Drag-Reduction Effectiveness of Xanthan Gum in Water Flow System

by

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JULY 2011

CERTIFICATE 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.

Awang Muhamad Safuan Bin Awang Sapawi

ABSTRACT

Drag reduction is the reduction of pressure drop and skin friction in turbulent flows. This is achievable by adding Drag Reducing Agents (DRA) such as polymers, surfactant solutions and fiber particles. This investigation focuses specifically on the potential of the Xanthan gum polymer as a DRA. The efficiency of water flooding and water injection is limited to the maximum injection rate executable. Some fields require a higher amount of water injected at one time to attain the desired reservoir pressure. Using DRA to improve the water transport in these could be an economic and efficient option for the oil and gas industry. The effectiveness of Xanthan gum as DRA is investigated using a water flow system made up of galvanized steel pipes and a reciprocal pump. Among variables tested are the concentration, degradation and pump RPM to determine the Xanthan gum's performance as a drag reducing agent. From the experiment results, it is found that drag reduction increases as Xanthan gum concentration and Reynolds number increases. The experiment results prove that Xanthan gum has great potential as a DRA. It is hoped that this research will lead to a widespread use of this polymer in improving water injection and transportation.

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Chapter 1

Introduction

1.1 Background Study

Oil and gas companies are now seeking new efficient and economic ways of maintaining and increasing their productions as energy costs have also increased. One of the aspects analyzed is to find a way to increase the flow rate of fluids through the pipeline. Replacing the current pipeline with larger diameter pipes increases the allowable flow rate but would take up production time and also cost a lot.

An alternative to replacing the pipes would be to reduce the drag friction in the pipelines by injecting Drag Reducing Agents (DRA). The addition of high-molecular-weight polymer into a liquid causes a drastic reduction in the frictional drag in turbulent flow. A DRA injection installation requires a smaller investment and can be installed quickly. The DRA used in this study will be Xanthan gum which is a polysaccharide also used in different applications such as viscosity-enhancing agent in foods, in the cosmetics and pharmaceutical areas, and in oil drilling fluids and enhanced oil recovery.

1.2 Problem Statement

A producing reservoir field depends on natural energy to enable hydrocarbon to flow into the wellbore. When this natural energy depletes over time, enhanced oil recovery methods such as water flooding and water injection is installed to maintain the reservoir pressure and further maintain the well's production.[11]

The efficiency of water flooding and water injection is limited to the maximum injection rate executable. Some fields require a higher amount of water injected at one time to attain the desired reservoir pressure. In order to inject more water into the reservoir, well operators would need to increase the pressure pumped.

But as time goes by, the water pipelines will face quality degradation in terms of wall thickness and smoothness. This is due to the drag friction forced upon the inner pipeline walls by the forced water transfer. Reduction in wall thickness lowers the operating pressure for fluid transfer because of the rising possibility of a fracture along the pipeline. Reduction in wall smoothness increases the tendency for water to flow more turbulent, increasing the drag friction and reducing the flow rate. Both reductions (thickness and smoothness) lower the operating pressure and flow rate of the water transfer which eventually reduces the main production.

In order to boost and maintain the production performance, the corroded pipelines could be replaced with new ones. But this option bares an expensive price tag and replacing works would take time putting production at a standstill. An option of high cost and low production is definitely one any company would favor the least.

Failure to properly handle the corroding pipeline and reducing operating pressure would lead to further monetary loss and casualties. Therefore, it is crucial to study the drag reducing options that are available.

1.3 Objective

- To determine the effectiveness of Xanthan gum as a drag reducing agent in water flow systems.
- To determine the relation between the concentration of Xanthan gum and the maximum obtainable flow rate.

1.4 Scope of Study

The whole project falls under flow assurance study. In order to execute this experiment, studies are carried out on the subject of friction factors and laminar and turbulent flow occurrences. The detailed properties of the polymer used (Xanthan gum) is also studied so that the reasons and explanation behind it's performance during the experiment can be identified accurately.

1.5 Relevance of the Project

As a future petroleum engineer, conducting this project would give a more precise understanding on the drag reduction issue in water flow systems. This project would also be able to contribute to the oil and gas industry by providing ways to improve water injection along the pipelines.

1.6 Project Feasibility

The whole project will involve two main phases which will be FYP1 and FYP2. FYP1 will mainly be about understanding the fundamental theories regarding the project. Previous works and published journal papers related will also be studied and compared in order to improve and perfect the research for future experiments. The experiments setup plus the materials will also be prepared during FYP1. In FYP2, the task would be to complete the experiments and acquire all the data needed. Based on the methodology and planning of the project milestones, the project will be able to be completed within the time given.

Chapter 2

Literature Review

2.1 Drag Reduction

Drag reduction is a reduction of pressure drop and skin friction in turbulent flow when polymer is added to the solvent. For drag reduction in an undisturbed water solution pipeline, it may easily reach the range of 70 - 80%.[8]

Some studies have already been carried out to determine the potential for drag reduction of different polymers in different systems. The dependency of drag reduction were tested on factors such as polymer molecular weight, polymer concentration, and temperature. Based on the previous papers, drag reduction:

1. Increases when DRA addition concentration increases. (up to a maximum point depending on the type of polymer)
2. Increases when flow rate inside the pipe is increased with DRA addition.
3. Decreases when pipe diameter increases.

