International Journal of the Physical Sciences Vol. 6(15), pp. 3672-3679, 4 August, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.647
ISSN 1992 – 1950 ©2011 Academic Journals

Full Length Research Paper

Investigating the effect of solid particle addition on the turbulent multiphase flow in pipelines

Hayder, A. A. B.*, A. H. Nour, Kim Kor and Ahmed N. Abdalla

Faculty of Chemical and Natural Resources Engineering, University Malaysia Pahang, 25300 Kuantan, Malasyia.

Accepted 21 July, 2011

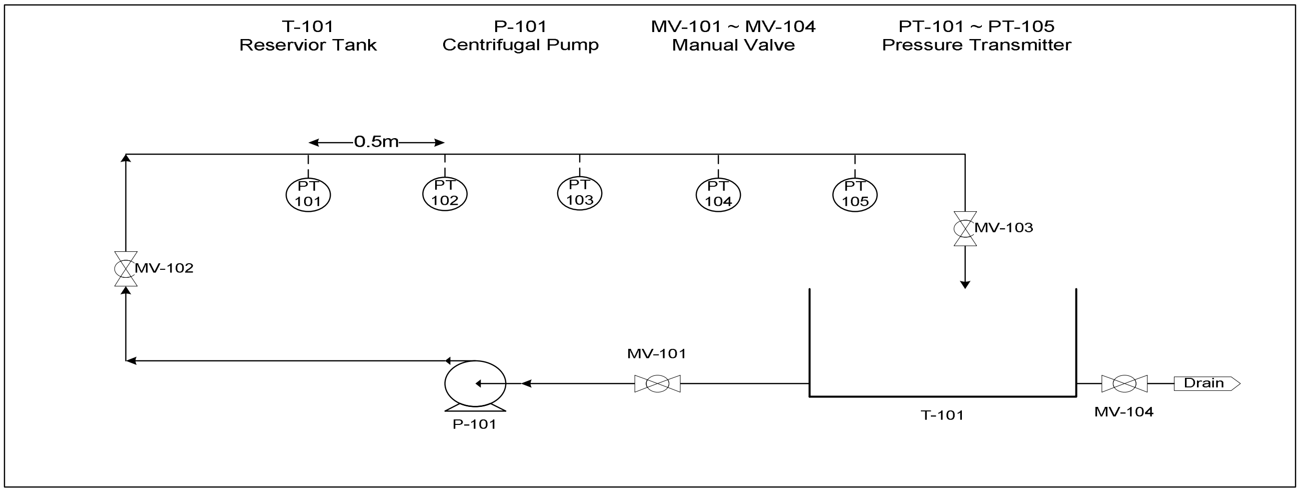
In this study, iron solid particle's role as a drag reducing agent was investigated. The experimental procedure was divided into two parts; to study the effect of iron particle addition on the turbulent multiphase flow, where iron concentration and particle size served as testing variables. Testing the drag reduction ability of the iron particles was done in a closed loop water circulation system. The other part was to investigate the influence of magnetic field on the turbulent flow behavior in pipelines. The results showed that the drag reduction is more superior at smaller particle sizes and higher particle concentration. The maximum drag reduction recorded was 46% during the addition 500 ppm of 45 µm iron particle at Reynolds number (Re) equal to 62586. It also showed that the presence of turbulence can be reduced under the influence of magnetic field; stronger magnetic field enhanced the effectiveness of drag reduction. However, the effect of magnetic field on the flow decreases as Re increases.

Key words: Drag reduction, suspended solids, magnetic field, pressure drop, turbulent flow.

