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DRAG REDUCTION IN TURBULENT PIPE FLOWS WITH POLYMER-POLYMER MIXTURES

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Abstract. *The turbulent drag reduction caused by polymer-polymer mixtures has been studied. Reynolds number was ranged from $7x10^4$ to $1.1x10^5$ and different concentrations were analyzed for flexible and rigid polymers. It is used an experimental apparatus compound by galvanized steel pipes which was thermally insulated. To minimize localized polymer degradation during the experiment, the solution was driven by aid of an air compressor, which is connecting pneumatically to a vessel that permits to fix the inlet pressure during the test. The inlet pressure was fixed in 250 kPa. The main results obtained are presented in terms of drag reduction as a function of the number of passes (Np) through the pipe line. The drag reduction is analyzed taking into account the friction factor of the polymeric solutions for each pass. Such a friction factor is compared with the solvent one (pure water) and drag reduction is calculated, as defined by Lumley (1969) Lumley (1969) $DR = (1 - f/f_0)$ measured in the same Reynolds number. It was observed a synergy between these polymers mixtures. We believe that the aggregation in the mixtures is a possible cause of the observed synergy. This observation is very important from the industrial point of view, because the rigid polymer used in the present work is less expensive and is non-toxic.*

Keywords: *Drag Reduction, polymer-polymer mixtures, turbulent flows, polymer concentration.*

1. INTRODUCTION

The friction factor reduction in turbulent pipe flows by additives has been studied since mid-century and has aroused abroad scientific and industrial interest until nowadays. Among the additives most utilized stand out the polymers (Polyacrylamide, Polyethylene Oxide, and Xanthan Gum), surfactants, fibers (nylon, cotton and asbestos), also paper pulp and gas bubbles. The drag reduction obtained by polymeric additives is a phenomenon that was first reported by Toms (1948). The author showed that adding small quantities of polymers of high molecular weight in a turbulent flow could reduce significantly the friction factor. Later, Lumley (1969) defined the drag reduction as the reduction of friction factor of the additives solution in relation to the solvent, measured in the same Reynolds number. Thenceforth, the phenomenon has been extensively studied, due the great benefit reached in practical applications in several areas of the engineering. The most famous example until the present time is the transport of crude oil in the "Trans-Alaska Pipeline" with 1300 kilometers of extension, where adding polymeric additive in the range of 10 ppm causes a drag reduction in the order of 40%, as is described by Burger and Chorn (1980). The phenomenon is also used with great successful in others pipelines around the world, for example, in the Iraq-Turkey pipeline, in the Bass Strait in Australia, Mumbai inter alia, Nijs (1995). The technique of drag reduction using polymer is found in other areas of great interest, as firefighting system, Fabula (1971), biomedical applications, Kameneva, et al., 2003, irrigation systems, operations in oil wells, etc. The idea of study the drag reduction by adding additives is to improve and expand the practical applications, as well as enhance the knowledge of the turbulence and their control. The huge limitation of the drag reduction in the industry is the irreversible polymer mechanical degradation due to the polymer exposition on the shear forces, which is generated by the turbulent flow. Researches have demonstrated that degradation of polymers is quite dependent on: concentration and molecular weight, Reynolds number, temperature, kinds of systems and solvent properties. In the recently years, some of these factors have been studied by numerical simulations, Dimitropoulos et al. 2005 and experimental procedures, Pereira and Soares (2012) and Andrade et al. 2014. Despite these experiments have shown some qualitative, the results can vary according to the level of turbulence and a number of different properties.

Concerning the polymer mixtures, there are different works of great interest as those reported by Dschagarowa and Bochossian (1978), Reddy and Singh (1985) and the recent research published by Steele et al. 2014, showing that Carbon Nanotubes (CNT) can enhance the drag reducing characteristics of polymers. Interestingly, there is not drag reduction when CNT are used as a single solution.

