INVESTIGATING THE EFFECT OF SOLID POWDER PARTICLE SIZE ON THE TURBULENT MULTI-PHASE FLOW IN PIPELINES

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Abstract

Drag reduction has been first reported by Tom in 1949 due to the effect produced by polymer addition in fluids. The problem of pumping power losses in pipeline flow cause the phenomenon drag reduction was introduced. In the present study, aluminium and carbon powder was investigated on the drag reduction efficiency in two phase flow (solid-liquid). The addition small amount of suspended solid particles was tested on water as a transported liquid. The variables that take part are fluid flow rate, concentration of suspended solid particle, size of suspended solid particle, type of suspended solid particle and pipe length (testing point distance). The variable is manipulated according to the subject studied. The experimental works is conducted in a closed loop of turbulence water flowing system. The obtained data was analyzed and the result show that the maximum percentage of drag reduction (Dr%) is 70% is achieved from the experiment. Some result shows that there is instability in the percentage of drag reduction (Dr%) the manipulated variables. Carbon particle were found possible to behave as a DRA but for the aluminium particles produce instability in the results.

Keywords: Drag reduction, suspended solid particles, power saving, two phase flow, turbulent flow.

1.0 Introduction

In pipe line, drag is major factors that cause the energy loss. Drag can be defined as the mechanical forces that resist the movement of fluid (liquid or gas) in transporting system. In fluid dynamics, drag was expressed by two components: skin friction component which is equal to the stream wise component of all shearing stresses over the surface and pressure drag component which is equal to the stream wise component of all normal stresses (Hayder et al, 2009).

Since the subject of drag reduction encompass a wide range of disciplines including hydrodynamics, fluid mechanics, computing simulation, rheology, polymer science, material science and chemistry, a large number of investigation on drag reduction have appeared in various scientific journals over the years. Drag reduction have been applied widely mostly in the industrial sectors. The most successful of drag reduction application was accomplished through the Trans Alaska Pipelines in 1979. It was the first large scale use of hydrocarbon soluble as drag reducing agents.

Pumping power loss in the pipeline become major headlines and as the point to solve the matter, drag reduction was introduced. When the pressure drop is high, more energy that carrying liquid is loss and then more pump power is needed to push the liquid in the pipeline. As the point to solve the matter, drag reduction was introduced. Drag reduction can be defined as the increase in pumpability of a fluid caused by the addition of small amounts of another substance known as drag reducing agent to the fluid (Savin, 1960). The main purpose of drag reduction is to delay the onset of turbulent flows. It is well known that the addition of a small amount of additives to a turbulent Newtonian fluid flow can result in a drag reduction and received attention since publication of (Mysels, 1949).

In liquid pipelines transportation, the addition of chemical additive will lead to the drag reduction phenomenon. Drag reduction can be achieved with several types of additives. It can be classified in three categories which is polymer, surfactants and suspended solids. The most spectacular of drag reduction is obtained through the addition of small amount of soluble polymers of certain types to the fluid (Zakin et al, 1969). Many of researchers have proven the efficiency of the chemical additive in their investigations.

The classification of the suspended solids (insoluble in liquid media) as Drag Reducing Agents opened the door wide for more research regarding the availability of the solubility condition in the drag reduction phenomena. Zandi et al. (1967) experimental show that the suspensions maybe considered as two different types granular or nearly spherical particles and fibers. He measured friction factors for the flow of water suspensions of coal, fly ash, clay and activated charcoal. He found drag reduction up to 57% for 1% clay flowing at 6 f/s in the 2-in. pipe. There a numerous investigation was carried out in the past few years to study the effect of suspended solid particles on the drag reduction efficiency.

Vanoni and Nomicos (1960) were interested in the anomalous behavior of natural streams of water laden with sand and other materials. It had been observed that such streams sometimes showed lowered flow resistance (higher flow rate at the same water level) but at other times increased flow resistance when heavily laden. Experimental work in flumes had failed to resolve the problem. Vanoni and Nomicos showed that the suspension loading and the particle properties (size, density, and shape) affected the amount of settling in the stream. With heavy settling and the formation of dunes, resistance was increased. With little settling, resistance could be decreased by as much as 28% below clear water. They used various grades of sand in their experiments in a 10-in. wide flume with liquid depths of about 3 in.

Lee et al. (1974) studied turbulent drag reduction in homogeneous mixture of polymeric solution and fibres. Their results indicated a maximum drag reduction of the order of 95%. These researchers further observed that the polymer possesses the ability to augment the drag reduction of the fibre suspension, although by itself it may not result a reduction of the drag. The addition of fibres to a degraded polymer solution has been found to have a high percentage drag reduction more than use degradation polymer alone.