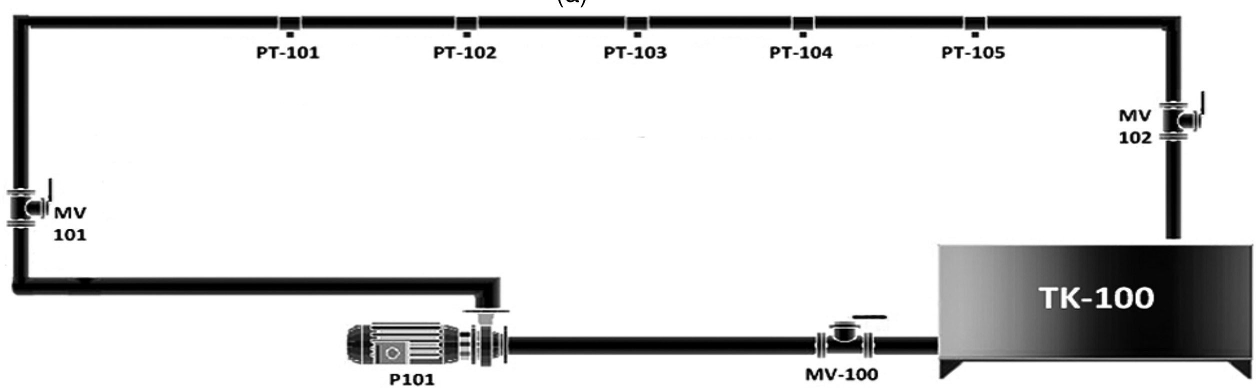
INTRODUCTION

In general, cost saving is one of the most essential concerns in the industry. One of the key to the present concern is by cutting down on the energy consumption. However in fluid transmissions, there are endlessly losses of energy in pipelines and other similar transportation channels due to drag. This drag is mainly caused by turbulence of the flow as well as friction against the pipe walls. Ever since Toms (1948) first discovered the idea of drag reduction (DR) when he studied the effect of polymer added into a turbulent Newtonian fluid, his findings was used as a core to develop effective drag reduction agents (DRA) (Li et al., 2006; Cho et al., 2007; Abdul Bari et al., 2008; Brostow, 2008).These studies have successfully proven the DRA's ability through the cutback of pressure drop in fluid transmissions. Suspended particles have been demonstrated as successful DRA in various studies. For instance, higher concentration of nanoparticle suspension in laminar pipe flows has been found to lead to a blunter velocity distribution (Ding and Wen, 2005). This proves that one of the variables that manipulate the degree of DR is the concentration of the suspended particles added. This also further clarified by Abdul Bari and Mohd Yunus (2009), who verified that DR will be enhanced with the increase of suspended solid particles concentration and size, as well as the addition of sodium lauryl ether sulphate (SLES) surfactant to the suspension transported. Polymeric drag reducing agent has been confirmed as a good DRA because significant pressure drop reduction was noticed after the addition of drag reducing polymer (PDRA). However, this pressure gradient reduction is dependent on the water fraction, mixture velocity, concentration and molecular weight of the PDRA (Al-Yaari et al., 2009). Benzi (2009) also added up that the amount of drag reduction as a function of polymer concentration can be qualitatively and quantitatively due to the fact that polymer can be stretched up to a maximum length.Nevertheless,eventually for infinite concentration, the drag reduction will reach a maximum. Beside DRA, there are also other DR techniques that have been developed which are equally effective. Gas injection is proven to be a useful drag reducing technique as the injection of air reduces pressure drop significantly in the piping multiphase flow. The amount of drag reduction

*Corresponding author. E-mail: ahmedras_76@yahoo.com.



(a)



(b)

Figure 1. Fluid friction pilot plant.

is significant upon injection of relatively low air flow rates and increases as liquid flow rate decreases. Nonetheless, the pressure drop tends to reach constant values after further increases in air flow rate (Ruiz-Viera et al., 2006). Aside from that, riblets have been successfully applied in the industry as drag-reducing devices because of their low production cost and easiness of maintenance. However, the amount of drag reduction triggered by riblets is rather low (Peet et al., 2008).

Effect of magnetic fields

In this current study, the influence of metal solid particle suspension under the action of magnetic fields on the turbulent drag reduction was investigated. This is believed to be a new attempt as there was no evident research on this particular subject matter. But, in some different areas of study, researches have been conducted to study the effect of magnetic fields on the flow characteristics and properties in various fluid transportation channels (Tzirtzilakis et al., 2006; Kuzhir et al., 2005; Nakaharai et al., 2007). The effect of magnetic field on the flow past a circular cylinder decreases as Reynolds Number (Re) increases. It is also discovered that as the magnetic field is increased, a convection motion in a direction opposite to the flow is produced and results in the increasing of drag coefficient values (Sekhar et al., 2007). In other similar study, it was demonstrated that increasing the magnetic field intensity causes the local velocity of a two-phase steady flow along a horizontal glass pipe to decrease. The magnetic fields affect the flow of the second phase; that is the pure water which has low conductivity and is not magnetizable, via the first phase, which is the micron-sized iron powder which has high conductivity and magnetizable (Recebli and Kurt, 2008).

