Effects of Additives on the Performance of Drag Reduction Agents

by

Chen Ming Hui

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

MAY 2012

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CERTIFICATION OF APPROVAL

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Mechanical Engineering Programme

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BACHELOR OF ENGINEERING (Hons)

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Approved by,

____

(Dr Azuraien Binti Japper @ Jaafar)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK.

May 2012

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 expect 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.

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(CHEN MING HUI)

ABSTRACT

Friction that occurs in the pipeline causes pressure drop and the decrease in flow rate of the fluid. This happens when a moving fluid completely stops at the pipe surface and assumed to experience zero velocity in relative to the pipe surface in a stationary pipeline. Fluid which contacts directly with the pipe “sticks” to the pipe surface because of the viscous effects. The adjacent fluid layer is being slowed down by the layer that sticks to the surface due to the viscous forces between the fluid layers. The additions of Drag Reduction Agents (DRA) are being used worldwide to overcome this problem. This study is intended to explore and compare the compatibility of additives which were added into the commercial DRA in different concentrations using the AR-G2 Double Concentric Cylinder (DCC) rheometer from TA Instruments. This study is important as power resources is one of the major concerns in the modern industrial development. Turbulent mode of liquid transported through pipelines often caused pumping power losses which is not economical. The flow rate of the liquid in the pipeline can be increased with the use of DRA without changing the mechanical parts of the process such as the size of the pipeline, the speed of the pump etc. Torque, which is one of the rheometer operating variables, has been measured experimentally on working fluids with the increase of angular velocity. The performance of DRA is directly linked to the magnitude of the drag reduction percentage (%DR) by utilizing the torque measured from the rheometer. This new method of evaluating the performance of DRA showed great potential in replacing the current flow loop study method with the small amount of sample required (~10 ml), large testing temperature range up to 200°C and pressure cell testing facility up to 2000 psi besides its rapidity. Experimental results showed that the presence of additives such as Xanthan gum and filtration control agent in water soluble DRA does not help in the performance of DRA. However, Pour Point Depressants (PPD) showed great compatibility with the oil soluble DRA where great effects of drag reduction was observed compared to the DRA alone.

ACKNOWLEDGEMENT

The last two semesters of my final year at Universiti Teknologi PETRONAS has taught me priceless skills and meaningful experiences in the process of completing my final year project. I could have not survived this journey alone without the kind help from all of those who directly or indirectly supported me from the very beginning.

I wish to acknowledge the many individuals that have helped and guided me in completing this project. First and foremost would be my supervisor, Dr Azuraien, whom has first, accepted me as her final year project student, and guided me continuously on my research project which related to drag reduction throughout these two semesters.

I would like to extend my gratitude towards my co-supervisor, Puan Mazuin for the dedication of her time and effort, relentlessly teaching and guiding throughout this period.

Also, I would like to acknowledge Mr Bertrand from Scomi Anticor, France for providing samples of chemicals and the continuous information input. Appreciation is extended to Mr Hazri Shahpin, personnel from TA Instruments, Jaspreet Kaur and Harvin Kaur for their technical assistance. Lastly, many thanks to my family back home for their sacrifices coupled with their continuous encouragement and support.

I hope all the things that I learned from this project will be useful in my education and life in the future at large. The little details of every moment in completing this final year project will surely be treasured wholeheartedly.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

The study of drag reduction has been carried out since the late 1940s by B. A. Toms. The phenomenon of drag reduction is commonly referred as "Toms phenomenon" as Toms was the first person to observe the phenomenon in his investigation of mechanical degradation in pipe flow using high polymer solutions. Toms found out that the same flow rate can be obtained with a lower pressure gradient from the mixture of polymethyl methacrylate in monochlorobenzene compared to the solvent itself.

In general, additives can be categorized into three groups: surfactants, fibers and polymers (Mowla & Naderi, 2005). Surfactants function by reducing the liquid surface tension while fibers which are long cylinder-like objects with high length to width ratio function by orienting in the major directions of fluid flow to experience drag reduction. Long chain polymers are also capable as drag reduction agents by reducing friction between a flowing fluid and a solid surface (Darbouret et. al., 2009). Reduction over 70% of friction is possible with only a few parts per million of polymer in solutions. Molecular weights, shear degradation resistance and solubility in pipeline fluid are main factors that influence the performance of the polymers (Mowla & Naderi, 2005; Darbouret et. al., 2009; Nelson, 2003)

Polymers can be subdivided into flexible polymer and rigid polymer. The difference between these polymers is the condition prior to shearing. Flexible polymer can be viewed as being in a randomly coiled configuration which requires some minimal value of shear rate to stretch the molecules while a rigid polymer is already stretched in a rod-like conformation. High molecular weights of flexible polymers tend to experience mechanical degradation while rigid polymers have more resistant to mechanical degradation. Rigid polymers are also biopolymers which can be derived through biological fermentation (Jaafar et. al., 2009).

There is still no fully accepted theory behind the drag reduction due to the complexity of physics, chemistry, rheology and hydrodynamic (Bari et. al., 2010). The disordered turbulent flow condition that drag reduction agents function in, where liquids move randomly in non-predictive manner and the absence of an accurate and comprehensive technique to establish a clear mapping of turbulence inside the pipe cause the scattered voids in the theory of drag reduction phenomena.

1.2 Problem Statement

Friction that occurs in the pipeline causes pressure drop and the decrease in flow rate of the fluid. This happens when a moving fluid completely stops at the pipe surface and assumed to experience zero velocity in relative to the pipe surface in a stationary pipeline. Fluid which contacts directly with the pipe "sticks" to the pipe surface because of the viscous effects. The adjacent fluid layer is being slowed down by the layer that sticks to the surface due to the viscous forces between the fluid layers. The additions of DRA are being used worldwide to overcome this problem. This study is intended to explore and compare the compatibility of additives which is added into the commercial drag reduction agent in different concentrations using a DCC controlled stress rheometer. The two main questions for this study are:

- What is the performance of a commercial DRA?
- What is the compatibility of additives which are present together with the commercial DRA?

1.3 Objectives

This research was studied to achieve the following objectives:

1. To evaluate the performance of commercial DRA
2. To assess the compatibility of additives which in practice, are also added into the fluid in transport

1.4 Scope of study

The scope of study involves:

1. Carrying out experiment using AR-G2 DCC rheometer by adopting and improving the method by Henaut et. al. (2009) for drag reduction assessment
2. Assessing the drag reduction ability of commercial DRA in water and crude oil at different concentrations using method from the first scope of study.
3. Determining the effectiveness of commercial DRA in the presence of other additives

1.5 Feasibility of Project

The study of drag reduction is important as power resources is one of the major concerns in the modern industrial development. Turbulent mode of liquid transported through pipelines often caused the pumping power losses and it is not economical from a company's perspective especially in the oil industry. DRA comes in useful when it has high capability in reducing the energy consumption. This means that the flow rate of the liquid in the pipeline can be increased with the use of drag reduction agents without changing the mechanical parts of the process such as the size of the pipeline, the speed of the pump etc.

Since the turbulent friction factor of a fluid can be greatly reduced with the small amount of additives, e.g. a few parts per million (ppm), there are many literatures available regarding the study of drag reduction for different conditions in the oil and gas industry. Among those studies are the study of drag reduction in coiled tubing (Shah et. al., 2001), water injection wells (Nelson, 2003), seawater injection system (Al-Anazi et. al., 2006) and also two-phase flow of crude oil and air in horizontal pipes (Mowla & Naderi, 2005).

Although many literature surveys on the study of drag reduction are available, there are only a few attempts that have been made to study the effect of additives on the performance of DRA. Besides that, most experiments on drag reduction performance are carried out using flow loop which consumes a lot of time and money. This study will be carried out using the AR-G2 DCC rheometer, which will certainly bring significant values to the drag reduction study due to its simplicity, rapidity, small sample volume required and large temperature range to be tested.

CHAPTER 2

LITERATURE REVIEW

2.1 Drag Reduction

Drag reduction is a phenomenon where turbulent friction of a fluid can be greatly reduced (over 70%) with the addition of small amount of additives (e.g a few parts per million) (Darbouret et. al., 2009). The main purpose of using drag reduction is to reduce energy consumption by using active agent known as DRA without changing the mechanical parts of the process such as size of pumps, pipes and fittings.

Virk (1975) published one of the most extensive review papers on drag reduction. The research paper covers wide areas of drag reduction studies including mechanisms of drag reduction, gross flow, turbulence structure and mean velocity profile. Virk (1975) proposed the concept of drag reduction envelope and maximum drag reduction asymptote. The Prandtl-Karman law for Newtonian turbulent flow and the maximum drag reduction asymptote were the two universal asymptotes which the drag reduction envelope was bounded within. The drag reduction envelope by Virk can be defined from the following laws:

Poiseuille's Law for laminar flow

$$\frac{1}{\sqrt{f}} = \frac{N_{Re\,s} f^{1/2}}{16} \qquad [1]$$

It is assumed that in laminar flow, dilute polymer solutions obey Poiseuille's law.

Prandtl-Karman Law

$$\frac{1}{\sqrt{f}} = 4.0\ log_{10}\ N_{Re\,s} f^{1/2} - 0.4 \qquad [2]$$

This law is applicable for Newtonian turbulent flow.

Maximum Drag Reduction Asymptote (Virk's Law)

$$\frac{1}{\sqrt{f}} = 19.0\ log_{10}\ N_{Re\ s} f^{1/2} - 32.4 \qquad [3]$$

Virk (1975) pointed out that the maximum drag reduction is not sensitive to molecular weight, polymer species and concentration. Therefore, the maximum drag asymptote and the Prandtl-Karman law define the best case of drag reduction and the zero drag case respectively. Polymeric regime is the regime between the maximum drag asymptote and the Prandtl-Karman law, in which the friction factor relations are approximately linear and can be characterized by two parameter, which are the slope increment (δ) and the wall shear stress at the onset of drag reduction (${\tau_w}^*$):

$$\frac{1}{\sqrt{f}} = (4.0 + \delta) log_{10}\ N_{Re\ s} f^{\frac{1}{2}} - 0.4 - \delta\ log_{10}\left[\frac{\sqrt{2}d}{v_s}\left(\frac{{\tau_w}^*}{\rho}\right)^{1/2}\right] \qquad [4]$$

2.2 Drag Reduction Quantification

There are several ways of quantifying the degree of drag reduction. Jaafar (2009) evaluates drag reduction by calculating the friction factor of water and the friction factor of the polymer solution at same Reynolds number such as below:

$$\%\ DR = \left[\frac{f_N - f_P}{f_N}\right] \times 100 \qquad [5]$$

where the subscripts N and P refer to the Newtonian fluid and the polymer solution respectively. Jaafar (2009) states that there are other ways of quantifying drag reduction such as using the same Reynolds number based on the friction velocity. However, the differences of other methods used are small regardless of definition.

Al-Anazi et. al., (2006) show that there is a relationship between the percent flow increase (% FI) and the percent drag reduction. % FI can be assessed using the equation below:

$$\%\ FI = \left\{\left[\frac{100}{100 - \%\ DR}\right]^{0.556} - 1\right\} \times 100 \qquad [6]$$

Mowla & Naderi (2005) define drag reduction as the difference in pressure drop between treated fluid (containing DRA) and the untreated fluid (without DRA) using a flow loop:

$$\%DR = \frac{\Delta P_u - \Delta P_t}{\Delta P_u} \times 100 \qquad [7]$$

where:

ΔP_u: Pressure drop of untreated fluid (without DRA)

ΔP_t: Pressure drop of treated fluid (containing DRA)

Out of the researches cited, only Henaut et. al. (2009) utilizes a rheometer for the assessment of drag reduction. Research by Henaut et. al. (2009) was carried out using a controlled stress rheometer as a fast screening of DRA in order to decide on the most suitable DRA due to the low volume of fluid and short period of time required to run the test. The performance of DRA is directly linked to the magnitude of the drag reduction percentage:

$$\%DR = \frac{T_u - T_t}{T_u} \times 100 \qquad [8]$$

where:

T_u: Torque of untreated fluid (without DRA) using a rheometer

T_t: Torque of treated fluid (containing DRA) using a rheometer

However, the limitation with this method is that very high Reynolds numbers cannot be reached in rheometers. More researches are also required to quantitatively link rheometer and flow loop measurements due to the way turbulence develops in the particular rheometer geometry.

2.3 Drag Reduction Phenomenon

Researches done by Darbouret et. al., (2009), Henaut et. al. (2009) and Jaafar et. al. (2009) show that DRA functions well in two conditions, which are turbulent flow and non Newtonian fluid.

Figure 1 shows the experimental result carried out by Darbouret et. al. (2009) using water with concentric cylinder geometry on the rheometer. It shows that the torque varies linearly with the angular velocity in the primary laminar regime for angular velocities below 50 rad/s. As speed increases, Taylor instabilities tend to develop progressively and the dependence of the torque on the angular velocity becomes more complex.

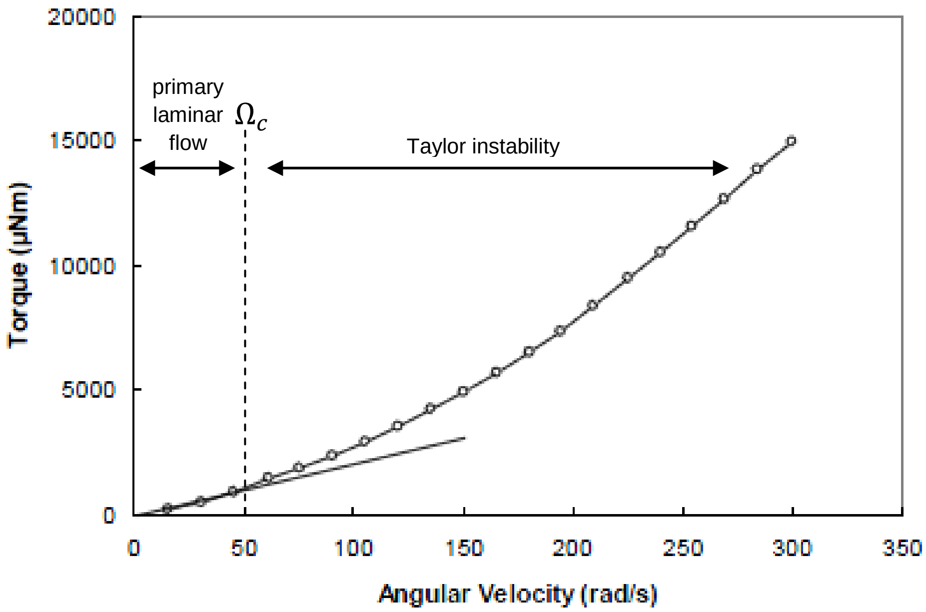


Figure 1: Laminar and turbulent regimes obtained with water on the rheometer of concentric cylinders geometry (Darbouret et. al., 2009)

The experiment was continued by Henaut et. al. (2009) to demonstrate that the effectiveness of drag reduction agents can be evaluated by comparing the flow curves of a treated solution to untreated solution. The result of the experiment (as shown in Figure 2) shows that there is no difference observed between the reactions of two solutions under laminar regime. However, significant reduction of torque in the rheometer and pressure drop in the flow loop can be observed in turbulent regime with the presence of DRA.

The result of experiment also shows that DRA 1 and DRA 3 work well in oil A (%DR=30%) whereas DRA 2 is not suitable (%DR=0%). DRA 2 was supposed not to function as it is made of a water soluble polymer which is designed for aqueous appliances.

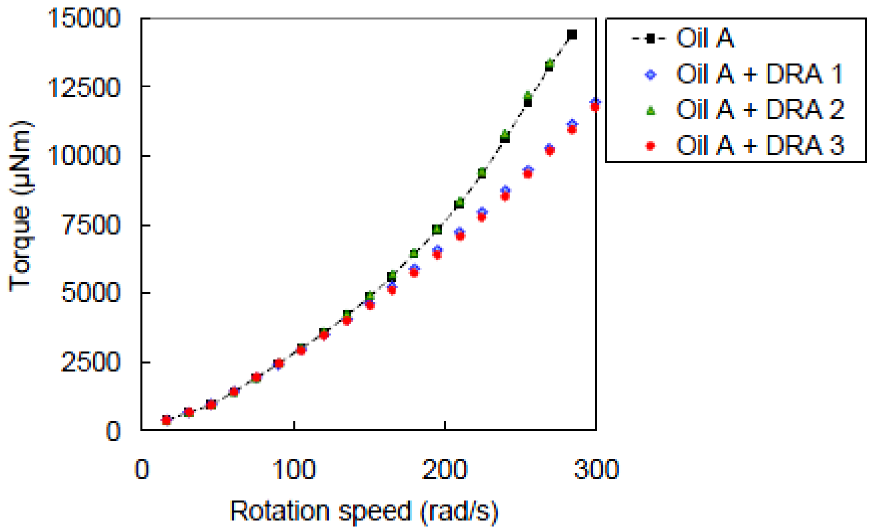


Figure 2: DRA screening with Oil A using rheometer with DRA concentration of 100 ppm (Henaut et.al, 2009)

Jaafar et. al. (2009) prove that drag reduction agents work well in non-Newtonian flow. It can be clearly seen in Figure 3 that the region where drag reduction agents work well is bounded by the drag reduction envelope, which are the Prandtl-Karman law for Newtonian turbulent flow and the maximum drag reduction asymptote by Virk (1975).

