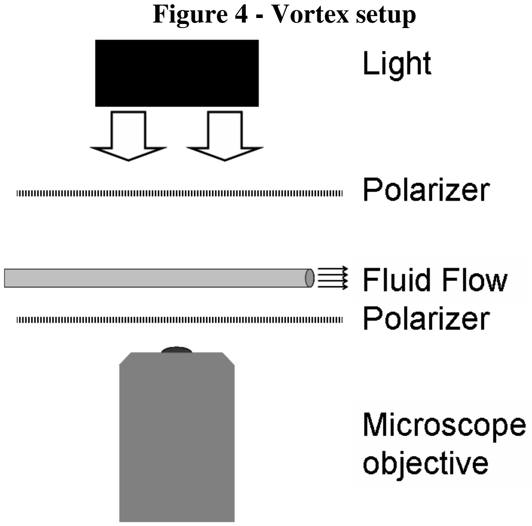

Figure 5 – Circular channel flow setup

3 *Discussion*

The results of the three setups described in Section 2 were all unsuccessful. The desired and expected result was to observe streaming birefringence, resulting in colors (isoclines) corresponding to the magnitude of shear in the liquid. There are possible explanations for the unsuccessful results observed during the experiments.

The square channel setup described in section 2.1 was not viable for the streaming birefringence phenoma. For unknown reasons, the polycarbonate sheet stock (McMaster Carr) was not suitable for use with polarization. This was determined by placing polarizing film on either side of the polycarbonate with the polarization directions orthogonal to each other, a configuration that would result in complete extinguishment of light for a non-polarized intermediate material. In this configuration, light was not extinguished, indicating that polycarbonate is not a suitable material for construction of the flow setup.

Conversations with the engineer responsible for designing the liquid revealed the most likely source of error– the working thickness of the liquid. The sample Blackstock fluid device uses a liquid thickness of .25” inches which allows significant transmission of the polarized light. It is possible that the 1” depth of liquid used in the vortex flow setup (section 2.2) overly attenuated the light and any isoclines of interest. This is consistent with a study published by Meisner and Rushner who reported a 1% bentonite solution being suitable for channels up to 15 mm [1]. An image of the liquid with ambient (non-polarized) lighting is shown in Figure 6.

While the liquid thickness explains the lack of streaming birefringence in the vortex flow setup, it does not explain the observations for the circular channel setup (section 2.3). The likely source of error for this setup was the agitation of the liquid in the ultrasonic bath. Ultrasonication of colloids is an effective way to fully disperse colloids and is capable of separating aggregated particles. However, ultrasonication is an aggressive dispersion method and may have mechanically degraded the particles in the Blackstock liquid. One requirement for colloidal streaming birefringence is particle asymmetry [2]. Ultrasonication is capable of mechanically degrading the colloid by fragmenting the particles, which would reduce the particle asymmetry. Consequently, this would attenuate the intensity of isoclines. This is consistent with observations made by the engineer/creator of the liquid for long time scale circulation experiments.

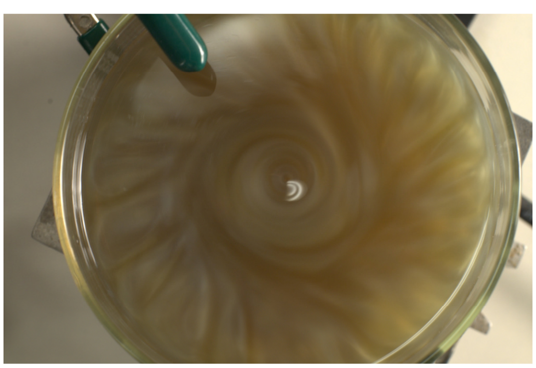

Figure 6 – Picture of Blackstock fluid in vortex flow setup with ambient (non-polarized) lighting

4 Conclusions

Based on the results of this study and a review of several published studies, I conclude that several adjustments to the methods presented in section 2 will yield successful streaming birefringence results.