MATERIALS AND METHODS

Experimental system

The fluid friction pilot plant as shown in Figure 1 was used. This custom-built pilot plant consisted of horizontal pipes with 0.0127 m (0.5 inches), 0.0254 m (1.0 inches) and 0.0381 m (1.5 inches) inside diameter. However in this research, only pipe of inner diiameter

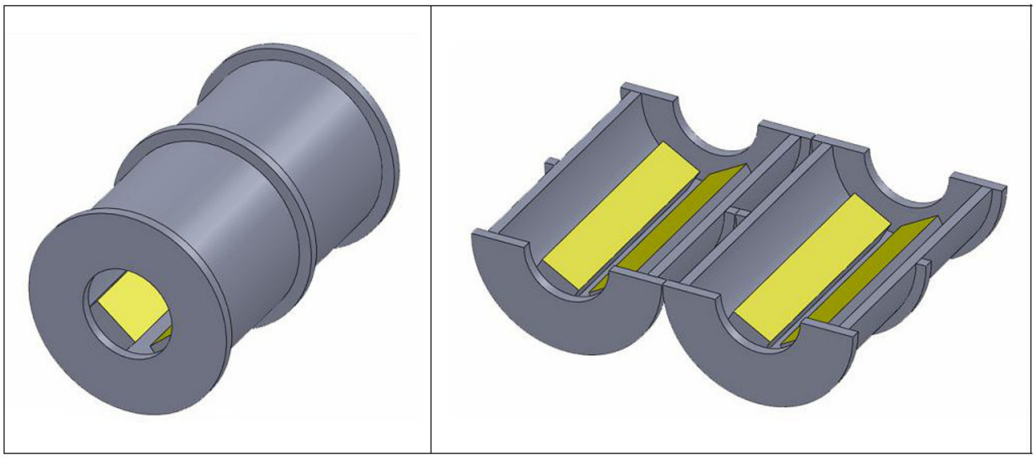


Figure 2. Portable magnetic device.

0.0381 m was used. The pipe consisted of four test sections with distance of 0.5 m between them, completed with a pressure transmitter (PT-101 to PT-105) to transmit the pressure data to the system computer. The first test section was placed at distance 50 times the diameter of the pipe. This was to ensure that a fully turbulent flow is established. The pipe was made from transparent PVC material to allow visual observation of the flow pattern during the experiment. It was also complemented with valves (MV-101 to MV-104) to control the flow rate. The entrance side of the pipe was connected to the centrifugal pump (P-101) while the other side of the pipe which was used as a draining exit was connected back to the reservoir tank (T-101) making the system a closed-loop flow.

An ultrasonic flow meter, Ultraflux Portable Flow meter Minisonic P was placed at the entrance of the pipe after the pump to indicate the volumetric flow rate. The flow meter has accuracy up to 0.001 $m^3\ h^{-2}$. The purpose of using this exterior portable ultrasonic flow meter was to avoid any disturbance that might interfere with the flow pattern. A custom-made portable magnetic device (Figure 2) was placed near to the entrance pipe on the way to the first test section to apply magnetic force to the flow in the pipe. It was clamped onto the pipe and supplied with electricity to magnetize the metal bar inside it, turning it into a portable magnet. The magnitude of magnetic force generated has the number of 1 up to 5, however in this research only magnitude 3, 4 and 5 were tested because the strength for the other two lower magnitudes is relatively low. The magnitude can be adjusted easily with the knob on the electronic component box of the magnetic device.

Materials

The material investigated in this study was iron (density: 7.86 g/cm^3 and molecular weight: 55.84), 99%, powder. The iron powder was sieved into few sizes accordingly; size 45 µm and size 120 µm were investigated. The transporting fluid used in this study was water, to be specific tap water.

