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Reduction of Drag in Non-Newtonian Flow Through Packed Bed

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Abstract: An experimental investigation of strength of drag reduction in a bed packed was carried out in this study. The study of drag reduction performed at particle Reynolds numbers in the range 10-250 and was found to depend on the concentration of drag reducing agent and the fluid velocity. The drag reduction effectiveness increased with fluid velocity. For the systems investigated, there exists an optimum concentration of drag reducing agent that produces a maximum drag reduction. The present study may be useful for further understanding and modeling of porous multiphase reactor with non-Newtonian system in industrial applications.

Key words: Packed bed, pressure drop, drag reduction, non-Newtonian liquid, DRA, Reynolds numbers

INTRODUCTION

The non-Newtonian fluid flow through particulate bed system is important in a variety of chemical and processing applications. Various examples of applications of the particulate system have been described by many researchers (Reay and Baker, 1985; Davidson *et al.*, 1985; Fan, 1989). Over the years, considerable research efforts have been expended in exploring and furthering understanding of the basic phenomena of momentum, heat and mass transfer processes with and without chemical reactions in the systems in packed bed. Recently, drag reduction of flow through packed beds and porous media has received considerable attention because of its important industrial applications for specific reactive process. Zhu and Satish (1992) studied of the flow drag decreases with a decrease in the flow behavior index and with an increase in the characteristic time. They studied of the degree of this reduction is found to be more significant at low voidages. It is found that both the second normal stress difference and the bed voidage have a great influence on the resistance of viscoelastic flow through a packed bed. Vossoughi (1999) studied the pressure drop of a porous media flow is only due to a small extent to the shear force term usually to derive the Kozeny-Darcy law and also studied the addition of small amounts of high molecular weight polymers to a solvent with Newtonian flow properties causes drastic pressure drop change if the flow rate exceeds an onset flow rate corresponding to a critical Deborah number of the porous matrix-polymer solution system. Drag Reduction (DR) has numerous applications in a variety of fields. In the chemical, oil and process industries, non-Newtonian liquids are encountered frequently through different process equipments. The drag is one of the most important factors in hydraulic transport of fluid flow depending on the physical properties and input fluxes of the phases and the size of equipments. The reduction of the drag is of practical importance from an economic viewpoint since, it may reduce the process energy of the fluid in equipments. Other applications of the drag reduction phenomenon are as: oil pipelines, oil well operations, flood water disposal, field irrigation, transport of suspensions and slurries, water heating and cooling systems (Mowla and Naderi, 2006). The reason of research in the area of drag reduction is in response to a challenge. Packed beds are widely used in industry at relatively low pressure drops. For process design purposes, it is essential that pressure drop is estimated for its proper operation. Physical design characteristics of columns-particularly packing type, size and column dimensions can greatly impact neighboring process units and the load induced upon compressors and pumps. The main advantage of using a packed column rather than just a tank or other reaction vessel is that the packing affords a larger surface area per unit volume for mass transfer. They are readily used in industry for catalytic reactions, combustion, gas absorption, distillation, drying and separation processes. Single phase drag reduction due to polymer based additives has been thoroughly studied and the mechanisms are beginning to be understood to be related to dampening of turbulent bursts and reduction of Reynolds stresses. In addition to mechanisms available to

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single-phase flow (e.g., dampening turbulent bursts, wall roughness reduction and pipe wall wettability reduction) has numerous additional unique mechanisms available to reduce drag. Brostow (2008) compiled extensive reviews on drag reduction in flow and its applications, mechanisms and prediction. In recent years, considerable research attention have made from chemical engineers on the investigation of the drag reduction phenomenon observed in the turbulent pipe flow of dilute solutions of various additives. A few studies on drag reduction have been done in aqueous and non-aqueous solvents and the laminar flow of non-Newtonian fluids through packed beds and porous media (Hanna *et al*., 1977; Mowla and Naderi, 2006; Helland *et al*., 2007). So from the literature, it is found that very few studies on drag reduction phenomena in packed bed. The objective of the present study is to study the strength of drag reduction by surfactants in packed bed.

