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Influence of non-thermal active fluctuations over colloidal dynamics under crowded conditions

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Abstract

In this project we measure the flow rates and the fluctuations that are observed in the flow rate due to the use of crowding agents. By looking at the fluctuations in the derivative of the mass we attempt to gain insight in the observed phenomenon of non-uniform flow. Studying the derivative allows us to establish a threshold on the driving force for both the 20% glycerol solution and the 10% ficoll 400 solution.We then move on to define the *Recovery time* as a potential way of assigning a timescale to the fluctuations as it is a parameter seen to not vary across applied flow rates or the solutions used.

Crowding and Jamming

Jamming is a phenomenon observed in crowded fluid flow where the fluid phase is seen to get jammed i.e. acts as a solid with a finite yield strain. The finite force required to unjam a jammed flow and re-initiate the flow is called the unjamming force. Jamming has been the subject of much interest There have been proposals for a phase diagram for jamming in order to ascertain the conditions under which jamming can take place (Liu & Nagel, 1998). Physical models for jamming view it as the formation of force chains in response to an applied stress in the direction of the applied stress which yield if a force in any other direction is applied and in turn new force chains are formed in that direction (Cates et al., 1998). Changing the packing fraction of a system is seen a one of the ways to get to a jamming condition.There have been numerical and experimental studies into the phenomenon of jamming. Here, very briefly, I would go over a few of them. Menon et al. (2016) found in their numerical work that considering a small attractive force between foam bubbles gave rise to jamming. Stoop and Tierno (2018) observed that along with higher packing fractions, driving flow across disordered landscapes also led to jamming-like phenomena. In case of direct flow measurements Campbell and Haw (2010) found that above a certain packing fraction, jamming becomes a reality yet once the flow rates driving the fluid are increased sufficiently the state is broken and flow is re-initiated through unexpected means such as vortex formation.

Experimental

SET-UP

In order to study the flow of a fluid the experimental set-up used is as follows: A syringe is fixed in a pump which can drive flow at a specified rate. The syringe of an inner diameter $5mm$ injects the fluid in it to a long tube of an inner diameter of $200\mu m$. The tube leads to a small vial to collect the outflow. This vial is placed inside a weighing balance in order to measure the change in mass due to the flow. This procedure was carried out for water, 10% glycerol solution, 15% glycerol solution, 20% glycerol solution and 10% ficoll 400 solution.

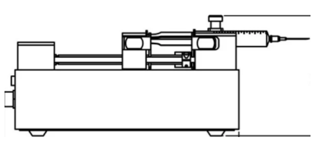

Figure 1: Schematic diagram of the set-up

The setup was placed in two separate locations in the lab first, on the lab counter in the lab and the second, an optical table inside a separate room.

OBSERVATIONS

Water

For the flow of water driven at a constant rate of 5 $\mu l/min$ the mass was recorded at one minute intervals for 30 minutes and this process was repeated five times. From this the following graph was obtained.

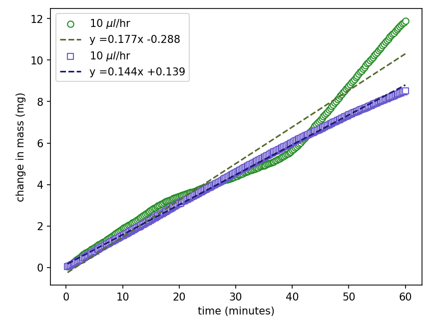

Figure 2: Mass of water versus time for water

10% Glycerol

For the 10% glycerol solution again mass was recorded at one minute intervals for a total period of 30 minutes. This was repeated three times. But while recording the data, fluctuations in the rate at which mass changed were seen but these were not properly captured when collecting data at one minute intervals. In order to correct for this, The mass was recorded at 30 second intervals to obtain the following:

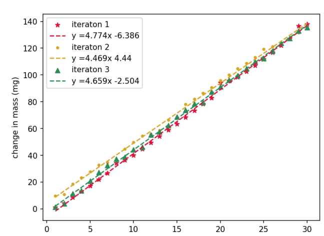

Figure 3: Mass of water versus time for the 10% glycerol solution measured every minute

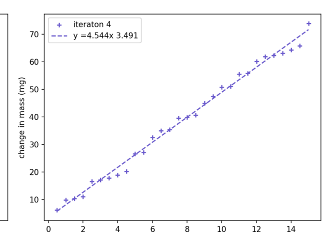

Figure 4: Mass of water versus time for the 10% glycerol solution measured every 30 seconds

15% Glycerol

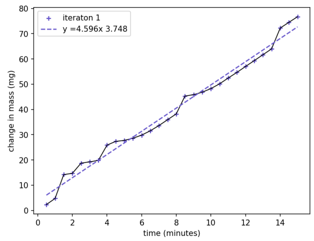

Figure 5: Mass of water versus time for the 15% glycerol solution measured every 30 seconds for 15 minutes