Experimental procedures

The experiment was carried out on the 0.0381 m diameter pipe. It began with a filled tank system running for two minutes to achieve a steady turbulent flow. A certain value of flow rate was set, ranged from 5 to 9 m^3/h using the manual valve at the entrance pipe section. Initial pressure readings of this flow rate were taken. Other desired flow rates were set and the corresponding pressure readings were taken. The same procedures were then repeated after the addition of the iron powder with different concentrations; 100, 300 and 500 ppm for both size 45 µm and size 120 µm. The overall experiment was repeated with the addition of magnetic field together with the iron powder with different concentrations and sizes. The pressure readings obtained was used to calculate the percentage of drag reduction. The percentage of DR was calculated using the following formula:

$$\mathrm{DR}(\%) = \left(1 - \frac{\Delta P_a}{\Delta P_b}\right) 100\% \quad (1)$$

where ΔP_a is pressure drop before and ΔP_b is after the addition of metal powder with or without the influence of magnetic field. The Reynolds number in pipe is defined as:

$$\mathrm{Re} = \frac{\rho V D}{\mu} \quad (2)$$

where ρ is density of transporting fluid, V is volumetric flow rate of fluid, D is internal diameter of pipe and µ is absolute viscosity of fluid.

RESULTS AND DISCUSSION

Effect of iron particle concentration

Three different concentration was being investigated; 100, 300 and 500 ppm. Figures 3 and 4, show the effect of Re on the %Dr iron particles flowing in the pipeline with three different concentrations (100, 300 and 500 ppm) and for the particle diameters investigated. Generally, it is very clear that the %Dr increases by increasing the addition concentration of the additive and that can be seen clearly in Figure 3 where the %Dr for the 500 ppm is much higher compared with the other two concentrations. Increasing the addition concentration means increasing

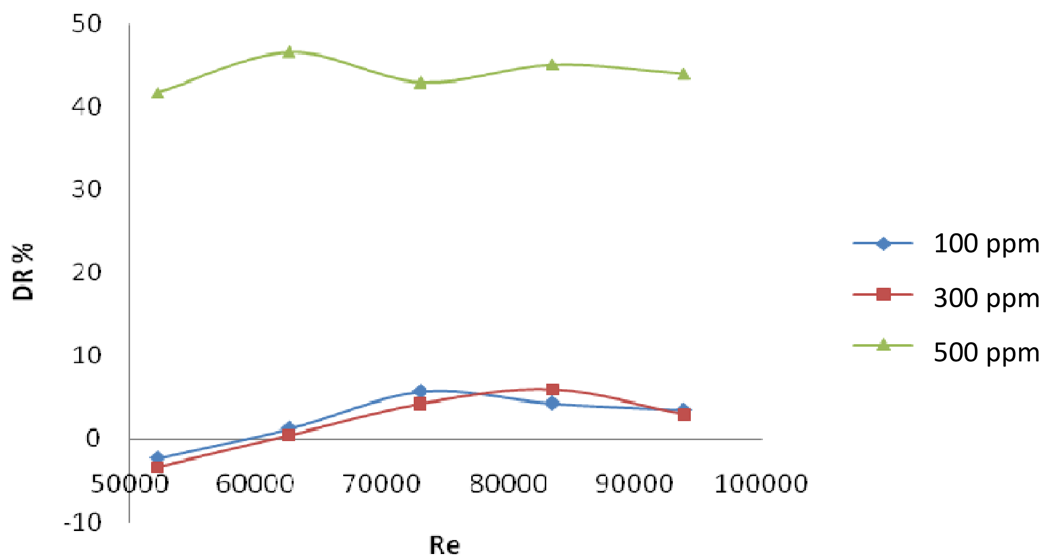


Figure 3. Relationship between iron particle concentration and percentage of DR for size particle 45 µm.

