**Wormlike Micelle as Drag Reducing Agent in Flow Assurance**

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# CERTIFICATION

CERTIFICATION OF APPROVAL

**WORMLIKE MICELLE AS DRAG REDUCING AGENT IN FLOW ASSURANCE**

BY

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A projection dissertation submitted to the
Petroleum Engineering Programme
Universiti Teknologi PETRONSAS
in partial fulfillment of the requirement for the
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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.

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MA SHIAN EE

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# ABSTRACT

Drag Reducing Agent (DRA) has been used to increase flow capacity in existing pipelines. This obviates the need to install additional booster pumps. Most of the commercial DRA is a polymeric system with high molecular weight Polyacrilamide (PAM) as typical DRA. When subjected to high shear stress, the polymeric DRA will suffer mechanical breakdown, thus reducing its effectiveness in dampening the turbulent flow inside the pipe. Consequently this reduces the drag reducing efficiency of the DRA.

In this study, alternative formulation is proposed by using worm-like micelles (WLM). WLM is a visco-elastic material derived from surfactant and salt mixture. While application is widespread in consumer personal care products and flow assurance agent for district cooling and heating, utility as DRA merits further study. Since WLM has ability to break and reform under high shear stress, it can overcome the mechanical degradation common in polymeric DRA.

The WLM system is formed from cationic surfactant consisting of Hexadecyltrimetyl-ammonium bromide (CTAB) at a fixed concentration of 0.15M mixed with Sodium Nitrate at 0.2 wt% to 1.0 wt%. Another system comes from Dodecyltriethylammonium Bromide (DTAB)/sodium dodecylsulfate (SDS) at the molar ratio of 27/73. The final concentration for the mixture will be in the range of 140mM to 200mM. The efficiency of WLM as potential DRA is compared with PAM DRA in a viscosity test and water flow test. Rheological behaviour of WLM is evaluated in the viscosity test as a function of apparent viscosity and shear rate. Non-Newtonian behaviour is expected since the mixture showed a shear thinning effect when exposed to high shear stress. WLM is injected into the water flow test to determine the drag reducing efficiency in turbulent flow.

Result from the water flow test proved that the both surfactant and polymer DRA can reduce the drag forces and hence improving flow rate. WLM is capable of performing the role of reducing the drag forces longer and more effective than polymeric DRA or PAM. The WLM system used in this research can improve the flow efficiency till 33.79% while PAM can improve the flow rate till a maximum of 20.38%.

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# Abbreviations and Nomenclatures

| | |
|---|---|
| DRA | Drag Reducing Agent |
| Re | Reynolds Number |
| CTAB | Hexadecytrimetyl-ammonium bromide |
| DTAB | Dodecytrimethyl Ammonium Bromide |
| SDS | Sodium Dodecysulfate |
| $NaNO_3$ | Sodium Nitrate |
| SD | Sodium Decanote |
| PAM | Polyacryalmide |
| M | Molarity |
| MW | Molecular Weight |
| wt% | Weight Percentage |
| Vm | Mean Average Flow Velocity |
| D | Diameter of the pipe (m) |
| v | Kinematic Viscosity |
| μ | Viscosity |
| rpm | Rotation Per Minute |
| ppm | Parts per million |

# CHAPTER 1:INTRODUCTION

## 1.1 Background of Study

The usage of low concentration of high polymer addictive and aluminum di-soaps (dilute solution of polyethyl-methacrylate in monochlorobenzene)was reported by Tom( 1949) and mysels in 1949 to have been useful in reducing the friction loss in turbulent flow. The term Drag Reduction is used to describe the reduction of friction force caused by turbulent flow inside a pipe or conduit, boosting the flowing rate as well as reducing the pressure drop. Drag Reducing Agent (DRA) is widely used in oil and gas industry over the years to improve the flow of oil and gas inside the pipeline.

The injection of DRA such as Polyacrylamide(PAM) is able improve the flow efficiency but the problem existed is that DRA is prone to degradation as it travels along the pipeline and exposed to high shear stress due to the turbulent flow. The DRA molecule could have partially degraded when the diameter of the pipeline changes, water or wax crystal is present or high velocity of flow. Once the molecule is degraded or destroyed, it can no longer perform the frictional-reducing action and the flow rate of the oil will be affected again. If DRA is to be used inside the pipeline to boost the flow capacity, continuous supply of the DRA fluid will be needed, which could cost extra cost.

The intention to look for the possible alternative to substitute Polymer DRA had drawn the path which lead to this research and study. The known option nowadays is wormlike micelle(WLM).WLM is well known for its viscoelasticity properties and strong surviving nature of reform after the molecular micelle chain is broken due to high shear rate, make it suitable to be inject into the pipeline with high rate of turbulent. Micelle can be used in different fields such as food emulsion, cosmetics, paints, air-conditioning, pharmaceuticals, adhesives and some household products. In this review, focus will be based on the wormlike micelle produced from different kinds of surfactant and how the concentration of salt in the wormlike micelle system can affect the rate of fluid flow inside a pipe conduit.

## 1.2 Problem Statement

The commercial polymer DRA that being used nowadays such as Polyacrylamide(PAM) is able to improve the flow efficiency. However, the limitation that existed is that this DRA is prone to degradation as it travels along the pipeline, especially when it is exposed to high shear stress due to the turbulent flow. The DRA molecule could have partially degraded when the diameter of the pipeline changes, water or wax crystal is present or high velocity of flow. Once the molecule is degraded or destroyed, it can no longer perform the frictional-reducing action. A continuous supply of the DRA fluid will need to be ensured in order to reduce the turbulent energy inside the pipeline as well as boosting the flow performance.

The next existing problem is the mixture of polymer DRA must be done on spot if injection is needed. The DRA will lost its effectiveness if the DRA fluid is prepared earlier, which might not give the drag reduce effect for the flowing fluid in the pipe. This problem will create issue for a offshore platform as large storage place is needed to store the chemical prior of injection into the pipe.

The intention to look for the possible alternative to substitute Polymer DRA had drawn the path to the research and study. The known option which might be able to replace the PAM is wormlike micelle(WLM). WLM is well known for its viscoelasticity properties and strong surviving nature of reform after the molecular micelle chain is broken due to high shear rate, make it suitable to be inject into the pipeline with high rate of turbulent.

## 1.3 Objectives and Scope of Study

### 1.3.1 Objectives

The research aimed to:

- Compare the efficiency of DRA and WLM in reducing the drag force
- Determine if WLM is a better alternative to inject into pipeline system compared to DRA
- Compare the efficiency of WLM made from different type of surfactant
- Determine the effect of salt concentration in a WLM system with respect with its performance
- Choose the best combination of surfactant and salt solution to form WLM
- The effect of temperature on the efficiency of WLM

### 1.3.2 Scope of Study

Rheology of fluid is focused in this research as both polymer and surfactant DRA will undergo deformation and their behavior during and after the deformation is very important. The different rheology of WLM and DRA is the main concern and factor that determine their ability in reducing the pressure losses and improving the fluid flow rate.

For polymer DRA, Polyacryalmide (PAM) is chosen as it is the most common DRA that utilized in the oil field nowadays.

For surfactant DRA, two kind of system are chosen. Cationic surfactant is the main surfactant to be studied in this research A Cationic surfactant DRA system consisted of Dodecytrimethyl Ammonium Bromide (DTAB) and Sodium Dodecyl sulfate(SDS) will be prepared. The DTAB/SDS will be kept in a constant molar ratio of 27/73. Another kind of Surfactant DRA will be prepared by mixing HexadecytrimetylAmmonium Bromide (CTAB) with sodium nitrate (NaNO3).

The polymer DRA and surfactant DRA will be test for their drag reducing ability and efficiency by a series of experiment such as shear stress, flow rate in horizontal and vertical pipe. The pressure drop before and after the addition of DRA will be observed and the effect of concentration of WLM on the drag reducing effect will be studied as well.

# CHAPTER 2:LITERATURE REVIEW

## 2.1 Introduction

Osborne Reynolds(1842-1912) had described the two parameter affecting the fluid flow which are viscous flow and the motion of the viscous fluid to balance the turbulent motion during a fluid flow. Tom (Toms 1949)then come out with his drag reducing technology and proved that the addition of little amount of polymer addictive can significantly decrease the turbulent flow. Nowadays, DRA is usually chosen as an inexpensive alternative to maintain the rate of flow instead of using a booster ump which require high installment and maintenance cost. Regardless of the effectiveness of polymer DRA in reducing the frictional pressure losses inside a pipeline, the major concern of using DRA is that the polymer will degrade easily and permanently upon shear stress and chemical reaction.

## 2.2 Type of Flow - Laminar and Turbulent

During an experiment did by Osborne Reynolds by injecting dye streak into the flow in a glass pipe, he observed that the dye streak formed smooth and straight flow line at flow rate of low velocity(Laminar), changing to burst of fluctuations with the increasing of flow velocity (Transitional) and end up with a zigzag with random flow line during flow at high velocity (Turbulent)(Çengel 2011).

During a Laminar Flow, the fluid particle is moving at constant axial velocity and there is no motion in radial direction, the velocity of the fluid particle is almost normal to the flow in every direction. Momentum or energy will be transferred along the streamline by molecular diffusion. The fluid flow in laminar is constant as there is no acceleration and deceleration, flow is said to be steady and is fully developed.

During a Turbulent flow, eddies is formed. Eddies is a kind of fluid particle that will move at random direction and rapidly. Those fluctuations caused by the eddies will create momentum and energy transfer. The problem for turbulent flow is that these eddies will transport energy and the momentum so much faster than the molecular diffusion, causing high value of friction, heat energy produced and reduced flow rate.

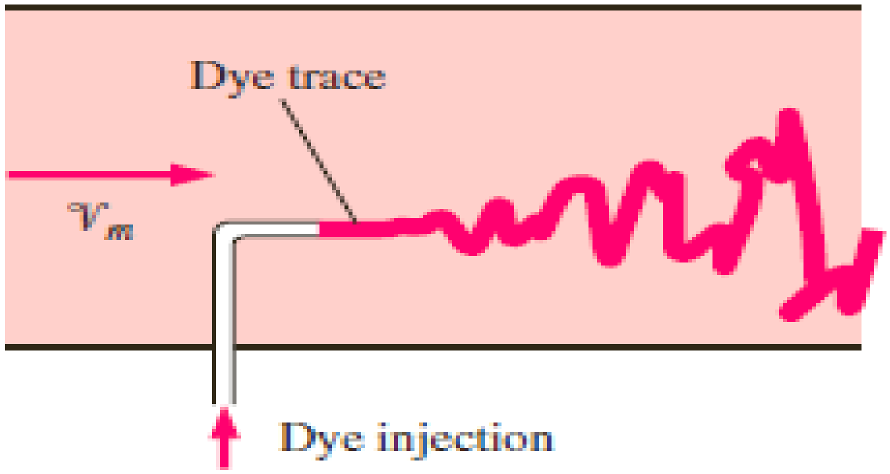


Figure 1: Turbulent Flow

(Source from Çengel, 2011).

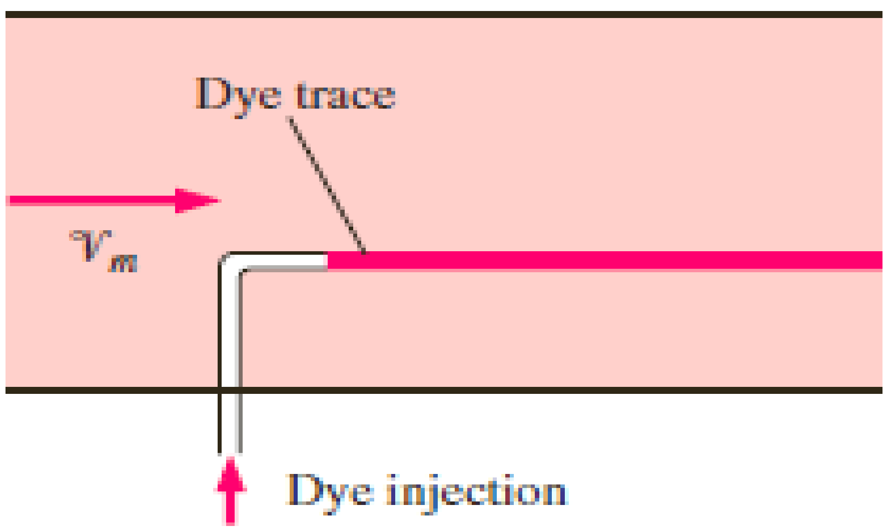


Figure 2: Laminar Flow

(Source from Çengel, 2011)

From the experiment, Osborne Reynolds discovered the flow regime depend mainly n the ration of Inertial Force over Viscous Force in a fluid, called Reynolds Number. Reynolds number of the sample fluid is expressed dimensionless quantity expressing the ratio between a moving fluid's momentum and its viscosity(Mechatronics).

