EFFECT OF MECHANICAL DEGRADATION ON DRAG REDUCTION ABILITY USING BANANA PEEL AS A BIOPOLYMER

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ABSTRACT

Reducing drag is reducing the frictional pressure loss under turbulent flow conditions. The main purpose of using drag reduction is to reduce energy consumption by using active agents known as drag reduction agents without changing the mechanical parts of the process such as pumps, pipes and fittings. Drag reduction in turbulent flow can be achieved by several types of additives. The additives can be split into three groups: polymers, surfactants and fibers. These additives can dramatically affect the turbulent structures of the flowing fluid, increase the flow rate and decrease the energy consumption. The addition of a small amount of polymer to a turbulent fluid flow can greatly reduce the amount of drag a fluid creates in a vessel. Synthetic polymers are widely studied and employed for drag reduction systems. These polymers harm our environment when used excessively. A biopolymer is then soughed for such purpose. A biopolymer is a macromolecule produced by living organisms and they are fairly shear stable, biodegradable and have drag reduction ability as well as flocculation tendency at relatively higher concentration. The drag reduction of a biopolymer produced from a local plant source within the turbulent regime was explored and assessed in this study using a rheometer where a reduced produced torque was perceived as a reduction of drag. An important problem in the application and study of drag reduction by polymer additives is the degradation of the polymers. It is well known that the drag reducing capability of a biopolymer is limited by mechanical degradation. Mechanical degradation occurs due to mechanical energy acting on the polymer in the solution. Mechanical stresses causes the biopolymer to break, thereby reducing the molecular weight of the biopolymer and thus its drag reducing capability. The biopolymers produced were then rheologically characterized where the viscoelastic effects and the normal stresses produced by these biopolymers were utilized to further relate and explain the drag reduction phenomena. The research was structure to focus on producing the biopolymer, to assess the drag reduction ability of the biopolymer produced and to test the mechanical degradation of the biopolymer using water and oil as a solvent. Bases on the results, the biopolymer produced works as a suitable drag reducing agent. The mechanical degradation study showed that after a mechanical pre-shearing of 60 minutes on the samples, it can be seen that the biopolymer does now have an effect on the drag reduction ability.

Keywords: Drag Reduction, Biopolymer, banana peel, mechanical degradation, rheology.

INTRODUCTION

Drag Reduction

Drag reduction is a phenomenon where turbulent friction of a fluid can be greatly reduced (over 70%) with the addition of small amount of additives (e.g. a few parts per million) (Darbouret et. al., 2009). The main purpose of using drag reduction is to reduce energy consumption by using active agent known as DRA without changing the mechanical parts of the process such as size of pumps, pipes and fittings (Bari et. al., 2010).

The experiment was conducted by Henaut *et al.* (2009) to demonstrate that the effectiveness of drag reduction agents can be assessed by comparing the flow curves of a treated solution (with DRA) to untreated solution (no DRA present). Jaafar *et al.* (2009) then proved that drag reduction is observed in what is termed as "Non-Newtonian flow". It can be clearly seen in 1 that the region where drag reduction is detected is bounded by the drag reduction envelope, which are the Prandtl-Karman law for Newtonian turbulent flow and the maximum drag reduction asymptote by Virk (1975).

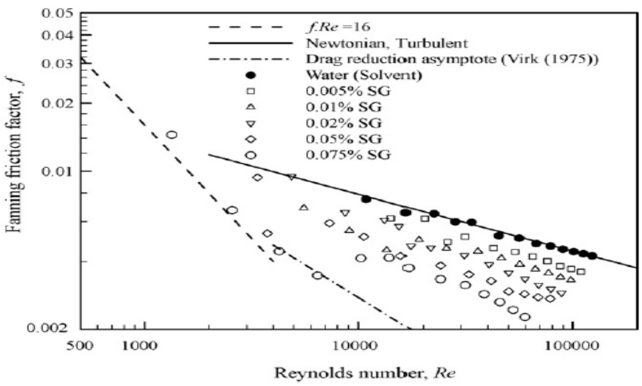


Fig. 1. f-Re data for various Scleroglucan concentrations (Jaafar et. al., 2009)

Drag Reduction Agent (DRA)

The main applications of DRA in oil and gas industries are in crude oil transportation and water injection systems. Toms (1949) was the first to report that drag reduction phenomenon and observed that the addition of few parts per million of long-chain polymers in a turbulent flow produces a dramatic reduction of the friction drag. The drag reducing agent reduces the frictional pressure lost in turbulent flow by interfering the sub-laminar layer and interaction between the fluid and the wall of the pipe. This phenomenon has been the subject of extensive reviews by Mowla and Naderi (2006), Ling and Hassan (2006), Li *et al.* (2007), Wan *et al.* (2008), Safri and Bouhadef (2008), Riccoa and Quadrio (2008), Bari and Yunus (2009) and many others. Amongst many different types of additives, polymeric drag reduction is considered an effective and economically feasible because of its rheological properties and resistance to shear force.