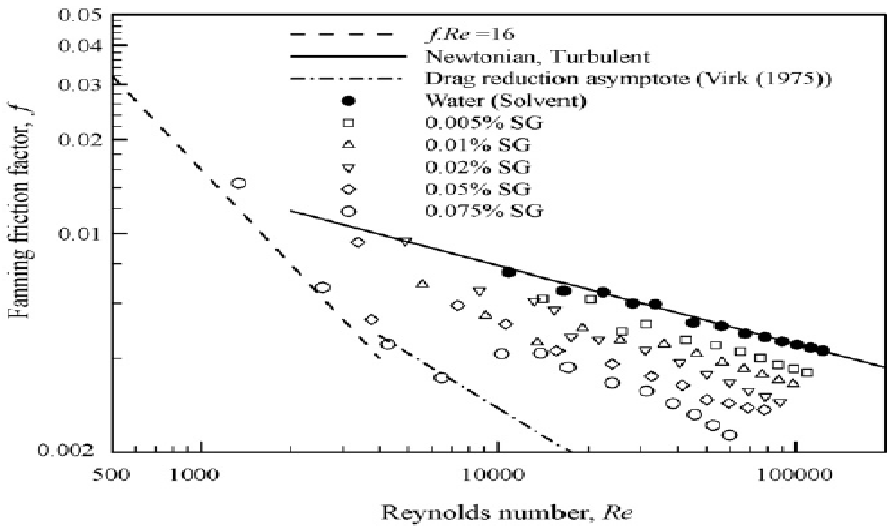


Figure 3: f-Re data for various Scleroglucan concentrations (Jaafar et. al., 2009)

2.4 Rheology

Jaafar (2009) states that the detailed fluid dynamics for non-Newtonian fluid flows is dependent on the rheology of the fluid, in addition to other well known factors such as the density and compressibility of the fluids and also the geometry within which the fluid flows. Rheology is the study of deformation and the flow of matter. The field of study is on the flow of materials that behave between the discipline of elasticity by Hooke's law for solid and the Newtonian fluid mechanics by the Newton's law for fluids, namely non-Newtonian.

In a Newtonian fluid, the relation between the shear stress and the shear rate is linear, passing through the origin. The constant of proportionality is the coefficient of viscosity. Non-Newtonian fluids are distinguished by how their apparent viscosity changes with shear rate (Munson et. al., 2010). Figure 4 shows the variation of shearing stress with rate of shearing strain for several types of fluids, including common non-Newtonian fluids.

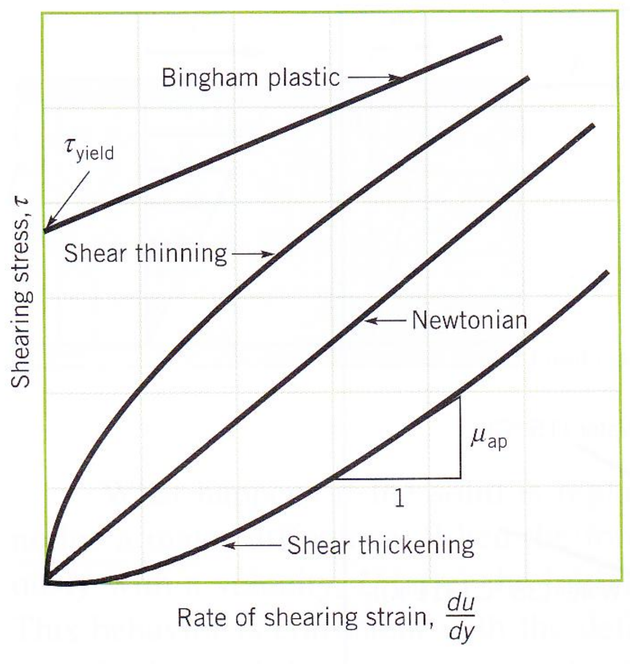


Figure 4: Variation of shearing stress with rate of shearing strain for several types of fluids, including common non-Newtonian fluids (Munson, et. al. 2010)

For shear thinning fluids the apparent viscosity decreases with increasing shear rate - the harder the fluid is sheared, the less viscous it becomes. Many colloidal suspensions and polymer solutions are shear thinning. For shear thickening fluids the apparent viscosity increases with increasing shear rate, where the harder the fluid is sheared, the more viscous it becomes. The other type of behavior indicated is the Bingham plastic, which is neither a fluid nor a solid. Once the yield stress is exceeded, it flows like a fluid.

The shear viscosity versus shear stress for various scleroglucan concentrations together with the Carreau-Yasuda fits in Figure 5 is one of the rheological measurement results conducted by Jaafar et. al. (2009). As can be seen from Figure 5, the shear viscosity, η shows an increased dependence on shear stress, τ. It can be seen that the stress at which the fluid started to experience shear-thinning behavior was delayed to higher stresses as the solution became more concentrated. This indicates higher molecular association as the solution concentration is increased hence requiring greater stress to break the molecular association or entanglement in the first Newtonian plateau to shift to the shear-thinning regime (Jaafar et. al., 2009).

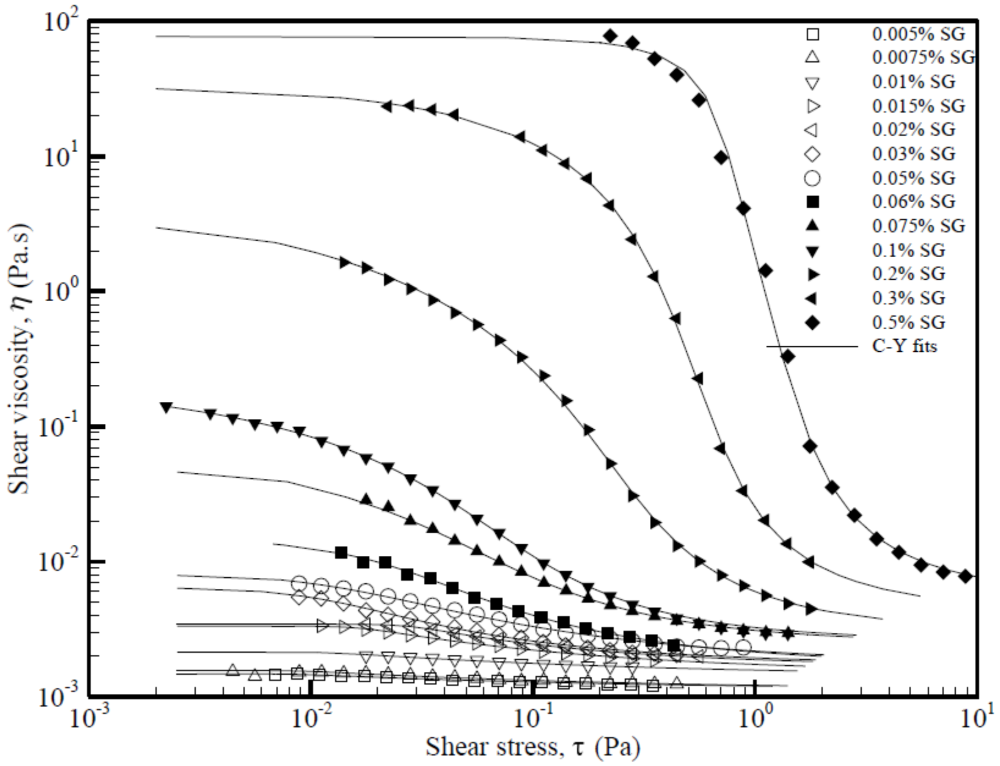


Figure 5: Shear viscosity versus shear stress for various scleroglucan concentrations together with the Carreau-Yasuda fits (Jaafar et. al., 2009)

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

Unlike other experiment set ups as discussed in most literatures, the AR-G2 DCC rheometer from TA Instruments is chosen as the experiment instrument for this research as precise data can be obtained and recorded. The small amount of sample required (~10 ml) and the large testing temperature range (0 - 200°C) are the main benefits of using this technology besides its rapidity. Flow loop, which is a common experiment set up for drag reduction study, is costly and time consuming.

Figure 6: Picture of AR-G2 Double Concentric Cylinder rheometer

3.2 AR-G2 Rheometer Layout

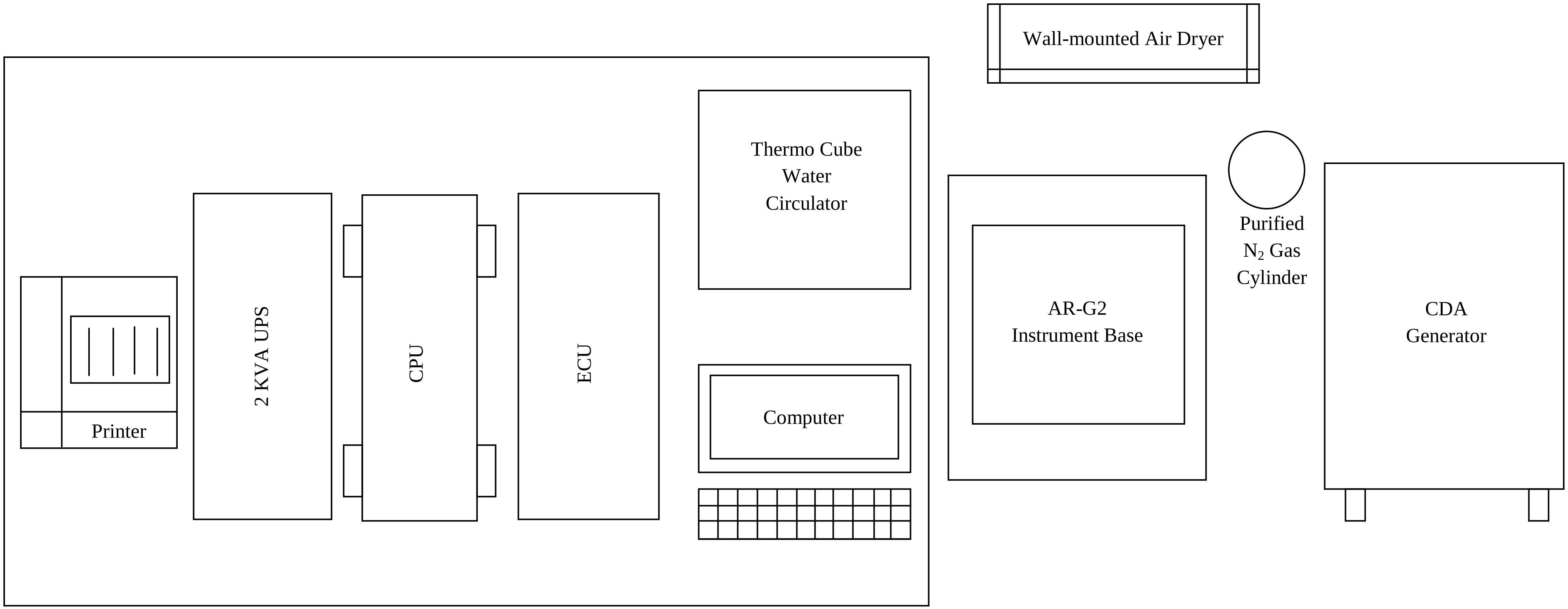


Figure 7: AR-G2 rheometer layout

3.3 Procedures on Running a Test on the Rheometer

To start:

1. Turn on the CDA generator (reading should be approximately 50 psi)
2. Turn on the air supply (reading should be approximately 30 psi)
3. Turn on the computer
4. Turn on the water circulator (water level should be sufficient)
5. Turn on the power to the instrument
6. Remove the black bearing lock and ensure that the spindle rotates freely once the lock is removed.
7. Start the instrument control software
8. Attach the test geometry (Double Concentric Cylinder)
9. Perform mapping
10. Perform zero gap
11. Calibrate geometry inertia
12. Set up procedure by selecting the appropriate file
13. Load the sample
14. Lower geometry to appropriate gap
15. Run the test

To stop / shutdown:

1. Raise geometry using the “up” button
2. Remove the geometry (Double Concentric Cylinder)
3. Clean the sample in the geometry
4. Turn off the instrument control software
5. Turn off the power to the instrument
6. Attach the black bearing lock
7. Turn off the water circulator
8. Turn off the computer
9. Turn off the air supply
10. Turn off the CDA generator

3.4 Double Concentric Cylinder

A double concentric cylinder is used to set in the rheometer for this study. The inner cylinder will be rotating while the outer one will be attached to the base of the rheometer.

Figure 8: Picture of Double Concentric Cylinder

Concentric cylinders type of geometry is suitable for fluid medium which is from very low to medium viscosity such as water. The figure below shows the suitable geometry for a rheometer based on the properties of the testing samples which varies from water to steel (left to right).

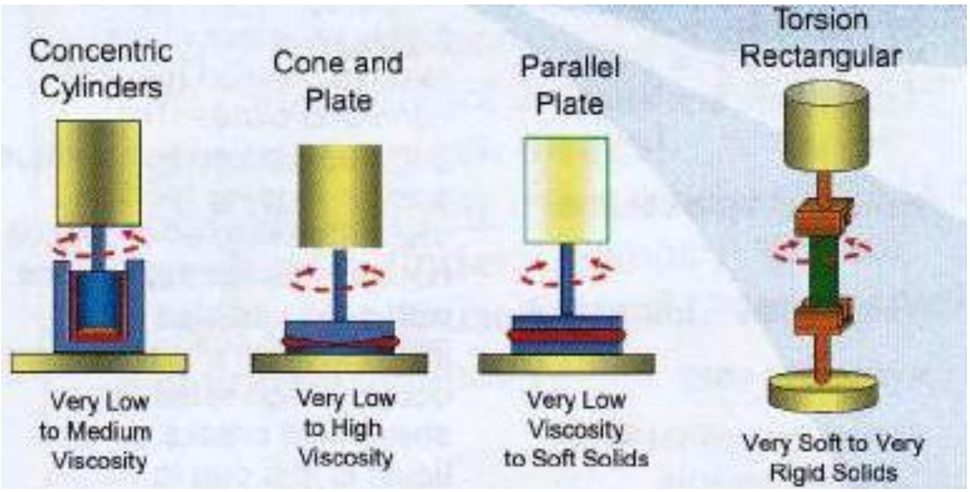


Figure 9: Types of geometries for a rheometer (Josh, 2011)

The geometry of a double concentric cylinder can be seen in the figure below, where:

R_1= 15.14 mm

R_2= 16.00 mm

R_3= 17.48 mm

R_4= 18.51 mm

H = 53.00 mm

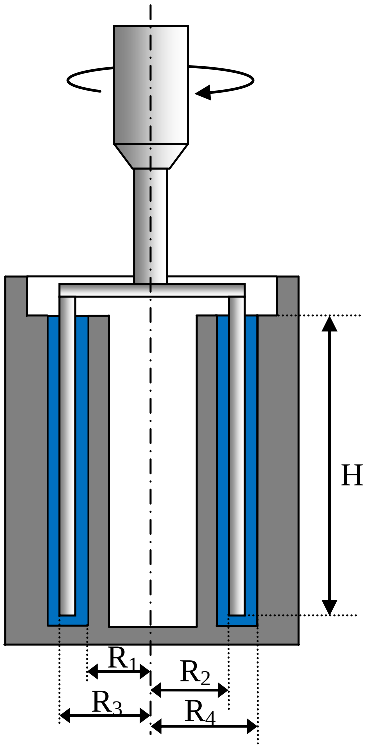


Figure 10: Double Concentric Cylinder geometry

The Reynolds number corresponding to this geometry, Re, is given by

$$Re = \frac{\Omega \rho R_m (\Delta R)}{\mu} \qquad [9]$$

where: Ω : Angular velocity (rad/s)

ρ : Fluid density (kg/m^3)

R_m: Radius of rotating cylinder of the rheometer (m), R_3

ΔR: Radius difference between the outer and inner cylinder (m), R_4-R_3

μ : Fluid viscosity (Pa.s)

Due to the centrifugal force, the flow fields developed in the two parts of the geometry is different. For the case of the outer cylinder rotating, the centrifugal force tends to stabilize the flow field. The flow field of a Newtonian liquid becomes unstable when the dimensionless Reynolds is higher than about 50000 (Darbouret et. al., 2009).

