CERTIFICATION OF APPROVAL

DRAG REDUCTION STUDY ON XANTHAN WATER SOLUTION AND XANTHAN OIL SOLUTION

By

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____

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD HISYAM BIN NOOR ASMI

ABSTRACT

Drag reduction using polymer additive in fluid flow is an interesting phenomenon in turbulent pipe flow which was discovered by Tom back in 1948. Due to its industrial importance, this subject have been undergoes extensive studies both in experimental and in theoretical domain. In practice, it has been observed that drag reduction as much as 90% has been achieved using higher molecular weight of certain flexible polymer at low concentration of 20 ppm. In this paper, the degree of drag reduction of biopolymer, xanthan gum in water and oil is examined by measuring the value of fanning friction factor. This is done by left the solution to flow inside the flow loop and the pressure drops and flow rate are measured. The effect of concentrations at 0.05wt% and 0.1wt% and polymer chain network on the level of drag reduction was examined. The hydraulic conditions were varied from pumping operation of 5Hz to 28 Hz.

Overall, the results show that the degree of drag reduction increases with increasing in polymer concentration and Reynold number. The percentage of drag reduction is measured to be within 20% to 30% for 0.05wt% and 90% to 98% for 0.1wt%. The level of fluctuation in turbulence of the fluid flow is observed to decrease as the polymer is introduced into the flow. At constant pumping operation, increasing in polymer concentration resulting in decreasing in value of Reynold's number.

The results also agree with the theory of polymer chain network in the degree of drag reduction. It is observed that pseudo homogeneous solution of 0.05wt% exhibit a much lower value in fanning friction factor compare to homogeneous solution of 0.05wt% at the early of the experiment. As the time increase, the polymer chain networks are subjected to the repeated shear stress resulting the distance between the polymer molecule distances to increase until it is equally distributed as in homogeneous solution. Resulting the value of fanning friction factor in pseudo homogeneous solution to decrease until it reached almost the same value of fanning friction factor in homogeneous solution.

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Nomenclature

%DR	Drag reduction percentage	$DR(\%) = \left[\frac{f_N - f_P}{f_N}\right] x\ 100$
f	Fanning friction factor	$f = \frac{2\tau_w}{\rho U_B^2}$
Re	Reynold number	$Re = \frac{\rho U_B D}{\mu}$
U_B	Bulk velocity (m/s)	$U_B = (\frac{4Q}{\pi D^2})$
τ_w	Wall shear stress (Pa)	$\tau_w = \frac{\Delta p D}{4L}$
L	Pipe length over which the pressure drop was measured (m)	
ΔP	Pressure drop (Pa)	
D	Diameter of test pipe (m)	
Q	Volumetric flowrate (m^3/s)	
μ	Viscosity (Pa s)	
ρ	Density ($\frac{kg}{m^3}$)	

Subscript

N	Newtonian
P	Polymer

(Jaafar, Escudier, & Poole, Turbulent Pipe Flow of a Drag Reducing Rigid "Rod Like" Polymer Solution, 2009)

CHAPTER 1

INTRODUCTION

1.1 Project Title

Drag reduction study of polymer-water solution polymer-oil solution

1.2 Background study

Drag reduction is a term used to describe reduction in pressure drop when polymer is added to solvent. It was first discovered by Tom in 1946 as he measured the rate of flow of polymer polymethyl methacrylate dissolved in monochlorobenzene across in circular pipe and observed increased in flow rate with polymer concentration. There are many literatures available on the drag reducing ability of synthetic, flexible polymer such as Polyarcylamide and polyethylene oxide but very few on rigid biopolymers like xanthan gum. The limited literature on these biopolymers has shown that the polymer solutions are also capable of drag reduction but possibly to a lesser degree than flexible polymer solutions.

At Microscopic level, the difference between flexible polymer and rigid polymer is that prior to shearing, flexible polymer can be viewed as being in a randomly coiled configuration requiring some minimal value of shear rate to stretch the molecules, while a rigid polymer is already stretched in a rod-like conformation. High molecular weight flexible polymer solutions are, however, very prone to mechanical degradation.

It is important for the use of these polymer solutions to be balance with pumping cost and degradation rate. Flexible polymer is found to be more prone to mechanical degradation after certain period of time. This drawback has suppressed its advantages even tough flexible polymer is known to have greater drag reducing effect. However, rigid polymer solutions on the other hand are more resistant to mechanical degradation. High resistance to the mechanical degradation resulting in constant performance in drag reduction over time.

The study is intended to explore and compare the drag reducing ability of a biopolymer, xanthan gum in water and oil at polymer concentrations of 0.05wt% and 0.1wt% and at various Reynold's number. The effect of polymer chain network on the level of drag reduction are also examined by varying the polymer mixing condition.

1.3 Feasibility of the project

In pumping operation operating under similar operating parameter, introducing polymer into the fluid will increase the mobility of the solution causing the flow to require less pressure gradient to maintain the same flow rate. Maintaining the similar pressure gradient resulting in higher flow rate. This finding have significant value in operation the required the movement of mass such as transportation on crude oil from offshore facilities to onshore facilities. Given the price of oil nowadays, having higher flow rate even under similar pumping operation can save million of money for transportation.

Effective drag reduction methods can also be used to increase the distance of water jet and flow rate of fire fighter water system, the speed of missile, the drain rate of sewage system and the discharge rate in flooding situations. In addition, the are many literature available regarding drag reduction study of polymer in water as the solvent and in 2 fluid system (water-oil) but few on oil as the solvent. The experiment is intended to compare the behaviour of xanthan gum in water and also oil. The experiment is started in May 2011 until December 2011. Given that amount of time, numerous areas and finding have been covered by the author.

1.4 Problem Statement

In fluid flow in pipeline, the fluid in contact with the inner surface of pipe tends to stick to the surface due to the viscous effect. This layer of fluid will slow down the movement of the adjacent fluid layer by dragging that fluid layer due to friction. Presences of certain additive have been proven to reduce friction and increase flow rate. The study is intended to explore the degree of drag reduction by measuring and compare the value of fanning friction factor of a biopolymer, xanthan gum in water and also in oil at various concentrations and Reynold's number and also to study the effect of polymer chain network by varying the mixing method on the fanning friction factor in water xanthan solution.

1.5 Objective

To measure the fanning friction factor within a circular pipe test section of Xanthan-water solution at different polymer concentration and various Reynold's number in turbulent region in order to assess the drag reducing ability of the polymer.

1.6 Scope of study

The scope of study involved:

1. Analyze the effect of different concentrations of Xanthan gum and different Reynolds number on the fanning friction factor and percentage of drag reduction.
2. Analyze the effect of polymer chain network on the fanning friction factor

CHAPTER 2

LITERATURE REVIEW

2.1 Flow in pipes

Drag reduction using polymer additive have been an active field in the research area of non Newtonian fluid. It was first discovered by Tom in 1948 and due to its importance in industry numerous studies have been carried out in the coming years. Toms reported that the drag of a dilute solution of polyethyl methacrylate in monochlorobenzene was reduced considerably under certain condition of turbulent flow. This suggest that a polymer solution flowing in a pipe require a much lower pressure gradient to maintain the same amount of flow rate compare to the solvent alone

During the fluid flow, the fluid velocity in a pipe changes from zero at the inner wall surface to maximum at the center of the pipe. The fluid velocity is zero at the wall due to no-slip condition and the velocity must be highest at the center to keep mass flow rate. The collision of the fluid particles of the fluid did cause the kinematic energy to be converted into thermal energy but the temperature rise is too small to be considered in calculation. For instance, in the absence of heat transfer, no significant changes in term of the temperature of the fluid that is noticeable.

Fluid flow can be described into 2 behaviors which is laminar flow and turbulent flow (A. Cengel & John, 2006). In laminar flow, the fluid flow in a uniform manner. Dye streak that is injected into the flow produced a smooth and straight line in laminar region. In contrast, dye streak will form random zig zag motion in turbulent flow. In turbulent flow, the fluid is flowing in highly disorder or chaotic manner. The transformation between laminar flow into turbulent flow is called transition state.

The flow behavior can be distinguished based on the Reynold's number. Reynold's number is given as the ratio between inertial forces and viscous forces and flow behavior is dependent on which forces are more dominant.

$$Re = \frac{inertial\ forces}{viscous\ forces}$$

Dominant inertial force resulting in laminar flow and turbulent if the viscous tend to be dominant. Under most practical condition, fluid behaviors are classified according to following value of Reynold’s number.

$Re < 2300$ laminar flow

$2300 < Re <$ transitional flow

$Re > 4000$ turbulent flow

Two regions will be form inside the pipe which is entrance region and fully developed region. In hydrodynamic entrance region, the velocity profile of the fluid is being developed. After a certain distance from the entrance of pipe, the velocity profile will become constant and this region is known as hydrodynamic ally fully developed region. Velocity profile in the fully developed laminar flow has a parabolic shape and somewhat flatter in fully developed turbulent flow. Research area in this paper is focusing in fully developed turbulent region.

(A. Cengel & John, 2006) classified velocity profile in turbulent region into few regions, characterized by the distance to the wall. The very thin layer next to the wall where viscous effect is dominant is the **viscous sublayer.** Next to the viscous sublayer is **buffer layer**, in which turbulent effect is significant, but the flow is still dominated by the viscous effect. Above the buffer layer is the **overlap layer** in which turbulent effect is significant. Above this layer is **turbulent layer** and the turbulent effect is much more significant compare to the overlap layer. Some literature classified these layers with other names.

Turbulent flow is characterized by random and a rapid fluctuation of swirling region of fluid called eddies, throughout the flow. In turbulent flow, the swirling eddies transport mass, momentum and energy to other region of flow much more rapidly compare to laminar flow (Escudier, M.P., & Smith, 1999). In the study, it is observed that the viscous sub layer plays a passive role in drag reduction effect. However the buffer zone and logarithmic layer are considerably affected. The buffer zone increase in thickness with increasing level of drag reduction. This results in high flow velocity in logarithmic layer, which is responsible for the increase in the flow rate with the introduction of drag reducing polymer.

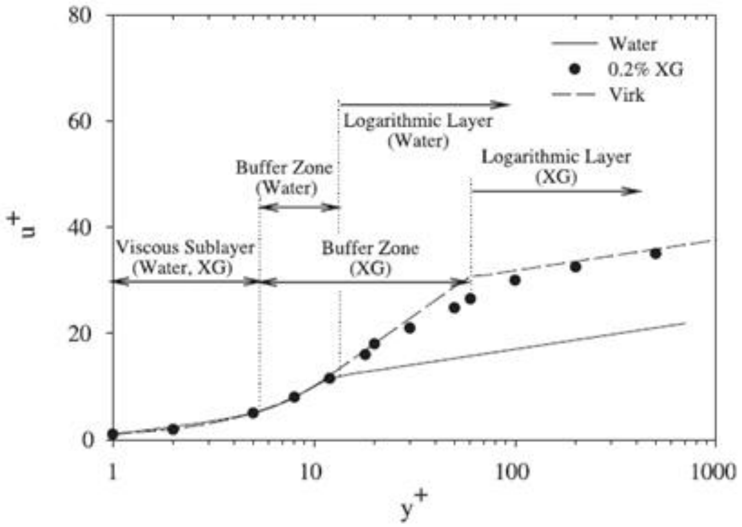


Figure 1: Thickness of Buffer Layer in Water and Xanthan Solution (Escudier, M.P., & Smith, 1999)

As the mechanism involved, De Gennes, attribute the drag reduction phenomenon to the shear waves caused by the elasticity of polymer chain. This shear waves are argued to suppress the turbulent velocity fluctuations at small scales thereby reducing the viscous drag. In recent experimental work, it has been shown that turbulent shear stresses are substantionally suppressed by polymer chain. This study revealed that unraveling of polymer chains is indeed an essential ingredient in the ability of a polymer to reduce viscous drag.