Drag reduction is directly proportional to the relative molecular weight of polymers[2]:

$$\frac{DR(t)}{DR_0} = \frac{M(t)}{M_0}$$

Drag reduction, D_r, can be calculated from[9]:

$$D_r(\%) = \frac{\Delta P_{without\ DRA} - \Delta P_{with\ DRA}}{\Delta P_{without\ DRA}}$$

With C_{DRA} indicating DRA concentration, drag reduction efficiency factor, E_{DRA}, can be calculated from:[10]

$$E_{DRA} = \frac{Dr(\%)}{C_{DRA}}$$

2.2 Drag Reducing Agents

Drag reducing agents are also known as flow improvers. There are various types of DRA such polymers, surfactant solutions and fiber particles. Among them, polymers are considered the most effective.

DRA is one of the solutions that could be used to reduce drag frictions in between the flowing fluid and the walls of the pipeline. This increases the operating pressure for fluid transfer and also lowers pumping costs as no extra energy would be required to achieve the pressure used. Small amounts of the polymer (parts per million, ppm) are injected into the pipeline to reduce the development of a large scale turbulent flow and reduces the frictional pressure loss at a given flow rate.[7]

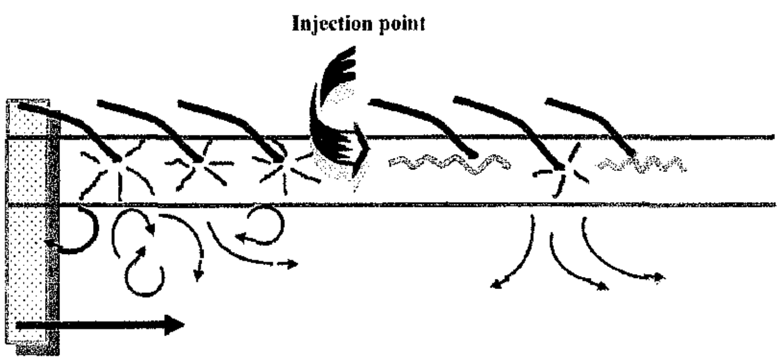

Figure 1: Illustration of how the DRA injection works inside the pipeline.[7]

It should be noted that DRA does not coat the internal pipeline wall but instead interacts with the pipeline flow. When DRA dissolves in water, the polymer molecules uncoil and outspreads.[11] The long chain molecule of the polymer dampens the turbulent bursts near the pipe wall similar to tiny shock buffers. This dampening effect reduces frictional pressure loss resulting in a decrease in energy consumption or an increase in flow rate.

2.3 Xanthan Gum

One of the drag reducing agent recommended is Xanthan gum. According to J.–I. Sohn, Xanthan gum is an extracellular polysaccharide polymer which is produced by the bacterium Xanthomonas campestris.[2] It is an example of a semi-rigid biopolymer currently being used as additive in drilling fluids and recovery methods such as polymer flooding of oil reservoirs.[4] It is also widely used as a food additive and as a stabilizer agent in cosmetic products. It also has relatively stable viscosity properties as a function of salt concentration, pH, temperature, and shear degradation. [5]

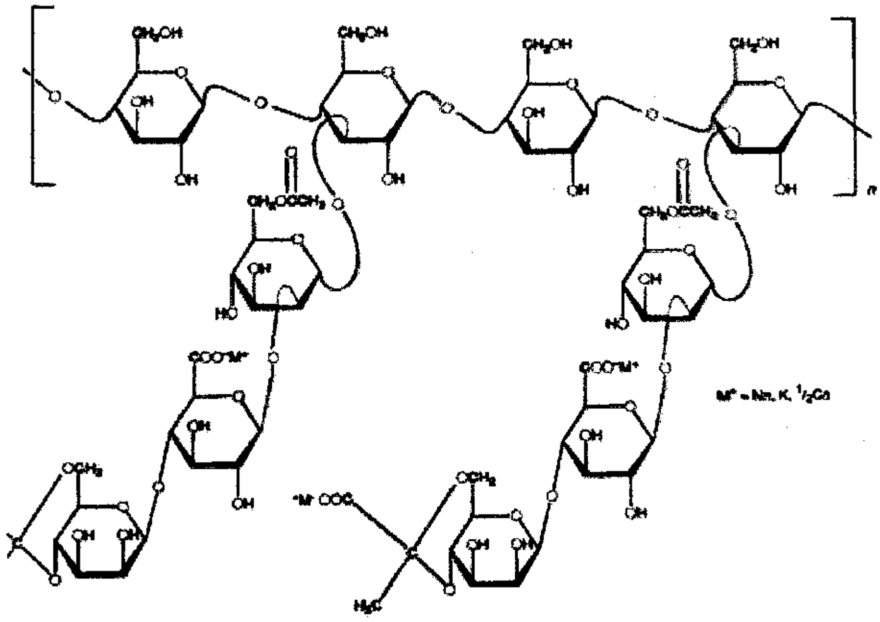

Figure 2: Structure of extracellular polysaccharide of *X. campestris*.[12]

