A New Synergistic Approach to Studying Drag Reduction of Rigid Polymer and Microbubbles in Turbulent Flow

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Abstract— Drag has been a challenge encountered in liquid transportation of liquids. A universal means of reduction has however, not been implemented. Most efforts made to study its working mechanism and finding best environmental friendly approaches have been major setback. Mostly, materials investigated to militate these challenges are either less effective or harmful to the environment. In this work, an environmental friendly approach which entails bubble injection into rigid polymer (Xanthan gum) was investigated. The materials were tested individually and as complex. 51%, 56% and 62% drag reduction were obtained for 700ppm of the xanthan gum alone in the RDA, 700ppm in the pipe and 700ppm of xanthan gum with microbubbles pipe respectively. Despite the fact that the individual additives were able to reduce drag, their complex mixture showed better performance. The performance of the complex could be attributed a synergy which occurs between these additives, thus suggested a new working mechanism of the duo. Based on the combination of these additives, it could be concluded that there is an extra drag reduction when they are combined than the individual additive. Aside this, there is a synergistic relationship in their drag reduction mechanism.

Keywords—Drag reduction, Rigid Polymer, Flexible Polymer, Turbulent Flow, Complexes, Fluid mechanics

1. INTRODUCTION

The concept of drag reduction is not a new one due to the numerous studies which have been conducted in the subject. Right from its first discovery in 1948 [1], many other studies have been carried out to investigate drag reduction. According to Toms [1], certain additives (polymers) are capable to reduce the drag encountered whenever fluids flow through pipes, conduits etc. From such discovery, continuous efforts is being made to study the working mechanism of the materials and it was observed in all the studies that polymers are capable of reducing drag [2-5]. However, they are often prone to mechanical degradation especially in turbulent flow systems and this reduce their working abilities [6]. In view of such setback, other additives have been looked into such as surfactants [7], bubbles [8], solid particles [9], rigid polymers [10], Nano fluids [11] or the combination of two or more of these such as polymer and surfactant [12], polymer and CNT [13]. Each of these additives have one setback or the other especially with environmental concerns which have hindered their wider acceptance. Others are the different working mechanism and less efficiency compared to the polymer, since it is believed that about 80% drag reduction could be achievable while working with the polymer (flexible).

In view of these, it is therefore a matter of necessity to investigate materials which are of similar working mechanism as the polymers and environmental friendly. Studies have revealed that many industrial polysaccharides are capable of shear-stable when undergoing such stresses [14,15]. These materials have advantages of great mechanical stability against degradation with respect to other flexible polymer, although susceptible to biological degradation. From the available literatures, Xanthan gum have been widely used in food, cosmetics, pharmaceutical industries as well as oil industries as drag reducers in drilling operations. XG could be compared to cellulose in their molecular weight, possessing linear chain (1-4)-β-D-glucose when compared to cellulose of trisaccharide side chain on every second D-glucose [16]. With this kind of structure, they are very stable and rigid against any form of mechanical degradation, although these structure depends on salinity and temperature. This could be noticed in organized helical conformation of XG in low ionic forces and moderate temperatures due to their rigid molecular structure [17,18].

Apart from the working mechanism consideration, another important aspect to look into is the environmental considerations and it has been reported that, there are numerous opportunities associated with the application of microbubbles in drag reduction. In addition to this, it was suggested that one of the most efficient method of viscous drag reduction is by injecting bubble into turbulent boundary layer to reduce drag [19]. Apart from all these, there are many advantages attributed to the use of microbubble in drag reduction such as: environmental friendliness, ease of operation, reduced cost and high energy saving capability apart from which, Microbubbles in drag reduction could reduce drag to as high as about 80% [20-22].

However, according to the literature available to the authors in the course of this paper, there is no known available study on the study of rigid polymers and microbubble, although the flexible ones have been investigated. As a result of this, it could be an interesting idea to investigate them due to the numerous opportunities enumerated above.

In this study, an environmental friendly and economical approach was developed to study the drag reduction of fluids flow at high turbulent using rigid polymers and microbubbles. The study entails the study of these additives individually and in combined form as complex.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

2.1. Materials

All materials used in the present work were purchased from Sigma Aldrich, Malaysia and no further treatment was carried out after supply. The Xanthan gum of 2.0×10^6 g/mol molecular weight was used as supplied in its solid form to prepare the bulk concentration. Verification of the molecular weight was further investigated with respect to the method suggested by [23] and the result conforms to the one given by the supplier. The material intrinsic viscosity, ŋ was applied to develop its overlap concentrations by [24] with agreeable result.

2.2. Preparation of polymer Working solution and Procedure

The material bulk solution was prepared by measuring the required quantity of the solid sample and dissolving in tap water. The materials was shaken and left for hours to allow for proper dissolution before the experiment was undertaken.