The Reynold Number is expressed as internal flow inside a circular pipe:

$$Re = \frac{Inertial\ \ Force}{Viscous\ \ Force} = \frac{Vm\ D}{v} = \frac{\rho VmD}{\mu}$$

where

Vm = Mean/Average Flow Velocity (m/s)

D= Diameter of the pipe (m)

v= $\frac{\mu}{\rho}$ = Kinematic Viscosity for the sample fluid ($m^2$/s)

μ= Viscosity of the fluid

At critical Reynolds number, the fluid flow in the pipe will change from laminar to turbulent and the general accepted value for the critical Reynolds number is 2300. At low Reynolds numbers, the viscous force of the fluid is able to overcome the Inertial/frictional force, hence keeping the dye streak to flow in a straight line and form a laminar flow regime. However, when the Reynolds number getting large, the viscous force of the fluid is no longer able to control the rapid fluctuation of the fluid due to the large inertial force, forming a turbulent flow regime.

Table 1: The range of  Reynolds Number for each type of flow

| **Reynolds Number** | **Type of Flow** |
|---|---|
| Re< 2300 | Laminar Flow |
| 2300<Re<4000 | Transitional Flow |
| Re>4000 | Turbulent Flow |

Table above table shown the categorization of the type of flow with respect to the Reynolds number.

## 2.3 Flow in a Pipe

The area where the fluid closest to the pipe and exposed to shear stress is known as ***viscous sublayer*** or ***laminar sublayer***, flow at this layer is almost laminar. The middle layer is known as **buffer layer**, where there is little of energy to overcome the frictional pressure against the pipe wall maintain the "in-line" flow. The outermost layer is known as ***turbulent layer(***Skoda Research 2001***)***.

When the fluid flow and come in contact with the pipe wall, due to the transfer of energy and frictional between the fluid flow against the pipe wall, there will be a significant lost of energy for flow. Turbulent flow is formed due to these friction, the flow rate is decreased as the eddies is produced, the friction in the boundary will "drag" the fluid particle and tend to hold them in place at the buffer layer.

## 2.4 Drag Reducing Agent(DRA)

Drag Reducing Agent(DRA) were used in 1943 where drops of certain synthetic oil soluble polymer is added into pipeline of turbulent flow. The finding from the addition of DRA proved that there is reduction in fluid flow resistance. The commercial use of DRA was during 1979 where DRA is injected into pipeline in Trans Alaska(Burger, E.D 1982). Result shown from Trans Alaska Pipeline after the addition of DRA shown that the flow was increased for 200,000bbl/day (Wahl, W.R 1982).

When pipeline has been used over the years, due to corrosion, deposition, and frictional pressure, the flow rate is decreased. The Maximum Allowable Operating Pressure will reduce when the wall thickness reduce, continuing to use the same pipeline at high pressure will put the pipe on the risk of getting rupture. Some choices are available:

- Install New Pipeline (Very Costly)
- Reduce pressure ( will cause reduction in flow, production not economic)
- Install booster pump(Very costly)
- Using Drag Reducer (Low Cost)

DRA is chosen and is injected into the pipeline during production time to maintain the same rate of production, DRA will decrease the tendency of the vortices to produce and increase the flow rate without needed any extra equipment or energy. The addition of DRA and WLM will absorb the energy caused by eddies, resulting in smoother and more laminar flow(Çengel 2011).

DRA is able to perform excellently in reducing the "drag" caused by the frictional pressure in the buffer region and prevent the recirculation effect due to turbulent flow. DRA work by changing the viscosity of the fluid, reducing the Reynolds number and also cause the thickening of the buffer region. However, the disadvantage of polymer solution being used nowadays like DRA is that once it is exposed to shear stress, it will deform permanently and more DRA is needed to maintain the flow of oil inside the pipeline. Besides, due to different salinity and chemical reaction, the DRA will be destroyed and lose it function.

The efficiency of a polymer DRA is greatly affected by it concentration. As mentioned in the research by Virk in 1975, he mentioned that the quantity of a polymer which is its molecular weight will affect its drag reduction. The drag reducing effect will increase as larger quantities of polymer being used to dissolve inside the solvent.

However, the drag reduction will reach its maximum performance until a certain concentration of the DRA, which known as the maximum drag reduction (MDR). At this point, any further increase in the quantity of the DRA will have no effect in improving the drag reduction(Virk, P.S., 1975).


Figure 3: Layer of Flow inside pipeline.

( Retrieved from QFLO at http://www.drag-reducer.com). Without DRA, the flow is highly turbulent due to the eddies exiting inside the fluid flow. The buffer zone is thin during this flow.

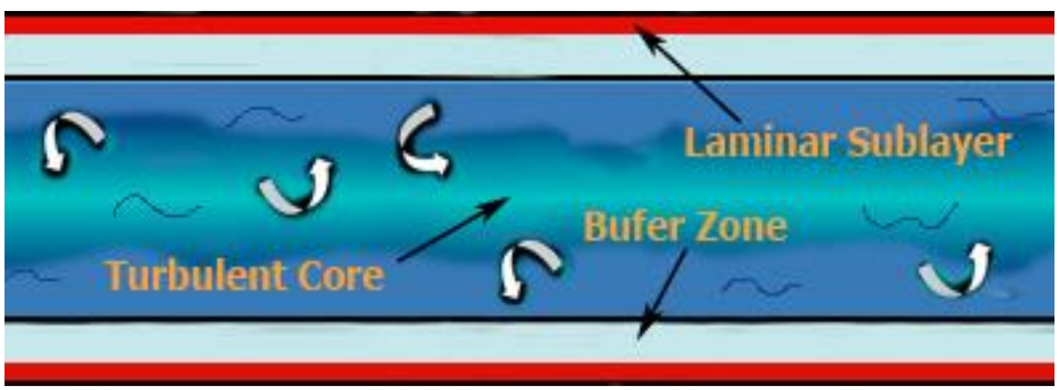


Figure 4: Flow with addition of DRA .

( Retrieved from QFLO at http://www.drag-reducer.com). The addition of DRA thickening the buffer layer. The thickening of buffer layer will help to reduce the turbulent energy created by the eddies, promoting a more laminar flow.

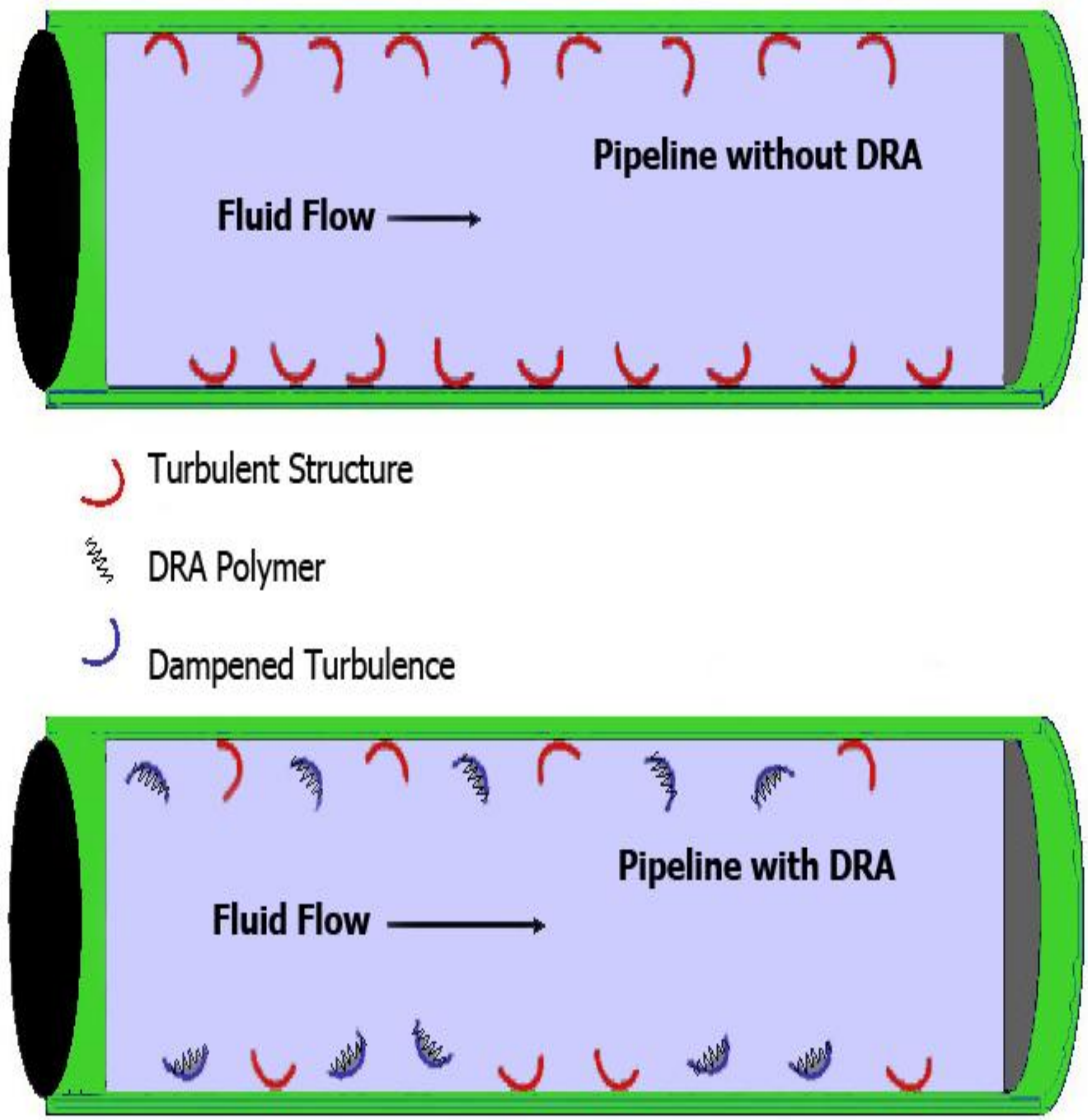


Figure 5: Dampening effect of DRA.

( Retrieved from QFLO at http://www.drag-reducer.com). The polymer from DRA will dampen the turbulent structure, reduce the energy in the flow rate. Therefore, the flow rate can be increased when the pressure drop can be reduced.

## 2.5 Wormlike Micelle(WLM)

The studies and researches done on wormlike micelle in recent years. Surfactant DRA is also known as wormlike micelle (WLM).. WLM is a viscoelastic polymer having high surface cavity, enable it to be apply in a wide range of different field such as personal and home product, personal product, cosmetics and many others.

Recent year, WLM is applied in oil field where WLM is used to produce viscoelastic surfactant(VES) in order to inject the propant down hole for hydraulic fracturing purposes. The "rheological drag reduction" is exhibited by WLM, which also known as "Toms effect", is studied and is expected to be applied in pipeline to reduce the energy losses like what polymer DRA had did over the past few years. This DRA is also been used in district heating and cooling systems, where the cold and hot water is produced from a central plant and later served to the surrounding area through pumping(Gyr A, 1995).

WLM is a self-assembled aggregates formed as a mixture of surfactant solution combine and the counter-ion in an electrolyte which can be found in bases, acids or salts. The surfactant can be of anionic, zwitterionic, non-ionic and cationic. Surfactants when add into the aqueous solution, will transform into different kind of microstructure such as micelles, liquids, crystal and vesicles.( Israelchvili, 1992) When the concentration of salt solution increase, the head group for the surfactant will decrease, promoting the formation of WLM.

Surfactant usually have a charged hydrophilic head and a short hydrophobic tail consisting of 8-20 carbon atom in the chain(Larson, R. G. 1999)Micelle will grow and can become microstructure like cylindrical, rod-like, rectangular, spherical and other as the polymer is entangled above a certain concentration, which known as critical micelle concentration(CMC)(Berret). The addition of salt into the aqueous solution will promote the growth of the small miceller aggregates' in term of their dimension and micelles of higher flexibility. At the molecular weight of about $10^6$, wormlike micelle will be formed(V 2007). The viscoelasticity can be achieved by the long and flexible entanglement transient network formed when salts or co-surfactant is added into the surfactant. WLM has a contour length varies from micrometer to nanometer, the overlapping and entanglement of WLM to form complex 3-D network structure made them a viscoelastic fluid, which is quite similar to a polymer chain(H. Rehage 1991).

