Scientific Research and Essays Vol. 7(18), pp. 1768-1776, 16 May, 2012
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE11.1483
ISSN 1992-2248 © 2012 Academic Journals

Full Length Research Paper

Introducing slag powder as drag reduction agent in pipeline: An experimental approach

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Accepted 20 September, 2011

Main by product in ore smelting from tin production in Malaysia has become a trigger for this investigation. Slag waste can be categorized as suspended solid. Utilization of this waste in fluid transportation can reduce the pressure drop in pipelines. Experimental works had conducted in order to test slag waste in a closed loop of turbulence water flowing system with water and fuel as the transport liquid. The procedures start by pumping liquid suspended solid combination from reservoir tank with varies flow rates into two different pipe diameters (0.0127 m ID and 0.038 m D.I). The types of pipe used are PVC pipe. The testing length of this flow system is 2.0 m. The pressure drop and drag reduction were measured in varied addition concentration. The results have show percentage drag reduction (Dr%) is over 60% in certain range and condition. It is proved that slag is a potential DRA.

Key words: Suspended solid, turbulent flow, drag reducing agent, pipeline system.

INTRODUCTION

Drag reduction in turbulent flow is a very important subject in technologies utilization and significant point of interest. As known, drag reduction can be achieved by using several numbers of additives that have been widely studied such as high molecular weight polymers (Roy and Larson, 2005; Al-Sarkhi, 2010, Mowla and Naderi, 2006; Shetty and Solomon, 2009; Parimal et al., 2008; Janosi et al., 2004; Dubief et al., 2004) surfactants study by Lu et al. (1998), Bari and Yunus (2009), Bari et al. (2008) and Suali et al. (2010) and suspended solid investigation have been determined by Roy and Larson (2005) and Dyer et al. (2004). Drag reduction is defined as addition of several ppm concentrations to accelerate radically in fluid transportation (Brostow et al., 2006; Suali et al., 2010; Dubief et al., 2004; Kim et al., 2000; Parimal et al., 2008) and many more. However, there are few studies regarding suspended solid. Mechanism involved is yet still a hesitation. Many researchers investigated the idea of particles inside liquid flow channel agreed in one point, turbulent characteristic are changed in present of suspended solid (Rashidi et al., 1990; Roy and Larson, 2005; Dyer et al., 2004; Filipson et al., 1977). There are fewer studies devoted to the effects of particle additives on the mechanisms of instability and transition to turbulence in free shear flows. The flow visualizations reported by Filipsson et al. (1977) represent one of the few available experiments on this subject. In this study, the authors presented results for a jet flow of viscoelastic (Polyox WSR-301), fibre suspension (chrysotile fibres) and Newtonian (water) fluids at high Reynolds numbers. Rashidi et al. (1990) have determined predominant effects of particle size, density and concentration. Their results point out that particle density has minor effects rather than particle size in effects of drag reduction.

Presently, the usage of the suspended solid (insoluble in liquid media) as drag reducing agent has broaden accesses for enthusiastic researcher to uncover the accessibility of this insoluble condition in the drag reduction phenomena (Toonder, 1997; Mowla and Naderi, 2006). The aim of this study is to test the efficiency of slag particle as drag reducer agent on transport of fuel inside pipes. Two different internal pipe diameters were used with four different concentrations in the purpose to investigate the concentration effect. The efficiency of suspended solid was tested using diesel.

