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Original Research Article

Drag Reduction Behavior of Aloe Vera in Horizontal Pipe with Variable Temperature

[1]Ibrahim, Y., [1,2*]Gimba, M.M. and [3]Edomwonyi-Otu, L.C.

[1]Department of Chemical Engineering, Ahmadu Bello University, Zaria, Kaduna State, Nigeria.
[2]Department of Chemical Engineering, Federal Polytechnic N'Yak Shandam, Plateau State, Nigeria.
[3]Department of Chemical and Petroleum Engineering, Delta State University, Abraka, Delta State, Nigeria.
*yibrahim1186@gmail.com; mail2gimba@gmail.com

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ABSTRACT

The drag force found in turbulent fluid flow in process industries dissipate the energy supplied by pumps in pipeline flow consequently leading to high utility cost. An environmentally friendly and low-cost material (Aloe vera mucilage, (AVM)) can reduce such cost by reducing the drag force in fluid flow. The drag-reducing characteristics of AVM in single-phase water flow (spwf) and multiphase flow was tested at ambient conditions (25 °C, 1 atm) and variable temperature (5-60 °C) in a 20 mm diameter pipe. The flow rig of 20 mm pipe ID was used for the experiment and the test fluid was water (viscosity, μ_w of 0.91 mPa.s, density, ρ_w of 1000 kg/m^3 at room temperature of 25 °C) and diesel (μ_o of 1.664 mPa.s, ρ_o of 832 kg/m^3 at 25 °C). Different AVM concentration (50-500 ppm), oil volume input fraction (Ovif), Reynolds number (12,917 – 48,872) and mixture velocity (u_m) were used. Maximum drag reduction (DR) of 50% at 25 °C, 59% at 5 °C and 41% at 60 °C in spwf at Re of 37,773 were obtained. The decrease in DR with increasing temperature and Ovif in multiphase flow observed may be due to change in AVM molecule structure or conformation and decrease in water phase mixture velocity.

1. INTRODUCTION

The engineering interference to reduce pressure drop in flow systems refers to drag reduction and it is divided into active and passive technique. The active involve the use of additives (polymers, surfactants, fibre among others) and the passive require the heating and modification of structures (Bewersdorff and Gyr, 1995; Mowla and Naderi, 2006; Al-Sarkhi, 2010; Gimba *et al.*, 2017). Drag reduction is an important area of interest in the transportation of oil-water mixture through channels (pipelines), which is a critical section of the oil industry. Liquids flowing under high Reynolds number commonly experience skin friction (pumping losses), specified by the pressure drop between 2 points. The drag phenomenon cannot be avoided, and pumping energy utilized to reduce pressure drop constitute 20% of electricity demand in the world (Hameed *et al.,* 2014). This pumping losses in flow systems increased the utility cost (Lim, 2010).

The materials or additives used for the reduction of drag in flow systems are called drag-reducing agents (Gimba *et al.,* 2020). Drag-reducing agents such as polymers, fibers and surfactant (natural or artificial) have been reported as available and cheaper means to reduce the energy losses associated with pumping systems (Edomwonyi-Otu *et al.,* 2020). Mucilage as a polysaccharide occurs naturally in plants and some micro-organisms. It swells up to form a gel-like viscous liquid. Plants containing mucilage include aloe vera, fenugreek seeds, okra and psyllium seeds among others (Lim, 2010; Hayder *et al.,* 2011; Kamarulizam, 2012).

However, pressure drop is one of the main features of pipeline oil-water flow, with temperature, pressure, density, viscosity, oil and water volume fraction, pipe diameter and mixture velocities of the liquids responsible for it (Edomwonyi-Otu *et al.,* 2020). Many researchers studied aloe vera mucilage as a drag-reducing agent at different concentrations and Reynolds number at constant temperature (Gimba *et al.,* 2018; Abdallah *et al.,* 2019). However, some industrial fluid pipeline transportation occurs at different temperatures.

