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Characteristics of Drag Reduction by Guar Gum in Spiral Pipes

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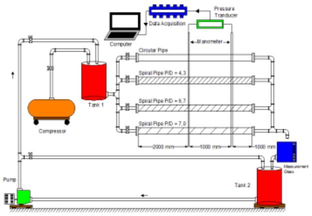
Graphical abstract



Abstract

On the transport of fluid using pipe, pressure drop is very important aspect because related with energy consumption. Special pipe as spiral pipe is used as a fuel mixing system of fuel oil on ships. It is intended to prevent precipitation and to reduce the pressure drop. The purpose of this research is to investigate the reduction of pressure drop in a spiral pipe with the addition biopolymer (guar gum). Spiral pipe with aspect ratio, P / Di = 4.3, 6.7 and 7.0 are used in this study. Working fluid used guar gum solution of 150 ppm and 300 ppm. Circular pipe with same diameter is used for comparison. Analysis of flow characteristics based on the power law model for non-Newtonian fluid. Experimental was conducted from low to high Reynolds number up to 50,000. The results showed that the effect of biopolymer guar gum solution can reduce drag either on a circular pipe or spiral pipe.

Keywords: Drag reduction, spiral pipe, guar gum, power law model

■1.0 INTRODUCTION

Since 1979 polymeric drag reduction reducers have been used in the Trans. Alaskan Pipeline. Following the initial success in large diameter pipe, the use of polymeric drag reduction reducers now has spread worldwide for crude oil pipeline transportation. The Hagen-Poiseuille, Darcy-Weisbach, and Colebrook equations and the Moody chart provide adequate solutions for flow in circular pipes, even if the flow is turbulent, no purely analytical solutions exist. Unfortunately, not all internal flows occur in circular pipes. In air and gas-handling systems such as home heating systems and power plants, air and flue gas ducts commonly employ rectangular ducts. A double-pipe heat exchanger has flow in a concentric annulus, and some of compact plate-fin heat exchangers in rectangular passages. Flows in shell and tube heat exchangers and in nuclear fuel-rod bundles occur in passages of highly complex cross sections. Experimental results of rectangular ducts (e.g. Shah and London 1978, Hartnett *et al*. 1962, Jones 1976) have been reported in the past. Theoretical formula for stream flow in ducts of the rectangular cross-section is proposed by Cornish [1] and interesting results are shown in the region at the critical Reynolds number. An analysis of laminar flow and pressure loss in ducts of complex sectional area has been reported by Zarling [2], application of the method is made to a variety of cross sections including the circular, elliptical, rectangular, triangular, and annular ducts. In most of the real fluid flow problems, however, it is well known that the constitutive equation of the fluid is analyzed by assuming no fluid slip on the solid surface. Most experimental results of a Newtonian fluid satisfy with this condition

The published reports concerned with the Toms effect in pipe flow are almost experimental, and the outline of the experimental results is as follows;

(i) The smaller the diameter of the pipe is, the larger the drag reduction will be.
(ii) The drag reduction increases with an increasing concentration initially but eventually it takes a certain value which is independent of the concentration.

The effect of just a few parts-per-million by weight of the polymer concentrations on laminar–turbulent- transition, boundary-layer properties and turbulent pipe flow and a long flat plates have know. The large drag reduction produced by these viscoelastic polymer solutions are being considered for practical application in many fields of engineering.

Sreenivasan and White [3] reported that polymer solutions undergoing a turbulent flow in a pipe thereby require a lower pressure drop to maintain the same volumetric flow rate. The addition of small amounts of additives to the flowing fluids can show significant effects on a lot of flow types, including the stability of laminar flow, transition to turbulence, vortex formation and break-up. Choi, *et al* [4]with injecting only 10˜ 50 ppm stock solution of a polymer additive in a tube can often produce a drag reduction more than 50%, implying that the energy cost necessary to transport the fluid is reduced by the same amount. However, the usage of these polymers is limited because of their susceptibility to flowinduced shear degradation. Friction reduction of up to 40% had been recorded in pipe flow with a low concentration of polymer. Properties of density and viscosity of this polymer solution can not be distinguished from water. At a concentration of 25 ppm. Fabula [5] get a 75% drag reduction in a 1.02-inch diameter pipe at a Reynolds number of about 100,000.