The experimental procedure involves the use of a rotating disk apparatus which have initially been used by [5] with the same approach. Polymer concentrations were individually tested in the rotating disk apparatus (RDA) and the data taken accordingly before it was taken to the pipe loop. Such was used to mimic the turbulent nature of the pipe and to simulate external flow of the samples. A schematic representation of the RDA is depicted by Fig. 1.

The pipe loop used in the current work is the same used by [25] following the same procedure. The experimental procedure which involves the materials dissolution as reported above. In furtherance to the dissolution, the sample was decanted into the tank without any form of disturbance for about 30 minutes after which it was circulated round the loop. After about a minute of circulation, data were taken and recorded to enable full elongation of any form of viscous substances which might have been form during the preparation stage. The data were taken in form of pressure drops at fixed flowrates and the experiment continued until the final flowrate under investigation. This was continued for all the materials types and concentrations until the final data recorded.

2.3. Microbubble Generator

Microbubble generated in the present work was achieved in form of a jet using a BT50 Micro-Nano Bubble Nozzle. Experimental set up is further explained with the Figures depicted in 3.16 and 3.17. The whole Ruggedized designed unit has the following basic features: Use of ozone, Better thermal stability and Chemical resistance. The major requirements for generating microbubbles is best explained with Table 3.1 and the basic guide per single unit comprises of a pump power between 50w-200w/1000 liters (264 Gallons) and dissolved oxygen increase using oxygen gas 8.4 -> 13 ppm. However, two pumps were stationed where one served as an alternative in case there is any problem. The air flow rate used was 0.1 l/m, 0.026 GPM Water flow rate 14 l/m, 3.7 GPM.

The Bubbles generated travel through a distance within the pipe to the bubble generator chamber and acted upon by turbulence and shear stresses for a period of time. They are further broken down into lesser bubbles. Air enters the chamber by air nozzles of the BT and mixes with the water flow inside the chamber. In circuit, the flow containing bubbles are circulated together with the solution within the pipe loop. It is further taken to the water and air separation tank where the water devoid of microbubbles is recirculated by the pump until the completion of the experiment.

Table 1: Capacity description of the BT50 unit

Pump Pressure	Water Flow Rate	Air Flow Rate
0.05 Mpa	7l/min	0.02-0.04l/m
7.25 psi	1.85 GPM	0.005 GPM
0.3 Mpa	20 l/min	0.1-0.4 l/m
43.5 psi	5.28 GPM	0.026-0.106 GPM

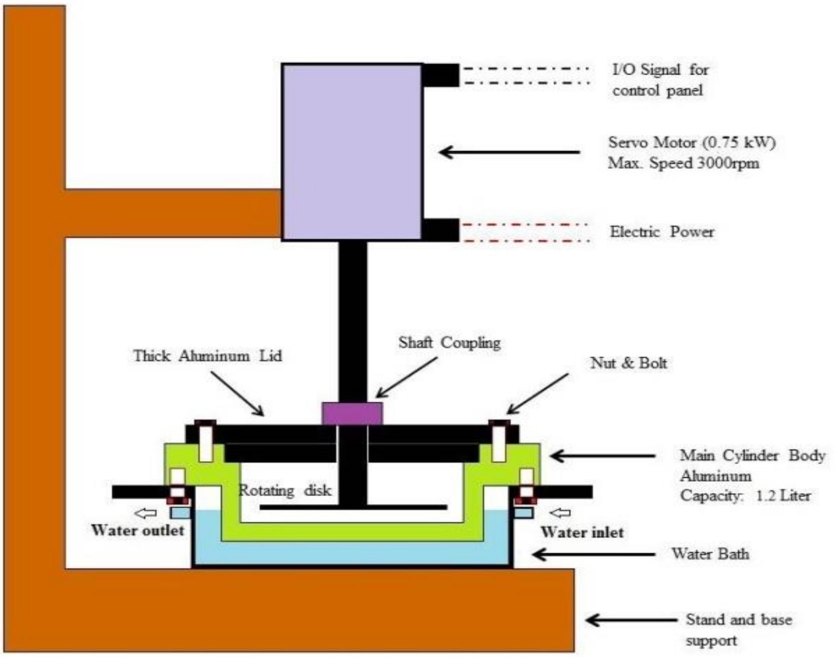

Figure 1: Example of a figure caption.