Wang et al. (1998) studied clay suspensions flowing over smooth gravel, and stone beds. At high concentrations, all flocs in clay suspension connect together and form a three-dimensional net structure, which affects the resistance in two ways that is by damping turbulence and by increasing the viscous resistance. For flows over rough boundaries, turbulent shear dominates the resistance and high clay concentrations cause drag reduction. For flows over a smooth bed, the effect of damping turbulence was counterbalanced by the effect of increasing viscous resistance. Therefore, no drag reduction occurred.

Kale and Metzner (1969) experimented with mixtures of nylon fibres and polyethylene oxide. They concluded that the unusual and superior drag-reduction characterize of mixed polymer-fibre systems are not merely specific to one or two fortuitous formulations but represent a general phenomenon.

H.A .Abdul Bari and R.B. Mohd Yunus et al. (2009) studied the effect of addition small amount of surfactants and solid particle into the transported kerosene. Their experiment shows that percentage of drag reduction is increase by increase the suspended solid particle concentration, suspended particle size, surfactants concentration and solution velocity.

Sheen, Jou and Lee et al. (1994) in their paper stated that the important parameters related to the two phase flow and suspension particle:

a) Characteristic length and characteristic velocity of the flow
b) Size of the suspension particle
c) The density ration between the suspension particles and the flow
d) Mass loading ration, or the ratio between particles mass flow rate and fluids mass flow rate
e) Body forces that affect the particles in the flow, such as in the gravitational field, electric field and magnetic field
f) Electrostatic effects formed on the particle surface while the particle is moving in the flow field

2. Materials and Methods

2.1 Liquid Circulation System

Figure 1 shows a schematic diagram of a build up liquid circulation system used in the present study. Generally, this system consists of reservoir tank, pumps, pipes, valve, pressure transmitter and flowmeter. The reservoir tank was supported with two exit pipes connection. The first exit pipe is connected to centrifugal pump while the other exit pipe is for discharge purpose. The system was build up with three galvanized iron pipe with diameter inside 0.015, 0.025 and 0.038 m. for this present study, only pipes with 0.038 m ID were use because we don't investigating the effect of diameter to drag reduction efficiency. The piping starts from reservoir tank through the pump and then splits into three sections with different pipe diameters at testing point. The testing point sections were 2 m long and it was located about 50 times of pipe diameter to ensure the turbulent flows are fully developed before the testing point. In order to measure the flow rate of fluid in pipelines, Ultraflux Portable Flow Meter Minisonic P has been used.

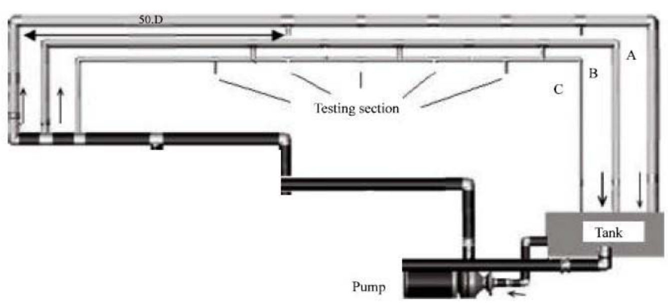

Figure 1.0: Closed loop of turbulence flow system

2.2 Materials Investigated

Aluminium and Carbon powder was selected as a samples for this present study because high difference in properties especially in desity. The density of Aluminium is 2700 kgm^{-3} while the carbon is 1800 kgm^{-3}.

2.3 Transported Liquid

The transported liquid used in the present study was waster. The physical property of water is shown in table 1:

Water properties @ 25^0C	Values
Viscosity (µwater @ 25^0C)	0.8973×10^{-3} Pa.s
Density (ρwater @ 25^0C)	997.08 kgm^{-3}

Table 1: Physical Properties of Water

2.4 Experimental Procedure

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

- Suspended solid type (Aluminium and Carbon powder)
- Suspended solid size (200µm and 400µm)
- Suspended solid concentration (100, 300, 500 700 and 900ppm)
- Solution flow rate (4.5 , 5.0, 5.5, 6.0 6.5, 7.0, 7.5 and 8.0 m^3h^{-1})
- Pipe length-testing point distance(1.0, 1.5 and 2.0 m)

The experimental procedure starts by testing one of the selected suspended solids in certain concentration and particle diameter and the mixing these particles with the water at the reservoir tank. The operation begins when the pump starts delivering the solution through the testing section. The solution flow rate is fixed at certain value by controlling it from the bypass section. Pressure reading is taken from computerized system. By changing the solution flow rate to another fixed point, pressure readings are taken again until finishing the eight desired values of flow rates. This procedure is repeated for transported water before and after addition of suspended solid particles to test its effect on the drag reduction operation.

