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Comparison on Experimental and Simulation Result on Drag Reducing Effect of Low Concentration Chitosan in Turbulent Flow

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ABSTRACT Polymeric drag reducing agent (DRA) is widely used in various industries due to its ability to enhance fluid flow inside a pipe. The drag reduction (DR) caused by the addition of chitosan extracted from shrimp shell has been recently discovered and shows a promising potential as DRA. In this study, the drag reducing effect of low concentration chitosan was observed and compared with a simulation done using HYSIS software. The experiment is conducted in a closed loop circulation system where water is the transporting medium. The pipe system consists of polyvinyl chloride (PVC) pipes with 0.013 m, 0.025 m and 0.038 m diameter. The chitosan was tested in five different concentrations. It was found that the highest DR obtained from experiment and simulation are 32% and 29% respectively which both obtained from the 0.038 m pipe with 30 ppm concentration. Both experimental and simulation results on DR show similar pattern with slight difference in value. In overall, it was found that low concentration DRA can reduce the formation of drag. The drag reduction increased as the concentration of chitosan increased and larger pipe diameter produced higher percentage of drag reduction.

KEYWORDS: Drag reduction; Chitosan; HYSIS simulation; Polymeric DRA; Turbulent flow
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Original Article

INTRODUCTION

Fluid flowing in a pipe is prone to drag due to friction between the fluid particles and pipe wall. Drag is defined as the frictional force occurs inside a pipeline the restrict the motion of flow of the fluid (Salehudin & Ridha, 2016). This drag phenomenon is indicated by the amount of pressure drop in the flow and the decrease in flow rate. Many methods were developed to solve this problem known as drag reduction (DR). Abdulbari *et al*. (2014) defined drag reduction as the science of improving fluid flow by reducing the pressure drop across a pipe.

One of the well-known methods to reduce drag is by using polymeric Drag Reducing Agent (DRA) and consist of three types: polymer, surfactant, and solid suspensions. Surfactants are compounds that lower the surface tension of liquid that lower the interfacial tension between two fluids. Surfactant has the ability to form micelle, which makes it susceptible to mechanical degradation and suitable to be used as DRA (Abdulbari *et al*., 2011). Solid suspension consists of solid particles that is introduced in fluid flow and can change the fluid rheological behaviour. The interactions between the particles and the formation of turbulence may result in increased viscosity thus promotes drag reduction (Gharehkhani *et al*., 2017).

Polymeric DRAs are extensively researched and considered as the most favourable as additives due to its strength and sturdiness against the chaotic turbulence inside the flow. Polymeric DRA is effective in pipe flow due to its rheological properties and its resistance to shear force (Abdulbari *et al*., 2014). It is very viscoelastic and mostly hydrocarbon which will not affect on the physical properties of the transported fluid. The solvent-DRA mixture between produces a solution that is shear-degradable, time-independent, viscoelastic, and non-Newtonian fluids (Martínez-Palou *et al*., 2011). Polymeric DRAs are the long-chain polymer with high molecular weight and when introduced into a flow, it will interact with the fluid flow and dampened the outbreak of turbulence namely in the buffer region of the flow. Lumley (1977) proposed that the stretching of a coiled polymer will increase the extensional viscosity and dampened the small eddies in the buffer layer resulting in a more effective drag reduction. Polymer DRA is widely applied in various sectors such as firefighting (Figueredo & Sabadini, 2003), district cooling and heating system (El-Azm *et al*., 2014; Kim *et al*., 2009), sewage system (Sellin, 1978) and also medical field (Marhefka & Kameneva, 2000; Marhefka *et al*., 2006). Recently, some concerns are raised on the toxicity and environmental impact of conventional polymer additives (Abdulbari *et al*., 2014).