Based on the previous investigations which use water as the test medium, the percentage of drag reduction for Xanthan gum increases alongside it's concentration but is only effective in the range of 300 ppm to 800 ppm. Beyond 800 ppm, the reverse effect of drag reduction will take place as drag on solid surfaces increases by increasing the concentration of Xanthan gum.[1] It was also observed that drag reduction by xanthan gum to be lower in mediums with low Reynolds number and higher for mediums with high Reynolds number.[1] In other terms, a larger amount of drag reduction will be achievable as the flow becomes more turbulent.

2.4 Surfactant

Besides xanthan gum, surfactants such as sodium stearate are also used as DRA. Surfactants require very little dosage (5 - 25 ppm) compared to xanthan gum (300 – 800 ppm). This makes it an excellent drag reducer to be applied for pipeline transport for crude oil. Surfactants can only be used for once-through applications (such as pipeline transport) and not for circulating fluid systems, such as district heating and cooling because the surfactant polymers will degrade when they flow through pumps and lose their efficacy.[8]

However, there are several obstacles regarding the usage of surfactant polymers as drag reducers.

1. Anaerobic degradation of cationic surfactants (environmental).
2. Heat capacity reduction (heat exchangers).
3. Polymer tubes will crack (tube material).
4. Dynamic meters become erroneous (flow meters).

Chapter 3

Methodology

3.1 Research methodology

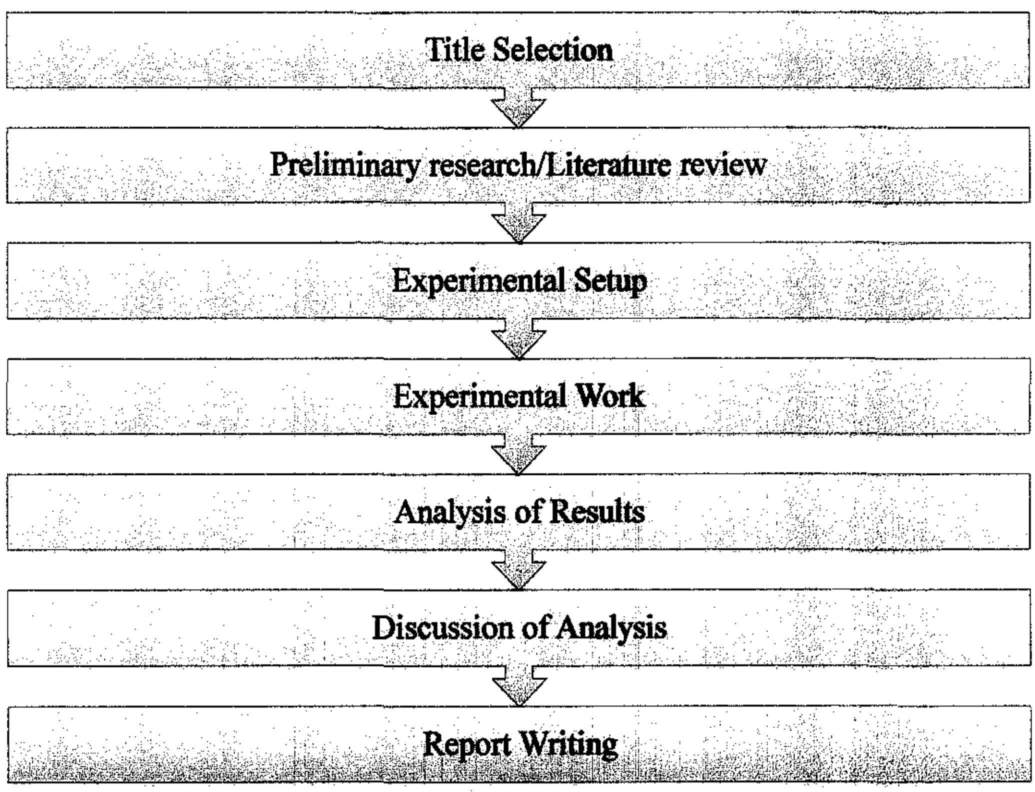

Figure 3: Flow chart of the research methodology

Title selection

An appropriate title is chosen for the final year project.

Preliminary research

This would be reading related research journal papers to better understand the theory and concept of the drag reduction and xanthan gum. All findings are compiled and elaborated in the literature review section of the report.

Experimental setup

The xanthan gum drag reduction measurements will be performed using a pipe flow system apparatus with a reference based on H.A. Abdul Bari, R.B. Mohd. Yunus, W.K. Mahmood and Z.B. Hassan's paper.[6] The turbulence will be produced by driving the fluid through a looping channel. The actual design model will be modified with an injection tap to insert the xanthan gum into the flowing liquid.