Lim (2010) studied the drag reduction potential of Malabar spinach extract in 25.4 mm diameter of a pipe in spwf at a constant temperature and achieved 78.2% drag reduction. Hayder *et al.* (2011) investigated the drag reduction characteristics using AVM in a spwf in a 25.4 mm diameter pipe and 2.0 m length at constant temperature. They reported that a maximum drag reduction of 63% was achieved. AVM was studied as a drag-reducing agent in spwf and multiphase (oil-water flow) through straight pipe of 12 mm ID at invariable temperature by Abdallah *et al.* (2019). They reported that drag reduction increased with increase in mixture velocity (u_m) and a maximum drag reduction of 64% for spwf and 53.8% for multiphase flow at u_m of 4.67 m/s and 0.25 Ovif was achieved. Magit *et al.* (2019) investigated the effect of temperature variation (5 – 60 ºC) on the effectiveness of partially hydrolyzed polyacrylamide in drag reduction through 20 mm ID horizontal pipe for both single-water flow and multiphase flow at different Reynolds number and u_m. They stated that drag reduction decreased with increasing temperature from 75% to 62% for spwf and 64.58% to 50% for multiphase flow. Recently, Gimba and Edomwonyi-Otu (2020) investigated drag reduction with polymer mixtures in multiphase flow using horizontal pipe of 20 mm ID diameter and length of 2800 mm (140D) at constant temperature using different Re, oil input and mixture velocities. They achieved synergistic effect on drag reduction for their polymer combination (polyethylene-oxide + Aloe vera and Hydrolyzed polyacrylamide (HPAM) + Aloe vera) at different mixing ratio.

Nevertheless, the works of aloe vera mucilage and other natural drag-reducing agents found in literature were based on constant temperature and there is need to generate data for variable temperature systems on drag reduction in multiphase flow, which is the main focus of this work.

2. MATERIALS AND METHODS

2.1. Flow Facility

The setup comprises of three storage tanks as shown in Figure 1. The separator tank drains water by gravity via the bottom opening and recycles the oil. A 3-phase heater (model IH 0509) heat the water to the desired temperature. A temperature controller (Rex-c100) connected to the heater stops the heater automatically when the desired temperature is reached. The temperature controller displays the desired temperature. A thermocouple with relay is attached at the test section to measure the temperature of the fluid at the test section. Thermocouple and temperature controller can maintain the desired temperature for about 15 minutes. The two pumps (centrifugal, model Jet 102M/N.21227) were used to channel the experimental test liquids into the test part. Regulation and measurement of the liquids flow rates with the globe valves and the variable area flow meters (LZM-20J) was done respectively. Two flow meters were used, one for each fluid. There exist a 45˚ Y-junction to ensure minimal mixing of the two test liquids before entering the test part. A 6 mm diameter hole was bored at 0.6 m apart just before the Y-junction on the water line for injection of the desired polymer concentration. A polymer injection pump (New Era programmable peristaltic pump, model NE-9000) was used. The test part made up of 20 mm acrylic pipe is 2.8 m from the 45˚ Y-junction to the second pressure port. The distance is to ensure fully developed flow before entering the measurement section. The pressure drop was measured from the pressure port with the U-tube manometer.