Polymers are divided into two categories: synthetic polymers and natural polymers. Synthetic polymers are derived from petroleum oil, while natural polymers can be extracted from resources in nature. Although synthetic polymers possess good mechanical properties and thermal stability when used as flow improvers in pipelines, these materials biodegrade very slowly, which is an environmental concern. Moreover, for similar molecular weights, synthetic polymers are more expensive than natural polymers. On the other hand, natural polymers are biodegradable and easily obtained because they are produced in the form of carboxymethylcellulose or polysaccharides by microorganisms and plants. Cellulose is a common natural polymer that can be found vastly in plants and fruits. Hence, using it from organic waste would not only help the environment plus improve water pollution.

Banana is an example of a fruit that contains a high amount of natural polymers. Banana peels, representing 40% of the total weight of fresh bananas (Tchobanoglous et al. 1993), have been underutilized. One way to utilize this waste is to synthesize the banana peel and convert it into Carboxymethylcellulose. Therefore, the author will use the Cavendish green banana peels for the project. The findings from the experiment will prove whether the Cavendish green banana peels is a good Drag Reduction Agent. Synthesizing the biopolymer will be shown in the next section.

Drag Reduction Quantification

The addition of a minute amount of drag reducing additives to a turbulent fluid flow can cause a large reduction in the frictional drag relative to a pure solvent at the same flow rate. The amount of drag reduction is generally expressed as the pressure gradient difference between the solvent and the drag reducing solution.

Jaafar (2009) evaluates drag reduction by calculating the friction factor of the polymer solution and the friction factor of water at same Reynolds number such as below:

Ta=ρ2Ω2R2-R13R1μ2<3400 $$\%DR = \left[\frac{f_N - f_P}{f_N}\right] \times 100 \quad [1]$$

where the subscripts N and P refer to the Newtonian fluid and the polymer solution respectively.

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

$$\%DR = \left[\frac{\Delta P_u - \Delta P_t}{\Delta P_u}\right] \times 100 \quad [2]$$

where:

ΔP_u: Pressure drop obtained with the untreated fluid using the flow loop

ΔP_t: Pressure drop obtained with the treated fluid using the flow loop

Jaafar (2009) states that there are also other methods of quantifying the degree of drag reduction such as using the same Reynolds number based on the friction velocity. However, regardless of definition, the differences of other methods used are small. Al-Anazi et. al., (2006) shows that there is a relationship between the drag reduction percentage and the percent flow increase (% FI). % FI can be estimated using the following equation:

$$\%\text{FI} = \left\{\left[\left[\frac{100}{100-\%DR}\right]\right]^{0.556} - 1\right\} \times 100 \qquad [3]$$

Ta=ρ2Ω2R2-R13R1μ2<3400

Research by Henaut et al., (2009) was carried out using a rheometer as a rapid screening of DRA due to the low volume of fluid and short period of time required to run the test. The performance of DRA is directly linked to the magnitude of the drag reduction percentage which is calculated based on the following:

$$\%\text{DR} = \left[\frac{T_u - T_t}{T_u}\right] \times 100\text{Ta=ρ2Ω2R2-R13R1μ2<3400} \qquad [4]$$

where:

T_u: Torque obtained with the untreated fluid using the rheometer

T_t: Torque obtained with the treated fluid using the rheometer

OBJECTIVES

The objectives of the research work proposed are:

- Extraction of cellulose from Cavendish banana peel.
- Modification of the structure of cellulose to produce CMC.
- Design the experiment protocol of assessing Drag reduction via a rheometer.
- Examine the drag reduction and mechanical degradation of the produced CMC in the solvent using a rheometer.

METHODOLOGY

The Methodology for this research has been divided into two parts which are synthesizing the Biopolymer and conducting the rheometer study using the biopolymers produced as a Drag Reducing Agent (DRA).