Despite the proven successful applications in drag reduction properties, these synthetic polymers can have a big impact on the environment due to the chemical contents build up in the ground and become pollutants (Kaur *et al*., 2013). Therefore, researchers are looking switch to new organic additives as alternatives to conventional DRA. These organic additives are called biopolymers which is obtained from natural resources and produced by living organisms. The polymer extracted includes polysaccharide which is a carbohydrate with long chains of monosaccharides which has the same properties as the conventional DRAs (Abdulbari *et al*., 2014). This study was investigating low concentration chitosan as drag reducing agent. Chitosan is produced commercially by deacetylation of chitin, which is the element that made up the exoskeleton of crustaceans. Previous study on the drag reduction ability of chitosan resulting in a significant reduction of drag which is 80 % at the concentration of 300 ppm (Abdulbari *et al*, 2011). This study was conducted to study the ability of chitosan to reduce drag at low concentration by doing experimental study and also simulation to justify the results.

METHODOLOGY

Preparation of Chitosan

The DRA for this research is chitosan which is extracted from shrimp shell. These shrimp shells consist of 20-30% of chitin, 30-40% of protein, and 30-50% of calcium (Abdulbari *et al*., 2011). Chitosan can be a used as DRA due to its abundance in nature and its non-toxicity, biocompatibility, biodegradability, and adsorption (Hudson & Smith, 1998). The raw material of fresh shrimp shells was dried up. The crispy shells were then ground into powder. The powder was demineralized using 5% HCl for 24 hours at room temperature. The ratio of the weight of shells and volume of HCl (w/v) is 1:5 following the method by Toan (2009). It was further rinsed with distilled water to neutralize its pH value. Then, it was treated with 10% HCl to ensure that complete demineralization of the shell has occurs which was indicated by no formation of bubbles from the treated powder. The powder was then deproteinized using 5% NaOH and dried up to produce chitin. Finally, the chitin was deacetylated by treating it into 60% of NaOH solution. The solution is heated then rinsed with distilled water and dried up to produce chitosan. The chitosan powder produced was mixed with distilled water and stirred constantly until the solution fully mixed and become homogenous. During the mixing, heat was constantly supplied to prevent clumping. The solution was cooled down at ambient temperature before the addition of 100% glacial solutions of acetic acids. Various concentrations of chitosan solution which are 10 ppm, 15 ppm, 20 ppm, 25 ppm, and 30 ppm were prepared based on the amounts of acetic acid solution added.

Experimental Rig Set Up

The rig is a closed loop circulatory piping system with water as the transporting medium. The design of the experimental rig is shown in Figure 1. The system equipped with reservoir tanks, pumps and valves.

