Studying the Effect of Magnetic Force on Increasing the Drag Reduction Performance of Suspended Solids on the Turbulent Flow in Pipelines: An Experimental Approach

Hayder A. Abdulbari and Yue Kim Kor

***Abstract*— Fluids transportation in pipelines tends to consume loads of energy because in moving fluid, energy will be dissipated mainly due to frictional drag, as well as turbulence. These energy losses are identified through pressure drop, which will results in more pumping power consumption. The significance of this study was to introduce a new scheme to reduce the turbulent drag, in which was the clue to the pumping power, and ultimately cost saving. In this study, magnetic field was investigated as a potential drag reduction technique along side with suspended metal solid particles i.e. iron. A custom-made portable magnetic device was used to apply magnetic force to the flow in the pipe. The new technique was tested experimentally in a closed loop liquid circulation system. Fluid flow rate, magnetic force, suspended iron particle size and concentration, where the main variables investigated in the present work. The experimental results showed that the presence of turbulence can be reduced under the influence of magnetic field. . It also showed that the drag reduction is more superior towards smaller particle sizes and higher particle concentration. The maximum drag reduction value recorded for iron particle of size 45µm is 46%; 38% for size 120µm, both taken within the range of Re = 60000 and Re = 65000 at concentration 500ppm.**

***Index Terms*—Drag reduction, magnetic field, pressure drop, suspended solids, turbulent flow**

I. Introduction

Cost saving is one of the most essential concerns in any industry. One of the key to the present concern is by cutting down on the power consumption. However due to the turbulence mode the fluids transported are in, pumping power dissipation has been one of the major problems since the beginning of fluid transportation through a pipeline. Several suggestions had been made to overcome this problem, and one of the most adopted methods commercially was the injection of minor quantity of viscous elastic chemical into the core of the transported liquid in the pipeline to reduce drag reduction.

This idea of drag reduction had been implemented in pipelines or other transportation channels and equipments, particularly those which handle crude oil and refinery products for flow improvements. With the same amount of energy, drag reducing agent (DRA) can decrease the pressure drop in the pipeline for the same flow rate of fluid, a clue to pumping power costs reduction and productivity increase [1].

Various drag reduction techniques have been studied, including the addition of polymers, fibers or surfactants as a drag reduction agent, addition of suspended solid particle, and gas injection in turbulent flows [2-5].

Pereira and Pinho demonstrated the suspended solids drag reduction mechanism using the clay suspensions based on laponite. The results showed that it could only induce a small amount of drag reduction; however, a blend of clay with polymer could produce a more significant effect of flow improvement. The polymer molecules being bonded to the clay particles increased their effective size and asymmetry, which increased the overall velocity of the particle and the likelihood of migration effects [6]. In Newtonian fluid, fiber suspension was proven to be able to reduce the turbulent intensity and the Reynolds stress [7]. Nanoparticle suspension with relatively higher concentration in laminar pipe flows can cause a more diminished velocity profile [8].

The addition of DRA, particularly polymer has an inconvenience, including the toxicity caused and the degradation of the molecules against shear force acting in the pipeline. Therefore, in this current study, the influence of magnetic fields acting on the metal solid particle suspension that was iron powder on the turbulent drag reduction was studied. In addition, using magnetic fields as a flow improver is believed to be a new attempt as there was no evident experimental-based research on this particular subject matter. The only approach for other papers was by Tzirtzikilas *et al.* [9] who studied the influence of a localized magnetic field to the turbulent flow of a bio-magnetic fluid (blood). They found that the effect of magnetic field significantly reduced in the presence of turbulence.

However, in some other 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 [10, 11]. The effect of magnetic field on the flow past a circular cylinder decreased as Reynolds Number (Re) increased. 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 [12]. Increasing of magnetic field intensity caused the local velocity of a two-phase steady flow along a horizontal glass pipe to decrease. The magnetic fields affected the flow of the second phase, that was the pure water which had low conductivity and was not magnetizable, via the first phase, that was the micron-sized iron powder which had high conductivity and magnetizable [13].

Manuscript received on July 9, 2011.

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II. Material and Methods

A. Experimental System

The custom-built fluid friction pilot plant as shown in Fig. 1 was used to carry out the experiments and it was supported with a pipe of inner diameter 0.0381m. The pipe consisted of four test sections with distance of 0.5m between them, completed with a pressure transmitter (PT-101 ~ 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 ~ 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.