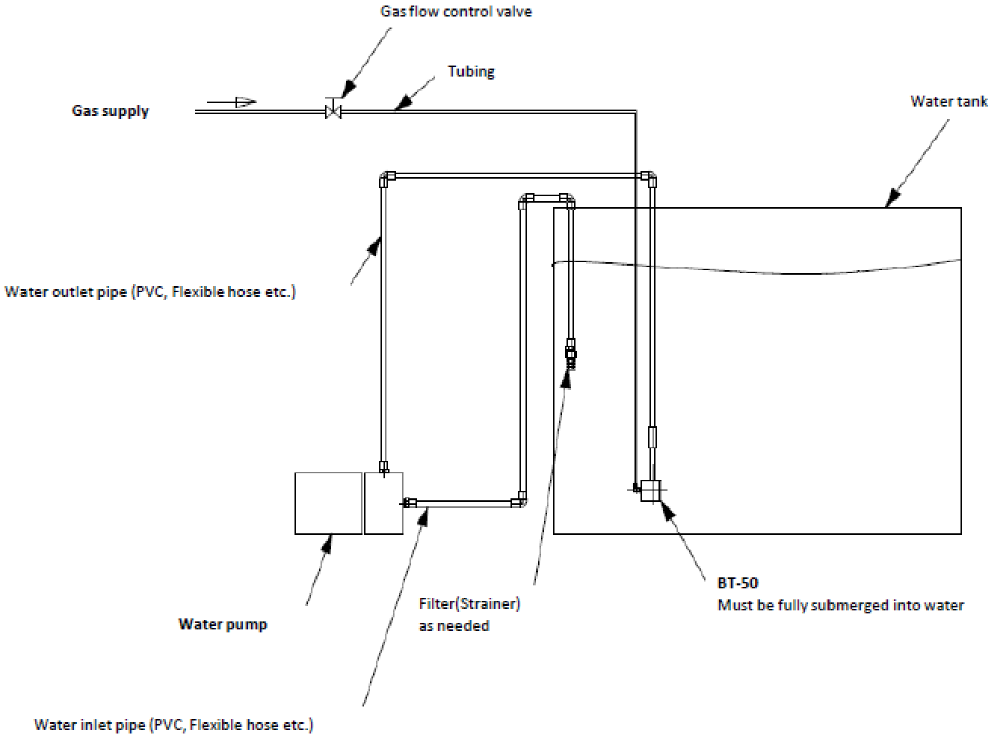

Figure 2: Schematic representation of the microbubble generation equipment

3. RESULTS AND DISCUSSION

The Results reported in the present work involves the one obtained in the rotating disk apparatus (RDA) and the pipe. In the RDA, the polymer was tested alone at different concentration to ascertain the role of concentration in drag reduction as well as their drag reduction ability. It was then taken to the pipe loop for final confirmation of the same. In addition to this, the effects of the various concentrations of these additives as well as their drag reduction with respect to the Reynolds number are also reported. Also in the pipe, individual additives were tested followed by their complex and the results obtained are highlighted in the subsection below.

3.1. Drag Reduction effects in the Rotating Disk Apparatus

Fig. 3 shows the impact of rotational speed on the torque for Xanthan gum concentrations. Their drag reduction ability when tested at various Reynolds numbers are also reported. From the Figure, it could be observed that drag reduction was favorably achieved as the concentrations increase. Such observation is in line with the trends of the results reported in the Figure. It could be observed that there is a divergence of the trends from that of water, which improves as the concentration increases. It could as well been observed that the higher the concentration of materials used, the more their ability to reduce drag. Such observation is similar to the one reported in few other studies on drag reduction [26-28]. These authors reported that, increase in concentration increases the drag reduction capability of drag reduction agents. It could as well be noticed that increase in percentage drag reduction is also achieved as the rotational speed of the RDA increases. It could be opined that such increment was as a result of the increased associated additive molecules as drag reduction takes place. This studies is in line with the result obtained by [26, 27].

Despite the fact that Xanthan gum are regarded as rigid polymers and do not degrade under the influence of shear stress, however, the behavior of this materials at the lower concentrations of Fig. 3 further confirms the impact of concentration in any polymeric additive. Overall, about 51% drag reduction was achieved with the best concentration of about 700ppm. Thus, the major concern here will be the 700ppm.