THEORETICAL BACKGROUND

Drag reduction is a flow phenomenon by which small amounts of additives, e.g., a few weight parts per million can greatly reduce the friction factor of a fluid or fluids. The aim for the drag reduction is to improve the fluid-mechanical efficiency using active agents known as polymers. In a single-phase flow, drag reduction is defined as the reduction of friction below that which would occur for the same flow without the drag reducing additive. The strength of the drag reduction is often described by the percentage drag reduction effect, the DR-effect. In fluid flow, the DR-effect can be obtained by measuring pressure drops with and without drag reducing agent using the following expression (Manfield *et al*., 1999):

$$DR-\% = \frac{\Delta P_{\text{without DRA}} - \Delta P_{\text{with DRA}}}{\Delta P_{\text{without DRA}}} \times 100$$

The readings of pressure drop through column with and without using drag reducing agent where obtained by experimentation. The percentage drag reduction is then calculated by the Eq. 1.

EXPERIMENTAL

The schematic of the experimental setup is shown in Fig. 1. A column of inner diameter 0.050 m and of length 0.49 m, packed randomly with uniform sized packing of ceramic rashing rings of 10 mm diameter and 10 mm height is used. The packed bed is connected to a storage tank. The pipe is connected to the packed bed through a nozzle just above the packing support. The nozzle is connected to a distributor inside the packed bed. The bottom of the packed bed is connected to a pipe to drain liquid from the packed bed after the experiment is over. There is a bypassing arrangement after the pump which returns the liquid back to storage tank. The column is kept approximately full-filled with packing for all trials. The inlet fluid is a CMC solution. CMC solutions of known concentration were prepared using cold distilled water by gradually adding the CMC powder to the water with gentle stirring until the solution becomes homogeneous. These solutions were then diluted as required in a mixing tank to provide the test solutions of desired concentration. The CMC solution is fed into the packed bed by using the centrifugal pump. The volumetric flow rate is measured by rotameter.

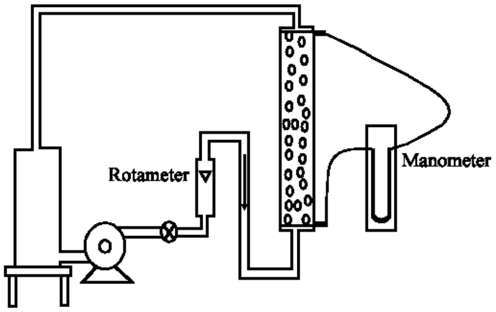

Fig. 1: Schematic diagram of the experimental setup

The CMC solution moved up through the packed bed and the overflowed solution returned to the storage vessel through a pipe. The U-tube manometer connected to the packed bed is used to measure the pressure drop across the bed at different flow rates and CMC concentrations. Because of the time needed to prepare the concentrated CMC solution, first the testing were started at low flow rates of CMC to obtain as many trial runs as possible. Several trial runs were conducted varying the water flow rate from 40-150 mL sec^{-1}. After the column reached a steady state, the steady state pressure drops data for both (before and after the addition of CMC) were recorded.

Triton 100 was used as a drag reducing agent in this study. The pressure drop at different concentration of carboxymethyl cellulose is measured with the different concentrations (ppm) of surfactants. The pressure tap connections to each column were situated in the packing sections at locations 5.0 cm from the top and from the bottom of the bed to yield a direct pressure drop measurement without the necessity of correction for end effects. Pressure differences were measured with differential carbon tetrachloride (sp. gr. = 1.65) or mercury in glass manometers depending on the pressure drop range. The readings were repeated four times to ensure the reproducibility.

RESULTS AND DISCUSSION

The voluminous literature available on the flow of a variety of non-Newtonian materials through packed beds has been critically reviewed previously by Kumar *et al.* (1981) and Wua and Pruessa (1996). From the studies, it is concluded that each studies has its some uniqueness in its morphology which is contributing in some measure to the complexity of the problem of assigning geometric description and of making cross-comparisons between different studies. Similarly often inadequate rheological characterization also adds to the complexity of such systems. From the experiment, it is seen that the pressure drop increases with the increase in liquid flow rate as shown in Fig. 2. This is due to the fact that the interfacial shear stress increases with increase in liquid velocity. Also, the viscous friction at the wall increases with the increase in liquid velocity which increases the pressure drop. Further, the pressure drop increases with the increase in CMC concentration for a given flow rate. The increase of CMC concentration leads to the increase in effective viscosity which leads to increase the shear stress and increase of pressure drop in the packed bed. There are different possible ways are available for drag reduction such as by addition of Drag Reducing Agent (DRA) by reduction of interfacial roughness by change in flow pattern and using a surfactant. Virk (1975) analyzed the drag reduction performance of numerous polymer solutions reported in the literature. He found that all tended towards a maximum drag reduction. Figure 3-6 show the observed drag reduction in the present study. The pressure drop, decreases with increase in reducing agent. Surfactant drag reducing agent has much smaller molecular chains than those of the polymers used in drag reducing agent. With surfactants, the mechanism of single phase drag reduction is related to the formation