4.1 Lighting & Polarization

The polarization scheme used for in the methods (Section 2) should be used for streaming birefringence. Two linear polarizing films in series with the light source and camera is appropriate and the polarizing axes should be orthogonal to each other for maximum color intensity [1]. Such a configuration minimizes the bright-field of the illuminated liquid, yielding visualization of the isoclines on a dark background and effectively increasing the signal to noise ratio [1].

4.2 Flow apparatus

The syringe pump apparatus shown in Figure 2 is recommended for volumetrically controlled flow. For higher flow volumes, the setup may be modified by adding additional syringes in parallel to provide greater volume and higher flow rates. The liquid thickness should be no greater than .25” to permit transmission of the light consistent with the sample Blackstock liquid device. The poly-carbonate material used in Section 2.1 is not suitable due to its inherent polarizing properties. Alternate materials include acrylic, which is used in the sample Blackstock liquid device, and glass. For ease of setup and optical quality, glass tubing is likely the most effective material.

Laminar flow is the most facile flow to visualize with streaming birefringence [3]. Since birefringence relies on different indices of refraction from the planes of the asymmetric particles, shear in the colloid will align the particles in a consistent direction and create well defined isoclines corresponding to the directions of fluid shear [1]. For a .25” diameter glass tube, the tube length should be a minimum of 2 ft (~100X the diameter) to allow fully developed Poiseuille flow.

4.3 Sample preparation

As mentioned in the results, ultrasonication should not be used to disperse the colloid. Simple manual agitation is sufficient for colloid dispersion and will yield the best results. In addition to a long channel length, fully developed flow can be achieved by increasing the viscosity of the liquid. The addition of glycerol to the liquid will significantly increase the viscosity and will not adversely affect the liquid due to the complete miscibility and absence of ionic dissociation of glycerol in water. Glycerol has also been used in a previous study to increase colloidal viscosity [1]. See Table 1 for example flow rates for various water/glycerol concentrations in a .25” circular tube within the laminar regime (Reynolds number of 1000). When working with glycerol, it should be noted that glycerol viscosity is highly dependent on temperature. See Figure 7 for the temperature dependent viscosity of 50% glycerol.

Glycerol content % (wt/wt)	Flow rate ($m \cdot sec^{-1}$)	Viscosity (mpa·sec)
0	1.005	0.16
10	1.31	0.21
20	1.76	0.28
30	2.50	0.39
40	3.72	0.59
50	6.00	0.94

Table 1 – Sample flow rates for aqueous glycerol solutions. Data from Dow Chemical.

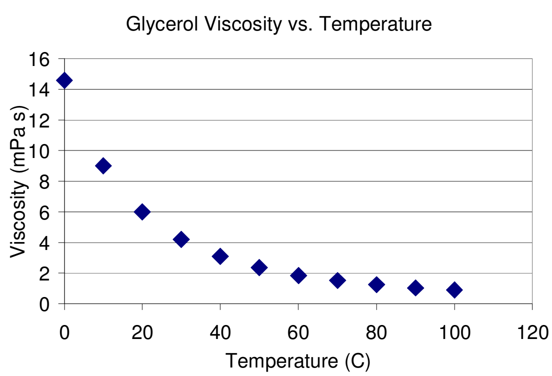

Figure 5 – Circular channel flow setup. Data from Dow Chemical.

5 References

1. Meisner, J. E. & Rushmer, R. F. Eddy Formation and Turbulence in Flowing Liquids. Circulation Research 12, 455-& (1963).
2. Joly, M. The Use of Streaming Birefringence Data to Determine the Size and Size Distribution of Rod-Shaped Interacting Particles. Transactions of the Faraday Society 48, 279-286 (1952).
3. Wayland, H. Streaming Birefringence as a Hydrodynamic Research Tool - Applied to a Rotating Cylinder Apparatus above the Transition Velocity. Journal of Applied Physics 26, 1197-1205 (1955).