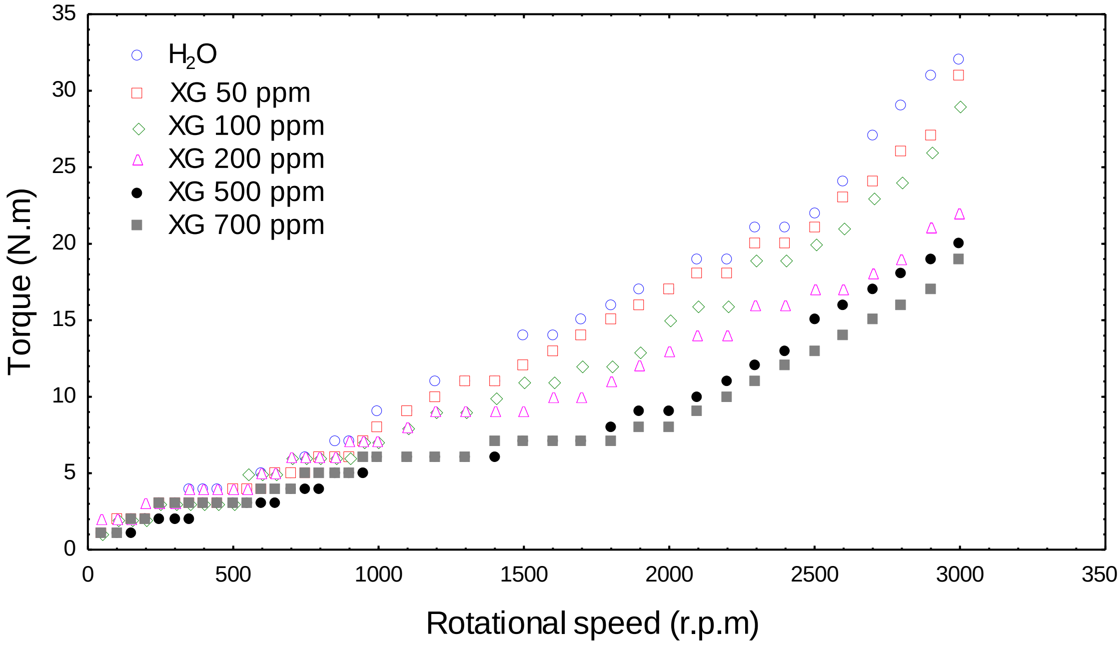

Figure 3: Torque effect at various rotational speed of the Xanthan gum

3.2. *Drag Reduction effects in the Pipe loop*

3.2.1 *Effects of Additive Concentration*

Fig. 4 shows the impact of concentration in the drag reduction ability of Xanthan gum tested with respect to various Reynolds numbers. It could be observed that drag reduction was enhanced as the concentration increased. In addition, it could be observed that the higher the concentration of materials used, the more their ability to reduce drag. This observation was in line with few studies [26, 27] on drag reduction who observed that, increase in concentration increases the drag reduction capability of drag reduction agents. These figures which could be obtained within different conditions ranges depict an increase in percentage drag reduction as the concentration of the additives increases. It could be opined that such increment was as a result of the increased associated additive molecules as drag reduction takes place.

However, it was observed that there was a point whereby the drag reduction of the additives were levelled off which is also the result obtained by [28], at this point, it is possible the additives have reached their maximum efficiency as their viscous layers could no longer expand or attained a state of critical concentration. Another observation is the drag reduction behavior shown by the highest concentration of additives, where they were observed to perform better than every others, it could be said that this observation supports the assertion that drag reduction is enhanced and best influenced by the concentration of the polymer master. Such observation was also reported by [29].

3.2.2 *Microbubble alone*

Fig. 5 depicts the result obtained for microbubbles at the various length of the pipe section. It could be observed that the trends followed a sequential order within the pie and across the sections. Such is an indication of the bubble burst which was prevented throughout the experiment. However, when the time taken for these bubbles to stay in the pipe was longer than, coalescence of the bubbles were observed and they were found breaking, which later led to bigger bubbles. Further general assessment on the Fig. 5 shows increase in the drag reduction at all sections as the Reynolds increased. Thus, it could be deduced that microbubbles generated are capable of reducing drag even without any form of additives. A typical suggestion in this regards is that the bubbles levelled up the pore and the walls of the pipe.

3.2.3 *Effect of Fluid Velocity (Reynolds Number*

One of the most important factor that determine and controls drag reduction efficacy is the fluid velocity, this determine and controls the degree of turbulence especially at the point of formation of eddies (typical turbulence structures), the fluid velocity will alter the contact between additive and their interactions with each other or with the turbulent structures produced within the pipe. Graphical representation of the effect of fluid velocity obtained from the experimental work are presented to show the influence of fluid velocity herein referred to as a dimensionless form of Reynolds Number against the percentage drag reduction (% Dr).

