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Effect of Calcium Carbonate Solution on Drag Reduction in a Pentagon Spiral Pipe

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ABSTRACT

Calcium carbonate is environmentally friendly substance that has not been widely studied. It is indicated that the powder has the potential to initiate drag reduction. Experimental study was conducted to determine flow behavior and drag reduction influenced by calcium carbonate solution. In this study, pure water-ethylene glycol mixtures with ratio 60:40 were used as the liquid and calcium carbonate 80-100 nmin size as the powder. Variations of calcium carbonate concentration were 100, 300, and 500 ppm, respectively. In the test section, there are pentagon spiral pipe and circular pipe with the same hydraulics diameter. The pressure drop data were obtained by pressure transducer. The correlation between the friction factor and the generalized Reynolds number was determined by the pressure drop and the flow rate data. At the Reynolds number 4 x 10^4, the maximum drag reduction rate would be over 21.77% by the circular pipe and 30.89% by the pentagon spiral pipe. It was found that calcium carbonate can contribute to drag reduction and used spiral pipe can enhance the phenomenon.

Keywords:
Drag reduction, pressure drop, pentagon spiral pipe, calcium carbonate

1. Introduction

Drag force is an inherent part of fluid flow, and there is a problem because of its effect to pressure loss. In the piping system, pressure drop affects energy consumption. The higher the pressure drops, the higher the energy is required to circulate the fluid. The pressure drop is expected to occur as small as possible, so that the fluid that flows through the pipeline becomes more efficient. In the piping system applications for heat transfer, the pressure drop effect cannot be avoided. Various methods are continuously developed to achieve good flow performance.

Nanoparticles application in heat transfer has been proven to provide significant performance improvements [1-6]. Breakthroughs that are considered new technologies are being developed for better and wide application in engineering[7, 8]. Besides having a good ability in increasing heat transfer, nanoparticles was also proven in increasing drag reduction (DR). With the addition of nanoparticles in relatively small amount, at acertain Reynolds number, Re the flow of nanofluids through the pipe produces lower frictional resistance than the pure water fluid. Nanoparticles of

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metal have a positive impact of DR, but they produce waste that is detrimental to the environment. Efforts must be done to develop for working fluids to have a positive impact on the environment and done to efficiently use environmentally friendly mixing materials. Hajar *et al*., [8] developed material biocompatibility like polyvinyl chloride to improve its blend properties. Yanuar *et al.,* [9,10] studied the drag reduction effect of guar gum biopolymer solutions, in which molecule concentration varied between 100 and 300 ppm. In this study, guar gum can reduce the friction in the pipe flow. On the other hand, the different material like biopolymer $CaCO_3$ was give effect of the damping phenomena in the buffer layer by which gives drag reduction in the turbulent regime. In the experiment, the solutions consist of $CaCO_3$-pure water mixture with 100, 300, and 500 ppm as comparison.

Efforts are made to improve flow performance for various purposes by mixing other materials into the main fluid called active control. The materials that were often used included solution, surfactant, polymer, fibber, and nanoparticles. The drag reduction in pipe line was reported by Toms, and he stated that in addition to the based fluid, other solvents can decrease the frictional pressure drop in turbulent flow [11]. Until now, drag reduction by active control must more to be developed for the piping system performance and then environmentally friendly.

The spiral pipe effect as proposed by Yanuar *et al.,* [9,12] was not only by the influence of biopolymer but also by the pipeline geometry. In the research, guar gum suspension through the spiral pipe resulted in the percentage of DR by 35%. The test of pure water without solution was carried out by Watanabe et al. with a lot of geometric size variations of spiral pipe and obtaining the most efficient DR results on pipes with P/Di geometry around 7 [13]. In this study, calcium carbonate particle ($CaCO_3$) solution with the mix of pure water and ethylene glycol (40:60) such as working fluid was investigated. The main aim of this work is to characterize in detail the pentagon spiral pipe flow behavior of 100, 300, and 500 ppm $CaCO_3$ solutions. Pressure drop and friction factor are presented in turbulent flow.