In 1964, Hoyt and Fabula [6] showed that the polymer solutions for rough surfaces and many wokers have been put on commercial pipes with a nominal roughness in their experiments. There have been studies to drag reduction in the pipes with containing a polymer coating which has been placed in a certain roughness of the pipe wall. In 1968, Lindgren and Hoot [7] has experimentes with a two pipe rectangular sides are made it slippery (smooth) surface and the others side sodes are made rough surface. Side in a rough surface is coated with silicon carbide grain size, k = 0,6 to 0,7 mm with a roughness parameter R/K = 58. Poly (ethyleneoxide) prepared in low concentrations ranging from 15 ppm to reduce friction in large pipe and 60 ppm for the lower friction factor with water flowing. The results that constant coefficient of friction seen at f = 0.06 with a Reynolds number of about 30,000.

Guar gum is a complex polysaccharide derived from cyamopsis tetragonologus, a plant raised commercially as a food additive and thickener. In petroleum technology, the use of this natural gum as a suspending agent for sand in drilling muds and fracturing fluids led to the discovery that guar solutions had a lower friction than water.

Guar became popular material because of the cheap price in addition to the molecular characteristics that tend to inhibit the degradation due to high shear stress. The Pressure drop losses of spiral pipe tend to increase slightly compared with circular pipe [8]. The purpose of this research is to know the reduction of pressure drop in a spiral pipe with the addition of the biopolymer latex (guar gum). Spiral pipe with aspect ratio, P / Di = 4.3, 6.7 and 7.0 are used in this study. Working fluid used is a biopolymer latex solution of 150 ppm and 300 ppm. Circular pipe with same diameter are used as a comparison. Analysis of flow characteristics follows the power law model for non-Newtonian fluid. Testing was conducted from low to Reynolds High Reynolds about 50,000. The results showed that the effect of biopolymer latex solution can lead to reduction in resistance (drag reduction) either on a circular pipe and spiral pipe.

2.0 EXPERIMENTAL SETUP

Guar gum biopolymer is used in this study. The concentration is used at 150 ppm and 300 ppm. Test pipes are presented in the table below:

Tabel 1 Specification of test pipe

Test Pipe	Di (mm)	Do (mm)	Δd	P (pitch)	P/Di
Circular	25,4	31,5	6,1	∞	∞
Spiral 1	23,9	32,3	8,4	167,3	7,0
Spiral 2	24,7	32,4	7,7	165,5	6,7
Spiral 3	26,4	33,2	6,8	113,5	4,3

Figure 2 shows the experimental set up, where the test equipment consisting of acrylic pipe with inner diameter (D) 25.4 mm and a spiral pipe with a diameter pitch ratio (P / Di) = 4.3, 6.7 and 7.0. Distance between pressure taps is 1000 mm. The length of "entry length" is enough to keep the full-developed flow (fully developed) is 2000 mm. Guar gum solution with a concentration of 150 and 300 ppm circulated in the test tube. The test is rapid maximal 1 hour in order to avoid degradation of the solution and replaced with a new solution. Use of diaphragm pump to keep the fluid does not occur in direct contact with the impeller which causes high shear stress will accelerate the widespread degradation of the fluid. Tests carried out of the low flow velocity toward the high flow velocity at high Reynolds number. The flow rate is regulated by gate valve settings to set Reynolds number value. The flow rate was measured by collecting the discharge that comes out of the pipe within a certain time period. Maintained constant fluid temperature 27^0 C. The pressure drop was measured between pressure tranducer. The coefficient of friction can calculate from the value of ΔP with the equation of Darcy-Wiesbach on the value of a particular Reynolds number.

