

Characteristics of calcium carbonate solution flowing in pipe

Yanuar¹, Pamitran A S¹, Sealtial Mau², Kurniawan T Waskito¹ and Winda Wulandari²

¹Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia, Kampus Baru UI Depok, 16424, Indonesia;

²Graduate Student Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia, Kampus Baru UI Depok, 16424, Indonesia

E-mail: yanuar@eng.ui.ac.id

Abstract. Issue of energy is important because energy is one of economic foundation to support a nation. Indonesia have abundant resources of renewable energy and it can be used as friendly energy source. Innovations continue to be developed to find the right method about good quality and cheap of energy sources that is widely available in nature. Calcium carbonate powder of shellfish are the one of the environmentally friendly materials that are available in nature. In this study, calcium carbonate are used in aqueous solution of water-ethylene glycol fluid with a ratio of 40:60. The purpose of this study is to determine characteristics and hydrodynamic behavior of non-Newtonian calcium carbonate solution that is flowed in a small pipe. Concentration of powder was from varied 100 ppm, 300 ppm and 500 ppm on the base fluid, respectively. The test was performed on a circular pipe with 4 mm of inner diameter, horizontally. Pressure drop was determined between two different points in which there were high pressure and low pressure taps by different data acquisition. Changes of friction factor value become a parameter of the indicator to drag reduction. The highest drag reduction in transition flow is about 26.3 % for the 300 ppm concentration with Reynolds number is around 3000.

1. Introduction

Existence of a nation is depended by need for energy to support various productivity processes. Absorption and release of heat are phenomenon that occurs in the application of thermodynamics. Car cooling system; the engine releases heat and then coolant fluid absorbs the heat for cooling. This process is inseparable from friction effects along the circulated fluid flowed. Friction factor is a resistance that can cause energy loss. This phenomenon needs to be examined to find the right method of handling, so that the resistance can be reduced. Until now, there are two methods to reduce of friction, i.e. active control method and passive control method. Active control is a method of adding substances to the base fluid such as surfactants, fibers, biopolymer and nanoparticles [1-4]. Passive control is a method to form a cross-section of the geometry, hence it can reduce frictional resistance as the cross section in the form of a spiral, ellipses, squares and others [1,5,6]. The phenomenon of reduction of friction resistance is called drag reduction (DR).

Toms was a first researcher that used polymers to increase DR. The phenomenon of DR using polymers continues to be developed by N. Yusuf et al, who investigated use of polymers in oil-water fluid flows. In the study, Yusuf determined DR up to 60%. The use of polymer was proven that it



could increase DR in piping systems, in the Trans-Alaska oil [7]. Research is already done by Pouranfard et al, proved to reveal one of the reasons for the occurrence of DR. On this research, nanoparticles is potential to coat the contact area between the working fluid and the pipe surface that could potentially occurring slip condition [8].

The use of materials as a trigger for the occurrence of DR should be developed. Not only it-has the potential to produce similar effects, but also environmentally friendly and inexpensive. The experimental investigation on fluid flow with adding biopolymer were developed to produce DR. Bacterial cellulose when is dissolved into the working fluid and flowed through high flow Reynolds regime is potentially influence of DR. Satoshi Ogata et.al, managed to reveal the value of DR as result of bacterial cellulose by 11% [9]. A different study that conducted by Yanuar et al, examining the DR caused by guar gum. Guar gum biopolymer can produce the DR by 30% in the spiral pipe measuring P/Di 7.0 [10]. DR Research on piping systems should be focused on the use of environmentally friendly and inexpensive materials. On this study, calcium carbonate particle will be used as mixed substances in base fluids to trigger the occurrence of DR. The base fluid which used is pure water and ethylene glycol (40:60). The purpose of this study was to determine characteristics and hydrodynamics behavior of non-Newtonian calcium carbonate solution dispersed in pipe.

2. Research methods

2.1. Calcium carbonate solution preparation

The first step of the study was nanofluids preparation. Water and ethylene-glycol were used as solution with ratio of 40:60. The solution was mixed with CaCO_3 powder with concentrations which varied from 100 ppm, 300 ppm, to 500 ppm, respectively. The working fluid was stirred on 2000 rpm by hand mixer for 30 minutes. Working fluid-was measured by it mass, to obtain the value density of each solution. Measurements were carried out at 27 °C of temperature. Thus, several values were obtained as shown in table 1.