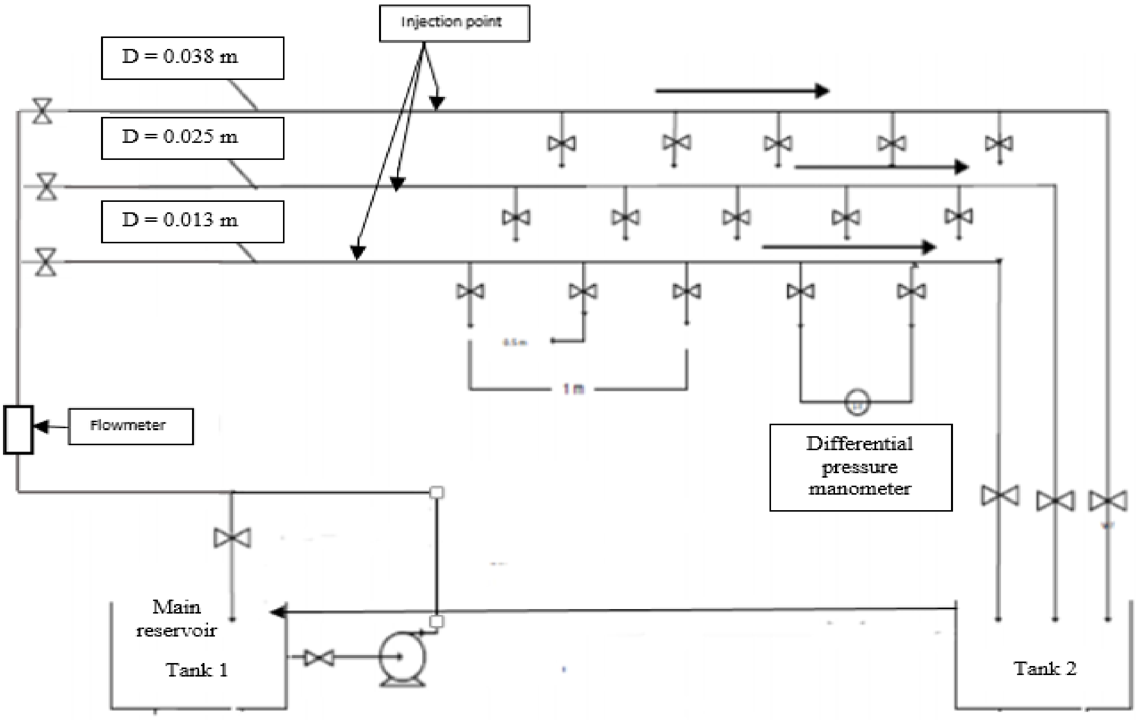


Figure 1. Schematic diagram of the experimental rig.

The water was circulated throughout the system with an aid of centrifugal pump. This piping system consists of three transparent PVC pipe that varied in diameter (0.013 m, 0.025 m, and 0.038 m). The difference in height has no effect on the experimental data since the fluid flowing in these pipes is not in fully turbulent flow, thus effect on drag reduction is negligible. The horizontal pipe before the testing sections is equal to 50 times diameter (50d) to ensure fully turbulent flow before the testing sections. Each of this pipe is completed with testing sections where all the readings for pressure drop was recorded during the experiment. The 1 m^3/h flowrate is controlled and determined using the flowmeter connected to the main pipe. The gradient in pressures were recorded before and after the addition of DRA. The chitosan concentrations were varied from 10 ppm to 30 ppm. The pressure drop reading is obtained by using the differential pressure manometer. The manometer is connected to the testing region using a portable tube. The height difference of the manometer is recorded and the changes in pressure drop is calculated using Equation (1) which is

$$\Delta P = P_2 - P_1 = \rho g h \tag{1}$$

where, ΔP is the pressure drop, P_1 is the pressure at the lower pressure connection, P_2 is the pressure at higher pressure connection, ρ is the density of the fluid, g is the gravitational acceleration, and h is the height of the manometer's reading. The solutions that were pumped across the pipeline reached the reservoir Tank 2 and returned to the main reservoir tank. The process is continuous until no external force applied to the flow.

Simulation Using HYSIS Software

The simulation of the fluid flow was conducted using Aspen HYSIS V10 in various concentrations of chitosan. The pipe design is similar to the experimental work. Figure 2 is the schematic diagram of the piping system simulated in the software which shows the simulation environment for components of water and chitosan.

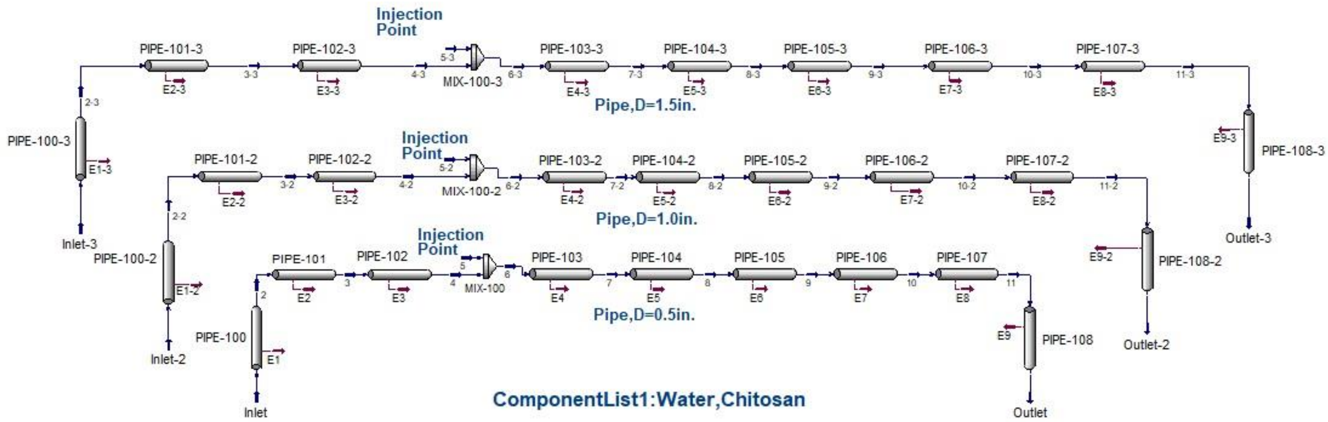


Figure 2. Simulation environment for component of water and chitosan using HYSIS Software.