2.2 Newtonian flow

There are many literatures available regarding the behavior of Newtonian fluid in laminar and turbulent pipe flow. For instance, in laminar flow region, Newtonian fluid will follow Poiseuille's law (Jaafar, 2009) given as follow:

$$f.Re = 16$$

Where f is the fanning friction factor and can be calculated from the τ_w measurement via. In this paper, f is referring to the fanning friction factor unless otherwise is state.

$$f = \frac{2\tau_w}{\rho U_B^2}$$

And τ_w is wall shear stress and can be calculated from pressure drop via

$$\tau_w = \frac{\Delta pD}{4L}$$

At turbulent region, relations between fanning friction factor, f and Reynold's number will follow Blausius approximation

$$f = 0.0791Re^{-\frac{1}{4}}$$

This equation is valid for Reynold number up to 100 000. The Reynold's number definition that we use in this argument is as follow:

$$Re = \frac{\rho U_B D}{\mu}$$

Where viscosity of fluid is remain constant and bulk velocity is given as follow:

$$U_B = \frac{4Q}{\pi D^2}$$

2.3 Non-Newtonian flow

In non-Newtonian turbulent region, the friction factor is bound between Blausius approximation used in Newtonian turbulent region

$$f = 0.0791Re^{\frac{1}{4}}$$

And Virk's maximum drag reduction asymptote:

$$f = 0.58\ Re^{-0.58}$$

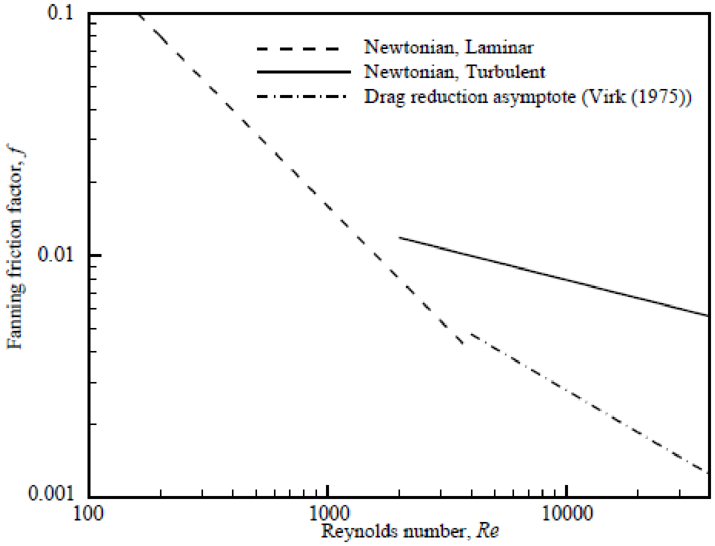


Figure 2: Poiseuille's Law Line and Blausius Approximation Line (Jaafar, Escudier, & Poole, 2009)

Virk's maximum drag reduction asymptote is the lower bound of friction factor that can be reached. The maximum drag asymptote however, is independent of pipe diameter, type of polymer, molecular weight and concentration (Virk, 1975). The Reynold's number definition that we use in the argument for non-Newtonian fluid flow is

$$Re = \frac{\rho U_B D}{\mu_w}$$

Where μ_w is wall shear viscosity and obtain from rheology study. The usage of wall Reynold's number follow the fact that polymeric liquid exhibit shear thinning properties. Its viscosity is shear rate dependent so it does not have constant value. Therefore we cannot use conventional Reynold’s number definition which is based on the constant viscosity everywhere.

The degree of deviation for non-Newtonian fluid from the Blausius approximation depend on many factors such as type of polymer used, polymer concentration, polymer molecular weight, and Reynold’s number.

2.4 Drag reduction in flexible polymer solution

Study regarding drag reduction of flexible polymer has been done using polyethylene oxide, PEO (Nam-Jin Kim, Sin Kim, Sang Hoon Lim, Kuan Chen, Wongee Chun, 2009). In the study, the effect of concentration and molecular weight of polymer on the degree of drag reduction have been done using polyethylene oxides with molecular weight $2*10^5$ at 4 concentration (1,5,10 and 20 wppm).

Polyethylene oxide is reported to be unsuitable for high temperature application. The polymer loses its effectiveness at temperature 87.8°C. Polyethylene oxide drag reduction also reported to be degraded due to action by pump (mechanical degradation).

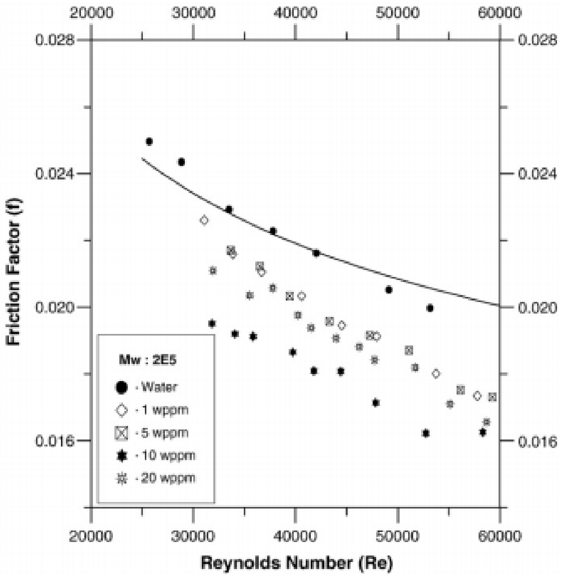


Figure 3: Graph friction factor versus Reynold number (Jin Kim, Kim, Hoon Lim, & Chen, 2009)

The result is recorded by plotting Darcy Weisbach friction factor versus Reynold's number for various polymer concentrations. The data for water is calculated using Haaland equation given as follow with roughness ratio 0.00005:

$$\frac{1}{f^{1/2}} = -1.8\log[\frac{6.9}{Re} + (\frac{\varepsilon/d}{3.7})^{1.11}]$$

From the result, it has shown that friction if decreasing or drag reduction is increase as the polymer concentration is increasing as shown except for the case of 20 wppm. Note that Darcy Weisbach friction factor is equivalent to four times fanning friction factor.

Drag reduction effectiveness; reduce significantly when it is exposed to turbulent flow for a curtain period of time. Drag reduction effectiveness reduce due to the mechanical degradation. Mechanical degradation is a term to describe fracture in polymer molecule. Polymer molecule has a long structure. When subjected to the repeated shear stress, this long molecule will break. The fractured molecule results in overall lower average molecular weight and changes in molecular weight distribution.

Another alternative explanation to this phenomenon is that some or all of the degradation is associate with decrease in the amount of polymer aggregation or entanglement. A decrease in aggregation would be cause by mechanical stress breaking up existing aggregates and preventing further aggregate formation in shear flow. Studies have shown that flexible polymer is more prone to the mechanical degradation compare to the biopolymer. Hence, even though flexible polymer solutions are more efficient drag reducers compared to rigid polymer solutions, their faster degradation rate might suppress the advantage.

2.5 Drag reduction in rigid rod like polymer solution

In the studies on the effect of concentrations and Reynold number on the degree of drag reduction using biopolymer solution shows that, drag reduction effectiveness increase as the solution concentration is increasing (Jaafar, Escudier, & Poole, 2009). The study is carried out for fully developed turbulent pipe flow of an aqueous solution of a rigid “rod-like” polymer, scleroglucan, at concentration between 0.005-0.075% SG. Fanning friction factor is calculated for the Newtonian fluid (water) and polymer solution and the results is plotted against Reynold number for different concentrations between 0.005-0.075% SG as shown in figure below.

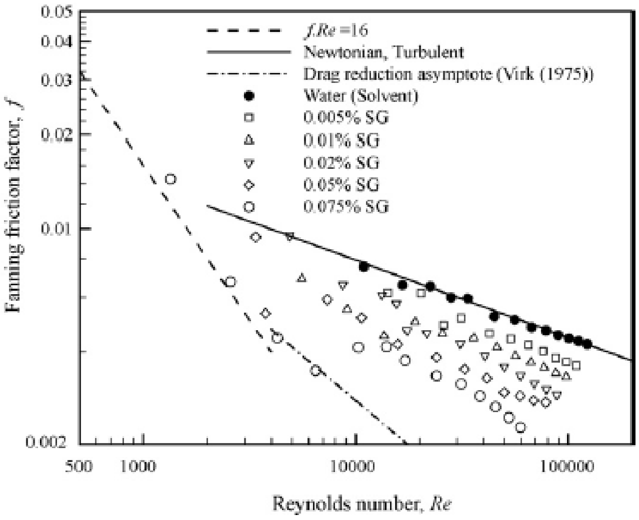
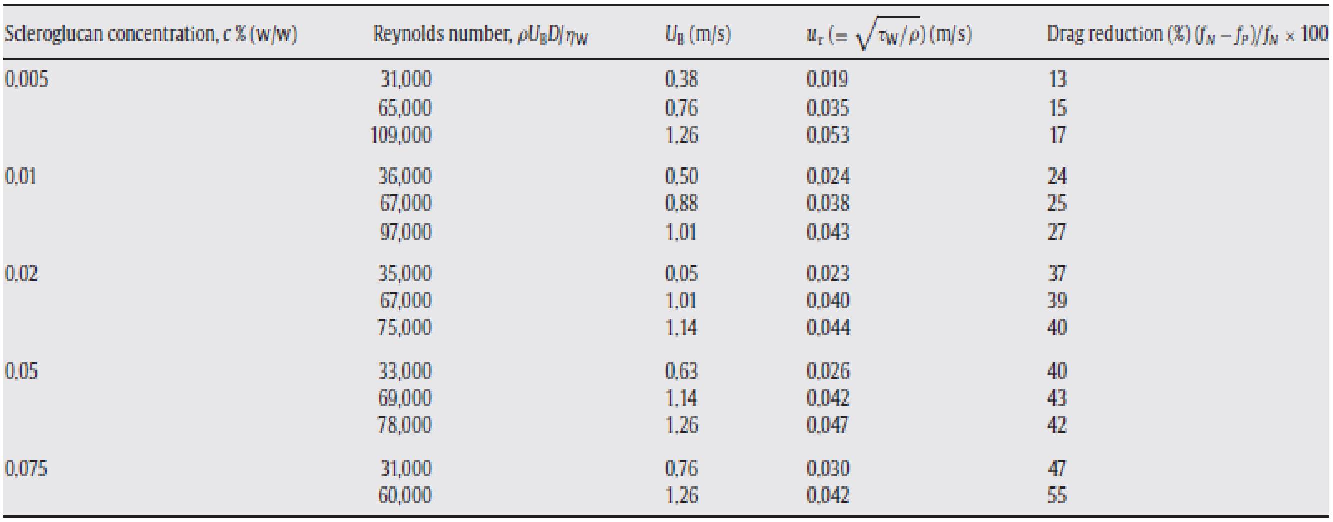


Figure 4: Graph of Fanning Friction Factor versus Reynold’s Number for Scleroglucan (Jaafar, Escudier, & Poole, 2009)

It is found that at constant Reynold number, Fanning friction factor decreased as the polymer concentration increased resulting increasing in percentage of drag reduction. It is also found that the degree of drag reduction in scleroglucan solution is highly dependent on concentration and mildly dependent on Reynold’s number.



Scleroglucan concentration, c % (w/w)	Reynolds number, $\rho U_B D/\eta_W$	U_B (m/s)	$u_\tau (= \sqrt{\tau_W/\rho})$ (m/s)	Drag reduction (%) $(f_N - f_P)/f_N \times 100$
0.005	31,000	0.38	0.019	13
	65,000	0.76	0.035	15
	109,000	1.26	0.053	17
0.01	36,000	0.50	0.024	24
	67,000	0.88	0.038	25
	97,000	1.01	0.043	27
0.02	35,000	0.05	0.023	37
	67,000	1.01	0.040	39
	75,000	1.14	0.044	40
0.05	33,000	0.63	0.026	40
	69,000	1.14	0.042	43
	78,000	1.26	0.047	42
0.075	31,000	0.76	0.030	47
	60,000	1.26	0.042	55

Figure 5: Relation between %DR with polymer concentration and Reynold number (Jaafar, Escudier, & Poole, 2009)

At the same Reynold's number, as the scleroglucan concentration is increasing, the solution show greater drag reduction in comparison with increasing Reynold's number at constant concentration. The drag reduction %DR is measured by using following equation:

$$DR(\%) = \left[\frac{f_N - f_P}{f_N}\right] x\ 100$$

Where subscripts N and P refer to Newtonian and polymer solution respectively. Similarity between Scleroglucan and Xanthan gum is they are both biopolymer and having rigid rod like conformation.

2.6 Drag reduction study on Xanthan-water solution

Study on the effect of polymer chain network and concentration of xanthan gum have been done using xanthan-water solution (B Wyatt, M. Gunther, & W. Liberatore, 2010). The study was conducted at constant value of Reynold's number at 32 000. In the study, the drag reduction properties are explored in different solvent environment (salt free versus salt solution) and different configuration (homogeneous versus pseudo homogeneous). In our scope of study, we are focusing more on salt free solution with homogeneous configuration.

Addition of small amount xanthan gun (as low as 20 ppm) resulting in measureable decrease in pressure drop. The result is observed by plotting the graph %DR versus concentration of xanthan gum at constant Reynold's number = 32 000.