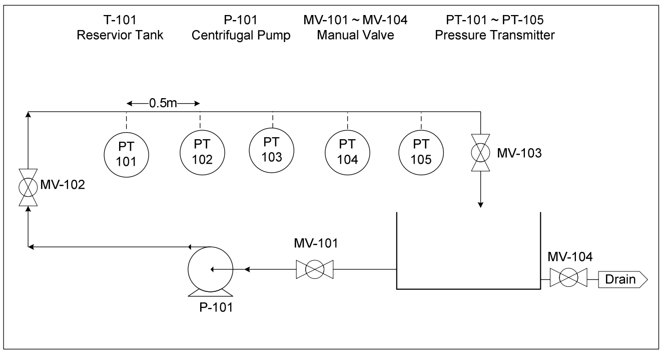


Fig. 1. Fluid friction pilot plant

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 cubic meter per hour. 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 (Fig. 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 DC power to magnetize the four metal bars inside it, turning it into a portable magnet. The power supplied to the magnet has five settings, i.e. 240W, 480W, 720W, 960W and 1200W. The power setting can be adjusted easily with the knob on the electronic component box of the magnetic device.

B. Materials

The material investigated in this study was iron (density: 7.86g/cm^3 and molecular weight: 55.84), 99%, powder, which was distributed by Fisher Scientific (M) Sdn Bhd. The iron powder was sieved into few sizes accordingly; size 45μm and size 120μm were investigated. The transporting fluid used in this study was water.

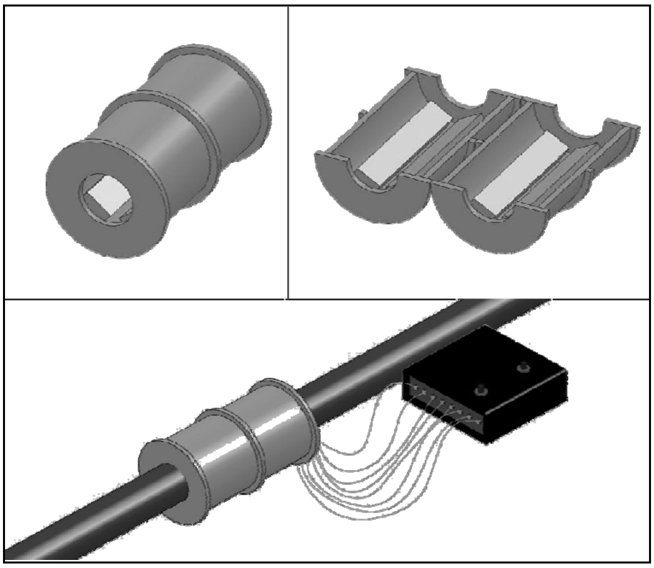


Fig. 2. Portable magnetic device

C. Experimental Procedures

The experiment was carried out on the 0.0381m 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 9m^3/hr 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; 100ppm, 300ppm and 500ppm for both size 45μm and size 120μm. 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:

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

where ΔP_a is the 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 a pipe is defined as:

$$Re = \frac{\rho V D}{\mu}$$

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

III. Results and Discussions

Fig. 3 and 4 show 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 to the addition of iron particles 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 particles, which resulting in a more rounded velocity distribution of the transporting fluid boosting and giving a consistent occurrence of drag reduction.

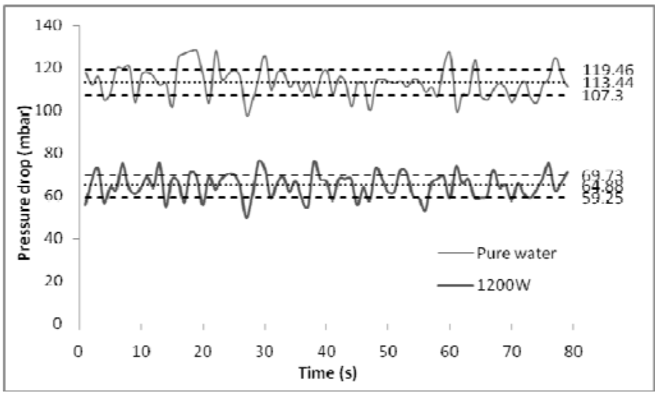


Fig. 3. Behavior of the pressure drop influenced by the magnetic field applied for iron particle 45µm of concentration 500ppm at Re=93879 (compared with pure water)

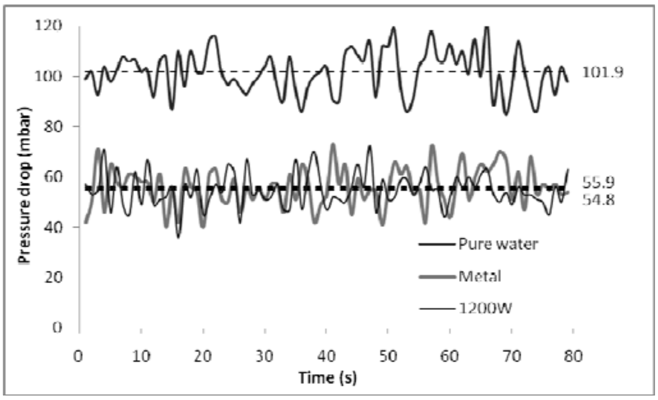


Fig. 4. Behavior of the pressure drop influenced by the magnetic field applied for iron particle 45µm of concentration 500ppm at Re= 83448