The goal of the present work is to analyze the phenomenon of drag reduction in turbulent pipe flows by polymer-polymer mixtures of: Poly(ethylene Oxide)-Xanthan Gum and Polyacrylamide-Xanthan Gum, where the Xanthan Gum is known as rigid molecule and the others are considered flexibles. For this purpose, it is used an experimental apparatus where the inlet pressure and the flow rate is under control.

2. EXPERIMENTAL APPARATUS AND PROCEDURES

The apparatus used to conduct the experiments is compound by a thermally insulated galvanized steel pipes (inside diameter 16.35 mm), one magnetic flow meter and three static pressure transducers, which are connected in the tube in a position where the flow is fully developed, as it is shown in Fig. 1. Especially, the test section (where is located the pressure transducer) is composed of stainless steel, previously polished to improve the quality of the pipe's surface. The solution was driven through a compressor, which is connected pneumatically to a vessel with fixed inlet pressure, 250 kPa.

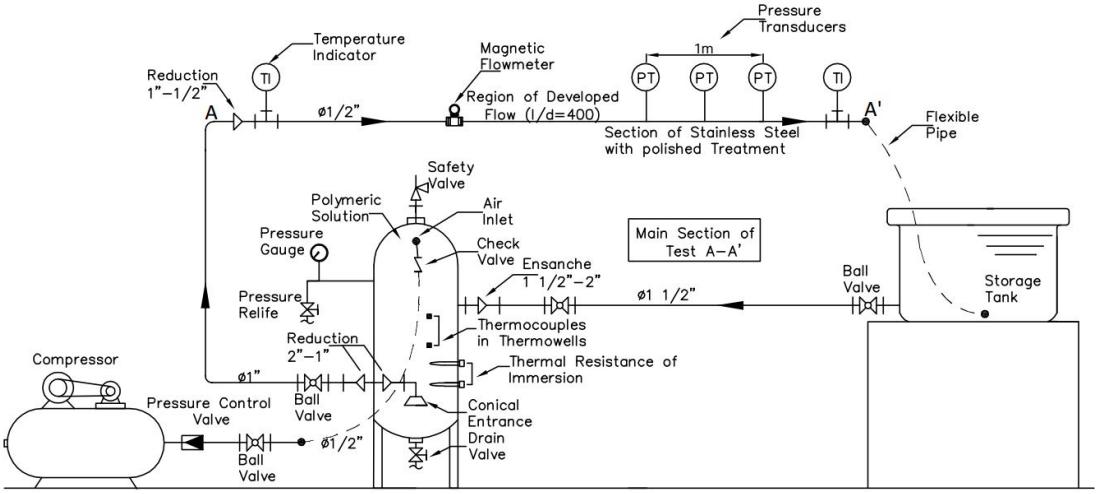

Figure 1. Diagram of experimental turbulent pipe flow.

We used filtered water as our solvent. The reduced friction factor was compared with that obtained for flows into smooth pipes (in our experiments, we used the Blasius friction coefficient for turbulent pipe flow as our reference). Using pure water, the maximum difference observed between our measured friction factor and the Blasius one was 6%, as it shown in Fig. 2.