2.5 Experimental Calculation

Velocity and Reynolds number calculations:

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

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

Percentage drags reduction calculations:

Pressure drop readings through testing sections before and after drag reducer addition were needed to calculate the percentage drag reduction Dr% as follow (Virk, 1975):

$$\%Dr = \frac{\Delta P_b - \Delta P_a}{\Delta P_b}$$

3. Result and discussion

3.1 Effect of suspended solid particles size

Two size of suspended solid particle were use in the present investigation which is 200µm and 400µm. Figure 3.1 and 3.2 shows that the Dr% for selected sample of a particle size effect data within certain solid particle types, concentration, pipe length and at the same Reynolds number. The result clearly shows that the Dr% of particle with 400µm is higher than the 200µm particle size. This happen may be because larger particles need larger momentum to transport it in the water and that make it difficult to control by the turbulence flow. The larger particles size make the eddies difficult to make the particle part of its shape and its lead the particles to break the larger eddies. The larger momentums from the particle then cause the decreasing in the turbulence flow. The momentum then acts as turbulence breaking agents which the increasing the Dr%.

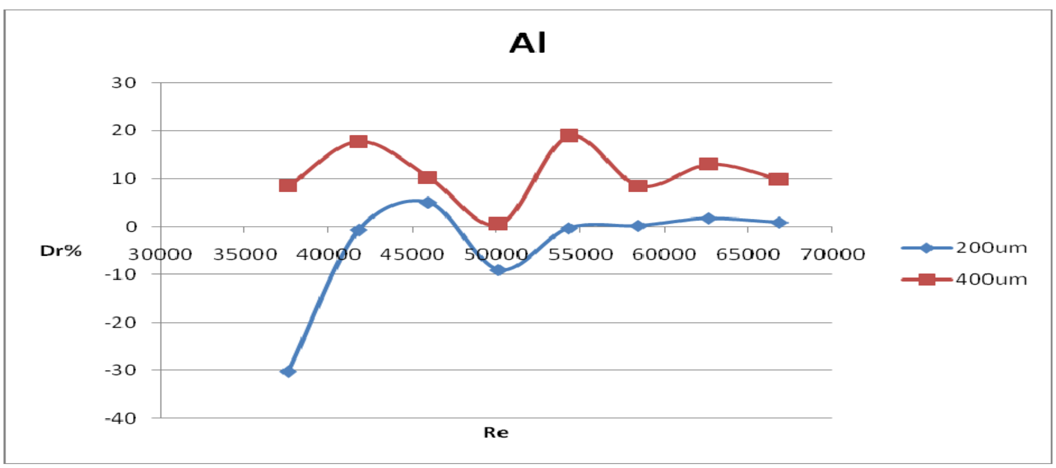

Figure 3.1: Effect on changing the particle diameter (200µm to 400µm) on the Dr% for transported water with aluminium as suspended solid with different Re.

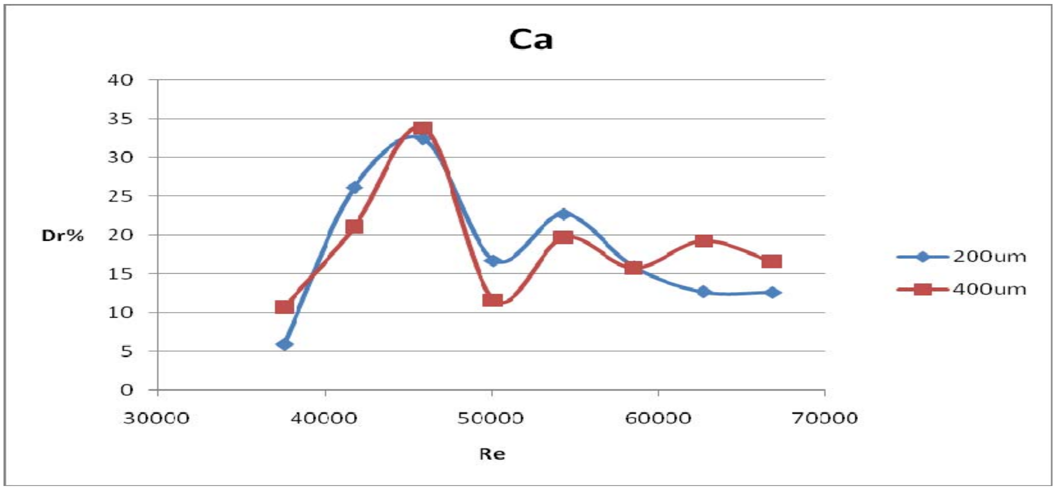

Figure 3.2: Effect on changing the particle diameter (200µm to 400µm) on the Dr% for transported water with carbon as suspended solid with different Re.

3.2 Effect of suspended solid particles type

Figure 3.3 and 3.4 shows that comparison in the Dr% for selected samples data of the two types of solid suspended solids used which is Aluminium and Carbon within certain particle size, concentration and at the same Reynolds number. From the figure it can be noticed that the Dr% for the carbon powder is higher than aluminium powder for both 500 and 700ppm particle concentrations. It may be due the difference in the physical properties for both powder especially in the density (carbon = 1800kgm^{-3} and aluminium = 2700kgm^{-3}) which makes the carbon particle have the large effect on the turbulent inside the pipe. Aluminium powder have the lower effect on Dr% may be because it have heavier particles and it tend to accumulate at the bottom part of reservoir tank and pipes. When there is some amount of particle accumulates, the effect of particle on drag reduction will be lower than the effect of lighter particles.