Fig. 5 and 6 show the relationship between Reynolds number and percentage of drag reduction with different iron particle concentration for both size 45µm and 120µm at power setting of 1200W. For 45µm, it can be clearly seen that the drag reduction percentage is increased as the concentration of the particles increased. The amount of drag reduced for concentration 500ppm is superior compared to the lower concentrations. This possibly caused by the certain degree of compatibility achieved between the iron particle concentration and the turbulence instability, resulting in effective drag reduction. Increasing the iron particles concentration helps better suppression of turbulent bursts formation in the flow because more molecules of iron will be involved in reducing the formation and propagation of turbulent eddies. However, the percentage of drag reduction value will reach a certain maximum value where the increment in concentration of the drag reduction agent additive will no longer produce a better result.

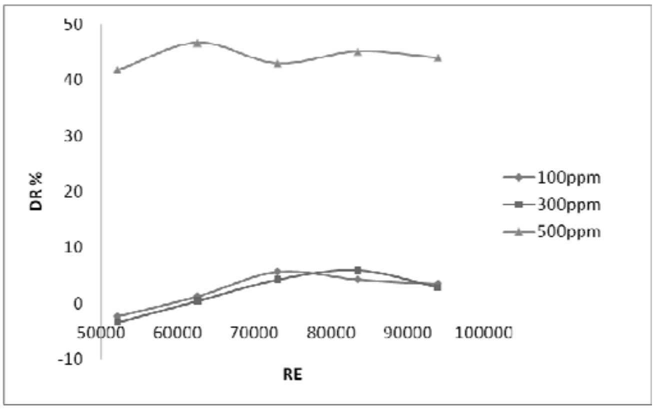


Fig. 5. Relationship between Reynolds number and percentage of drag reduction with different iron particle concentration for size 45µm at power setting 1200W.

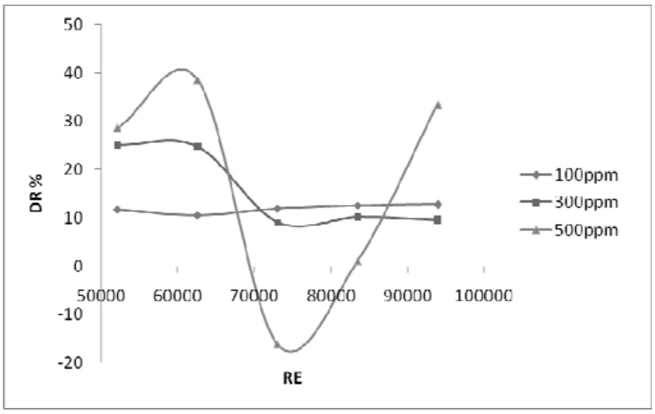


Fig.6. Relationship between Reynolds number and percentage of drag reduction with different iron particle concentration for size 120µm at power setting 1200W.

The relation between the degree of turbulent represented by Reynolds number with the flow pattern, particle size and pipe dimension yield a fine balance that results in effective drag reduction. It can be noted that for the size 45µm graph line (Fig. 5) at the range of Re = 50000 and Re = 60000 and 120µm graph line (Fig. 6) at the range of Re = 70000 and Re = 80000, the balance between all these factors went slightly off resulting in negative drag reduction effect. However, further increase in Reynolds number could regain back the balance and increase the drag reduction performance.

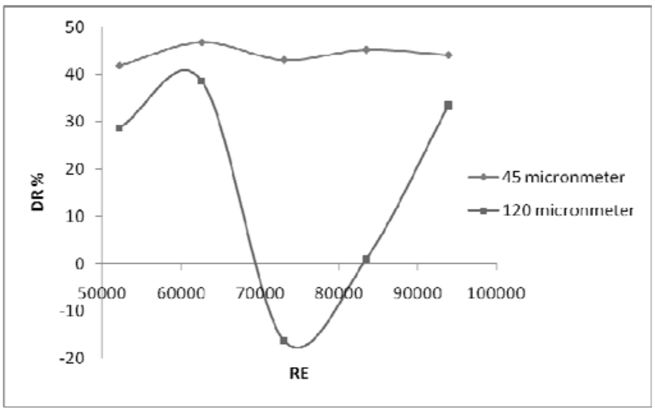


Fig. 7. Relationship between Reynolds number and percentage of drag reduction with different iron particle size for concentration 500ppm at power setting 1200W.