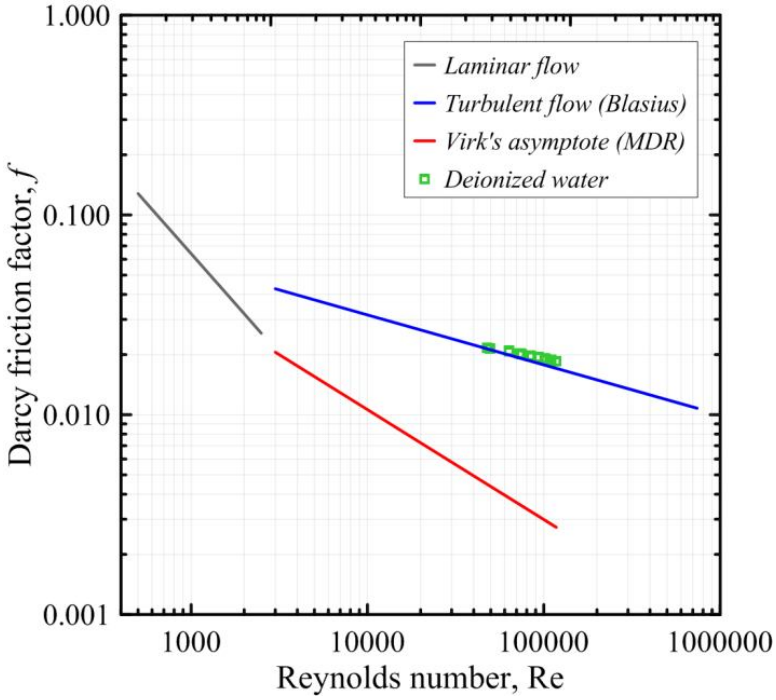

Figure 2. Comparison between the friction factor of experimental apparatus with the Blasius friction coefficient.

The first step of the test is to dilute small quantities of polymers in filtered water, which is later deposited in a reservoir. The solution (water with polymer mixture) is driven through the pipe repeatedly until the final values of drag reduction is reached, when the polymer reaches its minimum molecular weight caused by the mechanical degradation. The tests are conducted at fixed inlet pressure. Our data was acquired by using the program of the National Instruments called LABVIEW. The polymer degradation was analyzed by changing the mixture concentration (from 25 to 200 ppm), Reynolds number (range from 70.000 to 110.000). The molecular weight utilized for the polymers were: Mv of PEO ($4x10^6$ g/mol), PAM ($5x10^6$ g/mol) and XG ($2x10^6$ g/mol). All our chemical supplies were provided by Sigma–Aldrich. The data acquired during the test (pressure, temperature, viscosity and flow rate) was analyzed to calculate the drag reduction with the Eq. (4).

Using the density ρ, viscosity of the solution η, the mean velocity of the flow V_m and with the respectively inner pipe diameter d, then the Reynolds number is calculated by the Eq. (1).

$$R_e = \frac{\rho V_m d}{\eta} \tag{1}$$

As mentioned previously, the friction factor for pure water was calculated using the Blasius correlation, Eq. (2).

$$f = \frac{0.316}{R_e^{0.25}} \tag{2}$$

Through the pressure difference in the section test, $\frac{\partial p}{\partial x}$, with constant diameter, where the flow is fully developed, the friction factor of the experimental apparatus is calculated by the Darcy definition, using Eq. (3).

$$\frac{\partial p}{\partial x} = f_D \frac{\rho}{d} \frac{V_m^{\,2}}{2} \tag{3}$$

The percent Drag Reduction %DR was determined by Eq. (4), as defined by Lumley.

$$\%DR = \left(1 - \frac{f}{f_0}\right) * 100 \tag{4}$$

Where f_0 and f are respectively the friction factor of Newtonian and non-Newtonian turbulent flows.

3. RESULTS AND DISCUTIONS

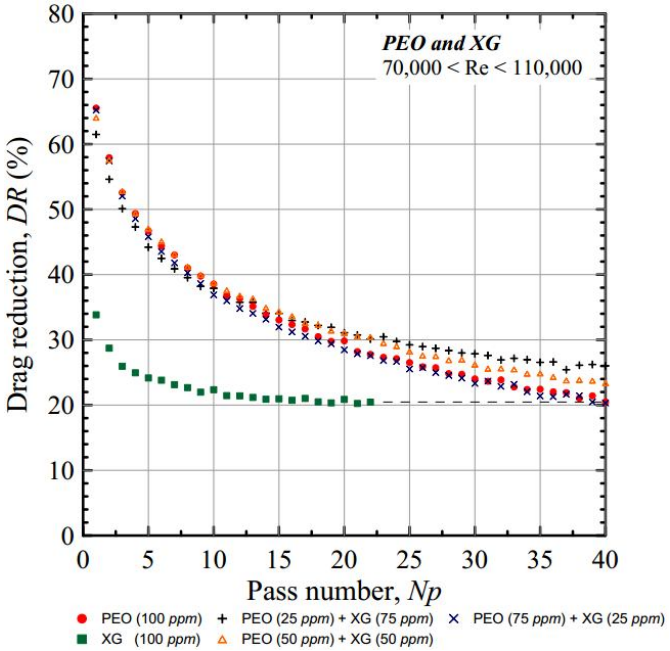

Figure 3. Mixture of PEO with XG for concentrations of 100 ppm.