Table 1. Density of working fluids.

Pure water	100 ppm of working fluid	300 ppm of working fluid	500 ppm of working fluid
996.45 kg / m ³	1263.91 kg / m ³	1264.69 kg / m ³	1265.37 kg / m ³

2.2. Research procedure

The main focus of this study was to observe the characteristics of CaCO_3 nanofluids which flowed through circular pipe with variations of Reynolds numbers. The set-up of experimental tools was designed on the horizontal position to obtain experimental data such as flow rate and pressure drop. A circular pipe with 4 mm of inner diameter and 800 mm of length was used. The length of inlet pipe to achieve fully develop flow was 1000 mm. Working fluid was flowed through a pipe by a pump and flow rate. The flow was measured using by flow meter. Pressure drop was measured with differential pressure application DAQ adapter for emant 300 (DAQ component). The different pressure tools were placed on the high pressure and low pressure, separately. The different pressure value data was recorded by computer. Set-up experimental is showed in figure 1.

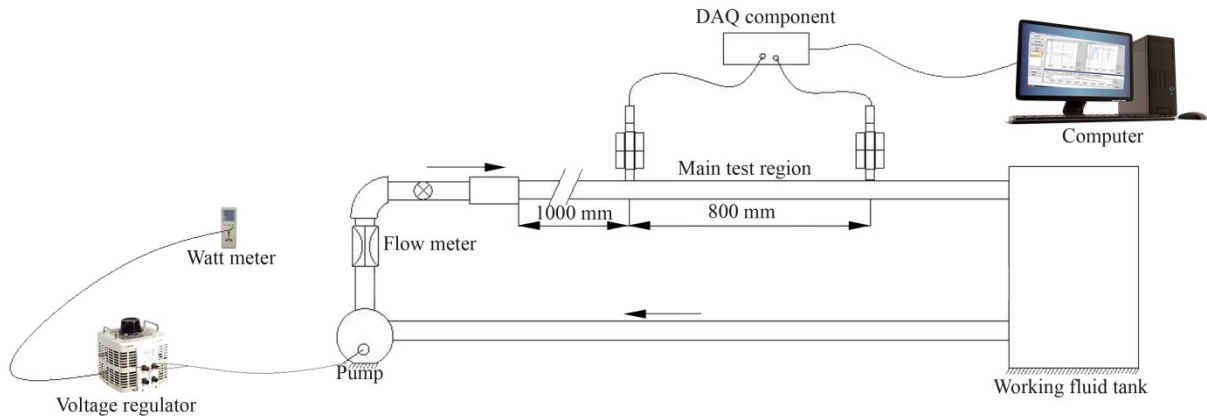


Figure 1. Experimental Setup.

First step after the experimental set-up was to validate in order to fully comply with testing standards on the piping system. The test with pure water and other data is processed using the relevant equations for Newtonian fluid, to know the correctness of horizontal designed tools. The calculation of validation data would be compared with the Hagen-Poiseuille equation for laminar flow and Blasius equation for turbulent flow. The computed data in this test would be calculated to obtain the friction factor correlation and the Reynolds number using the Fanning equation for Newtonian flow.

3. Method and rheological model

3.1. Methodology calculation

In this research, equations are used as the tools to get the results that accordance with the objectives of this research. Working fluids type of this study was non-Newtonian fluid, the equations are also adjusted for non-Newtonian fluid flow in circular pipe. Equation of generalize Reynolds number (Re') for circular pipe as follows:

$$Re' = \frac{\rho_n f D^n V^{2-n}}{K 8^{n-1}} \quad (1)$$

For non-Newtonian fluid flow in the circular pipe, friction factor of laminar flow can be predicted through the following equation:

$$\frac{\Delta P}{L} = \frac{2f \rho V^2}{D_h} \quad (2)$$

And to predict the friction factor in turbulent flow is used the equation as follow:

$$\frac{1}{\sqrt{f}} = \frac{40}{n^{0.75}} \cdot \log_{10} [R'_e (f_{turb})^{1-(1/2)}] - \frac{0.4}{n^{1.2}} \quad (3)$$

Where, ρ_{nf} is density of CaCO_3 solution and V is velocity.