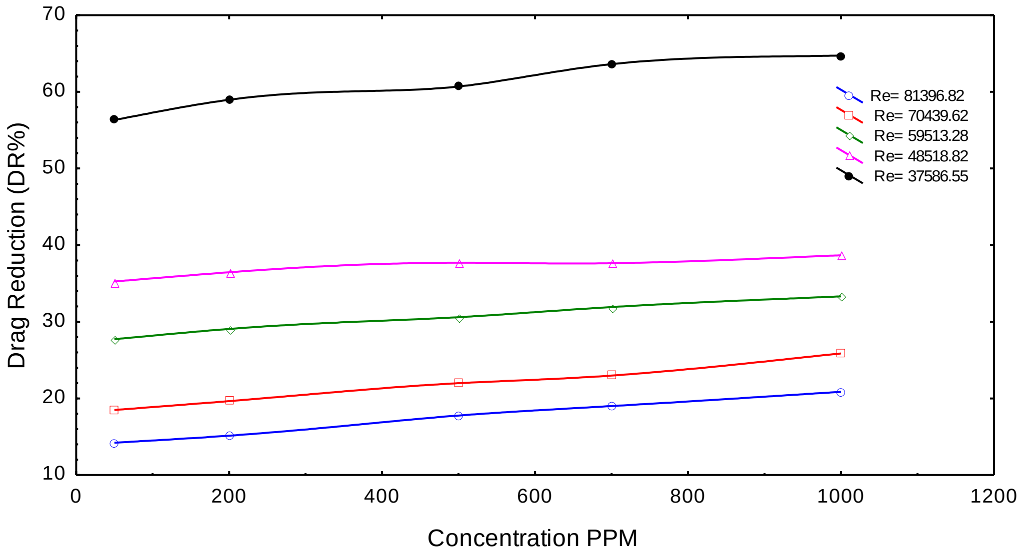

Figure 4: Effect of Xanthan gum concentration on the drag reduction percent different Reynolds number taken at length section two

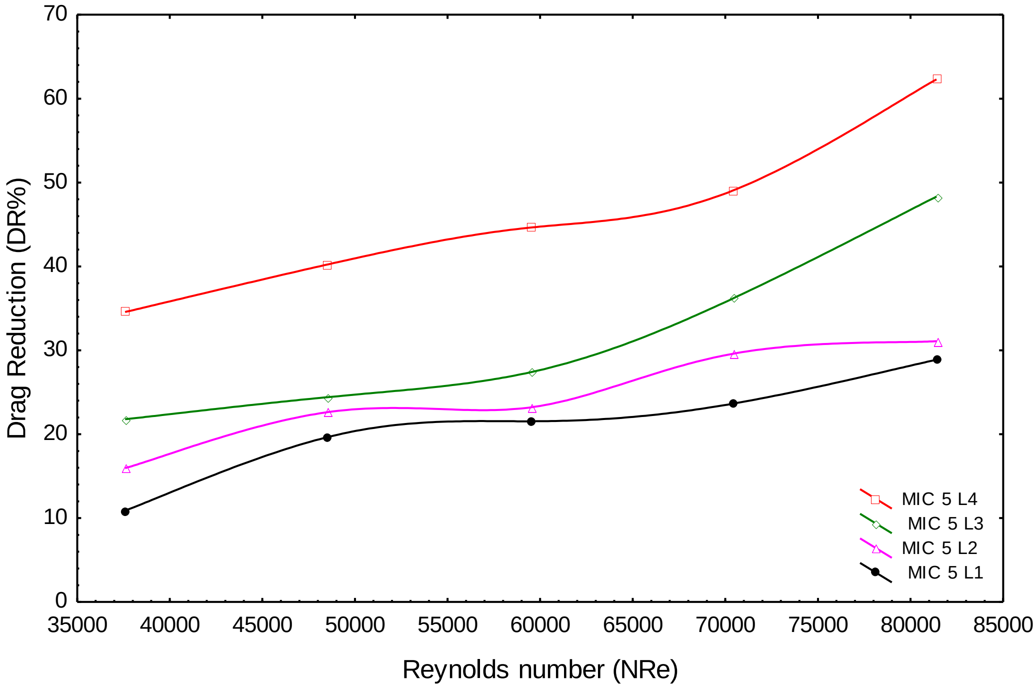

Figure 5: Drag reduction percent against Reynolds number for the generated microbubbles at different lengths

Figures 6-8 show the effects of the drag reduction percent against Reynolds number observed for different concentrations of Xanthan gum, Complex of Xanthan gum and microbubble and different complexes. Generally, there is observed increase in the drag reduction behavior of all the materials. However, there are various behavior in their trends. The drag reduction was best observed with the complex of the Xanthan and microbubbles. It was observed that the complex achieved 62% DR, while it was only 56% for Xanthan gum in the pipe. There are inherent fluctuations of the trends which suggests the rate of turbulence they are flowing in.