The main results obtained are presented in terms of drag reduction as a function of the number of passes (*Np*) through the pipe line. All our tests were conducted at a fixed inlet pressure.

The drag reduction is analyzed taking into account the friction factor of the polymeric solution for each pass. Such a friction factor is compared with the solvent one and DR (drag reduction) is calculated, as defined by Lumley (in the same Reynolds number).

Figure 3 shows the DR results for the polymers individually (filled symbols) and the results for polymers-polymers mixture, for concentrations of 100 ppm. The temperature and the pressure used to convey the fluid were constant during the experiment. It is noted that DR is larger mixing PEO and XG. It is also analyzed that increasing the concentration of XG (rigid polymer) and reducing the PEO concentration in the mixture, the asymptotic level of DR reaches a higher value. This is clear in Fig. 4, where the results are displayed for concentrations of 200 ppm.

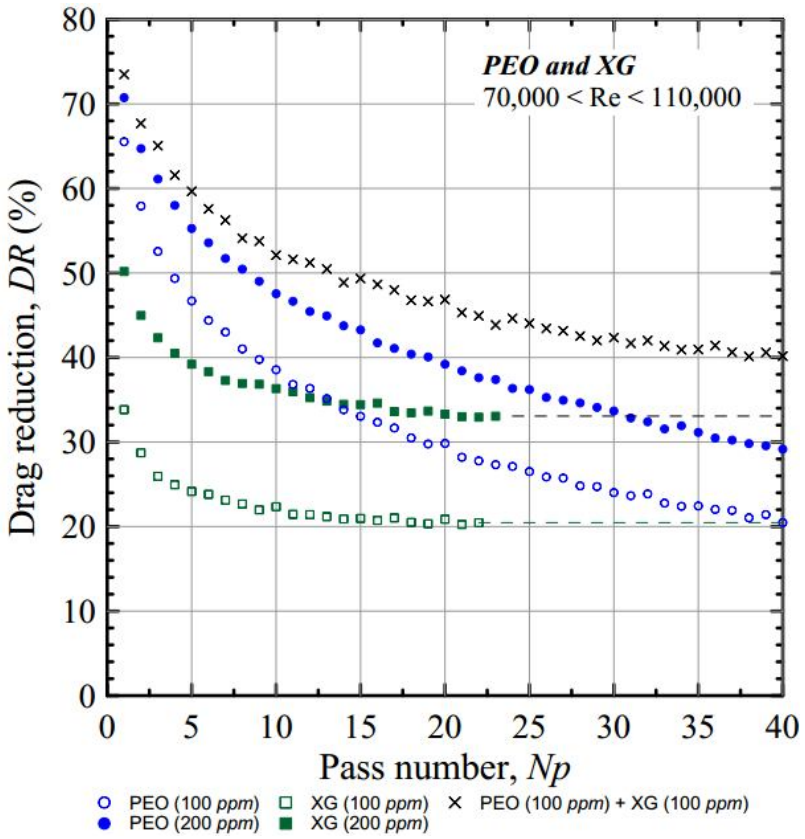

Figure 4. Mixture of PEO with XG for concentrations of 200 ppm.

It is verified again that the efficiency of DR increases when mixtures polymers are sued (25% with respect to PEO and 33% to XG, for concentration of 200 ppm), a clear synergy. For example: the final value of DR for single solutions of 100 ppm XG and 100 ppm of PEO is 20% (at the last step). By the other hand, the value obtained of DR for the mixture (100 ppm of PEO with 100 ppm of XG) in the same Np is 40%, which is the sum of the two results for a simple polymer. At the first passes this effect is not observed, since it is close to Virk's asymptote (approximately 82%). These results are very interesting from the practical point of view, since XG is a polymer cheaper than PEO and non-toxic. Meanwhile, the biological degradation of the XG is faster than PEO and PAM. The response of DR for the mixture of PAM with XG is depicted in Fig. 5.