Fig. 7 shows a comparison in the percentage of drag reduction for the two different iron particle size tested i.e. 45µm and 120µm for concentration 500ppm at power setting 1200W. It can be noted that drag reduction more superior towards smaller size particles. This possibly because smaller size particles have larger surface areas, increasing the chance of migration effect where bond is formed between the transporting fluid molecules and the drag reduction agents. The best reading of drag reduction is shown within the range of Re = 60000 and Re = 65000. At this range, the highest drag reduction value reached 46% for iron particle of size 45µm and highest value; 38% for size 120µm.

IV. Conclusion

From the results obtained, it can be concluded that generally iron particle is a good drag reduction agent. The influence of the magnetic field on the drag reduction of the iron particle can be noted through the behavior of the pressure drop reading as time passes. The magnetic field caused the fluctuation in the pressure drop reading to decrease, which proves that the presence of turbulence can be reduced under the influence of magnetic field. The percentage of drag reduction is also affected by the concentration and size of the particle, where it is more favored towards higher concentration and smaller particle sizes.

The maximum drag reduction value recorded for iron particle of size 45 µm is 46%; 38% for size 120 µm, both taken within the range of Re = 60000 and Re = 65000 at concentration 500ppm.

Acknowledgment

The authors gratefully acknowledge the financial support for this research from Universiti Malaysia Pahang.

References

[1] D. Murenzi and T. Descamps, "The Benefits of utilizing a Drag Reduction Agent (DRA)," *World Pipelines*, July 2008

[2] C.F. Li, B. Khomami and R. Sureshkumar, "Influence of rheological parameters on polymer-induced turbulent drag reduction," *J. Non-Newtonian Fluid Mech.*. 2006, 140, 23-40.

[3] S.H. Cho, C.S. Tae and M. Zaheeruddin, "Effect of fluid velocity, temperature and concentration of non-ionic surfactants on drag reduction," *Energy Conversion Manage.* 2007, 48, 913-918.

[4] Y. Peet, P. Sagaut and Y. Charron, "Turbulent Drag Reduction using Sinusoidal Riblets with Triangular Cross-Section," *38th AIAA Fluid Dynamics Conference and Exhibit*. 2008, June 23-26. Seattle, WA.

[5] M.J. Ruiz-Viera, M.A. Delgado, J.M. Franco, M.C. Sánchez and C. Gallegos, "On the drag reduction for the two-phase horizontal pipe flow of highly viscous non-Newtonian liquid/air mixtures: Case of lubricating grease," *International Journal of Multiphase Flow.* 2006 ,32, 232–247

[6] A.S. Pereira and F.T. Pinho "Turbulent pipe flow of thixotropic fluids," *International Journal of Heat and Fluid Flow.* 2002, 23, 36-51

[7] J.Z Lin, Z.Y. Gao, K. Zhou and T.L. Chan, "Mathematically modeling of turbulent fiber suspension and successive iterative solution in the channel flow,". *Applied Mathematical Modelling*. 2006, 30, 1010-1020

[8] Y. Ding, and D. Wen, "Particle migration in a flow of a nanoparticle suspensions," *Powder Technology.* 2005, 149, 84-92.

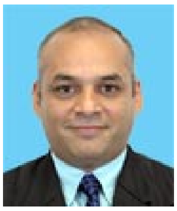
[9] E.E. Tzirtzikilas, M. Xenos, V.C. Loukopoulos and N.G. Kafoussias, "Turbulent biomagnetic fluid flow in a rectangular channel under the action of a localized magnetic field," *International Journal of Engineering Science.* 2006, 44, 1205-1224

[10] P. Kuzhir, G. Bossis, V. Bashtovoi and L. Vékás, "Capillary flow of a suspension of non-magnetic particles in a ferrofluid under highly non-uniform magnetic field," *International Journal of Multiphase Flow.* 2005, 31, 201-221.

[11] H. Nakaharai, J. Takeuchi, T. Yokomine, T. Kunugi, S. Satake, N.B. Morley and M.A. Abdou, "The influence of a magnetic field on turbulent heat transfer of a high Prandtl number fluid," *Experimental Thermal and Fluid Science* 2007, 32, 23–28

[12] T.V.S. Sekhar, R. Sivakumar, H. Kumar and T.V.R. Ravikumar, "Effect of aligned magnetic field on the steady viscous flow past a circular cylinder,". *Applied Mathematical Modelling.* 2007, 31, 130-139.

[13] Z. Recebli and H. Kurt, "Two-phase steady flow along a horizontal glass pipe in the presence of the magnetic and electrical fields," *International Journal of Heat and Fluid Flow*. 2007, 29, 263-268



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