For the case of the inner cylinder rotating, the centrifugal force contributes to a destabilization of the flow field. For a Newtonian liquid, the point at which the streamlines cease to be circular and at which the flow field presents Taylor instabilities has been found by Chhabra & Richardson (1999) to take place for a critical Reynolds number defined by:

$$Re_c = \frac{\Omega \rho R_m (\Delta R)}{\mu} > 58.3 \left(\frac{R_m}{\Delta R}\right)^{0.5} \qquad [10]$$

where:

$R_m = R_3$

$\Delta R = R_4 - R_3$

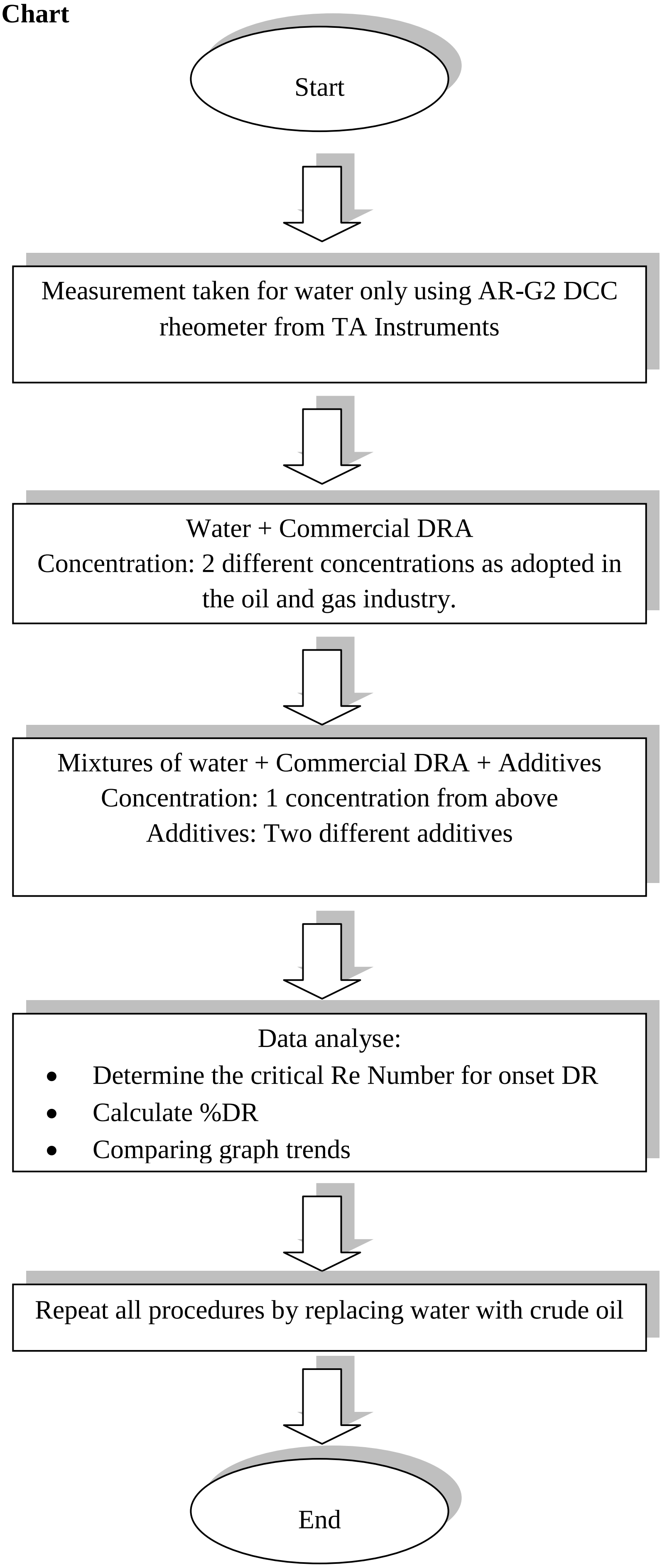
According to Chhabra & Richardson (1999), secondary flows are of particular concern in the controlled stress instruments which usually employ a rotating inner cylinder, in which case inertial forces cause a small axisymmetric cellular secondary motion (‘Taylor’ vortices). The stability criterion for a Newtonian fluid in a narrow gap is

$$T_a = \frac{\rho^2 \Omega^2 (R_2 - R_1)^3 R_1}{\mu^2} < 3400 \qquad [11]$$

where T_a is the ‘Taylor’ number. This corresponds to the Reynolds number of 240 for the set-up used in this study.

The relationship between ‘Taylor’ number and Reynolds number is derived and attached in the appendix for reference.

3.5 Flow Chart



3.6 Gantt Chart

Project Title: EFFECTS OF ADDITIVES ON THE PERFORMANCE OF DRAG REDUCTION AGENTS															
Project Tasks	**Final Year Project I**														
	Jan		*Feb*				*Mar*				*Apr*				*May*
	W1	*W2*	*W3*	*W4*	*W5*	*W6*	*W7*	*W8*	*W9*	*W10*	*W11*	*W12*	*W13*	*W14*	*W15*
Project Title Selection	■	■													
Preliminary Research Work															
Literature Review Research Methodology Drag Reduction Agents Rheology Water Based Solution Oil Based Solution Newtonian Fluids Non-Newtonian Fluids		■	■	■	■										
Extended Proposal Defence						▲									
Familiarization phase															
Commercial DRA contents -Methods to explore the contents?						■	■	■							
AR-G2 Rheometer Double concentric cylinder (DCC) measurements						■	■	■							
Experimental Phase															
Water measurements using DCC							■	■							
Oil measurements using DCC								■	■						
Water Based Solution															
• Water + Commercial DRA – DRA concentrations : 2 different concentrations as adopted in the industry										■	■				
• Water + Commercial DRA + additives with different concentration DRA concentration : 1 concentration from above # of additives : 2 different additives to be identified												■	■	■	
Analysis phase															
Data analysis - Determine the critical Re Number for onset DR - % DR - Comparison of graph trends							■	■	■	■	■	■	■	■	■
Presentation phase															
Report writing		■	■	■	■	■	■	■	■	■	■	■	■	■	■
Proposal Defense								▲							
Interim Draft Report													▲		
Interim Report														▲	

Project Title: EFFECTS OF ADDITIVES ON THE PERFORMANCE OF DRAG REDUCTION AGENTS															
Project Tasks	**Final Year Project II**														
	May		*June*				*July*					*Aug*			
	W1	*W2*	*W3*	*W4*	*W5*	*W6*	*W7*	*W8*	*W9*	*W10*	*W11*	*W12*	*W13*	*W14*	*W15*
Continuation work of FYP 1	■	■													
Rheology Study															
Oil Based Solution															
• Oil + Commercial DRA with different concentration DRA concentrations : 2 different concentrations as adopted in the industry			■	■											
• Oil + Commercial DRA + additives with different concentration DRA concentration : 1 concentration from above # of additives : 2 different additives to be identified					■	■	■								
Analysis phase															
Data analysis - Relating torque to pressure - % DR - Comparison of graph trends	■	■	■	■	■	■	■	■	■	■					
Presentation phase		■	■	■	■	■	■	■	■	■	■	■	■	■	■
Report writing	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Progress Report Submission								▲							
Pre-EDX preparation									■	■	■				
Pre-EDX											▲				
Draft Report Submission												▲			
Dissertation Submission													▲		
Technical Paper Submission													▲		
Oral Presentation														▲	
Project Dissertation Submission (Hard Bound)															▲

3.7 Test Matrix

Table 1: Test Matrix for Water

Fluids		Concentration	Method	Duration	Run(s)
Water (To assess the effects of inertia)			Apparatus: Double Concentric Cylinder (DCC) rheometer Temperature: 25°C Angular Velocity: 0 – 300 rad/s Parameters required: Torque, shear stress, shear rate, viscosity	1 Day	3
Water + DR 700 (Commercial DRA)		Concentration: 50 ppm	Apparatus: DCC rheometer, Beaker, Overhead stirrer, Electronic Weight Scale, Micropipette Temperature: 25°C Angular Velocity: 0 – 300 rad/s Parameters required: torque, Shear stress, shear rate, viscosity	1 Week	3
		Concentration: 100 ppm	Apparatus: DCC rheometer, Beaker, Overhead stirrer, Electronic Weight Scale, Micropipette Temperature: 25°C Angular Velocity: 0 – 300 rad/s Parameters required: Torque, shear stress, shear rate, viscosity	1 Week	3
Water + DR 700 + Additive	Additive 1: Hydro-Zan (Xanthan gum)	Concentration: 100 ppm	Apparatus: DCC rheometer, Beaker, Overhead stirrer, Electronic Weight Scale, Micropipette Temperature: 25°C Angular Velocity: 0 – 300 rad/s Parameters required: Torque, shear stress, shear rate, viscosity	1 Week	3
	Additive 2: Hydro-Star	Concentration: 100 ppm	Apparatus: DCC rheometer, Beaker, Overhead stirrer, Electronic Weight Scale, Micropipette Temperature: 25°C Angular Velocity: 0 – 300 rad/s Parameters required: Torque, shear stress, shear rate, viscosity	1 Week	3

<u>Note:</u>

1. 2 concentrations will be tested on water + DR 700 to ease the comparison on results. Both concentrations used are within the range of concentrations provided by Mr. Bertrand, R&D and lab manager of Scomi Anticor, France.
2. The concentration of water + DR 700 + Additive is subject to change. The concentration will be decided after knowing the performance of DR 700 in both concentrations.

Table 2: Test Matrix for Crude Oil

Fluids		Method		Duration	Run(s)
Crude Oil (Baseline for evaluating performance of DRA)		Apparatus: Double Concentric Cylinder (DCC) rheometer Temperature: 25°C Angular Velocity: 0 – 300 rad/s Parameters required: Torque, Shear stress, shear rate, viscosity		1 Day	3
Crude Oil + DR 742 (Commercial DRA)		Concentration: 25 ppm	Apparatus: DCC rheometer, Beaker, Overhead stirrer, Electronic Weight Scale, Micropipette Temperature: 25°C Angular Velocity: 0 – 300 rad/s Parameters required: Torque, Shear stress, shear rate, viscosity	1 Week	3
		Concentration: 50 ppm	Apparatus: DCC rheometer, Beaker, Overhead stirrer, Electronic Weight Scale, Micropipette Temperature: 25°C Angular Velocity: 0 – 300 rad/s Parameters required: Torque, Shear stress, shear rate, viscosity	1 Week	3
Crude Oil + DR 742 + Additive	Additive 1: Pour Point Depressants (PPD)	Concentration: 50 ppm	Apparatus: DCC rheometer, Beaker, Overhead stirrer, Electronic Weight Scale, Micropipette Temperature: 25°C Angular Velocity: 0 – 300 rad/s Parameters required: Torque, Shear stress, shear rate, viscosity	1 Week	3
	Additive 2: Demulsifiers	Concentration: 50 ppm	Apparatus: DCC rheometer, Beaker, Overhead stirrer, Electronic Weight Scale, Micropipette Temperature: 25°C Angular Velocity: 0 – 300 rad/s Parameters required: Torque, Shear stress, shear rate, viscosity	1 Week	3

Note:
1. 2 concentrations will be tested on crude oil + DR 742 to ease the comparison on results. Both concentrations used are within the range of concentrations provided by Mr. Bertrand, R&D and lab manager of Scomi Anticor, France.
2. The concentration of Crude oil + DR 742 + Additive is subject to change. The concentration will be decided after knowing the performance of DR 742 in both concentrations.

3.8 Working Fluids

2 commercial DRAs were utilized in this study; a water soluble DRA (DR 700) and an oil soluble DRA (DR 742). Both commercial DRAs were supplied by Scomi Anticor, France. DR 700 has the physical state of opaque liquid and its density at 20°C is 1050 kg/m^3 with the tolerance of ±20 kg/m^3. It is soluble in water and its viscosity is reported to be 1200 cps at 20°C by the supplier. It reduces friction in pipes and allows transporting more fluids with the same equipment. The three main applications of this product in the oil and gas industry are increasing water flow rate into injection wells, reducing operating costs in water injection facilities and increasing flow rate in oil pipelines having more than 10% water cut. In industry application, this product is injected continuously after pumps from the range of 20 to 100 ppm. Drag reduction begins almost immediately and increases until all the fluids in the line contain drag reducer.

Sample of DR 742 was also obtained from Scomi Anticor. It has the physical state of white paste and its density at 20°C is 920 kg/m^3 with the tolerance of ±20 kg/m^3. This sample consists of very high molecular weight polymer. Same as DR 700, DR 742 reduces friction in pipes and allows transporting more fluids with the same equipment. It is injected in downstream pumps in a turbulent area to ensure immediate mixing because shear in upstream pumps will degrade the polymer and decrease substantially its performances. In industry application, DR 742 is injected continuously from the range of 5 to 50 ppm versus oil.

Figure 11: DR 700 and DR 742 from Scomi Anticor, France

Samples of Hydro-Zan were obtained from Scomi Oiltools. The common name for Hydro-Zan is Xanthan gum and its appearance is cream to tan powder. It is soluble in water and having the specific gravity of 1.5 to 1.7. Hydro-Zan is a high molecular weight biopolymer used for increasing the rheological parameters in water-based drilling fluids. Small quantities will provide excellent viscosity for suspending weighting material for all water-based drilling fluids systems. It has the unique ability to produce a fluid that is highly shear-thinning and develops a true gel structure. In the oil and gas industry, Hydro-Zan delivers optimum hydraulics with maximised rates of penetration. The low shear rate experienced in the annulus enables the fluid to have a high effective viscosity for adequately cleaning of the well and suspend cuttings.

Samples of filtration control agent (Hydro-Star) were obtained from Scomi Oiltools too. It is a non-fermenting pre gelatinised high-temperature starch used to control filtration in water based muds. It is a polysaccharide, appearing in powder form with the specific gravity of 1.4 to 1.6. It is designed to reduce fluid loss and increase viscosity in all water base muds for saturated salt and brine systems where other products are not effective. In the oil and gas industry, it provides wellbore stability through filtration control and encapsulation.

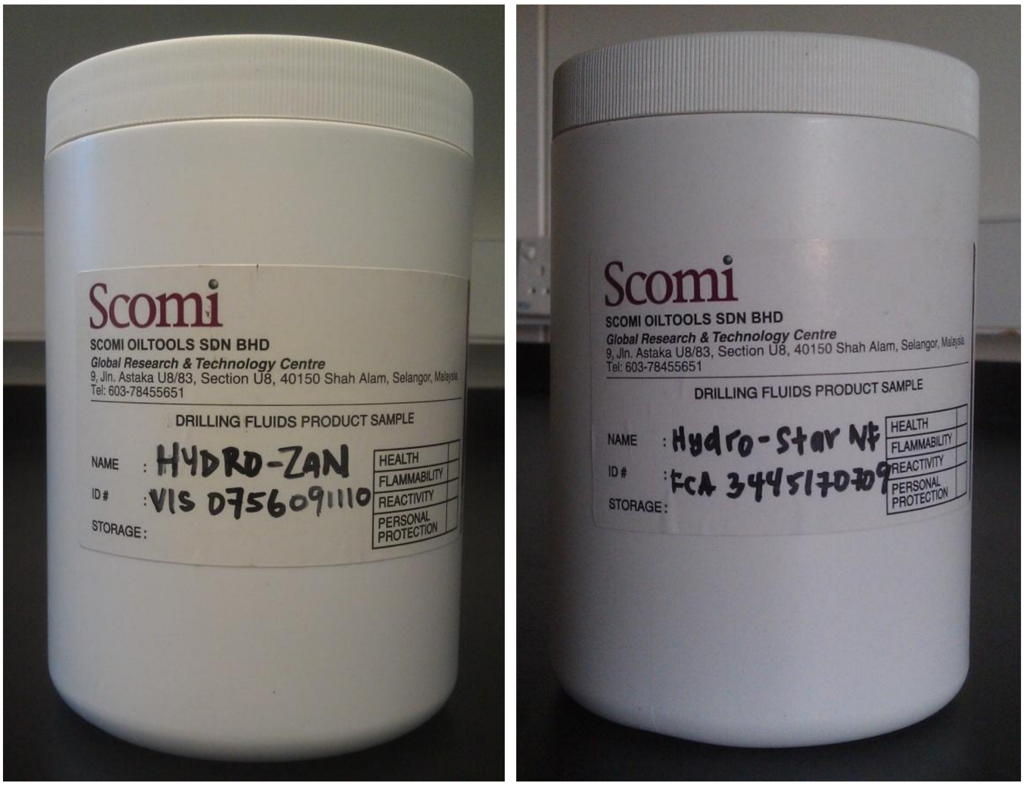


Figure 12: Hydro-Zan and Hydro-Star from Scomi Oiltools

A crude oil from the Malay Basin that was used for the evaluation of commercial oil soluble DRA was obtained from the PETRONAS refinery. It has the density of 795 kg/m^3 at 25°C with Wax Appearance Temperature (WAT) at 32°C. Figure 13 shows the WAT for the crude oil used.