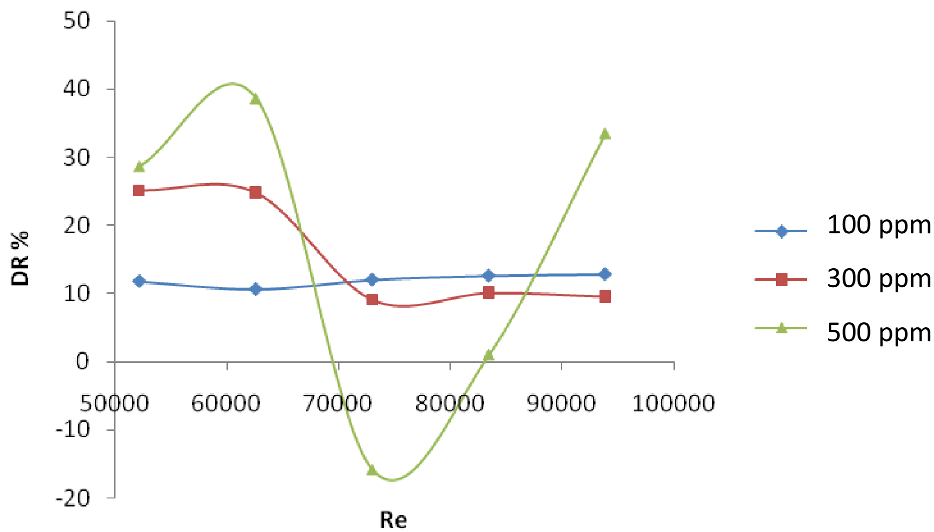


Figure 4. Relationship between iron particle concentration and percentage of DR for size particle 120 µm.

the number of suspended solid particles involved in the drag reduction system. In other words, increasing the addition concentration means increasing the number of suspended solid particles interfering within the turbulent structures formed in the core of the turbulent flow (eddies), and that will increase the turbulence spectrum that is under the drag reduction effect of the additive. Such fact can be seen also clearly in Figure 5 where the %Dr increases by increasing the addition concentration. Almost the same behavior was seen in Figure 4 for the 120 µm iron particles but the difference was not as high as the one observed in Figure 3 for the 45 µm iron particles. Furthermore, a sudden descend was observed in the value of the %Dr in the Re ranged between 70,000 and 80,000. Such behavior is so common in the drag reduction research work due to the high chaotic and unstable media these additives are working with (turbulent flow). Such turbulent media can provide the atmosphere to such radical behaviors of the additives as shown in Figure 4. Figures 5 and 6 show the effect of addition concentration on the %Dr of the iron powder used with the two particle diameters investigated. Generally, it can be seen that the %Dr increases by increasing the addition concentration but the behavior for

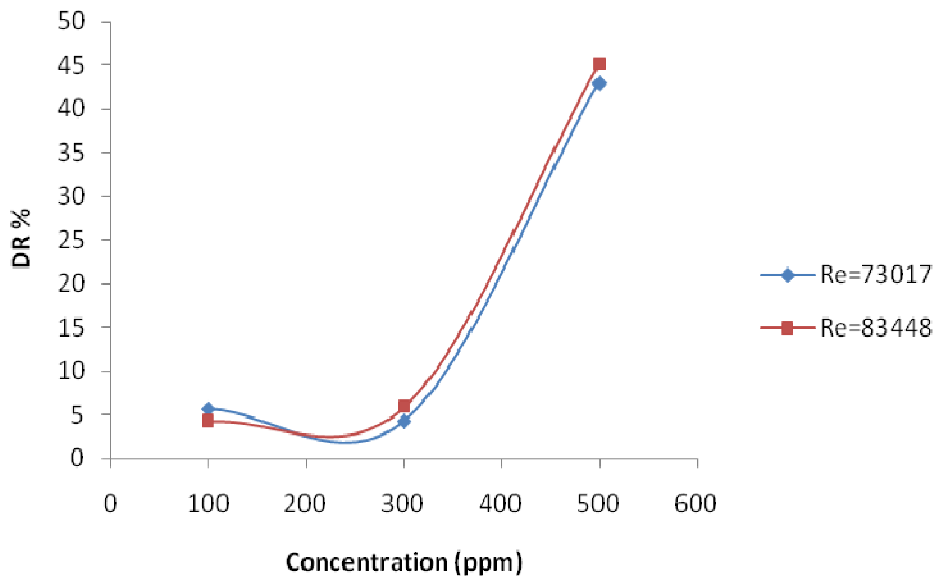


Figure 5. Relationship between iron particle concentration and percentage of DR for size particle 45 µm at Re = 73017 and Re = 83448.