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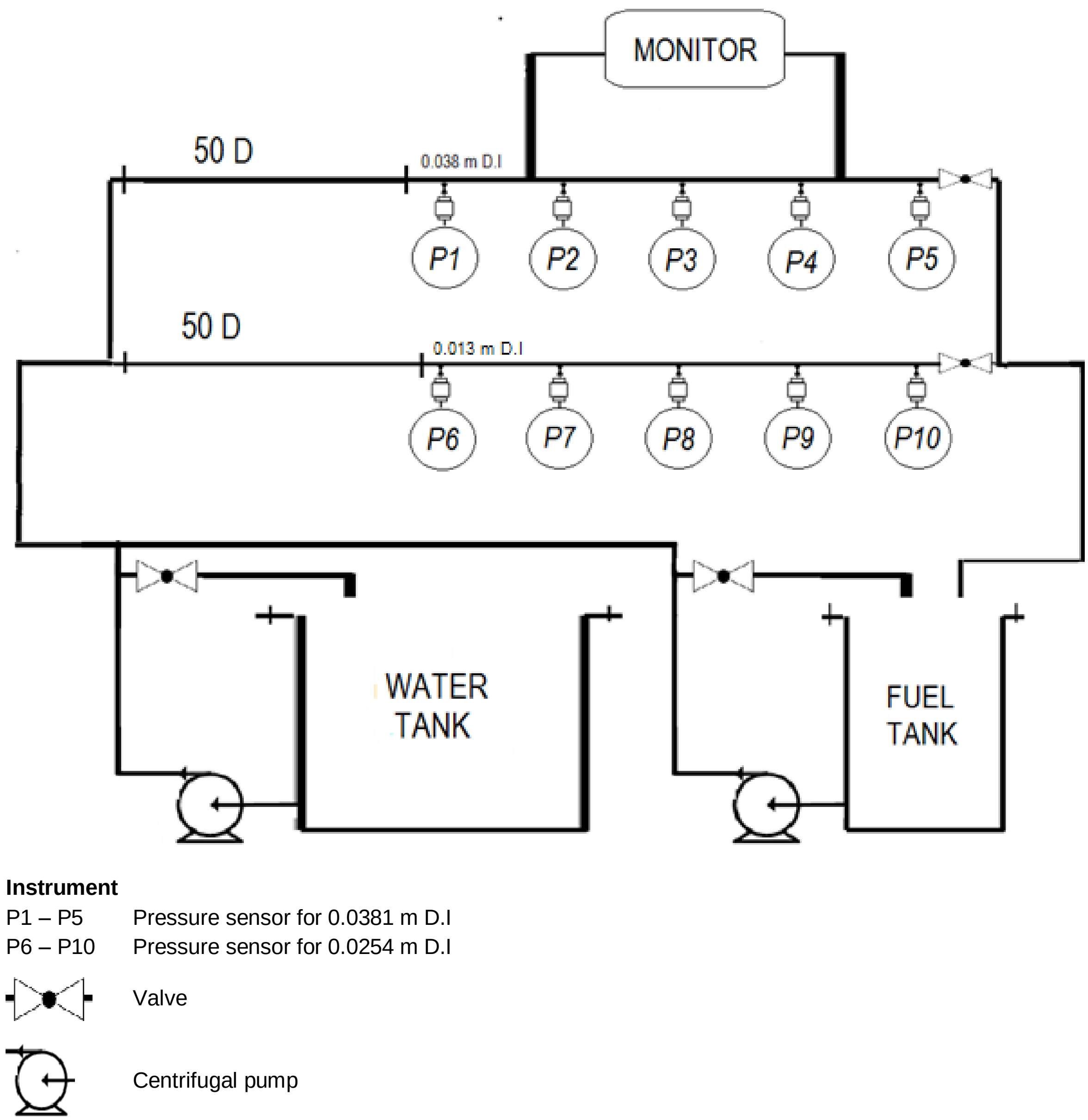
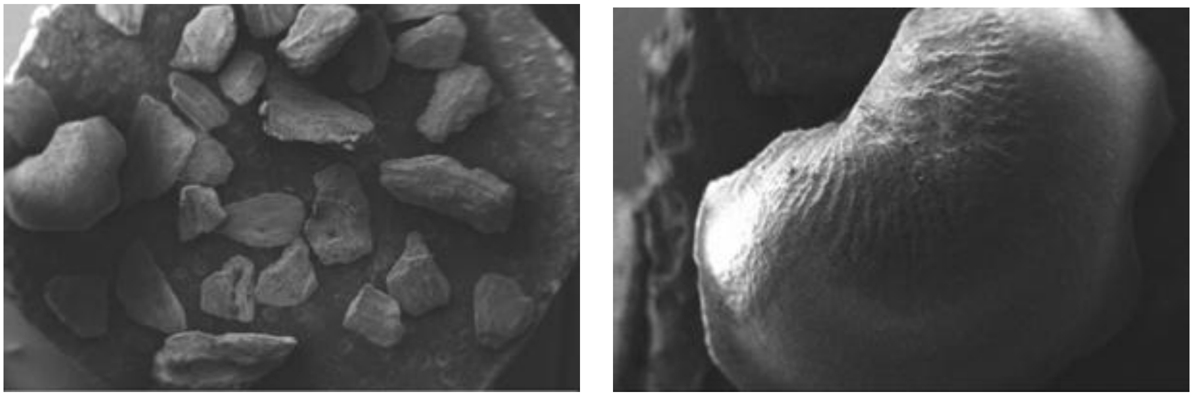


Figure 1. Schematic diagram of the flow system.

MATERIALS AND METHODS

Liquid circulation system

Liquid circulation system was built to test the effects of pipe diameter, pipe length, fluid velocity and concentration on pressure drop; hence to investigate the effects influence %Dr. Figure 1 shows a schematic diagram of a build up liquid circulation system used in the present investigation. Generally, this system consists of reservoir tank, pipes, valves, pumps, flow meter and pressure sensors. The reservoir tank was supported with an exit pipe connected to centrifugal pumps. The solution flows from reservoir tank directly into testing pipes before flowing back into the reservoir tank. Two visible PVC pipes connected to galvanized iron pipes of various inside diameters 0.0127 and 0.0381 m ID were used in constructing the flow system. A complete closed loop piping system was built. Flow starts from the reservoir tank through the pump reaching a split connected with three different pipes diameter with testing section. For measuring flow rate inside the pipe, Burkert attachable flow meter has been used. Power supply for this detector is 12 to 30 V and can measure flow pressure between 140 to 230 psi with fluid viscosity les then 200 cP. Material used to be immersed into fluid is ceramic. The pump brand for water circulation is Grundfos CH8-40. The energy usage of this pump is 1.02 kW and pump force is 415 V. On the other hand, hydrocarbon pump brand is DAB K-Series which is transfer pump for small flow operations. This centrifugal pump is designed with technopoymer impeller for domestic usage. The energy required for this pump is 0.75 kW and pump force is 240 V. The testing sections were 0.5, 1.0, 1.5 and 2.0 m long. First, testing point was located about 50 times of pipe diameter to ensure that the turbulent flows are fully developed before the testing process run. Five sets of build up