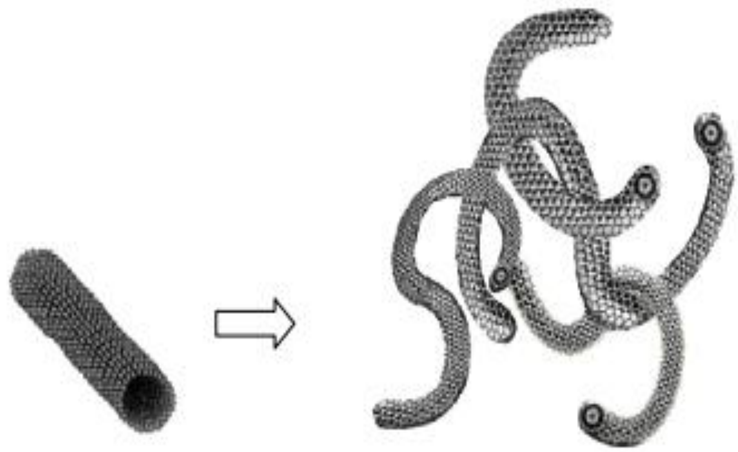

Figure 6: Wormlike Micelle

(Adapted from Ezrahi et al., 2000)

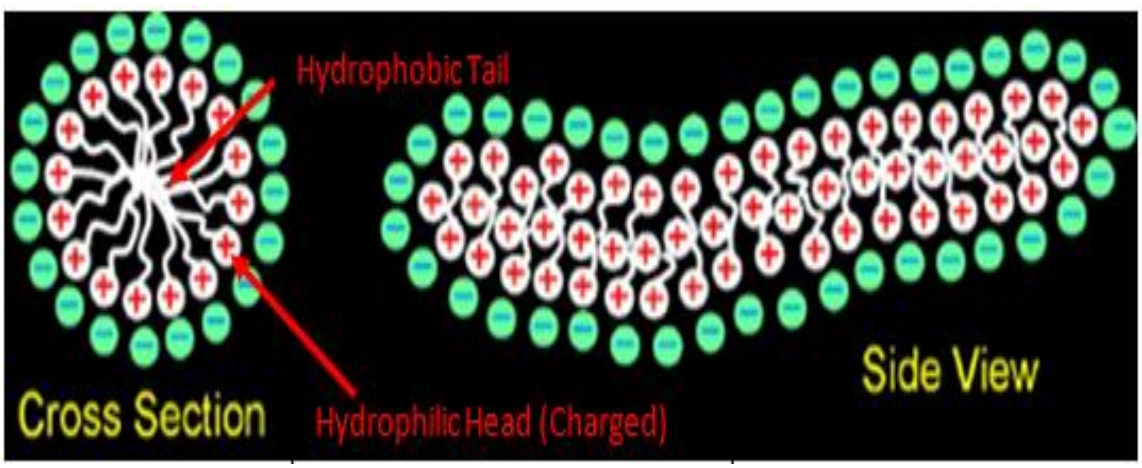


Figure 7: Schematic Diagram for a Wormlike Micelle

Above shown the schematic diagram for the wormlike micelle. The positively charged hydrophobic tail will attracted to each other and surrounded  by the negatively charged hydrophilic head from counter ion from salt solution.

The inter-rmicellar branch usually form at high salt concentration. However, condition like high surfactant concentration and temperature can reduce the length of WLM, which might affect the efficiency of WLM. Commonly used surfactant to produce WLM is from cationic and anionic can be used to form WLM too using the same procedure for cationic surfactant. Non-ionic surfactant can form WLM as well but the fatty alcohol ethoxylates is sensitive towards high temperature. For a zwitterionic surfactant having both positive and negative charged molecule, it offers a environmental-friendly advantage as it is biodegradable.

During the past research, Cationic surfactant like Hexadecyltrimethyl ammoniun bromide (CTAB) is capable of forming highly viscoelastic solution with the addition of salt solution(H Rehage, 1988). Research done shown that the micelle length is dependent on the concentration of salt solution. At a fixed amount of cationic surfactant CTAB, the increase of salt concentration ( will increase the curvature energy of the surfactant molecule and hence resulting in a longer micelle length..(K KUPERKAR, 2008 #5) The formation of wormlike micelle can also be formed upon the mixing of anionic surfactant (. R D Koehler, 2000).

The viscoelasticity of wormlike micelle carries both elastic and viscous properties. The molecules inside the polymer DRA is usually bonded covalently and rigid. However, the attraction that hold the micellar structure inside a WLM together is relatively weaker compared to ploymer DRA, this weak force allows WLM to continuously break and reform as times go, hence WLM is also known as "living polymer"(Cates 1990).WLM will deform when the equilibrium condition is disturbed(shear is applied) while reform after the equilibrium condition is restored (Shear stress is low or is removed).WLM is capable of reform after undergoing the shear stress during the flow, making it a stable and a better choice compared to DRA.

WLM behaves as a Non-Newtonian fluid like the polymer DRA. Its viscosity is very dependent on the shear stress. When exposed to high shear rate, the fluid will undergo shear thinning or shear thickening effect. As for the polymer DRA and surfactant DRA like WLM, shear thinning effect is indeed a significant properties. If the viscosity is reduced due to shear stress, this suggested that the molecular chain is undergoing stretching, which indicates that this DRA is capable of dampening the eddies current in a turbulent flow.

For this research, due to the lack of necessary machine and device to determine the existence of wormlike micelle in a surfactant system, the formula for the surfactant system to produce WLM is extracted from past research, which proven to be able to promote the formation of wormlike micelle. The research done by Kuperkar with his teammates in 2008 have proven that the mixtures of Hexadecytrimetyl-ammonium bromide (CTAB) and Sodium Nitrate ($NaNO_3$) can form WLM. The CTAB concentration for this project will be remained at 0.15M while varying the concentration(%wt) of NaNO3 from 0.2 to 1.0 with 0.2 increase for each interval.

There is a simple steps that could be taken to prove the existence of WLM in a surfactant system by observing the air bubbles formed in the solution. For a solution containing WLM, means that the solution is viscoelastic fluid, when given swirling(using a spatula) on the fluid continuously in circular direction, the bubbles will remain there and move in other direction when interruption is induced. The interruption can be changing the direction of the swirling by reverse the spatula movement. However, if the solution does not have any WLM, the bubbles will disappear when interruption is given. By having simple measures stated, the growth of the WLM can be determined for each of the solution produced.

## 2.6 Drag Reducing using Polymer DRA and Wormlike Micelle

The current DRA applied in oil field is made from polymer DRA system such as Polyacryalmide (PAM) and polymethyl methacrylate.

However, to produce WLM. Surfactant is the fundamental part of the WLM system. The major differences of using a Polymer DRA or Surfactant DRA will be compared and the comparison will be tabulated in the next page.

Both Polymer DRA and Surfactant DRA share the same ultimate goal and significant role in pipeline system, which is to reduce the pressure drop between the end of the pipe by dampening the eddies of turbulent currents, hence boosting the flow capacity for the pipeline. However, the ability of WLM to reform after experienced high shear stress condition is the main interest of various researchers to discover its possibility to be applied into the pipeline system.

Regardless of the cost and time to produce the most suitable WLM, WLM able to give a longer effect of drag reducing as compared to Polymer DRA .

Table 2:Difference between Polymer DRA ad WLM (Surfactant System)

| Polymer DRA | Criteria | WLM (Surfactant System) |
|---|---|---|
| Efficiency is affected by the concentration. Large amount of DRA is needed for higher efficiency of drag reduction. | Concentration | Small amount of WLM is needed to achieve the result of reducing the drag forces. |
| Less likely to be affected by temperature. | Temperature | Sensitive to changes in the temperature. |
| Undergo **permanent** mechanical degradation at high shear stress. | Reaction toward shear stress | Network of micellar deform at high shear stress but WLM manage to **rebuild its own structures**. |
| Biodegradable polymer is available but usage of synthetic polymer will cause problem. | Effect to Environment | Uncertainties exist but certain surfactant system is environmental friendly |
| Large quantities of DRA and storage spaces needed; big issue for offshore platform. | Limitation | No Limitation. Small quantities and small storage space needed. |

# CHAPTER 3: METHODOLOGY

## 3.1 Project Activities

The main activities which will be conducted in this research can be generally divided into 4 parts:

- **Research**
- **Procurement**
- **Experimentation**
- **Result Analysis**

During the research phase, paper from different authors were studied such as experiment report, research studies, conference proceedings, journal articles, books and many others. The research phase is aimed to get further information and knowledge on the subject before any work started. Besides that, meetings will be conducted to meet experience personnel such as lecturer and postgraduate student in order to have detailed explanation and improvement in knowledge. The main topic to be studied during research phase is DRA, WLM, Rheology of WLM, Experiment set-up, Material Selection and problem statement.

During the procurement phase, list of chemical, apparatus, devices and any related materials are to be prepared and confirmed for the experiment. The author will confirm with the lecturer and the lab technician regarding the available material that being provide and to make any necessary order according to the departmental financial budget. Devices and material from different department will be resourced for the experiment. Lastly, author will need to get the approval from the technician to utilize the needed material and make booking for the laboratory needed.

Experimentation is the phase where author will be conducting the test and experiment using the available resource. The efficiency of pure water flow, Water flow with addition of DRA, water flow with WLM will be compared. The objectives are such as the different concentration of WLM to affect the flow rate, the viscosity of WLM as a Non-Newtonian fluid, the drag reducing ability and shear stress will be discovered. The concept and problem statement for the research will be tested.

At the last stage, result analysis is to be performed to determine the if objective of research is achieved and result from the experiment is relevant and useful. Any observation and data will be noted down and included, further understanding and new theories perhaps then could me established by the end of the discussion.

### 3.2 Key Milestone

For the past key milestones, the author had managed to book for the equipment and queued up for the laboratory work, experiment had also been conducted in different laboratory. Meeting had been done with the supervisor to discuss about the research topic and the result gain. Any recommendation from the supervisor had been considered and carried out to improve the overall research result and experimentation.

The author has presented the data to the supervisor and any error had been corrected. Besides that, the author had also done with the presentation of VIVA to his supervisor due to the factor that the supervisor is leaving for his study soon in few weeks. The poster for this research topic had been produced and presented to the supervisor in order to prepare for the pre-sedex presentation in week 11.

Currently the key milestone for the research is the submission of dissertation of final year project report as well as the submission of technical report.

The milestones that expected to be achieved are to submit a finalized final project report, with a detailed result discussion and interpretation. The project report will cover everything including the cost analysis and the achievement of the project in term of the objectives and findings, the project will discuss the future work and any recommendation to improve the research topic.

## 3.3 Study Plan (Gantt-Chart)

Table 3: Gantt Chart for FYP 1

| **Activities** | **WEEK** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Selection of Project Topic | | | | | | | | | | | | | | |
| Preliminary Research Work | | | | | | | | | | | | | | |
| Submission of Extended Proposal | | | | | | | | | | | | | | |
| Proposal Defense | | | | | | | | | | | | | | |
| Project work continues | | | | | | | | | | | | | | |
| Submission of Interim Draft Report | | | | | | | | | | | | | | |
| Submission of Interim Report | | | | | | | | | | | | | | |

Table 4: Gantt Chart for FYP 2

| No | Detail/Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Project Work Continues | | | | | | | | | | | | | | | | |
| 2 | Submission of Progress Report | | | | | | | | | | | | | | | | |
| 3 | Project Work Continues | | | | | | | | | | | | | | | | |
| 4 | Pre-SEDEX | | | | | | | | | | | | | | | | |
| 5 | Submission of Draft Report | | | | | | | | | | | | | | | | |
| 6 | Submission of Dissertation | | | | | | | | | | | | | | | | |
| 7 | Submission of Technical Report | | | | | | | | | | | | | | | | |
| 8 | Oral Presentation | | | | | | | | | | | | | | | | |
| 9 | Submission of Project Dissertation | | | | | | | | | | | | | | | | |

## 3.4 Tools and Materials selection

Table 5: List of Tools and Materials

| Tools and Materials | Description |
|---|---|
| Brook Field Viscometer | • It is used to measure the effect of shear rate on the Non-Newtonian fluid such as shear thickening and thinning effect<br>• To measure the viscosity of the fluid |
| Tools and equipment to set up a pipe flow | • To measure the difference between pressure drop at the end of both pipe.<br>• To determine the efficiency of WLM and DRA in drag reducing of a turbulent flow |
| Conical Flask | • To prepare for the stock solution |
| Weighing Machine | • To measure the weight of the surfactant and the salt powder. |
| Measuring Cylinder | • To measure the amount of water needed for the mixture of the solution. |
| Water | • As the fluid to flow inside a aspirator and pipe flow |
| Stopwatch | • To calculate the time taken for the flow (Flow Rate) |
| Magnetic stirrer | • To stir the mixture until all the solute is dissolve in the solvent. |

Table 6: List of Chemical needed.

| | |
|---|---|
| Polyacryalmide (PAM) | • Drag Reducing Agent. |
| HexadecytrimetylAmmonium Bromide (CTAB) | • Surfactant used to produce wormlike micelle |
| Sodium Nitrate ($NaNO_3$) | • To add into the surfactant to promote the growth of wormlike micelle |
| Dodecytrimethyl Ammonium Bromide (DTAB) | • Surfactant used to produce wormlike micelle |
| Sodium Dodecyl sulfate (SDS) | • Surfactant used to produce wormlike micelle |

Hexadecytrimetyl Ammonium Bromide (CTAB) is available in the lab bought from Sigma-Aldrich in a powdered form contained in 100g container(**H5882-100G)**.

Dodecytrimethyl Ammonium Bromide (DTAB) is available in the lab bought from Sigma-Aldrich in a powdered form contained in 100g container(**D8638-25G)**.

Sodium nitrate, 99+%, for analysis is bought from Acros Organic in powdered form contained in 250g container

Sodium Dodecyl sulfate (SDS) is available in the lab bought from Fisher Scientific in a powdered form contained in 100g container.