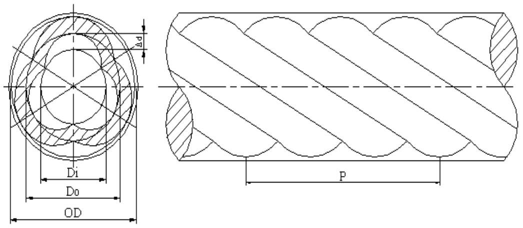


Figure 1 Test section in a spiral pipe

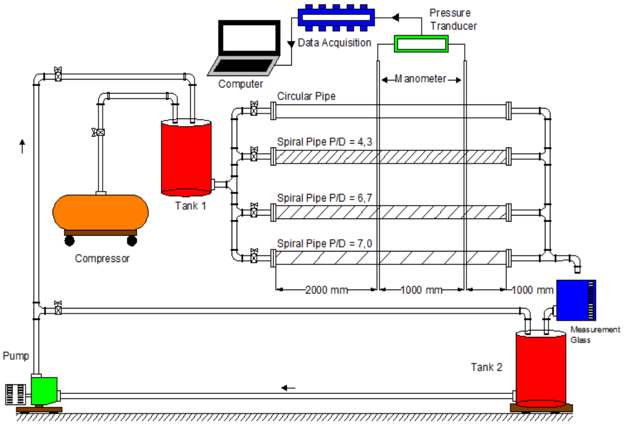


Figure 2 Experimental Setup

3.0 RHEOLOGICAL MODELS

Relationship of friction coefficient with Reynolds number ared plotted on Moody diagram. The equation of friction coefficient for laminar flow is described as a straight line from the Hagen-Poiseuille and Blasius to turbulent flow and the pipe roughness ratio.

Relationship changes the value of viscosity on non-Newtonian fluid is due to shear strain, Reynolds will be replaced by the Generalized Reynolds Number Re'. Where the apparent viscosity is associated with an absolute value of shear stress, τ_w. Equation of *Power Law Model*:

$$(\tau_w) = K\left(-\frac{du}{dy}\right)^n \qquad (1)$$

Where K and n are constant for the particular fluid the higher value of K, the more viscous the fluid. for n=1 that is for Newtonian behavior $K=\mu$ corresponds to the Newtonian viscosity. $n<1$ for pseudoplastics model and $n>1$ for dilatant model. The

Newtonian viscosity depends on the temperature and the pressure and is independent of the shear rate. The viscosity is defined as the ratio of shear stress to shear rate.

Power Law Index (n), can be calculated from tangent arc curved of sheear stress, τ and shear rate, γ from equation:

$$n = \frac{\log\left(\frac{\tau_1}{\tau_2}\right)}{\log\left(\frac{\gamma_1}{\gamma_2}\right)} \qquad (2)$$

Re’ is the Generalized Reynolds Number can be obtained from eqution:

$$Re' = \frac{8n^n \rho d^n U^{2-n}}{2^n \left(3n+1\right)^n K} \qquad (3)$$

U is velocity, d is inner diameter and ρ is density.
Coefficient of friction, f, can be obtained by Darcy Equation:

$$f = \left(\frac{2D}{\rho L U^2}\right)\Delta P \qquad (4)$$

Where: f is the coefficient of friction, ΔP is presure drop.
Drag reduction, DR in pipe can be obtained by equation:

$$DR = \left|\frac{f(water) - f(ggum)}{f(water)}\right| \times 100(\%) \qquad (5)$$

Where f (water) is the coefficient of friction pure water, f (ggum) is the coefficient of friction guar gum solution.

4.0 RESULTS AND DISCUSSION

In figure 3 Measurement of the apparent viscosity of guar gum solution are carried out by horizontal pipe viscometer and the data of guar gum at 150 ppm and 300 ppm concentration. It can be seen that the viscosity increased with increasing concentration. Measurements of viscosity depend on the type of viscometer and the hysteresis of the shear stress or shear rate may be occurred. Because the viscosity of guar gum solution is complicatedly depend on many parameters. It is shown that the viscosity decreases with an increase in gradient velocity and indicating that the material is a Power Law fluid and classified as shear thinning fluid over this range of shear stress. The value of power law index for guar gum solution are n = 0.5 - 0.7.