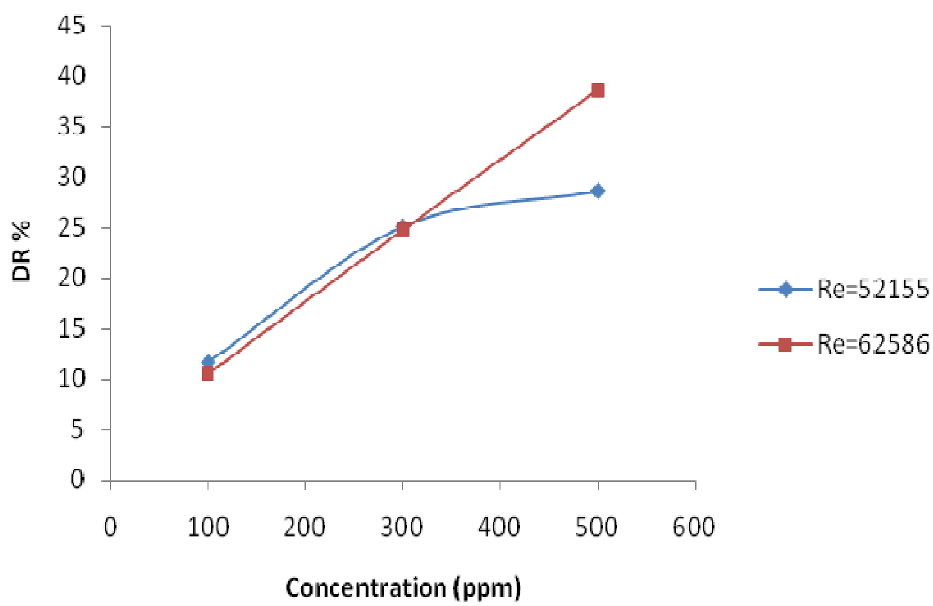


Figure 6. Relationship between iron particle concentration and percentage of DR for size particle 120 µm at Re = 52155 and Re = 62586

the particle diameters investigated was different. Figure 5 show that the %Dr increases rapidly between 300 and 500 ppm while it is not possible to observe the same behavior in Figure 6 for the 120 µm iron particles. The behavior in Figure 5 highlights the relation between the suspended solid concentration, particle diameter and the degree of turbulence where the optimum interaction between the suspended solid particles in certain concentration (500 ppm) and the degree of turbulence reaches its " drag reduction Onset Point." This point was not clear or was not reached in Figure 6 due to the increase in the particle size which means reducing the number of particles involved in the drag reduction performance (the concentration was taken on the weight/wieght scale) and that is clear from the values of the %Dr in both cases where the %Dr was higher for the

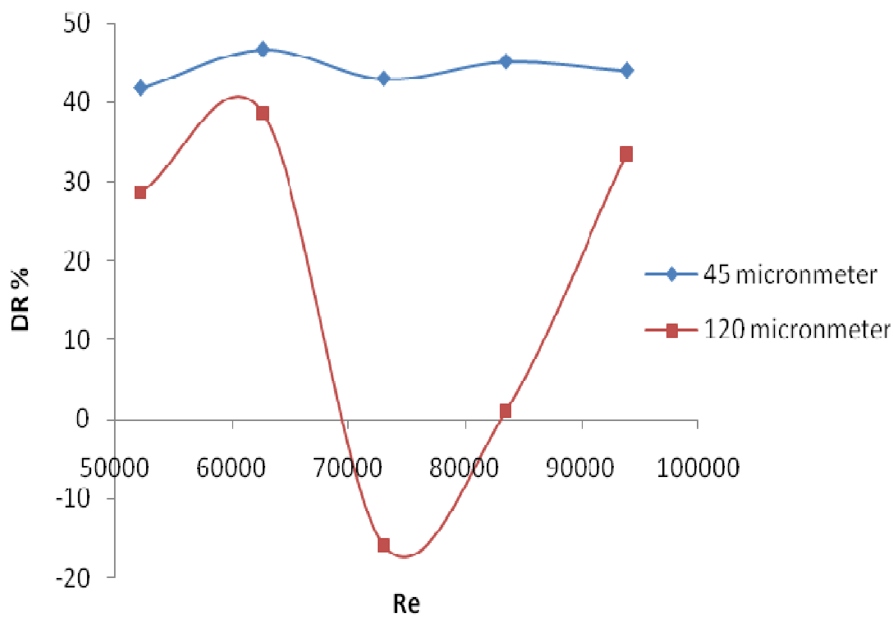


Figure 7. Relationship between iron particle size and percentage of DR for concentration of 500 ppm.