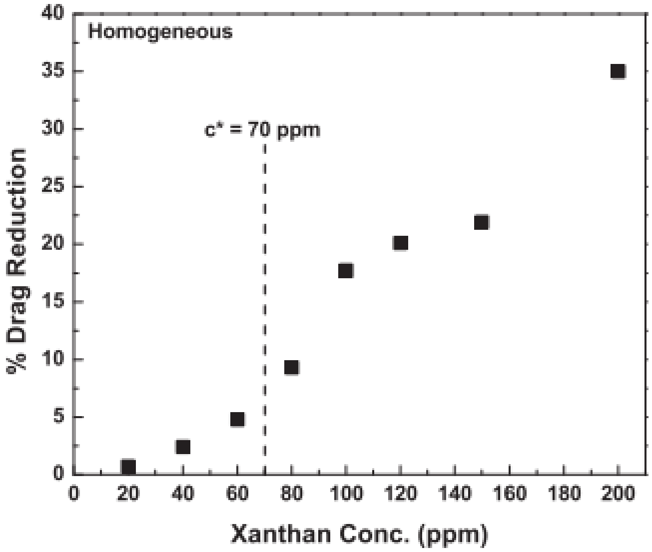


Figure 6: Drag reduction for several Xanthan concentrations when the experiment is done homogeneously. The vertical dashed line marks the overlap concentration, c*. Re= 32 000b (B Wyatt, M. Gunther, & W. Liberatore, 2010)

The result shows that the %DR increases with the increasing in Xanthan gum solution (5% for 60 ppm Xanthan and near 15% for 100 ppm Xanthan). The increasing in %DR is significant near the critical concentration c*≈ 70 ppm.

In that experiment (B Wyatt, M. Gunther, & W. Liberatore, 2010), three critical concentrations were determined from the dependence of zero shear rate viscosity on polymer concentration.

- The overlap concentration ($c^* \approx 70\ ppm$),
- The entanglement concentration ($c_e \approx 400$ ppm)
- Critical concentration labeled c_D ($c_D \approx 2000$ ppm).

The overlap concentration marks the transition from the dilute to semidilute unentangled concentration. The entanglement concentration marks the transition from semi dilute unentanglement concentration to semidilute entanglement regime. The final concentration, c_D marks the onset of neutral polymer behavior. (i.e viscosity scaling above c_D is well described by theory for neutral polymers)

Polymeric liquid (liquid that contain polymer) can be divided into few states. The simplest polymeric state is the **molten state.** Simple terminology to describe molten state is pure polymer (with no additives) that is melt in high temperature. When small amount of polymer is added with additives (water) this state is called **dilute solution.** This is similar to put one polymer chain in the sea of solvent. It is equivalent to one polymer because the solution is so dilute and that one chain of polymer did not influence other polymer in that solvent. If the polymer concentration in dilute solution is increasing, **semi-dilute solution** is form where the polymer in that solution begin to 'touch each other' or form a network. Further increase in concentration will cause **concentrated solution** to form. In concentrated solution, there are significant overlaps or entanglements.

It is believe that, network polymer structure plays a major role in drag reduction effectiveness. As the polymer network increase or become more entangle the drag reducing effect will also increase. As shown in this study (B Wyatt, M. Gunther, & W. Liberatore, 2010) as polymer concentration is increasing, the polymer solution state change from dilute to semi-dilute and causing the polymer to touch more with each other and form a network and become more entangle.

This is proven in pseudo homogeneous solution (B Wyatt, M. Gunther, & W. Liberatore, 2010). In pseudo homogeneous solution, concentrated polymer solution were prepared first (500 ppm, 1000 ppm, 4000 ppm, 10 000 ppm). The concentrated solution later is added with more water to obtain final Xanthan gum concentration of 60 ppm. The solution then is pump is the equipment and pressure drop is measured. In concentrated polymer solution, the individual polymer chain is entangled with other polymer chain. Simply diluting the entangle polymer may not allow all the polymer chain to become unentangled and free from each other. This resulting in higher percentage of drag reduction (%DR) in the case of homogeneous solution compare to the homogeneous solution.

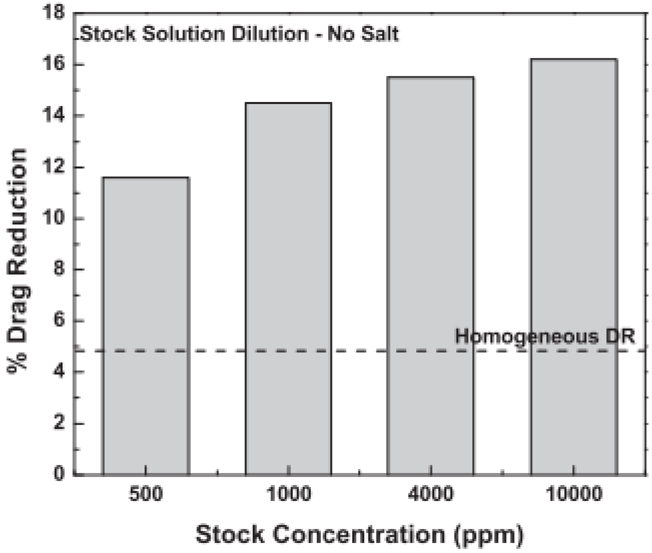


Figure 7: Drag reduction as function of concentrated solution (pseudo homogeneous) when the concentrated solution is diluted to 60 ppm Xanthan. Dashed line represents drag reduction for the homogeneous experiment with 60 ppm Xanthan solution. Re=27 000. (B Wyatt, M. Gunther, & W. Liberatore, 2010)

Drag reduction study of xanthan gun show similar result in another experiment using rotating disc apparatus (J-L, C.A, & H.J, 2000). Drag reduction of xanthan gum is investigated using rotating disc apparatus at various molecular weight. Since xanthan gum exist in only single molecular weight, $M_V = 3.61*10^6$ ultrasonic degradation method is applied to obtain different fraction of molecular weight of xanthan gum. The degree of drag reduction on various factor is investigate including polymer molecular weight, polymer concentration, rotational disc speed, ionic strength of solution and temperature.

Drag reduction cause by xanthan gum is found to increase with polymer concentration, reaching a maximum at its critical concentration, while the concentration required for maximum drag reduction decrease with increasing molecular weight. It also shows that xanthan gum is suitable for high temperature application. Since only a single molecular weight of xanthan gum is available commercially, the ultrasonication method was adopted to produce several different molecular weights of xanthan gum by polymer chain scission. This method has been adopted as the best means to produce xanthan gum with different molecular weight since it did not alter its chemical properties.

2.7 Xanthan rheology

Xanthan gum is polymer derive by the bacteria *xanthomonas campestris* which bacteria can be found in cabbage by fermentation process. Xanthan gum has backbone structure similar to cellulose with 3 branches of glucose, mannose and glucuronic acid that cause the polymer to form right handed helix. Right handed helix is referring to the 3d molecular structure of the polymer. By putting the axis of rotation of parallel to the line of sight, in clockwise motion the helix will move away from observer.

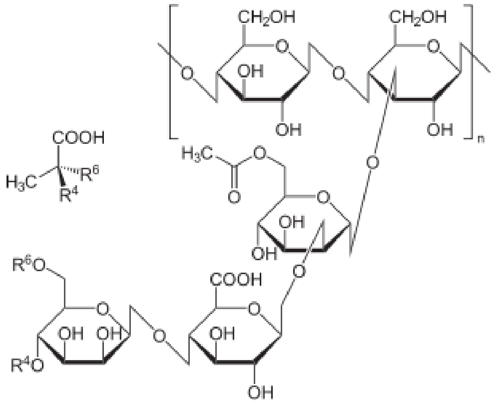


Figure 8: Xanthan gum molecular structure

Xanthan gum is widely used in food industry and cosmetic as thickening agent. Increasing of xanthan gum concentrations in water as the solvent resulting in increasing in viscosity (Xuewu, Xin, Dexiang, Wei, Tong, & Yonghong, 1994)

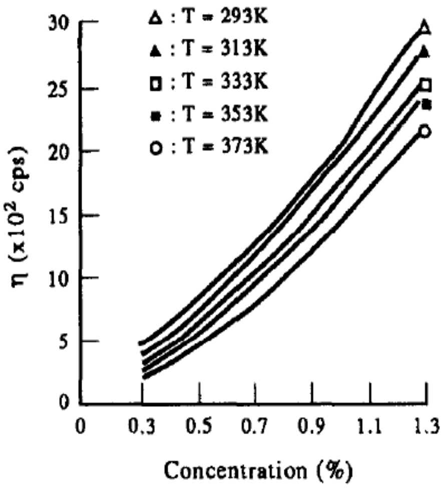


Figure 9: Effect of concentration on viscosity

In the same study, it also found that Xanthan-water solution exhibit shear thinning properties. Water is Newtonian fluid however as polymer is added into it the solution become Newtonian fluid. The viscosity of the solution is effect by the shear stress applied. Increase in shear stress causing the viscosity of polymeric solution to reduce.

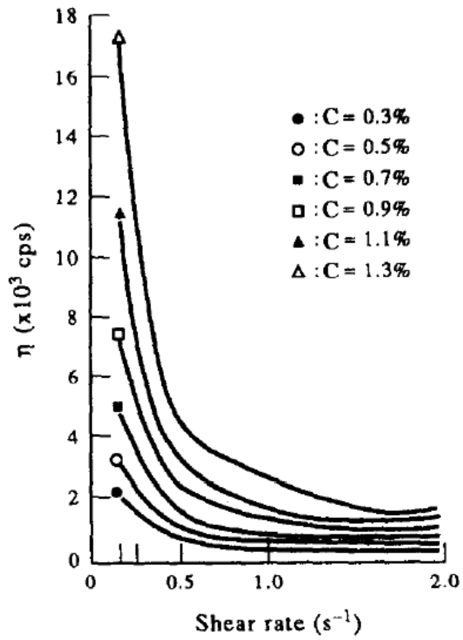


Figure 10: effect of shear stress on Viscosity

Nicholas B. Wyatt, Casey M. Gunther, Matthew W. Liberatore (Nicholas, Casey, & Matthew, 2010) had summarized the dilute and semidilute behavior of polyelectrolyte xanthan in salt free and salt solution. Specifically three critical concentration for xanthan were determined in salt free solution, namely the overlap concentration c*, entanglement concentration, c_e and c_D. Interestingly, the degree of changes in viscosity near the overlap concentration for xanthan gum is also correspond to the similar increasing in drag reducing properties of the polyelectrolyte in salt free solution.

The study also shows that, presence of salt is found to alter the viscosity of polymer solution. In 50mM NaCl, xanthan zero shear rate viscosity decreased in the dilute and semidilute concentration regime by as much as 89%. To ensure the difference in viscosity reported here were caused by the addition of salt rather than slight variations in concentrations or preparation method, one parent polymer solution were made, divided and salt added to one of the daughter solution. The end result was two solutions of identical polymer concentration but differing only in salt concentration.

In salt free solution, xanthan exhibit shear viscosity behavior typical of many polymer solutions. A Newtonian plateau is observed at low shear rate followed by shear thinning properties at higher shear rate.

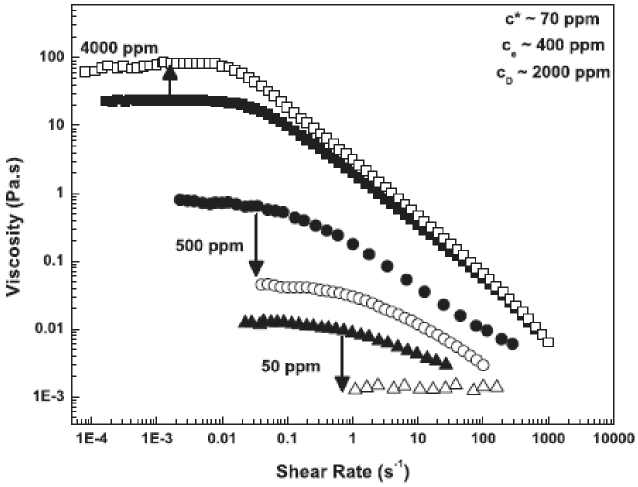


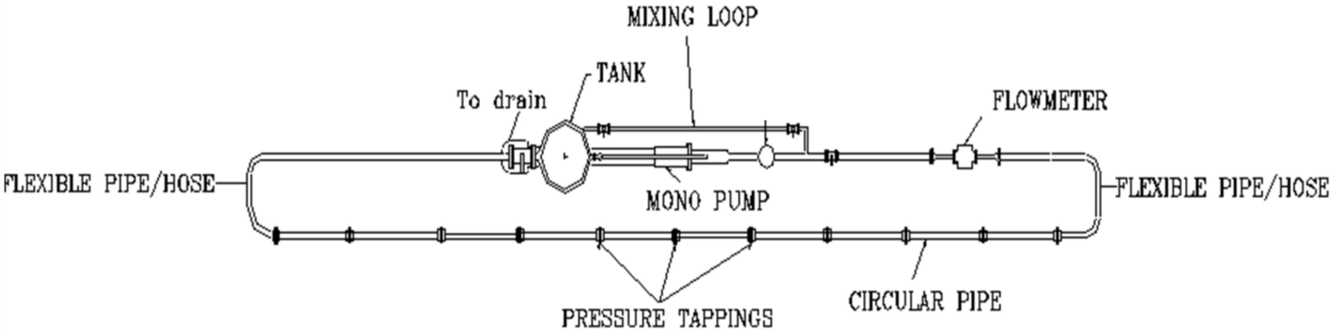
Figure 11: effect of shear stress on Viscosity (Nicholas, Casey, & Matthew, 2010)

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

Experimental Arrangement



The experiments were carried out in a close flow loop facility as shown in the figure above. The tank has the capacity to fill the fluid up to 40 liters. The flow loop consists of 3.6 m circular test pipe made of acrylic with 10 pressure tapping and the internal diameter of the test pipe is 0.003 m. The fluid was driven from mono CP 1600 pump with nominal flow rate of 125 L/min and maximum pressure of 28 meters. The flow rate measurement is taken using Parker type flow meter. Pressure drop is measured by first setting the desired flow rate by adjusting the pump regulator. Differential pressure transducer Delta S is attached to the data logger. Pressure drop reading was recorded from data logger using Picoscope 6 software. 3 ml Formaldehyde was added to 1.5 liter polymer solution to retard bacteriological degradation. Measurements of fluid rheology were conducted using AR-G2 rheometer. In this study, 6 cm 2 deg cone and plate (hard anodized) with gap of 500 micron is utilized.