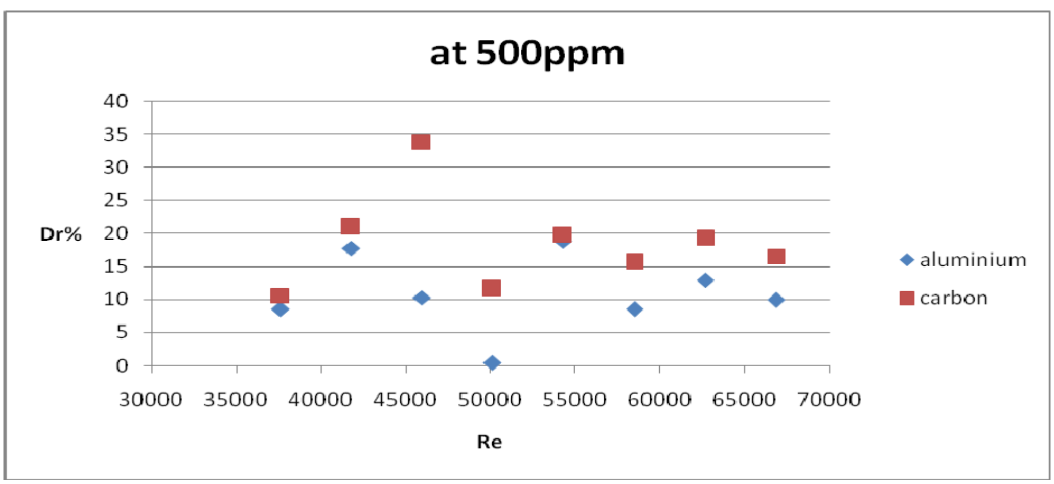

Figure 3.3: Effect of particle types (aluminium and carbon) on the Dr% for transported water with solid concentration of 500ppm.

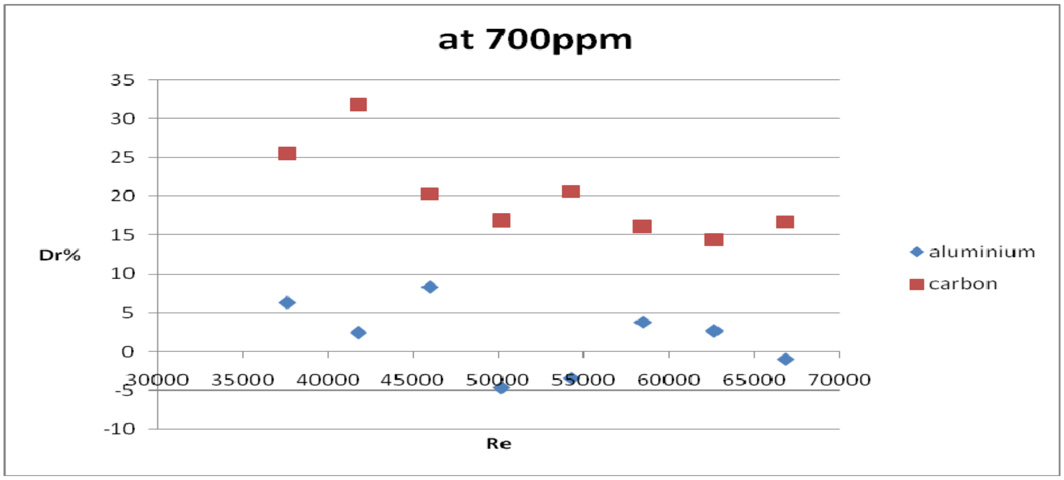

Figure 3.4: Effect of particle types (aluminium and carbon) on the Dr% for transported water with solid concentration of 700ppm.

3.3 Effect of pipe length (testing point distance)

The experimental result was collected at three different testing point distance which is 1meter, 1.5meter and 2meter. The figure 4.9 to 4.18 shows that Dr% for the effect of pipe length within certain particles size, types, concentration and at the same Reynolds number. The result for both particle (aluminium and carbon) shows that the larger length of pipe (further testing point distance) has the highest Dr% compared to the shorter length. This may be due the residence time have by the particles in the pipeline. The larger length of the pipeline, larger residence time has by the particle to decreasing the turbulence flows. At the certain point, the result for 2 meter distance of testing point for both type particles, produce the highest Dr%. When the testing point is further, the more time have by the particle to involve in the drag reduction process.