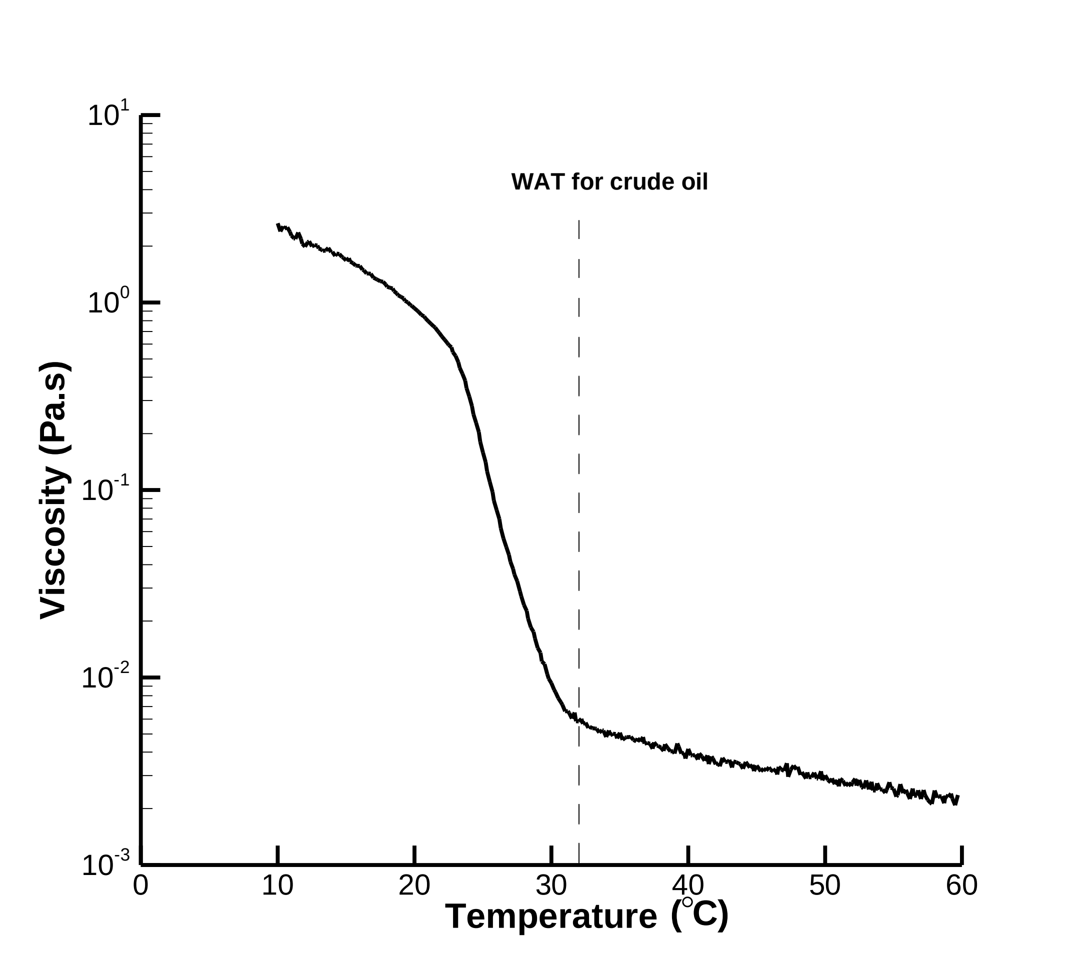


Figure 13: Wax Appearance Temperature for crude oil

Pour Point Depressants (PPD) and Demulsifiers were the sample additives obtained from PETRONAS Carigali Sdn. Bhd. In real practice, both additives are commonly present in crude oils transport. PPD are used to modify the crystal structure of the wax crystallization process while Demulsifiers (emulsion breaker) are used to break down oil emulsions. It separates water from crude oils by increasing the radius of water droplets and decreases the viscosity of crude oils.

3.9 Rheometer Measuring System

According to the operator's manual for AR-G2 rheometer by TA Instruments, the rheometer operating variables are angular displacement (ϕ), angular velocity (Ω), torque (M) and normal force (F_z). Factors are required to convert from the mentioned operating variables to sample variables, which consists of shear strain, shear rate, shear stress and normal stress respectively. The factors are depending on the type and dimensions of the measuring system used.

Thus,
$$\gamma = F_{\gamma}\phi \qquad [12]$$

$$\dot{\gamma} = F_{\dot{\gamma}} \cdot \Omega \qquad [13]$$

$$\sigma = F_{\sigma}M \qquad [14]$$

$$N = F_N \cdot F_z \qquad [15]$$

where: F_{γ} is the shear strain factor

$F_{\dot{\gamma}}$ is the shear rate factor

F_{σ} is the shear stress factor

F_N is the normal force factor

By referring to the dimensions in Figure 10, shear rate factor ($F_{\dot{\gamma}}$), shear stress factor (F_{σ}) and measuring system factor (F_m) can be calculated.

$$F_{\dot{\gamma}} = \frac{{R_1}^2+{R_2}^2}{{R_2}^2-{R_1}^2} \qquad [16]$$

$$F_{\sigma} = \frac{1}{4\pi H}\left[\frac{{R_1}^2+{R_2}^2}{{R_2}^2({R_1}^2+{R_3}^2)}\right] \qquad [17]$$

$$F_m = \frac{1}{4\pi H}\left[\frac{{R_2}^2-{R_1}^2}{{R_2}^2({R_1}^2+{R_3}^2)}\right] \qquad [18]$$

Measuring System Factors in S.I. unit provided in the manual is as below:

Shear Rate	Shear Stress	Measuring System	Fluid Density	Normal Force
-	m^{-3}	m^{-3}	m^5	-
17.29	5313	307.3	1.029E-9	-

When the double gap system is used, information on normal stresses cannot be obtained.

3.10 Sample Preparation

For sample preparation (eg. water + commercial DRA of 100 ppm concentration),

$$\frac{x}{x+y} \times 100\% = \frac{100}{1 \times 10^6} \times 100\% \qquad [19]$$

where:

x = mass of commercial DRA (gram)

y = mass of water (gram)

By using 1 litre of non-filtered tap water which is approximately 1000 gram, 0.1 gram of commercial DRA is needed to produce the concentration of 100 ppm. For working fluid that is in liquid form (e.g. commercial DRA), volume needed is calculated using the below formula:

$$\rho = \frac{m}{v} \qquad [20]$$

where:

ρ = density of fluid (kg/m^3)

m= mass of fluid (kg)

v = volume of fluid (m^3)

A micropipette is used in order to obtain an accurate amount of volume needed as shown in the figure below.

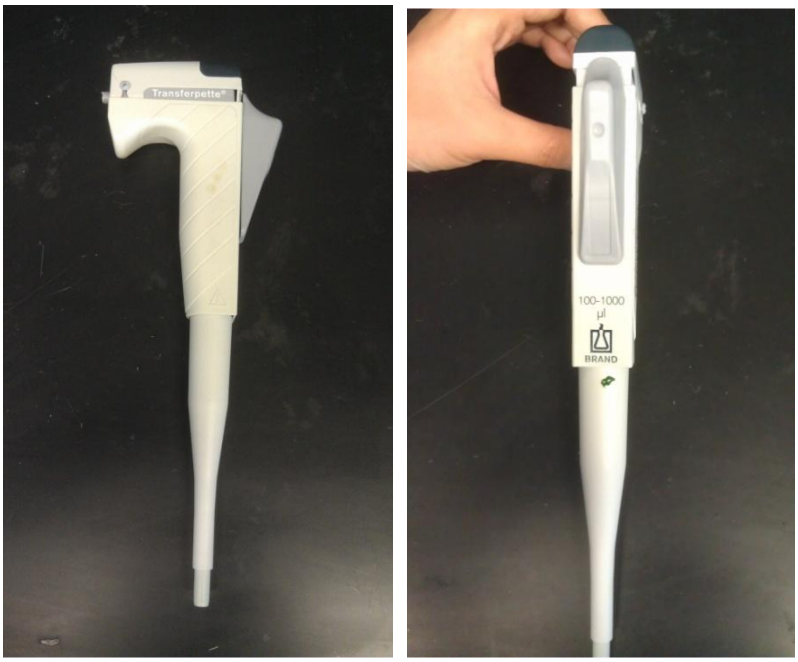


Figure 14: Micropipette from Transferpette®

For working fluid that is in powder form (e.g. Hydro-Zan), the mass needed is obtained using an electronic weight scale.

Figure 15: Electronic weight scale

In order to make sure that the fluid mixture mixes well in water, an overhead stirrer is used with constant low speed (approximately 200 rpm) for the duration of 3 hours until the polymer solutions appeared to be visibly homogeneous. Low speed stirring was applied to ensure that the polymer molecules do not mechanically degrade (eg. break) during the mixing process. Constant speed and time used throughout the mixing process will also help to reduce and eliminate the possible factors which affect the accuracy of experimental data obtained.

Figure 16: Overhead stirrer

Fish eyes or lumps were observed when DRA was introduced into the fluid but disappeared after 3 hours of continuous mixing. Some salt (sodium chloride) was added into the solution to enhance the solubility for the water soluble DRA. Once mixing was completed, the solution was sealed to avoid water loss by evaporation. The evaporation will lead to the increase of concentration in the solution hence causing inaccuracy of experimental data obtained. Solutions were left for at least 8 hours before rheological tests were conducted. This is to ensure complete de-aeration in the solution.

A pipette was used for loading the solution into the DCC due to the small amount needed and the small gap provided for the geometry.

Figure 17: Pipette

The solution was left to rest for 2 minutes in the DCC before rheological tests were conducted. This is to ensure that the molecules are sufficiently relaxed after shear was applied to the solution at the tip of pipette during the extraction of solution from the beaker and also the loading of solution into the DCC.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Water

Figure 18 shows the plotted result for water using the AR-G2 DCC rheometer. The angular velocity varies from 0 rad/s to 300 rad/s, which is the maximum angular velocity that the rheometer can perform. Fresh sample is used for each run due to the poor repeatability of experimental results gained without using fresh sample. Critical Reynolds number where the fluid starts to experience Taylor instabilities is calculated using equation [10] and found out to be at approximately 240 with the critical angular velocity, Ω_c to be 13 rad/s. Experimental results showed that water starts to experience Taylor instabilities above 13 rad/s, where the torque does not vary linearly with the angular velocity anymore. As the velocity increases, the relationship between torque and angular velocity becomes more complex. The progressiveness of Taylor instabilities development can be clearly seen from the graph below as the angular velocity increases.

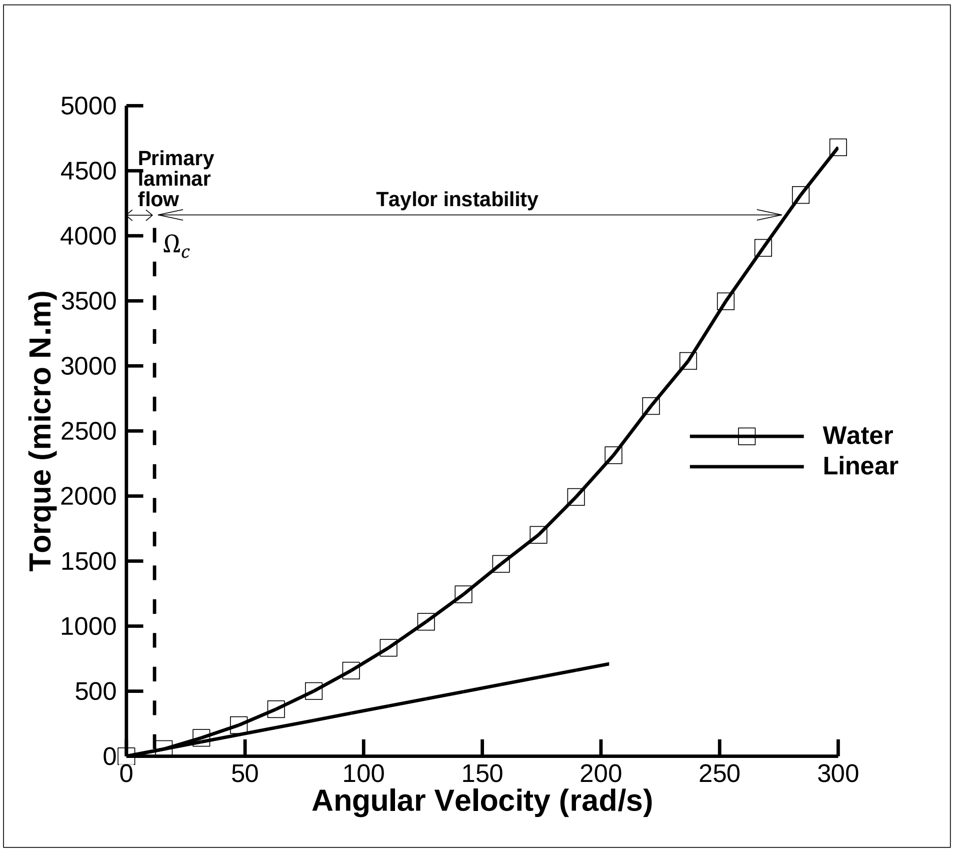


Figure 18: Laminar and Taylor instability regimes of water

Graph of viscosity versus shear rate for water is plotted in Figure 19 in log scale to assess the effects of inertia. The viscosity of water is supposed to be constant throughout the experiment, which is 0.001 Pa·s. However, the viscosity increases when the shear rate increases. This phenomenon is believed to happen due to the effects of inertia. Barnes (2011) states that higher viscosity might be expected from the DCC (circular symmetric geometries) when extra energy was absorbed by the secondary flows which is vortex-like compared to the primary flow. Barnes (2011) also mentioned that apparatus used to measure fluid with low viscosity (less than 10 mPa·s) will normally show the increasing of viscosity due to the secondary flows that are inertially driven. DDC is coincidentally the type of geometry that is used for fluid medium which is from very low to medium viscosity such as water as shown in Figure 9.