For the flow simulation, water is used as the reference flowing fluid with fixed flow rates of 1 m^3/h. The chitosan is injected from the injection point. The fluid packages selected is extended NRTL as it is suitable for various concentration range between components. The NRTL model assumes that the local concentration around a molecule is different from the bulk concentration due to the difference between interaction energy of the molecules. NRTL model can be used in study involving hydrocarbon for dilute systems.

The feed condition for initial flow is 25 °C and 111.5 kPa. The assumptions made for this simulation is that the system is in steady state, no heat transfer occurs between the fluids to and the pipe walls to ensure that there are no energy dissipation occurs inside the flow other than the pressure drop. The flow is single phase which the primary phase is water. The surface roughness of the pipe is fixed throughout the pipe which is 0.015 x 10^{-5} m. The pressure drop was calculated by referring to the pressure difference indicated in the pipe profile view tab under performance using Equation (2) which is

$$\Delta P = P_2 - P_1 \quad (2)$$

where, ΔP is the pressure drop, P_1 is the pressure at the lower pressure connection, P_2 is the pressure at higher pressure connection.

RESULT AND DISCUSSION

The performance of chitosan as DRA is determined by the drag reduction percentage. The drag reduction percentage of pipe flow is obtained based on pressure drop or head loss before and after the addition of DRA into the water circulation system as expressed by Equation (3) given by

$$\%DR = \frac{\Delta P - \Delta P_{DRA}}{\Delta P} \times 100 \quad (3)$$

where, ΔP is the value of the head loss of tap water before the addition of chemical additive and ΔP_{DRA} is the value of pressure drop after addition of DRA into the system.

Comparison of DR

The experimental results were compared with simulation and tabulated in Figure 3. Generally, the graph shows an increasing trend in DR. The graph also shows that the percentage of DR increased as the concentration of chitosan increased for each pipe. The highest DR obtained through experiments was 33%, 30% and 15% for 0.0381 m, 0.0254 m and 0.0127 m, respectively. For the simulation, the highest drag reduction depicted are 29% for pipe diameter 0.038 m, 27% for 0.025 m and 25% for 0.013 m. The graph obtained shows that the drag reduction percentage increase linearly as the concentrations increase.

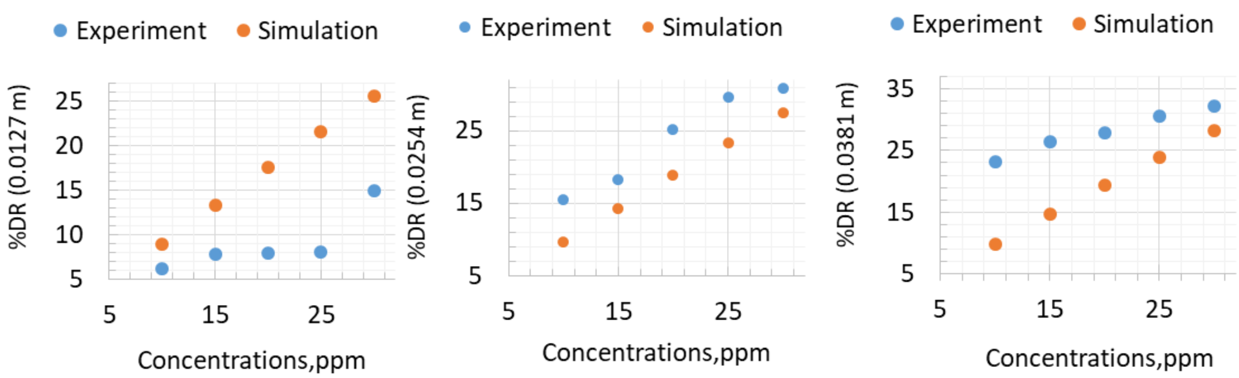


Figure 3. Comparison of DR obtained through experiment and simulation in individual pipe.