## 3.5 Experimentation set up

Different kind of DRA will be tested for their efficiency in reducing the drag force for a flow as well as the pressure drops. The DRA will be tested are surfactant DRA, CTAB and polymer DRA,PAM.

### 3.5.1 Preparation of the chemical

1. Both the surfactant CTAB and and DTAB will be mixed with distilled water to the desired concentration.

2. A Cationic surfactant system consisted of DTAB and SDS will be prepared. The DTAB/SDS will be kept in a constant molar ratio of 27/73. The final concentration for both the mixture will be 140mM, 160mM, 180mM and 200mM.

3. Another WLM will be formed by mixing anionic surfactant (CTAB) with sodium nitrate ($NaNO_3$). The CTAB is fixed at a concentration of 0.15M while varying the concentration of NaNO3 of 0.2, 0.4, 0.6, 0.8, 1.0 (wt%).

4. Polyacryalmide (PAM) will be dissolved in distilled water at a concentration of 500, 1000, 2000 and 4000ppm

### 3.5.2 Experimentation

#### 3.5.2.1 Shear Stress vs. Viscosity Test

The mixtures will be tested for their viscosity. Viscosity is a measure of a fluid's resistance to flow and viscometer will be used to measure their resistance to flow upon different shear rate applied. The initial viscosity will be recorded. Shear stress will be applied to the solution and the viscosity after the shear test will be recorded. Different concentration of DRA will be bring to the test and to determine the behavior of DRA when exposed to shear stress.

During the test, Shear thinning or shear thickening will occur when Non-Newtonian fluid like DRA experience high shear stress. Shear thinning means that the viscosity of the sample fluid will drop when shear rate is increase and vice versa for shear thickening . For a successful and ideal DRA, a shear thickening effect is expected by the end of the experiment. This test is significant and must be carried out before the flow rate test is to be performed.

In this research, BrookeField viscometer from Chemical Engineering department is chosen. The different sample fluid will be place on the testing plate, then shear rate of 200rpm,400rpm,600rpm,800rpm and 1000rpm will be run for each sample fluid. The time for each shear rate will be set at 2 minutes (120 seconds) for stabaization of viscosity reading.

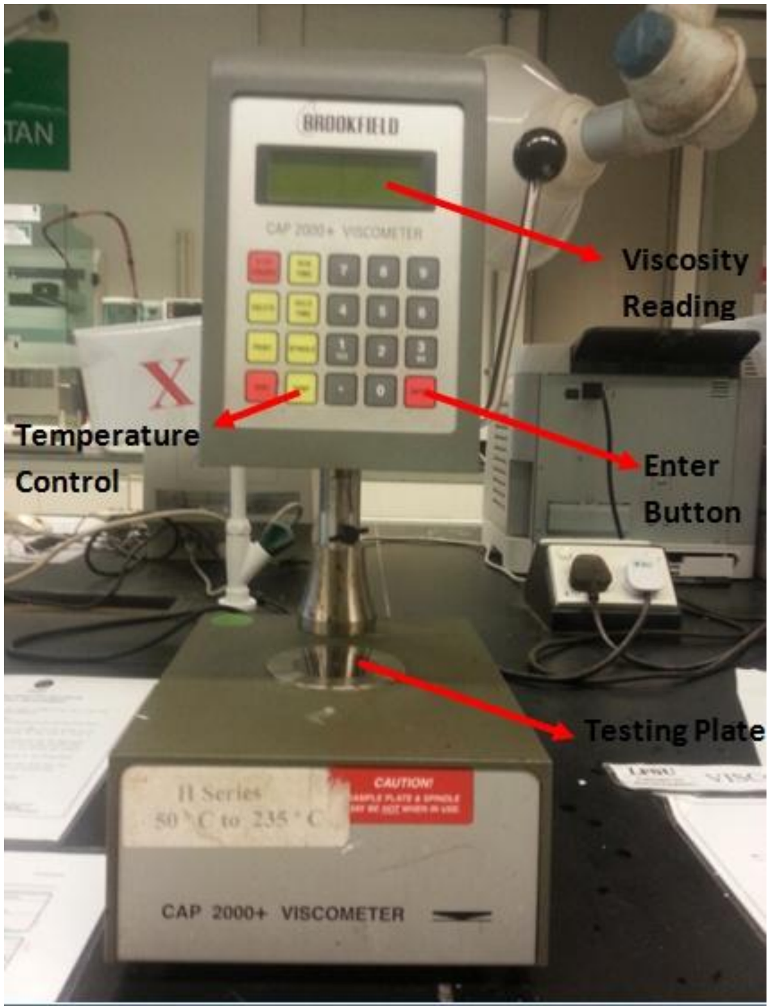


Figure 8: BrookeField Viscometer

Brooke Field visometer will be used to test for the viscosity for each sample fluid at different shear rate. All the test will be conducted in room temperature of 25 Degree Celcius.

#### 3.5.2.2Turbulent Flow Test

A turbulent flow experiment is to be designed to test for the efficiency of different DRA during a turbulent flow. Before applying DRA into the water, the turbulent flow rate for pure water will be run once as the reference case. Reynolds number will be calculated. The same test will be carried out over and over again until all the DRA with different system and concentration are tested. Then the Reynolds number before and after the addition of DRA will be compared.

Centrifugal pump is selected to be installed. Turbulent flow can be created when the power supply to the centrifugal pump is increased. The effect of DRA on the turbulent flow can hence be determined.

The amount of water used for each sample will be about 20liters. The time taken for the 20 liters of water to completely flow from one water tank to another will be recorded using a stopwatch. Hence using simple calculation , Flow Rate=Volume/Time, the flow rate Q can be easily calculated.

The changes in pressure between two ends of the pipe will be measured and it is expected to see the decrease in the change of pressure drop when DRA is applied into the flow rate test.

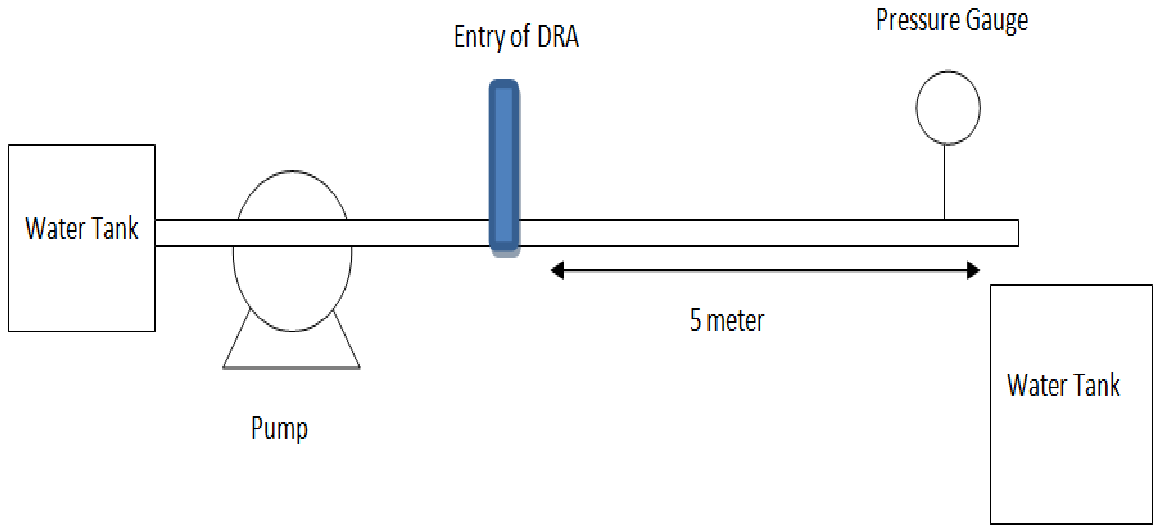


Figure 9: Proposed experiment design for a turbulent flow

# CHAPTER 4 : RESULT AND DISCUSSION

## 4.1 Experimentation

### 4.1.1 Preparation for Surfactant and Polymer DRA

#### 4.1.1.1 Mixture of CTAB and $NaNO_3$ WLM

The first Cationic Surfactant DRA being prepared is a CTAB and $NaNO_3$ Mixture. A total of 6 samples for the Surfactant DRA system were prepared at different salt solution concentration. The CTAB is fixed t be at 0.15M while the $NaNO_3$ salt solution is varied between 0.2 wt% to 1.0 wt%.

The final volume for each sample of different salt concentration will be of 200ml. Before that, a concentrated stock solution for both CTAB and $NaNO_3$ were prepared first they are mixed and diluted to the less concentrated final mixture.

Stock solution of 1 litre(0.3M) is prepared as the base solution. To prepare a fixed 0.15M of CTAB with a different concentration of $NaNO_3$, the amount of stock solution from CTAB and volume of salt solution has to be calculated. The mixture of both solution will later than diluted with certain amount of distilled water to the desired concentration. The volume needed for three of the solution are as shown below in the table.

Table 7: CTAB(0.15M) with different weight percentage(wt%) of Sodium Nitrate solution.

| **CTAB** | **Volume of CTAB** | **$NaNO_3$** | **Volume of $NaNO_3$** | **Volume of Distilled Water** |
|---|---|---|---|---|
| 0.15 M | 60ml | 0.2 wt% | 2ml | 138ml |
| 0.15 M | 60ml | 0.4 wt% | 4ml | 136ml |
| 0.15 M | 60ml | 0.6 wt% | 6ml | 134ml |
| 0.15 M | 60ml | 0.8 wt% | 8ml | 132ml |
| 0.15 M | 60ml | 1.0 wt% | 10ml | 130ml |

**To prepare for Stock Solution of CTAB ( 0.5 Mole):**

Molecular weight of CTAB (MW)= 364.45g/mol

According to the formula,

Concentration (M) = Mole / Litre

For a CTAB of 0.5M,

Mole x MW = 0.5(mol / litre) x 364.45 (g/mol)

=182.225 g/ litre

From the calculation above, to prepare a stock solution for CTAB of 0.5M, 182.225g of CTAB powder need to be mixed in 1000ml of distilled water

**Volume of 0.5M CTAB solution needed for dilution:**

To determine the volume of CTAB needed to extracted from 0.3M of CTAB solution to prepare 0.15M of CTAB, the following formula is used:

Concentration (A) x Volume (A) = Concentration (B) x Volume (B)

C1V1=C2V2

0.15M x 200ml = 0.15M x A ml

A=60ml

60ml of CTAB solution is needed to extracted from the 0.3M of stock solution.

**To prepare the Stock Solution of $NaNO_3$ ( 20wt%):**

20 weight percentage(wt%) of $NaNO_3$ solution simply means that 20 gram of $NaNO_3$ exist in 80ml of water.

20gram of NaNO3 powder is weighed and pour into the conical flask of 100ml. Distilled water is the poured into the conical flask to about 70ml. The mixture is then mixed and shake well with hand. When the NaNO3 is dissolved completely, the distilled water was added in again till the water level reached the 100ml water line on the conical flask.

**Volume of $NaNO_3$ salt solution of 20wt% solution needed for dilution:**

C1V1=C2V2

0.2wt% x 200ml = 20wt% x Aml

A=2ml

**Volume of distilled water needed to add into mixture to completion the dilution:**

Volume of distilled water = Final Volume - Volume of CTAB - Volume of salt solution

In this case, the final volume for each sample is set to be of 200ml.

Hence for the first case,

Volume of distilled water = 200ml - 60ml - 2ml

= 138ml

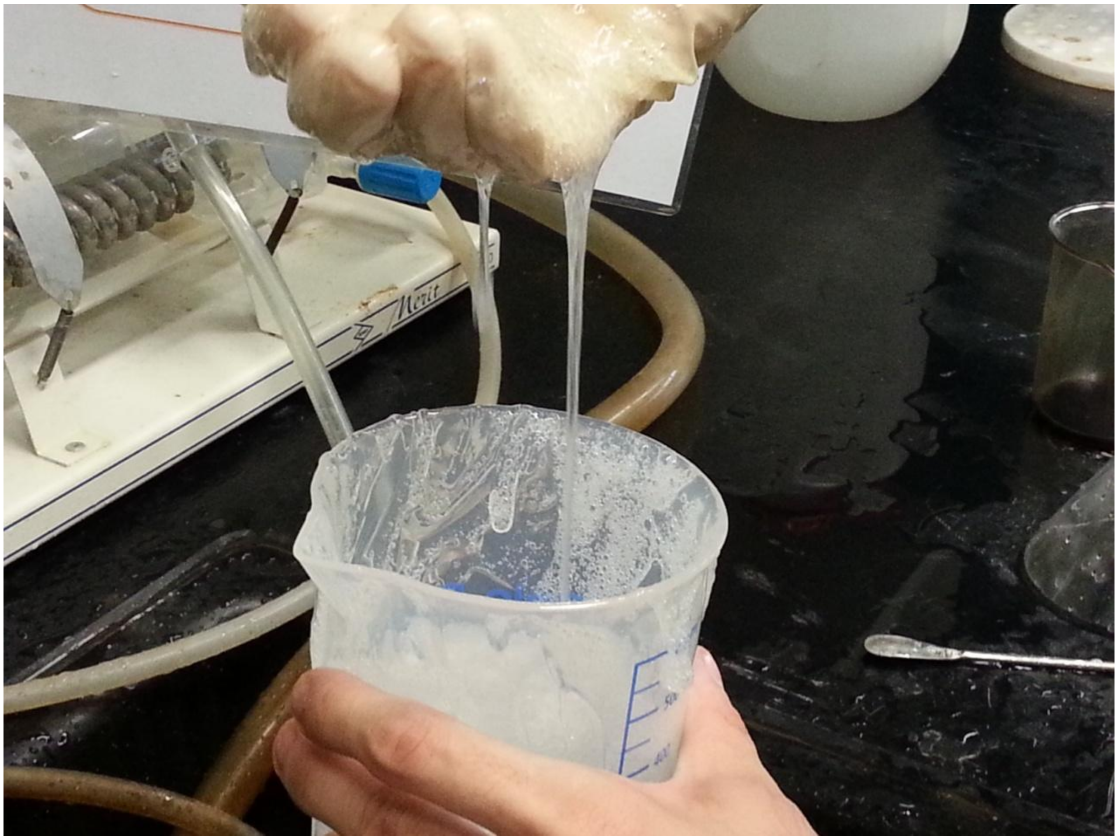

Figure 10: Formation of viscous WLM(Mixture of CTAB and $NaNO_3$)

The WLM formed from the mixture of CTAB and $NaNO_3$ is a highly viscous liquid.