In figure 4 shows the apparent viscosity of guar gum solution in spiral pipes. Apparent viscosity in spiral pipes depend on aspect ratio (P/Di). The viscosity is slightly increasing by decreasing of aspect ratio (P/Di).

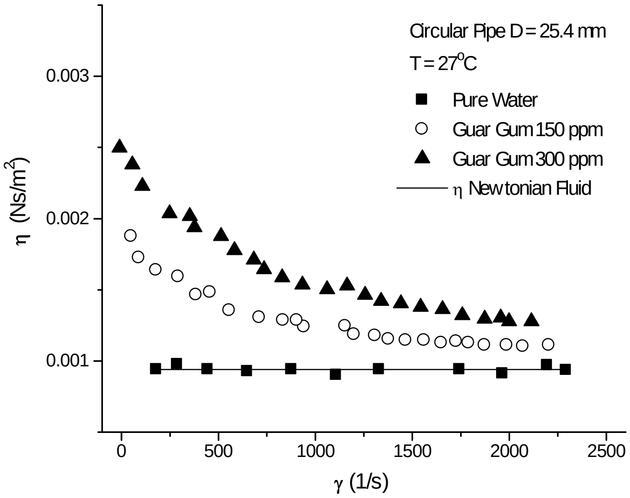


Figure 3 Relationship between apparent viscocity and shear rate in a circular pipe

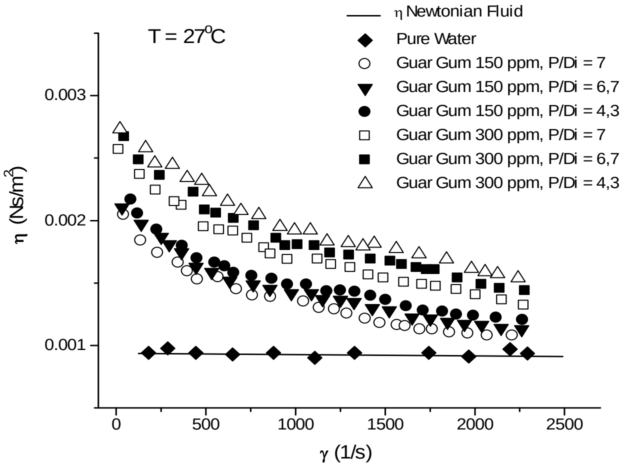


Figure 4 Relationship between apparent viscocity and shear rate in spiral pipes

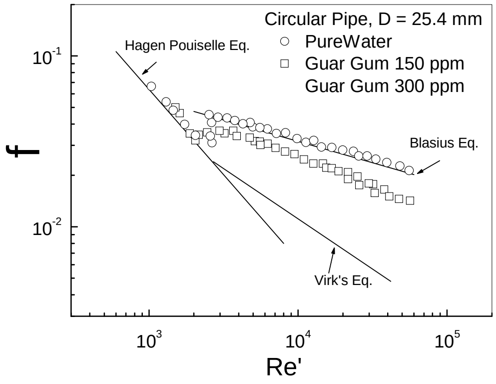


Figure 5 Relationship between coefficeint friction and Generalized Reynolds Number with guar gum solution in a circular pipe D = 25.4 mm