The results for experimental study and simulation study both shows the same trend proving that the chitosan has a promising potential as drag reducing agent. This indicates that the addition of chitosan into the fluid flow are able to dampened eddies formation inside the flow. Both results also show that pipe with bigger diameter produces higher drag reduction compared to smaller diameter. However, there are slight difference between the results. The DR percentage in experimental study is higher than the percentage obtained from simulations. This is probably due to the difference in pipe conditions between the experimental study and simulation.

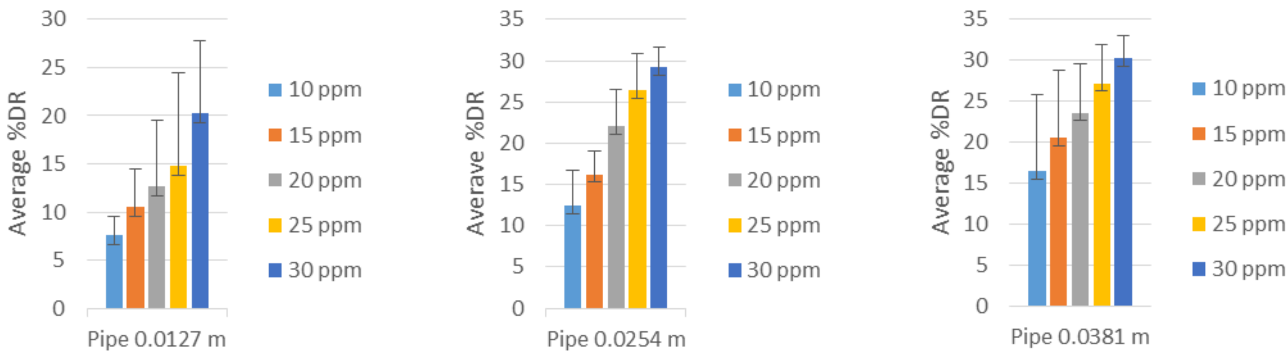
Even though the conditions for both studies are the same, the roughness for pipe in simulation is fixed throughout the flow while in experimental study, the surface roughness has a significant effect to the flow behaviour. The pipes in experimental study have different roughness along the pipeline due to fittings which may results in the increase of pipe roughness profile. This condition may result in higher eddies formation which were supressed by the DRA. Petrie *et al.* (2003) stated that in some cases, percentage of drag reduction in rougher pipe surfaces is larger and the skin friction forces was less than the results observed on a less rough surface at comparable conditions. However, their results were obtained from experimental studies involving pipe with different roughness and not a comparison between experimental study and simulation study. Thus, study on surface roughness by comparing experimental and simulation data can be proposed for future work.

It is also observed that the drag reduction only increase slightly as the concentrations were 25 and 30 ppm respectively in the experimental study compared to the results obtained in simulation which show significant difference in DR percentage obtained for the same concentrations. This may indicate that in actual application of the DRA, the drag reduction is approaching its maximum value or optimum point and further addition in the concentration may not produce significant drag reduction as the simulation suggested.

The result from this study agrees with the early observation made by Tom in 1948 which stated that only a small number of additives needed to reduce drag significantly. From the graph, it is suggested that a bigger diameter pipe could produce higher DR compared to a smaller pipe. Several researchers have investigated the effects of internal diameter to DR performance and found that the %DR increased as the diameter increased (Khadom & Abdul-Hadi, 2014; Virk, 1975). Theoretically, this phenomenon is related to eddies formation inside the turbulent flow and the capabilities of the DRA to suppress that formation. At larger pipe, the magnitude of eddies is smaller but in a larger size. Thus, they can be broken and suppressed easily by the DRA. In comparison, eddies in smaller pipe are higher in number but smaller in size, therefore it takes longer to break up caused high energy consumption (Abdulbari *et al.*, 2008). Maximum value of drag reduction is reached when the addition of concentration of DRA may no longer enhance the fluid flow or reduce in performance is observed (Mucharam *et al.*, 2018). These findings is crucial in understanding the behaviour of the flow and choosing the most suitable DRA according to pipe parameters and flow conditions.