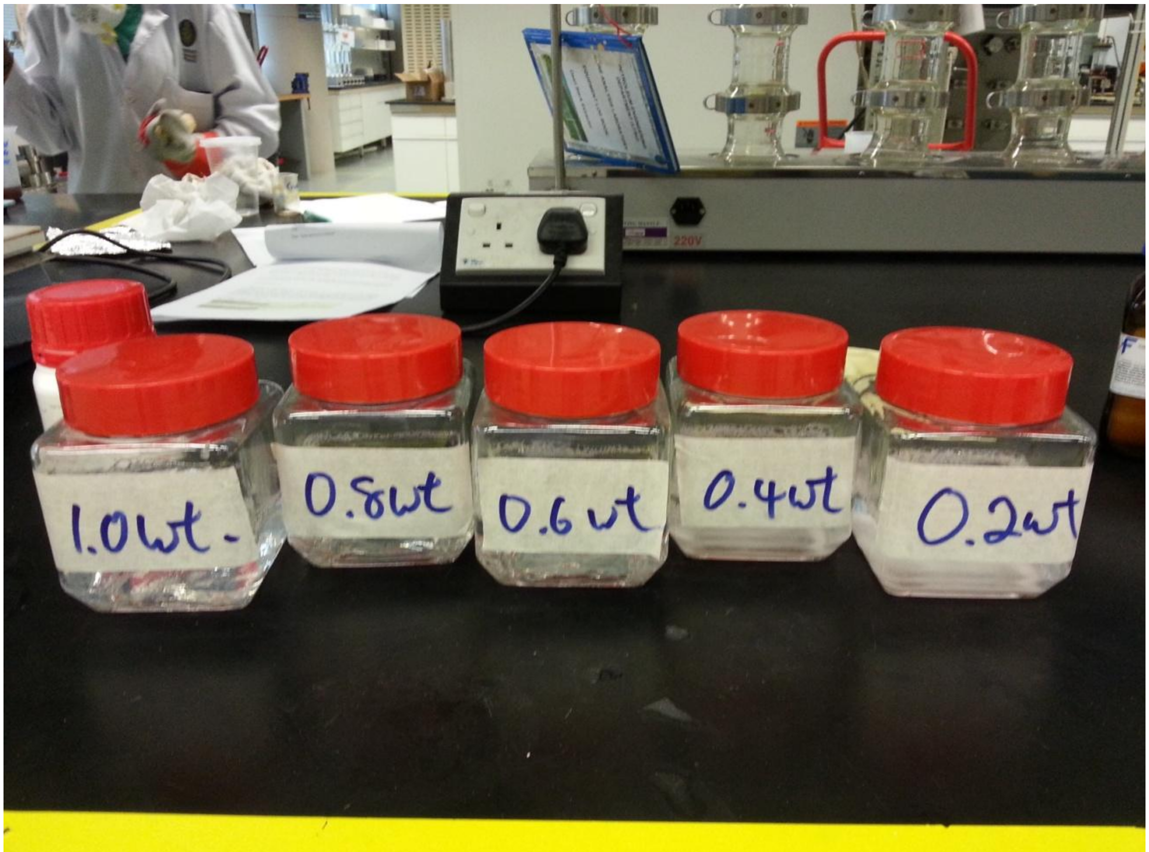


Figure 11: WLM ( DTAB + $NaNO_3$ )  of different concentration

The Mixture of CTAB at 0.15M with different salt concentration from 0.2wt% to 1.0wt% . All the sample were left for 2days for stabilization prior to further experimentation.

### 4.1.1.2 Mixture of DTAB and SDS WLM

The second Cationic Surfactant DRA system consisted of DTAB and SDS. The molar ratio of DTAB to SDS is kept at the constant of 27/73. However, the final concentration for this surfactant DRA is varied between 140mM to 200mM with 4 samples produced.

For every sample, a total volume of 400ml is produced.

**Preparation of DTAB and SDS with final concentration of 160mM:**

According to the technical data sheet for both the chemical, the molecular weight are:

DTAB = 308.34 g / mol

SDS = 288.38 g / mol

Assume,

DTAB =A while SDS = B

A / B= 27 / 73 -------------------------------------------**(1)**

A + B = 0.16 (160mM)---------------------------------**(2)**

By rearranging equation 1,

$$A = \frac{27}{73}B$$ -------------------------------------------**(3)**

Substitute equation (3) into (2)

$$\frac{27}{73}B + B = 0.16$$

B = <u>0.1168 Mole</u>

Since B= 0.1168,

A + B = 0.16

A = <u>0.0432 Mole</u>

From the calculation above, the concentration needed for DTAB is 0.1168 mole while SDS is 0.0432 mole. In order to determine the weight needed for both chemical:

For DTAB (0.1168 mole)

Mole x MW = 0.1168 (mol / litre) x 364.45 (g/mol)

= <u>33.68 g/ litre</u>

For this case, only 400ml of sample DRA is needed so the ratio of mass over volume can be reduce to:

33.68 g / 1000ml x 400 ml = <u>**13.48 g / 400ml**</u>

For SDS ( 0.0432 nole)

Mole x MW = 0.0432 (mol / litre) x 308.34 (g/mol)

= <u>13.32 g/ litre</u>

13.32 g / 1000ml x 400 ml = <u>**5.32 g / 400ml**</u>

Based on the calculation, 13.48 gram of DTAB and 5.32 gram of SDS is needed to dissolved in 400ml of distilled. The final concentration of the mixture will be of 160mM with a molar ratio of 27 / 73.

Both the chemicals were weighed using the weighing machine and was put aside. A conical flask of 400ml was chosen and the both chemical were poured into the conical flask. Distilled water was added till half full of the conical flask and was shake well. When the powder was observed to be completely dissolved, distilled water was added into the conical flask again until it reach the red line indicating the volume of water had reached to 400ml. The final mixture was shake again to make sure the mixture of the solution is even. Finally, the solution was poured into the glass container and kept at room temperature for at least 2 days for stabilization.

Table 8 : DTAB and SDS with fixed molar ratio of 27 over 73 at different final concentration.

| DTAB | SDS | Final Concentration |
|---|---|---|
| 4.66 g | 11.78 g | 140mM |
| 5.32 g | 13.48 g | 160mM |
| 6 g | 15.16 g | 180mM |
| 6.66 g | 16.84 g | 200mM |

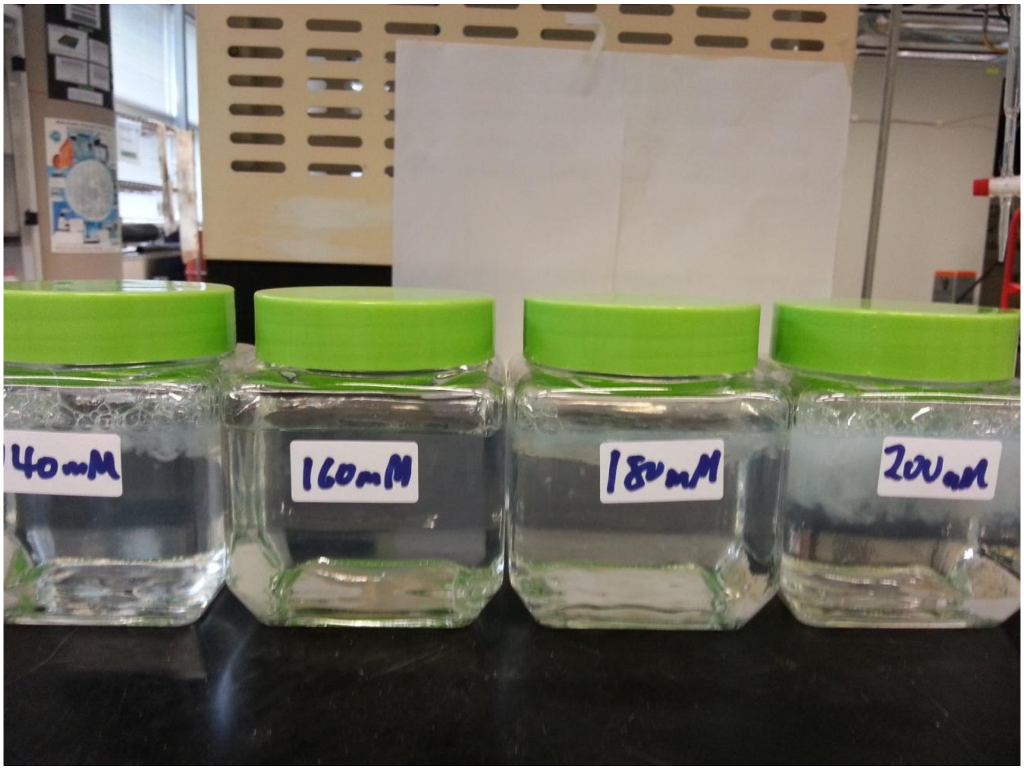


Figure 12 : WLM ( DTAB + SDS) of different final concentration.

The four samples formed using DTAB and SDS at different concentration is left for 2 days upon the completion of mixture. The sample formed a clear and highly viscous liquid after stabilization.

### 4.1.1.3 Preparation of Polyacryalmide(PAM)

Before the experiment for turbulent flow test, different concentration of polyacryalmide (PAM) are prepared. A total of 5 sample are prepared for the experiment with concentration of 500ppm, 1000ppm, 2000ppm, 3000ppm, 4000ppm. The difference in the concentration of PAM solution is required in order to determine the effect of PAM concentration in affecting the ability of the DRA to reduce the drag forces during a turbulent flow.

For all the five solution, a total of 150ml of PAM solution were prepared. Polyacryalmide(PAM) is in powder form and the amount of PAM powder needed to produce the desired concentration can be calculated using the simple calculation as shown below:

For example,

**To prepare a PAM solution of 500ppm.**

500ppm = 500 parts in one million (1 x$10^6$)

Hence,

$$\frac{500}{1{,}000{,}000}\,x\,150\,ml = \mathbf{0.075\,grams}$$

This simply means that in 150ml of distilled water, a 0.075 grams of PAM powder is needed to add into the distilled water in order to form a PAM solution having a concentration of 500ppm.

Table 9 : Amount of PAM powder needed for different concentration of PAM solution.

| Concentration of PAM solution (ppm) | Weight of PAM powder needed (g) |
|---|---|
| 500 | 0.075 |
| 1000 | 0.15 |
| 2000 | 0.3 |
| 3000 | 0.45 |
| 4000 | 0.6 |

## 4.2 Result and Discussion

### 4.2.1 Viscosity Test

All the sample prepared were brought to viscosity test using viscometer. Different shear rates were applied to the samples to test for their reaction upon the shear stress.

The viscometer chosen is Brook Field Viscometer. For this viscometer, six spindles is used to test for the sample with trial and error method. For each run, all the six spindles need to be used and the viscosity reading with the highest percentage of accuracy will be chosen.

The temperature is set to be at 25 degree Celsius. Using a syringe, a few drop of sample will be placed on the testing plate until it is enough to cover the entire surface of the spindle. After that, the shear rate will be set with a minimum of 200 rpm till 1000rpm. For each run, a total of 120 seconds is selected. The result shown will be recorded and tabulated.

Experiment is carried out for all the sample produced, which is surfactant DRA of CTAB and $NaNO_3$ as well as the surfactant DRA of DTAB and SDS. For all drag reducing agent regardless of Surfactant DRA or Polymer DRA, they generally exhibited the drag reducing ability to reduce the turbulent forces during the flow. The flow rate was increased after the addition DRA into the water tank. Among the three DRA, Surfactant DRA of CTAB and $NaNO_3$ proved their effectiveness by improving with the highest drag efficiency of 33.79% while Polymer DRA of PAM show a drag efficiency that read 20.25%, which is the lowest among the three sample DRA.