2. Methodology

2.1 Experimental Set-Up

Figure 1 shows the experimental apparatus schematic of the used in this study. This series of test equipment consists of working fluid tank, pump, volt regulator, watt meter, flow meter, spiral pipe, DAQ component, and computer. The equipment was designed horizontally to get the results in accordance with the objectives to be achieved. Table 1 presents the specification of test pipes. The main test pipe was a pipe spiral pipe with P/Di 10.8 and length of 800 mm and length of fully development is 1000 mm. On both sides of the test pipe was installed a different pressure measurement instrument respectively on high pressure tap and low pressure tap. The pressure drop tool used was a different pressure transducer. The measurement data of the pressure drop were recorded in each variation of the test with duration of 60 minutes. The recorded data were subsequently processed to get the right average value. The flow rate measurements were performed using a flow meter (Aichi Tokei Denki Co., Ltd., TAV-40) placed on the upstream of the pipe. The test was carried out in a room, where the temperature was kept constant at 27°C. The pressure data obtained were shown on the computer and then processed to plot in a graphical form.

Preliminary research was undertaken to ensure the experimental set-up in a standard circumstance. This preliminary test was carried out using pure water as the working fluid. The data of the pressure drop and the flow rate obtained were calculated by the flow equations for Newtonian fluid [14]. The result of the calculating coefficient of friction was compared with Hagen-Poiseuille equation for laminar flow and Blasius equation for turbulent flow [15]. The Newtonian flow data retrieval process was done at constant temperature conditions and without the influence of the shear rate and shear stress. The equation expressed by Dodge-Metzner [16], for flow with Re' ≤2100, can be used to predict the value of the turbulent flow friction factor to the non-circular cross section.

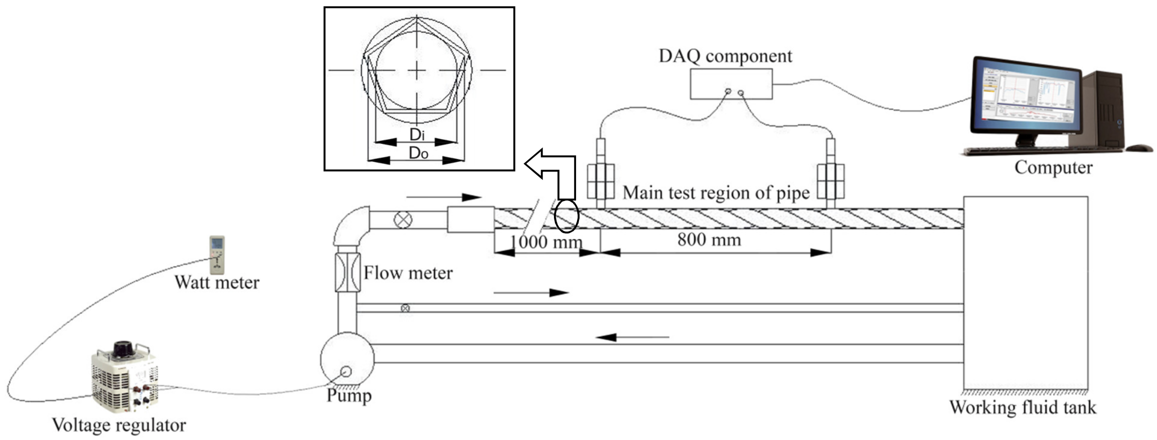

Fig. 1. Experimental set-up

Table 1
Test pipe specification

Test pipe	Di (mm)	Do (mm)	ΔD (mm)	P (Pitch)	P/Do
Pentagon Spiral	5.25	8.55	3.3	60.7	7.1
Circular	6.3	-	-	-	-

2.2 Rheological Model

The base fluids are pure water and ethylene glycol with the ratio of 60:40, as some previous heat transfer studies were using ethylene glycol [14, 17]. Furthermore, the working fluids were the mixture of basic fluid with the powder of CaCO3. The solution was mixed by 100, 300, and 500 ppm concentrations and flowing in the test pipe using a pump. The $CaCO_3$ solution used the average size of 80-100 nm and the mixing process was done by a magnetic stirrer with 200 rpm rotation for 30 minutes. Each concentration of the solution was circulated to the test pipe for 60 seconds to obtain the pressure drop and flow rate value from each concentration.