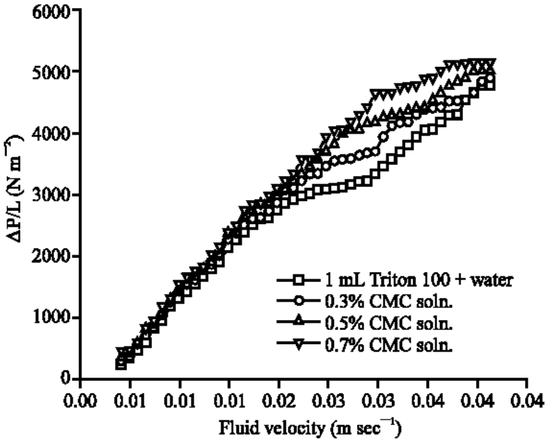

Fig. 2: Variation of pressure drop at different CMC solution with Triton 100

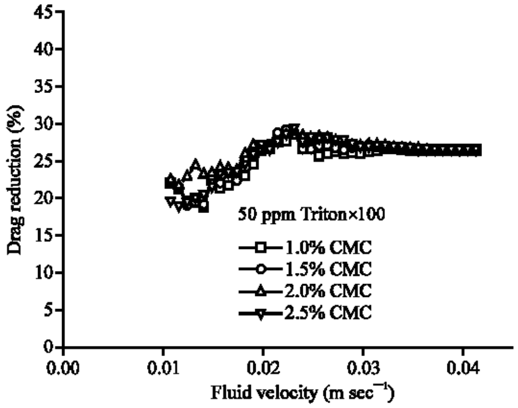

Fig. 3: Drag reduction at different CMC solution with 50 ppm Triton 100

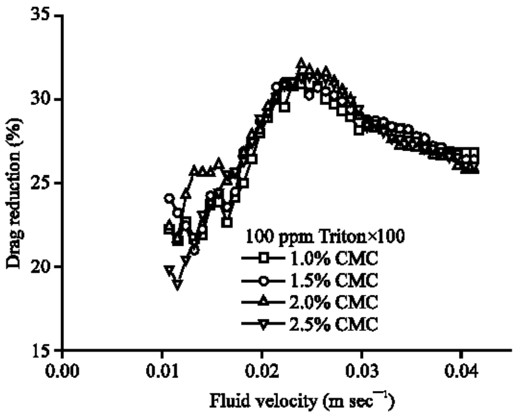

Fig. 4: Drag reduction at different CMC solution with 100 ppm Triton 100

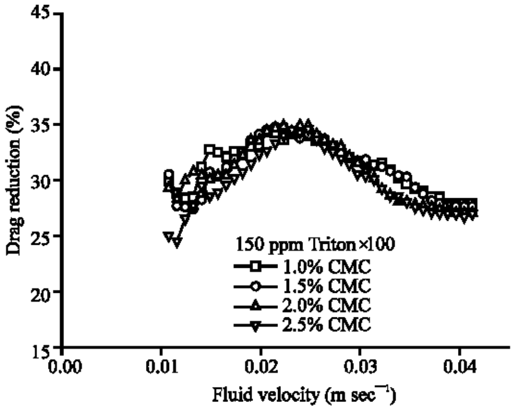

Fig. 5: Drag reduction at different CMC solution with 150 ppm Triton 100

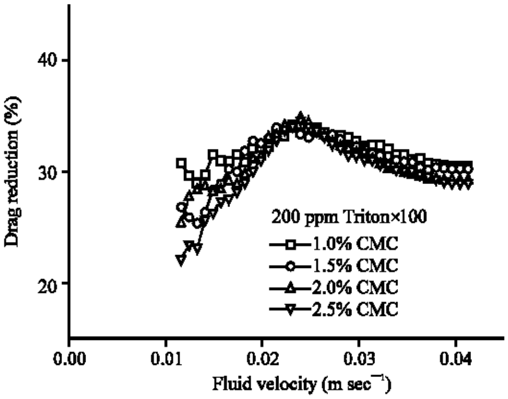

Fig. 6: Drag reduction at different CMC solution with 200 ppm Triton 100

of micelles. When surfactants are added to a liquid, they go to the liquid surface and act to reduce the surface tension. Above the Critical Micelle Concentration (CMC), additional surfactant molecules no longer migrate to the surface and they begin to form micelle structures within the liquid. In single-phase flow, surfactant drag reduction occurs if the micelle structures formed are rod-like (Ohlendorf *et al*., 1986). These rod-like micelles then mimic the performance of long chain polymers in dampening turbulent bursts near the pipe wall.