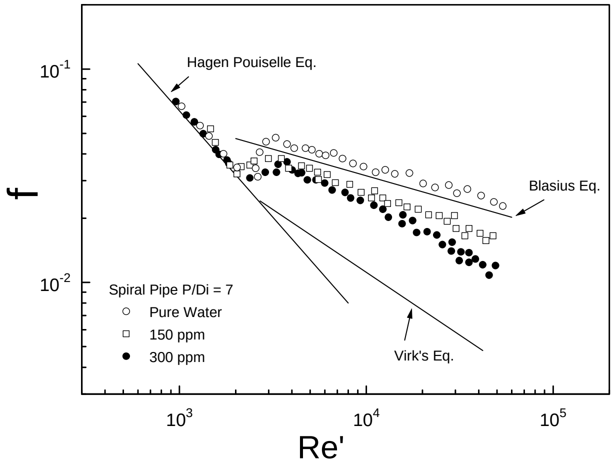


Figure 6 Relationship between coefficeint friction and Generalized Reynolds Number with guar gum solution in a spiral pipe with P/Di = 7

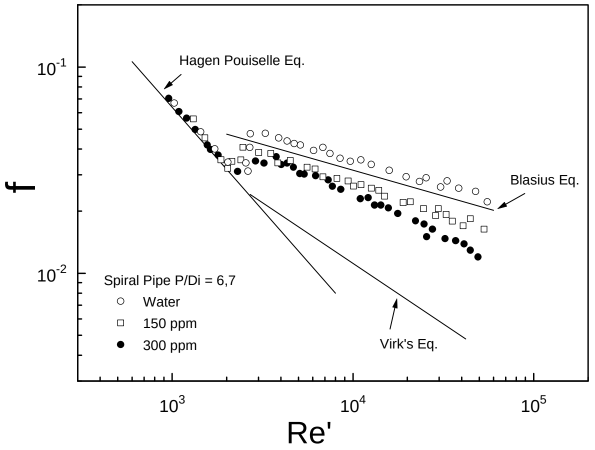


Figure 7 Relationship between coefficeint friction and Generalized Reynolds Number with guar gum solution in a spiral pipe with P/Di = 6.7

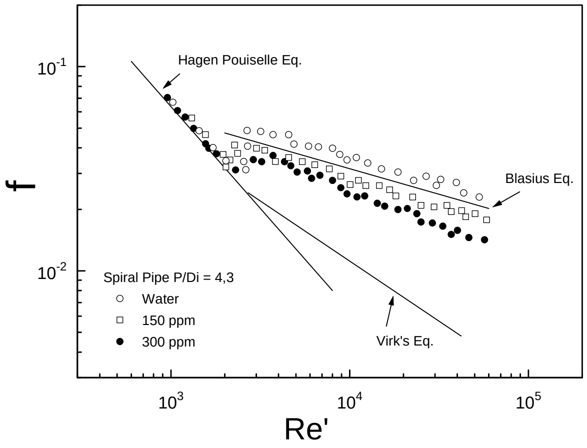


Figure 8 Relationship between coefficeint friction and Generalized Reynolds Number with guar gum solution in a spiral pipe with P/Di = 4.3

The experimental coefficient of friction results of guar gum solution in circular pipe is shown in Figure 5. The data will be compared with Hagen Pouiselle equation in laminar flow and the Blasius equation in turbulent flow. The coefficient of friction of guar gum solution fit with the coefficient of friction of water for circular pipe in laminar flow, but in turbulent flow, the coefficient of friction is lower than coefficient friction of water. It is indicating that in turbulent flow drag reduction occurs from guar gum solution. With equation 5, drag reduction that occurred about 35% and 27% for 300 ppm slime solution and 150 ppm at Reynolds number $2x10^4$.

The experimentally determined coefficients of friction of guar gum solution in spiral pipe are shown in figure 6,7 and 8. The experimental coefficient of friction results of guar gum at 300 ppm and 150 ppm in spiral pipe with P/Di = 7 are shown in figure 6. The analytical result of Hagen Pouiselle equation for laminar flow and the the Blasius equation for turbulent flow, $f=0.3164\ Re^{*-1/4}$ will be compared with experimental result. The coefficient of friction for guar gum is spiral pipe is near with the coefficient of friction for circular pipe. Correlation for the coefficient of friction and Reynolds number can also be used by designers to more accurately predict the pressure drop characteristics for guar gum in spiral pipe. Because the viscosity of guar gum is complicatedly dependent on many parameters, the Reynolds number regenerative is calculated using the apparent viscosity of guar gum. For spiral pipe the data of friction coefficient in turbulent regime is higher than circular pipe.