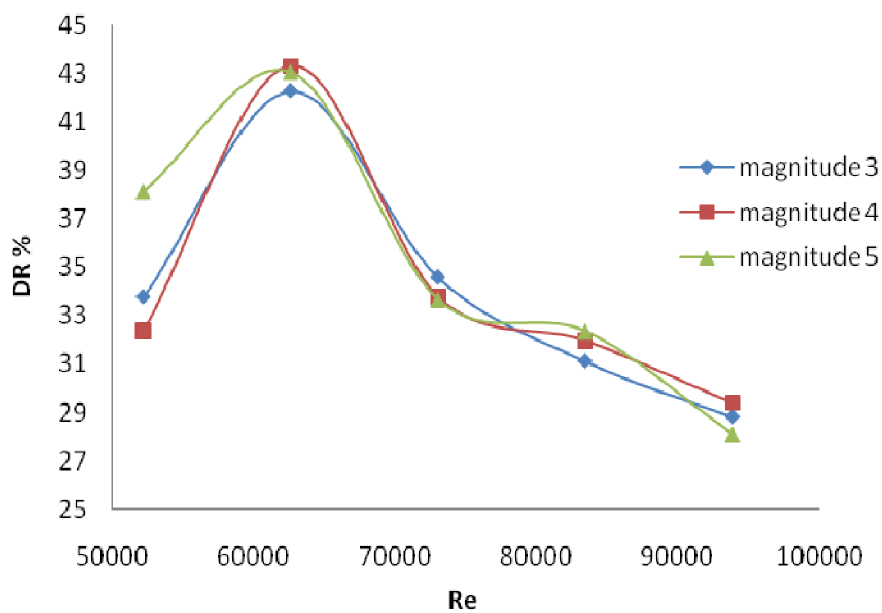


Figure 8. Relationship between the strength of the magnetic field and the percentage of DR for iron particle size 45 µm at concentation 500 ppm.

smaller iron particles size compared with the larger ones in Figure 6.

Effect of iron particle size

Figure 7 shows the relationship between the iron particle sizes and percentage of DR with the increment of Reynolds number representing the volumetric flow rate of the transporting fluid for iron particle concentration of 500 ppm. It is clearly shown that the percentage of drag reduction is more favored towards smaller iron particle size. The best reading of drag reduction is shown within the range of Re = 60000 and Re = 65000. At this range,

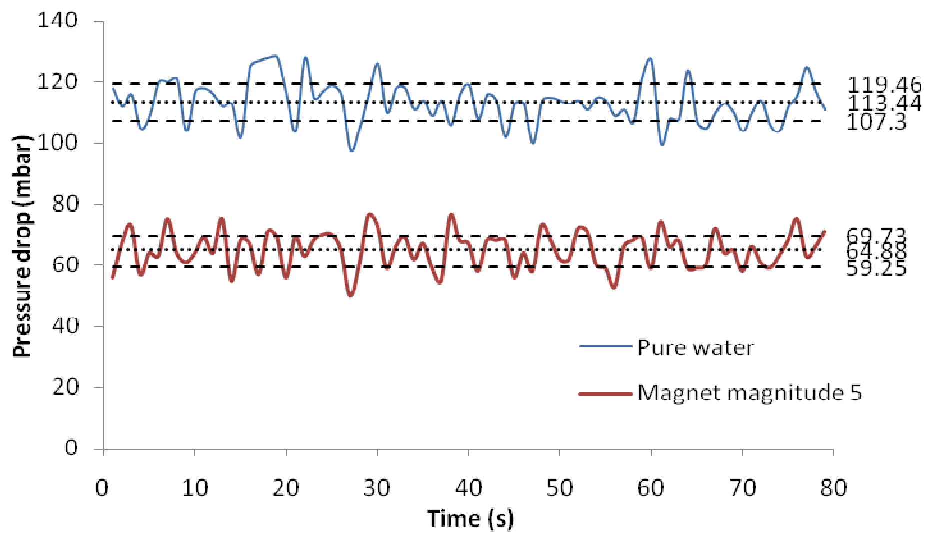


Figure 9. Behavior of the pressure drop influenced by the magnetic field applied for iron particle 45 µm of concentration 500 ppm at Re = 93879 (compared with pure water).

the highest drag reduction value reached 46% for iron particle of size 45 µm and lowest value; 38% for size 120 µm.