Gantt Chart & Key Milestones

FINAL YEAR PROJECT I																
No	Activities/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1.	Selection of Project Topic	🟩	🟩					MID SEM BREAK								
		🟨	🟨													
2.	Preliminary Research Work		🟩	🟩	🟩	🟩										
			🟨	🟨	🟨	🟨	🟨									
3.	Submission of Extended Proposal Defence						🟩									
							🟨									
4.	Proposal Defence								🟩	🟩						
									🟨	🟨						
5.	Project work continue										🟩	🟩	🟩			
											🟨	🟨	🟨	🟨	🟨	
6.	Submission of Interim Draft Report													🟩		
														🟨	🟨	
7.	Submission of Interim Report														🟩	
															🟨	

🟩 **planned** 🟨 **actual**

FINAL YEAR PROJECT II

No	Activities/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.	Drag reduction measurement		🟩	🟩	🟩	🟩		**MID SEM BREAK**								
			🟨	🟨	🟨	🟨	🟨									
2.	Rheology study				🟩	🟩	🟩		🟩							
					🟨	🟨	🟨		🟨							
3.	Progress Report Submission								🟩							
									🟨							
4.	Draft report submission												🟩			
													🟨			
5.	Dissertation Submission													🟩		
														🟨		
6.	Technical Paper submission													🟩		
7.	Oral Presentation														🟩	
															🟨	
8.	Project Dissertation Submission															🟩
																🟨

🟩 **plannedl** 🟨 **actual**

3.1.1 1st experiment

In this experiment, two different types of solutions are used which is xanthan-water solution and xanthan-oil solution at 0.05 wt% and 0.1 wt%. First, 0.05wt% solution is prepared by adding 20g xanthan with 40 liters of water. The solution is prepared homogeneously by left the solution to flow inside the flow loop for 10 minutes with pump operate at 25 Hz in order to ensure the polymer chain are mix properly. Pressure drop reading is taken at various Reynold number by adjusting the speed of pump starting from low speed and into high speed (5Hz, 8Hz, 10Hz, 13Hz, 15Hz, 8Hz, 20Hz, 23Hz, 25Hz, and 28Hz). The experiment is repeated for 0.1 wt% xanthan solution by adding 40g of xanthan gum with 40 liters of water.

Note that for each xanthan concentrations, pressure drop reading is taken without too much noise inside the laboratory since the pressure transducer is sensitive to vibration. Polymeric solution exhibit shear thinning properties, sample of 1.5 liter xanthan solution are taken before the readings are taken. These samples are used to measure the viscosity of the solution for Reynold's number calculation by using AR-G2 rheometer. Density measurements are carried out using a simple equation:

$$\rho = \frac{mass}{volume}$$

Based on pressure drop data, the relations between the effects of various Xanthan gum concentrations with the degree of fanning friction factor are analyzed. The results are prepared by plotting fanning friction factor versus Reynold number at various Xanthan concentrations. The effect of Xanthan concentrations also are analyzed by plotting %DR versus concentration and the result are compared for both solutions. The experiment is repeated for oil.

3.1.2 2^{nd} experiment

This experiment is carried out to measure the effect of polymer chain network on drag reducing performance and to measure xanthan gum solution performance with time. In this experiment 0.05wt% XG is prepared homogeneously by adding 20g of xanthan gum with 40 liter of water. The solution is left to run inside the equipment for 10 minutes. After 10 minutes, it is assumed that the polymer chain is equally distributed in water. The pump is operated at 20 Hz and 23 Hz and the reading is taken every 10 minutes for 2 hours. The result is analyzed by plotting fanning friction factor versus time.

The experiment is proceed by preparing concentrated xanthan-water solution of 0.3wt% by adding 11.64 gram of xanthan gum with 3.9 liter of water. The calculation to produce concentrated xanthan-water solution is given as follow.

For the case of 0.3wt% xanthan-water stock solution

Let

x = mass of water (gm)

y = mass of xanthan gum (gm)

z = mass of 20 liters of water = 19 400 gm

Preparing for 0.3wt% xanthan water stock solution

$$\frac{y}{y+x} * 100 = 0.3$$

y = 0.003y + 0.003x

0.997y – 0.003x = 0 Eqn (1)

20 liter of water is added to the 0.3wt% xanthan water stock solution to produce 0.05wt% solution.

$$\frac{y}{y+x+z} * 100 = 0.5\text{wt\%}$$

$$\frac{y}{y+x+19\,400} * 100 = 0.5\text{wt\%}$$

y = 0.0005y + 0.0005x + 0.97

0.9995y – 0.0005x = 9.7 Eqn (2)

Solving the simultaneous equation

x = 3868 gm = 3.9 liter

y = 11.64 gm

11.64 gm of xanthan gum is added to the 3.9 liter of water to produce 0.3wt% stock solution and it is diluted by adding 20 liter of water to produced 0.05wt% solution.

In concentrated solution, it is assume that the polymer is forming a network and entangle with each other. This solution later is dilute by adding more water. The concentrated solution later is added with more water to obtain final xanthan gum concentration of 0.05wt%.

The solution then is pump at 20Hz and 23Hz and pressure drop is measured and the reading is taken every 10 minutes for 2 hours. In concentrated polymer solution, the individual polymer chain is entangled with other polymer chain. Simply diluting the entangle polymer may not allow all the polymer chain to become unentangled and free from each other.

3.2 Precaution

In the experiment setup, there are few important aspects that need to be considered:

1. Pressure drop reading
    - Pressure transducer need to be attached to the test section before the fluid is pump in the flow loop. Attaching pressure transducer during the fluid flow might cause some of the solution to flow out from the pressure tapping due to the build in pressure, resulting in less polymer concentration in the solution.
    - Make sure the connection between pressure transducer and pressure tapping is not pinched or it will disrupt the reading.
    - Pressure transducer need to bleed out to ensure it is free from any bubble
    - Make sure pressure transducer is properly connected to the test section by attaching the positive terminal (+) to the higher pressure of the test section.

2. Make sure the flow loop is empty from any fluid each time before switching to different concentrations of polymer solution. The critical area is located at the flow meter section of the flow loop. At this section the flow meter is attach at the bottom of the vertical section of pipe. The flow meter is equipped with one way valve causing the fluid to trap inside the vertical pipe. This problem can be solve by running tap water inside the flow loop for a few minutes in order to remove any residual from the previous experiment before the tap water is flush out. Never leave the equipment with Xanthan solution inside otherwise it will accumulate inside the pump.

3. To get accurate reading it is important to ensure the fluid flow exists in only single phase. This can be done by removing any air bubble inside the equipment by bleeding small amount of fluid from the pressure tapping.

CHAPTER 4

4.1 RESULT AND CALCULATION

4.1.1 Data collection for 1st experiment

From the experiment runs, the following data was recorded:

1. Flow rate of solution (L/min)
2. Pressure transducer's voltage reading (mV)

Sample of the water was taken early on the experiment for density and dynamic viscosity measurement. The following tables show the results and calculation recorded during the experiment.

Results

4.1.1.1 UTP tap water

Density of sample : 970 kg/m^3

Viscosity : 0.000891 kg/ms

Pump frequency, Hz	Flow rate, m^3/sec	Voltage, mV	Current, mA
5	0.00015	595.80	4.77
8	0.00027	583.60	4.67
10	0.00033	610.50	4.88
13	0.00048	615.40	4.92
15	0.00057	612.90	4.90
18	0.00067	652.00	5.22
20	0.00073	669.10	5.35
23	0.00082	705.70	5.65
25	0.00090	722.80	5.78
28	0.00098	747.30	5.98

Table 1: Pump frequency, Flow rate, Voltage and current for UTP tap water

Since resistance of resistivity box is constant throughout the entire experiment (R=125 ohm). The reading for current is measured based on $I = \frac{V}{R}$.

Pump frequency, Hz	Pressure drop, Pa	Bulk velocity U, m/s	Wall shear stress, Pa
5	165.3029	21.21791	0.30994
8	144.2594	37.72073	0.27049
10	190.6587	47.15091	0.35749
13	199.1106	68.36881	0.37333
15	194.7984	80.15654	0.36525
18	262.2413	94.30181	0.49170
20	291.7367	103.73199	0.54701
23	354.8674	115.51972	0.66538
25	384.3629	127.30745	0.72068
28	426.6225	139.09517	0.79992

Table 2: Pump frequency, Pressure drop, Bulk velocity and wall shear stress for UTP tap water

Pump frequency, Hz	Fanning friction factor, f	Reynold number, Re
5	0.000001419	69298
8	0.000000392	123196
10	0.000000332	153995
13	0.000000165	223292
15	0.000000117	261791
18	0.000000114	307989
20	0.000000105	338788
23	0.000000103	377287
25	0.000000092	415785
28	0.000000085	454284

Table 3: Pump frequency, Fanning friction factor and Reynold's number for UTP tap water

4.1.1.2 0.05 wt% XG

Density of sample : 985 kg/m^3

Pump frequency, Hz	Flow rate, m^3/sec	Voltage, mV	Current, mA
5	0.00015	615.40	4.9232
8	0.00028	625.20	5.0016
10	0.00037	634.90	5.0792
13	0.00048	649.60	5.1968
15	0.00055	654.50	5.2360
18	0.00067	671.60	5.3728
20	0.00072	696.00	5.5680
23	0.00083	735.00	5.8800
25	0.00092	747.30	5.9784
28	0.00100	769.20	6.1536

Table 4: Pump frequency, Flow rate, Voltage and current for 0.05wt% XG

Pump frequency, Hz	Pressure drop, Pa	Bulk velocity U, m/s	Wall shear stress, Pa
5	199.1106	21.21791	0.37333
8	216.0144	40.07827	0.40503
10	232.7458	51.86600	0.43640
13	258.1016	68.36881	0.48394
15	266.5535	77.79900	0.49979
18	296.0489	94.30181	0.55509
20	338.1361	101.37445	0.63401
23	405.4064	117.87727	0.76014
25	426.6225	129.66499	0.79992
28	464.3974	141.45272	0.87075

Table 5: Pump frequency, Pressure drop, Bulk velocity and wall shear stress for 0.05wt% XG

Polymeric solutions are observed to exhibit shear thinning properties. Its viscosity dependent on the shear rate applied. In this experiment viscosity and shear rate measurement have been carried out using rheometer. Graph of wall shear stress versus shear rate and graph of viscosity versus shear rate are plotted as follow:

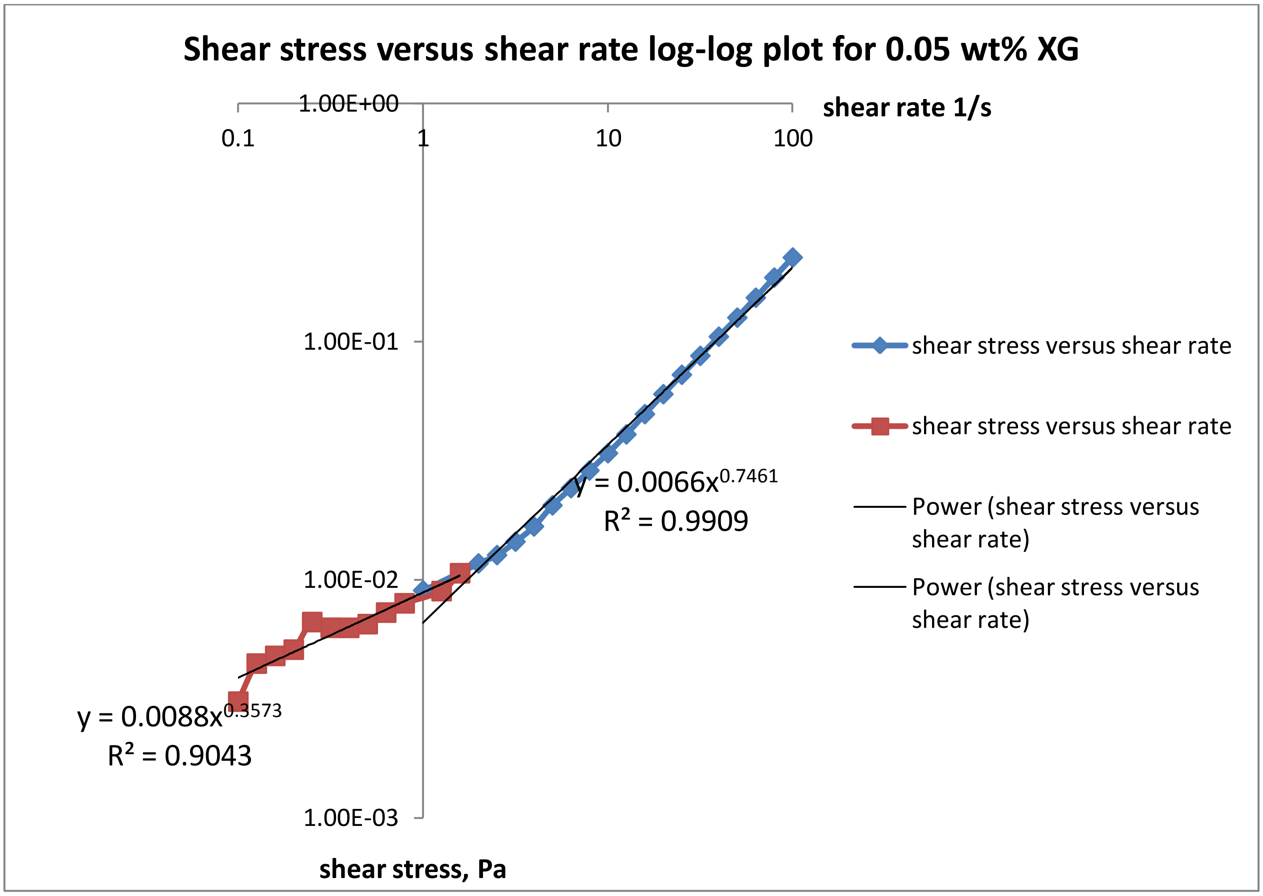


Figure 12: Shear stress versus shear rate log-log plot for 0.05 wt% XG

From the graph above, the line can be represent using the equation $y = 0.0066x^{0.7461}$ since the value of R^2 is closest to 1 and the shear rate measurement can be find using same equation by finding the value for x.

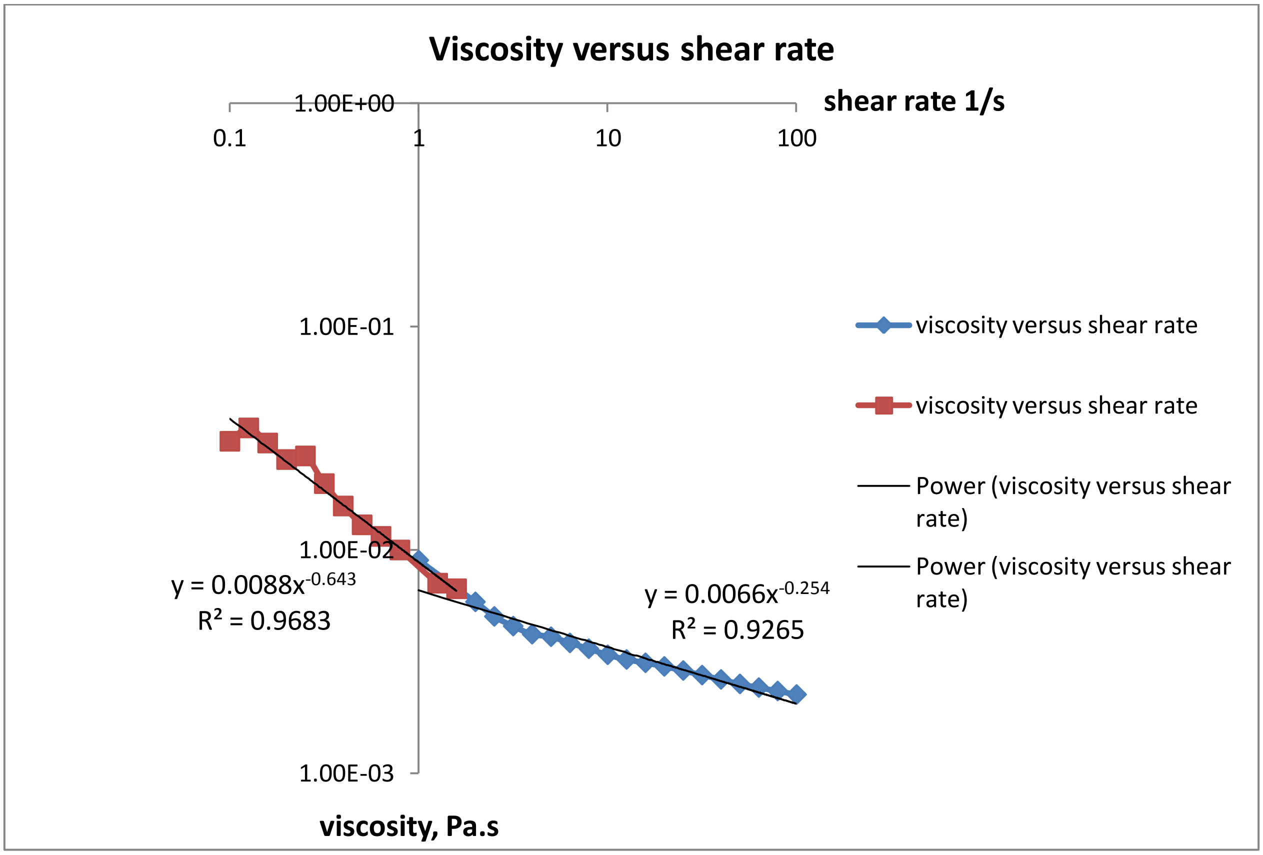


Figure 13: Viscosity versus shear rate for 0.05wt% XG

The graph of viscosity versus shear rate above can be represent using the equation $y = 0.0066x^{-0.254}$ since the value of R^2 is closest to 1 and the viscosity measurement at corresponding shear rate can be find using same equation by finding the value for y.

Pump frequency, Hz	**Viscosity, Pa.s**	**Fanning friction factor, f**	**Reynold number, Re**
5	0.001670747	0.000001684	37527
8	0.001625036	0.000000512	72879
10	0.001584285	0.000000329	96740
13	0.001529483	0.000000210	132090
15	0.001512797	0.000000168	151968
18	0.001459701	0.000000127	190903
20	0.001395118	0.000000125	214721
23	0.001311550	0.000000111	265584
25	0.001288971	0.000000097	297260
28	0.001252274	0.000000088	333787

Table 6: Pump frequency, Viscosity, friction factor and Reynold number for 0.05wt% XG

4.1.1.3 0.1 wt% XG

Density of sample : 995 kg/m^3

Pump frequency, Hz	Flow rate, m^3/sec	Voltage, mV	Current, mA
5	0.00015	615.40	4.9232
8	0.00030	603.20	4.8256
10	0.00038	635.05	5.0804
13	0.00048	654.45	5.2356
15	0.00057	675.65	5.4052
18	0.00068	683.80	5.4704
20	0.00073	700.90	5.6072
23	0.00083	698.40	5.5872
25	0.00092	739.90	5.9192
28	0.00100	759.50	6.0760

Table 7: Pump frequency, flow rate, voltage and current for 0.1wt% XG

Pump frequency, Hz	Pressure drop, Pa	Bulk velocity U, m/s	Wall shear stress, Pa
5	199.1106	21.21791	0.37333
8	178.0671	42.43582	0.33388
10	233.0045	54.22354	0.43688
13	266.4672	68.36881	0.49963
15	303.0347	80.15654	0.56819
18	317.0925	96.65936	0.59455
20	346.5880	103.73199	0.64985
23	342.2758	117.87727	0.64177
25	413.8583	129.66499	0.77598
28	447.6660	141.45272	0.83937

Table 8: Pump frequency, Pressure drop, bulk velocity and wall shear stress for 0.1wt% XG

Polymeric solutions are observed to exhibit shear thinning properties. Its viscosity dependent on the shear rate applied. In this experiment viscosity and shear rate measurement have been carried out using rheometer. Graph of wall shear stress versus shear rate and graph of viscosity versus shear rate are plotted as follow

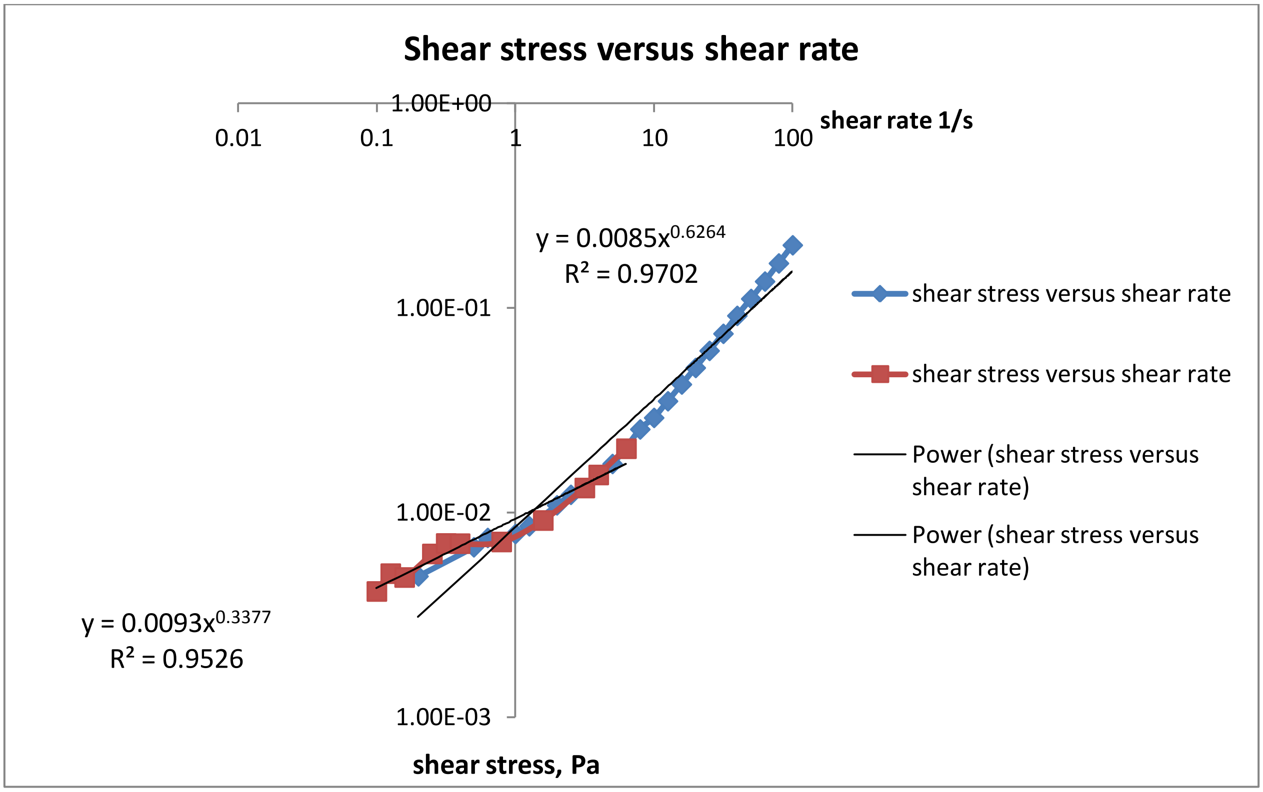


Figure 14: shear stress versus shear rate for 0.1wt% XG

From the graph above, the line can be represent using the equation $y = 0.0085x^{0.6264}$ since the value of R^2 is closest to 1 and the shear rate measurement can be find using same equation by finding the value for x.