In the non-Newtonian flow, apparent viscosity was influenced by the value of n and K which are the power law index and coefficient consistency respectively. The values of n and K were derived from the log intersection of the shear rate and shear stress. Where the equation can be seen as follows

$$n = \frac{\log(\tau_1/\tau_2)}{\log(\gamma_1/\gamma_2)} \tag{1}$$

where shear stress (τ_w)can be found by the equation:

$$\tau_w = \mu_a \gamma_w \tag{2}$$

where, $\mu_a$is apparent viscosity and γ_w is the wall shear rate.

$$\mu_a = K{\gamma_w}^{n-1} \tag{3}$$

The nominal shear rate, γ_w was determine of 8u/D

2.3 Methodology Equations

Mathematical equations were used as the tools to calculate the experiment data. The generalized Reynolds number ($R_e{}'$) on non-Newtonian fluids through polygon pipes is as follows

$$\mathrm{R_e}' = \frac{\rho V^{2-n} D_h^n}{8^{n-1} k\left(b+\frac{a}{n}\right)^n} \tag{4}$$

The values of a and b were used in Reynolds and friction factor values were constant for polygon pipe [16]. The equation is used in calculating the friction factor values for the turbulent flow in the pentagon spiral pipe as follows

$$\frac{1}{\sqrt{f}} = \frac{4}{n^{0.75}} log_{10}\left(\mathrm{R_e}' f^{(2-n)/2}\right) - \frac{0.4}{n^{1.2}} + 4n^{0.25} log\frac{4(a+bn)}{(3n+1)} \tag{5}$$

The friction factor in the turbulent regime in the circular pipe is proposed by Dodge and Metzner [18].

$$\frac{1}{\sqrt{f_{F,turb}}} = \frac{4.0}{n^{0.75}} . log_{10}\left[R_e'\left(f_{F,turb}\right)^{1-\left({n}/{2}\right)}\right] - \frac{0.4}{n^{1.2}} \tag{6}$$

3. Results and Discussion

The effect of particle concentration on the rheological properties of the working fluid is presented in the flow curve in Figure 2. In the graph, the shear stress in all working fluid mix was linearly dependent on the shear strain. The shear stress value was strongly influenced by the particle concentration and the cross-sectional geometry. The variations of value occur as seen in the trend line of the figure. The shear stress with time on the flow inside the test pipe increases proportionally to the velocity gradient that occurs between the fluid and the pipe wall. The shear stress shows a linear increase in the increase of the shear rate on the wall and particle concentration. The increase value of shear stress due to different addition of particles for observed solutions. The graph shows that the working fluid with a large concentration of 500 ppm has a higher shear stress compared with other concentrations and the lowest value in pure fluid flow. This indicates that the higher the concentration of solution mixture, the higher the value of shear stress.

Figure 4 shows the comparison of apparent viscosity value with the shear rate. On the graph the apparent viscosity value for each concentration solution has another similar trend, in the case of a decrease in the value of the viscosity at the beginning, and it has gradually stabilized at each level.

The solution with particles concentration of 500 ppm experienced higher shear stress then followed by the working fluid with the concentration of 300 ppm and 100 ppm which occurred on a circular pipe and a spiral pipe.