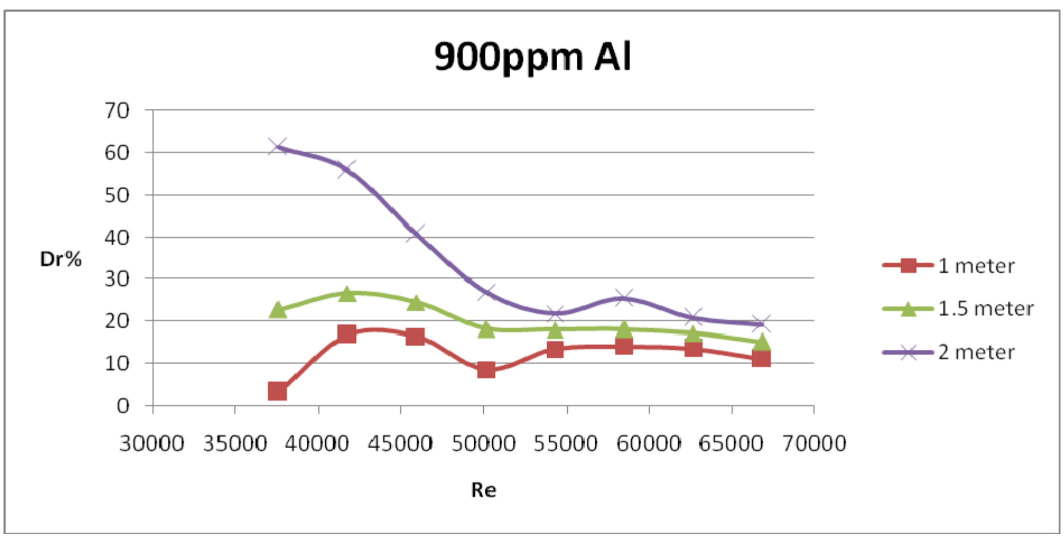

Figure 3.5: Effect of pipe length (testing point distance) on Dr% for transported water with aluminium particle (400µm) with addition of 900ppm concentration as suspended solid.

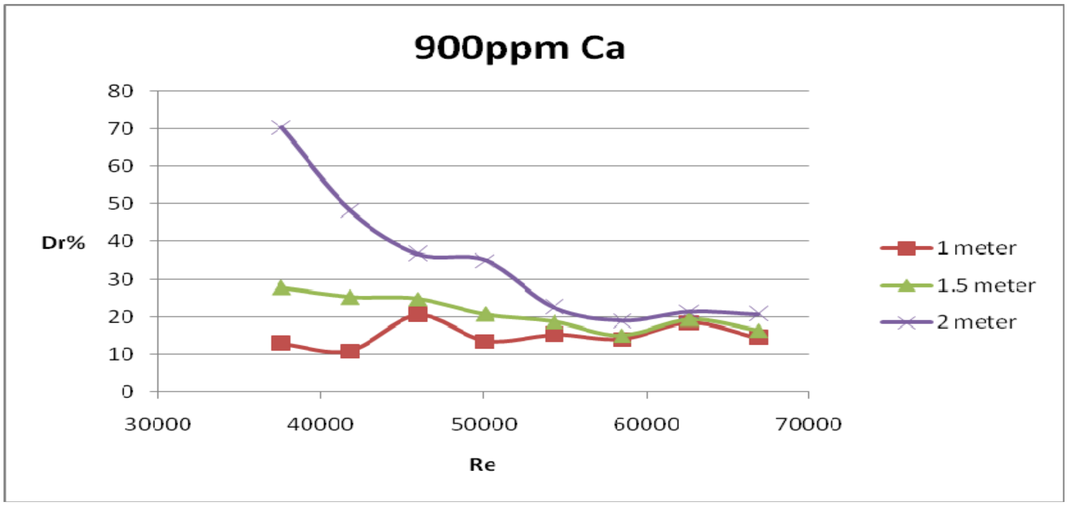

Figure 3.6: Effect of pipe length (testing point distance) on Dr% for transported water with carbon particle (400µm) with addition of 900ppm concentration as suspended solid.

3.4 Effect of suspended solid concentration and fluid velocity (Re)

Figure 3.7, 3.8, 3.9 and 3.10 shows the effect of the transported fluid velocity on Dr%. The velocity was represented by the dimensionless form of Reynolds number (Re). Figure 3.7 and 3.8 shows the effect of Reynolds number on Dr% for transported water with aluminium (200µm and 400µm) and with different addition of concentration and at certain pipe length (testing point distance). While the figure 3.9 and 3.10 shows the effect of Reynolds number on Dr% for transported water with carbon (200µm and 400µm) and with different addition of concentration and at certain pipe length (testing point distance). For both particles (carbon and aluminium), there are no such clear difference in the Dr% for the effect of Reynolds number because the graph is going up and down with instability. The highest Dr% is achieved when the Re is 45950 for both sizes of aluminium particles at 700ppm concentration. For both sizes carbon powder, the highest Dr% also achieve when the Re is 45950. At Re 45950, the turbulent provide suitable media for the both types and size particle to work properly and produce the maximum Dr%.