#### 4.2.1.1 Viscosity Test result for Surfactant DRA of CTAB and $NaNO_3$

Table 10 : Viscosity Reading for DRA of CTAB with different $NaNO_3$ Concentration

| Shear (rpm) / Concentration | 200 | 400 | 600 | 800 | 10000 |
|---|---|---|---|---|---|
| 0.2 wt% | 118 cp | 71 cp | 55 cp | 41 cp | 21 cp |
| 0.4 wt% | 1984 cp | 1027 cp | 488 cp | 315.8 cp | 108 cp |
| 0.6 wt% | 1279 cp | 388 cp | 344 cp | 117.5 cp | 4.3 cp |
| 0.8 wt% | 1658 cp | 711.7 cp | 409.7 cp | 92.5 cp | 70.8 cp |
| 1.0 wt% | 1453 cp | 739 cp | 498.8 cp | 191 cp | 184 cp |

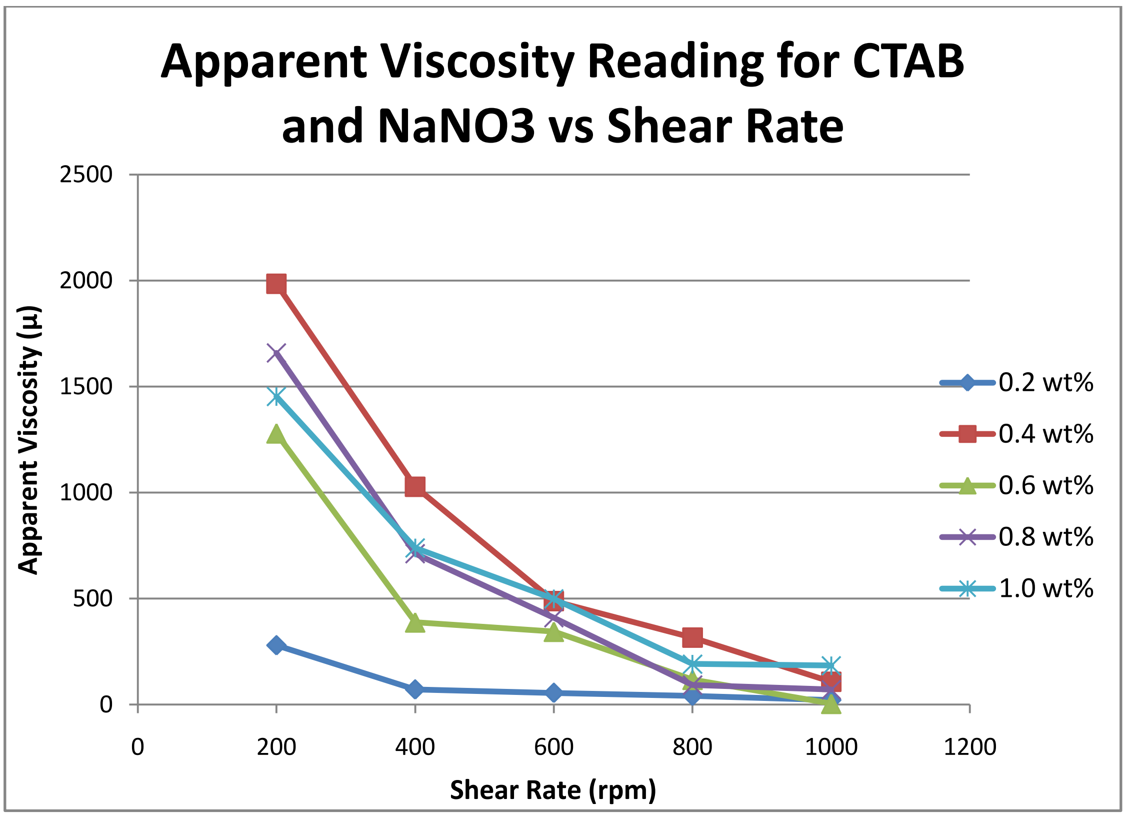


Figure 13: Apparent viscosity reading of CTAB and $NaNO_3$ vs. Shear Rate

Result from the viscosity test shown that for a Surfactant system consisted of CTAB and $NaNO_3$ at different concentration, the viscosity generally shown a decrease in the viscosity as the shear stress is increasing from 200 rpm till 1000 rpm. This phenomena can be described as Shear Thinning Effect. The shear thinning effect shown in the experiment signified that when shear is applied to the DRA, the micellar chains of the WLM is being broken or stretched.

As shown in the figure, for all the sample, the WLM DRA was initially at high viscosity. When the shear stress is applied, reduction in viscosity of the WLM was reflected. This reduction in viscosity continues as higher and higher shear stress was applied to the samples.

During production where oil is transported to the surface using the pipeline facilities , due to the turbulent flow, eddies current and energy will be formed and this will prevent the oil to flow smoothly in a laminar way. By injecting the DRA into the pipeline, the WLM DRA can actually absorbed the energy caused by the turbulent flows by dampening the eddies. During absorption of turbulent energy, the viscosity of DRA will decrease dramatically as the micellar chain is disturbed.

#### 4.2.1.2 Viscosity Test result for Surfactant DRA of DTAB and SDS

Table 11 : Viscosity Reading for DRA of DTAB and SDS with different Final Concentration

| Shear (rpm) / FInal Concentration | 200 | 400 | 600 | 800 | 10000 |
|---|---|---|---|---|---|
| 140 mM | 640 | 135 | 488 | 38.4 | 19.5 |
| 160 mM | 824 | 204 | 54 | 24.9 | 10.8 |
| 180 mM | 1860 | 975 | 326 | 73.5 | 17 |
| 1200 mM | 1582 | 1457 | 717 | 525 | 250.2 |

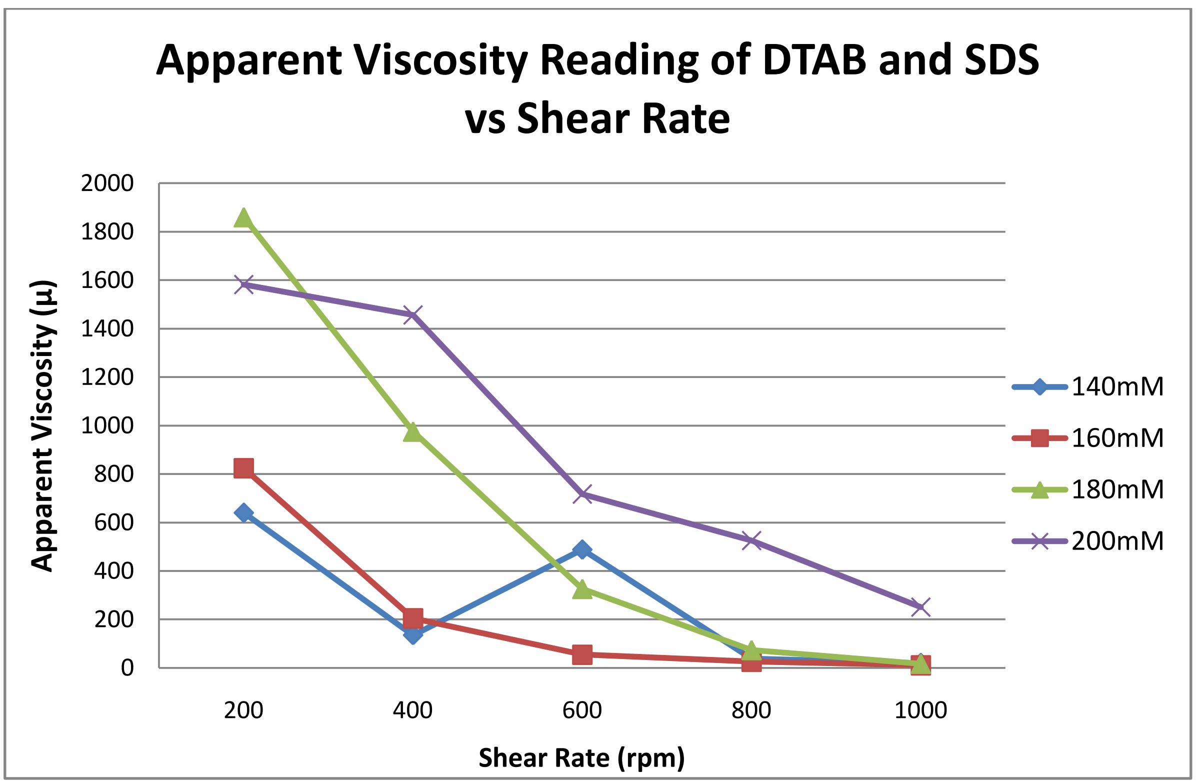


Figure 14 :Viscosity Reading of DTAB and SDS vs. Shear Rate

The next viscosity test was carried out using Surfactant DRA formed from DTAB and SDS with different final concentration but kept at a constant molar ratio.

The result and viscosity reading shown for this DRA is somehow similar to the previous experiment. Viscosity of the sample will reduce when higher shear stress is applied. The shear stress for this experiment also ranged from 200 rpm to 1000 rpm.

From the graph, by keeping the molar ratio of DTAB and SDS at a constant of 27 to 73, viscosity was observed to be varied as final concentration of the mixture is modified. The viscosity of the sample will increase when the final concentration of the Surfactant DRA mixture is increased. For the DRA mixture having a final concentration of 120 mM (0.0012M), the viscosity shown when a 200 rpm applied is 640 cp. However, when the final concentration is increased to 180mM, the viscosity shown when a 200 rpm of shear stress is applied is 1860cp. When the final concentration reached 200mM, the viscosity shown a slight decrease instead of increase. This might be due to the maximum concentration had achieved so any further increase in final concentration can no longer increase the viscosity of the sample.

Since shear thinning effect was observed for this sample, it is believed that the surfactant DRA produced using this formula could help to improve the flow efficiency inside an oil pipeline.

### 4.2.2 Flow Rate Experiment

A water suction pump with pumping power of 50 liter per minutes has been selected for the water flow experiment. The water pump is connected with two rubber pipe to two container of equivalent size. The water container is capable of containing 40 liter of water. The time taken for the water pump to pump the water from one container to another was recorded using a stopwatch. The experiment was first run with pure water while continue with a mixture of water and wormlike micelle. The difference between the two flow rate was recorded and compared. Besides that, a normal DRA of PAM was also mixed with water and run once for the water flow experiment. The efficiency of the commercial DRA of PAM and WLM were compared as well.

The flow rate for all the mixture of water and DRA as well as pure water can be computed using the simple equation as shown below:

$$Flow\ Rate\ (Q) = \frac{Volume\ (Litre)}{Time\ (Second)}$$

Whereas, to compute the drag reducing efficiency of the DRA. The simple calculation can be achieved by using the formula as shown below:

$$Efficiency(\%) = \frac{Flow\ Rate\ with\ DRA - Pure\ Water\ Flow\ Rate}{Pure\ Water\ Flow\ rate}$$

After the experiment has been carried out, it was recorded that the time taken for the water pump to pump pure water of 40 liter from one container to another is around 55.19 seconds. This means that the water pump is capable to pump water at a flow rate of 0.725 liter per second.

For all drag reducing agent regardless of Surfactant DRA or Polymer DRA, they generally exhibited the drag reducing ability to reduce the turbulent forces during the flow. The flow rate was increased after the addition DRA into the water tank. Among the three DRA, Surfactant DRA of CTAB and $NaNO_3$ proved their effectiveness by improving with the highest drag efficiency of 33.79% while Polymer DRA of PAM show a drag efficiency that read 20.25%, which is the lowest among the three sample DRA.