The spiral pipe produced different variations of flow resistance value into the flow rate. The resistance was also influenced by the amount of nanoparticles concentration and also the geometry of the spiral pipe. In pure water there is no viscosity change by shear rate variations. Each pipe produces different value but tends to be constant as long as the shear rate changing. This is in accordance with previous research that addresses the use of active control on the piping system [9, 14]. Pure water is the Newtonian fluid that changes viscosity due to temperature.

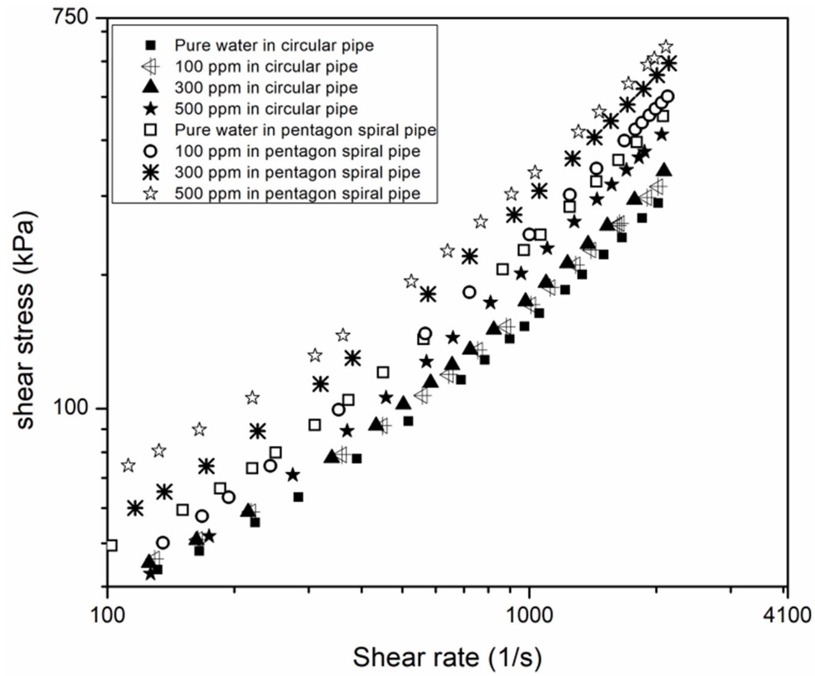

Fig. 2. Rheological behavior graph

The relation of the apparent viscosity with the nominal shear rate at each particle concentration is shown in Figures 3 and 4. The apparent viscosity is defined as the ratio of shear stress to shear rate. The viscosities in non-Newtonian flows tend to have constant value at certain temperature and pressure. This indicates that the change in the apparent viscosity value occurs due to the $CaCO_3$ solution suspended in the fluid and the cross section of the pipe.

The apparent viscosity value that was affected by shear stress indicates the difference of values that vary on each concentration. In the spiral pipe, the working fluid with a concentration of 500 ppm has n value smaller which is 0.88 and has a trend line apparent viscosity which decreases at the beginning of the shear rate more sharply. On the other hand, the higher the particle concentration value, the higher shear stress due to an increase in the value of K. The solution with a concentration of 100 ppm appearings to produce relatively small values and tendings to increase, but this occurs because the type of working fluid is 1.04 for the spiral pipe and 1.01 for the circular pipe.

The correlation between the generalized Reynolds number and the friction factor is shown in Figures 5 and 6. On the graph it could be seen that all working fluids mixed with powder tend to increase to close Virk's line; the maximum drag reduction. A higher value of the friction factor, $1/\sqrt{f}$ indicates the drag reduction. This value corresponds with the Fanning friction factor and the generalized Reynolds number for non-Newtonian fluid shown by Chhabra and Richardson [16].