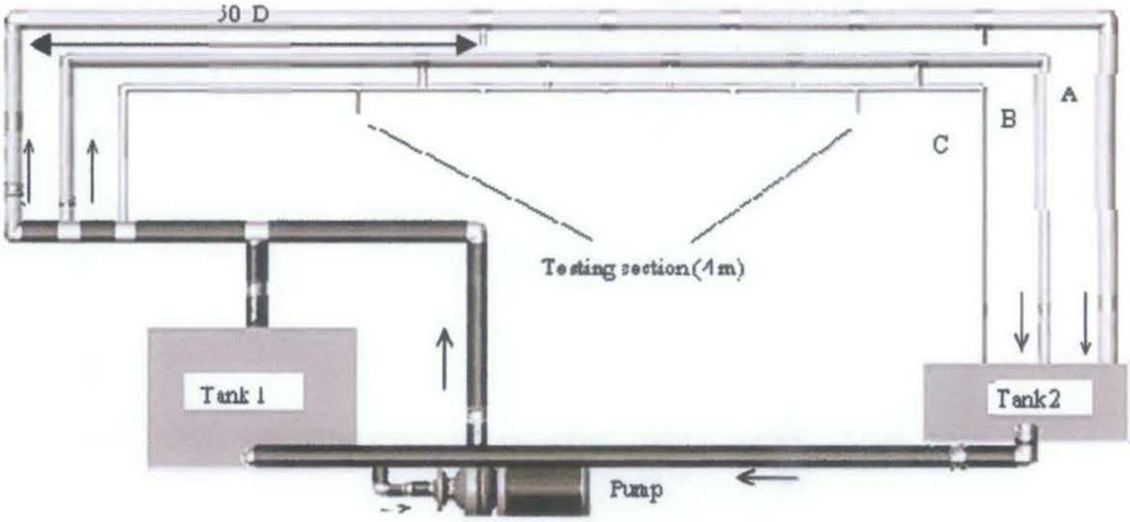

Figure 4: The reference pipe flow system design

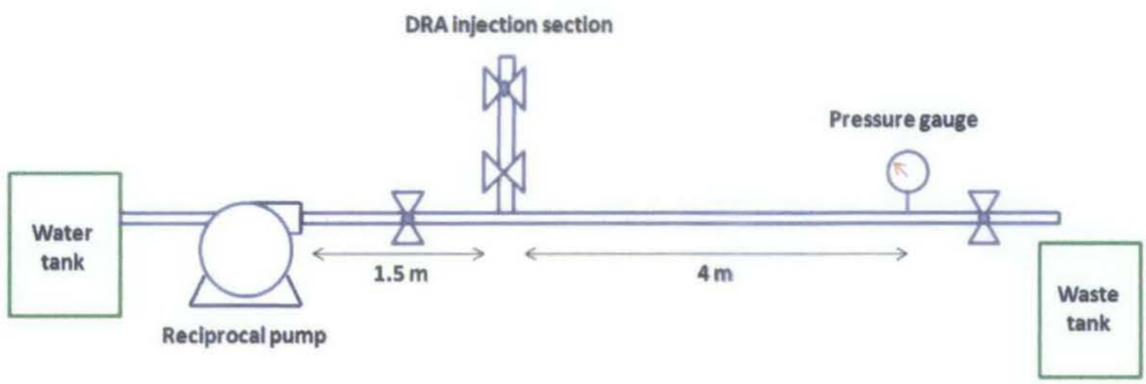

Figure 5: The actual pipe flow system design

Figure 5 shows the actual pipe flow system design used for this research. The system was mainly fabricated using:

1. 1-inch galvanized steel pipes
2. 2-inch galvanized steel pipe
3. Reciprocal pump
4. 2 pails (each acting as a water tank and a waste tank)

The water tank is elevated from ground level by placing it on a stand as shown in figure 4. With a set of PVC pipes, connectors and ball valve, the bottom of the tank is connected to the reciprocal pump's input.

Figure 6: The water tank.

The outlet of the reciprocal pump is connected to a 1.5 meter long 1 inch diameter galvanized steel pipe. The purpose of this part is to give enough travel distance for the test fluid to become turbulent. This part ends at a tee connector connected to the DRA injection section and the main test section.

Figure 7: The reciprocal pump.

The DRA injection section is made up of a vertical 0.5 meter long 2 inch galvanized steel pipe connected to valves at both ends as shown in figure 7. This injection section was fabricated to purposely fit a volume of 1 liter fluid containing DRA. It is placed after the pump so that the DRA tested does not got through critical degrading and damage which will reduce it's drag reducing effect on the test fluid.

Figure 8: The DRA injection section.

The testing section is a 4 meter long 1 inch galvanized steel pipe. The length of the pipe is fixed at 4 meter to provide the space required for the DRA to mix and take maximum effect on the test fluid. A 100 psi water pressure gauge is positioned after the 4 meter testing section to enable observation of the pressure change through out the whole run. After the pressure gauge, an elbow is placed at the end to direct the fluid into the waste tank. The pressure gauge is shown in figure 8.