#### 4.2.2.1 Flow result for Polymer DRA of Polyacryalmide(PAM)

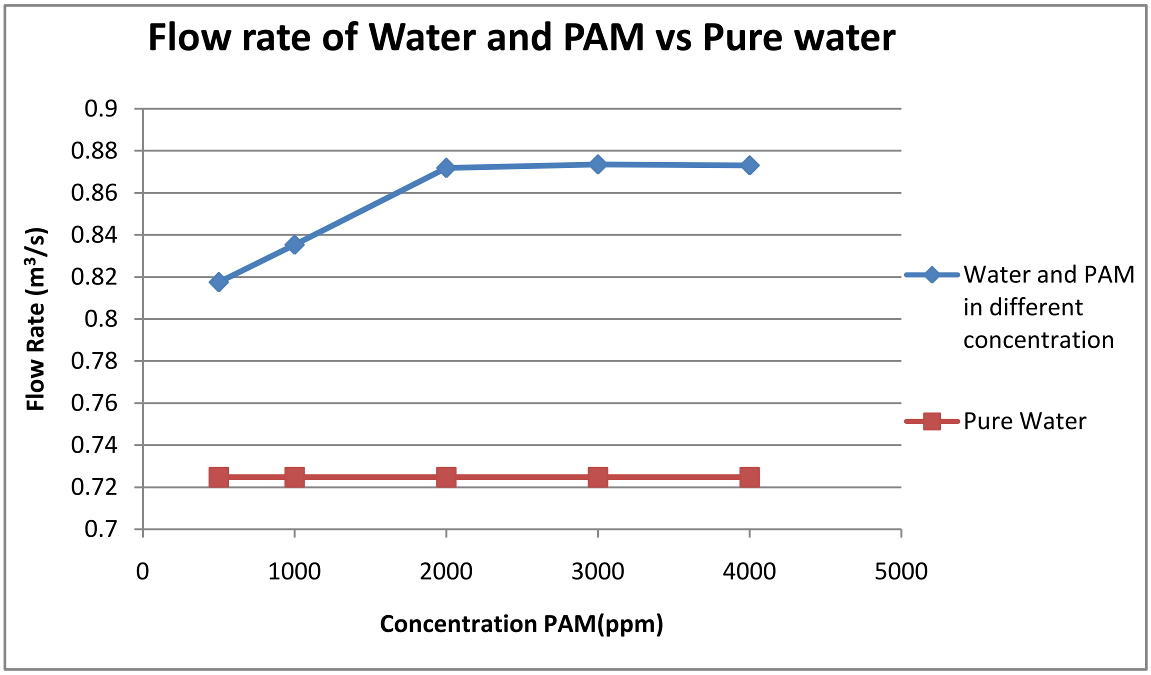


Figure 15: Graph showing the flow rate of PAM with water vs Pure Water

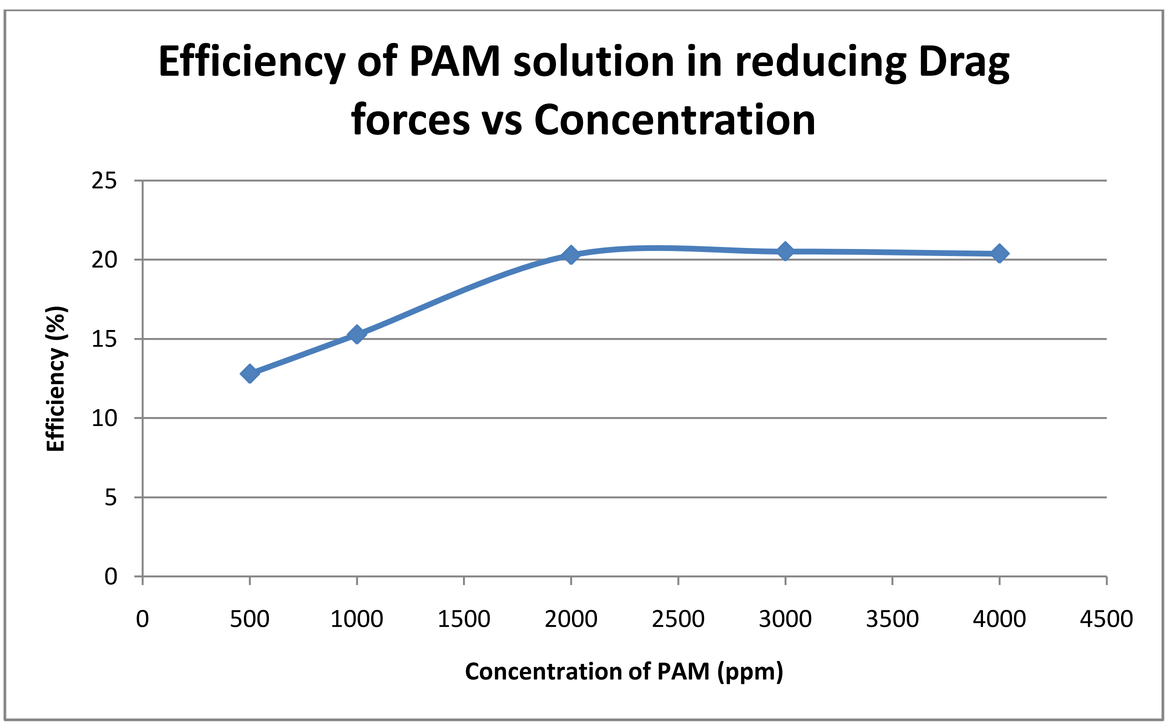


Figure 16:Graph showing the efficiency of PAM in reducing drag forces vs Concentration

As shown in the graph above, PAM solution of polymer DRA had improved the flow rate of the water. Polymer DRA which is currently being applied in the oil field had proved its ability in reduce the drag forces during a turbulent flow in order to promote a more laminar flow, hence improving its flow rate. Compared with the water flow test did on purely water which give a flow rate of 0.725 liter per second, PAm had proved its efficiency by increasing the flow rate from 0725 to 0.817 liter per second with a PAM concentration of 500ppm. The flow rate shown improvement from 500ppm till 2000ppm and when the concentration exceeding 2000ppm to 4000ppm, the flow rate remained constant. The maximum flow rate that can be achieved by PAM solution is around 0.87 liter per second.

As salt concentration increases from 500ppm to 1000ppm and 2000ppm, the flow rate shown a gradual increase. The increase in the flow rate indicates that when concentration of PAM solution increases, there is more number of polymer DRA molecule that existed in the PAM solution to carry out the drag reducing action. When more DRA molecule is in the PAM solution, more turbulent energy can be absorbed by PAM and the drag reducing efficiency can improved as well. However, when the concentration of PAM reached 2000ppm, any further increase in the concentration of PAM can no longer improve the flow rate. This can be explained where the maximum efficiency of DRA had been reached. As this maximum point, the polymer DRA at 2000ppm already had enough DRA molecule to remove most of the drag forces during the turbulent flow so any addition in the number of DRA molecule will be just redundant.

From this experiment, the efficiency of the polymer DRA when mixed with water can improve the water flow rate to a a maximum efficiency of 20.52%. The flow rate when the maximum efficiency is achieved is 0.87 liter per second.

#### 4.2.2.2 Flow result for Surfactant DRA of DTAB and SDS

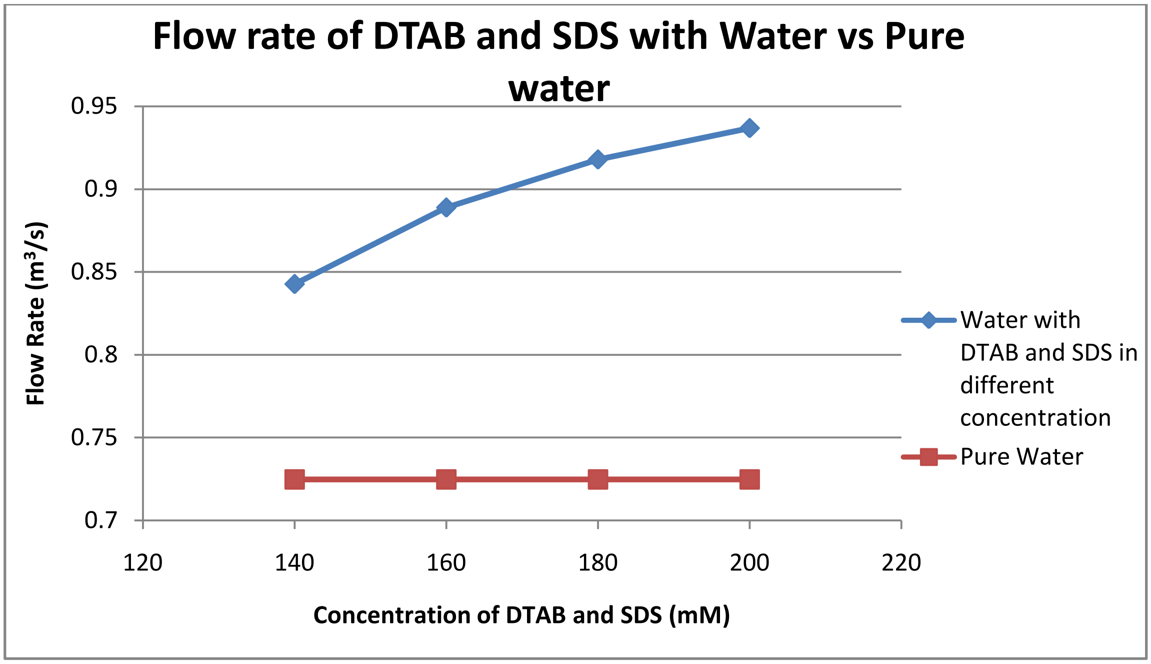


Figure 17:Graph showing the flow rate of DTAB and SDS with water vs Pure Water

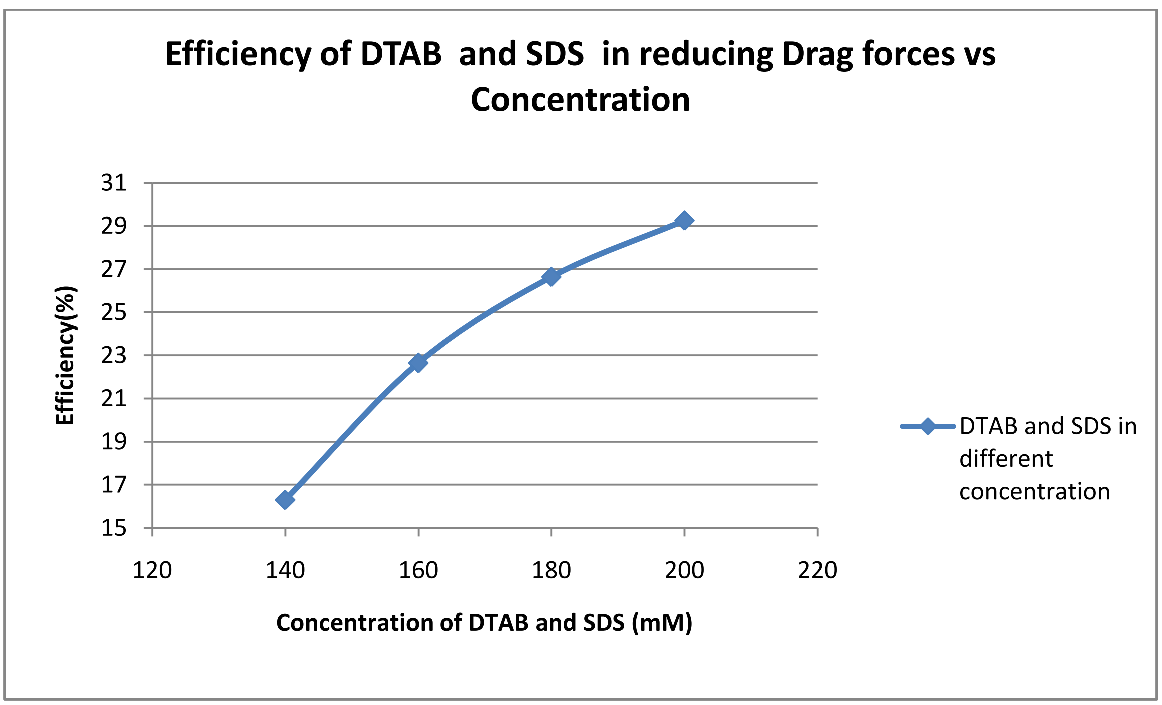


Figure 18:Graph showing the efficiency of DTAB and SDS in reducing drag forces vs Concentration

Based on the graph, The WLM system formed by mixing DTAB and SDS generally shown an improvement in flow rate when they are added into the water. The surfactant DRA produced can efficiently improve the flow rate by reducing the frictional forces as well as the turbulent energy that created when the water comes in contact with the pipe wall during the flow test. The experiment also started by running the experiment once with pure water as a comparison. Result from the water flow test using pure water gives a flow rate that read 0.725 liter per second. Upon the addition of DTAB and SDS mixture into the water container and started the pumping, the water flow rate had improved from an initial water flow rate of 0.725 liter per second to 0.84 liter per second. The concentration for the mixture of DTAB and SDS first being applied is 140mM.

As the final concentration for the mixture of DTAB and SDS increases from 140mM to 200mM, the flow rate increases. The water flow rate can be improved by using a higher concentration of WLM for this system. The increase in flow rate can be reasoned when their final concentration increases, there will be more and more micellar chains formed in the WLM system. When concentration increases, the micellar chain will becoming stronger and more complex. The increase in the number of micellar chain and the complication of its network structure is the main key. As micellar bond get stronger and large in quantities, more drag energy can be absorbed by the micellar networks. Hence, the WLM can perform better in reducing the turbulent energy and improving the overall flow rate.

The efficiency of this surfactant DRA can help to improve the water flow rate till a maximum efficiency of 29.25%. The flow rate when the maximum efficiency is achieved read 0.94 liter per second.

This experiment can help to conclude that WLM made from DTAB and SDS can perform drag reducing job and considered as a ideal surfactant DRA.