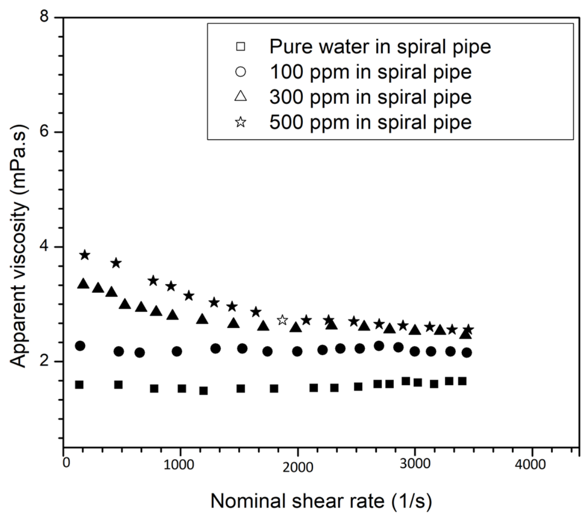

Fig. 3. Apparent viscosity of $CaCO_3$ in a spiral pipe

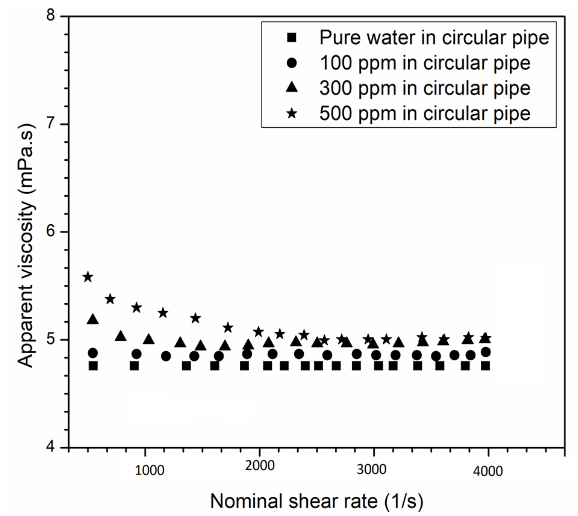

Fig. 4. Apparent viscosity of $CaCO_3$ solution in a circular pipe

Table 2
Parameter of power low index

Test pipe	Parameter	100 ppm	300 ppm	500 ppm
Circular	n	1.01	0.97	0.93
	K	5.16	7.32	8.00
Pentagon spiral	n	1.04	0.91	0.88
	K	4.91	8.14	11.00

The graph shows the trend line for each flow concentration, where the focus of this discussion is on turbulent flow because in the laminar the effect of drag reduction is not found. In the laminar regime, all working fluid likes Newtonian flow, so it is important to calculate the value of power low index and coefficient consistency. The influence of the value of n and K has been submitted by some previous researchers.

The friction factor graph of the circular pipe is shown in Figure 5. The figure demonstrates that the DR in the working fluid is compared with pure water for turbulent flow. Overall, the $CaCO_3$ powder used in the working fluid increases more than pure water and when Re' enhancement reaches 1×10^4 of working fluid with a ratio of 300 and 500 ppm, which is close to the maximum drag reduction asymptote line by Virk. By Eq. 5 the highest drag reduction of the circular pipe was determined at 21.77% for 500 ppm by the generalized Reynolds number of 4×10^4.

Figure 6 shows the schematic diagram of the friction factor in a spiral pipe focuses on turbulent flow. At critical velocity, the drag reducing $(1/\sqrt{f})$ in the solution is under pure water. At the same Reynolds number, the working fluid of 300 and 500 ppm $CaCO_3$ has higher drag reduction in the spiral pipe. The correlation between power low index value and coefficient consistency was close related to the influence of drag reduction. Concentrations of 300 ppm and 500 ppm produce lower n value in the working fluid through a spiral pipe but produce higher K value. Both of these values indicate relatively large shear stress at the low shear rate but gradually decrease sharply when the shear rate increases. The correlation of the viscosity value to the friction factor results in the highest drag reduction on the working fluid with the solution ratio of 500 ppm by 30.89% at Re 4×10^4. Through the comparison of experimental values that have been done, from the point view of economy, the piping system network to get the flow with low energy consumption is by utilizing powder $CaCO_3$ in the pentagon spiral pipe.