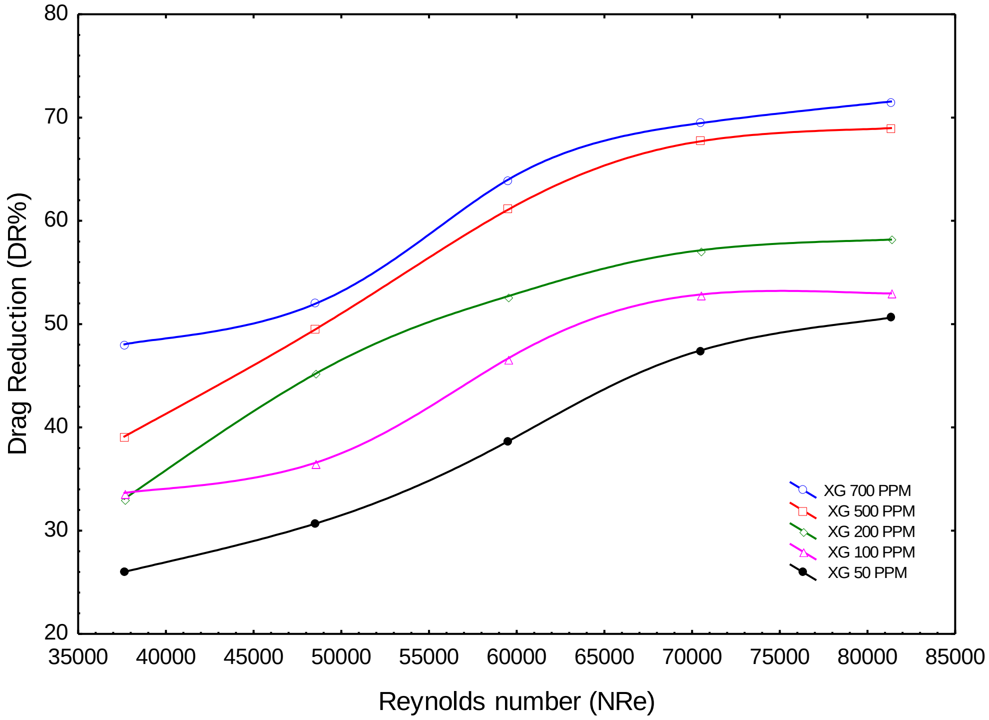

Figure 6: Drag reduction percent against Reynolds number for different concentrations of Xanthan gum

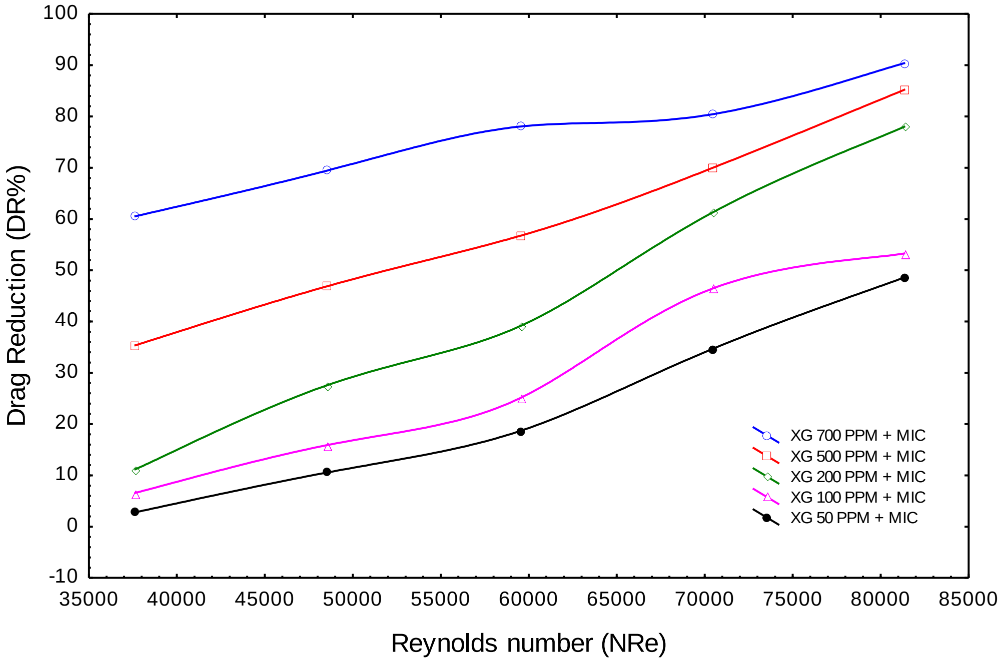

Figure 7: Drag reduction percent against Reynolds number for the complex mixtures of Xanthan gum and microbubbles

From Figures 6-8, it could be seen that there is increase in the %Dr as the NRe increased. This could be as a result of the increase in the degree of turbulence which in turns suppressed eddies formation, in this type of behavior, there are favorable flow media for the additives to be effectively interact together within the turbulent structures in the pipe. The second section represent the point where the DRAs are at their best performance, in which case, optimum Re is noticed with an equilibrium state between additive interference at maximum point as well as the turbulence, the %Dr is observed after which it begins to go down. At this equilibrium state and highest peak of the Re, any alteration in the flow behavior of further increase in Re will lead to a decrease in the %Dr as a result of the high state of degree of turbulence which were able to act above the additive effects.