(a) (b)

Figure 2. Grinded slag waste particle for 200 μm: (a) SEM picture of 9x mag and (b) Scaled up picture of a particle (33x mag).

Table 1. Physical properties of diesel.

Hydrocarbon properties at 27°C	
Viscosity (μ diesel at 27°C)	1456 cP
Density (ρ diesel at 27°C)	853.2 kg/m^3

Table 2. Physical properties of water.

Water properties at 27°C	
Viscosity (μ water at 27°C)	937.3 cP
Density (ρ waterat 27°C)	996.59 kg/m^3

pressure sensors.

The pressure sensor is a build up pressure transmitter and transducer made by silicon as the base materials. The membrane detector is made by 316 L stainless steel diaphragm. The optimum range for pressure is 0 to 60 bar, temperature range between -10 until 60°C and be detected in absolute gauge. The accuracy for this transmitter is 0.1% fault. These sensors are integrated construction specially design for rigid and robust flow in industry.

Materials investigated (slag waste particle)

Slag waste is obtained from Malaysia Smelting Corporation at Butterworth, Penang. The slag waste was dried by the oven overnight at a temperature of 100°C. Once dry, the suspended solid is graded into fine particle by using grinder then sample was sieve using a screen into 200 μm in size (Figure 2). The density of this new material is 1400 kg/m^3.

Transported liquid

The transported liquid used in the present investigation was diesel fuel obtained from Shell. However, for comparison, pure water was used. The physical properties of diesel fuel and water are shown in Tables 1 and 2.

Experimental procedure

All the experiments were carried in a constructed liquid circulation system, testing different variables which are:

i) Suspended solid concentration (50, 100, 200 and 400 ppm).
ii) Pipe diameter (0.0127 and 0.0381 m D.I).
iii) Pipe length (0.5, 1.0, 1.5 and 2.0 m).
iv) Solution flow rates.

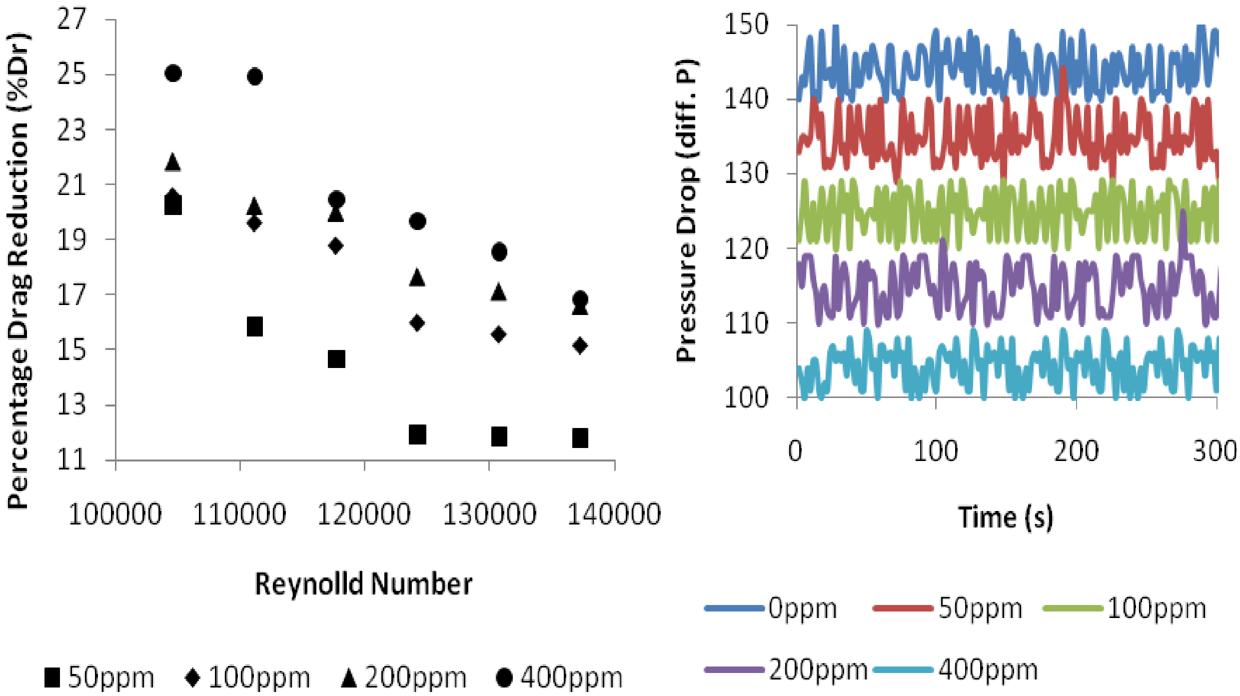


Figure 3. Effect of particle concentration in transported fuel on Dr% with different Re in 0.0381 n D.I and 2.0 m pipe length and pressure drop analysis for Re = 105000.