Synthesizing the Biopolymers

Banana Peel is rinsed with water until clean and then sun-dried for 4 days. The dried banana peel was kept in an air-tight container to prevent moisture. It will be grinded and then cooked with NaOH at 100°C. Black slurry will then be obtained. It will be filtered and washed with water. The residue will then be dried in an oven at 55°C to constant weight for 24 hours, and the pulp would be produced. It will be washed with water, filtered and then the pulp will be dried again at 55°C for 24 hours. The dried pulp will be grounded again into powder with size below 1 mm and stored in polyethylene bags. Preparation of CMC sample consists of two reactions which are alkalization and carboxymethylation reaction. Alkalization reaction begins after adding NaOH into 15g of pure cellulose and isopropanol under mechanical stirring for an hour. Then, carboxymethylation reaction start once the sodium monochloroacetate (SMCA) is added while the reaction continuously stirs at 400rpm. Reaction time and NaOH concentration are controlled in this reaction. The mixture is then filtered and suspended in 100mL of methanol overnight. The slurry was neutralized using glacial acetic acid. The samples undergo washing process using 70% ethanol solution for four times to remove undesired product. Lastly, the sample was dried in the oven at 55°C temperature. The parameter that was varied is the concentrations of sodium hydroxide (NaOH).

Rheometer Study

Unlike other experiment set ups as discussed in most literatures on Drag Reduction, the AR-G2 DCC rheometer from TA Instruments is chosen as the experiment instrument for this research as precise data can be obtained and recorded. A double concentric cylinder is used to set in the rheometer for this study. The inner cylinder will be rotating while the outer one will be attached to the base of the rheometer. The Reynolds number corresponding to this geometry, Re, is given by

$$Re = \frac{\Omega \rho R_m(\Delta R)}{\mu} \quad [5]$$

where: Ω : Angular velocity (rad/s), ρ : Fluid density (kg/m^3), R_m: Radius of rotating cylinder of the rheometer (m), R_3, ΔR: Radius difference between the outer and inner cylinder (m), R_4-R_3, Fluid viscosity (Pa.s)

Due to the centrifugal force, the flow fields developed in the two parts of the geometry is different. For the case of the outer cylinder rotating, the centrifugal force tends to stabilize the flow field. The flow field of a Newtonian liquid becomes unstable when the dimensionless Reynolds is higher than about 50000[2]. For the case of the inner cylinder rotating, the centrifugal force contributes to a destabilization of the flow field. For a Newtonian liquid, the point at which the streamlines cease to be circular and at which the flow field presents Taylor instabilities has been found by Chhabra & Richardson (1999) to take place for a critical Reynolds number defined by:

$$Re_c = \frac{\Omega \rho R_m(\Delta R)}{\mu} > 58.3 \left(\frac{R_m}{\Delta R}\right)^{0.5} \quad [6]$$

where: $R_m = R_3$, $\Delta R = R_4 - R_3$

Sample Preparation

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

$$\frac{x}{x+y} \times 100\% = \frac{100}{1\times10^6} \times 100\% \quad [7]$$

where: x = mass of commercial DRA (gram), y = mass of water (gram)

In order to make sure that the DRA mixed well in water, an overhead stirrer was used with constant low speed (approximately 200 rpm) for the duration of 3 hours until the polymer solutions appeared to be visibly homogeneous. Once mixing was completed, the solution was sealed to avoid water loss by evaporationSolutions were left for at least 8 hours before rheological tests were conducted. Sample was loaded into the DCC The temperatures for all the DRA assessments were set to 25°C. The gap was set to 2000micron. The solution was then left to rest for 2 minutes in the DCC before rheological tests were conducted. Drag Reduction test was performed from 0rad/s to 300rad/s with 20 sample points taken. The torque over the angular velocity will then be calculated to measure the drag reduction efficiency. The drag reduction percentage, %DR can be calculated using Equation (8).

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

where the subscripts u and t refer to the untreated fluid (without DRA) and treated fluid (with DRA).

The Mechanical degradation assessment was conducted by applying a peak hold step at a constant angular velocity of 200 rad/s for 60 minutes prior to the drag reduction assessment.