At the figure 3.7, 3.8, 3.9 and 3.10 the result shows that there is instability in the effect of particle concentration. Figure 3.7 and 3.8 shows that the aluminium (200µm and 400µm) with the addition 700ppm has the highest Dr%. The addition of 700ppm of particle concentration give the highest Dr% for aluminium powder may be because at 700ppm and at Re 45950, most of the particle involved in the drag reduction process. While for the highest Dr% for the carbon (200µm and 400µm) is with the addition 500ppm of concentration is shown at figure 3.9 and 3.10. The addition 500ppm of carbon particle concentration produce the highest Dr% may be because at 500ppm and at Re 45950, most of particle was involved in the drag reduction process.

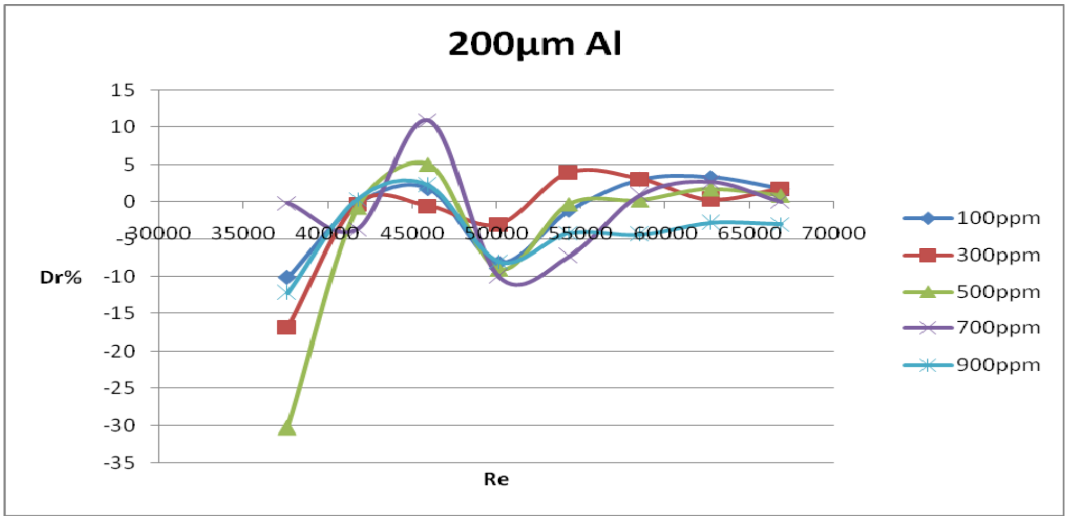

Figure 3.7: Effect of Re on Dr% for transported water with Aluminium solid particles (200µm) with different addition concentrations as suspended solid.

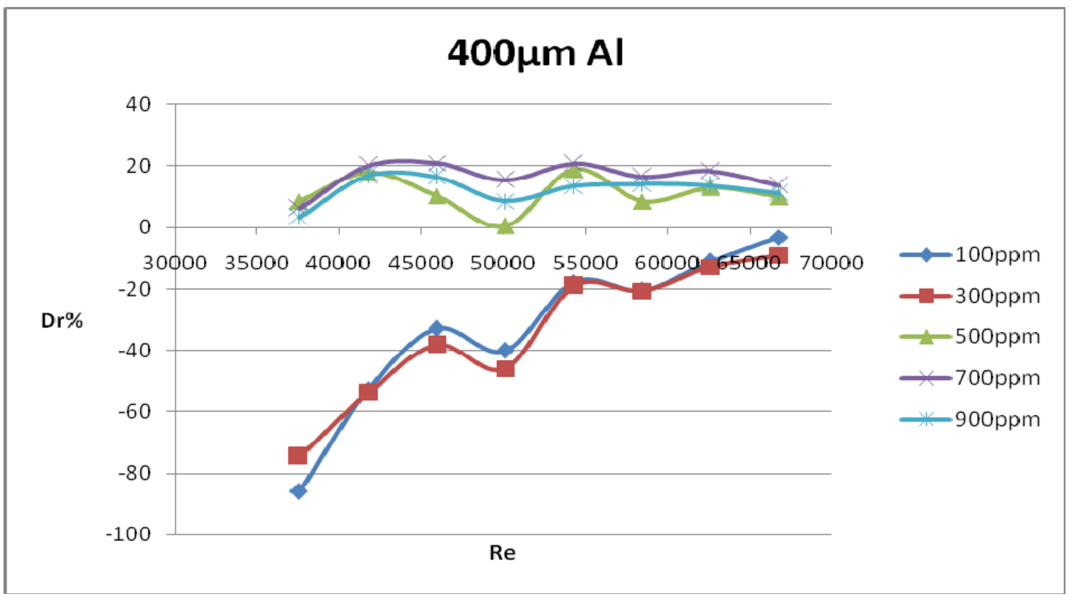

Figure 3.8: Effect of Re on Dr% for transported water with Aluminium solid particles (400µm) with different addition concentrations as suspended solid.