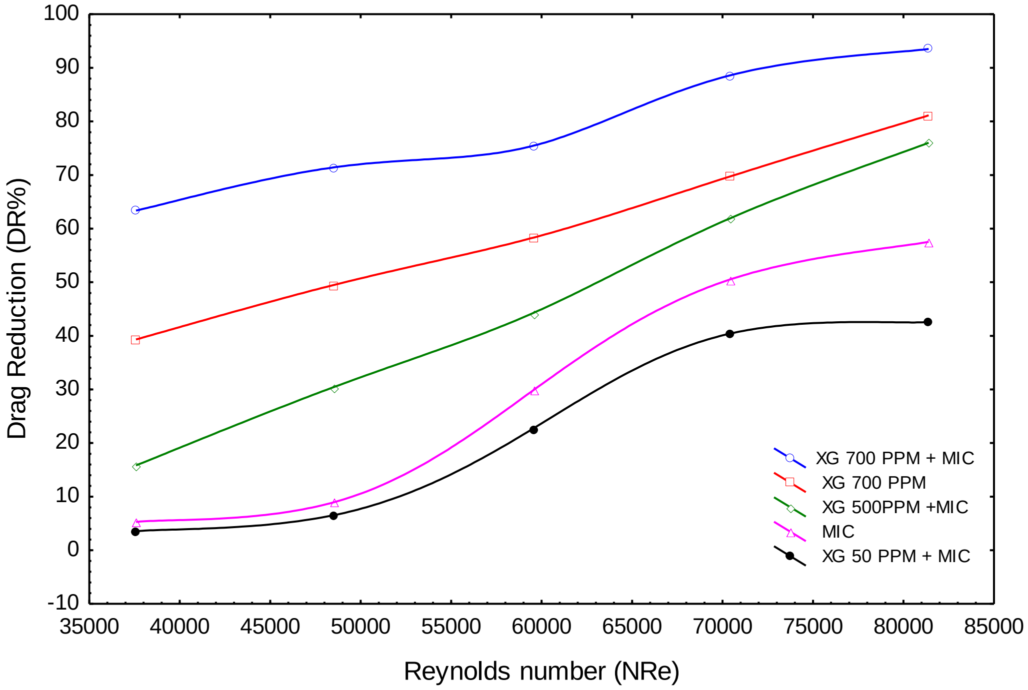

Figure 8: Drag reduction percent against Reynolds number for various complex mixtures

Fig. 6 illustrates the effects of the drag reduction percent observed for different concentrations of Xanthan gum against Reynolds number at section two. Although the drag reduction percentage at all the concentrations increase with increasing Reynolds number. But there is no regular pattern of their trends. At concentration 700ppm, it behaves like the pattern observed for 500ppm. However, there was a steady increase in 200ppm and 100ppm respectively which later met at the final point of drag reduction. It is worthy to note that 50ppm has a linear trend. This behavior could be as a result of the reports by various scholars that Reynolds number does not play any crucial role in the drag reduction behavior of Xanthan gum.

4. CONCLUSION

It could be concluded that the complex mixture of rigid polymers and microbubble could be another solution to the problem of drag reduction in pipeline compared to their individual enhancement. A major contributory factor to such is the concentration of the additives tested. There is also a synergy which occurs between the two which enhanced their drag reduction capability.

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REFERENCES

[1] Toms BA, Some observations on the flow of linear polymer solutions through straight tubes at large Reynolds numbers. in Proceedings of the 1st International Congress on Rheology 1949; 2:135–141 North Holland, 1948.
[2] M. Dass, C. Kang, W.P. Jepson. Society of Petroleum Engineers (SPE) Annual Technical Conference and Exhibition 62944, Dallas, Texas, 2000.
[3] F.C. Li, B. Yu, J.J. Wei, Y. Kawaguchi, K. Hishida. Experimental study of drag reduction mechanics for a dilute surfactant solution flow. Int. J. Heat and Mass Transf. 2008; 51 (3-4): 835-843.
[4] A. Gyr, J. Buhler. Secondary flows in turbulent surfactant solutions at maximum drag reduction. J. Non-Newtonian Fluid Mech. 2010; 165 (11-12): 672-675.

[5] E.O Akindoyo et. al. Drag Reduction Efficacy of CTABr and Nanosilica Particles Using Rotating Disk Apparatus (RDA). Australian Journal of Basic and Applied Sciences 9 (8), 136-144.

[6] A.S. Pereira, R.M. Andrade, E.J. Soares. Drag reduction induced by flexible and rigid molecules in a turbulent flow into a rotating cylindrical double gap device: comparison between poly (ethylene oxide), polyacrylamide, and xanthan gum. J. Non-Newtonian Fluid Mech. 2013; (202):72-87.