Figure 9: The galvanized steel pipe sections.

Figure 10: The pressure gauge.

Experimental work

Numerous runs were conducted to collect the results based on the initial properties and the variables set. The main variables tested:

1. Xanthan gum concentration
2. Xanthan gum degradation
3. Pump RPM

The flow system has only one pressure gauge at the end of the testing section. To create the control state for the experiments, the experiment was first ran using only tap water without any DRA addition. The pressure drop for the next runs after this was then able to be calculated using this control state pressure reading.

A previous drag reduction research chose to run their experiment using xanthan gum solution concentration of 300 ppm, 400 ppm, 600 ppm, and 800 ppm.[3] Based on that research, the xanthan gum solution concentration for this research was decided to be 100 ppm, 200 ppm, 400 ppm, 700 ppm, and 800 ppm. In order to observe the effect of polymer degradation on the drag reduction results, a set of degraded xanthan gum is prepared with the same concentration as the fresh set. The reciprocal pump allows us to manipulate the output flow rate of the test fluid. Since there is no specific scale at the motor lever, runs will be done based on two variations only, the highest and the lowest. All the experiment runs are carried out on Malaysian standard ambient room temperature and pressure.

Table 1: The main variables

VARIABLES		*Concentration (ppm)*				
Degradation		Fresh				
Pump RPM	High	100	200	400	700	800
	Low	100	200	400	700	800
Degradation		Degraded				
Pump RPM	High	100	200	400	700	800
	Low	100	200	400	700	800

Xanthan gum preparation

Table 2 shows the amount of xanthan gum required to prepare the concentration mixtures accordingly. Each of the amount needed is dissolved in 1 liter of distilled water at the lab using magnetic stirrers inside a beaker. The stirring time was set at 5 hours by referring to a previous research paper which also used xanthan gum.[4] The mixtures were stirred at a low speed to prepare the fresh set and stirred at a high speed to prepare the degraded set of xanthan gum concentration.

Table 2: Amount of xanthan gum required

Xanthan Gum (ppm)	100	200	400	700	800
Amount needed* (g)	0.1	0.2	0.4	0.7	0.8

Experimental procedure

1. The setup is prepared by filling the water tank with water and filling the DRA injection section with the xanthan gum mixture.
2. Water from the water tank is released into the system.
3. The pump is started using the according pump RPM.
4. The xanthan gum mixture inside the injection section is released into the system.
5. After 5 seconds, the outlet valve is opened releasing the test water into the waste tank.
6. At this point, the pressure readings are observed and the time for the water to fill up the waste tank is recorded.
7. When the waste tank is filled, the pump is stopped.
8. A sample of the test water inside the waste tank is taken.
9. The flow system is flushed using water to prepare it for the next run and the waste tank is emptied.
10. This procedure is repeated with the next xanthan gum concentration to be tested.

3.2 Gantt Chart

Table 3: Gantt chart

No	Task	Week														
		1	2	3	4	5	6	7	MB	8	9	10	11	12	13	14
1	Experiment setup preparation															
2	First test run of setup															
3	Submission of progress report															
4	Project work continues															
5	Seminar															
6	Poster exhibition															
7	Submission of dissertation (soft bound)															
8	Oral presentation															
9	Submission of dissertation (hard bound)															

	Process
	Key milestone
	Mid semester break

3.3 Tools, Equipments and Materials

Materials:

1. Xanthan gum
2. Water
3. 1.5 meter 1-inch galvanized steel pipe
4. 4.0 meter 1-inch galvanized steel pipe
5. 0.5 meter 2-inch galvanized steel pipe
6. 2-inch PVC pipe
7. Steel ball valves
8. PVC ball valves
9. Gate valves
10. Various steel pipe connectors
11. Various PVC pipe connectors
12. Tank stand
13. Pipe stand
14. PVC pipe cement
15. PTFE tape
16. Plastic pipe hose

Equipments:

1. Honda reciprocal pump
2. 100 psi pressure gauge

Tools:

1. Pipe wrench
2. Measuring tape
3. Handsaw
4. Basic stencils

Chapter 4

Results and Discussion

4.1 Experiment results

From the experiment runs, the following was recorded:

1. Time to complete one run.
2. Pressure at the outlet.

Sample of the mixture of DRA and water was also taken at the end of each run to determine the density and dynamic viscosity. The following tables show the results recorded during the experiment runs.

