

**The Study of Drag Reduction Ability and Mechanical Degradation of
Biopolymer in Water Injection System**

by

Loh Chun Liang

14840

Dissertation submitted in partial fulfilment of
the requirement for the
bachelor of Engineering (Hons)
(Petroleum)

JANUARY 2015

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

The Study of Drag Reduction Ability and Mechanical Degradation of Biopolymer in Water Injection System


by

Loh Chun Liang

14840

A project dissertation submitted to the
Petroleum Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(PETROLEUM)

Approved by,



(SITI SARAH SALEHUDIN)
Siti Sarah Bt Salehuddin
Lecturer, Petroleum Engineering
Universiti Teknologi PETRONAS


UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2015

CERTIFICATION 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.



(LOH CHUN LIANG)

ABSTRACT

Drag is characterized as a force that acting opposite the relative motion of an object through a fluid which lead to frictional pressure loss in pipeline fluid flow and Drag Reducing Agent (DRA) is a common solution of this problem. This research concerns only the application of water injection system due to the environmental concerns of the injection of the commercialized synthetic DRA into the formation because of its chemical contents. Thus, the CMC is synthesized with the objective to serve as a feasible alternative of synthetic DRAs. This study describes the synthesizing of biopolymer, Carboxymethylcellulose (CMC), study the effectiveness of the synthesized CMC in drag reduction at different concentration and different flow rate, and observe the mechanical degradation of the synthesized CMC that causes the drop in its drag reduction performance. The residue of coconut fibre after the extraction of coconut milk or so called Coconut Residue (CR) is selected as the candidate for CMC extraction. CMC is extracted by synthesizing the cellulose under the alkali-catalysed reaction using monochloroacetic acid. Its effectiveness of drag reduction ability and degradations are studied at different concentration and different flow rate by using flow loop to observe the performance drop in drag reduction after a period of time of flowing. This research shows that for every 30 g of dried coconut residue cellulose powder, 27.18 g to 28.77 g of CMC can be synthesized at the controlled condition. The extracted CMC able to reduce the drag by 13.64 % to 38.14 %, depending on the flow rate and concentration, and able to withstand the shear force with only slight decrease drag reduction performance. In conclusion, this research shows the possibility of using CMC extracted from coconut residue to serve as a replacement for current commercialized synthetic DRAs.

ACKNOWLEDGEMENT

First and foremost, I would like to express my highest gratitude to my one and only supervisor, Madam Siti Sarah Salehudin, for her continuous support, advices, constructive comments and motivations which are important for me to carry on this project to the fullest.

Special thanks to my Drag Reducing Agent (DRA) colleague, Mr Mohamad Nor Rafie bin Jainuddin for sharing their ideas and thoughts from the beginning of the research phase until the lab sessions and completion of this project. Besides, I would I to show my appreciation to Dr. Muhammad Ayoub for his advices and opinions during the progress presentations.

I also would like to take this opportunity to thank the lab technicians in UTP laboratories located in Block 15, Block 14 (Petroleum Engineering Department), and Block 20 (Mechanical Engineering Department) for teaching and advising me on how to handle the equipment in the labs and their willingness to standby outside their working hours to allow us to conduct the experiment in the lab.

Not to forget to my beloved parents, family and friends for being very supportive and keen to know the outcome of my research until the completion of this report.

Last but not least, thank you to Universiti Teknologi PETRONAS for all the opportunities and providing sufficient yet state-of-the-art equipment for me to complete this research. With that, I hoped all the experiences and knowledge that I have gained from this research will be a kick-start for my future career development.

TABLE OF CONTENTS

CERTIFICATION OF APPROVAL	i
CERTIFICATION ORIGINALITY	ii
ABSTRACT	iii
ACKNOWLEDGEMENT	iv
TABLE OF CONTENTS	v
LIST OF FIGURES	vii
LIST OF TABLES	viii
CHAPTER 1: INTRODUCTION	1
1.1 Background of Study	1
1.2 Problem Statement.....	2
1.3 Objectives	3
1.4 Scope of Study.....	3
CHAPTER 2: LITERATURE REVIEW	4
2.1 Drag	4
2.2 Drag Reduction.....	5
2.3 Drag Reducing Agent	6
2.4 Mechanical Degradation.....	8
2.5 Water Injection System	8
2.6 Biopolymer	9
CHAPTER 3: METHODOLOGY	13
3.1 Research Methodology	13
3.2 Project Activities	14
3.3 Key Milestones	22
3.4 Gantt Chart	22
3.5 Equipment, Apparatus, Chemicals and Software	23
CHAPTER 4: RESULTS AND DISCUSSION.....	26
4.1 Variables.....	26
4.2 Assumptions	27
4.3 Yield of Carboxymethylcellulose (CMC) Extraction.....	28
4.4 Drag Reduction of CMC at Different Concentration and Different Flow Rate	28
4.5 Mechanical Degradation of CMC.....	32

CHAPTER 5:	CONCLUSION AND RECOMMENDATIONS	35
	5.1 Conclusion	35
	5.2 Recommendation	36
REFERENCES		37
APPENDICES		39

LIST OF FIGURES

Figure 1: Drag Reduction Mechanism (Kelland, 2014).....	6
Figure 2: Schematic of Polymer Waterflood System (Lake, 1989).....	8
Figure 3: Injection line and additional facilities for waterflood purpose in Tapian Timur Field (Nuni Handayani & Simamora, 2012).	9
Figure 4: Research Methodology	13
Figure 5: Washed CR was put in the oven for 24 hours.	15
Figure 6: Dried CR is cooked with NaOH using hotplate magnetic stirrer until the solution turns into dark purple.....	15
Figure 7: The formation of white precipitate are observed after adding NaOH, isopropanol and chloroacetic acid to the cellulose. The precipitate dissolved during the heating.	16
Figure 8: CMC before grinded using Cole Mortar Grinder	17
Figure 9: Schematic View of Flow Loop.....	18
Figure 10: 2000 ppm CMC Solution.....	20
Figure 11: Flowmeter with flow rate maintaining at 2m ³ /h.....	20
Figure 12: Pressure drop of sample with different concentration (200 ppm, 500 ppm and 1000 ppm) at different flow rate (1 m ³ /h and 2 m ³ /h)	29
Figure 13: Drag reduction of sample with different concentration (200 ppm, 500 ppm and 1000 ppm) at different flow rate (1 m ³ /h and 2 m ³ /h)	30
Figure 14: Pressure drop of tests with different flow rate (1 m ³ /h and 2 m ³ /h) for sample with different concentrations concentration (200 ppm, 500 ppm and 1000 ppm).....	30
Figure 15: Drag reduction of tests with different flow rate (1 m ³ /h and 2 m ³ /h) for sample with different concentrations concentration (200 ppm, 500 ppm and 1000 ppm).....	31
Figure 16: Mechanical degradation of sample with different concentration (200 ppm, 500 ppm and 1000 ppm) pumping at the flow rate of 1 m ³ /h for 60 minutes.	32
Figure 17: Mechanical degradation of sample with different concentration (200 ppm, 500 ppm and 1000 ppm) pumping at the flow rate of 2 m ³ /h for 60 minutes.	33

LIST OF TABLES

Table 1: Reynolds Number of Each Type of Flow Regimes	5
Table 2: The Cellulose Composition of Different Organic Wastes	10
Table 3: Amount of CMC for preparation of sample solutions with different concentrations	19
Table 4: Key Milestones of the Research	22
Table 5: Gantt Chart of FYP I.....	22
Table 6: Gantt Chart of FYP I.....	23
Table 7: List of Equipment	23
Table 8: List of Apparatus.....	24
Table 9: List of Chemical.....	24
Table 10: List of Software.....	25
Table 11: Yield of CMC Synthesizing.....	28
Table 12: Pressure drop and drag reduction of tests with different flow rate (1 m ³ /h and 2 m ³ /h) and different concentration (200 ppm, 500 ppm and 1000 ppm).....	29
Table 13: Decrease of %DR after 60 minutes of pumping	34

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Drag or frictional force is characterized as force that acting opposite the relative motion of an object through a fluid. Due to the existence of drag, the transfer of a fluid from a point to another in a pipeline always leads to a significant frictional pressure loss. As a result, the energy loss reduces the flow capacity of the fluid along the pipeline. Thus, in order to increase the pumpability of a fluid, a small amount of additive is added to reduce the drag and achieve a higher flow rate while remaining the same pumping pressure. The additive added is known as drag reducing agent (DRA) which can be classified into three major types: polymer, surfactant and suspended solids (Kaur, Singh, & Jaafar, 2013).

The main applications of DRA in oil and gas industries are in crude oil transportation and water injection systems (Campbell & Jovancevic, 2001). The crude oil produced need to be transported through thousands of kilometre of pipeline from platform to other facilities and to consumers. Without the use of DRA, it will resulted in a significant loss of frictional pressure. The first successful application of the use of polymeric DRA in crude oil pipeline was began in 1979 in the Trans Alaska Pipeline System(Burger, Munk, & Wahl, 1982).

Besides the application in crude oil transportation, DRA is widely used in water injection system. Water injection or water flooding is the injection of water into the formation to maintain or enhance the reservoir pressure to improve the recovery. Water flooding is one of the secondary recovery operation that are widely used in the industry nowadays. In order to provide sufficient pressure support to the reservoir, the water

flooding system employed in the field need to be able to meet certain amount of the injection. In the cases where the injection does not perform as well as expected and the reservoir is not supported effectively, there would be problems such as high producing gas oil ratio (GOR), early gas breakthrough, high percentage of unrecoverable oil or left behind oil and so on. There are several reasons that might lead to these problems. For instance, issues due to formation like skin or damage problem, clay swelling and fine migration, and ineffective of the water flow in the water injection wells due to frictional force or drag.

In order to achieve the targeted total injection, there are several options can be considered, such as install new pump with greater the pumping power and capacity, increase number of injection wells, employ horizontal water injection wells and so on. Even though these options able to increase the total water injection, it require millions of dollar and of course it needs time to implement. Instead of spending a huge amount of money, the application of using DRA is often preferred because by the addition of a small amount of DRA to the fluid, the pumpability of the fluid can be increased significantly by reducing the pressure drop cause by the turbulence in the well (Nelson, 2004; Oskarsson, Uneback, & Hellsten, 2005).

1.2 PROBLEM STATEMENT

DRA is widely used in oil and gas industries due to its ability to reduce the frictional pressure losses under the turbulence flow condition and therefore greatly increase the flow rate of the fluid. Despite its successful applications, there are concerns of the accumulation of DRA under the ground with its application in water injection systems. There are several types of commercialized DRAs. Most of these agents are high molecular weight, synthetic polymers which are proven to provide excellent in drag reduction properties, however excessive use of such artificial additives will eventually pollute the environment due to their chemical contents (Kaur et al., 2013).

Thus, this research aims to determine a potential biodegradable environmental friendly organic DRA candidate extracted from natural waste material as an alternative of synthetic DRA.

1.3 OBJECTIVES

This research aims to study the potential of an environmental friendly organic DRA extracted from natural waste material. The material is chosen as a potential DRA candidate to be tested in this research is coconut residual (CR). Thus, the objectives of this research are:

- i. To extract the Carboxymethylcellulose (CMC) from coconut residue.
- ii. To assess the drag reduction ability of the prepared CMC at different concentration and flow rate.
- iii. To study the mechanical degradation of the prepared CMC.