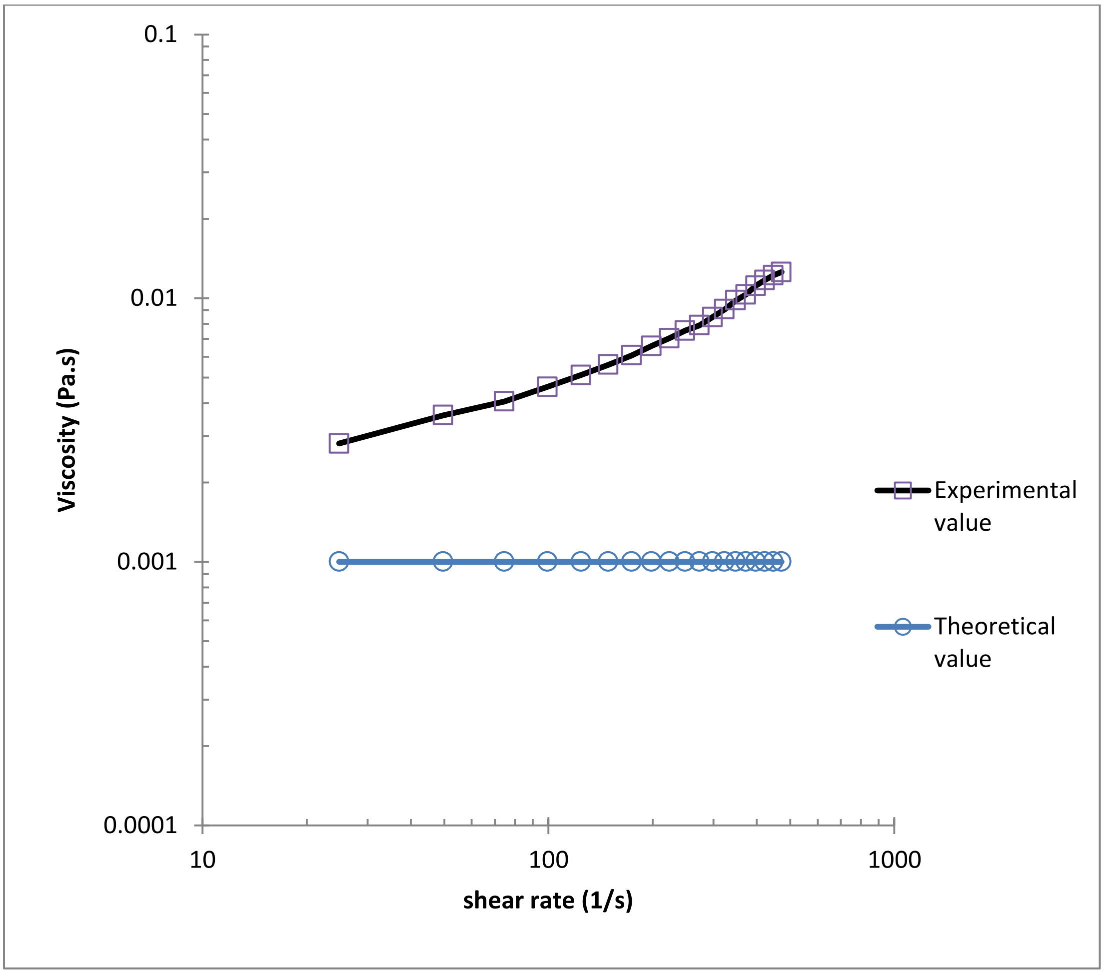


Figure 19: Viscosity of water obtained using DCC rheometer

Stress sweep and frequency sweep on water are also being carried out in order to fully characterize water, where any non-zero value of the elastic modulus is taken as the effects of inertia. Figure 20 shows the stress sweep while Figure 21 shows the frequency sweep carried out on water. The rheological characterization on water will set as the baseline in evaluating the performance of DRA in later results.

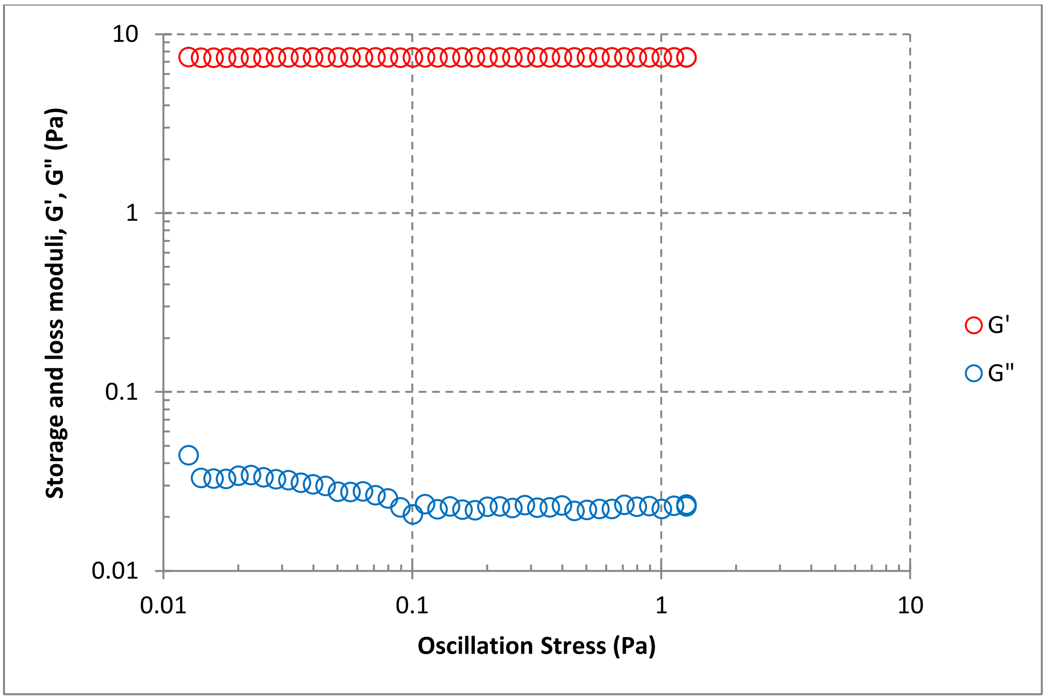


Figure 20: Storage and loss moduli versus oscillation stress for water

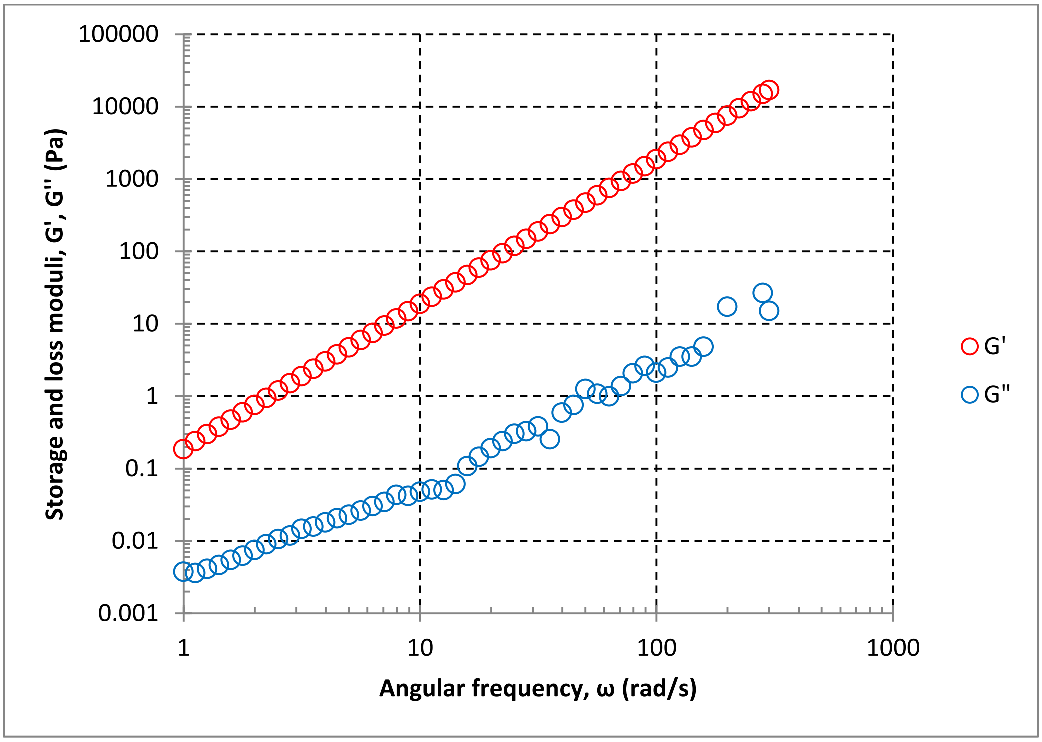


Figure 21: Storage and loss moduli versus angular frequency for water

In this study, the volume of fluid sample used for each run is 10 ml. Lower amount of fluid sample (e.g. 5 ml) has been tried on and the result is shown in the figure below. It can be noticed that there is a sudden increase of torque at 270 rad/s, which is believed to happen due to insufficient fluid sample in the DCC. Therefore, 10 ml of fluid sample is used throughout this study.

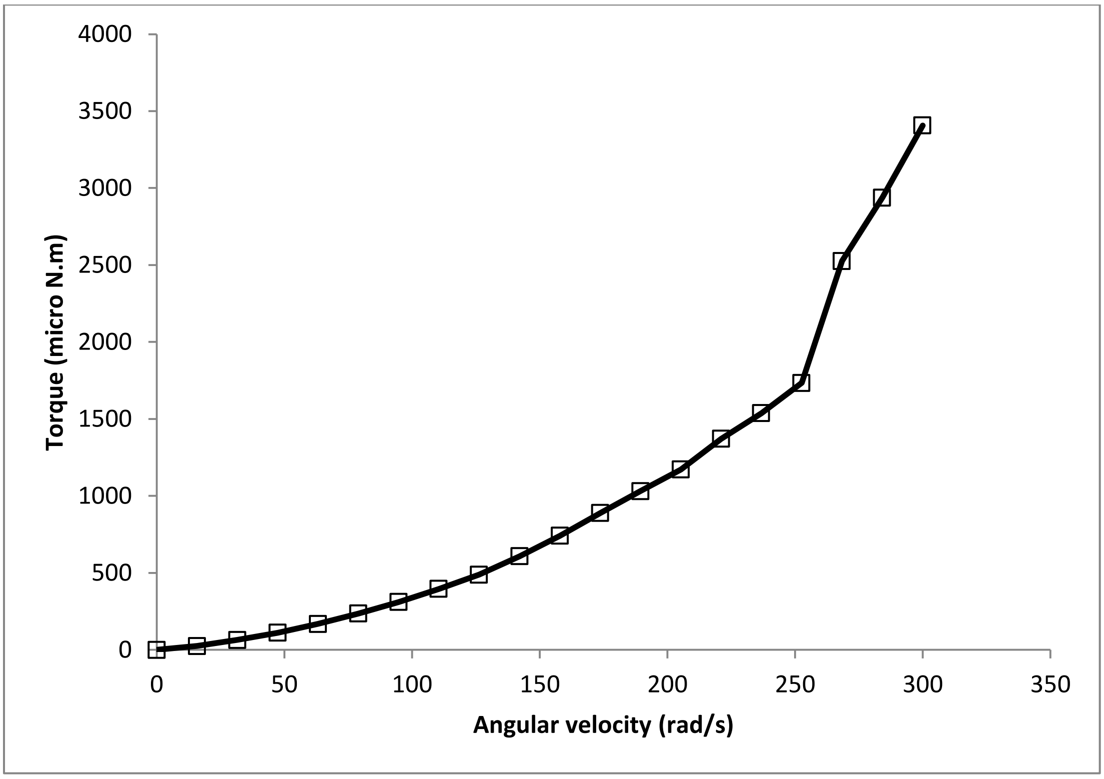


Figure 22: Torque for 5 ml water using DCC rheometer

4.2 Water Soluble DRA (DR 700)

Experiments on DR 700 with UTP tap water as the solvent are carried out at the concentrations of 50 ppm and 100 ppm. The results were plotted and shown in Figure 23. For 50 ppm of DR 700 in water, the critical angular velocity is 110 rad/s, where the critical Reynolds number for onset drag reduction can be calculated using equation [9], which turned out to be 335.5. The operating range for 50 ppm DR 700 in water is from 110 rad/s to 300 rad/s. The drag reduction percentage, %DR can be calculated using equation [8]. The result calculated shows that the presence of 50 ppm DR 700 in water is able to reduce the drag as much as 18.9% at 300 rad/s.

For 100 ppm of DR 700 in water, the critical angular velocity is delayed to 175 rad/s as compared to 50 ppm and the critical Reynolds number for onset drag reduction is calculated to be at 412.6. The operating range for 100 ppm DR 700 in water is from 175 rad/s to 300 rad/s. The drag reduction percentage, %DR calculated shows that the presence of 100 ppm DR 700 in water is able to reduce the drag as much as 26.4%.

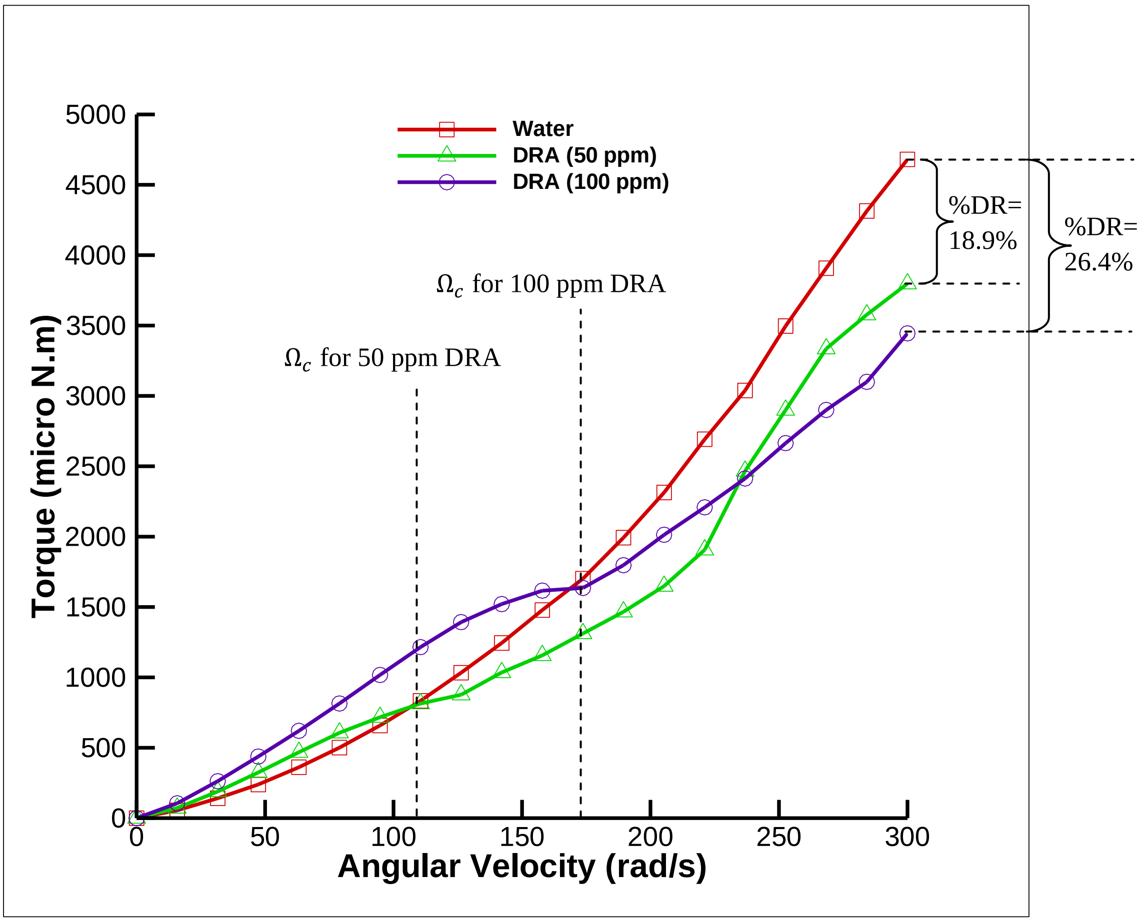


Figure 23: Drag reduction ability of commercial water soluble DRA at various concentrations

It is interesting to note that from 15 rad/s to 160 rad/s, the torque required for DRA with 100 ppm is higher than water alone, indicating adverse drag reduction within this range. This is believed to be due to the fact that the 100 ppm solution has a higher viscosity (prior to onset of shear thinning) and hence greater torque required to flow. Figure 24 shows that once the viscosity of DRA is lesser than water (baseline of this drag reduction study) for the case of both concentrations, drag reduction starts to be observed.