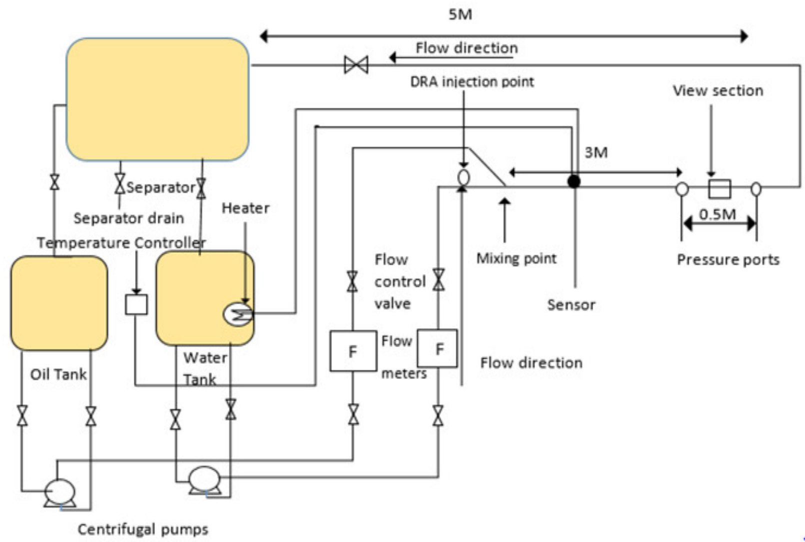

Figure 1: Experimental flow set-up

2.2. Polymer Preparation

Aloe vera leaves were collected and then washed with tap water thoroughly to remove impurity. Each of the leaves edges was cut and soaked for 600 seconds in water, to further remove other impurities. The leaves were then peeled, and the AVM was extracted by scraping the gel from the aloe leaves. Aloe Vera leaf contains 98% water while the remaining 2% is the AVM as described by Gimba *et al.* (2018). AVM master solution of 20,000 ppm was prepared. The pH, density and specific gravity of the AVM used were 5.8 at 25 ºC, 1059.49 kg/m^2 at 25 ºC and 1.06 – 1.17 at 25 ºC using the pH meter, Viscometer, density bottle respectively, where the specific gravity was calculated from the density. AVM suffers from chemical degradation within the first 24 hours after preparation hence, it was used after preparation. The AVM master solution was injected at specific flowrate into the water-phase only to achieved desired concentration in the flow rig, because AVM was soluble in water. During the experiment, concentration of 50-500 ppm was introduced into the water-phase at desired flow rate using a pump with low or no mechanical degradation effect on the polymer (Ahmad *et al.,* 2009; Abdul-Bari *et al.,* 2010; Gimba *et al.,* 2019). For elevated temperature studies, a 3-phase heater was used to heat the water in the 200 l water tank at a desired flow rate. The experiment was a batch process and repeated for other flow rates (Ahmad, 2011). When the desired temperature was attained for any flowrates, the polymer was then injected into the water phase.

2.3. Experimental Procedure

Before starting the experiments, the calibration of the pumps, flow meters and injection pump were done to minimize error in the amounts of fluid delivery and AVM master solution into the test unit. Water (μ_w of 0.91 mPa.s, ρ_w of 1000 kg/m^3 at room temperature of 25 ºC) and diesel (μ_O of 1.664 mPa.s, $\rho_O$of 832 kg/m^3 at 25 ºC) were used as the test liquid. The drag reduction experiment was carried out in 20 mm ID horizontal pipe of and 2800 mm (140D) length at variant temperatures (5 – 60 ºC) and 1 atmospheric pressure. Drag reduction was expressed as:

$$DR = \frac{\Delta p_{ot} - \Delta p_t}{\Delta p_{ot}} \times 100 \quad (1)$$

Where; Δp_{ot} and Δp_t in (N/m^2) are the pressure drop of the liquid without and with drag-reducing agent respectively.

3. RESULTS AND DISCUSSION

The temperature variation on drag reduction of the AVM was investigated in spwf at different mucilage concentrations (50 - 500 ppm), Reynolds numbers (12,917 – 48,872) and temperature (5-60 ºC) as well as in multiphase flow.

3.1. Drag Reduction in Single-Phase Water Flow at 25 ºC

The drag reduction of the AVM in spwf against mucilage concentrations (50 - 500 ppm) at different Reynolds numbers (12,917 – 48,872) and temperature of 25 ºC is shown in Figure 2. Figure 2 also shows the effect of Re and concentration on drag reduction. It was observed that drag reduction increased with addition of mucilage concentration until it reached plateau where a maximum drag reduction of 50% was obtained at 400 ppm above which no significant increase in drag reduction. The increased in mucilage particles in the flow dominate the eddies formation which allow the pumping energy to be used in moving the fluid down the pipe instead of irregular motion of the fluid (Gimba *et al.,* 2017). The irregular motion of the fluid lead to dissipation of the pump energy supplied as a result of drag force (Gimba and Edomwonyi-Otu, 2020). This is in agreement and the same trend with findings of Al-Wahaibi *et al.* (2012).

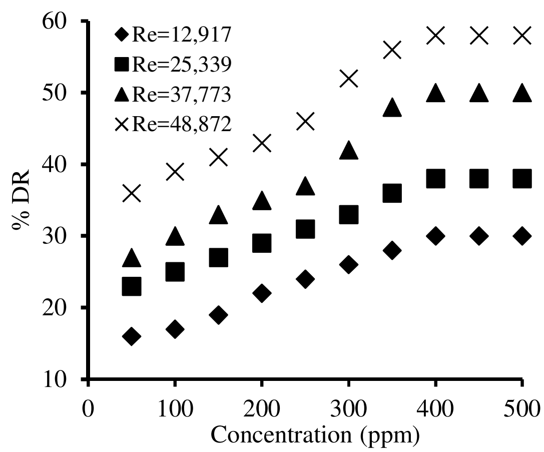

Figure 2: Effect of Aloe vera mucilage concentration drag reduction DR in spwf at different Reynolds number in 20 mm pipe diameter at 25 ºC