1.4 SCOPE OF STUDY

The scope of this paper is focusing on evaluating the potential and effectiveness of biopolymer extracted from natural wastes, in this case is CMC, in water injection well only. This research is only focus on the tap water as injected fluid for the evaluation of the DRA performance in lab scale. Besides the evaluation of the effectiveness of CMC as DRA, this research will study the mechanical degradation of the CMC after certain time of pumping. This study does not include the effect of DRA under the dynamic changes in reservoir temperature and pressure with depth as well as the chemical reaction between DRA and inner wall of the well.

CHAPTER 2

LITERATURE REVIEW

2.1 DRAG

Drag or frictional pressure drop is the resistance faced by the flowing fluid coming contact with the wall of the pipeline. Drag always been a major problem in oil and gas industry. The presence of drag limit the flow rate, hence involve higher cost of operation to provide more energy for the pumping. The type of flow can be generally divided into two types; laminar and turbulent. In most of the cases, the turbulence will give additional drag. As in turbulence flow regime, the fluid molecules move in a random manner, unlike the “layering” movement in laminar flow, which causing a lot of the applied energy to be wasted as eddy currents or other motions. The transition of laminar to turbulence is complex. In the paper published by Avila et al. (2011), the authors tried to understand the transition to turbulence in pipelines. The type of flow regime is typically characterized by using the dimensionless Reynolds number (N_{RE}) which is defined as following equation:

$$N_{RE} = \frac{Du\rho}{\mu} \quad (\text{Eq 2.1})$$

where

- D = pipe diameter, ft
- U = flow velocity, ft/sec
- ρ = fluid density, lbm/cu ft
- m = fluid density, lbm/ft sec

N_{RE} is the ratio of fluid momentum forces to the ratio of fluid momentum forces to viscous shear forces. The change from laminar to turbulent flow is usually assume to

occur at a N_{RE} of 2100 for flow in a circular pipe (Ikoku, 1984). The fluid behaviours are generally classified according to the following table.

Table 1: Reynolds Number of Each Type of Flow Regimes

$N_{RE} < 2100$	Laminar flow
$2100 < N_{RE} < 4000$	Transitional flow
$N_{RE} > 4000$	Turbulence flow

2.2 DRAG REDUCTION

Drag reduction is a well-known phenomenon the pumpability of a fluid is increased by reducing the turbulence friction of the fluid. There are many techniques to reduce the drag suggested by a lot of researchers in many applications: with baffles of different heights in the turbulence flow region to suppress the eddy currents, reduce the skin factor by using layers of bubble, and one of the well-known techniques is by the addition of a small amount of chemical additives to the liquid transported through pipelines (Abdulbari, Shabirin, & Abdurrahman, 2014). The technique was first discovered by Toms (1948). Since then, there were a lot study were done by researchers. Among different type of additives, polymeric drag reduction is considered as an effective and economically feasible additive by many authors because of its properties, namely its rheological properties and also its resistance to shear forces (Abdulbari et al., 2014).

The drag reducing agent reduces the frictional pressure lost in turbulent flow by interfering the sub-laminar layer and interaction between the fluid and pipe wall (Wahl, Beaty, & Hass, 1982). To understand the mechanism of drag reduction, it is necessary to first understand the structure of fluid flow in a pipeline. Generally, there are three parts in the turbulence flow inside a pipeline as shown in *Figure 1*. The largest region which include most of the fluid is turbulence core that lies in the very center of the pipe. The layer lies nearest to the inner wall of the pipeline is known as laminar sublayer where the fluid move laterally in sheets. The third part of the flow lies between laminar sub layer and turbulent core, where the turbulence is first formed. This region is known as buffer region.

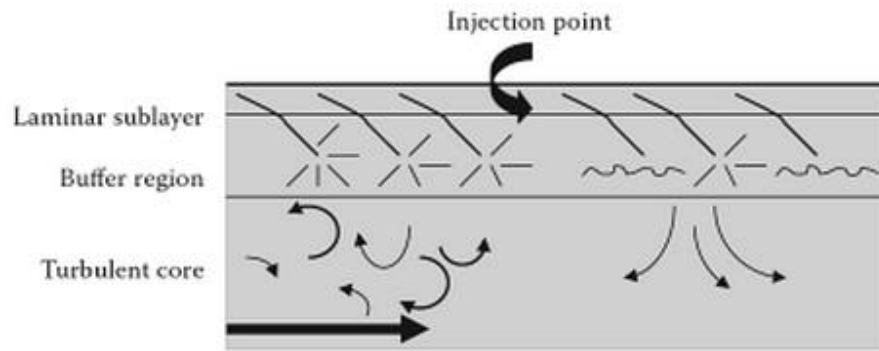


Figure 1: Drag Reduction Mechanism (Kelland, 2014)

As the fluid flow inside the pipeline, a part of the laminar sub layer, known as "streak", will at times move to the buffer region. Then, the streak starts to vortex and oscillate, moving faster as it gets closer to the turbulent core. At last, the streak gets unstable and breaks up as it throws fluid into the turbulent. This ejection of fluid into the turbulent core is called a "turbulent burst" which results in wasted energy.

The mechanism of the drag reducing agent is by interrupting these bursting process. The added polymeric DRA will meddle with the bursting process and dampen the burst as shock absorber, hence reduce the subsequent turbulent bursts. This dampening effect reduces frictional pressure loss resulting in less wasted energy.

2.3 DRAG REDUCING AGENT

Drag reducing agent can be divided into three main categories: polymers, surfactants and fibres. As mentioned, polymer are the most effective and economically feasible and is widely used in the industry. There are two types of polymers: synthetic polymer, which derived from petroleum oil, and natural polymer or biopolymer, which extracted from natural resources. Even though synthetic polymers are proven to exhibit excellent drag reducing ability, there are environmental concerns due to the accumulation of these synthetic polymers that biodegrade very slowly. On the contrary, biopolymer can easy obtain from plants are biodegradable.

There are several factors governing the effectiveness of the drag reduction, such as the polymer's molecular weight, solubility, concentration, shear rate, cloud point,

degradation, flow turbulence, injection location, etc. According to Salamone (1996), the linear flexible chain structure and ultra-high-molecular-weight (UHMW) polymers are considered as the most important factors. Another important parameter is solubility that controls the coil dimension. The molecular parameters depends on external condition such as polymer concentration and shear rate as well. The percentage of drag reduction is increased with the increased of concentration and shear rate.

The performance of DRA can be assessed by determining the percentage drag reduction ($\%DR$) at a given concentration and flow rate which can be represented by the following equation (Al-Anazi, Al-Faifi, Tulbah, & Gillespie, 2006):

$$\%DR = \frac{\Delta P - \Delta P_{DRA}}{\Delta P} \times 100 \quad (\text{Eq 2.2})$$

where

ΔP = pressure drop of untreated fluid, psi

ΔP_{DRA} = pressure drop of fluid containing DRA, psi

While the relationship of the $\%DR$ and the percent flow increase ($\%FI$) can be estimated using the following equation (Al-Anazi et al., 2006):

$$\%FI = \left\{ \left[\frac{100}{100 - \%DR} \right]^{0.556} - 1 \right\} \times 100 \quad (\text{Eq 2.3})$$

The volume of DRA (V_{DRA}) to be added to the liquid in order to obtain the desired concentration can be calculated with following equation:

$$V_{DRA} = \frac{C_{DRA} \times V_{TOTAL}}{1 \times 10^6} \quad (\text{Eq 2.4})$$

where

C_{DRA} = desired DRA concentration, ppm

V_{TOTAL} = total liquid volume in the system, cu ft

2.4 MECHANICAL DEGRADATION

The main drawback of polymeric DRAs is their mechanical sensitivity. As explained in the previous section, DRAs are most active in the buffer zones that separate the laminar sub layer and turbulent core. This exposes the DRAs to high extensional rate along the pipe length, mechanically degrade the polymer and makes them lose their effectiveness in drag reduction (Hénaut et al., 2012). Thus, one of the important properties of DRA is to be transported in pipelines for a certain distance without significantly degrade (Hénaut et al., 2012) (Jouenne et al., 2014) (Liberatore, Baik, McHugh, & Hanratty, 2004).

2.5 WATER INJECTION SYSTEM

At the early stage of production, the field is produced naturally from a producing well. This is refer as primary production. In most cases, primary recovery is not sufficient for an optimum recovery. As the reservoir depleted, reservoir pressure drop continuously. Thus, it is common practice to inject fluids into reservoir to maintain the reservoir pressure and provide artificial drive to sweep the oil toward the production wells. This injection of fluid is known as secondary recovery. Water injection, or waterflood, is a form of this secondary recovery process.

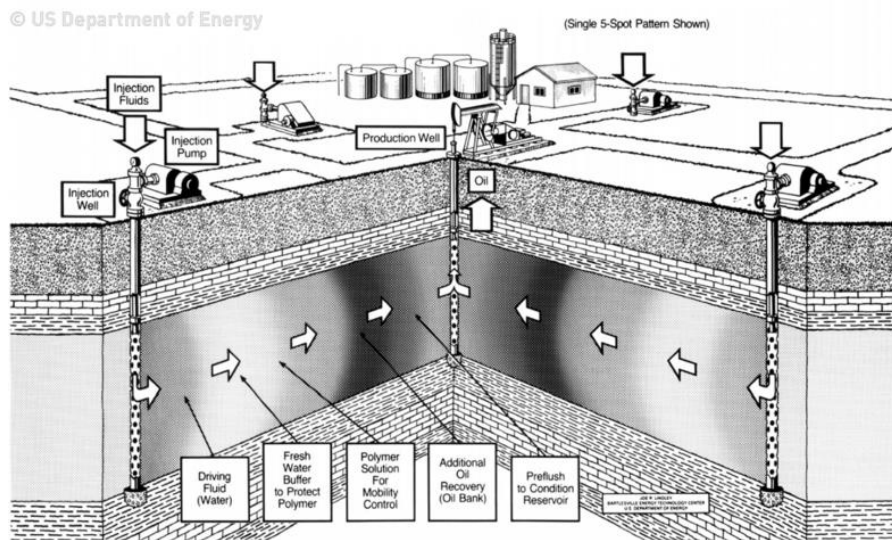


Figure 2: Schematic of Polymer Waterflood System (Lake, 1989)

With reference to a study of a mature field by Nuni Handayani and Simamora (2012), water injection line and other facilities for waterflood operation includes water storage tank, injection pump, cartridge filter and water injection wells.

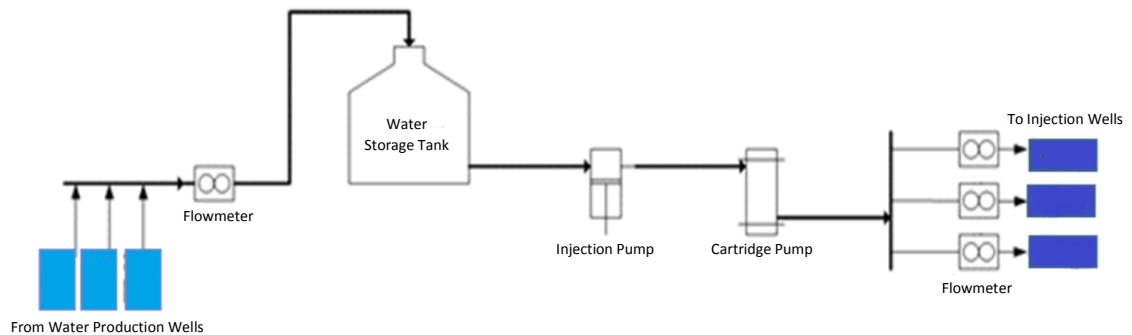


Figure 3: Injection line and additional facilities for waterflood purpose in Tapian Timur Field (Nuni Handayani & Simamora, 2012).