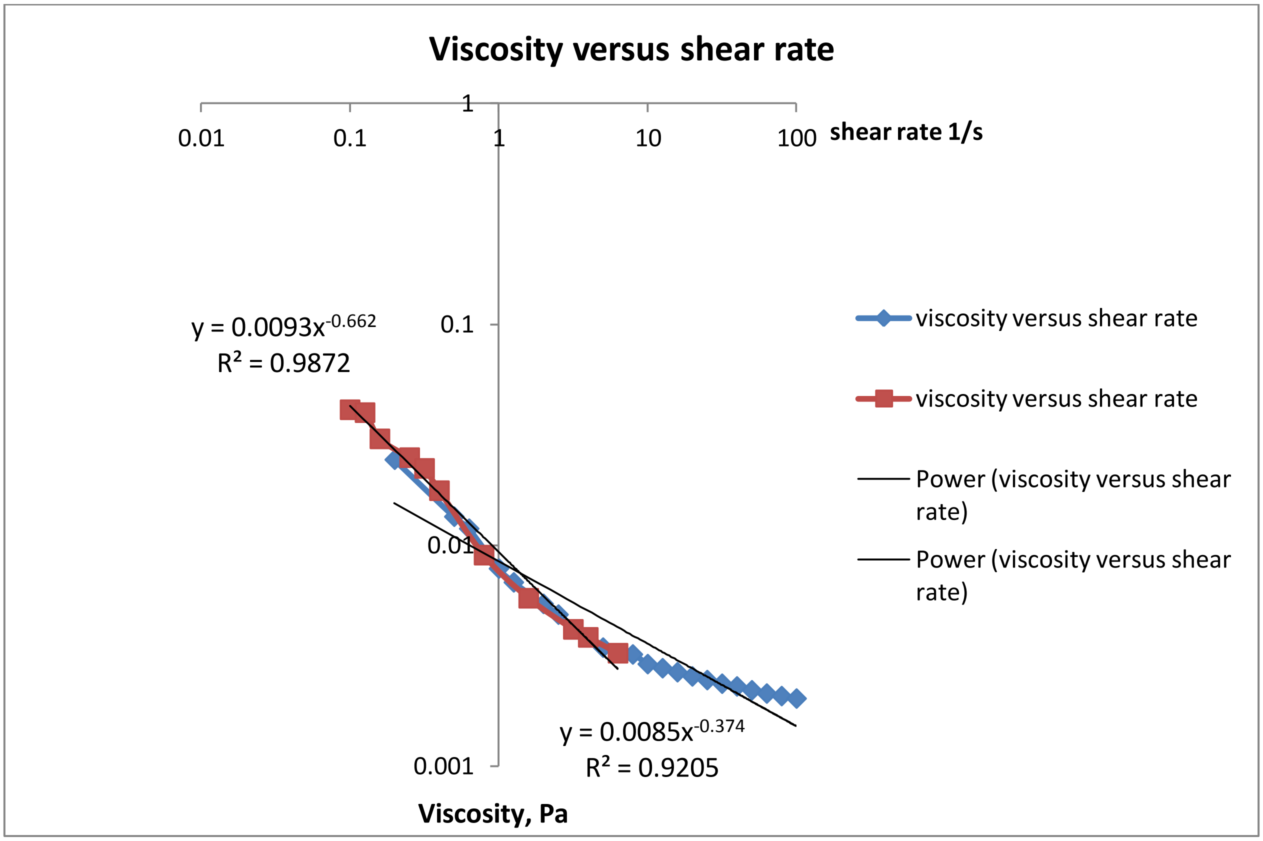


Figure 15: viscosity versus shear rate for 0.1wt% XG

The graph of viscosity versus shear rate above can be represent using the equation $y = 0.0085x^{-0.374}$ since the value of R^2 is closest to 1 and the viscosity measurement at corresponding shear rate can be find using same equation by finding the value for y.

Pump frequency, Hz	Viscosity, Pa.s	Fanning friction factor, f	Reynold number, Re
5	0.006781735	0.000001667	9339
8	0.006827115	0.000000373	18554
10	0.006718382	0.000000299	24092
13	0.006664768	0.000000215	30621
15	0.006613792	0.000000178	36177
18	0.006595910	0.000000128	43744
20	0.006560975	0.000000121	47194
23	0.006565882	0.000000093	53590
25	0.006491854	0.000000093	59621
28	0.006461489	0.000000084	65347

Table 9: Pump frequency, viscosity, friction factor and Reynold number for 0.1wt% XG

4.1.1.4 Fanning friction factor versus Reynold's number

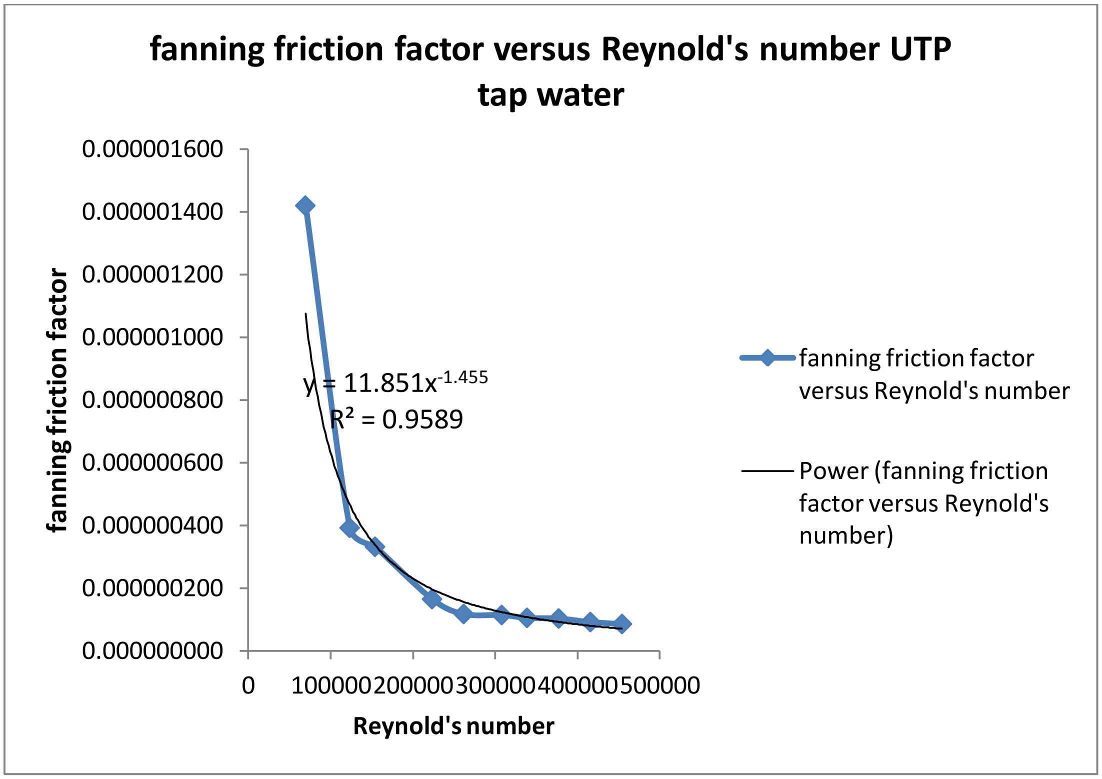


Figure 16: fanning friction factor versus Reynold's number for UTP tap water

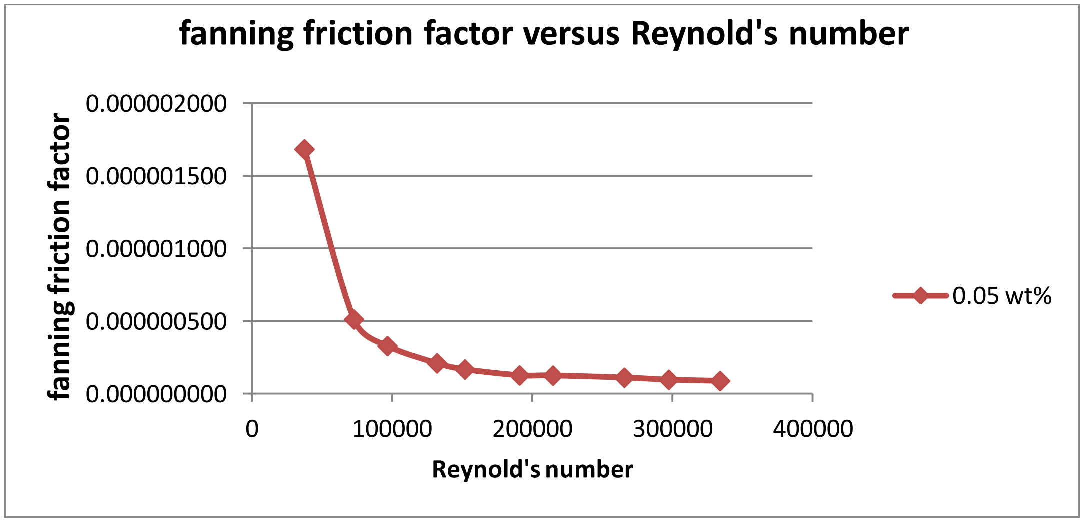


Figure 17: fanning friction factor versus Reynold's number for 0.05wt% XG

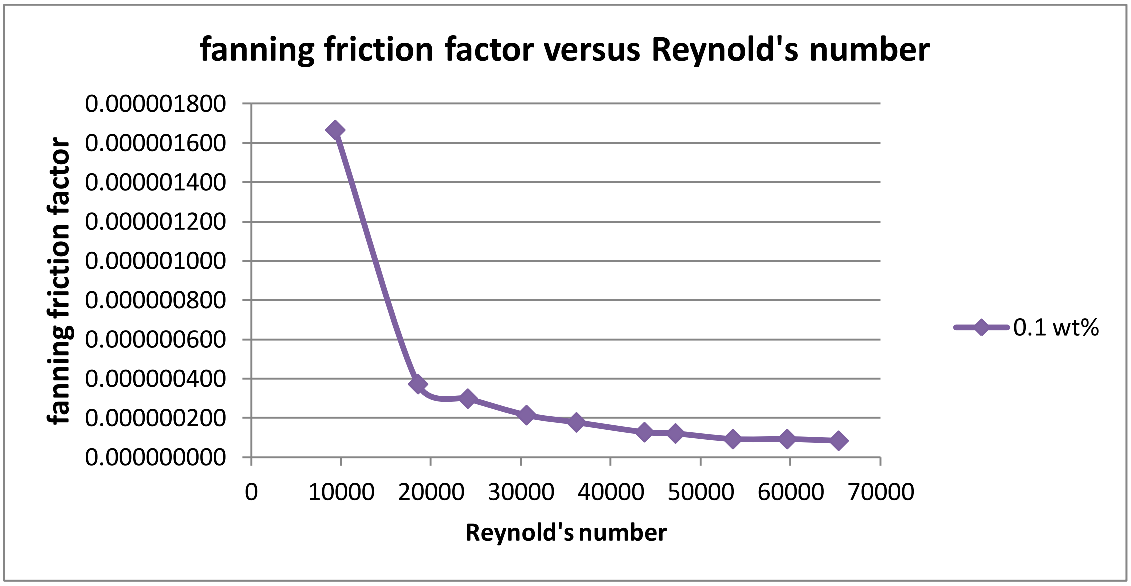


Figure 18: fanning friction factor versus Reynold's number for 0.1wt% XG

Fanning friction factor versus Reynold's number for UTP tap water, 0.05 wt% XG and 0.1 wt% XG are plotted as in the figure above. For the graph it showed that fiction decrease as the Reynold's number increase. The friction factor seems to drop drastically as the Reynold's number reached certain range and the value varies for each concentration. It is observe that at each solution, there is a sudden drop of fanning friction factor as the Reynolds' number reached certain value. This value of Reynold's number is known as optimum value. This value decrease as polymer concentration increase and the value is given as follow:

Solution	Optimum Value
UTP tap water	100 000- 200 000
0.05wt% XG	50 000 – 100 000
0.1wt% XG	10 000 – 20 000