The experimental procedure starts by testing every additive concentration and pipe diameter, the operation begins when the pump starts delivering the solution through section of pipe length. The solution flow rate is fixed at the certain value by controlling it from the bypass section. Pressure readings are taken to this flow rate. By changing the solution flow rate to another fixed point, pressure readings are taken again until finishing desired values of flow rates. This procedure is repeated for each suspended solid concentrations to test its effect on the drag reduction operation. From the flow rate obtain, Reynolds number calculated based on formulae, which represent velocity of flow depending on pipe diameter and pipe length.

Velocity and Reynolds number calculations

The average velocity (V) and Reynolds number (Re) were calculated using the solution volumetric flow rate readings (Q), density (ρ), viscosity (μ) and pipe diameter (D) for each run as follows:

$$Re=\frac{\rho V D}{\mu} \qquad (1)$$

Where:

ρ is density of the fluid (kg/m^3),
μ is viscosity of the fluid (Pa. s),
D is diameter of internal pipe (m),
V is velocity of fluid (m/h),

Where: $V=\frac{v}{A}=\frac{\text{flow rate of fluid}}{\text{Area of internal pipe diameter}}$

Where: $A=\pi r^2=\pi(\text{radius})^2=A=\pi\left(\frac{\text{Diameter}}{2}\right)^2$

After obtaining Reynolds number, percentage drag reduction (%Dr) determined to plot graft in order to see the patent of drag reduction.

Percentage drag reduction calculations

Pressure drop readings through testing sections before and after drag reducer addition were needed to calculate the percentage drag reduction %Dr as follows (Virk, 1967):

$$\%Dr=\frac{\Delta P_b-\Delta P_a}{\Delta P_b} \qquad (2)$$

Where:

ΔP_b = Pressure drop before addition of DRA.
ΔP_a = Pressure drop after addition of DRA.

RESULTS

The analysis in Figures 3 and 4 shows slag particle performance on drag reduction as a function of particle concentration in hydrocarbon liquid and water and fluid velocity represented by Re which is from 50 to 400 ppm in the range of Re equal to 65000 to 140000 for fuel and 65000 to 105000 for water transportation. Scale down for