[7] Nguyen Anh Tuan, Hiroshi Mizunuma. High-shear drag reduction of surfactant solutions. Journal of Non-Newtonian Fluid Mechanics 198 (2013) 71–77

[8] D.P.M. Van Gils, D.N. Guzman, C. Sun, D. Lohse. The importance of bubble deformability for strong drag reduction in bubbly turbulent Taylor-Couette flow. J Fluid Mech 2013; (722): 317-347

[9] Forrest F and Grierson GA. Friction losses in cast iron pipe carrying paper stock. Paper Trade Journal 1931; 92 (22): 39–41.

[10] A. Japper-Jaafar, M.P. Escudier, R.J. Poole. Turbulent pipe flow of a drag-reducing rigid ’’rod-like’’ polymer solution. J. Non-Newtonian Fluid Mech. 2009; 161(1): 86-93.

[11] A.R. Pouranfard, D. Mowla, F. Esmaeilzadeh. An experimental study of drag reduction by nanofluids through horizontal pipe turbulent flow of a Newtonian liquid. Journal of Industrial and Engineering Chemistry 20 (2014) 633–637

[12] M. Al-Yaari, A. Al-Sarkhi , I. A. Hussein and B. Abu Sharkh. Effect of drag reducing polymers on surfactant-stabilized water–oil emulsions flow. Experimental Thermal and Fluid Science 51 (2013) 319–331

[13] Edward O. Akindoyo, Hayder A. Abdulbari. Investigating the Drag Reduction Performance of Rigid Polymer – Carbon Nanotubes Complexes using Rotating Disk Apparatus. Journal of Applied Fluid Mechanics, Vol 9 No. 3, 2016

[14] C.A. Kim, K. Lee, H.J. Choi, C.B. Kim, K.Y. Kim, M.S. Jhon, The turbulent drag reduction by graft copolymers of guar gum and polyacrylamide, Journal of Applied Polymer Science 31 (1985) 4013–4018.

[15] S.R. Deshmukh, R.P. Singh, Drag reduction characteristics of graft copolymers of xanthan gum and polyacrylamide, Journal of Applied Polymer Science 32 (1986) 6163–6176.

[16] H.W. Bewersdorff, R.P. Singh, Rheological and drag reduction characteristics of xanthan gum solutions, Rheologica Acta 27 (1988) 617–627.

[17] I.T. Norton, D.M. Goodall, S.A. Frangou, E.R. Morris, D.A. Ress, Mechanism and dynamics of conformational ordering in xanthan polysaccharide, Journal of Molecular Biology 175 (1984) 371–394.

[18] E.R. Morris, Molecular origin of xanthan solution properties, Extracellular Microbial Polysaccharides, ACS Symposium Series 45 (1977) 81–89.

[19] N.M. Nouri, S. Yekani Motlagh, M. Navidbakhsh, M. Dalilhaghi, A.A. Moltani, Experimental Thermal and Fluid Science 44 (2013) 592–598.

[20] Ortiz-Villafuerte ,J., Hassan, Y., 2006. Investigation of microbubble boundary layer using particle tracking velocimetry. ASMEJ. Fluid Eng .128, 507–519.,

[21] Skudarnov, P.V., Lin, C.X., 2006. Drag reduction by gas injection into turbulent boundary layer: density ratio effect. Int. J. Heat Fluid Flow 27, 436–444.

[22] Hassan, Y.A., Gutierrez-Torres, C.C., Bernal, J.A.J., 2005. Temporal correlation modification by microbubbles injection in achannel flow. Int. Commun. Heat Mass Transf. 32, 1009–1015.

[23] P.J. Flory. Principles of Polymer Chemistry, Cornell University Press, Ithaca, NY, 1971

[24] R. Lapasin, S. Pricl. Rheology of Industrial Polysaccharides: Theory and Applications, Blackie Academic and Professional, 1995.

[25] Edward Oluwasoga Akindoyo, Hayder A. Abdulbari. Drag reduction Efficiency of Micro bubble aided Rigid and Flexible Polymer solutions in turbulent flow. International Conference on Fluids and Chemical Engineering (FLUIDSCHE 2015) 25th-27th November, 2015, Adya Hotel, Langkawi, Malaysia.

[26] Hayder A. A. Reducing drag of flowing kerosene and gas oil using traces of anionic surfactants. PhD thesis, Chem. Eng. Dept., University of Baghdad; 2004.

[27] Al-Sarkhi, A., and Hanratty, T. J. 2001. Effect of drag-reducing polymers on annular gas–liquid flow in a horizontal pipe. International journal of multiphase flow. 27 (7): 1151-1162

[28] Mowla, D., and 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 science. 61 (5): 1549-1554.

[29] Al-Sarkhi, A., and Hanratty, T. J. 2001. Effect of pipe diameter on the performance of drag-reducing polymers in annular gas-liquid flows. Chemical Engineering Research and Design. 79 (4): 402-408.