The experimental data on the first processed is determined by kind of fluids through the power law index value, n and consistency coefficient, K . The same relation of Newtonian fluid for non-Newtonian calculation which can be rheological model as follows:

$$\tau_w = \mu_a \gamma_w = \mu_a \gamma_w \quad (4)$$

Where, μ_a is the apparent viscosity, and γ_w is the wall shear rate.

$$f(\tau_w) = \gamma_w = \left[\left(\frac{3n+1}{4n} \right) \frac{8u}{D} \right] \quad (5)$$

and,

$$\mu_a = K \gamma_w^{n-1} \quad (6)$$

The parameter of γ_w is the nominal shear rate. For fully developed laminar pressure drop, the shear stress, τ_w is computed as follows:

$$\tau_w = \frac{D \Delta P}{4L} \quad (7)$$

Where D is diameter, ΔP is pressure drop, L is the length and f is friction factor.

3.2. Rheological model

The each value of the shear rate and shear stress calculations from experimental data are plotted into the logarithmic graph. The value of power law index and coefficient consistency can be known through plotting the graphic line in figure 2.

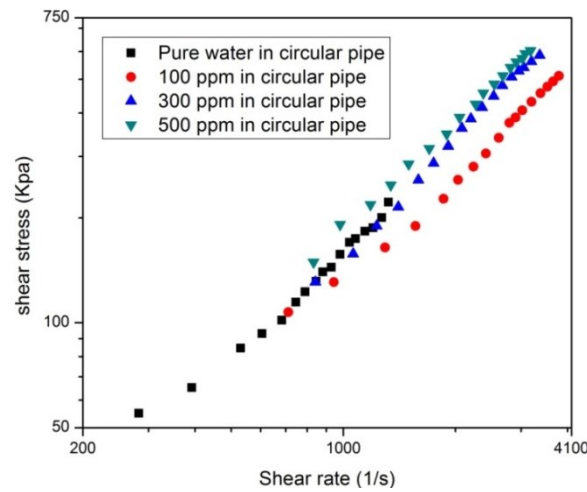


Figure 2. Graph of shear stress versus shear rate

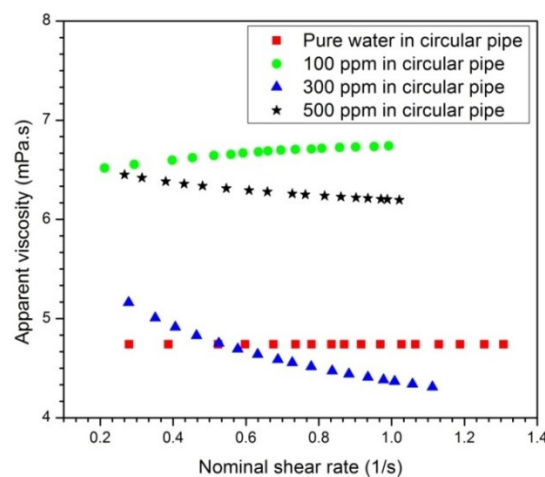


Figure 3. Apparent viscosity of nanofluids versus nominal shear rate.

On figure 2, it can be seen that maximum of shear stress and shear rate of pure water is lower than solution of 100 ppm, 300 ppm and 500 ppm. On figure 2, it also can be determined the value of n and K as in table 2.

Table 2. Power law power index values and consistency coefficients for solution

Power law parameters	100 ppm	300 ppm	500 ppm
n	1.02	0.87	0.97
K	6.71	7.03	6.20

The values of n and K at different functions is showed. The value of n can be used to determine the flow type of working fluid. For $n = 1$ is Newtonian fluid, for $n > 1$ is dilatant flow and for $n < 1$ is pseudoplastic fluid. For $n = 1$, the increase of viscosity value is constant to the shear rate. For $n > 1$, the viscosity value increases slowly in the low shear rate but at the high shear rate, it will increase of shear rate sharply. For $n < 1$, the viscosity value tends to decrease when shear rate is increased. Figure 3, can be seen that the value of K indicates the intensity of the apparent viscosity. The higher value of K , will indicate that generated shear stress will increase when fluids if flowed.