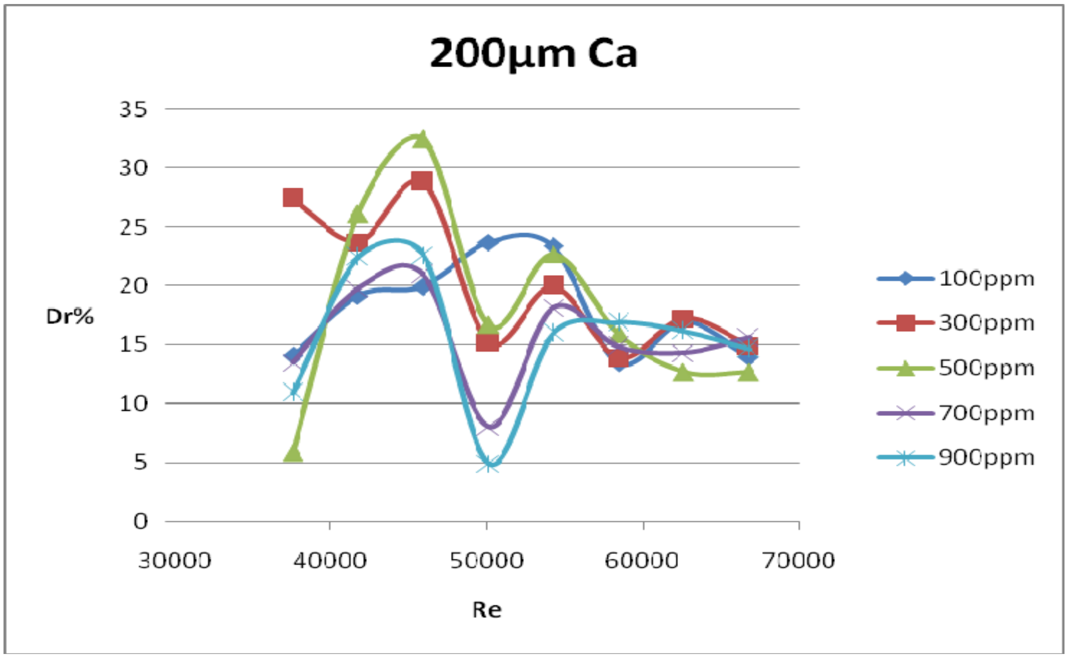

Figure 3.9: Effect of Re on Dr% for transported water with Carbon solid particles (400µm) with different addition concentrations as suspended solid.

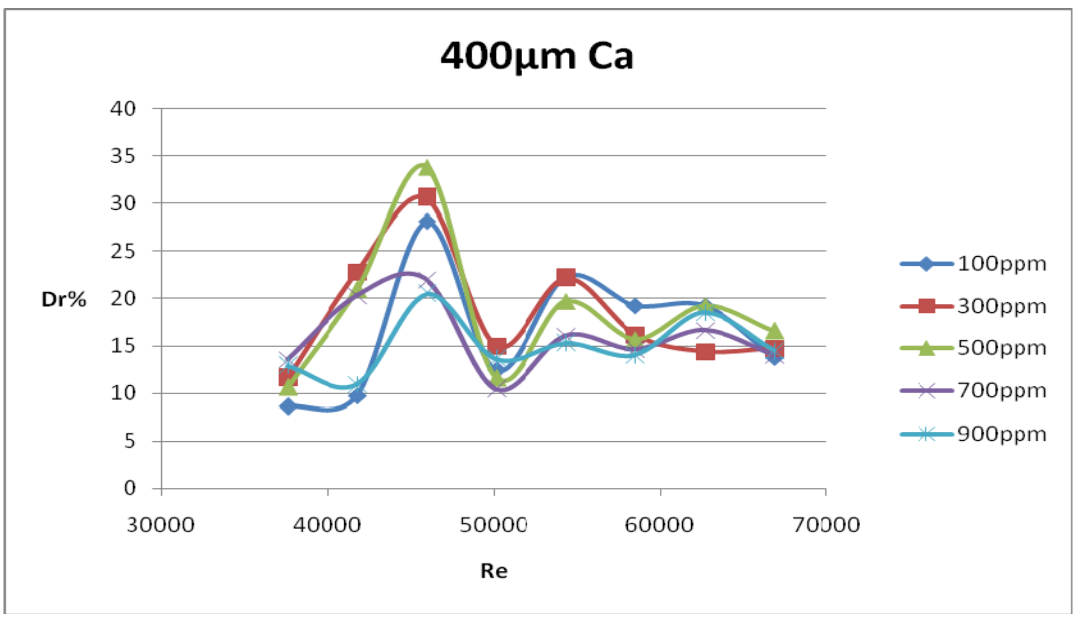

Figure 3.10: Effect of Re on Dr% for transported water with carbon solid particles (400µm) with different addition concentrations as suspended solid.