#### 4.2.2.3 Flow result for Surfactant DRA of CTAB and NaNO3

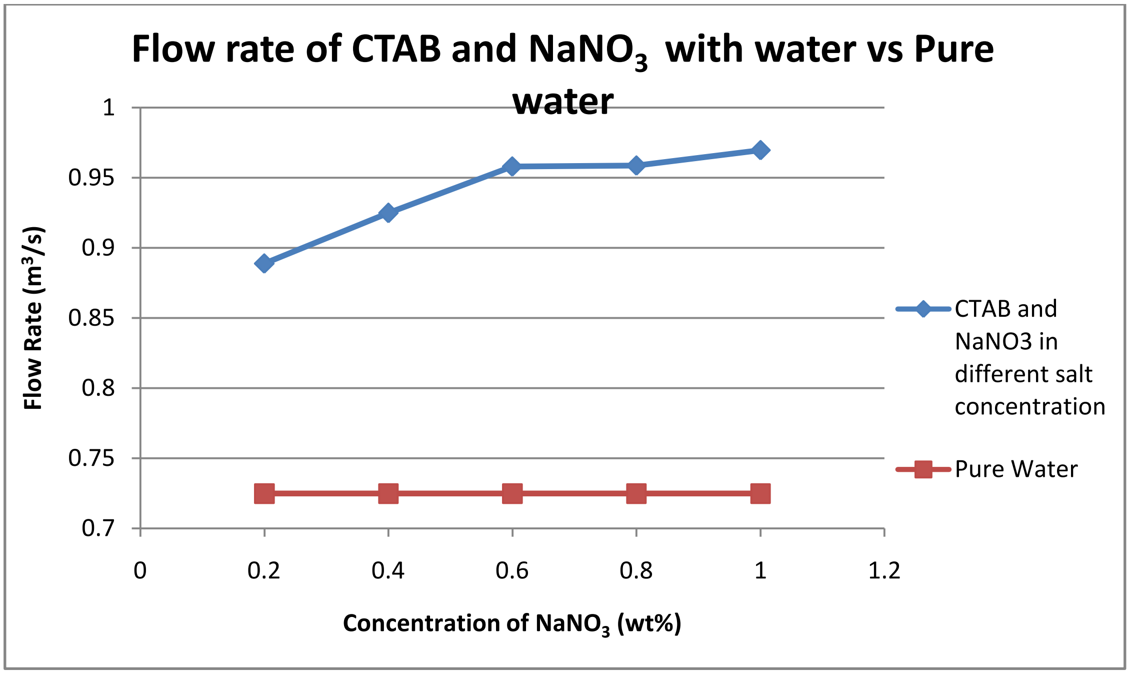


Figure 19: Graph showing the flow rate of CTAB and NaNO3 with water vs Pure Water

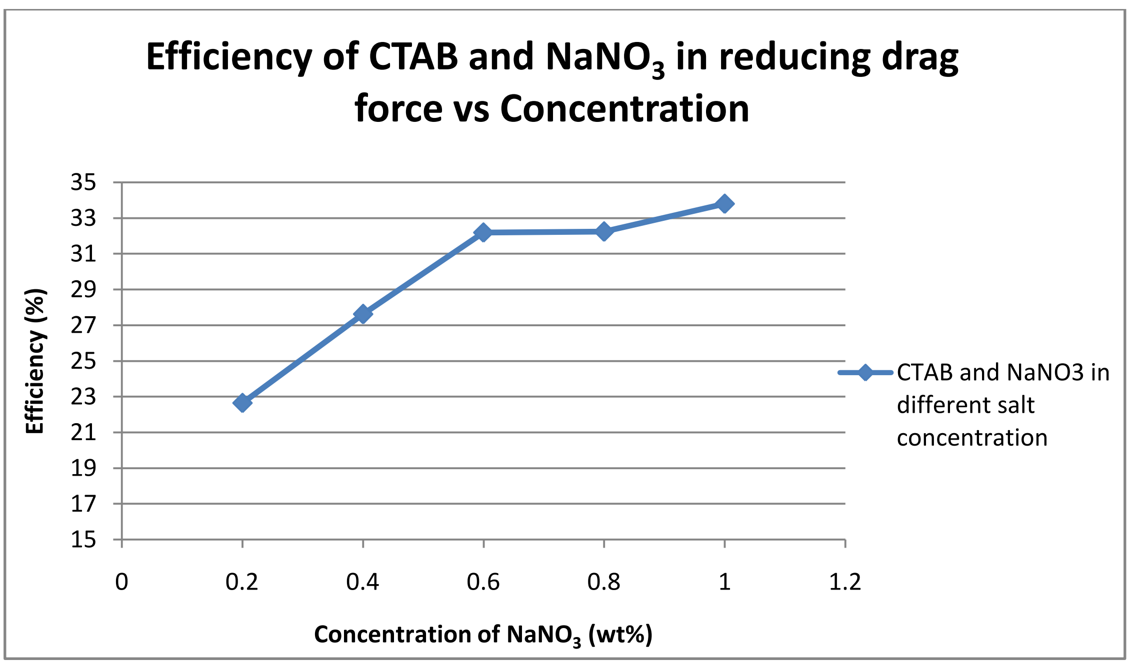


Figure 20:Graph showing the efficiency of CTAB and NaNO3 in reducing drag forces vs Concentration

From the graph, it is obvious that CTAB and $NaNO_3$ can indeed improve the flow of water by reducing the drag forces during a turbulent flow inside pipeline. Pure water was run before the addition of surfactant DRA is to be added into it. The purpose to run the pure water is to get the original water flow rate so it can be used as a base case and also as a reference to compare the changes before and after the addition of surfactant DRA. In this experiment, the original water flow without any DRA is 0.725 liter per second. Upon the addition of WLM system consisting CTAB and $NaNO_3$ into the water, the water flow rate shown an improvement from 0.725 liter per second to 0.97 liter per second.

As salt concentration increases, the flow rate shown a gradual increase. This means that WLM work better as the salt concentration is increasing. The increase in flow rate could be due to the reason that when salt concentration increases, the number of wormlike micellar chains formed in the WLM system increases as well. The increase in number of micellar chains means that more turbulent energy or drag forces can be absorbed and the flow will be relatively more laminar in WLM of higher concentration of salt.

From this experiment, the efficiency of the surfactant DRA when mixed with water increased the water flow rate to a maximum efficiency of 33.79%. The flow rate when the maximum efficiency is achieved is 0.97 liter per second.

The result from this water flow test indicates that WLM can perform drag reducing job as a normal polymer DRA and is believed to be able to apply into the oil pipeline to reduce the turbulent energy and improving the flow rate. The WLM system made up of CTAB and $NaNO_3$ had become the best DRA so far as compared to PAM and DTAB with SDS.

### 4.2.3 Cost Analysis

Table 12: List of Price for the Chemicals.

| Chemical | Price per bottle | Price per gram |
|---|---|---|
| Hexadecytrimetyl Ammonium Bromide (CTAB) | RM254.15 (100 gram) | RM 2.54 |
| Sodium nitrate ($NaNO_3$) | RM 101 (250 gram) | RM 0.40 |
| Sodium Dodecyl sulfate (SDS) | RM 266.49 (100 gram) | RM 2.66 |
| Dodecytrimethyl Ammonium Bromide (DTAB) | RM1322.48 ( 100 gram) | RM 13.22 |
| Polyacrylalmide (PAM) | RM220.50 (500 gram) | RM 0.44 |

Table 13: Comparison of price for the chemical used to produce the same flow efficiency.

| DRA | Efficiency | Chemical Price | Chemical Price | Final Price |
|---|---|---|---|---|
| Surfactant DRA of CTAB and $NaNO_3$ | 22.64% | CTAB (10.93g) = RM27.77 | $NaNO_3$ (1 g) = RM 0.08 | RM27.85 |
| Surfactant DRA of DTAB and SDS | 22.64% | DTAB (5.32g) = RM70.33 | SDS (13.48g) = RM 35.85 | RM106.18 |
| Polymer DRA of PAM | 20.52% | PAM (0.45g) =RM 0.20 | | RM0.20 |

Table 14: Comparison of price for the chemical used to produce the highest flow efficiency.

| DRA | Efficiency | Chemical Price | Chemical Price | Final Price |
|---|---|---|---|---|
| Surfactant DRA of CTAB and $NaNO_3$ | 33.79% | CTAB (10.93g) = RM27.77 | $NaNO_3$ (0.2G) = RM 0.40 | RM28.17 |
| Surfactant DRA of DTAB and SDS | 29.25% | DTAB (6.66g) = RM88.05 | SDS (16.48g) = RM 43.84 | RM131.89 |
| Polymer DRA of PAM | 20.52% | PAM (0.45g) =RM 0.20 | | RM0.20 |

From the table above, the price to produce WLM using CTAB and $NaNO_3$ to yield the efficiency around 20% will be RM 27.85 and will a total of RM 28.17 in order to improve the water flow efficiency to 33.79%. WLM of DTAB and SDS is way more expensive as the improvement is not that impressive yet cost over RM100. Whereas for PAM, it is the cheapest among the three DRA and cost only RM0.20.

However, the PAM is prone to mechanical degradation and a large amount of DRA will need to produce and stored in order to maintain flow rate at platform and the large storage place is the greatest concern for an offshore platform. WLM of CTAB and $NaNO_3$ is recommendable as it is not that expensive and yet, it can boost the flow efficiency up till 33.79 %.

Unlike PAM, WLM is not prone to mechanical degradation, WLM has the ability to reform its own network structures after they react upon the turbulent energy during the flow. Their ability to reform the structure enable them to carry out the drag reducing task more efficiently than PAM as only small quantity is needed. Since WLM only needed in small quantity, it can actually help to solve the problem of finding a big storage place contain the PAM especially at offshore platform which having limited space.

The choice to use PAM or WLM of CTAB and $NaNO_3$ is actually a quantity vs quality case. It is recommendable that WLM is chosen to be injected into the pipeline, even the cost of this WLM is more expensive than polymer DRA of PAM, WLM of this system only required in small quantity and the small quantity can perform a longer period of drag reducing task when we apply it in the oil and gas pipeline.

# CHAPTER 5: CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

The WLM for both system were formed successfully in this research and both were highly viscous liquid. The first WLM being formed is the mixture of CTAB and $NaNO_3$ with different concentration of $NaNO_3$ while another WLM being produced was DTAB mixed with SDS with different final concentration while keeping the molar ratio of a constant of 27 (DTAB) to 73 (SDS). These liquid were stored in the lab for 2 days for stabilization before the commencement of experiment and test.

In the first part of the experiment, which is to test for the apparent viscosity of WLM upon the shear rate. Result from the viscosity test shown that for both the WLM, even at different salt concentration, all the sample shown reduction in viscosity when the shear rate is increased. This result simply indicate that both the WLM system are Non-Newtonian fluid, while the phenomena of viscosity reduction is known as shear thinning effect. Shear thinning effect is a desirable properties for a drag reducing agent in order to reduce the drag forces in a turbulent flow inside a pipeline. When shear thinning was observed during high shear rate, we can conclude that the inter-miceller chains in WLM is undergoing stretching and the chain is being broken, making it more capable of dampening the eddies current in a turbulent flow.

After the viscosity test and the WLM proven to be a Non-Newtonian fluid which exhibit shear thinning properties, the research was brought to the next step, which is water flow experiment. Two WLM made of different chemical were brought to water test and their efficiency was compared with the pure water flow test. Besides that, a commercial polymer DRA, PAM solution of different concentration also produced and tested for their efficiency in the water flow test. The first WLM made from CTAB and $NaNO_3$ managed to improve the fow rate with a maximum efficiency of 33.79% while a maximum efficiency of 29.25% for WLM made of DTAB and SDS. Both the WLM has a higher flow efficiency as compared to the PAM which provide the maximum efficiency of 20.52%.

WLM is much efficient as they are considered as "living polymer" as they are able to reform their own network structure even when their structure is destroyed by the high shear stress. Unlike WLM, PAM do not have the ability to reform their own DRA structure when exposed to high shear stress. The unique properties exhibited by WLM give them a long lasting effect when we compare it with PAM which can only reduce the drag forces in a turbulent flow temporarily.

The higher flow efficiency for both the WLM as compared to PAM suggested that WLM is having the potential to replaced PAM in oil pipeline. WLM is believed to be an alternative solution for polymer drag reducing agent.

## 5.2 Suggestion and recommendation for future work

In this research, due to the limitation that the water pump in the lab is not suppose to come in contact with oil and hence only water is chosen as the medium to run the water flow test. However, in oil field, the reservoir usually is produced in multi phase fluid rather than single phase flow such as pure water flow. It would be great that if a water flow experiment with multiphase flow can be carried out. The multiphase flow can be achieved by simply adding a few droplets of oil into the water. The result produced from this multiphase flow will be even more accurate and can represent the real flow in the oil pipeline better.

Besides that, the experiment for viscosity and water flow measurement are carried out both in normal room temperature. In the real oil field, the temperature will be even higher as we want to avoid the formation of hydrates and waxes inside the pipeline. It is suggested that for the future experimentation, the viscosity test can be done using the High Pressure High Temperature(HPHT) viscometer. Due to the breakdown of HPHT viscometer in the lab, the apparent viscosity of the WLM upon the induction of shear stress when they are in high temperature cannot be run. Apart from that, a warmer water can be chosen as a medium to run the turbulent water flow test. The warmer water can be achieved by installing a heater in the water container at inlet point. By improving and increasing the temperature for both this experiment, a better result can be acquired.

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