Water injection system in this case study is defined as the travelling path of the injected fluid from the injection pump to the end of injection tubing in the wellbore before enters the formation. In this application, it involves vertical travelling path along injection tubing. Despite the different position of the fluid flow from normal DRA application in the horizontal pipelines, the theory of the drag reduction still applies in both cases as despite the size of the pipeline, the only different in both application is the position of the travelling path. The turbulent flow still occurs along the paths for both cases. On top of that, the action of gravity favour the vertical position the most. Thus, the application of DRA in water injection system is applicable.

2.6 BIOPOLYMER

2.6.1 Coconut Residue

Coconut residues (CR) is the leftovers of coconut meat after extraction of milk by mechanical squeeze is done. According to researches, CR contains 72.6% of cellulose (Ng, Tan, Lai, Long, & Mirhosseini, 2010) which make it a good candidates for extracting CMC. The comparison of cellulose contents of different types of organic waste are summarized in *Table 2*. Besides, coconut is vastly

available in Malaysia. Malaysia is one of the top ten coconut producing countries in the world. In 2014, Malaysia had a total coconut production of 23,000 MT. Due to its availability and high cellulose contents, CR is chosen as a potential candidate of extracting CMC in this study.

Table 2: The Cellulose Composition of Different Organic Wastes

Organic Waste	Cellulose (%)	Reference
Bean straw	40.2	(Kopania, Wietecha, & Ciechańska)
Burley leaves	17.05	(Kopania et al.)
Burley stalks	34.15	(Kopania et al.)
Carrot leaves	31.58	(Kopania et al.)
Cassava flour waste	16	(Kopania et al.)
Citrus junos peels after CO ₂ extraction	29	(Kopania et al.)
Coconut residue	72.6	(Ng et al., 2010)
Corn stalks	17.7	(Kopania et al.)
Corn stalks	22.8	(Kopania et al.)
Corn straw	38.83	(Kopania et al.)
Flax straw-oil variety	41.86	(Kulić & Radojičić)
Hemp straw	60.09	(Kulić & Radojičić)
Japanese beech <i>Fagus crenata</i>	45	(Kulić & Radojičić)
Maize straw	25.5	(Kulić & Radojičić)
Oil palm fronds	44	(Cardenas-Toro, Alcazar-Alay, Forster-Carneiro, & Meireles)
Oil palm shell	39.7	(Cardenas-Toro et al.)
Rape straw	40.85	(Kopania et al.)
Retted flax straw-fibre variety	51.56	(Cardenas-Toro et al.)
Rice husks	25.4	(Cardenas-Toro et al.)
Rye straw	45.07	(Cardenas-Toro et al.)
Sugarcane bagasse	36.4	(Cardenas-Toro et al.)
Sugi wood <i>Cryptomeria japonica</i>	43	(Cardenas-Toro et al.)

Sunflower straw	40.41	(Cardenas-Toro et al.)
Virginia leaves	19.59	(Cardenas-Toro et al.)
Virginia stalks	30.35	(Cardenas-Toro et al.)
Water lettuce biomass	53	(Cardenas-Toro et al.)
Wheat bran	38.6	(Cardenas-Toro et al.)
Wheat husks	36	(Cardenas-Toro et al.)
Wheat straw	40.8	(Cardenas-Toro et al.)
Wheat straw	23.5	(Cardenas-Toro et al.)

2.6.2 Carboxymethylcellulose

CMC is a modified cellulose that derived from the modification of cellulose by the reaction of acid and alkali such as NaOH and monochloroacetic acid (Kaur et al., 2013). Cellulose is a common natural polymer that can be found vastly in plant. Thus, the usage of CMC from CR is environmental friendly and sustainable.

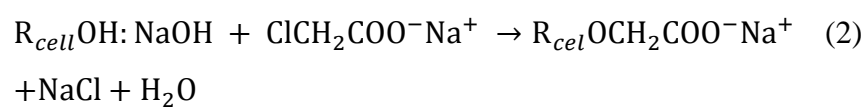
2.6.3 CMC Synthesizing

CMC can be synthesized from different source with high cellulose content. The source selected for this research is coconut residue. CMC's synthesizing process is adopted from a study by Kaur et al. (2013). The process can be divided into 2 main steps, namely alkalization and carboxymethylation. The first step, cellulose is suspended in alkali to swell the cellulose fibre. The reaction will obtain an alkali-cellulose complex which allows an access to the next reaction which is carboxymethylation. During this stage, sodium carboxymethyl cellulose is formed when the alkali cellulose is reacted with sodium monochloroacetate (Saputra, Qadhayna, & Pitaloka, 2014). These reaction is carried out with isopropanol as solvent. The two steps reaction are shown as following:

Step 1:



Step 2:



CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

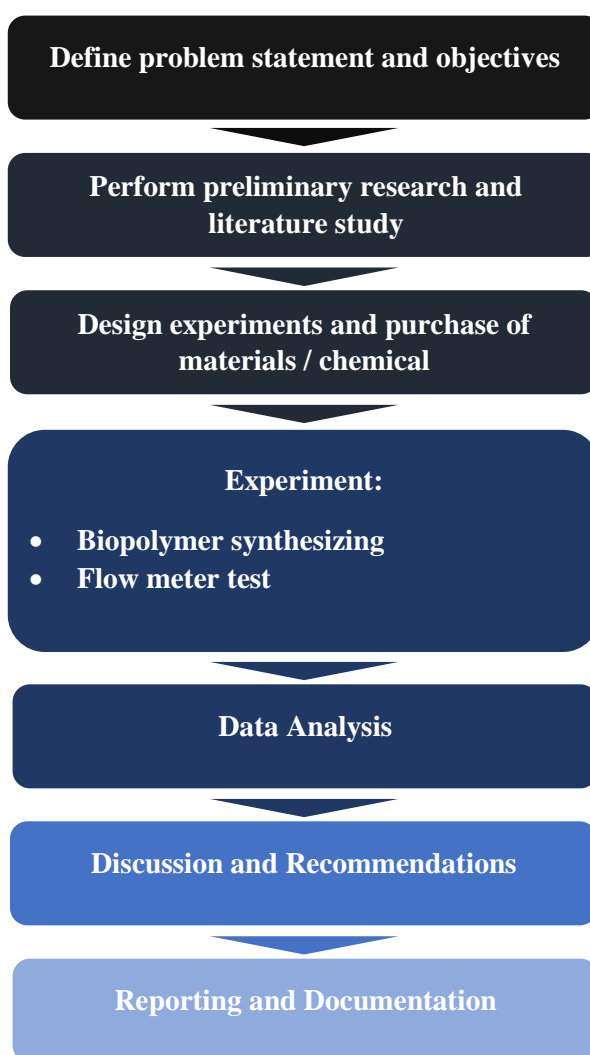


Figure 4: Research Methodology

3.2 PROJECT ACTIVITIES

3.2.1 Biopolymer Synthesis

3.2.1.1 Materials and Chemical

- i. Coconut Residue
- ii. Sodium Hydroxide Pellets
- iii. Isopropanol
- iv. Ethanol 96% Denatured
- v. Methanol
- vi. Chloroacetic Acid
- vii. Acetic Acid
- viii. Distilled Water
- ix. Filter Paper
- x. Aluminium Foil
- xi. Tap Water
- xii. Polyethylene Bags

3.2.1.2 Tools and Apparatus

- i. Cole Parmer Mortar Grinder
- ii. Oven
- iii. Electronic Weight Scale
- iv. Hotplate Magnetic Stirrer
- v. Beaker
- vi. Conical Flask
- vii. Measuring Cylinder
- viii. Filter Funnel

3.2.1.3 Procedure of Cellulose Extraction

- i. Coconut residue (CR) is cleaned with tap water and oven dried CR at 60 °C for 24 hours. The CR is ensured to be completely dried by comparing the weight of the CR after drying for 24 hours with the

weight after drying for another 1 hour. The dried CR is then kept in air-tight container.



Figure 5: Washed CR was put in the oven for 24 hours.

- ii. The 40 g of dried CR is cook at 100 °C with 1 L of 1M of NaOH under stirring for 1 hour to remove undesired products. The brownish mixture is cooked until turn into dark purple. The mixture turn to purple due to the present of protein in the coconut residue.



Figure 6: Dried CR is cooked with NaOH using hotplate magnetic stirrer until the solution turns into dark purple

- iii. The purplish slurry is then filtered and washed with tap water until the dark purple colour fade away.
- iv. The filtrate is then oven dried once again at 60 °C for 24 hours.
- v. The first batch of dried cellulose powder is obtained. The process is repeated to prepare more cellulose powder.

3.2.1.4 Procedure of CMC Synthesizing

- i. Consist of 2 reaction: alkalization and carboxymethylation.
- ii. Alkalization: 100 mL of NaOH (60%) and 900 mL of isopropanol to is added 30 g of cellulose powder under mechanical stirring for 30 minutes. The formation of white precipitate are observed after adding NaOH and isopropanol to the cellulose.
- iii. Carboxymethylation: 36 g of chloroacetic acid is added into the mixture while continue stirring. The reaction starts once chloroacetic acid is added.
- iv. The reaction is continued for 240 minutes reaction time at 60 °C reaction temperature. The precipitate dissolved during the reaction.

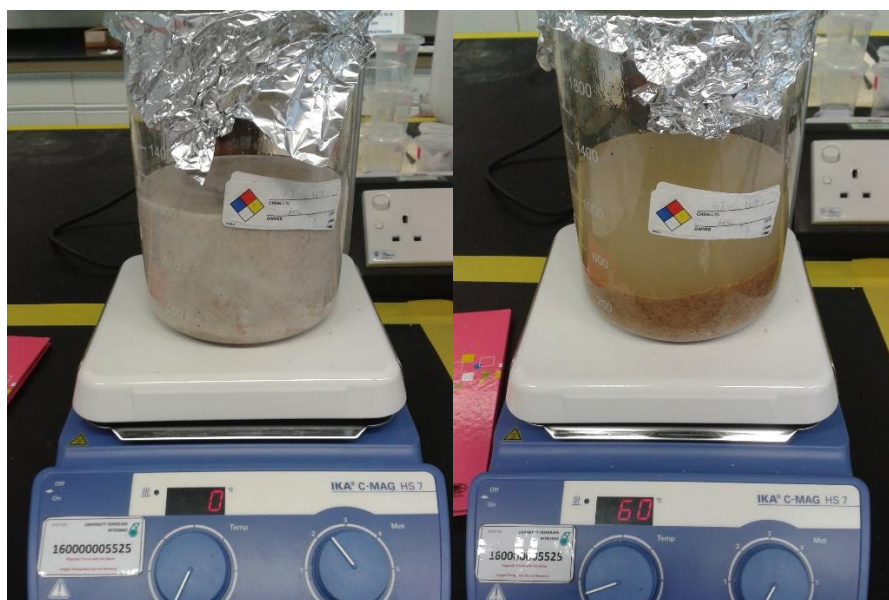


Figure 7: The formation of white precipitate are observed after adding NaOH, isopropanol and chloroacetic acid to the cellulose. The precipitate dissolved during the heating.