4.0 Conclusion

In the investigation, the maximum Dr% of 70% was achieved. Dr% was found increase when increase the size of suspended particle and increase testing point distance. Dr% was found increase when decrease the fluid velocity (Reynolds number). Addition both solid particles (aluminium and carbon) on the transported water produce instability in the result.

For this present study, most result for the effect of carbon powder produce a positive result and were found possible to behave as DRA. While for the aluminium powder, there are instability in the results and it's hard to know the possibilities of the aluminium powder to be a possible DRA or not.

As the recommendations, to prove aluminium and carbon powder can be use as DRA, a serious investigation is needed to ensure it can produce the good or bad result on the drag reduction.

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A thesis submitted in fulfillment of the requirements for the award of the degree of

Bachelor of Chemical Engineering (Gas Technology)

Faculty of Chemical and Natural Resources Engineering

Universiti Malaysia Pahang

MARCH 2011

DECLARATION

I declare that this thesis entitled *"Investigating the Effect of Solid Powder Particle Size on the Turbulent Multi-phase Flow in Pipelines"* is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………………...

Name : **MOHAMMAD RAZIF BIN ABDUL RAHMAN**

Date : **MARCH 2011**

DEDICATION

Special to:

To my beloved parents and siblings

Thankful to

My supervisor for his kindness helping me all the way

ACKNOWLEDGEMENT

First of all, I like to express my gratitude to Allah s.w.t because giving me a good health condition during the period of finishing this project. The opportunities by doing this project have taught me lots of new things.

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Thank you very much.

ABSTRACT

Drag reduction has been first reported by Tom in 1949 due to the effect produced by polymer addition in fluids. The problem of pumping power losses in pipeline flow cause the phenomenon drag reduction was introduced. Drag reduction be defined as the increase in pumpability of a fluid caused by the addition of small amounts of another substance to the fluid. In this present study, aluminium and carbon was investigated as drag reducing agents in two phase flow and the flow tested were conducted using water as the carrying liquid. The variables that take part are flowrate, concentration of suspended solid particle, size of suspended solid particle, type of suspended solid particle and pipe length (testing point distance). The variable is manipulated according to the subject studied. The experimental works is conducted in a closed loop of turbulence water flowing system. The obtained data was analyzed and the result show that, in the effect of types of particles, carbon powder produce the higher percentage of drag reduction compared to aluminium powder. That means carbon is better DRA compared to aluminium. Both particles with size 200µm produce higher percentage of drag reduction compared to the particles with size 400µm. The result also show that the addition of 700ppm of particle give the higher percentage of drag reduction for both types of particles. This experiment also show that higher percentage of drag reduction is achieved when the Reynolds number (Re) is 45950 and at 2m pipe length. The maximum percentage of drag reduction (Dr%) is 84% achieved from aluminium 400µm with 700ppm at 2m pipe length. The result also shows that there is instability in the percentage of drag reduction (Dr%) for all the variables. Carbon particle were found possible to behave as a DRA but for the aluminium particles, there are no clear explanation about the results.

ABSTRAK

Pengurangan heretan pertama kali dilaporkan oleh Tom pada tahun 1949 disebabkan kesan yang dihasilkan dari penambahan polimer terhadap bendalir. Masalah kehilangan kuasa mengepam didalam saluran paip menyebabkan phenomena pengurangan heretan di cetuskan. Pengurangan heretan boleh didefinasikan sebagai peningkatan abliti mengepam bendalir disebabkan penambahan sesuatu bahan yang lain dalam jumlah yang sedikit terhadap bendalir. Dalam kajian ini, aluminium dan karbon telah dikaji sebagai ejen pengurangan geseran didalam arus dua fasa dan arus tersebut telah diuji dengan air sebagai medium pengangkutan. Pembolehubah yang digunakan dalam kajian ini ialah kadar kelajuan bendalir, kepekatan serbuk solid, saiz serbuk solid, jenis serbuk solid dan panjang paip (jarak titik ujian). Pembolehubah diubah mengikut objektif kajian. Kerja eksperimen dilakukan dengan menggunakan system loop tertutup untuk pengaliran air yang turbulent. Data yang diperolehi telah dianalisis dan keputusan menunjukkan maksimum persen pengurangan geseran adalah 84% diperolehi dari serbuk aluminium (400µm) dengan kepekatan 700ppm dengan titik ujian pada jarak 2 meter. Keputusan juga menunjukkan ada ktidakseimbangan pada persen pengurangan geseran (Dr%) untuk semua pembolehubah. Serbuk karbon telah dikenalpasti berkebolehan menjadi ejen pengurangan daya tetapi untuk serbuk aluminium, tiada penjelasan yang kukuh boleh dibuat berdasarkan kepetusan yang diperolehi.

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