Table 10: Table of Optimum Value for each solution

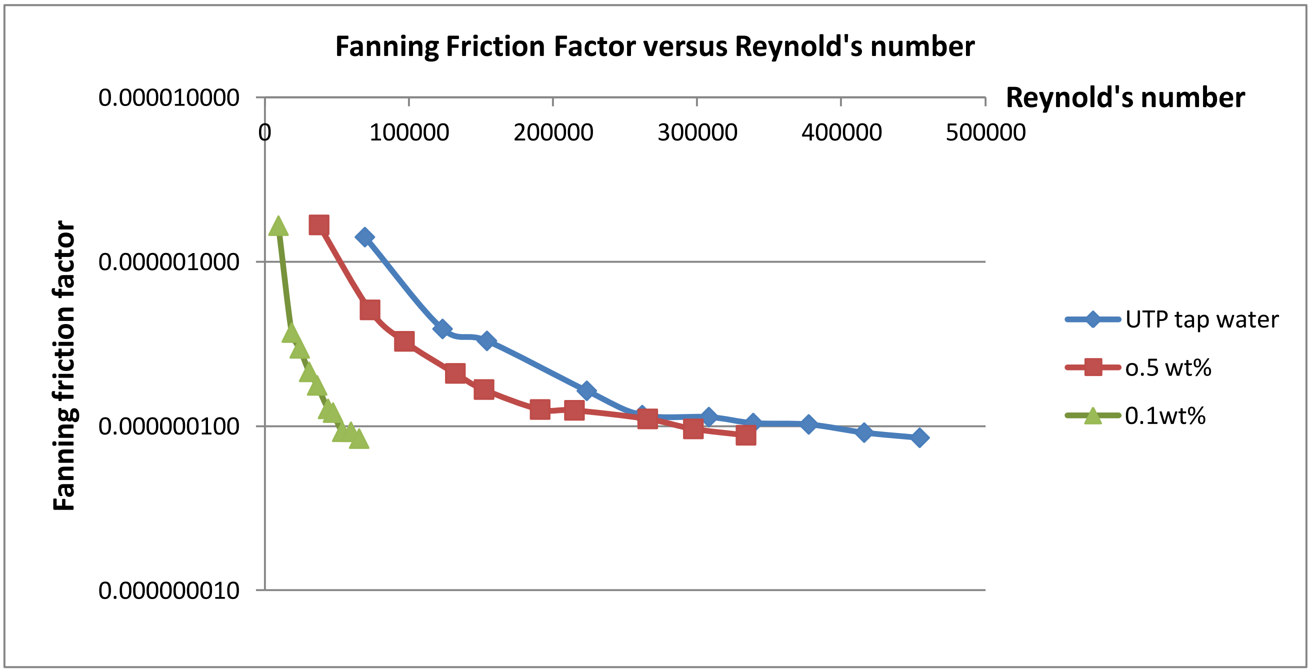


Figure 19: fanning friction factor versus Reynold's number for 3 solutions

Graph of fanning friction factor versus Reynold's number is plotted for all the three solutions. From the graph above it showed that friction factor decrease as the Reynold's number increase. At constant Reynold's number friction factor decrease as xanthan concentration increase. At constant pumping operation, it is observe that the flow become less turbulent as we added xanthan gum. The flow becomes less turbulent as we increase the polymer concentration.

4.1.1.5 Drag reduction versus flow rate

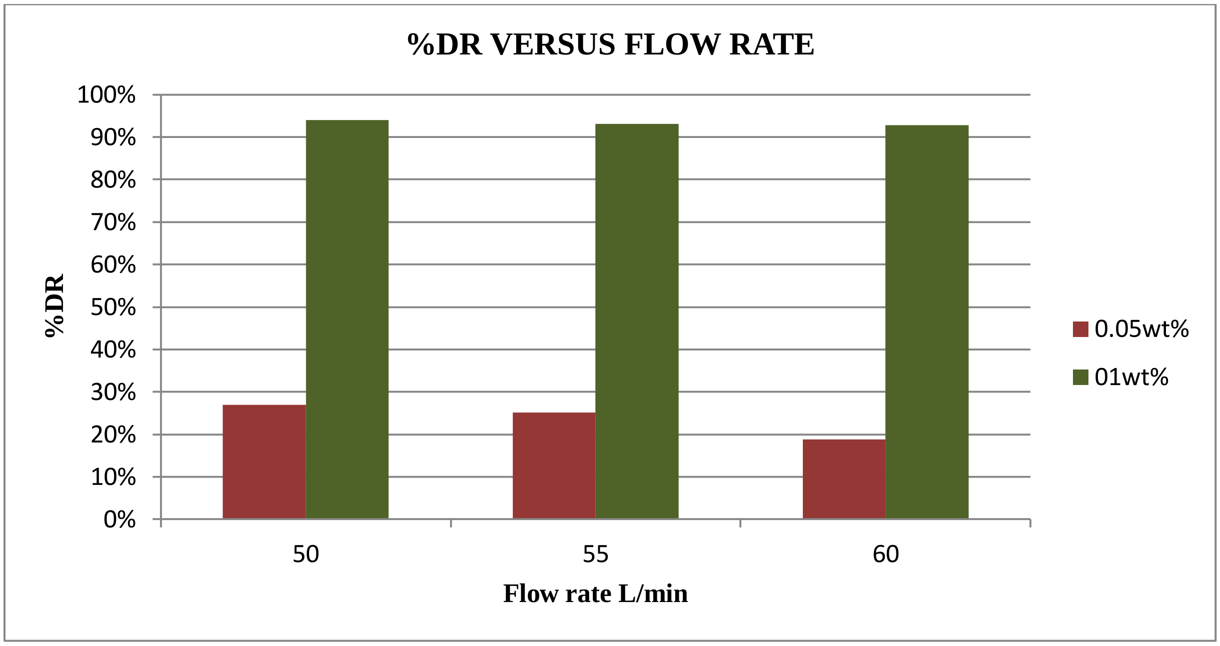


Figure 20: %DR for 0.05wt% XG and 0.1wt% XG

From the graph above, for 0.05wt% solution the percentage in drag reduction is within the range of 20%-30% while 0.1wt% solution shown a percentage in drag reduction within the range of 90% - 95%. This proves that percentage of drag reduction increase with increasing in flow polymer concentration.

4.1.1.6 Drag reduction study on xanthan-oil solution

The flaw in the design of the flow loop make it almost impossible to ensure the system is free from any water since some of the water might trap at the critical fitting and inside the pump itself. Oil has low density compare to water and our first observation shows that it is not mix with water. The idea to remove the rest amount of water is by adding 40 liter of cooking oil to the tank and the solution of oil-water is left to flow inside the flow loop. Water can be removed from the tank once it is settle down inside the tank.

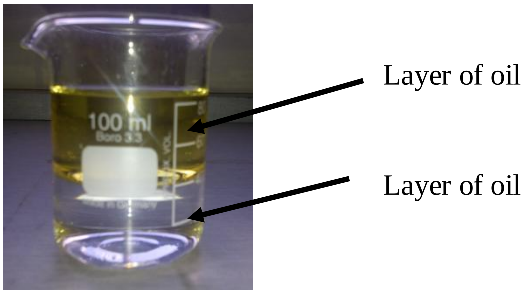
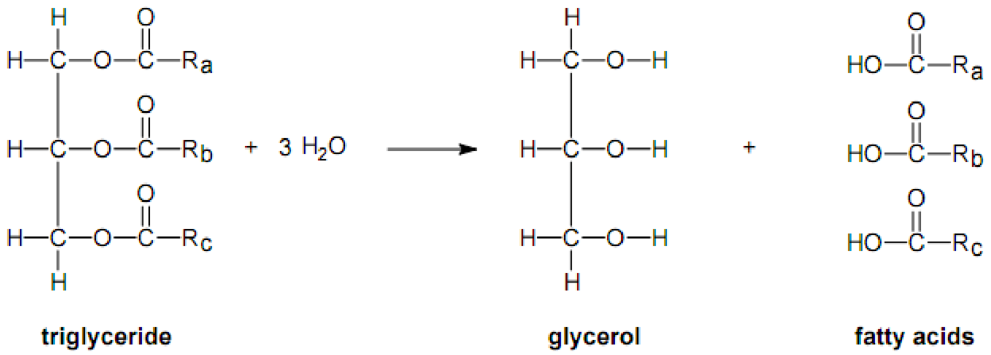


Figure 21: solution of oil and water

From our observation, it is found that the 2 fluid systems is subjected to the shear force exerted by the pump enough to cause the molecular structure of cooking oil to breakdown and form a new mixture and started to clog the flow loop.

Figure 22: mixture of glycerol and fatty acid

From our deep research it is found that, molecular structure of oil contains three ester functional groups called triglycerides. Triglycerides consist of double bond and it has tendency to react with other substance. The reaction between oil and water produced glycerol and fatty acid.



Due to limited amount of material, the study of drag reduction in xanthan-oil solution needs to be abandoned.

4.1.2 Data collection for 2nd experiment

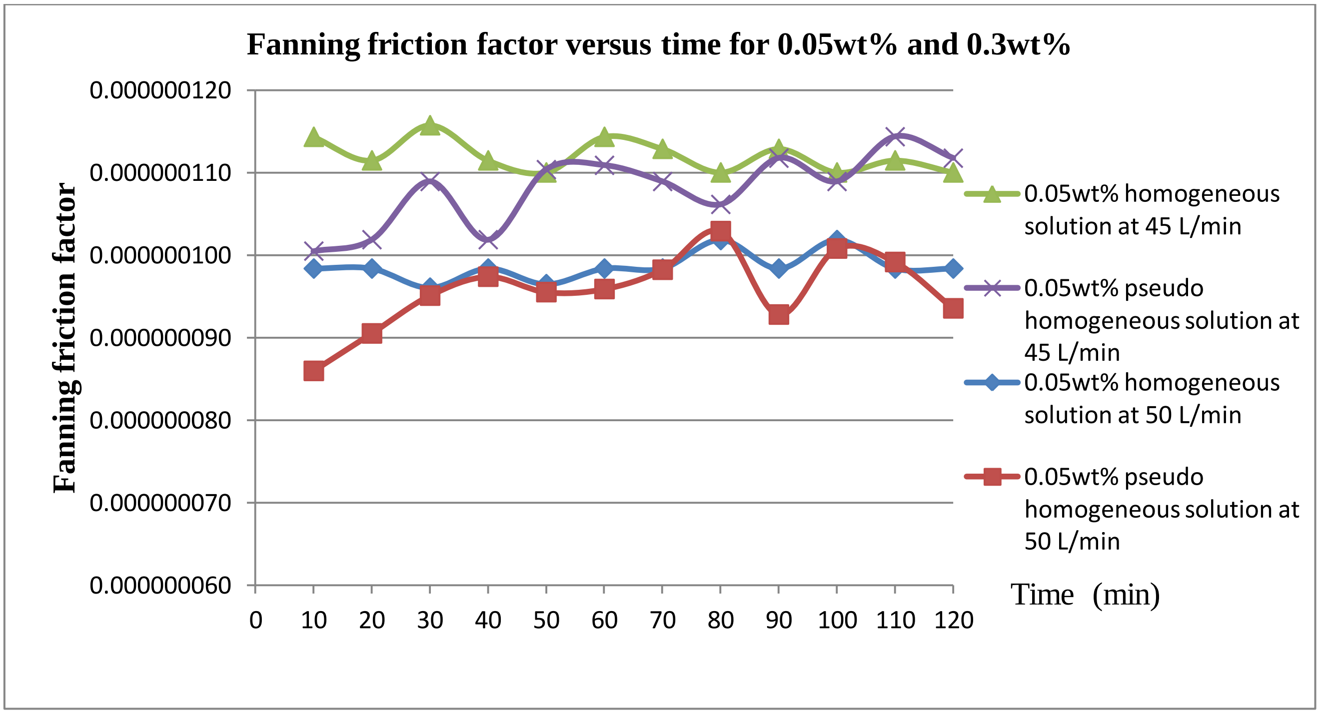


Figure 23: graph of fanning friction factor versus time

From the results, it is found that homogeneous solution shows a constant value of Fanning friction factor over time. The constant performance indicate that xanthan gum possess a good resistance to mechanical degradation. It is also observed that, in the early of the experiment, pseudo homogeneous solutions give a lower value of fanning friction factor compare to the homogeneous solution at corresponding pump operation.

Pseudo homogeneous solution is subjected to the shearing force exerted by pump and over time the distance of the polymer chain network will grow larger until it reaches the same distance as polymer chain in homogeneous solution. This low value of fanning friction factor will increase until it reaches almost the same value of fanning friction factor for 0.05wt% homogeneous solution.

From the graph, in pumping operation of 20 Hz, it took about 50 minutes for the fanning friction factor in pseudo homogeneous solution to reach the same value as homogeneous solution and it took approximately 30 minutes for the fanning friction factor in pseudo homogeneous solution to reach the same value as homogeneous solution in pumping operation of 23 Hz. As the pumping speed increase, the distance between the polymer chains grows larger at higher rate until it reaches equilibrium state.