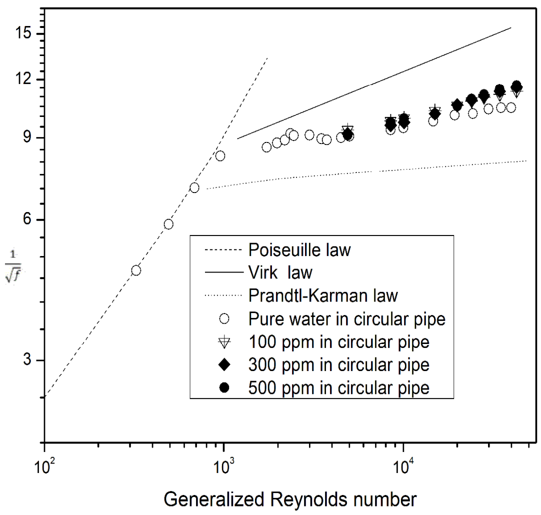

Fig. 5. Comparison of generalized Reynolds number versus the friction factor in a circular pipe

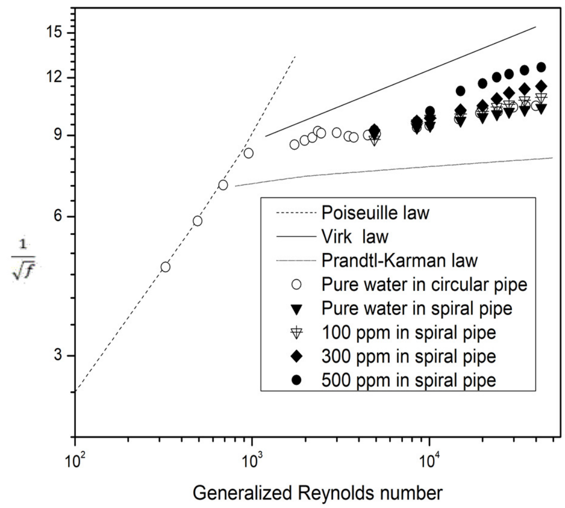

Fig 6. Comparison of generalized Reynolds number versus the friction factor in a spiral pipe

4. Conclusion

The characteristic curve of $CaCO_3$ solution has successfully determined the DR effect. The solution of $CaCO_3$ and pure water-ethylene glycol mixture flows through the horizontal pipe to calculate the shear rate and shear stress by the flow rate and pressure measurement. The acquisition of value can be as follows:

The working fluid was flowed through the circular pipe at the turbulent flow above 1×10^4 drag reduction occurring, while in the pentagon spiral pipe only with the working fluids of 300 ppm and 500 ppm does the drag reduction happen in the same of *Re'*. The working fluid with the concentration of 100 ppm is indicated as the Newtonian flow, where the friction factor occurs linearly with the Blasius equation line. The working fluid with the particle concentration of 500 ppm of both in a circular pipe results in the highest drag reduction of 21.77% and in the pentagon spiral pipe 30.89%, at the same Re' of 4×10^4. In this study, significant drag reduction was influenced by pipe geometry and viscosity. The $CaCO_3$ solution is an environmentally friendly material suitable for reducing pressure drop effect on the piping system.

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References
[1] Yu, Wei, Huaqing Xie, Lifei Chen, and Yang Li. "Investigation of thermal conductivity and viscosity of ethylene glycol based ZnO nanofluid." *Thermochimica Acta* 491, no. 1-2 (2009): 92-96.

[2] Yanuar, Waskito KT, Budiarso Gunawan, André Luiz Salvat Moscato, Santiago del Rio Oliveira, H. Z. Hassan, Marcos Galante Boato, Ezio Castejon Garcia et al. "Drag reduction and Velocity Profiles Distribution of Crude Oil Flow in Spiral Pipes." *International Review of Mechanical Engineering* 9, no. 1 (2015): 1-10.