- v. The mixture is filtered and suspended in 100mL 70% v/v methanol overnight.
- vi. The mixture is then neutralized using 100 mL glacial acetic acid.
- vii. Undesired products are removed by undergoing washing process with 300 ml of 70% v/v ethanol and 300 mL of absolute methanol.
- viii. The filtered Carboxymethylcellulose CMC is oven dried at 60 °C for 24 hours.
- ix. The dried CMC is grinded with Cole Parmer Mortar Grinder to obtain the residue in powder form.

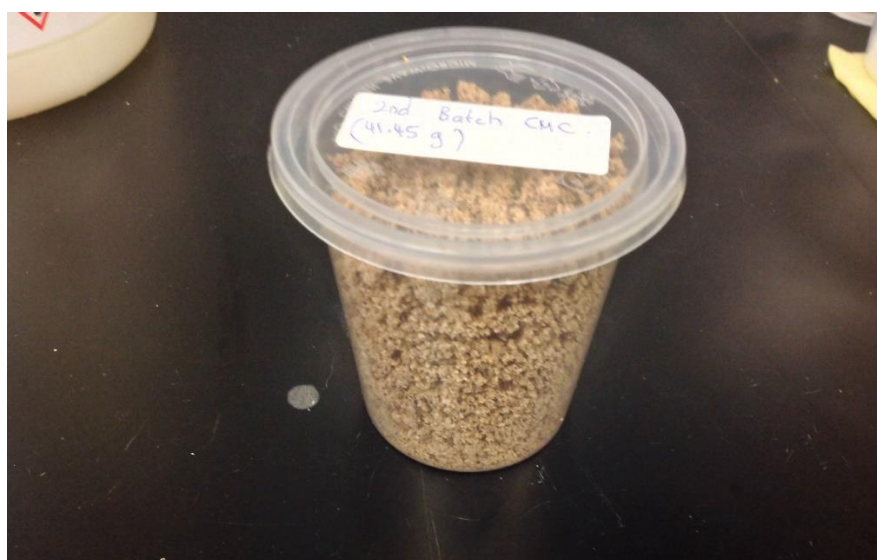


Figure 8: CMC before grinded using Cole Mortar Grinder

3.2.2 Flow Loop Test

3.2.2.1 Materials and Chemical

- i. Tap water
- ii. CMC powder

3.2.2.2 Tools and Apparatus

- i. Beaker
- ii. Flow Loop

- iii. Electronic Weight Scale
- iv. Measuring Cylinder
- v. Magnetic Stirrer
- vi. Spatula

3.2.2.3 Interested Components of Flow Loop Equipment

- i. Centrifugal Pump
- ii. Flow Control Valve
- iii. Flowmeter
- iv. Water Manometer
- v. 1 m 23.5 mm I/D smooth pipe

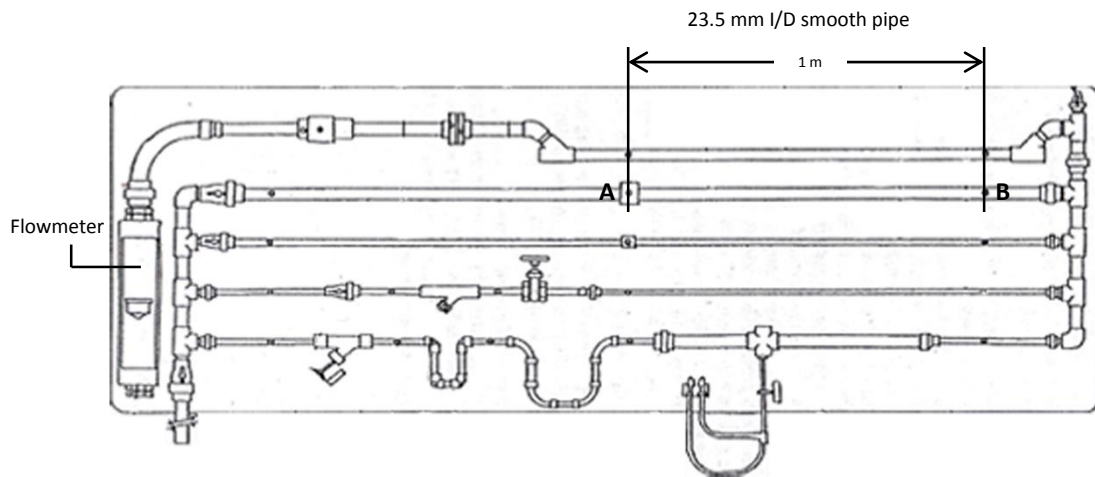


Figure 9: Schematic View of Flow Loop

3.2.2.4 Procedure of Sample Preparation

In order to prepare a CMC solution of certain concentration, the mass of CMC to be added to tap water need to be calculated. The mass of CMC to be added can be calculated with *Equation 2.3*.

To prepare CMC solution with concentration of 200 ppm,

$$V_{CMC} = \frac{C_{DRA} \times V_{TOTAL}}{1 \times 10^6}$$

$$V_{CMC} = \frac{200 \text{ ppm} \times 40000 \text{ mL}}{1 \times 10^6}$$

$$V_{CMC} = 8 \text{ g}$$

From the above calculation, it shows that in order to prepare a CMC solution with a concentration of 200 ppm, 8 g of CMC is needed. The amount of CMC need for preparation of other concentrations for the analysis are tabulated in the following table.

Table 3: Amount of CMC for preparation of sample solutions with different concentrations

Concentration (ppm)	CMC (g)
200	8
500	20
1000	40

- i. 8 g of CMC is added to 2 L of water under stirring at 200 °C (4000 ppm).
- ii. Any impurities are removed by filter.
- iii. Diluted with 39 L of water (200 ppm).
- iv. Repeat the process (i to iii) for sample with 20 g and 40 g of CMC to prepare sample of different concentration (500 ppm and 1000 ppm respectively).

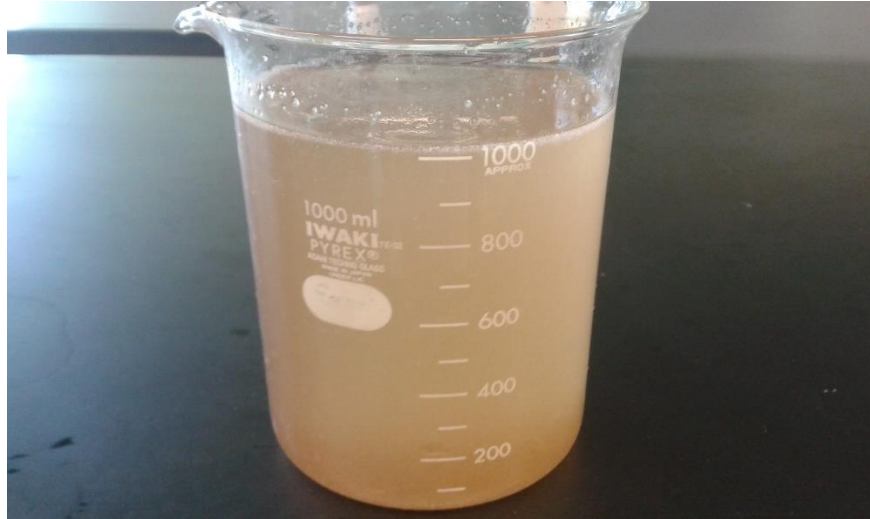


Figure 10: 2000 ppm CMC Solution

3.2.2.5 Procedure of Flow Loop Test and Mechanical Degradation Evaluation

- i. Tank of flow loop is filled with 40 L of water sample without CMC.
- ii. The pump is switched on and the liquid level in manometer is kept to stabilize after 1 minute and recorded as initial reading of the atmospheric pressure.
- iii. The flow control valve is then slowly opened to reach liquid flow rate of 2 m³/h by monitoring the flowmeter.



Figure 11: Flowmeter with flow rate maintaining at 2m³/h

- iv. The water manometer readings at the points before and after the 1 m long smooth inner surface pipe with inner diameter of 23.5 mm, which are label point A and B in *Figure 9*, are observed and recorded after let to stabilize for 1 minute.
- v. The experiment is continued by slowly decrease the liquid flow rate to 1 m³/h by adjusting the flow control valve and monitoring the flowmeter. Step iv is repeated.
- vi. The pump is then switched off and flow control valve is fully opened to let all liquid drained out into the tank below.
- vii. The drain valve at the side of the tank is fully opened to drain all water from the tank to prepare for the new run.
- viii. Tank of flow loop is filled with 40 L of water sample with 200 ppm CMC.
- ix. Step ii to iv is repeated. The pumping is continue for another 1 hours and the manometer readings are recorded every 1 minute.
- x. The flow loop setup is flushed once with clean water to remove any leftovers inside the system.
- xi. The experiments are repeated with water sample containing CMC of different concentration (500 ppm and 1000 ppm) and at different flow rate (1 m³/h and 2 m³/h).
- xii. Results are recorded and tabulated.

3.3 KEY MILESTONES

Table 4: Key Milestones of the Research

Milestones	Date
Draft Extended Proposal to Supervisor	27 Oct. 2014
Submit Extended Proposal	31 Oct. 2014
Proposal Defence	28 Nov. 2014
Synthesization of Biopolymer	18 Feb. 2015
Data Collection Complete (Solubility, Degradation, Performance of Different Concentration)	20 Mar. 2015
Data Analysis Complete	27 Mar. 2015
Review Findings with Supervisor	1 Apr. 2015
Review Draft Final Report with Supervisor	1 Apr. 2015
Submit Dissertation and Technical Paper	Week 14 of FYP 2

3.4 GANTT CHART

Table 5: Gantt Chart of FYP I

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 Defence						█								
Proposal Defence							█	█						
Project work continues: - Experiment Designing - Lab booking - Chemicals purchasing										█	█	█		
Submission of Interim Draft Report													█	
Submission of Interim Report														█

Table 6: Gantt Chart of FYP I

Activities	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project work continues: - Experiments	█	█	█	█	█	█	█								
Submission of Progress Report							█								
Project work continues: - Reporting and Documenting								█	█						
Pre-SEDEX										█					
Submission of Draft Report											█				
Submission of Dissertation (Soft Bounded)												█			
Submission of Technical Paper													█		
Viva														█	
Submission of Project Dissertation (Hard Bounded)															█

3.5 EQUIPMENT, APPARATUS, CHEMICALS AND SOFTWARE

Table 7: List of Equipment

No.	Equipment	Purpose
1.	Cole Parmer Mortar Grinder	<ul style="list-style-type: none"> To grind the CMC to obtain fine powder form for better solubility
2.	Hotplate Magnetic Stirrer	<ul style="list-style-type: none"> To continuously stir the mixtures while heating up the solutions to a desired temperature To prepare CMC solution
3.	Heating Oven	<ul style="list-style-type: none"> To speed up the drying process of the samples.
4.	Fz-200i A&D Electronic Weighting Scale	<ul style="list-style-type: none"> To accurately measure the weight of the samples and chemical needed for CMC synthesizing and CMC solution preparation
5.	Laboratory Scale Flowloop Experimental Setup	<ul style="list-style-type: none"> To assess the drag reduction ability of prepared CMC and evaluate the mechanical degradation the CMC.