Deviation Between Experimental and Simulation Data

Figure 4 shows the average of %DR between the experimental data and simulation data. The line indicates the deviation between the results. Standard deviation is the measures of dispersion of a dataset relative to its mean, which in this study indicated by the average %DR obtained.



(a) (b) (c)

Figure 4: Graph of deviation between experimental data and simulation data of (a) pipe 0.0127 m (b) pipe 0.0254 m and (c) pipe 0.0381 m.

For pipe diameter 0.0127 m shown in Figure 4(a), the average deviation is 5 with margin about ±5 between the deviations. The average deviation of results between experiment and simulation of pipe diameter 0.0381 m as shown in Figure 4(c) is also 5 with margin about ±5. This indicates that there are some variations on the data obtain from experiment and simulation. The results obtained from both pipe diameter is more spread out and higher standard deviation suggest that the %DR obtained from experiment are significantly different from the results of simulations. Figure 4(b) shows the deviation between the data with average deviation of 3 with margin about ±1. The standard deviation of pipe 0.0254 m is lower than pipe 0.0127m and 0.0381m showing that the results obtained from both experiment and simulation have closer values. This indicates that the data in pipe 0.0254m is more consistent compared to the other pipes.

By comparing the values of deviations between the pipes, the results of %DR in pipe 0.0127 m and pipe 0.0381 m has a higher variability compared to the results on pipe 0.0254 m pipe. However, the values of standard deviations for all pipes diameter are considerably lower which suggest that the variations between those results are still closer to the average mean. This suggest that there a strong similarity between the results in terms of trends and values thus justifying the drag reduction percentage obtained in both experimental and simulation studies.

CONCLUSION

Chitosan is a biopolymer with polysaccharides properties such as non-toxicity and biodegradability. The process involves in the extraction of chitosan from shrimp shell is demineralization, deproteinization, deacetylation, and dilution. The results from experimental study indicates that the drag reduction percentage when chitosan was introduced to the flow increase as its concentration increase. The simulation results show the same trend which justify the results obtained with experiments. Chitosan produced good drag reduction ability with the highest %DR is 32% for experimental study and 29% in simulation study for 30 ppm chitosan concentration in 0.038 m pipe diameter and 1 m^3/h flowrate. The roughness of the pipe also affects the drag reduction as there are more eddies suppressed compared to less rough surface represented by the pipe conditions depicted in simulation study. The deviation between experimental results ranges from 3 – 5 with margins of ±1 to ±5 which indicates variability of data obtained. However, the low standard deviation of the results suggests that the difference between %DR obtained from experiment and simulation is relatively small. Similar in trends and average values justify the results obtained from both studies. The diameter of the pipe also has effects on the drag reduction performance. Bigger pipe diameter produces a smaller number of eddies compared to smaller pipe diameter but bigger in size. This will provide enough time for the chitosan to interact and suppress eddies formation. This interaction makes the flow streamline inside the pipe in parallel order and lower the pressure drop.

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REFERENCES

[1] Abdulbari, H. A., Suali, E. & Hassan, Z. 2008. Glycolic Acid Ethoxylate Lauryl Ether Performance as Drag Reducing Agent in Aqueous Media Flow in Pipelines. *Journal of Applied Sciences*, 8(23), 4410–4415.

[2] Abdulbari, H. A., Hassan, Z. & Suali, E. 2011. *Surfactants-Suspended Solid Drag Reduction Systems in Pipelines* (First). LAP LAMBERT Academic Publishing.

[3] Abdulbari, H. A., Shabirin, A. & Abdurrahman, H. N. 2014. Bio-Polymers for Improving Liquid Flow in Pipelines-A Review fnd Future Work Opportunities. *Journal of Industrial and Engineering Chemistry*, 20(4), 1157–1170.

[4] Abdulbari, H. A, Mohamad, N. K., Mohd, N. & Nour, A. H. 2011. Effect of Chitosan Solution on Turbulent Drag Reduction on Aqueous Media Flow, 6(14), 3058–3064.