RESULTS AND DISCUSSION

Mechanical Degradation using water as a solvent

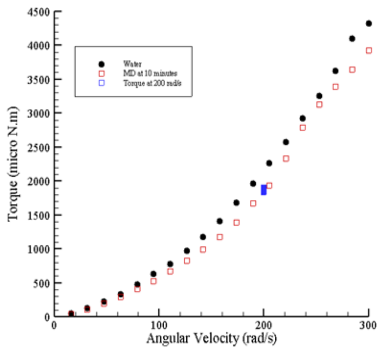
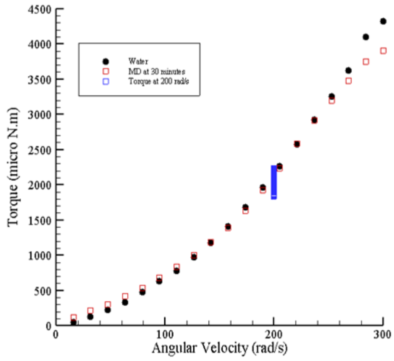
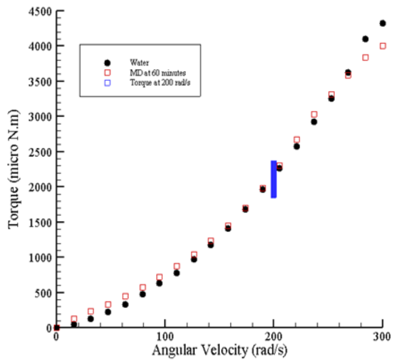
Mechanical Degradation (MD) is conducted to test how brittle or flexible the polymer via mechanical pre-shearing. In this section, experiments were conducted to evaluate the drag reduction percentage after the sample was subjected to mechanical pre-shearing under the rheometer at an angular velocity of 200rad/s, for 10 minutes, 30 minutes and 60 minutes respectively. The optimized samples are shown as per below. Comparison was done between the three samples as all the samples were synthesized with different reaction time.

Sample 1:

Table 1: Biopolymer for Mechanical degradation Sample 1

Reaction Time (min)	60
Reaction Temperature (°C)	55
Concentraion of NaOH (w/w %)	60

Table 2: Mechanical degradation of the sample 1

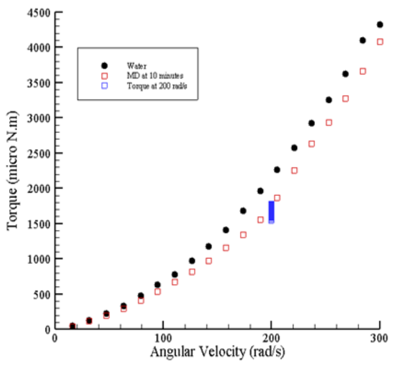
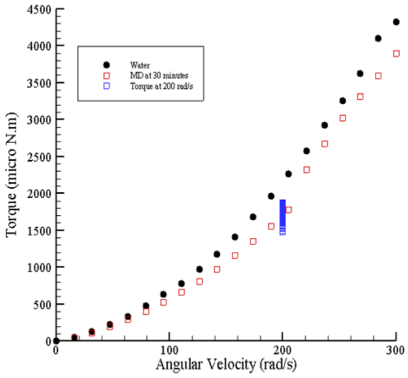
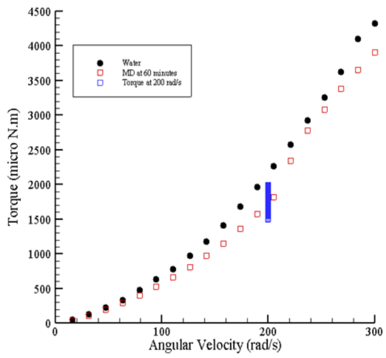
Mechanical Pre-shearing (minutes)	Critical Angular Velocity (rad/s)	Critical Reynolds number	Observation	%DR		
				100 rad/s	200 rad/s	300 rad/s
10	47	271.35		2.60	6.99	9.21
30	47	279.9		-0.79	1.02	9.74
60	47	271.35		-2.48	1.05	7.44

Sample 2:

Table 3: Biopolymer for Mechanical degradation Sample 2

Reaction Time (min)	150
Reaction Temperature (°C)	50
Concentraion of NaOH (w/w%)	20