Table 8: List of Apparatus

No.	Apparatus	Purpose
1.	Glass beakers (100 mL, 1 L and 2 L)	<ul style="list-style-type: none"> To store the mixtures and solutions For heating and stirring activities.
2.	Glass bottle with lid (2L)	<ul style="list-style-type: none"> To store the chemical and chemical waste before disposal.
3.	Aluminium foil	<ul style="list-style-type: none"> To prevent the evaporation while heating To minimize the release of hazardous fume To cover the sample while heating in oven to speed up the process
4.	Filter funnel (with 3mm holes)	<ul style="list-style-type: none"> To filter the filtrate out of the solutions. To use in pouring
5.	Filter papers	<ul style="list-style-type: none"> To filter the filtrate out of the solutions.
6.	Stopwatch	<ul style="list-style-type: none"> To measure the time for each test of each sample
7.	Measuring cylinder (100 mL)	<ul style="list-style-type: none"> To measure the amount of solutions or solvents to be use accurately
9.	Air-tight containers	<ul style="list-style-type: none"> To store the filtered powders while maintain minimal moisture content.
10.	Spatula	<ul style="list-style-type: none"> To transfer the chemical powder or crystal For mechanical stirring

Table 9: List of Chemical

No.	Chemical/Solvent	Purity/Grade	Supplier
1.	Distilled water	100%/SLR	UTP Laboratory
2.	Sodium hydroxide pellets AR QREC S5158-1-1000	99%/AR	Irama Canggih Sdn Bhd
3.	Isopropanol AR QREC PR141-1-2500	99%/AR	Irama Canggih Sdn Bhd
4.	Ethanol 96% denatured AR QREC E7045-1-2500	99%/AR	Irama Canggih Sdn Bhd
5.	Methanol AR QREC M2097- 1-2500	99%/AR	Irama Canggih Sdn Bhd
6.	Chloroacetic acid for synthesis MERCK 8004121000	99%/AR	Irama Canggih Sdn Bhd
7.	Acetic acid AR QREC A1020- 1-2500	99%/AR	Irama Canggih Sdn Bhd

Table 10: List of Software

No.	Software	Purpose
1.	Microsoft Office Word 2010	For reporting purpose
2.	Microsoft Excel 2010	For tabulating the results

CHAPTER 4

RESULTS AND DISCUSSION

4.1 VARIABLES

4.1.1 Constant variables

CMC Synthesizing

- i. NaOH concentration (60 % wt)
- ii. Reaction Time (240 min)
- iii. Reaction Temperature (60 °C)

CMC Percentage of Drag Reduction (%DR) Analysis

- i. Volume of solution in the mixing tank (40 L)
- ii. Inner diameter of the pipe (0.0235 m)
- iii. Total pipe length of the flow meter
- iv. pipe length that the pressure drop measured (1 m)
- v. Water temperature (25 °C)
- vi. Stabilization time before recording the pressure drop (1 min)

CMC Mechanical Degradation Analysis

- i. Volume of solution in the mixing tank (40 L)
- ii. Inner diameter of the pipe (0.0235 m)
- iii. Total pipe length of the flow meter
- iv. pipe length that the pressure drop measured (1 m)
- v. Water temperature (25 °C)

- vi. Stabilization time before recording the pressure drop (1 min)
- vii. Time of pumping (60 min)
- viii. Interval of each pressure drop reading (1 min)

4.1.2 Manipulated variables

CMC Percentage of Drag Reduction (%DR) Analysis

- i. Flow rate (1 m³/h and 2 m³/h)
- ii. Concentration (200 ppm, 500 ppm and 1000 ppm)

CMC Mechanical Degradation Analysis

- i. Flow rate (1 m³/h and 2 m³/h)
- ii. Concentration (200 ppm, 500 ppm and 1000 ppm)

4.2 ASSUMPTIONS

i. Flow regime

It is impossible to determine at what Reynolds number the fluid flow in the pipe will be either persistently turbulent or laminar. Only through extensive experiments and computer simulations able to characterize the process that ultimately responsible got sustaining turbulence (Avila et al., 2011). Thus, it is hard to estimate the turbulence flow of the liquid flowing in the flowloop. It is assumed that the fluid flow in the interested pipe section is in turbulence flow in this experiment.

ii. CMC solubility

The CMC solution prepared prior to flowmeter test is assumed to be completely mixed with the water in the tank. This assumption is important because complete solubility of CMC in the solution is required to ensure drag reduction.

iii. Full-pipe flow

Assumption has been made that the liquid flow inside the flowmeter experimental setup is in conduit flow. As mentioned in the literature review, the CMC acts as dampener in between the flowing liquid and along the pipe internal wall.

4.3 YIELD OF CARBOXYMETHYLCELLULOSE (CMC) EXTRACTION

The CMC synthesizing is carried out at control variables which are listed in *Section 4.1.1* that prove to be the optimum condition that give the highest mass of yield with the most effective DRA. Five batches of CMC sample have been prepared and the yields are tabulated in the following table.

Table 11: Yield of CMC Synthesizing

No.	Material				Yield
	CR Cellulose (g)	60 % wt NaOH (mL)	Isopropanol (mL)	Chloroacetic Acid (g)	CMC (g)
1	30	100	900	36	28.77
2	30	100	900	36	27.35
3	30	100	900	36	27.18
4	30	100	900	36	27.83
5	30	100	900	36	28.58
Total					139.71

Table 10 shows that for every 30 g of dried CR cellulose powder, 27.18 g to 28.77 g of CMC powder can be produced. These yields are taking in account some loss of sample during the transferring between containers and filtration. Despite the losses, a total of 139.71 g CMC is prepared for further analysis.

4.4 DRAG REDUCTION OF CMC AT DIFFERENT CONCENTRATION AND DIFFERENT FLOW RATE

The drag reduction ability of the samples with different concentration are tested at different flow rate. The results are summarized in *Table 12*. The Drag Reduction Percentage (%DR) calculated in *Table 12* are calculated using *Equation 2.1*.

Table 12: Pressure drop and drag reduction of tests with different flow rate (1 m³/h and 2 m³/h) and different concentration (200 ppm, 500 ppm and 1000 ppm)

Flow Rate (m ³ /h)	Sample							
	40 L Tap Water		40 L Tap Water + 200 ppm CMC		40 L Tap Water + 500 ppm CMC		40 L Tap Water + 1000 ppm CMC	
	ΔP (Pa)	%DR (%)	ΔP (Pa)	%DR (%)	ΔP (Pa)	%DR (%)	ΔP (Pa)	%DR (%)
1	43.16	-	37.28	13.64	32.37	25.00	31.39	27.27
2	115.76	-	85.35	26.27	74.56	35.59	71.61	38.14

From the data recorded in *Table 12*, four graphs have been plotted each to visualize the relationships on %DR of samples with different concentration at different flow rate.

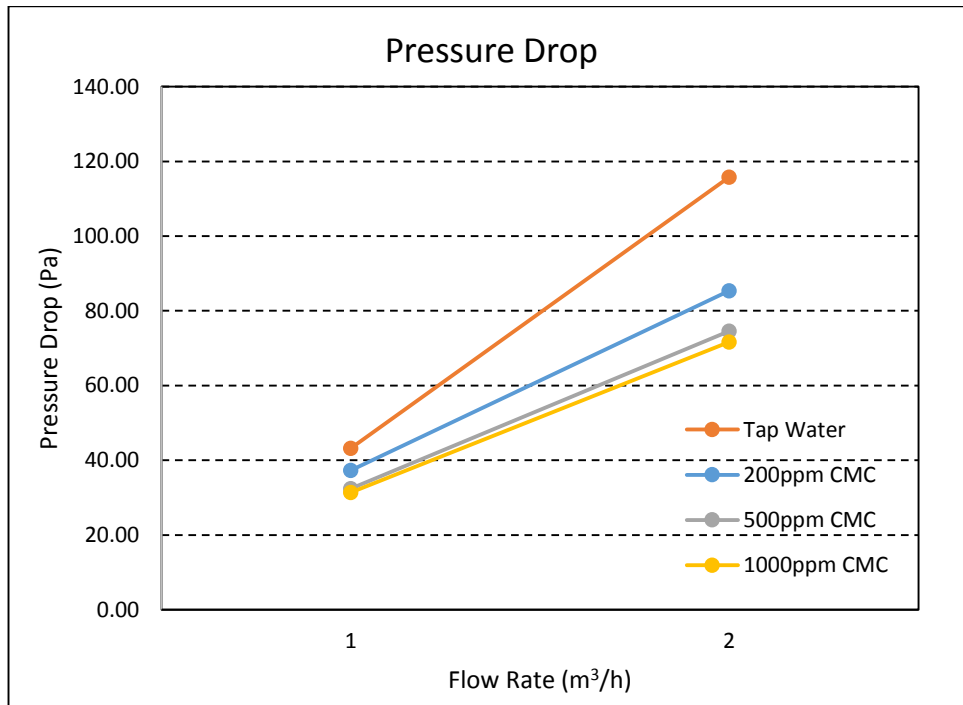


Figure 12: Pressure drop of sample with different concentration (200 ppm, 500 ppm and 1000 ppm) at different flow rate (1 m³/h and 2 m³/h)

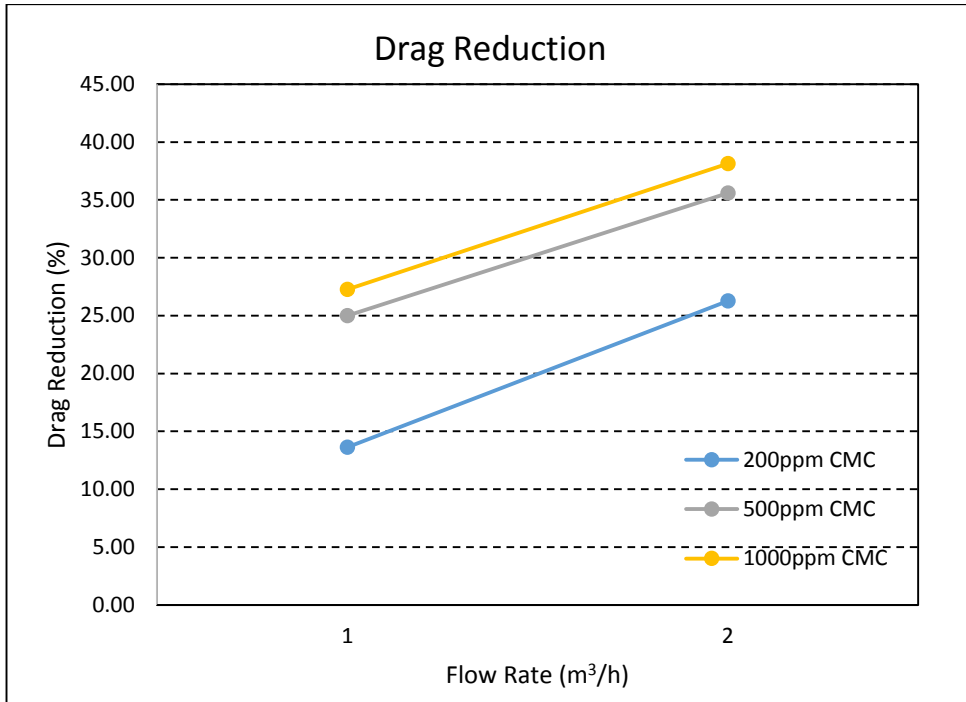


Figure 13: Drag reduction of sample with different concentration (200 ppm, 500 ppm and 1000 ppm) at different flow rate (1 m³/h and 2 m³/h)