For the concentration of 200 ppm is important to note that the DR for PAM is significantly larger that for XG, 43% and 33% respectively. It is interesting that, such a level of efficiency can be achieved combining 100 ppm of PAM with 100 ppm of XG. In fact, the gain of efficiency by adding 100 ppm of XG into the solution of 100 ppm of PAM was quite the same as to increase the concentration of PAM from 100 to 200 ppm.

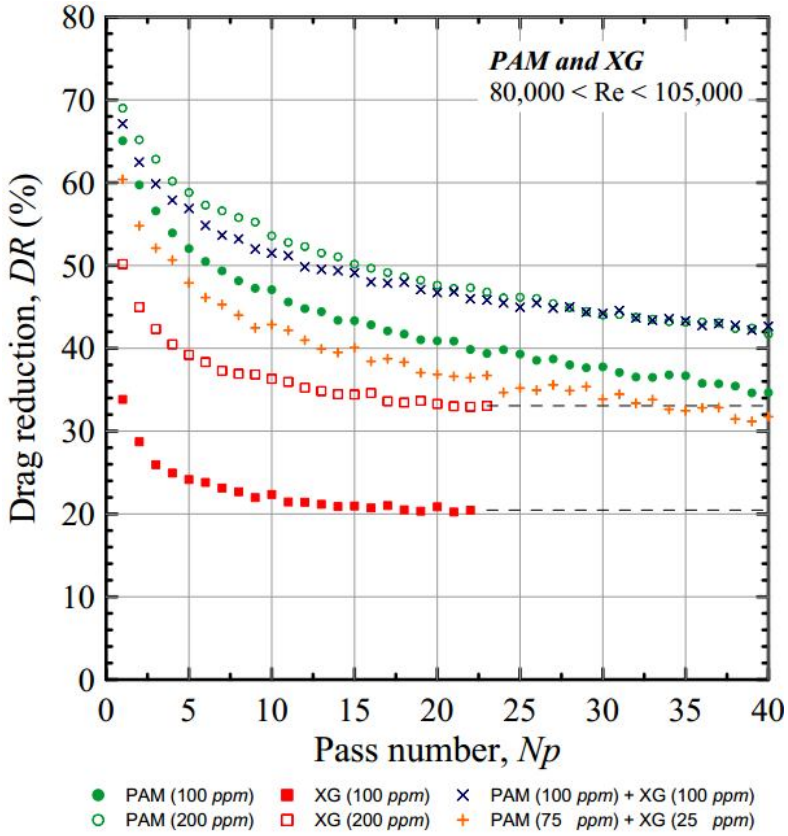

Figure 5. Mixture of PAM with XG for concentrations of 100 ppm and 200 ppm.

One hypothesis for the synergy observed is the aggregation of the polymers, originated by the intermolecular forces in the solution, as shown by Shetty and Solomon (2008). Dschagarowa and Bochossian (1978) also observed such a synergy. They used mixtures of polyisobutylene and isoprene rubber (both drag reducers) in toluene. The result of DR obtained in that mixture was quite good. Possibly, the rigid molecules was essential in the mixture for improving the efficiency of DR. The same idea was also considered by Dingilian and Ruckenstein (1974), they indicated that the synergy of the mixture occur when at least one of the components of the mixture is a rigid structure.

4. FINAL REMARKS

We present an experimental approach developed to analyze polymer-polymer mixtures in drag reduction phenomenon, using an experimental turbulent pipe flow apparatus. The tests were carried out with solutions of PEO, PAM (flexible polymers) and XG (rigid polymer) into pure water as a solvent. The results shown that the mixtures of additives, in some proportions and molecular weights, are more efficient than using single solutions of polymers. The values obtained were computed pass-by-pass through the experimental apparatus at a fixed inlet pressure and temperature.

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