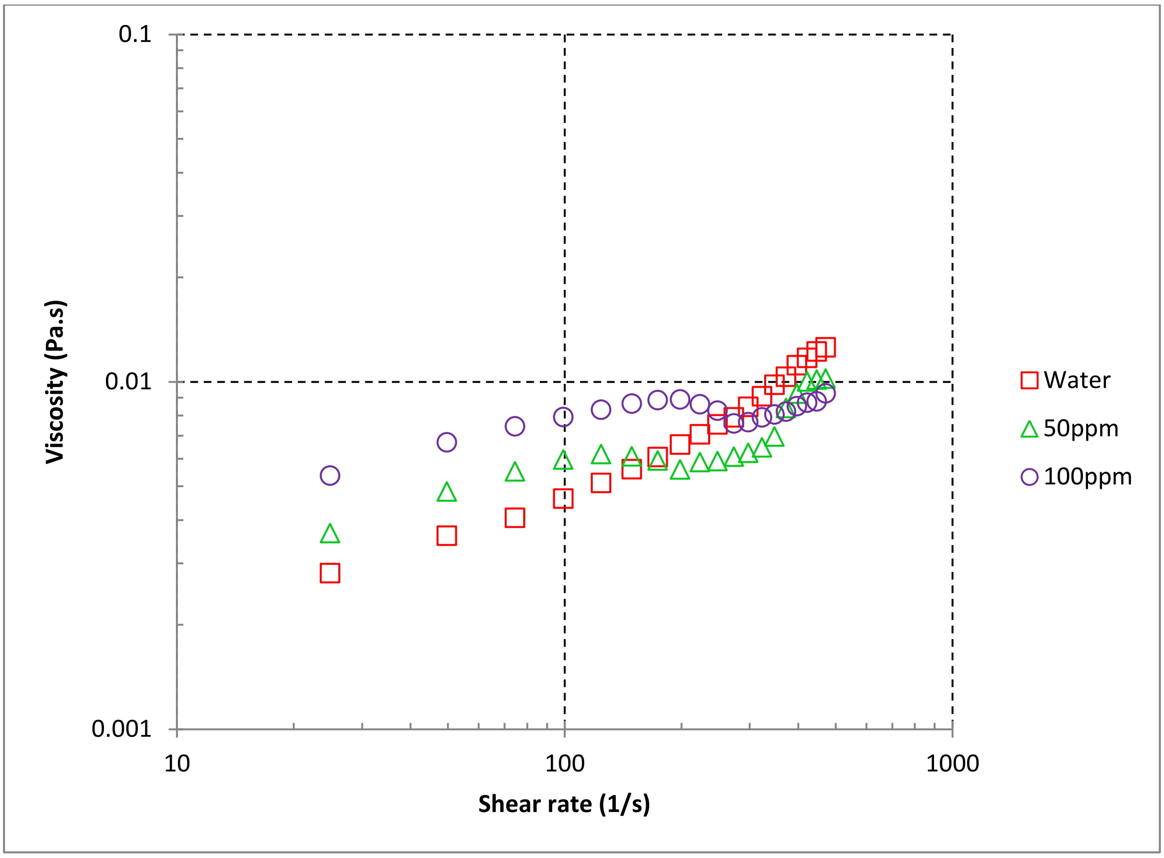


Figure 24: Viscosity versus shear rate for DR 700 with 50 ppm, 100 ppm and water

Concentration of 100 ppm is chosen to evaluate the compatibility of additives which are present together with DR 700. This is because the concentration of 100 ppm shows a greater result in drag reduction compared to the concentration of 50 ppm. Although the torque required for the concentration of 100 ppm might be slightly higher than the concentration of 50 ppm at the beginning, it can be paid lesser attention as the commercial DRA is injected continuously after pumps at high flow rate to ensure immediate mixing in the oil and gas industry. This means that the last few points obtained from the DCC controlled-stress rheometer are more significant in relating this study to the application of industry.

4.3 Additives for DR 700

Xanthan gum (Hydro-Zan) and filtration control agent (Hydro-Star) were the additives used to evaluate the compatibility and effectiveness in DR 700. Both Hydro-Zan and Hydro-Star were being tested individually with water with the concentration of 100 ppm first. The experiments were being carried on with the presence of DR 700 once the additives are able to show drag reduction ability in water.

The common name for Hydro-Zan is Xanthan gum. It is a high molecular weight polysaccharide biopolymer used for increasing the rheological parameters. For the experiment carried out on 100 ppm of Hydro-Zan in water, the critical angular velocity is 205 rad/s and the critical Reynolds number for onset drag reduction is calculated to be at 416.7. The operating range for 100 ppm Hydro-Zan in water is from 205 rad/s to 300 rad/s as shown in Figure 25. The drag reduction percentage, %DR calculated shows that the presence of 100 ppm Hydro-Zan in water is able to reduce the drag as much as 11.2%. There are currently many literatures available on the drag reduction ability of Xanthan gum. Research did by Jaafar & Poole (2009) show that Xanthan gum has the drag reduction ability of 3-13% depending on Reynolds number. Wyatt et. al. (2010) also state that Xanthan gum provides measurable drag reduction results with the concentration as low as 20 ppm.

For the experiment carried out on 100 ppm of Hydro-Star in water, the critical angular velocity is 265 rad/s and the critical Reynolds number for onset drag reduction is calculated to be at 418.9. The operating range for 100 ppm Hydro-Star in water is from 265 rad/s to 300 rad/s as shown in Figure 26. The drag reduction percentage, %DR calculated shows that the presence of 100 ppm Hydro-Star in water is able to reduce the drag as much as 9%.

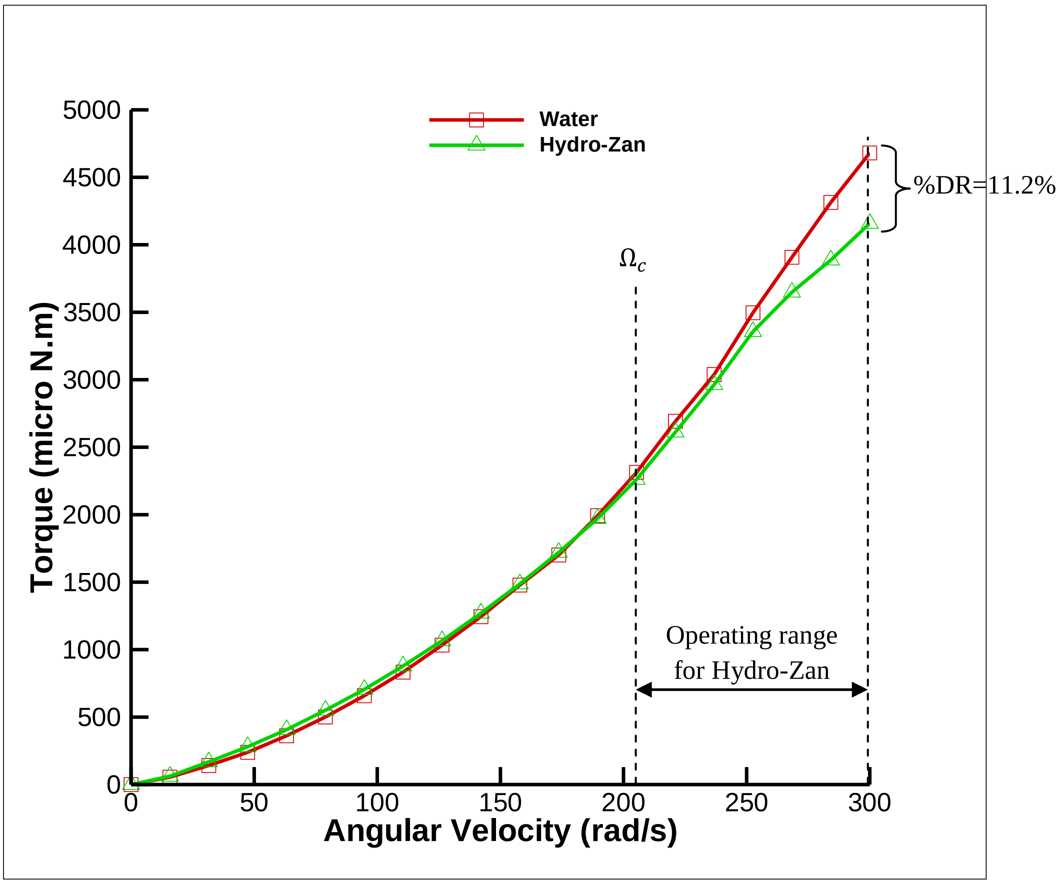


Figure 25: Drag reduction ability of 100 ppm Hydro-Zan in water

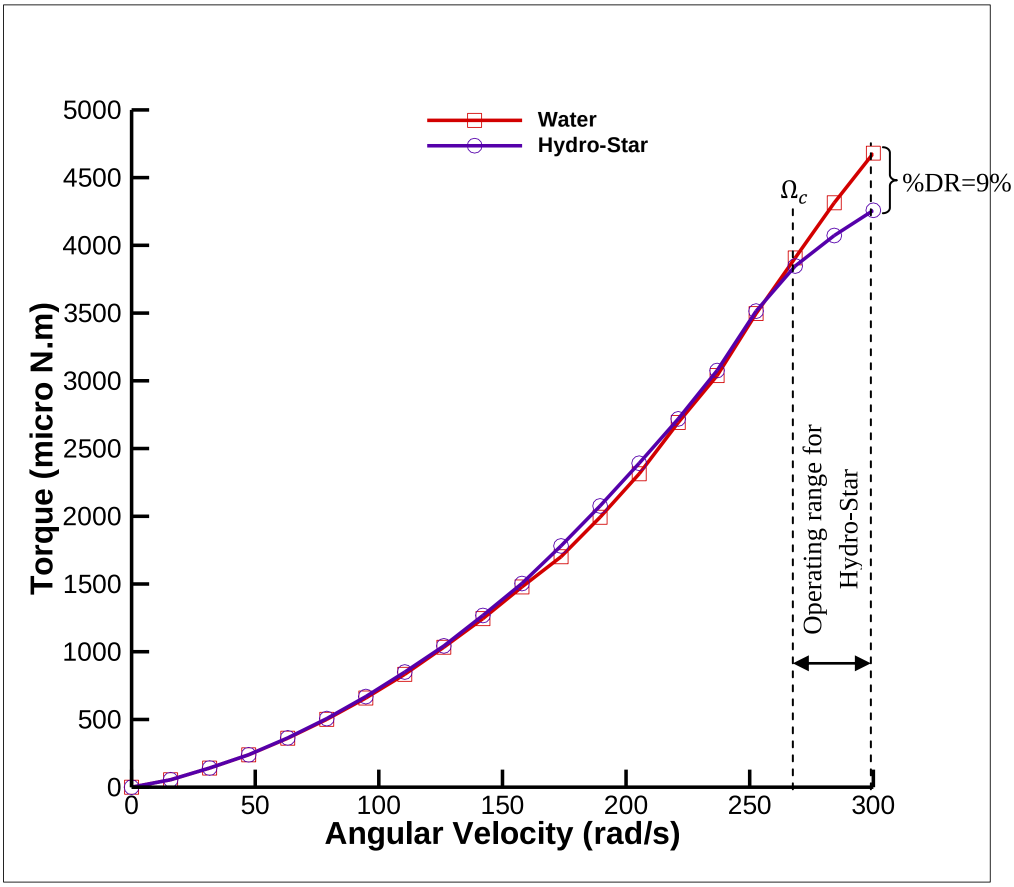


Figure 26: Drag reduction ability of 100 ppm Hydro-Star in water

4.4 Water Soluble DRA with the Presence of Additives

Figure 27 shows the experimental results gained for the drag reduction ability of water soluble DRA with the presence of additives in 100 ppm.

For the presence of DR 700 and Hydro-Zan in water, the critical angular velocity is 190 rad/s and the critical Reynolds number for onset drag reduction is calculated to be at 412.6. The operating range for 100 ppm Hydro-Zan in water is from 190 rad/s to 300 rad/s. The drag reduction percentage, %DR calculated shows that the presence of 100 ppm DR 700 and Hydro-Zan in water is able to reduce the drag as much as 22.4% at 300 rad/s. However, the result showed reduction of %DR compared to 100 ppm of DR 700 in water without additive, which is 26.4%. This can probably be explained with the unique ability of Hydro-Zan to produce a fluid that is highly shear-thinning and develops a true gel structure which leads to a higher torque.

For the presence of Hydro-Star in DR 700, the critical angular velocity is 125 rad/s and the critical Reynolds number for onset drag reduction is calculated to be at 355.9. The operating range for 100 ppm Hydro-Star in water is from 125 rad/s to 300 rad/s. The drag reduction percentage, %DR calculated shows that the presence of 100 ppm DR 700 and Hydro-Star in water is able to reduce the drag as much as 17.8%. Althought the presence of Hydro-Star is able to reduce the torque at the beginning, it does not intesify the effect in drag reducing ability as the torque starts to increase and exceed the torque of DRA at 250 rad/s. This leads to the reduction of %DR showed compared to DR 700 in water without additive, which is from 26.4% to 17.8%. This can probably be explained with the design of filtration control agents to reduce fluid loss and increase viscosity in all water base muds.

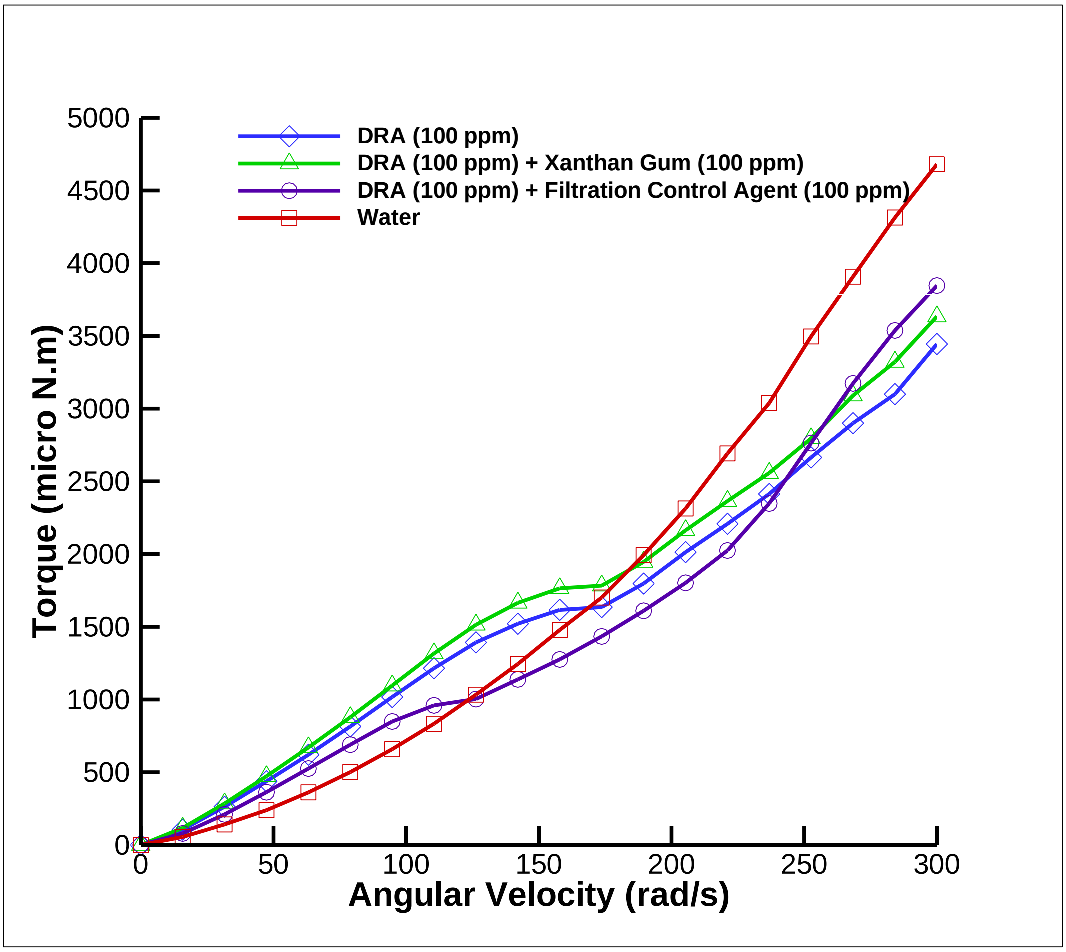


Figure 27: Drag reduction ability of commercial water soluble DRA with the presence of additives.