CHAPTER 5

CONCLUSION & RECOMMENDATION

The data present here confirm that biopolymer, in our case xanthan gum, are effective as drag reduction agents. Increasing in percentage of drag reduction as polymer concentration increase shows that drag reduction effectiveness increase with concentration. The fluctuation of turbulent which is also known as eddies is surpassed as xanthan gum is introduced throughout the flow. This can be seen by comparing the value of Reynold's number at each pump speed. At constant pumping speed, the value of Reynold number decreasing as polymer concentration increase.

This study also highlights the role of polymer chain network degree of drag reduction. The drag reduction effectiveness of xanthan gum can be significantly improved over the homogeneous case if the experiment is done pseudo homogeneous. Polymer chain network are different in 2 set of solutions even though they have similar final concentration of 0.05wt%. In 0.05wt% homogeneous solution that is prepared by adding 20g of xanthan gum into 40 liter of water, the distance between the polymers chains are said to be equal in distance between each other. The distance is slightly far and equally distributed inside the water in comparison with 0.05wt% solution that is prepared by diluting concentrated solution of 0.3wt%.

In concentrated polymer solution of 0.3wt%, the individual polymer chain is entangled with other polymer chain. Simply diluting the solution by adding more water to produce solution with concentration of 0.05wt% may not allow all the polymer chain to become unentangled and free from each other. For the future study, it is an interesting area to compare the similar effect of polymer concentration, Reynold's number and polymer chain network on fanning friction factor using flexible polymer.

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APPENDICES

Example of sample calculation for the case of 0.05wt% at pump frequency of 5 Hz.

Data measurement

Parameter	**Value**	**Unit**
Flow rate, Q	0.00015	Liter/min
Voltage	615.4	mV

Given the resistance value is constant which is 125 ohm

Current = $\frac{V}{I} = \frac{615.4\, mV}{125\, ohm} = 4.9232$ mA

Bulk velocity = $\frac{4Q}{\pi D^2} = \frac{4*0.00015}{3.142*0.003*0.003} = 21.21791$ m/s

Based on the value of voltage, pressure drop, Δp measurement is calculated using table given by the manufacturer using interpolation method

Input (kPa)	**Output (mA)**
0	4
0.8625	8
1.725	12
2.5875	16
3.45	20

From interpolation, the value of the pressure drop is measure to be

Pressure drop, Δp = 199.1106 Pa

Wall shear stress (Pa) = $\tau_w = \frac{\Delta p D}{4L} = \frac{199.1106*0.003}{4*0.4} = 0.37333$ Pa

Fanning friction factor, f = $\frac{2\tau_w}{\rho U_B^2} = \frac{2*0.3733}{985*21.21791^2} = 0.000001684$

From rheology study, graph of wall shear stress versus shear rate and graph of viscosity versus shear rate are plotted as follow:

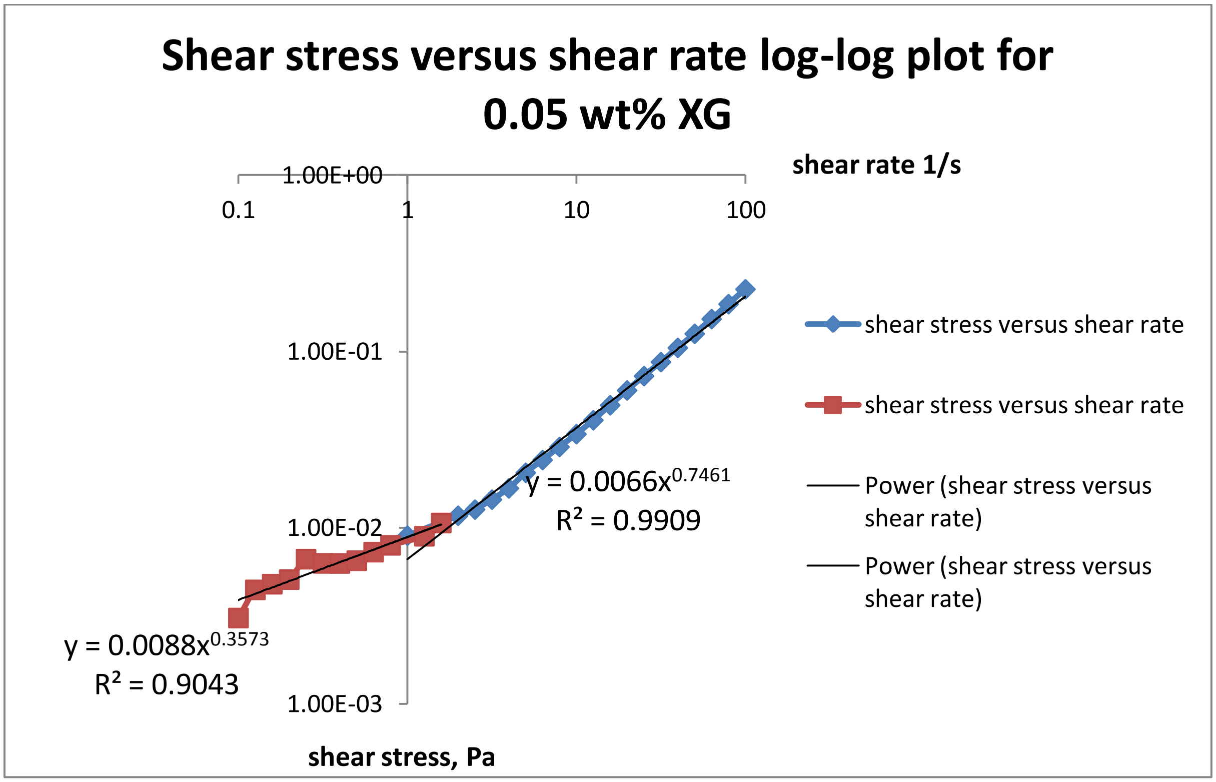


Figure 12: Shear stress versus shear rate log-log plot for 0.05 wt% XG

From the graph above, the line can be represent using the equation $y = 0.0066x^{0.7461}$ since the value of R^2 is closest to 1 and the shear rate measurement can be find using same equation by finding the value for x.

Shear rate, 1/s = 223.3316 1/s

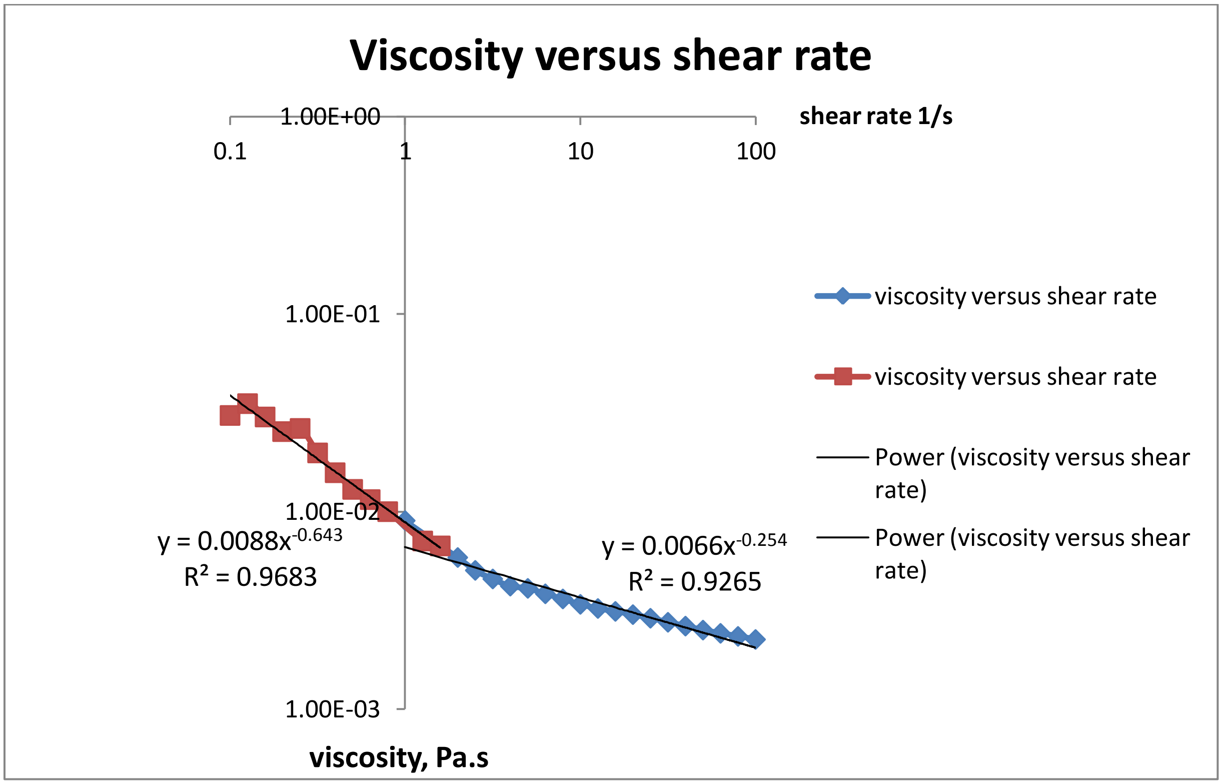


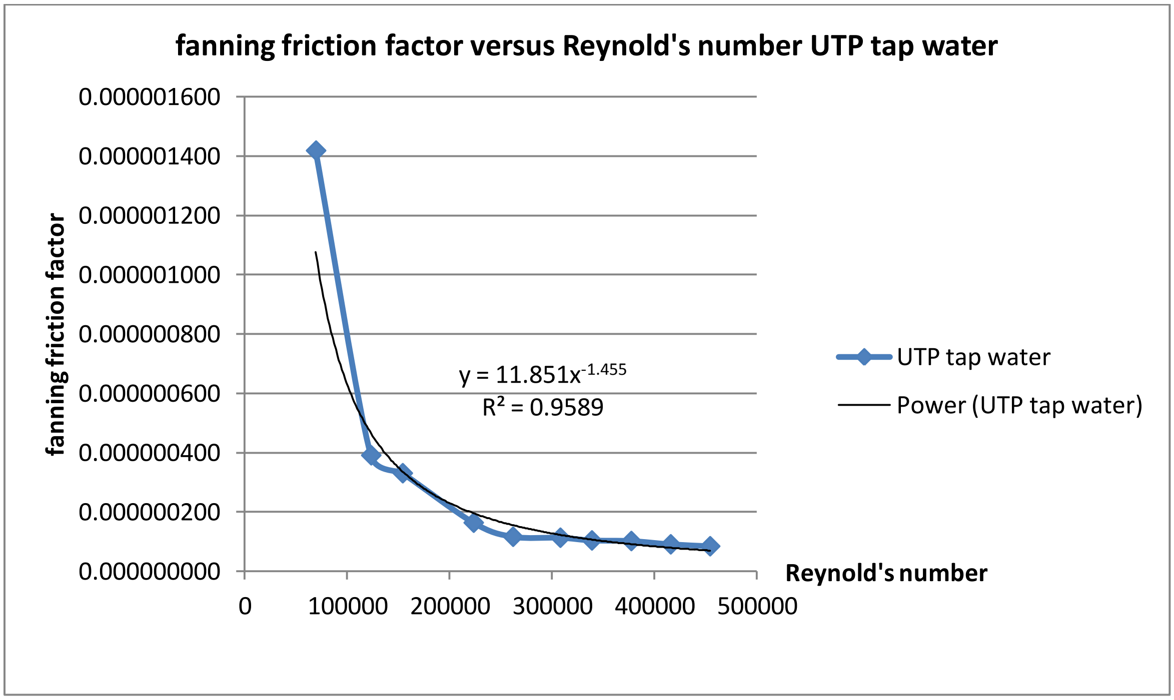
Figure 13: Viscosity versus shear rate for 0.05wt% XG

The graph of viscosity versus shear rate above can be represent using the equation $y = 0.0066x^{-0.254}$ since the value of R^2 is closest to 1 and the viscosity measurement at corresponding shear rate can be find using same equation by finding the value for y.

Viscosity, Pa.s = 0.001670747 Pa.s

Reynold number, $\mathrm{Re} = \frac{\rho U_B D}{\mu} = \frac{985*21.21791*0.003}{0.001670747} = 37527$

From rheology study, graph of fanning friction factor versus Reynold's number are plotted as follow:



From the graph above, the line can be represent by this equation

y = $11.851x^{-1.455}$

Equivalent value of fanning friction factor for UTP tap water is measure as follow using equation above

Faning friction factor, f = $11.851*37527^{-1.455}$ = 0.000002619

Drag reduction percentage, %DR = $\left[\frac{f_N - f_P}{f_N}\right] x\ 100 = \left(\frac{0.000002619 - 0.000001684}{0.000002619}\right) * 100 = 36\%$