Table 4: Mechanical degradation of the sample 2

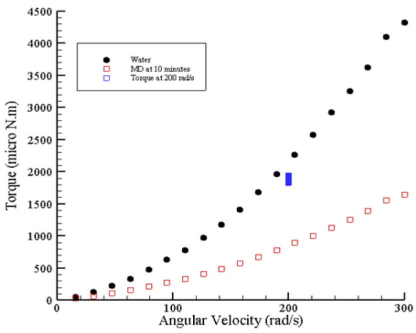
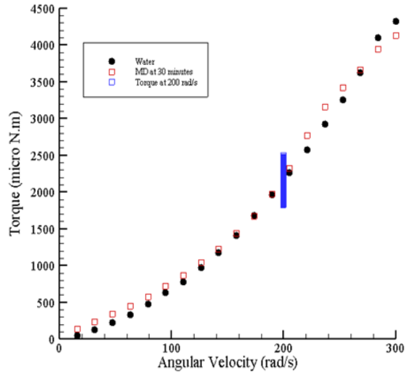
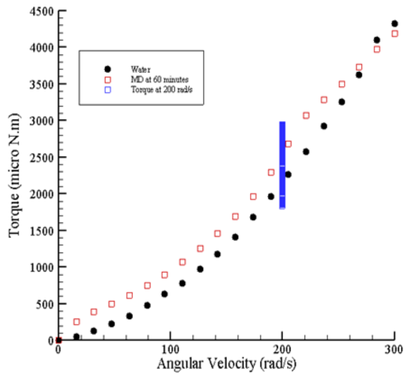
Mechanical Pre-shearing (minutes)	Critical Angular Velocity (rad/s)	Critical Reynolds number	Observation	%DR		
				100 rad/s	200 rad/s	300 rad/s
10	47	271.35		1.97	8.39	5.66
30	47	271.35		2.05	12.53	10.16
60	47	271.35		1.06	11.13	8.18

Sample 3:

Table 5: Biopolymer for Mechanical degradation Sample 3

Reaction Time (min)	240
Reaction Temperature (°C)	50
Concentraion of NaOH (w/w%)	40

Table 6: Mechanical degradation of the sample 3

Mechanical Pre-shearing (minutes)	Critical Angular Velocity (rad/s)	Critical Reynolds number	Observation	%DR		
				100 rad/s	200 rad/s	300 rad/s
10	47	271.35		12.04	45.99	60.43
30	47	271.35		-2.85	-0.99	3.74
60	47	271.35		-5.47	-7.98	2.67

Based on sample 1, 2 and 3, at 10 minutes, adverse drag reduction is less obvious as compared to mechanical pre-shearing for 30 and 60 minutes. For sample 1, the onset for DR after 10 minutes, 30 minutes and 60 minutes, respectively are 60rad/s, 120 rad/s and 140 rad/s. For sample 2, the onset for DR after 10 minutes, 30 minutes and 60 minutes, respectively are 60rad/s, 80rad/s and 90 rad/s. For sample 3, the onset for DR after 10 minutes, 30 minutes and 60 minutes, respectively are 35rad/s, 200rad/s and 240 rad/s. The adverse drag reduction can be clearly seen in samples where mechanical pre-shearing is 60 minutes. This probably happened as this is an organic material and the long duration of pre-shearing has changed the effectiveness of it where it takes some time before it starts to reduce the drag.

The blue points on all graphs show the torque produced when the sample was placed under mechanical shearing at an angular velocity of 200 rad/s for 10 minutes, 30 minutes and 60 minutes. Based on the three samples, it can be observed that the time involved for mechanical pre-shearing has an effect on the drag reduction percentage. Therefore, the time for the mechanical pre-shearing was then standardized to 60 minutes for the remaining samples. The results in the tables above show the drag reduction percentage at 100 rad/s, 200 rad/s and 300 rad/s. Based on sample 1, 2 and 3, it reduced the drag up to 7.44%, 8.18% and 2.67% respectively.

The sample which showed the best drag reduction percentage was discussed in the previous subsection and it has been taken here again to show the comparison. Based on all samples, adverse drag reduction occurs before the flow becomes turbulent. This can be clearly seen as the water points start off higher than the biopolymer mixed with water. After 3-5 minutes, drag reduction comes into play.