The benefit of these self-assembling structures is that they break apart when subjected to conditions of high shear (Wilkens and Thomas, 2007; Kuntz and Walker, 2007). The drag reduction mechanism that occurs within the liquid phase is one that acts to disrupt turbulent structures. When the pressure reducing agent is used, it is generally a long chained polymer that is added to the liquid phase, generally with a co-solvent. The pressure reducing agent is reduces pressure within the liquid phase.

The DRA mechanisms are involving the interference of the polymer with the turbulent structures in the fluid near the wall. Proper micelle formation is necessary for the equivalent surfactant pressure reduction to occur. Turbulent fluctuations normal to the pipe wall, significantly reduced in the presence of a pressure reducing agent.

Certain Drag Reducing Agents (DRA) reduce frictional pressure drop in process equipments. The phenomenon of friction reduction or drag reduction by DRA in flow offers potential for energy saving and cost reduction in process equipments. These benefits can be interpreted as process intensification. The reduction of drag is also based on the interaction of flow characteristics and DRA molecule so that the time scales of flow characteristics is in relation to the relaxation time of the DRA.

In other words, the Kolmogorov time scale should be less than the relaxation time of DRA (Cunha and Andreotti, 2007). In this research, the efficiency of the DR-effect was studied in different flow conditions. The effect of DRA concentration on the drag reduction effectiveness is shown in Fig. 3- 6 which show plots of percentage drag reduction as a function of the bulk DRA concentration. As the concentration increases, the magnitude of the drag reduction first increases sharply and then reduces with a further increase in DRA concentration. At low surfactant concentration, it is seen that the reduction initially increases but after certain velocity, it remains constant as shown in Fig. 3. But at higher concentration of surfactant of Triton 100, it is seen that the reduction abruptly falls after a certain liquid velocity as shown in Fig. 4-6. This may be due to degradation of DRA at higher liquid velocity. Shear forces in the flow break, the DRA chain into smaller chains. Even though, the polymer chains are broken, they still have the ability to reduce drag.

The degradation experiments were not performed in this study. The mechanical degradation in turbulent flow is known to be affected by various properties like DRA molecular weight, temperature, DRA-solvent interactions, DRA concentration, turbulent intensity and flow geometry. Most studies on degradation equilibrium and kinetics were performed in non-uniform, ill defined shear fields such as high-speed mixers, turbulent pipe flow or laminar capillary flows with entrance effects which enhance degradation. Furthermore, Horn and Merrill (1984) reported that midpoint scission of macromolecules occurs in turbulent flow which strongly suggests that the polymer chains can indeed be fully extended by turbulent flow as well as by laminar extensional flow. This hypothesis concurs with some proposed drag reduction theories which propose that drag reduction is caused by the suppression of the extensional portion of the turbulent flow by increasing the extensional viscosity and causing a shear viscosity change. Several theories have indicated that extreme extension of polymer chains causes the polymer molecules to degrade (Odell *et al*., 1990). Recently, Kim *et al*. (2000) reported that the extent of the degradation depended on the solubility parameter of the solvents. Single phase drag reduction due to polymer based additives has been thoroughly studied and the mechanisms are beginning to be understood to be related to dampening of turbulent bursts and reduction of Reynolds stresses. With surfactants, the mechanism of single phase drag reduction is related to the formation of micelles. When surfactants are added to a liquid, they go to the liquid surface and act to reduce the surface tension. Above the Critical Micelle Concentration (CMC), additional surfactant molecules no longer migrate to the surface and they begin to form micelle structures within the liquid.