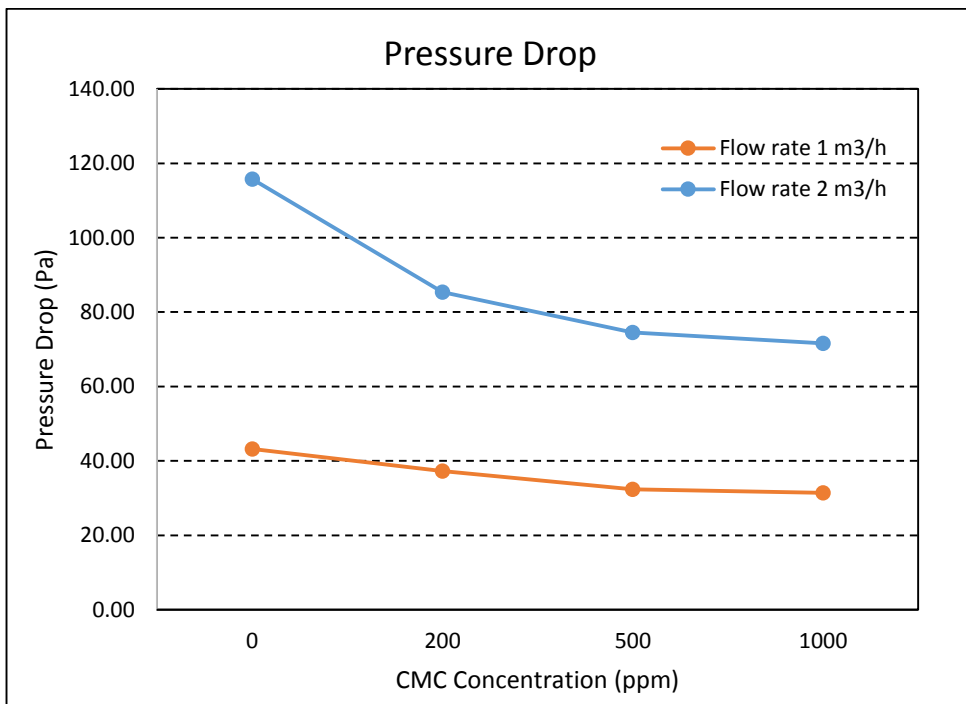


Figure 14: Pressure drop of tests with different flow rate (1 m³/h and 2 m³/h) for sample with different concentrations concentration (200 ppm, 500 ppm and 1000 ppm)

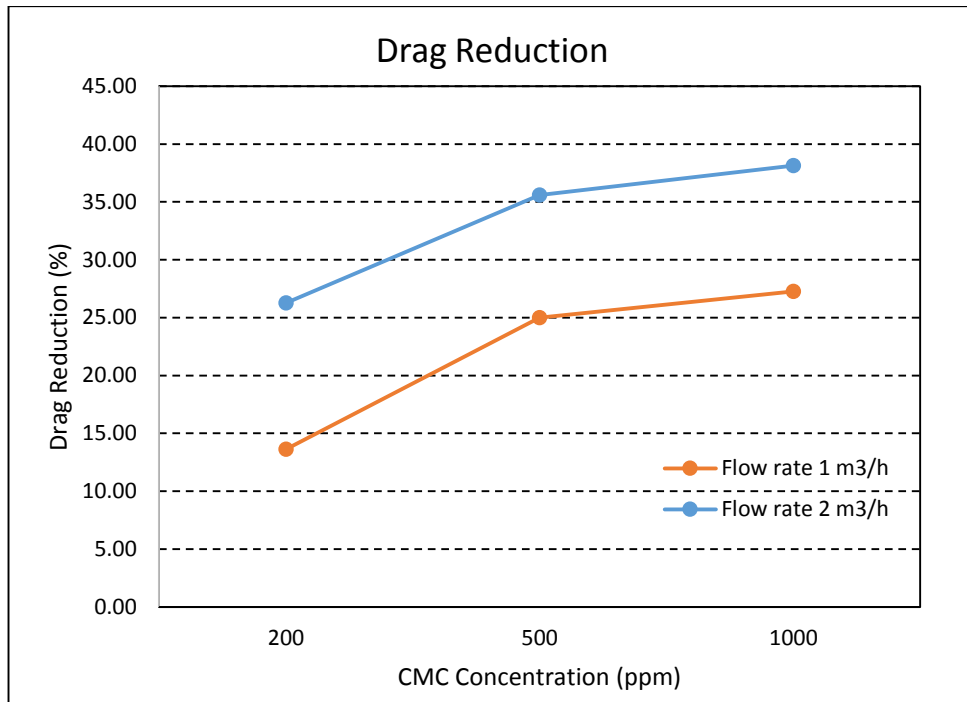


Figure 15: Drag reduction of tests with different flow rate (1 m³/h and 2 m³/h) for sample with different concentrations concentration (200 ppm, 500 ppm and 1000 ppm)

From the graphs shown in *Figure 12* and *13*, the effect of the drag reduction of CMC is more significant in the case of higher flow rate (2 m³/h) as compare to the lower flow rate (1 m³/h). For flow rate of 2 m³/h, the pressure drop of tap water across 1 m long smooth pipe is 115.76 Pa which is higher than 43.16 Pa of flow rate of 1 m³/h. The high flow rate inside a pipeline results a high friction force which eventually lead to a high pressure drop. Thus, the effect of CMC is more visible in the case of 2 m³/h flow rate as compare to the case of 1 m³/h flow rate.

From the graphs shown in *Figure 14* and *15*, the drag reduction ability is increased along with the increase of CMC concentration. CMC reduces the drag by interrupting the eddy currents in turbulent flow and dampens the current which results in reduction pressure drop across the flow. Thus, with the increase of concentration, the content of polymer to dampen currents increase. At the flow rate of 1 m³/h, %DR for 200 ppm CMC is 13.64 %, for 500 ppm is 25.00 % and for 1000 ppm is 27.27 %. While at the flow rate of 2 m³/h, %DR for 200 ppm CMC is 26.27 %, for 500 ppm is 35.59 % and for 1000 ppm is 38.14 %. Even though the %DR increases as the concentration of CMC increases, the increase of %DR when the concentration is increased from 500

ppm to 1000 ppm is not as great as the increase of %DR when the concentration is increased from 200 ppm to 500 ppm. This is believed due to the saturated of polymer. For the drag reduction of a pipe flow with the length of 1 m, the polymer contents in the solution is already sufficient to reduce the drag in the turbulence flow regime. It is anticipated that if the CMC concentration continue to increase, it will eventually reach a point that %DR will not increase anymore. This analysis can be done to identify the optimum DRA concentration for the best %DR performance when considering the economic aspect.

4.5 MECHANICAL DEGRADATION OF CMC

The degradation of the CMC for each test is observed for 60 minutes. The results is visualized in *Figure 16* and *17*. The pressure drop and %DR of every minutes for each test can be found in *Appendix 1* and *2*.

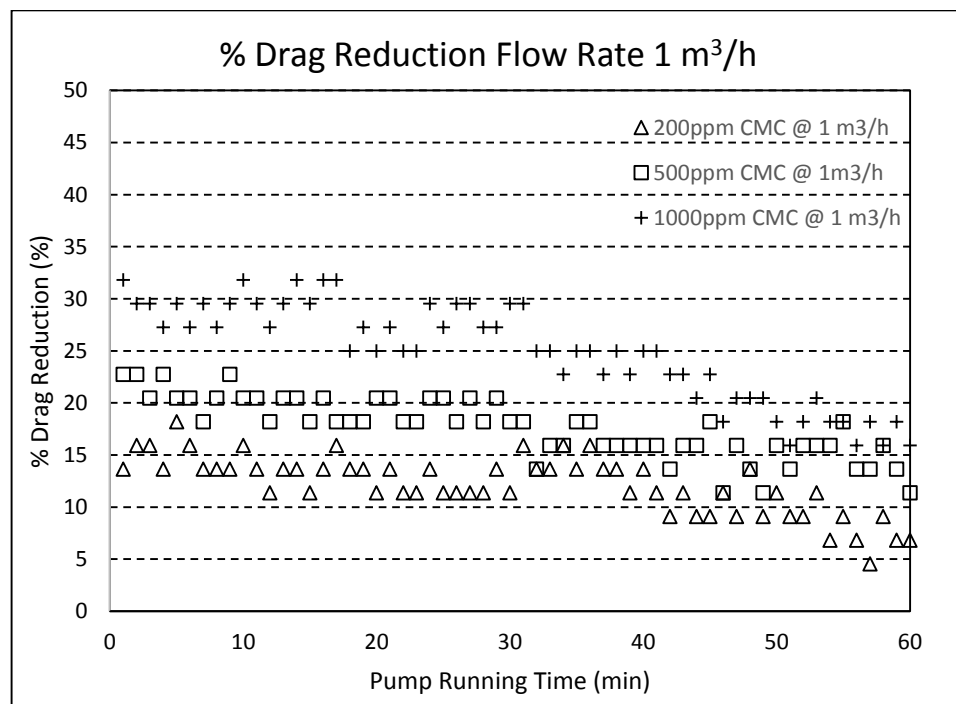


Figure 16: Mechanical degradation of sample with different concentration (200 ppm, 500 ppm and 1000 ppm) pumping at the flow rate of 1 m³/h for 60 minutes.

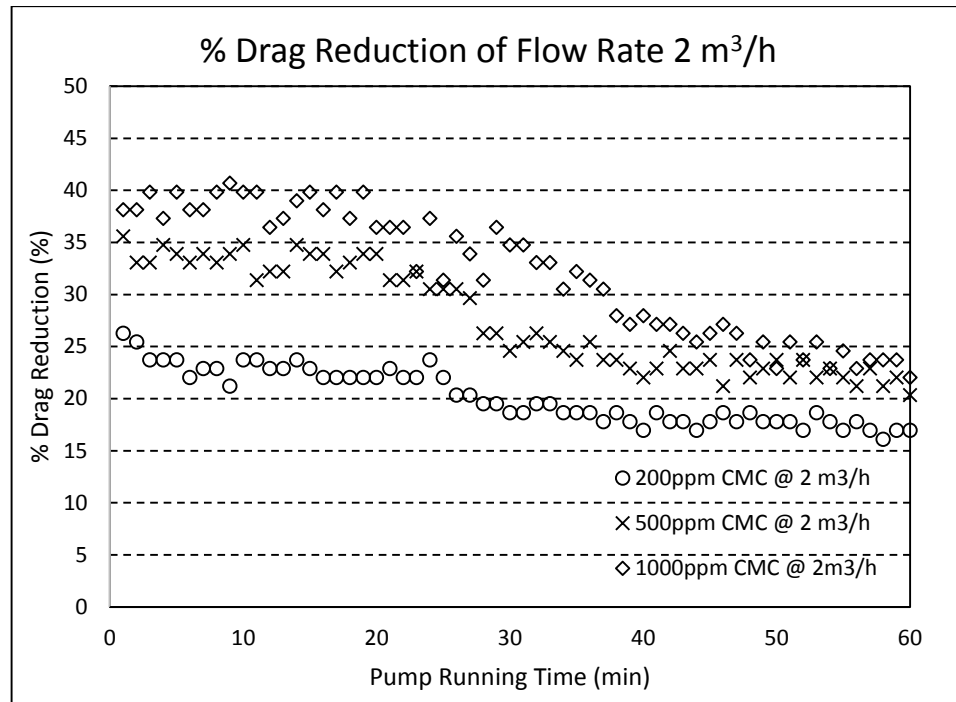


Figure 17: Mechanical degradation of sample with different concentration (200 ppm, 500 ppm and 1000 ppm) pumping at the flow rate of 2 m³/h for 60 minutes.