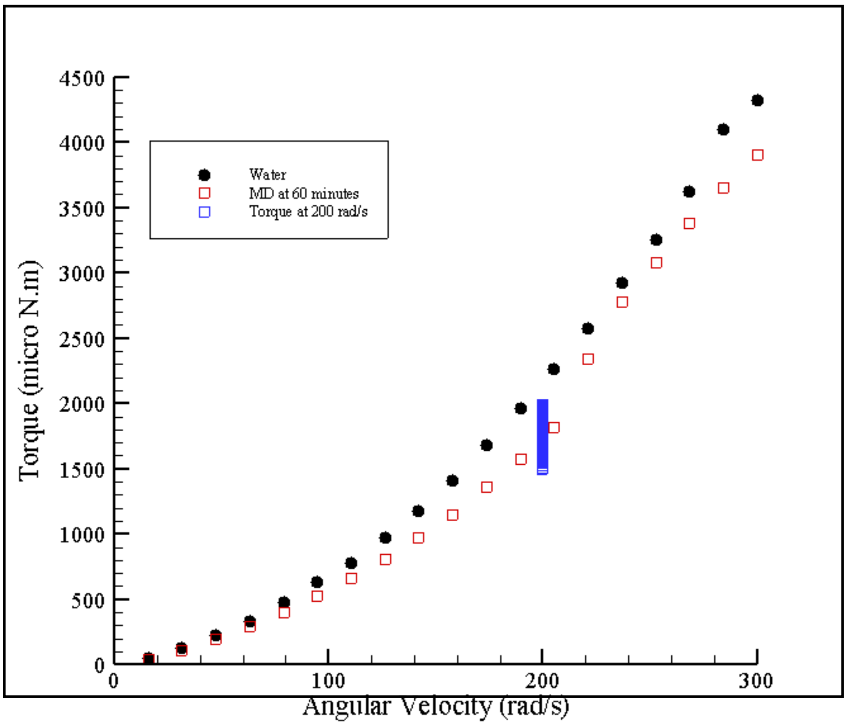


Figure 29: Mechanical degradation with a pre-shearing of 60 minutes

Mechanical degradation is linked to shear-flow, causing degradation of dilute solutions when present (Sellin et al.). It has been documented in the literature that biopolymers, being environmental friendly, show great resistance to mechanical degradation. According to Singh (2000), biopolymers are high molecular weight polysaccharides, which are made by living organisms and exhibit effective drag reduction.

Kulmatova (2013) mentioned that polysaccharides like fresh water biological growths are excellent drag reducers. Yet, due to their production of fouling substances, these biological additives can substantially reduce DRA efficiency. It has been found that polysaccharides such as CMC show significant resistance to mechanical degradation compared to flexible polymers with similar molecular weights. Bueche (2011) showed evidence that the mechanical degradation of the polymer within elongated flows, which exist in some regions of turbulent pipe flow, is extremely severe. This is because a polymer molecule in a turbulent flow is subjected to stretching and rotation, due to interaction of the vortices. The practical use of polymers in a turbulent drag reduction application is consequently mostly hindered by mechanical shear degradation. Some polymers tend to have the quick self-repairing ability after mechanical degradation and they can keep the drag-reducing effect for some time (Wu Ge, 2008).

CONCLUSION

Drag reduction is a phenomenon where turbulent friction of a fluid is greatly reduced with addition of small amounts of additives. The drag reduction of water is explored within this research. Due to the friction of the fluid and the eddy currents in the pipeline, the flow of the fluid is not smooth and a higher pumping power is required to ensure a smoother flow. A biopolymer was then invented in this research to aid in reducing the drag. The main purpose of drag reduction is to reduce the energy and increase the fluid flow capacity in the pipeline. This research was structured to focus on producing the biopolymer and also to assess the drag reduction ability of this biopolymer. The drag reduction of the biopolymer produced was explored and assessed using the rheometer, within which the reduction in torque produced is perceived as a reduction of drag.

In conclusion, from the results shown, Carboxymethylcellulose could be synthesized from Banana peel by carboxymethylation. Using a DCC rheometer to evaluate DRA shows great potential in replacing the current method which is the flow loop. The study of the performance on the biopolymer made from banana peel has shown great characteristics as a drag reduction agent and results which are added into water that will serve to reduction of pumping power losses in the oil and gas industry and reduction in energy consumption. Experimental results showed that the presence of biopolymers in water helps in the performance of DRA. The mechanical degradation study showed that after a mechanical pre-shearing of 60 minutes on the samples, it can be seen that the biopolymer does have effect on the drag reduction and it reduced the drag up to 8% overall on all three samples. After 60 minutes of mechanical pre-shearing, the biopolymer shows a high drag reduction percentage.

Hence, the CMC from Cavendish banana peel can be considered a good drag reduction agent and works effectively in water by reducing as much as 30.62% and fairly in oil as much as 16.06%. Thus, this biopolymer can help many industries especially those involving fluid flows to reduce drag and increase production. All the objectives in this research were achieved.

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