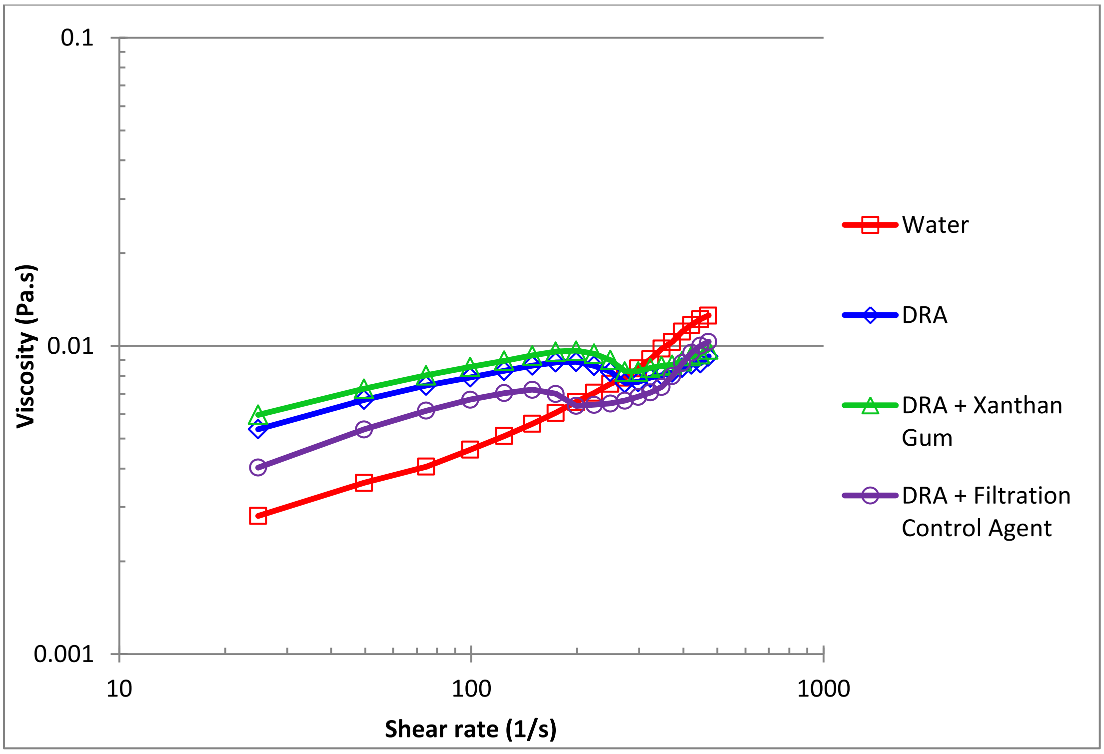


Figure 28: Viscosity versus shear rate for water soluble DRA with the presence of additives

Table 3: Summarized results for water soluble DRA

Fluid	Critical Re for onset DR	%DR at 300 rad/s
Water + DR 700 (50 ppm)	335.5	18.9
Water + DR 700 (100 ppm)	412.6	26.4
Water + Hydro-Zan (100 ppm)	416.7	11.2
Water + Hydro-Star (100 ppm)	418.9	9.0
Water + DR 700 (100 ppm) + Hydro-Zan (100 ppm)	412.6	22.4
Water + DR 700 (100 ppm) + Hydro-Star (100 ppm)	355.9	17.8

Both additives tested did not show an increase of drag reduction ability compared to the commercial water soluble DRA itself. It is worth highlighting that from the experiments conducted, there is no specific way to determine the onset of turbulence. Jaafar (2009) however, states that drag reduction might not be observed immediately after the onset of transition to turbulence but occuring at some delayed Reynolds number between the critical Reynolds number and the limit where the maximum value of turbulent intensity is reached.

4.5 Crude Oil

Crude oil from the Malay Basin that is used for the evaluation of commercial oil soluble drag reducer, DR 742 is obtained from the PETRONAS refinery. Figure 29 shows the plotted result for crude oil using the AR-G2 DCC rheometer. The angular velocity varies from 0 rad/s to 300 rad/s, which is the maximum angular velocity that the rheometer can perform. Fresh sample is used for each run due to the poor repeatability of experimental results gained without using fresh sample. Critical Reynolds number where the fluid starts to experience Taylor instabilities is calculated using equation [10] and found out to be at approximately 240. As the velocity increases, the relationship between torque and angular velocity becomes more complex. The progressiveness of Taylor instabilities development can also be clearly seen from the graph below as the angular velocity increases.

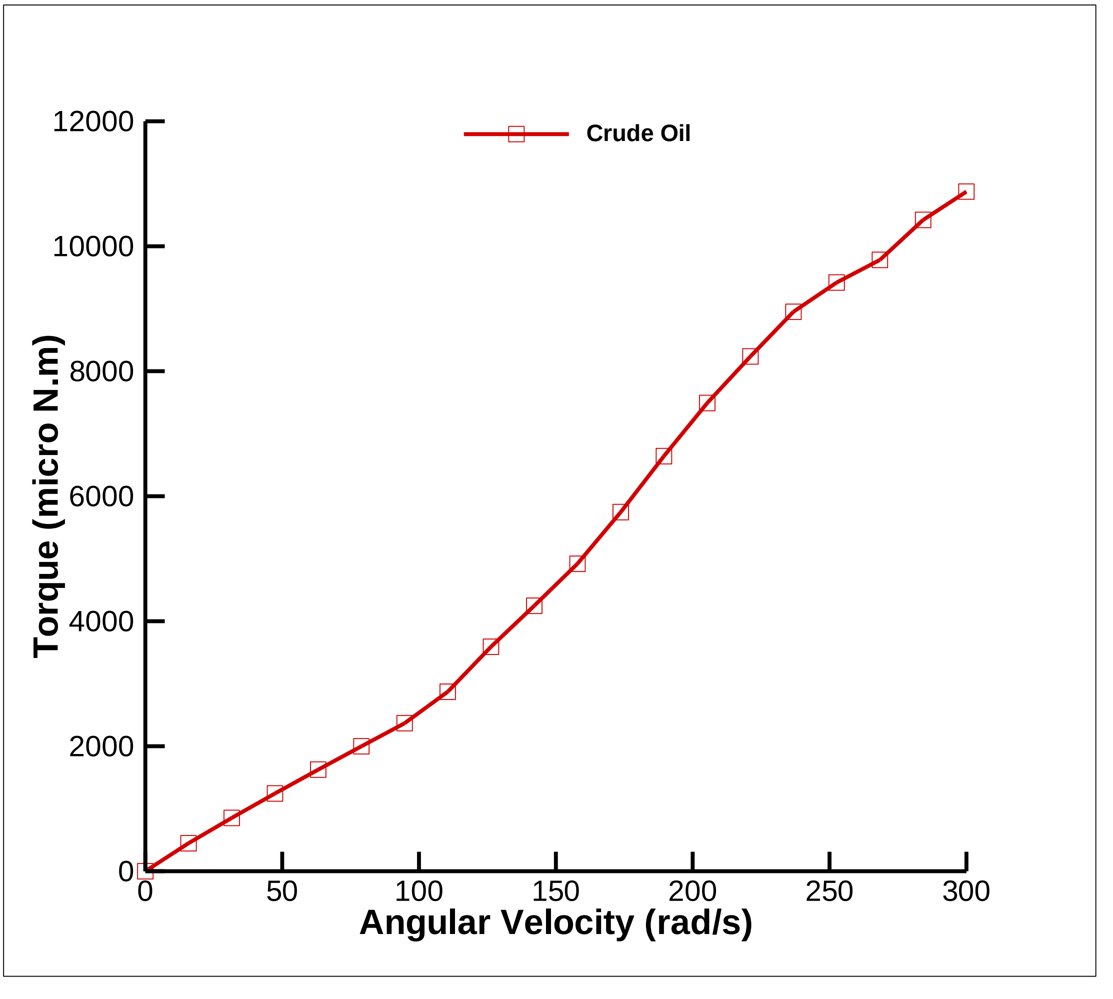


Figure 29: Torque versus angular velocity for crude oil

4.6 Oil Soluble DRA (DR 742)

Experiments on DR 742 with crude oil are carried out at the concentrations of 25 ppm and 50 ppm. The results are plotted and shown in Figure 30. For 25 ppm of DR 742 in crude oil, the critical angular velocity is 95 rad/s, where the critical Reynolds number for onset drag reduction calculated turned out to be 69.4. The operating range for 25 ppm DR 742 in crude oil is from 95 rad/s to 300 rad/s. The drag reduction percentage, %DR can be calculated using equation [8] showed that the presence of 25 ppm DR 742 in crude oil is able to reduce the drag as much as 24.6% at 300 rad/s.

For 50 ppm of DR 742 in crude oil, the critical angular velocity is delayed to 110 rad/s as compared to 25 ppm and the critical Reynolds number for onset drag reduction is calculated to be at 81.9. The operating range for DRA in crude oil is from 110 rad/s to 300 rad/s. The drag reduction percentage, %DR calculated shows that the presence of 50 ppm DR 742 in crude oil is able to reduce the drag as much as 31.5%.

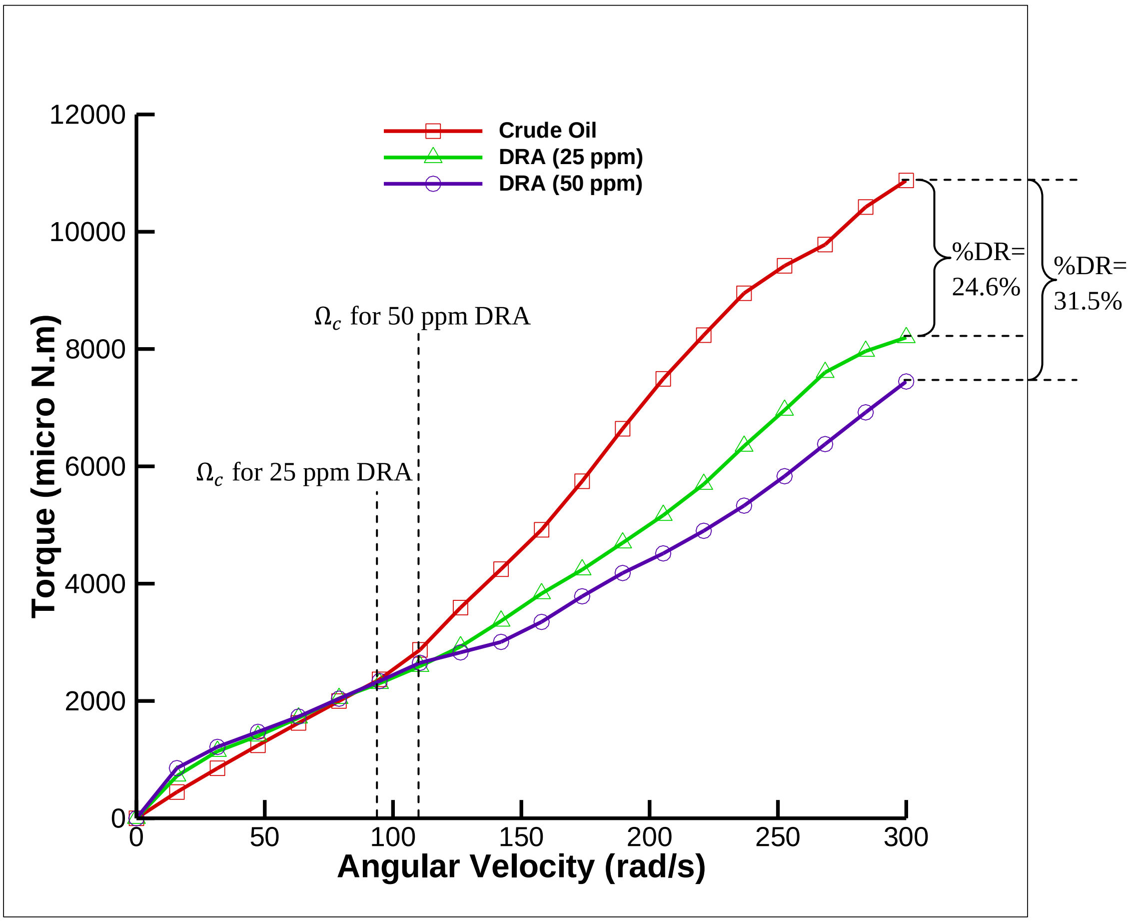


Figure 30: Drag reduction ability of commercial oil soluble DRA at various concentrations

Although the torque required for both concentrations of 25 ppm and 50 ppm are slightly higher at the beginning, it can be paid lesser attention with the same explanation for the water soluble DRA, where the commercial DRA is injected continuously after pumps at high flow rate to ensure immediate mixing. This means that the last few points obtained from the DCC controlled-stress rheometer are more significant in relating this study to the application in the oil and gas industry. The concentration of 50 ppm is used to evaluate the compatibility of additives which are present together with the commercial oil soluble DRA due to the greater results obtained in %DR compared to the concentration of 25 ppm.

4.7 Oil Soluble DRA with the Presence of Additives

Figure 31 shows the experimental results gained for the drag reduction ability of oil soluble DRA, DR 742 with the presence of additives. The onset of drag reduction for DR 742 and the presence of Demulsifiers both occured at the same point, which is at the critical angular velocity of 110 rad/s. The operating range for both fluids in this case are the same, which are from 110 rad/s to 300 rad/s. Concentration of 100 ppm is used for all additives as it is the common concentration practised in the industry while concentration of 50 ppm is used for commercial oil soluble DRA with the reasons mentioned in the previous section.

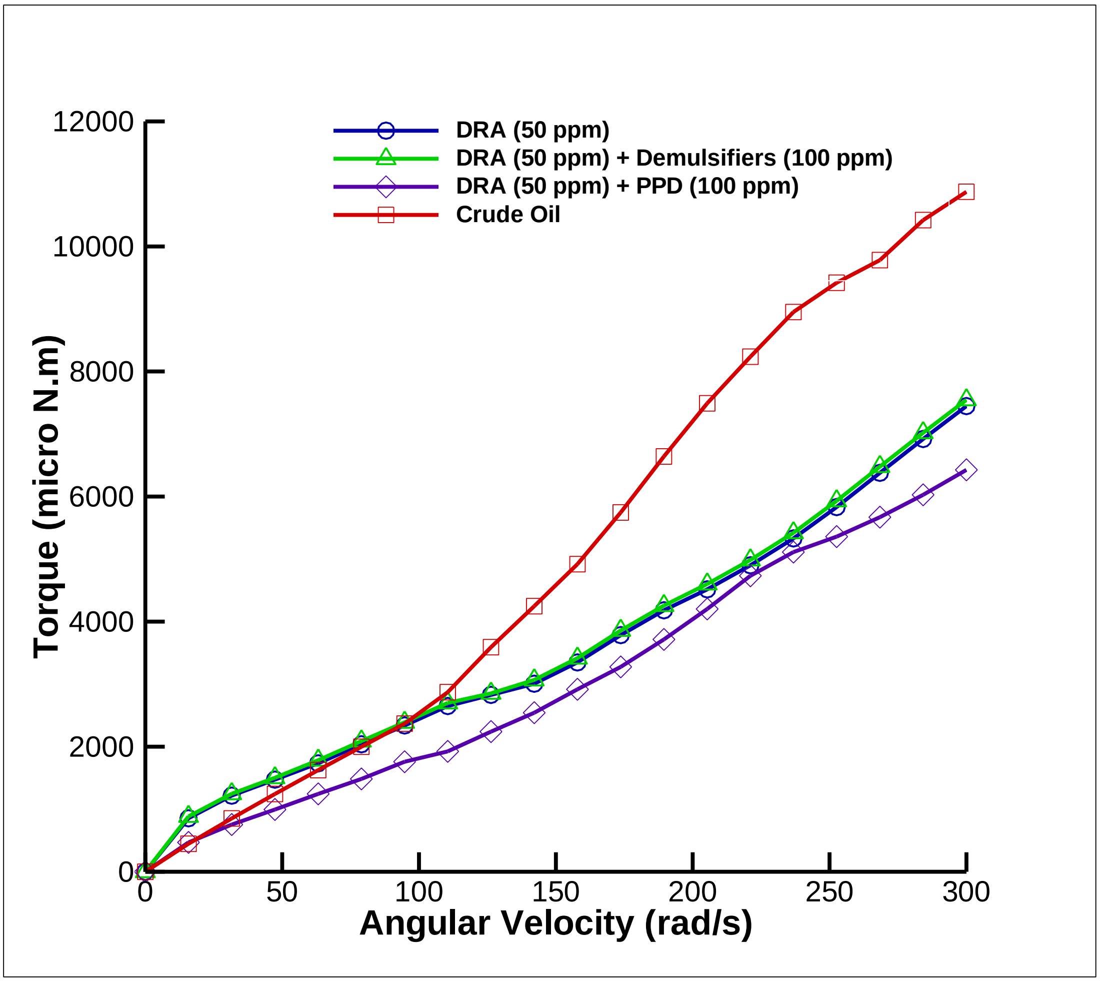


Figure 31: Drag reduction ability of commercial oil soluble DRA with the presence of additives

The graph of viscosity versus shear rate is plotted below to see the effects of viscosity in affecting the torque obtained from the rheometer.