CONCLUSION

In this present study, the interfacial drag characteristic has been investigated in packed bed with non-Newtonian liquid. The pressure drop increases with the increase in liquid flow rate. This is due to the fact that the interfacial shear stress increases with increase in liquid velocity. Also, the viscous friction at the wall increases with the increase in liquid velocity which increases the pressure drop. Further, the pressure drop increases with the increase in CMC concentration for a given flow rate. The increase of CMC concentration leads to the increase in effective viscosity which leads to increase the shear stress and increase of pressure drop in the packed bed. The drag reduction phenomenon is also exhibited in non-Newtonian fluid system. The drag reduction effectiveness increased with fluid velocity. There exists an optimum DRA concentration that produces a maximum drag reduction. The present study may be useful for further understanding and modeling of specific multiphase reactor in industrial applications.

NOMENCLATURE

DR = Drag reduction [-]
ΔP = Pressure drop [N m^{-2}]
$\Delta P_{\text{without DRA}}$ = Pressure without DRA [N m^{-2}]
$\Delta P_{\text{with DRA}}$ = Pressure with DRA [N m^{-2}]

REFERENCES

Brostow, W., 2008. Drag reduction in flow: Review of applications, mechanism and prediction. J. Ind. Eng. Chem., 14: 409-416.

Cunha, F.R. and M. Andreotti, 2007. A study of the effect of polymer solution in promoting friction reduction in turbulent channel flow. J. Fluids Eng., 129: 491-505.

Davidson, J.F., R. Clift and D. Harrison, 1985. Fluidisation. 2nd Edn., Academic Press, New York.

Fan, L.S., 1989. Gas-Liquid-Solid Fluidization Engineering. Butterworth-Heinemann Publishers, UK., ISBN-13: 978-0409951790, pp: 784.

Hanna, M.R., W. Kozicki and C. Tiu, 1977. Flow of drag-reducing fluids through packed beds. Chem. Eng. J., 13: 93-99.

Helland, E., H. Bournot, R. Occelli and L. Tadrist, 2007. Drag reduction and cluster formation in a circulating fluidised bed. Chem. Eng. Sci., 62: 148-158.

Horn, A.F. and E.W. Merrill, 1984. Midpoint scission of macromolecules in dilute solution in turbulent flow. Nature, 312: 140-141.

Kim, C.A., J.T. Kim, K. Lee, H.J. Choi and M.S. Jhon, 2000. Mechanical degradation of dilute polymer solutions under turbulent flow. Polymer, 41: 7611-7615.

Kumar, S., J. Kishore, P. Lal and S.N. Upadhyay, 1981. Non-newtonian flow through packed beds and porous media. J. Sci. Ind. Res., 40: 238-245.

Kuntz, D.M. and L.M. Walker, 2007. Solution behavior of rod-like polyelectrolyte-surfactant aggregates polymerized from wormlike micelles. J. Phys. Chem. B, 111: 6417-6424.

Manfield, C.J., C. Lawrence and G. Hewitt, 1999. Drag-reduction with additive in multiphase flow: A literature survey. Multiphase Sci. Technol., 11: 197-221.

Mowla, D. and A. Naderi, 2006. Experimental study of drag reduction by a polymeric additive in slug two-phase flow of crude oil and air in horizontal pipes. Chem. Eng. Sci., 61: 1549-1554.

Odell, J.A., A.J. Muller, K.A. Narh and A. Keller, 1990. Degradation of polymer solutions in extensional flows. Macromolecules, 23: 3092-3103.

Ohlendorf, D., W. Interthal and H. Hoffmann, 1986. Surfactant systems for drag reduction: Physico-chemical properties and rheological behaviour. Rheol. Acta, 25: 468-486.

Reay, D. and C.G.J. Baker, 1985. Drying. In: Fluidization, Davidson, J.F., R. Clift and D. Harrison (Eds.). 2nd Edn., Academic Press, London, pp: 529-562.

Virk, P.S., 1975. Drag reduction fundamentals. AICHE. J., 21: 625-656.

Vossoughi, S., 1999. Flow of non-newtonian fluids in porous media. Rheol. Ser., 8: 1183-1235.

Wilkens, R.J. and D.K. Thomas, 2007. Multiphase drag reduction: Effect of eliminating slugs. Int. J. Multiphase Flow, 33: 134-146.

Wua, Y.S. and K. Pruessa, 1996. Chapter 2 Flow of non-newtonian fluids in porous media. Adv. Porous Media, 3: 87-184.

Zhu, J. and M.G. Satish, 1992. Non-newtonian effects on the drag of creeping flow through packed beds. Int. J. Multiphase Flow, 18: 765-777.