[3] Yang, Chen, Kanglei Peng, Akira Nakayama, and Ting Qiu. "Forced convective transport of alumina–water nanofluid in micro-channels subject to constant heat flux." *Chemical Engineering Science* 152 (2016): 311-322.

[4] Xie, Huaqing, Wei Yu, and Yang Li. "Thermal performance enhancement in nanofluids containing diamond nanoparticles." *Journal of Physics D: Applied Physics* 42, no. 9 (2009): 095413.

[5] Xie, Huaqing, and Lifei Chen. "Adjustable thermal conductivity in carbon nanotube nanofluids." *Physics Letters A* 373, no. 21 (2009): 1861-1864.

[6] Azwadi, CS Nor, and I. M. Adamu. "Turbulent force convective heat transfer of hybrid nano fluid in a circular channel with constant heat flux." *J. Adv. Res. Fluid Mech. Therm. Sci.* 19, no. 1 (2016): 1-9.

[7] Yu, W., David M. France, Stephen US Choi, and Jules L. Routbort. *Review and assessment of nanofluid technology for transportation and other applications*. No. ANL/ESD/07-9. Argonne National Laboratory (ANL), 2007.

[8] Hajar, MD Siti, A. G. Supri, and A. J. Jalilah. "The Effect of Poly (ethylene glycol) Diglycidyl Ether as Surface Modifier on Conductivity and Morphology of Carbon Black-Filled Poly (vinyl chloride)/Poly (ethylene oxide) Conductive Polymer Films." *Journal of Advanced Research in Materials Science, ISSN* (2015): 2289-7992.

[9] Yanuar, Gunawan, and M. Baqi. "Characteristics of Drag Reduction by Guar Gum in Spiral Pipes." *Jurnal Teknologi (Sciences & Engineering)* 58 (2012): 95-99.

[10] Yanuar, Ir, M. Eng, Marcus Alberth Talahatu, Sealtial Mau, Kurniawan Teguh Waskito, and Winda Wulandari. "The Effect of Calcium Carbonate (CaCO3) Nanoparticles on the Flow through a Pentagon Spiral Pipe." *Mechanical Engineering* 8, no. 7 (2017).

[11] Toms, Be A. "Some observations on the flow of linear polymer solutions through straight tubes at large Reynolds numbers." *Proc. of In. Cong. On Rheology, 1948* 135 (1948).

[12] Yanuar, Gunawan, and Dedih Sapjah. "Characteristic of Silica Slurry Flow in a Spiral Pipe." *International Journal of Technology* 6, no. 6 (2015): 916-923.

[13] WATANABE, Keizo, Touichi MAEDA, Toshiyuki IWATA, and Hiroshi KATO. "Flow in a Spiral Tube: 1st Report, Velocity Distribution and Pressure Drop." *Bulletin of JSME* 27, no. 228 (1984): 1105-1111.

[14] Kristiawan, Budi, and Samsul Kamal. "A Modified Power Law Approach for Rheological Titania Nanofluids Flow Behavior in a Circular Conduit." *Journal of Nanofluids* 4, no. 2 (2015): 187-195.

[15] Virk, Preetinder S. "Drag reduction fundamentals." *AIChE Journal* 21, no. 4 (1975): 625-656.

[16] Chabra, R. P., and J. F. Richardson. "Non Newtonian Flow in the Process Industries: Fundamentals and Engi neering." (1999).

[17] Li, Yanjiao, Simon Tung, Eric Schneider, and Shengqi Xi. "A review on development of nanofluid preparation and characterization." *Powder Technology* 196, no. 2 (2009): 89-101.

[18] Dodge, D. W., and A. B. Metzner. "Turbulent flow of non-Newtonian systems." *AIChE Journal* 5, no. 2 (1959): 189-204.