Effect of magnetic field

The magnetic field was applied to the turbulent flow in the pipe to study its influence on the iron particle in the course of drag reduction. Figure 8 shows the relationship between the strength of the magnetic field and the percentage of DR. It is noted that the magnetic field did influence the percentage of drag reduction of the iron particle. At the range within Re = 50000 and 55000, it can be observed that the stronger the magnetic field, the higher drag reduction took place. At the range within Re = 60000 and 65000, the percentage of drag reduction reaches the maximum value. Beyond the range, it is noted that the effect of magnetic field on the flow decreases as Re increases. Figure 9 shows the behavior of the pressure drop readings influenced by the magnetic field applied. It can be observed that compared to pure water alone, applying the magnetic field caused the fluctuation in the pressure drop reading to decrease significantly as time passes. This proves that the presence of turbulence can be reduced under the influence of magnetic field. This performance may be caused by the influence of the magnetic field on the iron particle, which results in a more rounded velocity distribution of the transporting fluid boosting the drag reduction.

Conclusion

Iron powder dag reduction ability was proven in the present investigation with maximum %Dr up to 46% when transporting 500 ppm suspended solid-water solution in a pipe. The drag reduction performance of the iron powder was proven to be influenced positively when applying magnetic force to the flowing solution.

REFERENCES

Abdul Bari HA, Mohd Yunus R (2009). Drag Reduction Improvement in Two Phase Flow System Using Traced of SLES Surfactant. Asian J. Indust. Eng., 1(1):1-11.

Abdul Bari HA, Suali E, Hassan Z (2008). Glycolic Acid Ethoxylate Lauryl Ether Performance as Drag Reducing Agent in Aqueous Media Flow in Pipelines. J. Appl. Sci., 8(23): 4410 - 4415.

Al-Yaari M, Soleimani A, Abu-Sharkh B, Al-Mubaiyedh U, Al-sarkhi A (2009). Effect of drag reducing polymers on oil-water flow in a horizontal pipe. Int. J. Multiphase Flow, 35: 516-524.

Benzi R (2009). A short review on drag reduction by polymers in wall bounded turbulence. Physica D, doi:10.1016/j.physd,.2009.07.013

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

Cho SH, Tae CS, Zaheeruddin M (2007). Effect of fluid velocity, temperature and concentration of non-ionic surfactants on drag reduction. Energy Conversion Manage., 48:913-918.

Ding Y, Wen D (2005). Particle migration in a flow of a nanoparticle suspensions. Powder Technol., 149:84-92.

Kuzhir P, Bossis G, Bashtovoi V, Vékás L (2005). Capillary flow of a suspension of non-magnetic particles in a ferrofluid under highly non-uniform magnetic field. Int. J. Multiphase Flow. 31:201-221.

Li CF, Khomami B, Sureshkumar R (2006). Influence of rheological parameters on polymer-induced turbulent drag reduction. J. Non-Newtonian Fluid. Mech., 140:23-40.

Nakaharai H, Takeuchi J, Yokomine T, Kunugi T, Satake S, Morley NB, Abdou MA (2007). The influence of a magnetic field on turbulent heat transfer of a high Prandtl number fluid. Experimental Thermal Fluid Sci., 32:23–28.

Peet Y, Sagaut P, Charron Y (2008). Turbulent Drag Reduction using Sinusoidal Riblets with Triangular Cross-Section. 38th AIAA Fluid Dynamics Conference and Exhibit, Seattle, WA.

Recebli Z, Kurt H (2007). Two-phase steady flow along a horizontal glass pipe in the presence of the magnetic and electrical fields. Int. J.

Heat Fluid Flow. 29:263-268.
Ruiz-Viera MJ, Delgado MA, Franco JM, Sánchez MC, Gallegos C (2006). On the drag reduction for the two-phase horizontal pipe flow of highly viscous non-Newtonian liquid/air mixtures: Case of lubricating grease. Int. J. Multiphase Flow. 32:232–247.
Sekhar TVS, Sivakumar R, Kumar H, Ravikumar TVR (2007). Effect of aligned magnetic field on the steady viscous flow past a circular cylinder. Appl. Math. Modelling, 31:130-139.
Toms BA (1948). Some observation on the flow of linear polymer solutions through straight tubes at large Reynolds numbers. Proceedings of the First Int. Congress on Rheol., 2:135–141.
Tzirtzikilas EE, Xenos M, Loukopoulos VC, Kafoussias NG (2006). Turbulent biomagnetic fluid flow in a rectangular channel under the action of a localized magnetic field. Int. J. Eng. Sci., 44:1205-1224.