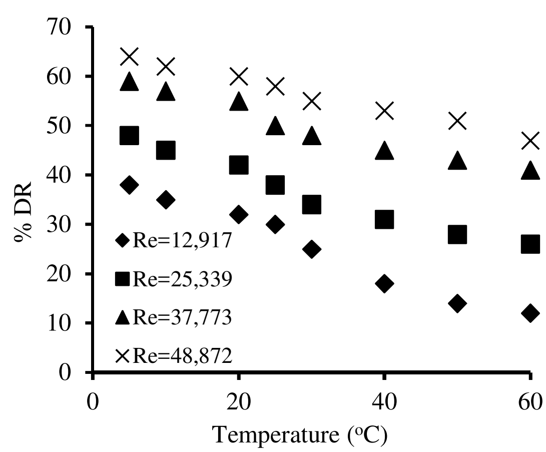

Figure 3: Effect of temperature on DR at different Re for optimum concentration

3.2. Effect of Temperature on DR at Different Re

In view of these findings, the polymer concentration of 400 ppm that gave the maximum drag reduction was chosen for the investigations of the effect of different temperatures (5 - 60 ºC) at different Re. Figure 3 shows drag reduction as a function of temperature. The maximum drag reduction was achieved at a low temperature (5 °C) and it decreased with increase in temperature at different Re. It was experiential that at lower Re and high temperature drag reduction decreased much more and vice versa which can be seen at high Re. Drag reduction decreased from 59% at 5 ºC to 41% at 60 °C. The dwindling of the mucilage macromolecules size, the weakness of hydrogen bonding in the water molecules and decrease in radius of rotation of the molecule as temperature raises may be responsible for the decrease in drag reduction (Choi *et al.,* 2007; Magit *et al.,*

2019) At elevated temperature the eddies formation increases due to increase in turbulent fluctuations which reduce the interaction water and drag reducing polymers (Magit *et al.,* 2019).

3.3. Multiphase Flow Experiment

The drag reduction of AVM was investigated in oil-water flow at different Ovif and velocity of the mixture (Umix) or mixture velocity (u_m) at optimal concentration of 400 ppm. The different percentage of the Ovif (%δo) are 0, 25, 50, 75, 100%. Figure 4-7 show the effect of oil volume input fraction, temperature and mixture velocities on drag reduction. The same trends were observed as drag reduction decreased with increase in temperature and oil input. A drag reduction of 35% was obtained at 1.68 m/s u_m, 0.25 Ovif and 5 °C in Figure 4.

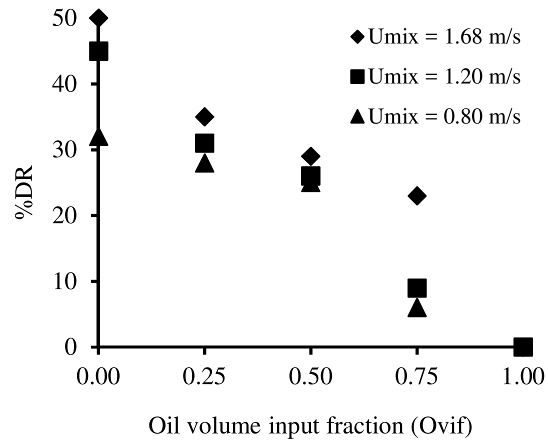

Figure 4: Effect of oil volume input fraction (Ovif) on DR at different Umix (u_m) at room temperature