Concentration	Time	Initial Pressure, P_1	Final Pressure, P_2	Pressure Drop, ΔP	Drag Reduction
ppm	s	psi	psi	psi	%
100	45.90	15	14.5	0.5	3.33
200	45.75	15	14.0	1.0	6.67
400	44.50	15	14.0	1.0	6.67
700	41.47	15	13.5	1.5	10.00
800	40.26	15	13.0	2.0	13.33

Table 4: Results for fresh xanthan gum at low RPM

Concentration ppm	Time s	Initial Pressure, P_1 psi	Final Pressure, P_2 psi	Pressure Drop, ΔP psi	Drag Reduction %
100	31.90	46	44	2	4.35
200	31.15	46	44	2	4.35
400	30.50	46	42	4	8.70
700	26.60	46	38	8	17.39
800	23.80	46	37	9	19.57

Table 5: Results for fresh xanthan gum at high RPM

Concentration ppm	Time s	Initial Pressure, P_1 psi	Final Pressure, P_2 psi	Pressure Drop, ΔP psi	Drag Reduction %
100	47.10	15.0	15.0	0	0
200	45.80	15.0	14.5	0.5	3.33
400	44.15	15.0	14.5	0.5	3.33
700	45.90	15.0	14.0	1.0	6.67
800	45.10	15.0	14.0	1.0	6.67

Table 6: Results for degraded xanthan gum at low RPM

Concentration ppm	Time s	Initial Pressure, P_1 psi	Final Pressure, P_2 psi	Pressure Drop, ΔP psi	Drag Reduction %
100	32.02	46	45	1	2.17
200	32.85	46	44	2	4.35
400	32.22	46	44	2	4.35
700	31.66	46	45	1	2.17
800	29.69	46	43	3	6.52

Table 7: Results for degraded xanthan gum at high RPM

4.2 Analysis of results

Based on the results achieved, the following analysis are carried out.

Drag reduction versus DRA concentration

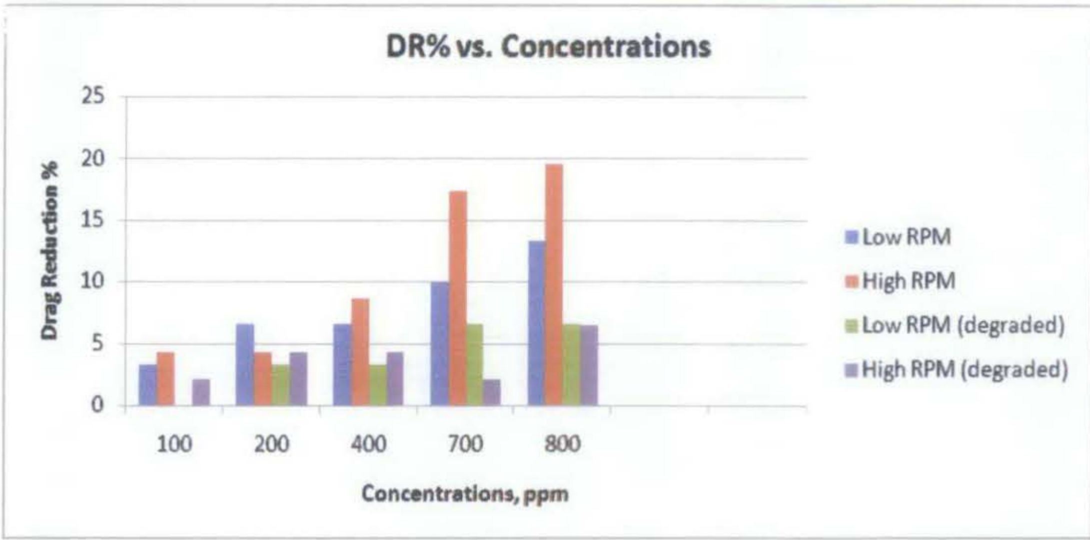

Figure 11: Drag reduction versus concentration chart

Figure 11 shows the effect of Xanthan gum concentration on the percentage of drag reduction. It is expected that, as xanthan gum concentration increases, drag reduction increases. This is proven by the chart with 800 ppm at high RPM showing the highest drag reduction percentage achieved which is 19.6%. As opposed to that, the lowest drag reduction percentage achieved is by 100 ppm at low RPM which is 0%.