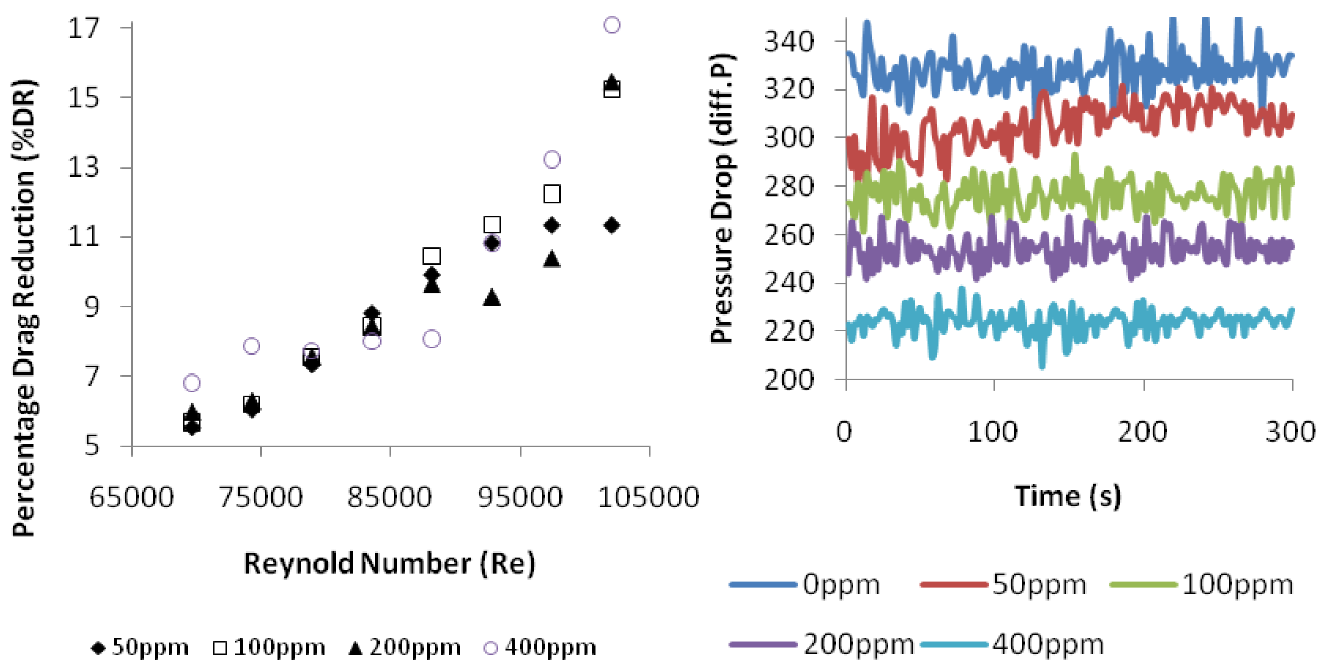


Figure 4. Effect of particle concentration in transported water on Dr% with different Re in 0.0381 n D.I and 2.0 m pipe length and pressure drop analysis for Re = 105000.

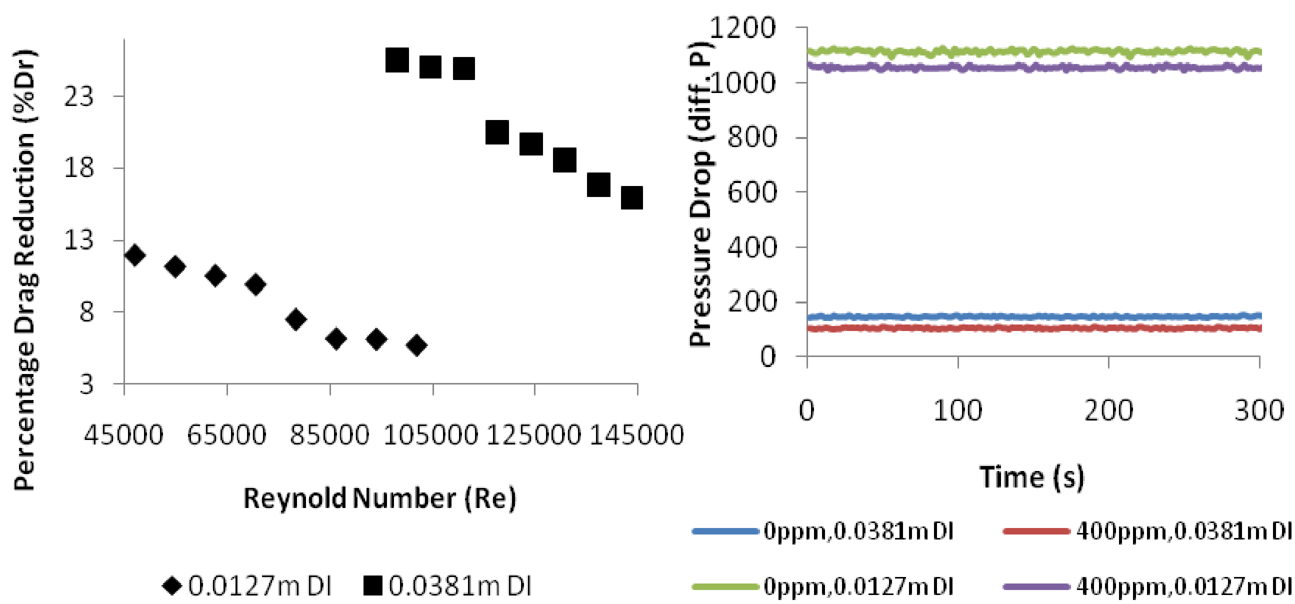


Figure 5. Effect of pipe diameter flowing through 2 m pipe length in fuel and 400 ppm concentration addition and pressure drop data for pipe diameter of 0.0127 and 0.0381 m D.I.

one Re showed different pressure drop from raw data obtained as seen in Figures 3 and 4 for Re = 14000 for fuel and 105000 for water. The analysis in Figures 5 and 6 shows slag particle performance on drag reduction as a function of pipe diameter in hydrocarbon liquid and water and fluid velocity represented by Re which is for 400 ppm in the range of Re equals 45000 to 145000 for fuel and Re equals 32000 to 95000 for water. Scale down for one Re, the different of pressure drop in two different pipe diameters. For hydrocarbon, Re for raw pressure drop data taken at 105000 for 0.0127 m D.I and 145000 for 0.0381 m D.I. For water, Re for raw pressure drop data