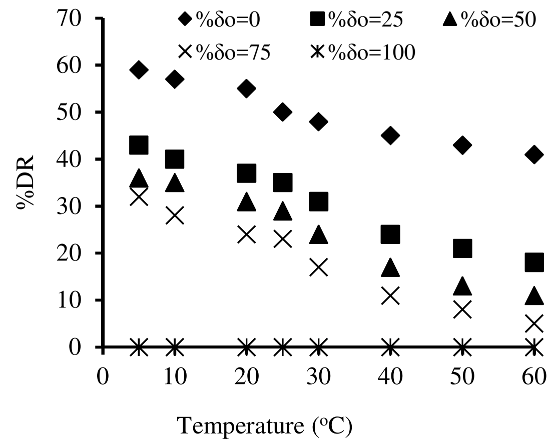

Figure 5: Effect of temperature on DR at different oil input for u_m = 1.68 m/s

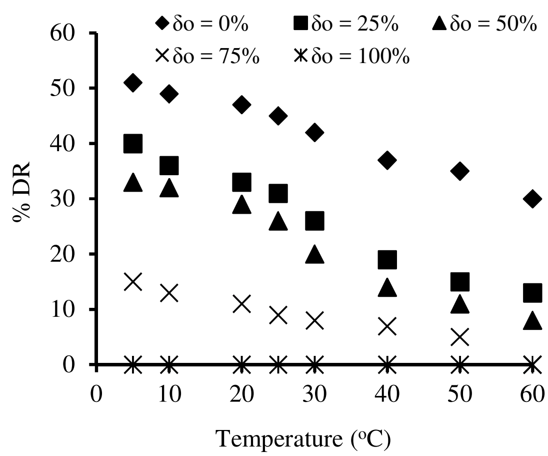

Figure 6: Effect of temperature on DR at different oil input for u_m = 1.2 m/s

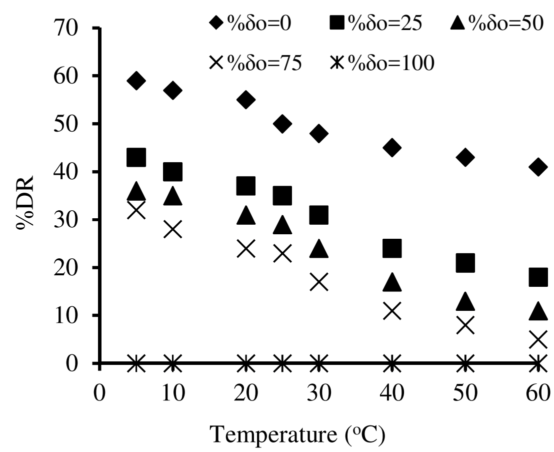

Figure 7: Effect of temperature on DR at different oil input for u_m = 0.8 m/s

Figure 4 show decreased in drag reduction with increased in Ovif and mixture Reynolds number due to decrease in the superficial velocity and Re of the water-phase. consequently, reduced the eddies formation (turbulence) of the water-phase flow owing to the reduction in the mucilage molecules elongation or water-mucilage interaction in the flow because drag-reducing agents perform better at high Re (Gimba *et al.,* 2020). Hence, lead to decrease in drag reduction. Similarly, Figure 4-7 show decreased in drag reduction with increase in temperature due to changes in viscosity and hydrodynamic of the flowing fluid (Magit *et al.,* 2019). Since viscosity is a function temperature, hence intrinsic viscosity of the fluid with the drag-reducing agents decreased and the drag-reducing agent molecular structure changes at high temperature resulting in deteriorating of drag reduction even at high Re (Magit *et al.,* 2019). This was in conformity with earlier reports (Eshrati *et al.,* 2015; Gimba and Edomwonyi-Otu, 2020). It can be observed from these experimental results of oil-water flow that drag reduction is a function of Ovif, temperature and water-phase superficial velocity because the drag-reducing agent used was only soluble in the water phase.

4. CONCLUSION

Drag reduction behavior of aloe vera in horizontal pipe at elevated temperature was studied. A maximum drag reduction of 50% was obtained at 25 ºC in a single-phase water experiment and 35% at 5 ºC for oil input volume fraction of 0.25 in oil-water flows. It can be deduced from these experimental results of oil-water flow that drag reduction is a function of oil volume input fraction, temperature and water-phase superficial velocity.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Abdallah, M., N., Edomwonyi-Otu, L., C., Yusuf, N. and Baba, A. (2019). Aloe Vera Mucilage as Drag Reducing Agent in Oil-water Flow. *Arid Zone Journal of Engineering, Technology & Environment*, 15(2), pp. 248-258.

Abdul-Bari, H., A., Ahmad, M., A. and Yunus, R., B., M. (2010). Formulation of Okra-Natural Mucilage as Drag Reducing Agents in Different Size of Galvanized Iron Pipes in Turbulent Water Flowing System: An Experimental Study. *Journal of Applied Science*, 10(23), pp. 1812–5654.

Ahmad, M., Abdul-Bari, A., H. and Yunus, R., M. (2009). Studying the effect of addition of Okra-natural mucilage as drag reducing agent in different size of pipes in turbulent water flowing system. *National conference on postgraduate research (NCON-PGR).* pp. 128-133.

Ahmed K., A., H. (2011). Drag reduction behavior of polymers in straight and coiled tubing at elevated temperature. *Electronic scientific journal "Oil and Gas Business"*,1(1), pp. 107-128.

Al-Sarkhi, A. (2010). Drag Reduction with Polymers in Gas-Liquid/Liquid-Liquid Flows in Pipes: A Literature Review. *Journal of Natural Gas Science and Engineering,* 2(1), pp. 41–48.