The drag reduction ability of CMC decreases throughout the 60 minutes of the test. The drag reduction performance decreases over time because the CMC in the fluid degrades mechanically in high shear rate flow. The shear force in the fluid flow inside the pipeline causes the polymer to elongate and eventually break the polymer chains (Jouenne et al., 2014).

Figure 16 and 17 shows that the degradation increases with the increase of concentration. The degradation started earlier for the case of higher flow rate. For the flow rate of 2 m³/h, the degradation begins around 20 minutes of pumping, while for the flow rate of 1 m³/h, the degradation is visible after around 35 minutes of pumping, regardless the concentration. After the critical point where CMC start to degrade, the drag reduction performance of the polymers reduce continuously. The decrease of %DR increases with concentration. This is because the higher polymer content indicates higher amount of polymer exposes to the shear force, which mean more polymer will degrade even at the same flow rate. The decrease of the %DR of all cases are tabulated in Table 13.

Table 13: Decrease of %DR after 60 minutes of pumping

	1 m ³ /h	2 m ³ /h
Conc. (ppm)	Reduction of %DR	Reduction of %DR
100	6.82	6.93
200	9.08	12.71
1000	11.36	15.25

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This research proven CMC extracted from coconut residue, which is an organic waste of coconut industries, can be used as a DRA. In the experiment carried out during this research, for every 30 g of dried coconut residue cellulose powder, 27.18 g to 28.77 g of CMC can be synthesized at the controlled condition which is 60 %wt NaOH, 60 °C reaction temperature and 240 min reaction time.

On the other hand, the outcome from this research also concluded that the CMC extracted from CR can perform well as DRA. This can be seen from the results that there is significant pressure reduction as compared to fully water bearing flowing across the 1 m smooth pipe with 23.5 in inner diameter. The extracted CMC able to reduce the drag of in the pipe flow by 13.64 % to 38.14 % depending on the flow rate and concentration. The drag reduction effect of CMC increases along with the increase of the rate of fluid flow and at higher CMC concentration, the drag reduction ability of CMC is more significant too. Besides, the experimental results showed the synthesized CMC is sensitive to mechanical degradation during the flow in the pipeline which reduces the overall DRA performance after a period of time. The degree of degradation of the CMC differs at different concentration and different flow rate. The CMC degrades faster when the fluid is flowing at a higher rate. Since environmental issues always are everyone's concern, this research shows the possibility of using CMC extracted from natural waste (coconut residue) to serve as a replacement for current commercialized synthetic DRAs.

5.2 RECOMMENDATION

Due to the limitation of time and equipment, there are several parameters have not been included as part of this research. Thus, it is recommended to consider these parameter in future study.

The recommendations includes:

- Include the consideration of the dynamic reservoir pressure and temperature in the study.
- Consider the chemical reaction between CMC and the inner wall of the pipeline and injection well.
- Study the other properties of the prepared CMC that are important as DRA, such as solubility.
- Evaluate the stability of CMC in high temperature.

REFERENCES

- Abdulbari, H. A., Shabirin, A., & Abdurrahman, H. (2014). Bio-polymers for improving liquid flow in pipelines—A review and future work opportunities. *Journal of Industrial and Engineering Chemistry*, 20(4), 1157-1170.
- Al-Anazi, H. A., Al-Faifi, M., Tulbah, F. M., & Gillespie, J. (2006). *Evaluation of Drag Reducing Agent (DRA) for Seawater Injection System: Lab and Field Cases*.
- Avila, K., Moxey, D., de Lozar, A., Avila, M., Barkley, D., & Hof, B. (2011). The onset of turbulence in pipe flow. *Science*, 333(6039), 192-196.
- Burger, E., Munk, W., & Wahl, H. (1982). Flow increase in the trans Alaska pipeline through use of a polymeric drag-reducing additive. *Journal of petroleum Technology*, 34(2), 377-386.
- Campbell, S. E., & Jovancicevic, V. (2001). *Performance Improvements From Chemical Drag Reducers*.
- Cardenas-Toro, F. P., Alcazar-Alay, S. C., Forster-Carneiro, T., & Meireles, M. A. A. (2014). Obtaining Oligo-and Monosaccharides from Agroindustrial and Agricultural Residues Using Hydrothermal Treatments. *Food and Public Health*, 4(3), 123-139.
- Hénaut, I., Glenat, P., Cassar, C., Gainville, M., Hamdi, K., & Pagnier, P. (2012). *Mechanical Degradation Kinetics of Polymeric DRAs*. Paper presented at the 8th North American Conference on Multiphase Technology.
- Ikoku, C. U. (1984). *Natural gas production engineering*: Wiley.
- Jouenne, S., Anfray, J., Cordelier, P. R., Mateen, K., Levitt, D., Souilem, I., . . . Waldman, T. E. (2014). *Degradation (or Lack Thereof) And Drag Reduction Of Hpam During Transport In Pipelines*. Paper presented at the SPE EOR Conference at Oil and Gas West Asia.
- Kaur, H., Singh, G., & Jaafar, A. (2013). *The Study of Drag Reduction Ability of Naturally Produced Polymers from Local Plant Source*. Paper presented at the IPTC 2013: International Petroleum Technology Conference.
- Kelland, M. A. (2014). Drag-Reducing Mechanisms *Production Chemicals for the Oil and Gas Industry, Second Edition* (pp. 376): Taylor & Francis.
- Kopania, E., Wietecha, J., & Ciechańska, D. (2012). Studies on isolation of cellulose fibres from waste plant biomass. *Fibres & Textiles in Eastern Europe*.

- Kulić, G. J., & Radojičić, V. B. (2011). Analysis of cellulose content in stalks and leaves of large leaf tobacco. *Journal of Agricultural Sciences, Belgrade*, 56(3), 207-215.
- Lake, L. W. (1989). *Enhanced oil recovery*: Prentice Hall.
- Liberatore, M. W., Baik, S., McHugh, A. J., & Hanratty, T. J. (2004). Turbulent drag reduction of polyacrylamide solutions: effect of degradation on molecular weight distribution. *Journal of non-newtonian fluid mechanics*, 123(2), 175-183.
- Nelson, J. (2004). Optimising production using drag reducing agents in water injection wells. *Offshore Engineer*, 29(1), 47-49.
- Ng, S., Tan, C. P., Lai, O. M., Long, K., & Mirhosseini, H. (2010). Extraction and characterization of dietary fiber from coconut residue. *J Food Agric Environ*, 8, 172-177.
- Nuni Handayani, S., & Simamora, J. H. (2012). Challenge in Mature Field's Waterflood Project: Facing Limited GGRP Data & Budget Issue.
- Oskarsson, H., Uneback, I., & Hellsten, M. (2005). *Surfactants as Flow Improvers in Water Injection*. Paper presented at the SPE International Symposium on Oilfield Chemistry.
- Salamone, J. C. (1996). *Polymeric Materials Encyclopedia, Twelve Volume Set*: Taylor & Francis.
- Saputra, A. H., Qadhayna, L., & Pitaloka, A. B. (2014). Synthesis and characterization of carboxymethyl cellulose (cmc) from water hyacinth using ethanol–isobutyl alcohol mixture as the solvents. *International Journal of Chemical Engineering and Application*, 5(1), 36-40.
- Toms, B. A. (1948). *Some observations on the flow of linear polymer solutions through straight tubes at large Reynolds numbers*. Paper presented at the Proceedings of the 1st International Congress on Rheology.
- Wahl, H. A., Beaty, W. R., & Hass, G. R. (1982). *Drag Reducer Increases Oil Pipeline Flow Rates*.

APPENDICES

Appendix 1

Mechanical Degradation Analysis of flow rate 1 m³/h

1m3/h 200ppm				1m3/h 500ppm				1m3/h 1000ppm			
time (min)	P1 (mmH2O)	P2 (mmH2O)	DR (%)	time (min)	P1 (mmH2O)	P2 (mmH2O)	DR (%)	time (min)	P1 (mmH2O)	P2 (mmH2O)	DR (%)
1.0	45.2	41.4	13.6	1.0	46.1	42.8	25.0	1.0	46.9	43.7	27.3
2.0	45.2	41.5	15.9	2.0	46.1	42.7	22.7	2.0	47.1	44.0	29.5
3.0	45.2	41.5	15.9	3.0	46.1	42.6	20.5	3.0	47.1	44.0	29.5
4.0	45.1	41.3	13.6	4.0	46.0	42.6	22.7	4.0	47.0	43.8	27.3
5.0	45.0	41.4	18.2	5.0	46.1	42.6	20.5	5.0	47.0	43.9	29.5
6.0	45.0	41.3	15.9	6.0	46.0	42.5	20.5	6.0	47.0	43.8	27.3
7.0	45.1	41.3	13.6	7.0	45.9	42.3	18.2	7.0	46.9	43.8	29.5
8.0	45.1	41.3	13.6	8.0	46.0	42.5	20.5	8.0	47.0	43.8	27.3
9.0	45.1	41.3	13.6	9.0	45.9	42.5	22.7	9.0	46.9	43.8	29.5
10.0	45.2	41.5	15.9	10.0	46.0	42.5	20.5	10.0	47.0	44.0	31.8
11.0	45.1	41.3	13.6	11.0	45.9	42.4	20.5	11.0	47.1	44.0	29.5
12.0	45.2	41.3	11.4	12.0	46.0	42.4	18.2	12.0	47.0	43.8	27.3
13.0	45.1	41.3	13.6	13.0	45.9	42.4	20.5	13.0	46.9	43.8	29.5
14.0	45.1	41.3	13.6	14.0	45.8	42.3	20.5	14.0	46.8	43.8	31.8
15.0	45.2	41.3	11.4	15.0	45.9	42.3	18.2	15.0	46.9	43.8	29.5
16.0	45.0	41.2	13.6	16.0	45.7	42.2	20.5	16.0	46.7	43.7	31.8
17.0	45.0	41.3	15.9	17.0	45.8	42.2	18.2	17.0	46.8	43.8	31.8
18.0	45.0	41.2	13.6	18.0	45.9	42.3	18.2	18.0	47.0	43.7	25.0
19.0	45.0	41.2	13.6	19.0	45.7	42.1	18.2	19.0	46.9	43.7	27.3
20.0	45.1	41.2	11.4	20.0	45.6	42.1	20.5	20.0	47.0	43.7	25.0
21.0	45.0	41.2	13.6	21.0	45.6	42.1	20.5	21.0	46.9	43.7	27.3
22.0	45.0	41.1	11.4	22.0	45.8	42.2	18.2	22.0	46.9	43.6	25.0
23.0	45.0	41.1	11.4	23.0	45.9	42.3	18.2	23.0	46.9	43.6	25.0
24.0	45.0	41.2	13.6	24.0	45.7	42.2	20.5	24.0	46.7	43.6	29.5
25.0	45.0	41.1	11.4	25.0	45.7	42.2	20.5	25.0	46.7	43.5	27.3
26.0	45.0	41.1	11.4	26.0	45.7	42.1	18.2	26.0	46.7	43.6	29.5
27.0	45.0	41.1	11.4	27.0	45.7	42.2	20.5	27.0	46.7	43.6	29.5
28.0	45.0	41.1	11.4	28.0	45.8	42.2	18.2	28.0	46.8	43.6	27.3
29.0	45.0	41.2	13.6	29.0	45.6	42.1	20.5	29.0	46.6	43.4	27.3
30.0	45.0	41.1	11.4	30.0	45.7	42.1	18.2	30.0	46.7	43.6	29.5
31.0	44.9	41.2	15.9	31.0	45.8	42.2	18.2	31.0	46.8	43.7	29.5
32.0	44.9	41.1	13.6	32.0	45.9	42.1	13.6	32.0	46.9	43.6	25.0
33.0	44.8	41.0	13.6	33.0	45.8	42.1	15.9	33.0	46.8	43.5	25.0
34.0	44.7	41.0	15.9	34.0	45.9	42.2	15.9	34.0	46.9	43.5	22.7
35.0	44.8	41.0	13.6	35.0	45.8	42.2	18.2	35.0	46.8	43.5	25.0
36.0	44.7	41.0	15.9	36.0	45.8	42.2	18.2	36.0	46.8	43.5	25.0
37.0	44.7	40.9	13.6	37.0	45.8	42.1	15.9	37.0	46.8	43.4	22.7
38.0	44.7	40.9	13.6	38.0	45.7	42.0	15.9	38.0	46.7	43.4	25.0
39.0	44.8	40.9	11.4	39.0	45.8	42.1	15.9	39.0	46.8	43.4	22.7