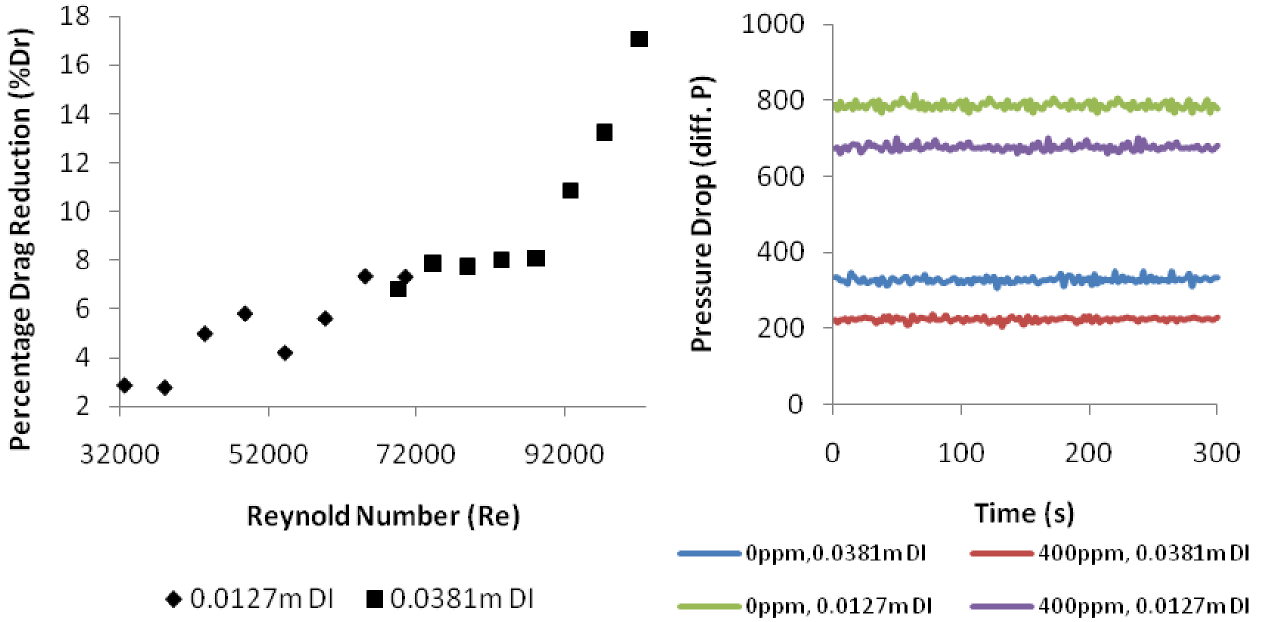


Figure 6. Effect of pipe diameter flowing through 2 m pipe length in water and 400 ppm concentration addition and pressure drop data for pipe diameter of 0.0127 and 0.0381 m D.I.

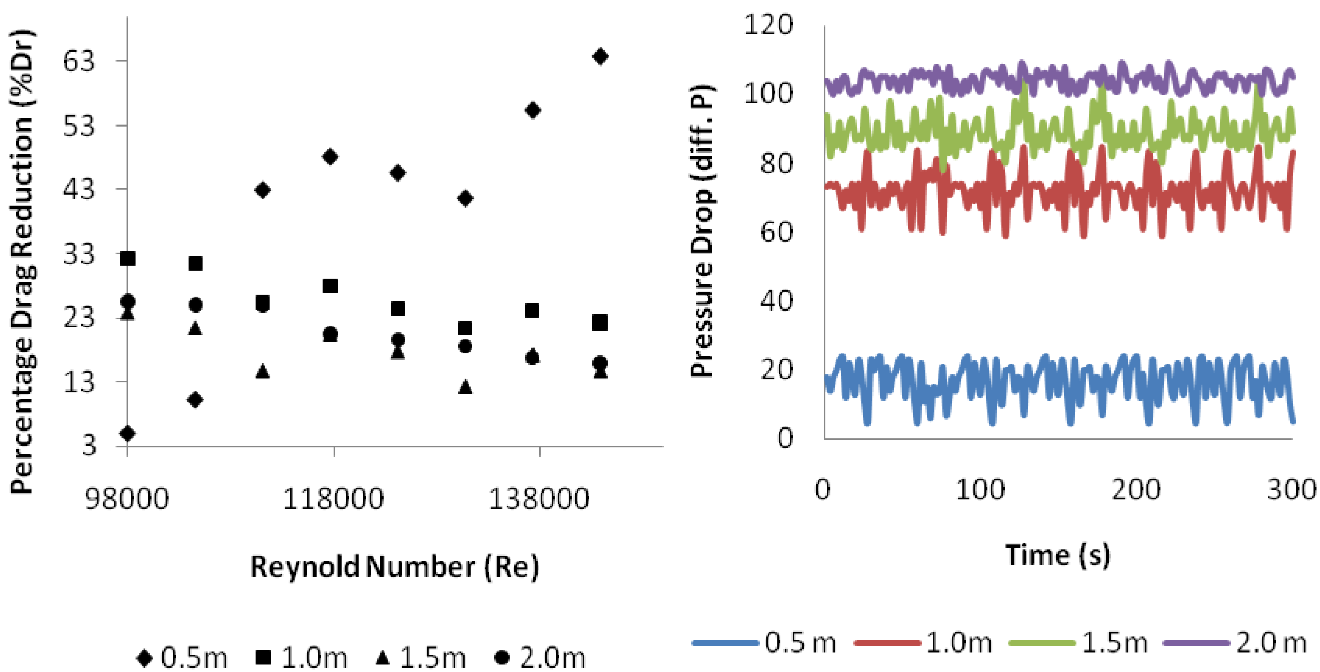


Figure 7. Effect of pipe length in 400 ppm addition concentration flowing in fuel with pipe diameter 0.0381 m D.I and pressure drop data for Re = 139000.