Al-Wahaibi, T., Al-Wahaibi, Y., Al-Ajmi, A., Yusuf, N., Al-Hashmi, A. R., Olawale, A. S. and Mohammed, I., A. (2012). Experimental investigation on the performance of drag reducing polymers through two pipe diameters in horizontal oil-water flows. *Experimental Thermal and Fluid Science*, 50, pp. 129–146.

Bewardoff, H. and Gyr, A. (1995). Drag Reduction of Turbulent Flows by Adittives. Fluid Mechanics and its Applications, 2, pp. 101-153.

Choi, S., H., Tae, C., S. and Zaheeruddin, M. (2007). Effect of fluid velocity, temperature and concentration of non-ionic surfactants on drag reduction. *Energy Conversion Management*, 48, pp. 913-918.

Edomwonyi-Otu, L., C., Gimba, M., M. and Yusuf, N. (2020). Drag Reduction with Biopolymer-Synthetic Polymer Mixtures in Oil-Water Phase Flow: Effect of Synergy. *Engineering Journal (EJ),* 24(6), pp. 1-6.

Eshrati, M., Al-Hashmi, A., R., Al-Wahaibi, T., Al-Wahaibi, Y., Al-Ajmi, A. and Abubakar, A. (2015). Drag reduction using high molecular weight polyacrylamides during multiphase flow of oil and water: A parametric study. *Journal of Petroleum Science and Engineering*, 125, pp. 402–409.

Gimba, M., M., Edomwonyi-Otu, L., C., Abubakar, A. and Yusuf, N. (2018). Synergistic effect of polymer-polymer mixtures as drag reducing agents in turbulent water flows. *Research Journal of Engineering and Environmental Sciences (RJEES),* 3(2), pp. 560-570.

Gimba, M., M., Edomwonyi-Otu, L., C., Abubakar, A. and Yusuf, N. (2017). Synergistic effect of natural and synthetic polymers as drag reducing agents in water flow: Effect of Pipe Diameter. *FUPRE Journal of Scientific and Industrial Research,* 4(2), pp. 2578-1119.

Gimba, M., M., Edomwonyi-Otu, L., C., Yusuf, N. and Abubakar A. (2019). Drag Reduction with Polymer Mixtures in Pipes of Different Diameter. *Arid Zone Journal of Engineering, Technology & Environment*, 15(3), pp. 792-801.

Gimba, M., M. and Edomwonyi-Otu, L., C. (2020). Drag Reduction with Polymer Mixtures in Oil-Water Phase Flows: Effect of Synergy. *Journal of Turkish Chemical Society Section B (JOTCSB),* 3(1), pp. 1-8.

Hameed, A., M., Hamied, R., S. and Shnain, Z., Y. (2014). Drag-Reducing Agent for Aqueous Liquid Flowing in Turbulent Mode through pipelines. *Al-Khwarizmi Engineering Journal,* 10(2), pp. 15-22.

Hayder, A., A., Kumaran, L. and Rosli, M., Y. (2011). Drag Reduction Characteristics Using Aloe Vera Natural Mucilage: An Experimental study, *Journal of Applied Sciences,* 11 (6), pp. 1039-1043.

Kamarulizam, S., N., B. (2012). Formulation of A Dual Effect Natural Drag Reduction Agent. MSc Thesis, Faculty of Chemical and Natural Resources Engineering. Universiti Malaysia Pahang.

Lim, J. (2010). Formulation of Natural Drag-Reducing Agent from Malabar Spinach for Drag Aqueous Liquid Flowing in Turbulent Mode Through Pipelines. MSc Thesis, Faculty of Chemical and Natural Resources Engineering. Universiti Malaysia Pahang. Available at: *http://umpir.ump.edu.my/3257/1/CD5831_LIM_JOO_ANN.pdf* (Accessed: 22 May 2016).

Mowla, D., Naderi, A. (2006). Experimental study of drag reduction by a polymeric additive in slug two-phase flow of crude oil and air in horizontal pipes. *Chemical Engineering Sci*ence, 61, pp. 1549–1554.

Magit, K., D., Edomwonyi-Otu, L., C., Abubakar, A. and Yusuf, N. (2019). Effect of Temperature Variation on the Effectiveness of Partially Hydrolyzed Polyacrilamide in Drag Reduction. *Nigerian Research Journal of Engineering and Environmental Sciences (RJEES),* 4(2), pp. 569-577.