[5] El-Azm, M.M.A., Kassab, S. Z. & Elshafie, S.A. 2014. Experimental and Numerical Study for Turbulent Flow Drag Reduction in District Cooling Systems. *CFD Letters*, 6(3),113-125.

[6] Figueredo, R. C. R. & Sabadini, E. 2003. Firefighting Foam Stability: The Effect of the Drag Reducer Poly(Ethylene) Oxide. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 215(1–3), 77–86.

[7] Gharehkhani, S., Yarmand, H., Goodarzi, M.S., Shirazi, S.F.S., Amiri, A., Zubir, M.N.M., Solangi, K., Ibrahim, R., Kazi, S.N. & Wongwises, S. 2017. Experimental Investigation on Rheological, Momentum and Heat Transfer Characteristics of Flowing Fiber Crop Suspensions. I*nternational Communications in Heat and Mass Transfer*, 80, 60-69.

[8] Hudson, S. M. & Smith, C. 1998. Biopolymers from Renewable Resources. *In*: Kaplan, D.L. (Ed.). *Biopolymers from renewable resources* (pp. 1-29). Springer, Berlin, Heidelberg.

[9] Kaur, H., Singh, A. P. G., Jaafar, A. & Petronas, U. T. 2013. The Study of Drag Reduction Ability of Naturally Produced Polymers from Local Plant Source. *Proceedings of the International*

Petroleum Technology Conference. 26-28 March, 2013, Beijing, China, IPTC-17207-MS.

[10] Khadom, A. A. & Abdul-Hadi, A. A. 2014. Performance of Polyacrylamide as Drag Reduction Polymer of Crude Petroleum Flow. *Ain Shams Engineering Journal*, 5(3), 861–865.

[11] Kim, N. J., Kim, S., Lim, S. H., Chen, K. & Chun, W. 2009. Measurement of Drag Reduction in Polymer Added Turbulent Flow. *International Communications in Heat and Mass Transfer*, 36(10), 1014–1019.

[12] Lumley, J.L., 1977. Drag Reduction In Two Phase and Polymer Flows. *The Physics of Fluids,* 20(10), S64-S71.

[13] Marhefka, J.N. & Kameneva, M.V. 2016. Natural Drag-Reducing Polymers: Discovery, Characterization and Potential Clinical Applications. *Fluids,* 1(2), 6.

[14] Marhefka, J. N., Marascalco, P. J., Chapman, T. M., Russell, A. J. & Kameneva, M. V. 2006. Poly(N-vinylformamide) A Drag-Reducing Polymer for Biomedical Applications. *Biomacromolecules*, *7*(5), 1597–1603.

[15] Martínez-Palou, R., Mosqueira, M. de L., Zapata-Rendón, B., Mar-Juárez, E., Bernal-Huicochea, C., de la Cruz Clavel-López, J. & Aburto, J. 2011. Transportation of Heavy and Extra-Heavy Crude Oil by Pipeline: A Review. *Journal of Petroleum Science and Engineering*, 75(3–4), 274–282.

[16] Mucharam, L., Rahmawati, S. & Ramadhani, R. 2018. Drag Reducer Selection for Oil Pipeline Based Laboratory Experiment. *Modern Applied Science,* 12(1), 112–121.

[17] Petrie, H. L., Deutsch, S., Brungart, T. A. & Fontaine, A. A. 2003. Polymer Drag Reduction with Surface Roughness in Flat-Plate Turbulent Boundary Layer Flow, *Experiments in Fluids, 35*, 8–23.

[18] Salehudin, S. S. & Ridha, S. 2016. Coconut Residue as Biopolymer Drag Reducer Agent in Water Injection System. *International Journal of Applied Engineering Research*, 11(13), 8037–8040.

[19] Sellin, R. H. J. 1978. Drag Reduction in Sewers: First Results From a Permanent Installation. *Journal of Hydraulic Research*, 16(4), 357–371.

[20] Toan, N. V. 2009. Production of Chitin and Chitosan from Partially Autolyzed Shrimp Shell Materials. *The Open Biomaterials Journal*, 1(1), 21–24.

[21] Virk, P. S. 1975. Drag Reduction Fundamentals. *AIChE Journal*, 21(4), 625–656.