Figure 3 shows effect the viscosity of solution at a certain velocity. Through the graph, the base fluid has a constant trend line or fluid viscosity is not affected by shear rate. For the working fluid with the addition of particles, there are variations of viscosity value at each point, so this phenomenon is known as apparent viscosity. Working fluid with concentration 100 ppm shows behavior of dilatant fluid, where the trend line describes increasing viscosity with increasing shear rate. Working fluid with concentration of 300 ppm and 500 ppm shows behavior of pseudoplastic fluid type where the higher the shear rate value, the lower apparent viscosity value. The higher apparent viscosity value in the preliminary data of the working fluid of 100 and 500 ppm is influenced by the value of K which is lower than 100 ppm. From the graph, it can be assumed that higher the value of K will determine lower apparent viscosity value.

4. Result and discuss

4.1. Pressure drop investigation

The test apparatus which is flowed by working fluid is deemed to be standard, after its validated process. This research was focused on the pipe area with length of 800 mm and at both points: high pressure and low pressure points is mounted pressure measurement. The pressure tool to get the value of pressure drop and a flow meter on the up-stream to get the value of flow rate, flow meter is used to accommodate the flow of fluid on the up-stream per 60 minutes. Measurements were continuously recorded during the tests performed for each working fluid. In figure 4, it can be seen the value of pressure drop versus flow rate.

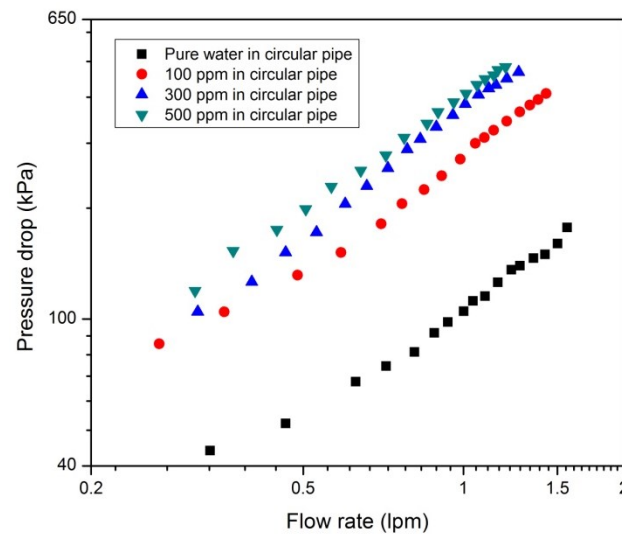


Figure 4. Comparison of pressure drop and flow rate.

Figure 4 shows the ratio of pressure drop and flow rate. In the graph, it was showed that pressure drop value of CaCO_3 nanoparticles concentration is higher from water. It also could be said that the increasing pressure drop was influenced by powder of CaCO_3 , and so did the flow rate. The trend of graph corresponded to other references that applied nanoparticles [11,12]. Through this observation, the use of powder at high concentrations was ineffective, because the higher concentration will higher pressure drop will be generated.

4.2. Friction factor

Further experimental data are calculated using the relevant formulas for non-Newtonian fluid flow in relation with friction factor. The study was conducted at 27 °C temperature of room.

Figure 5 shows comparison of friction factor and generalize Reynolds number. In the graph, data ranges around laminar flow to the turbulent flow region. In figure, there are some points occurring delay in the transition flow. Where, in calculation of experimental data for the friction factor value is not fit on the trend line Hagen-Poiseuille or Blasius. The friction factor value in the transition region is caused by delay fluid flow that will enter to the turbulent region while the value of Re' number has reached 4000. Delaying flow phenomenon maybe influenced by Brownian motion of powder. This is seen in the graph that has a trend line transition flow that occurs below the value of Blasius equation.