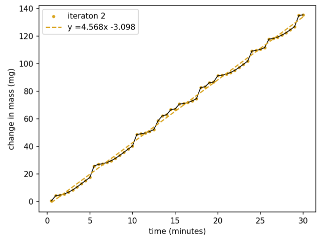

Figure 6: Mass of water versus time for the 15% glycerol solution measured every 30 seconds for 30 minutes

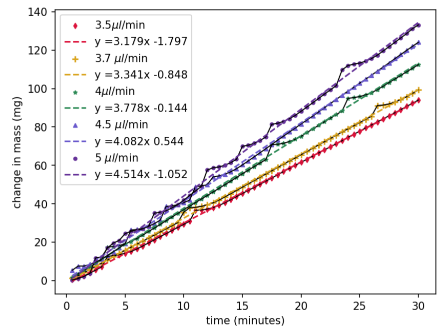

Figure 7: Mass vs time graphs for various applied flow rates, mass was recorded every 30seconds for a period of 30 minutes

Similar fluctuations were obtained for the 15% glycerol solution as seen in the 10% glycerol solution. These are suggestive of sudden increase in the flow rate followed by a short period of extremely slowed down rate of flow which is then seen to increase slowly and reach a constant flow rate until another fluctuation occurs. These sudden fluctuations are indicative of jamming-like behaviour.

20% **Glycerol**

At this concentration the flow rate was studied in various ways. In order to capture the fluctuations in the flow rate clearly the mass was recorded every 15 seconds in later instances and every 30 seconds initially. For an initial period the experimental setup was placed in the lab on a counter and data was collected for various flow rates. Fluctuations were seen for all observed flow rates. As presented in the graph below.

We can take a look at the first derivative of the flow rate by at each time-step subtracting the recorded mass at the previous time-step from the mass at that time-step. For the data shown in the graph above the derivative of the flow rate for various rates of driving the flow are as follows.

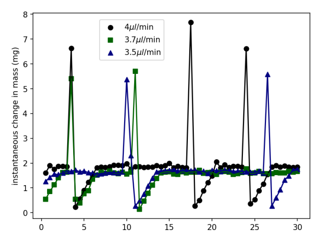

Figure 8: Derivative of the mass measured every 30 sec

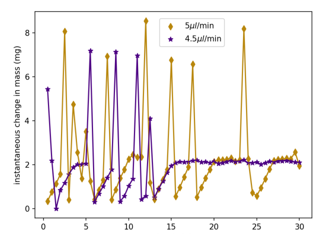

Figure 9: Derivative of the mass measured every 30 sec

The derivative reveals the nature of the flow. Immediately after a large fluctuation the flow rate drops to a very low value and increases slowly with each time-step until a constant value of flow rate is reached. The flow rate remains steady at this value till the next fluctuation. For the graphs at a higher flow rate of $5\mu l/min$ there also a lot of smaller fluctuations present along with the large jumps in flow rate seen before. The set-up was then moved to an optical table in a separated room in the lab. After doing so the following graphs were obtained for $5.00\mu l/min$ and $2.50\mu l/min$

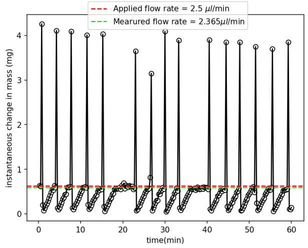

Figure 10: Derivative of the mass at an applied flow rate of $2.50\mu l/min$

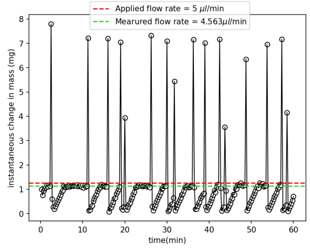

Figure 11: Derivative of the mass at an applied flow rate of $5.00\mu l/min$

In the next step lower flow rates were used to drive the flow and there appeared to be a threshold flow rate below which no large fluctuations as the ones seen at higher flow rates were observed in the derivative of the flow rate. The derivatives of the flow rates were seen to be as follows:

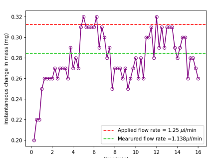

Figure 12: $1.25\mu l/min$

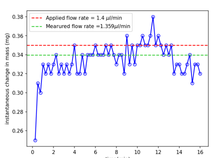

Figure 14: $1.40\mu l/min$

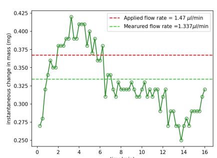

Figure 16: $1.47\mu l/min$

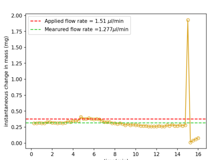

Figure 13: $1.51\mu l/min$

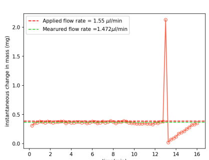

Figure 15: $1.55\mu l/min$

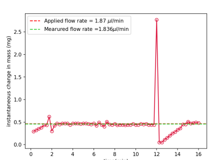

Figure 17: $1.87\mu l/min$

from the nature of the derivative it can be seen that the lowest flow rate at which a large fluctuation was observed was at $1,51\mu l/min$ the flow rates closest to this value that were tested were $1,55\mu l/min$ and $1,47\mu l/min$.