taken at 70000 for 0.0127 m D.I and 95000 for 0.0381 m D.I. The analysis in Figures 7 and 8 shows slag particle performance on drag reduction as a function of pipe length in hydrocarbon liquid and water and fluid velocity represented by Re which is for 400 ppm in the range of Re equal to 98000 to 145000 for fuel and Re equal 65000 to 105000 for water. Scale down for one Re, the different of pressure drop in four different testing sections which

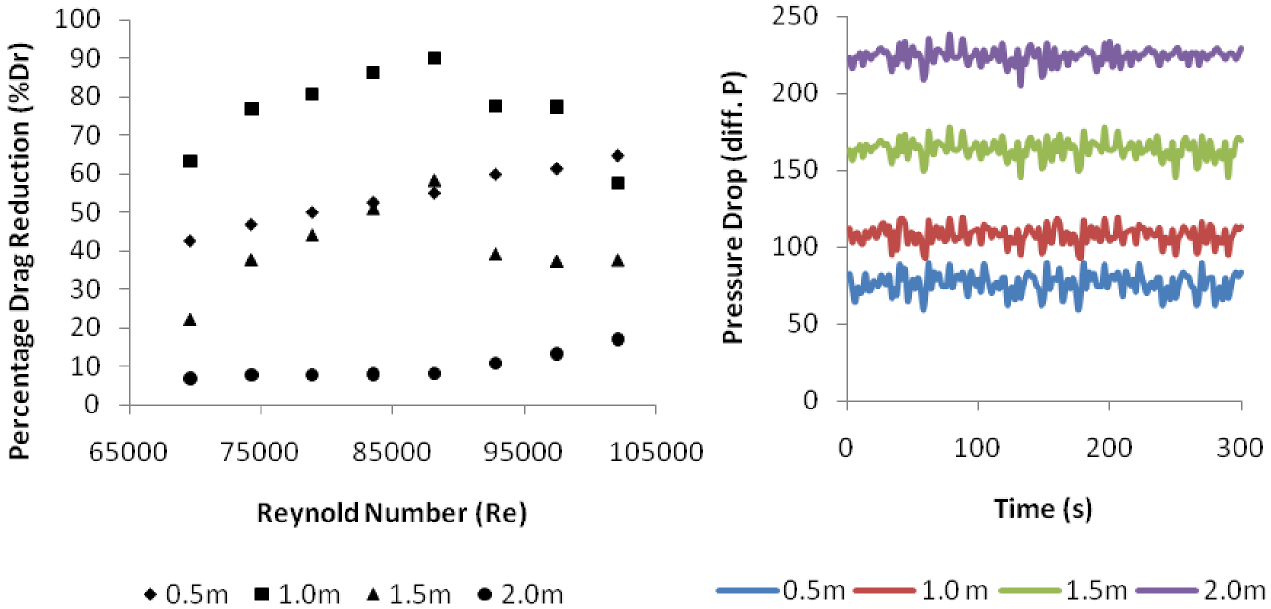


Figure 8. Effect of pipe length in 400 ppm addition concentration flowing in water with pipe diameter 0.0381 m D.I and pressure drop data for Re = 100000.

are 0.5, 1.0, 1.5 and 2.0 m. For hydrocarbon, Re taken at point equal to 139000 and for water, Re taken at point equal to 100000.

DISCUSSION

Note that the profile pattern of each concentration and fluid velocity is similar but varies in its value. Both result shows, either in fuel or water, drag reduction is increased by increasing of particle addition concentration. These data complied with many other researchers such as Rashidi et al. (1990), Roy and Larson (2005), Dyer et al. (2004) and Filipson et al. (1977). There are two result which shows drag reducer performance towards each solvent. These results showed that the optimum performances of suspended solid additive are limited to the degree of turbulence. The increment of fluid velocity in flow will establish a degree of turbulences in its own fluid range. However, there are two explanations that can be made for these two results. For Figure 3, drag reduction efficiency are decreased by increasing Reynolds number. However, drag reduction are still recorded in the flow. For different type of solvent, efficiency for same drag reducer are different. Due to lighter fuel density and viscosity compare to water, slag particle seem too ‘heavy’ to be pushed; so that, along pipe flow, the particle are deposited at the bottom of pipe wall little by little and result to few particle to stay flow with fluid. These phenomena have been explained by Dyer et al. (2004). Figure 4 shows higher fluid velocity gives higher degree of turbulent which will provide more suitable environment or possibility for the drag reduction mechanism to perform. Further increase can happen until it comes to the limitation. Over its degree of turbulent will cause the reduction static due to decrement of additive efficiency. The reason for these phenomena is because of the impairing ratio of additive concentration and degree of turbulence.