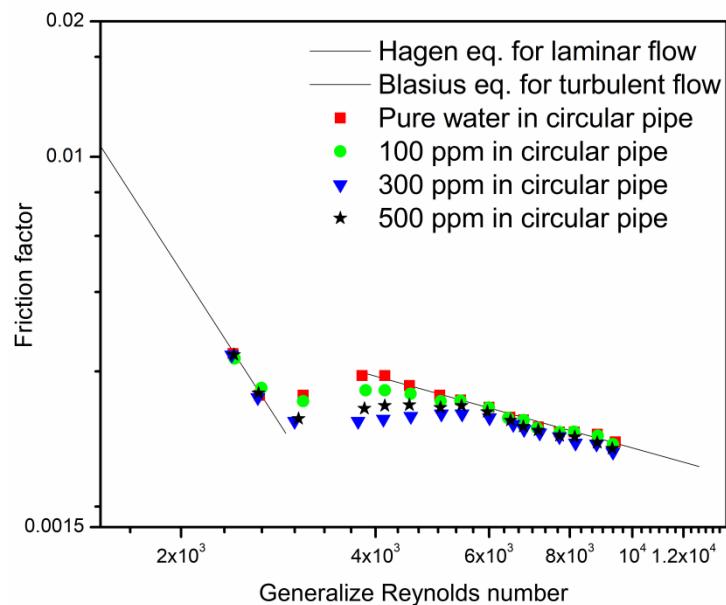


Figure 5. Comparison of friction factor with generalize Reynolds number.

Pseudo-random motion powder in solution for working fluid with the lowest coefficient of friction at concentration 300 ppm then followed by 500 ppm and 100 ppm which happened at transition regime. This value is influenced by the value of power law index on each working fluid. The n value, tend to near 1, where it will tend to linear which is similar to the trend line of Newtonian fluid.

Figure 6 shows the percentage of the DR value of the working fluid with an increase in Re' value. In the picture, it can be seen that there is a difference in value of the DR that is quite extreme percentage on the value of Re' laminar and turbulent.

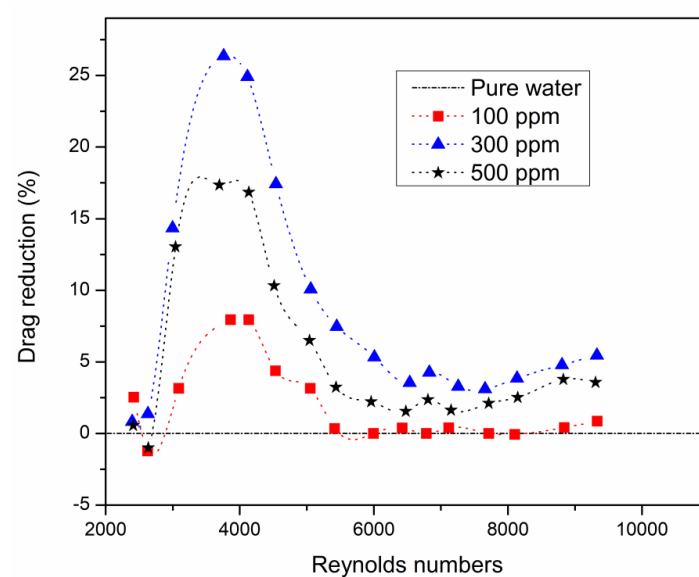


Figure 6. Comparison of DR values with generalize Reynolds number.

At the transition flow, DR is 26.3 % with 300 ppm concentration of nanoparticles and the Re' is around 3000. The percentage of the DR value is an interpretation of friction values in figure 5. In transition flow, maximum Brownian interaction of powder which pseudo-random motion is reduced frictional resistance in the boundary layer.

5. Conclusion

The present study was conducted to determine the hydrodynamic flow characteristics of calcium carbonate solution to increase flow efficiency in pipe. The effect of solution into friction factor value is varied. The highest DR in transition region is 26.3 % at 300 ppm and Re' is around 3000. Increase of Pressure drop when depends on the increasing concentration of the $CaCO_3$ solution. Adding more concentration can cause increase pressure drop.

6. References

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