Drag reduction versus Reynolds number

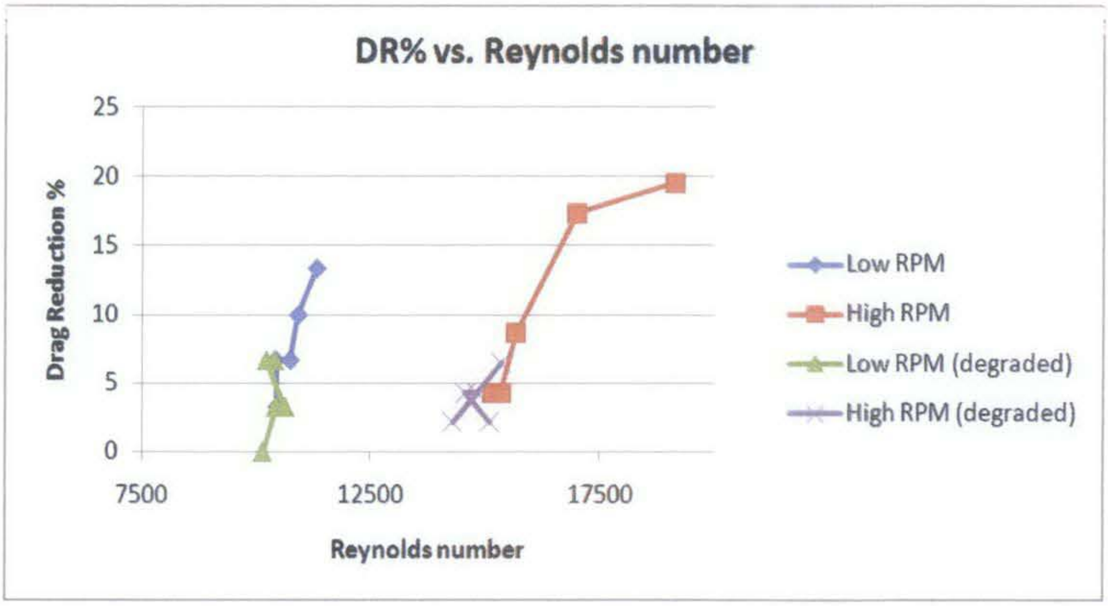

Figure 12: Drag reduction versus Reynolds number graph

Figure 12 shows the relationship between Reynolds number and drag reduction. The expected result is the drag reduction increases as Reynolds number increases. This is proven by the graph where all xanthan gum mixtures tested exhibit a positive slope. The highest drag reduction percentage achieved is 29% at 19158 Reynolds number. All the runs throughout the experiment achieved Reynolds number ranging from 10000 to 20000. From this it can be noted that all the runs throughout the experiment are done on turbulent flow taking the Reynolds number for turbulence is above 3000.[1] Reynolds number is calculated from:

$$Re = \frac{\rho V D_H}{\mu} \quad [6]$$

Where ρ is density, V is velocity, D is pipe diameter, and μ is viscosity.

Flowrate versus DRA concentration

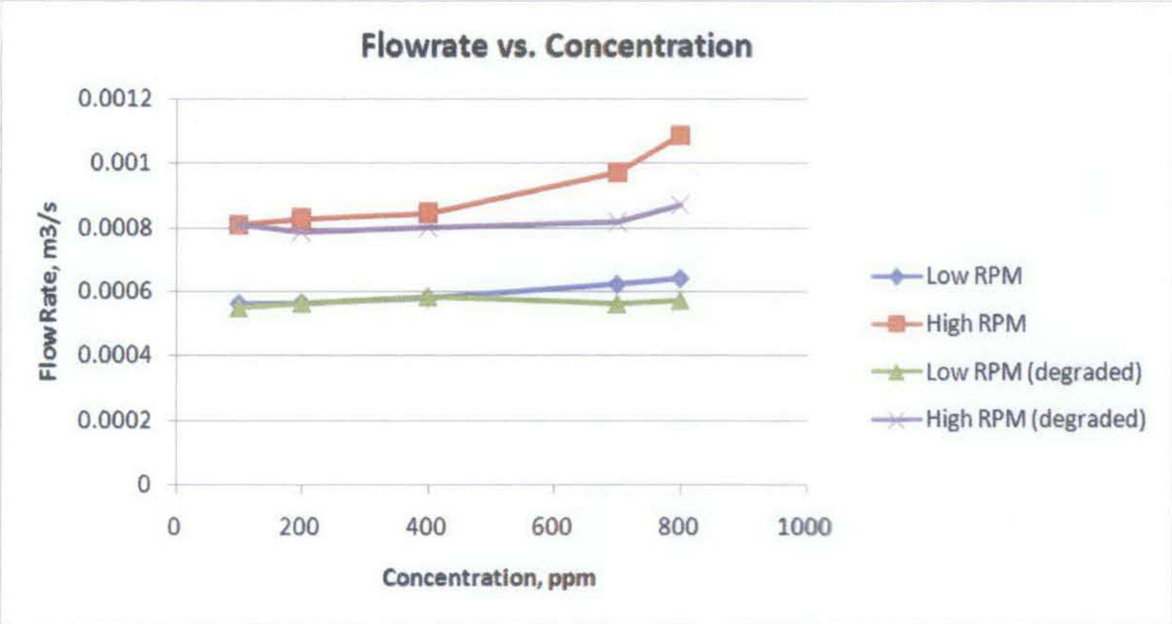

Figure 13: Flowrate versus concentration graph

Figure 13 shows the effect of Xanthan gum concentration on the water flowrate. The graph shows that the water flowrate through the system increases as Xanthan gum concentration increases. The highest flowrate achieved is 0.001085084 m^3/s by 800 ppm concentration in high RPM. This clearly proves that Xanthan gum is capable of increasing the water volume transported at one time.

Polymer degradation

From all the analysis shown, the fresh set of xanthan gum mixtures perform better at achieving higher drag reduction compared to the degraded set of xanthan gum mixtures. This shows that polymer degradation decreases the DRA's performance efficiency. It is interesting to note that even after degraded, the xanthan gum still showed significant drag reduction through the runs although not as high as the fresh set.