Figures 5 and 6 shows the same pattern of drag reduction in function of additive concentration and fluid velocity. However, the value in 0.0127 m D.I is obviously smaller compared to 0.0381 m D.I. Increasing the pipe diameter means increasing the velocity inside the pipe in range of same flow rate resulting in increment of turbulence. The presence of eddies means that the local velocity is not the same as the bulk velocity and that there are components of velocity in all directions. The result complied with Bari et al. (2008). In larger pipe, the energy in the pipe is larger than smaller pipe due to fluid quantity itself. Higher energy is maintained inside large pipe rather than small pipe because of less different of local and bulk velocity hence decrease shear stress formation. However, in smaller pipes, high pressures are obtained because of fluid flow from large area to small area. When pressure is high, shear stress between local velocity and bulk velocity is significantly, resulting to more amount of energy absorbed to form eddies. However, due to higher volume of fluid, higher degree of turbulence are obtained in larger pipes because of higher Reynolds number resulting to higher possible collisions between eddies and more space of DRA to take action. These collisions provide extra number of eddies absorbing energy from the main flow to complete their shape. By addition of DRA, eddies is bursting and pressure can be maintained along the pipes. However, pressure are not at the same maintaining state in order to burst eddies along the pipes. Also include friction of particle itself with pipe walls will reduce the efficiency. This can be proofed by Figures 5 and 6. Both figure shows by increasing pipe length, most of %DR is decreased slightly after maintaining the reduction for a while. For additional information, particle diameter effect towards slag particle flexibility to act as drag reducer. In order to be a good drag reducer, basic criteria such as flexibility and surface roughness should be fulfilled (Singh, 1990). However, fluctuation in drag reduction reading is due to high turbulent intensities which mean that the flow is very unstable. This phenomena happen in all variables (concentrations, time, pipe length and pipe diameter) as can be seen in Figures 3, 4, 5, 6, 7 and 8 for both solvent conditions.

From Figures 7 and 8, drag reduction have occur in first section which means higher drag reduction and the effectiveness lesser within the length due to less momentum inside these particles. As known, slag particle cannot be degraded so that when particles are ‘pushed’ by instable turbulent flow; it then increased the momentum back and performs drag reduction again. These processes will be repeated along the pipe as long as these particle remains inside the flow and not be degraded by any condition. For the industrial activities, longer pipes and bigger diameters are vital in long distance transportation. The patterns that drag reduction have proved can be considered as potential DRA. Due to very stable particles, the drag reduction will give up and down result as explained earlier. However, these particles are maintained to give effect on drag reduction along pipe length without addition of extra DRA. Bigger pipe also give advantages to this DRA since more space for DRA mechanism to perform and give less turbulent intensities hence increased drag reduction efficiency. As proved in these graphs data and present results, there are some weaknesses in using present DRA. Time consumption is needed in order to separate DRA with transported solvent. The separation begins by sedimentation of DRA to bottom of tank and transported solvent can be flow gravitational or by pump to other section for further use. However, because this particle is inert and stable which do not react with transported liquid, letting DRA immersed for a while is not a big problem. These present DRA also give certain advantages compared to polymeric DRA, surfactant DRA and fibers DRA. Compared to other DRA, there were no reinsertions of DRA once added into transported liquid. This will reduce operation cost. By using present DRA, the characteristic and properties of transported liquid will not ever be disturbed. Compare to polymer, degradation is a major problem since polymer chain can broke due to mechanical force (pump rotation) and biodegradable over time. For surfactant, micelle formation due to shear stress will reduce drag reduction efficiency.

In hydrocarbon, surfactant can trap water to move along and will give emulsion. This emulsion is a great problem since to separate required much more time and temperature control. Fibre which categorized as suspended solid also is not very suitable in transporting hydrocarbon since it can change the hydrocarbon characteristic.

Conclusion

It is concluded that slag waste particle is applicable as suspended solid DRA since it is economic, inert (do not react with transported fluid), effective in water and diesel, potentially in refinery products. Several effects have been investigated in order to this new economic solver and how the drag reducing work. It had proved that slag particle will increase %Dr by increasing fluid velocity and concentration and pipe diameter. There is several limitation of using this suspended solid. Suspended solid can be effective in certain range degree of turbulent but will give sedimentation at the base of storage tank. As for recommendation, stirrer can be installed inside tank to ensure particles are evenly distributed. This suspended solid is not harmful to living organism and environment since there is no hazardous chemical that have been used.

ACKNOWLEDGEMENTS

Deepest gratitude is expressed to Universiti Malaysia Pahang and Faculty of Chemical and Natural Resources Engineering for providing the grant and facilities to support this research work. Appreciation extended to the supervisor, co-supervisor and laboratory staff for their guidance, advice, support and encouragements.

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