10% **Ficoll 400**

In order to check whether the fluctuations persisted in presence of a crowder other than glycerol. for the flow rates of $5.00\mu l/min$ and $2,50\mu l/min$ The following fluctuations were seen in the derivative of the flow rate were as follows,

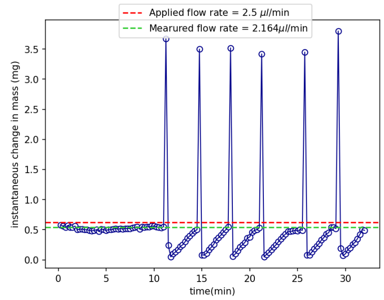

Figure 18: Derivative of the mass at an applied flow rate of $2.50\mu l/min$

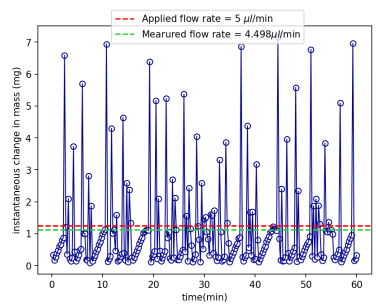

Figure 19: Derivative of the mass at an applied flow rate of $5.00\mu l/min$

In order to obtain the flow rate threshold for the 10% Ficoll 400 solution, Lower flow rates were applied to drive the flow. The following graphs were obtained for the following graphs.

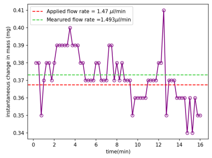

Figure 20: $1.47\mu l/min$

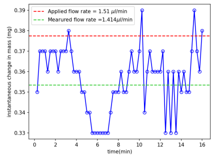

Figure 22: $1.51\mu l/min$

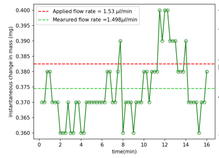

Figure 24: $1.53\mu l/min$

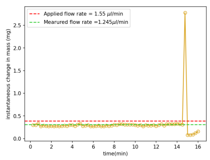

Figure 21: $1.55\mu l/min$

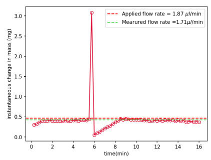

Figure 23: $1.87\mu l/min$

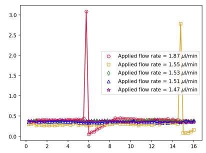

Figure 25: All flow rates

from the graphs we can see that the for applied flow rates below $1,55\mu l/min$ did not show large fluctuations. Thus for the 10% Ficoll 400 solution the flow rate threshold was seen to be higher than the one observed for the 20% Glycerol solution.

Recovery Time

After a large fluctuation the the derivative of the flow rate takes 1low values and then increases in a linear manner till the derivative becomes steady at the value of the measured flow rate or in certain cases, especially at a flow rate $5.00\mu l/min$ a few jumps in the derivative take place and the value of the derivative crosses the measured flow rate. let us call this time taken taken by the flow rate to increase back to the measured flow rate or beyond the *recovery time*.

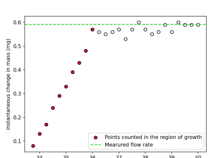

Figure 26: Example of recovery time

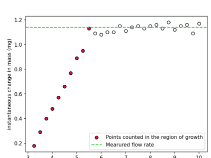

Figure 27: Example of recovery time

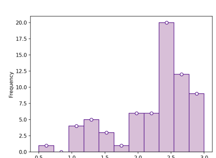

Figure 28: Histogram of recovery times

Interestingly, This recovery time remains the same across the whole range off flow rates as well as for the two different crowding agents. This might provide a way of quantifying this behaviour such that the recovery time could be one of the ways through which active fluctuations could have an effect on the behaviour of the system.

Future Work

The next step in this project would be to look at the effect of active fluctuations on the nature of the flow a crowded solutions. Active fluctuations have been seen to influence the dynamics of systems in many interesting ways. It would thus be valuable to see hoe this system responds to the presence of active fluctuations.

References

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