Pump RPM

Each mixture of fresh and degraded set of xanthan gum concentration used in the experiment is ran twice, first with the pump running at a low RPM and second with the pump running at a high RPM. The analysis shows that the mixtures ran at high RPM performs better at achieving drag reduction compared to the mixtures ran at low RPM. From this, we can note that the drag reducing performance of Xanthan gum increases in water flowing at higher speed.

Uncertainties

Throughout the experiment, a few uncertainties have been identified.

1. Pump performance

   The reciprocal pump used in this experiment does not perform at a constant rate although it clearly distinguishes the high RPM from the low RPM. When the pump is switched off from a run, the next run could be at a slightly higher or at a slightly lower rate.

2. Mixing of water and Xanthan gum

   The flow system was setup using galvanized steel pipes which does not allow us to observe what is happening throughout the test section. So, how well does the DRA mixture from the injection section mix with the test water is unknown. The only indicator showing that the flow inside the pipe is turbulent is from the calculation of Reynolds number.

Chapter 5

Conclusion

From the results obtained, the performance of Xanthan gum as a drag reducing has been able to be analyzed and studied. It can now be concluded that:

- Through the experiment, Xanthan gum has been proven to be very effective as a drag reducing agent in water flow systems.
- The maximum obtainable flow rate increases as the concentration of Xanthan gum increases.

Studies on xanthan gum and its effectiveness as a drag reducing agent will be able to contribute in improving fluid transfers in pipeline. Hopefully, this research will inspire more researches and provide the oil and gas industry with more feasible and economic ways of maximizing field production.

Recommendations

In order to further improve the study of drag reduction, here are a few recommendations.

1. The reciprocal pump

   The pump could be taken into workshop maintenance for a performance check before it is further used for research purposes again. This could decrease the level of uncertainties and errors in future experiments.

2. The testing section

   It would be great if an acrylic pipe section could be used on the flow system. The acrylic pipe section would enable researchers to observe inside the pipeline at that certain section. With this advantage, the flow patterns and the changes inside will be able to be further studied.

3. The testing fluid

   The initial plan for this study was to use crude oil as the test fluid replacing water. By using crude oil as the test fluid, studies on the effect of Xanthan gum as drag reducing agent on oil pipelines can be carried out. This could definitely help the industry on improving oil transfers through pipelines.

4. The pressure gauge

   The pressure gauge can be improved by installing a stabilizer which would help show a more accurate pressure reading. It would also help to install a pressure gauge with a closer range to the average experiment pressure readings. A digital pressure indicator would also be great in improving the pressure reading process and decreasing the errors to a minimum.

References

1. Subhash N. Shah & Y. Zhou (2001). An Experimental Study of Drag Reduction of Polymer Solutions in Coiled Tubing. SPE, Mewborne School of Petroleum & Engineering, University of Oklahoma. SPE 68419.
2. J.-I. Sohn, C.A. Kim, H.J. Choi & M.S. Jhon (2001). Drag-reduction effectiveness of xanthan gum in a rotating disk apparatus. Carbohydrate Polymers 45 (2001) 61-68.
3. Iyyaswami Regupathi, Ponnan Ettiyappan JagadeeshBabu, M. Chitra, & Thanapalan Murugesan (2010). Drag reduction in co-current down flow packed column using xanthan gum. Korean J. Chem. Eng. (Vol. 27, No. 4), 1205-1212 (2010)
4. A. Jaafar, R.J. Poole (2011). Drag reduction of biopolymer flows, Journal of Applied Sciences, ISSN 1812-5654, DOI 10.3923/jas.2011.
5. J. C. Salamone, S. B. Clough, A. Beal Salamone, K. I. G. Reid, D. E. Jamison. Xanthan Gum – A lyotropic, liquid crystalline polymer and its properties as a suspending agent.
6. H.A. Abdul Bari, R.B. Mohd. Yunus, W.K. Mahmood and Z.B. Hassan (2008). Sodium Stearate as Drag Reduction Agent in Non-Aqueous Media. ISSN 1996-3416.
7. Hamad Al-Arji (2007). The Effect of Drag Reducing Agent on Intake Valve Deposit.
8. Martin Hellsten (January 2002). Drag-Reducing Surfactants. Paper no S1282 in JSD 5, 65-70.
9. H.A. Abdul Bari, M.A. Ahmad and R.B.M. Yunus (2010). Formulation of Okra-natural Mucilage as Drag Reducing Agent in Different Size of Galvanized Iron Pipes in Turbulent Water Flowing System. Universiti Malaysia Pahang. Journal of Applied Sciences 10(23): 3105-3110, 2010. ISSN 1812-5654.
10. Robert M. Vancko, Jr. (1997). Effect Of A Drag Reducing Agent On Pressure Drop And Flow Regime Transitions In Multiphase Horizontal Low Pressure Pipelines. Ohio University.
11. J. Nelson, (2003). "Optimizing Production using Drag Reducing Agents in Water Injection Wells". Offshore Engineer.
12. F. Garcia-Ochoa, V.E. Santos, J.A. Casas, and E. Gomez (2000). Xanthan gum: production, recovery, and properties. Biotechnology Advances 18 (2000) 549 – 579.