40.0	44.7	40.9	13.6	40.0	45.7	42.0	15.9	40.0	46.7	43.4	25.0
41.0	44.8	40.9	11.4	41.0	45.7	42.0	15.9	41.0	46.7	43.4	25.0
42.0	44.9	40.9	9.1	42.0	45.8	42.0	13.6	42.0	46.8	43.4	22.7
43.0	44.7	40.8	11.4	43.0	45.7	42.0	15.9	43.0	46.7	43.3	22.7
44.0	44.8	40.8	9.1	44.0	45.8	42.1	15.9	44.0	46.8	43.3	20.5
45.0	44.8	40.8	9.1	45.0	45.7	42.1	18.2	45.0	46.7	43.3	22.7
46.0	44.7	40.8	11.4	46.0	45.9	42.0	11.4	46.0	46.9	43.3	18.2
47.0	44.8	40.8	9.1	47.0	45.8	42.1	15.9	47.0	46.8	43.3	20.5
48.0	44.7	40.9	13.6	48.0	45.9	42.1	13.6	48.0	46.9	43.4	20.5
49.0	44.7	40.7	9.1	49.0	45.9	42.0	11.4	49.0	46.9	43.4	20.5
50.0	44.7	40.8	11.4	50.0	45.9	42.2	15.9	50.0	46.9	43.3	18.2
51.0	44.7	40.7	9.1	51.0	45.9	42.1	13.6	51.0	46.9	43.2	15.9
52.0	44.7	40.7	9.1	52.0	45.9	42.2	15.9	52.0	46.9	43.3	18.2
53.0	44.7	40.8	11.4	53.0	45.8	42.1	15.9	53.0	46.8	43.3	20.5
54.0	44.7	40.6	6.8	54.0	45.9	42.2	15.9	54.0	46.9	43.3	18.2
55.0	44.7	40.7	9.1	55.0	45.8	42.2	18.2	55.0	46.8	43.2	18.2
56.0	44.7	40.6	6.8	56.0	45.9	42.1	13.6	56.0	46.9	43.2	15.9
57.0	44.8	40.6	4.5	57.0	45.9	42.1	13.6	57.0	46.9	43.3	18.2
58.0	44.7	40.7	9.1	58.0	45.9	42.2	15.9	58.0	46.9	43.2	15.9
59.0	44.8	40.7	6.8	59.0	45.9	42.1	13.6	59.0	46.9	43.3	18.2
60.0	44.9	40.8	6.8	60.0	46.0	42.1	11.4	60.0	47.0	43.3	15.9

Appendix 2

Mechanical Degradation Analysis of flow rate 2 m³/h

2m ³ /h 200ppm				2m ³ /h 500ppm				2m ³ /h 1000ppm			
time (min)	P1 (mmH2O)	P2 (mmH2O)	DR (%)	time (min)	P1 (mmH2O)	P2 (mmH2O)	DR (%)	time (min)	P1 (mmH2O)	P2 (mmH2O)	DR (%)
1.0	51.7	43.0	26.3	1.0	53.3	45.7	35.6	1.0	54.5	47.2	38.1
2.0	51.8	43.0	25.4	2.0	53.5	45.6	33.1	2.0	54.6	47.3	38.1
3.0	52.0	43.0	23.7	3.0	53.4	45.5	33.1	3.0	54.4	47.3	39.8
4.0	52.0	43.0	23.7	4.0	53.3	45.6	34.7	4.0	54.5	47.1	37.3
5.0	52.0	43.0	23.7	5.0	53.3	45.5	33.9	5.0	54.4	47.3	39.8
6.0	52.0	42.8	22.0	6.0	53.3	45.4	33.1	6.0	54.4	47.1	38.1
7.0	51.9	42.8	22.9	7.0	53.5	45.7	33.9	7.0	54.5	47.2	38.1
8.0	51.9	42.8	22.9	8.0	53.4	45.5	33.1	8.0	54.4	47.3	39.8
9.0	52.0	42.7	21.2	9.0	53.3	45.5	33.9	9.0	54.3	47.3	40.7
10.0	51.8	42.8	23.7	10.0	53.3	45.6	34.7	10.0	54.4	47.3	39.8
11.0	51.8	42.8	23.7	11.0	53.3	45.2	31.4	11.0	54.4	47.3	39.8
12.0	51.8	42.7	22.9	12.0	53.5	45.5	32.2	12.0	54.4	46.9	36.4
13.0	51.8	42.7	22.9	13.0	53.4	45.4	32.2	13.0	54.5	47.1	37.3
14.0	51.7	42.7	23.7	14.0	53.3	45.6	34.7	14.0	54.3	47.1	39.0
15.0	51.8	42.7	22.9	15.0	53.3	45.5	33.9	15.0	54.4	47.3	39.8
16.0	51.8	42.6	22.0	16.0	53.3	45.5	33.9	16.0	54.4	47.1	38.1
17.0	51.8	42.6	22.0	17.0	53.5	45.5	32.2	17.0	54.4	47.3	39.8
18.0	51.8	42.6	22.0	18.0	53.4	45.5	33.1	18.0	54.5	47.1	37.3
19.0	51.8	42.6	22.0	19.0	53.3	45.5	33.9	19.0	54.3	47.2	39.8
20.0	51.8	42.6	22.0	20.0	53.3	45.5	33.9	20.0	54.3	46.8	36.4
21.0	51.8	42.7	22.9	21.0	53.0	44.9	31.4	21.0	54.3	46.8	36.4
22.0	51.9	42.7	22.0	22.0	53.1	45.0	31.4	22.0	54.3	46.8	36.4
23.0	51.9	42.7	22.0	23.0	53.0	45.0	32.2	23.0	54.2	46.2	32.2
24.0	51.7	42.7	23.7	24.0	53.1	44.9	30.5	24.0	54.2	46.8	37.3
25.0	51.8	42.6	22.0	25.0	53.1	44.9	30.5	25.0	54.1	46.0	31.4
26.0	51.9	42.5	20.3	26.0	53.1	44.9	30.5	26.0	54.2	46.6	35.6
27.0	51.8	42.4	20.3	27.0	53.1	44.8	29.7	27.0	54.3	46.5	33.9
28.0	52.0	42.5	19.5	28.0	53.3	44.6	26.3	28.0	54.7	46.6	31.4
29.0	51.9	42.4	19.5	29.0	53.4	44.7	26.3	29.0	54.3	46.8	36.4
30.0	52.0	42.4	18.6	30.0	53.4	44.5	24.6	30.0	54.5	46.8	34.7
31.0	52.0	42.4	18.6	31.0	53.3	44.5	25.4	31.0	54.5	46.8	34.7
32.0	52.0	42.5	19.5	32.0	53.2	44.5	26.3	32.0	54.6	46.7	33.1
33.0	51.9	42.4	19.5	33.0	53.2	44.4	25.4	33.0	54.6	46.7	33.1
34.0	52.0	42.4	18.6	34.0	53.3	44.4	24.6	34.0	54.7	46.5	30.5
35.0	52.0	42.4	18.6	35.0	53.4	44.4	23.7	35.0	54.6	46.6	32.2
36.0	52.0	42.4	18.6	36.0	53.3	44.5	25.4	36.0	54.7	46.6	31.4
37.0	52.0	42.3	17.8	37.0	53.4	44.4	23.7	37.0	54.7	46.5	30.5
38.0	51.9	42.3	18.6	38.0	53.4	44.4	23.7	38.0	54.7	46.2	28.0
39.0	52.0	42.3	17.8	39.0	53.4	44.3	22.9	39.0	54.8	46.2	27.1
40.0	52.1	42.3	16.9	40.0	53.5	44.3	22.0	40.0	54.9	46.4	28.0
41.0	51.9	42.3	18.6	41.0	53.5	44.4	22.9	41.0	54.7	46.1	27.1
42.0	52.0	42.3	17.8	42.0	53.3	44.4	24.6	42.0	54.7	46.1	27.1
43.0	52.0	42.3	17.8	43.0	53.4	44.3	22.9	43.0	54.8	46.1	26.3

44.0	52.1	42.3	16.9	44.0	53.4	44.3	22.9	44.0	54.9	46.1	25.4
45.0	52.0	42.3	17.8	45.0	53.4	44.4	23.7	45.0	54.7	46.0	26.3
46.0	51.9	42.3	18.6	46.0	53.5	44.2	21.2	46.0	54.7	46.1	27.1
47.0	52.0	42.3	17.8	47.0	53.4	44.4	23.7	47.0	54.8	46.1	26.3
48.0	51.9	42.3	18.6	48.0	53.5	44.3	22.0	48.0	54.9	45.9	23.7
49.0	52.0	42.3	17.8	49.0	53.4	44.3	22.9	49.0	54.8	46.0	25.4
50.0	52.0	42.3	17.8	50.0	53.4	44.4	23.7	50.0	54.9	45.8	22.9
51.0	52.0	42.3	17.8	51.0	53.3	44.1	22.0	51.0	54.9	46.1	25.4
52.0	52.1	42.3	16.9	52.0	53.4	44.4	23.7	52.0	54.8	45.8	23.7
53.0	51.9	42.3	18.6	53.0	53.5	44.3	22.0	53.0	54.8	46.0	25.4
54.0	52.0	42.3	17.8	54.0	53.4	44.3	22.9	54.0	54.9	45.8	22.9
55.0	52.1	42.3	16.9	55.0	53.3	44.1	22.0	55.0	54.9	46.0	24.6
56.0	52.0	42.3	17.8	56.0	53.4	44.1	21.2	56.0	54.8	45.7	22.9
57.0	52.0	42.2	16.9	57.0	53.4	44.3	22.9	57.0	54.8	45.8	23.7
58.0	52.1	42.2	16.1	58.0	53.5	44.2	21.2	58.0	54.9	45.9	23.7
59.0	52.0	42.2	16.9	59.0	53.3	44.1	22.0	59.0	54.8	45.8	23.7
60.0	52.0	42.2	16.9	60.0	53.3	43.9	20.3	60.0	55.0	45.8	22.0