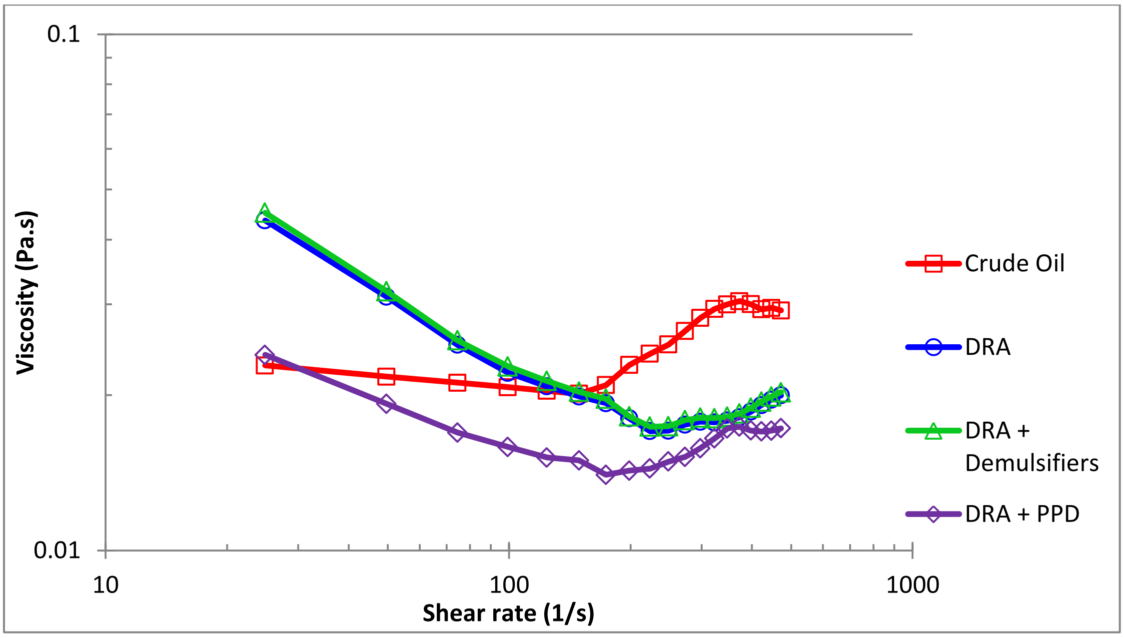


Figure 32: Viscosity versus shear rate for oil soluble DRA with the presence of additives

For the presence of Demulsifiers in DR 742, no sign of improvement in drag reduction is observed. The presence of Demulsifiers in DRA has very close drag reduction ability compared to the DRA alone, which is 30.6%. This shows that Demulsifiers will not cause much negative effect when it is present together with DRA.

For the presence of PPD in DR 742, a great effect of drag reduction has been observed. The presence of PPD in DRA has increased the drag reduction ability of DRA alone as much as 9.4%, resulting the %DR of 40.9%. This can probably be explained with the function of PPD, which is used to modify the crystal structure of the wax crystallization process, resulting in lower pour point of the crude and thus creates a better flow behaviour.

In order to justify on this, experiment on the presence of PPD in crude oil has been carried out and shown in Fig. 33. The experiment was carried out using the AR-G2 rheometer with the 4 cm roughen plate geometry on a peltier plate. Conditioning steps were done at the beginning of experiment to remove shear history. Ramp rate of 1°C/min was used and shear rate of 10 s^{-1} was set as the controlled variable. From Fig. 33, it can be clearly seen that the WAT of crude oil has been shifted from 32°C to 24°C in the presence of PPD with the concentration of 100 ppm.

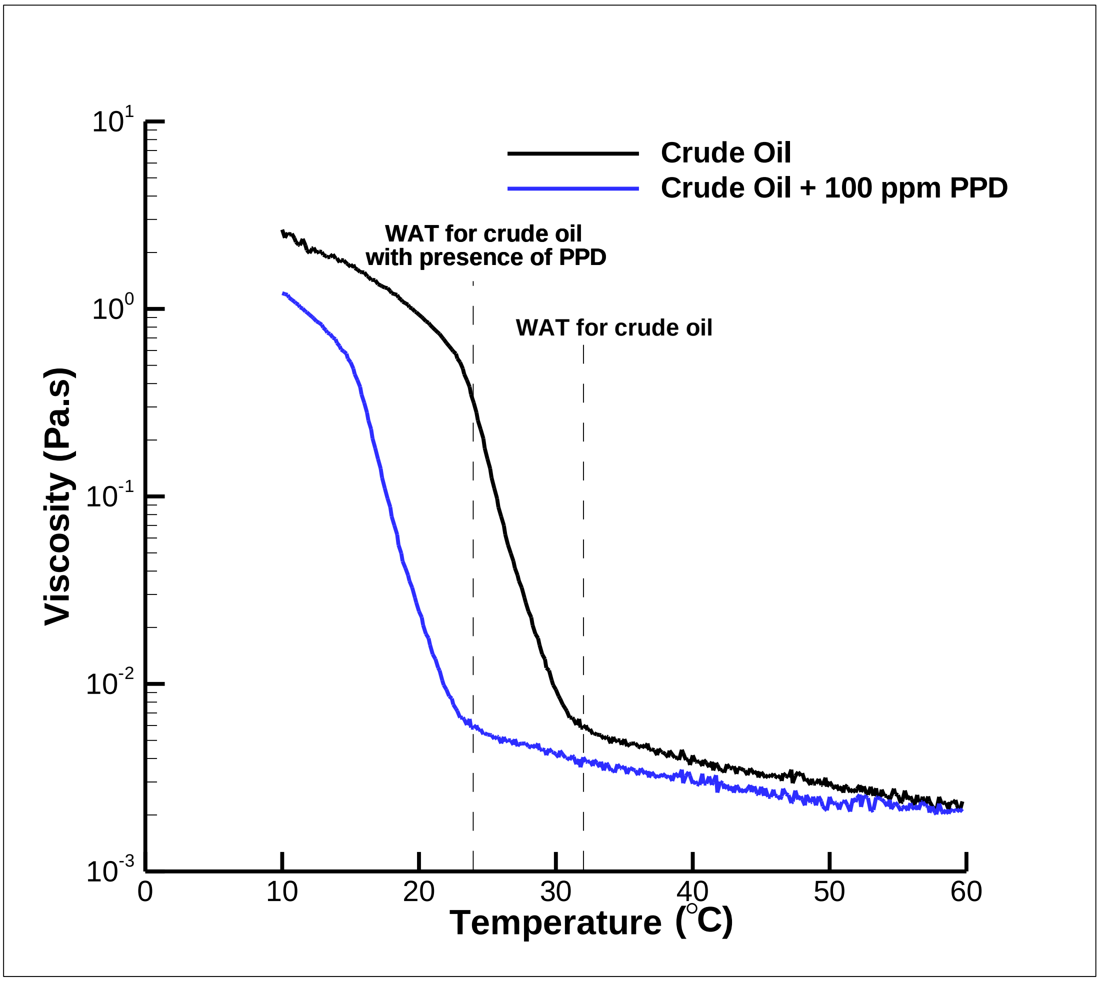


Figure 33: Wax Appearance Temperature of crude oil with and without PPD

Table 4: Summarized results for oil soluble DRA

Fluid	Critical Re for onset DR	%DR at 300 rad/s
Crude oil + DR 742 (25 ppm)	69.4	24.6
Crude oil + DR 742 (50 ppm)	81.9	31.5
Crude oil + DR 742 (50 ppm) + Demulsifiers (100 ppm)	90.5	30.6
Crude oil + DR 742 (50 ppm) + PPD (100 ppm)	40.1	40.9

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

In conclusion, the new method of evaluating the performance of DRA using a DCC rheometer showed a great potential in replacing the current flow loop which is costly and time consuming. The study of the performance on commercial DRA and the compatibility of additives which is added into the commercial DRA will certainly serve to the followings:

- Reduction of pumping power losses in the oil and gas industry
- Reduction of energy consumption
- Avoid changing of mechanical parts used in the process such as the size of the pipeline, the speed of the pump etc.

Experimental results showed that the presence of additives such as Xanthan gum (Hydro-Zan) and filtration control agent (Hydro-Star) in water soluble DRA does not help in the performance of DRA. However, PPD showed great compatibility with the oil soluble DRA where great effects of drag reduction was observed compared to DRA alone.

For the recommendation part of this project, effects of pressure and temperature can be taken into consideration as some studies confirmed that viscosity increases with pressure. Since this method of development is still at an infancy stage, measurements are concentrated at ambient conditions only. The AR-G2 rheometer should be fully utilized as it comes with a pressure cell testing facility up to 2000psi and also capable in measuring temperature up to 200°C.

Customization and further modifications on the existing geometries of AR-G2 rheometer can also be done for a thorough and complete assessment of DRA effectiveness. The DCC geometry still has room of improvements to provide measurements for a full range of turbulent regime. In the mean time, the methodology of this experiment can be applied as a preliminary test for the purpose of selecting an appropriate DRA.

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APPENDICES:

Relationship between 'Taylor' number and Reynolds number

According to Chhabra & Richardson (1999), stability criterion for Newtonian fluid in narrow gap is:

$$T_a = \frac{\rho^2 \Omega^2 (R_2 - R_1)^3 R_1}{\mu^2} < 3400$$

R_1 = external radius of internal cylinder, R_2 = internal radius of external cylinder

For turbulent regime,

$$T_a = \frac{\rho^2 \Omega^2 (R_2 - R_1)^3 R_1}{\mu^2} > 3400$$

$$T_a = \frac{\rho^2 \Omega^2 (R_2 - R_1)^3 R_1}{\mu^2} \cdot R_1 > 3400 \cdot R_1$$

$$T_a = \frac{\rho^2 \Omega^2 (R_2 - R_1)^2 (R_2 - R_1) {R_1}^2}{\mu^2} > 3400 R_1$$

$$T_a = \frac{\rho^2 \Omega^2 (R_2 - R_1)^2 {R_1}^2}{\mu^2} > \frac{3400 R_1}{(R_2 - R_1)}$$

$$T_a = \sqrt{\frac{\rho^2 \Omega^2 (R_2 - R_1)^2 {R_1}^2}{\mu^2}} > \sqrt{\frac{3400 R_1}{(R_2 - R_1)}}$$

$$T_a = \frac{\rho\, \Omega\, (R_2 - R_1)\, R_1}{\mu} > 58.3 \left(\frac{R_1}{(R_2 - R_1)}\right)^{0.5}$$

↑

Reynolds number according to Van Wazer et. al., 1963

$$\therefore Re = \frac{\rho\, \Omega\, (R_2 - R_1)\, R_1}{\mu} > 58.3 \left(\frac{R_1}{(R_2 - R_1)}\right)^{0.5}$$

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HYDRO-STAR NF — Product Data Sheet

Product Description

HYDRO-STAR NF is a non-fermenting pre gelatinised high-temperature starch used to control filtration in water-base muds.

Typical Properties

COMMON NAME	Modified Starch	CHEMICAL FORMULA	Polysaccharide
APPEARANCE	Powder	SOLUBILITY IN WATER @ 20 °C	Dispersible
SPECIFIC GRAVITY	1.4-1.6		

Applications/ Functions

HYDRO-STAR NF is designed to reduce fluid loss and increase viscosity in all water base muds. **HYDRO-STAR NF** is especially applicable and economical in saturated salt and brine systems where other products are not effective. **HYDRO-STAR NF** encapsulates particles with a protective colloid.

Advantages

- **HYDRO-STAR NF** is an economical, one sack, preserved product for filtration control and viscosity which is effective in a wide range of make up water, including high salinity, high hardness brines.
- **HYDRO-STAR NF** is pre gelatinised for maximum effectiveness.
- **HYDRO-STAR NF** provides wellbore stability through filtration control and encapsulation.

Recommended Treatment

Normal treatments range from 2 - 6 lb/bbl (5.7 - 17.1 kg/m^3) depending on the make up water chemistry and desired fluid loss. Treatment levels of 2 - 3 lb/bbl (5.7 – 8.6 kg/m^3) will reduce the API fluid loss values to the 6 - 8 ml range in freshwater mud systems. At higher temperatures and salinities it is recommended that fluid formulations include polymer extenders and oxygen scavengers.

Limitations

1. **HYDRO-STAR NF** rapidly degrades when exposed to temperatures in excess of 275 ^{0}F (135 ^{0}C).
2. **HYDRO-STAR NF** is less effective in high pH/high calcium, saturated brine system.

Recommended Handling

Consult MSDS before use and use personal protective equipment as advised.

Packaging

HYDRO-STAR NF is packaged in 25 kg multi-wall paper bags. Store in dry location away from sources of heat or ignition.

November 2010

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HYDRO-ZAN Product Data Sheet

Product Description

HYDRO-ZAN Xanthan gum is a high molecular weight biopolymer used for increasing the rheological parameters in water-based drilling fluids. Small quantities provide excellent viscosity for suspending weighting material for all water-based drilling fluids systems. **HYDRO-ZAN** has the unique ability to produce a fluid that is highly shear-thinning and develops a true gel structure.

Typical Properties

COMMON NAME	Xanthan Gum	**SOLUBILITY IN WATER**	Soluble
APPEARANCE	Powder	**SPECIFIC GRAVITY**	1.5 -1.7
COLOUR	Cream to tan		

Applications/ Functions

HYDRO-ZAN provides an optimised rheological profile with elevated low-shear-rate viscosity (LSRV) and shear thinning characteristics with low "n" values. This results in fluids with inverted flow properties, low effective viscosity for minimal pressure losses and standpipe pressure. **HYDRO-ZAN** delivers optimum hydraulics with maximised rates of penetration and at the low-shear-rate experienced in the annulus enables the fluid to have a high effective viscosity for adequately cleaning of the well and suspend cuttings.

Advantages

- Highly effective viscosifier.
- Provides shear-thinning rheology for improved hydraulics.
- Easy to mix.
- Viscous laminar flow in the annulus for improved well-bore stability with maximum hole-cleaning and suspension capacity.

Recommended Treatment

The normal application is from 0.25 - 2.0 lb/bbl (0.71 – 5.7 kg/m^3). For special applications, such as difficult hole cleaning may require up to 4 lb/bbl (11.4 kg/m^3).

Limitations

- Effective up to 250 ^{0}F (121 ^{0}C). Above this temperature include oxygen scavengers in the formulation.
- Efficacy is reduced in high salinity environments.
- Needs shear and temperature to fully yield.

Recommended Handling

Consult MSDS before use and use personal protective equipment as advised.

Packaging

HYDRO-ZAN is packaged in 25 kg (55.1 lb) multi-wall, paper sacks. Store in a dry location away from sources of heat or ignition.

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Technical Data Sheet on DR 700

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ANTICOR DR 700

Drag Reducer

TECHNICAL DATA SHEET

Composition : Emulsion in hydrocarbon solvent of a water solution of polymer.

Properties : ANTICOR DR 700 reduces friction in pipes and allows to transport more fluids with the same equipment.

Application : Increase water flow rate into injection wells.
Reduce operating costs in water injection facilities.
Increase flow rate in oil pipelines having more than 10% water cut.

Recommendations : 20 to 100 ppm to inject continuously after the pumps.
Drag reduction begins almost immediately and increases until all the fluids in the line contain drag reducer. Flow rate can be increased up to factor 1.6.

Safety and handling : For handling the product goggles and protective gloves should be worn.
See also Material Safety Data Sheet for specific handling and health information.

Caracteristics :

Physical state		Opaque liquid *
Density at 20°C (± 0,02 g/cm^3)		1,05 *
Viscosity at 20°C (cps)		1000
Flash point (°C) :		> 100
pH (pure) (± 0.3) :		NA
Freezing point :		
Packing net (kg):	Steel drum:	225
	IBC:	1050
Storage :		6 months
		0°C / 35°C

The Scomi Anticor company is certified according to **ISO 9001 V 2000** Date of Revision : 2008 08 25

* Specifications

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ANTICOR DR 742

Oil soluble
Drag Reducer

TECHNICAL DATA SHEET

Composition: Very high molecular weight polymer dispersion in aquous solution.

Properties: ANTICOR DR 742 reduces friction in pipes and allows to transport more fluids with the same equipment

Application: Inject ANTICOR DR 742 downstream pumps in a turbulent area to ensure immediate mixing. Do not inject upstream pumps because the shear in pumps degrades the polymer and decreases appreciably its performances.

The polymer will decrease turbulence in the stream and can lead to 20 to 50% increase in throughput with same pumping equipment.

Recommendations: Inject continuously 5 to 50 ppm versus oil.

Safety and handling: For handling the product goggles and protective gloves should be worn.
See also Material Safety Data Sheet for specific handling and health information.

Characteristics:

Physical state:		White paste
Density at 20°C (± 0,02):		0,92
Viscosity at 20°C (cps):		NA
Flash point:		> 100°C
pH 1% in water (± 0.3) :		NA
pH 1% in W/IPA (5/5) (± 0.3) :		NA
pH (pure) (± 0.3):		NA
Freezing point (°C):		0°C
Packing net (kg):	HDPE drum	184
	IBC	920
Storage:		12 months
		5°C / 40°C

The Scomi Anticor company is certified according to **ISO 9001 V 2008** Date of Revision : 2010 09 09

* Specifications

Information given in this document is the result of our research and our experience.They are given in good faith, but it is for the User to satisfy itself of the suitability of the product for its own particular purpose.

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