Based on figure 6, 7 and 8 we found that ratio pitch per diameter (P/Di) for spiral pipe has a considerable effect on the drag reduction, the reduction being greater with the higher P/Di, for the same guar gum concentration and Reynolds number. It can be seen from these results that drag reduction for a given guar gum concentration only occurs above a critical value Reynolds number which depends on the P/Di. Below this critical value the fluid exhibits normal Newtonian viscous behavior, although for the pipes of very small bore ordinary turbulent flow is never established since the critical value Reynolds number for these is less than 2000. The friction factors of high-concentration solutions data sit close to the Virk's equation according to the increase in the Reynolds number, Re'. The drag reduction decreased with the increase in Re' and concentration of guar gum solutions.

As can be seen from the Figure 5 through 8, the drag reduction is significantly affected by the type of pipe, P/Di for spiral pipe and the viscosity of the fluid. The drag reduction increased slightly with increasing concentrations. The reported value for guar gum solution of 300 ppm and 150 ppm in the turbulent flow range in cir cular pipe has drag reduction about 35% and 27%. For same concentration and Reynolds number, drag reduction for spiral pipe P/Di = 7,0 is 30% and 24%. The drag reduction decrease with decreasing P/Di, for P/Di = 6,7 and 4,3 drag reduction occured about 23%, 18% and 16% , 12% respectively.

Figure 9 shows the scheme of friction factor behaviour for guar gum solution with different pipe. In this representation the friction line intersect with the one representing the Blasius line. Different concentration of guar gum effect to the slope anggle between this line and Blasius line. The drag reduction increased with increasing of slope angle. But for different type of pipe for example for spiral pipe, the line of data have no same start point with another pipe. With increasing of aspect ratio (P/Di), the start point of scheme guar gum solution is near with start point of circular pipe.

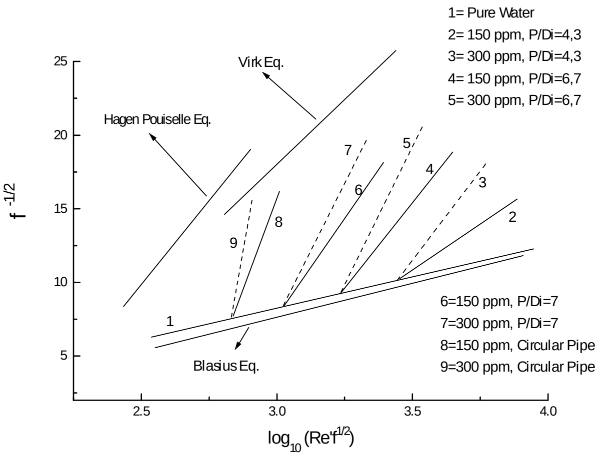


Figure 9 Scheme of the friction-factor behaviour for dilute drag reducing guar gum solution.

5.0 CONCLUSION

Pressure losses of guar gum solutions in circular and spiral pipe with various concentration ppm were measured in a region from laminar to turbulent flow. The drag-reduction effect of the guar gum additive was verified. The effect occurred only above some critical Reynolds number which was affected by the concentration of the guar gum solutions. The mean drag reduction ratios of 35% and 27% were obtained at Re = 2 x 10^4 at 300 ppm and 150 ppm for circular pipe with 25,4 mm of diameter. Drag reduction is significantly affected by the type of pipe, P/Di for spiral pipe and the viscosity of the fluid. For spiral pipe the range drag reduction is about 12% through 30% depend on ratio pitch per diameter (P/Di). The best ratio is 7,0 and have drag reduction 30% for 300 ppm and 24% for 150 ppm.

Acknowledgement

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