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Investigating Drag Reduction Characteristic using Okra Mucilage as New Drag Reduction Agent

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Abstract: A concern in reserving environment from water pollution is a trigger for this investigation. Abundant source of okra in Malaysia, as well as cheap and easy to get are the advantages. Okra mucilage extracted from okra pod can be additive to reduce drag in pipeline and conserve the energy along pipeline. In this study, the effect of the presence of a Drag Reducing Agent (DRA) on the pressure drop in horizontal pipes carrying water is investigated. An experimental rig is set-up. The test section of the experimental set-up is consisted of: a smooth PVC pipe with length of 50 time pipe diameter connected to rough galvanized iron with 5 testing section 0.5 meter each The employing DRA is a new natural additive which is okra mucilage as polymeric DRA. The percent drag reduction (%DR) is calculated using the obtained experimental data, in presence of the DRA. The results show that addition of DRA could be effective with several doses of DRA after average reading for 5 min. Highest %DR for about 60% is obtained for some experimental conditions. The result shows that okra mucilage is a potential DRA to be use in water transportation.

Key words: Natural DRA, percentage drag reduction, pipeline system, turbulent flow

INTRODUCTION

The well-known phenomena know as Tom Effect suggested by Toms (1948) stated that the addition of small concentrations of high molecular weight polymer to water or other solvent can produce large reductions in frictional pressure drop for turbulent flows hence leading to the possibility to maintain the flow energy resulting increment in pipeline capacities. Liquid flow such as water is frequently encountered in long-distance liquid transportation, sewage and flood water disposal, fire fighting, transport of suspensions and slurries, irrigation, water-heating and cooling circuits, jet cutting, marine and biomedical operations (Den Toonder *et al*., 1997) and many industrial units such as distillation columns, pipelines, boiler tubes, condensers, evaporators and chemical reactors.

Turbulent flow has many unique features that must be evaluated in each situation. However, high axial pressure gradient phenomenon is nearly always undesirable is the, resulting large energy usage per unit volume of liquid throughput. It can be seen from the literature survey that although some studies have been done on drag reduction by polymer solution in single phase flow.

Small amounts of certain materials are surfactants, fibers or suspended solid (insoluble in aqueous media) and polymers included in range of macromolecules (Gyr and Bewersdroff, 1995) may give significant drag reduction in wall bounded flow. Many of previous research (Ptasinski *et al*., 2003; Bari *et al*., 2010; Mowla and Naderi, 2006) have focused on wall bounded flow such in pipelines because of their importance in technological utilization in this modern day. Allied to this study, there are wide attention of using minute quantity of high molecular weight polymer to reduce pressure drops and friction inside flow.

The mechanism of this boundary layer effect is still doubt but supporting experimental evidences have been given by Choi *et al*. (2000), Shetty and Solomon (2009) and Dubief *et al*. (2004). Drag reduction mechanism are still do not have sturdy exact explanation on how the mechanism occur. Roy and Larson (2005) cited that high extensional stress in dilute polymer solution have been reported in earliest explanations on drag reduction mechanism including a “viscous” mechanism proposed by Lumley (1969) and an “elastic” mechanism proposed by De-Gennes (1990).

However, certain of industrial polymeric DRA are harmful to environment either realized or not. These

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present research has emphasizes of using natural DRA. Using natural DRA is one of major concern in this modern day. The natural DRA is okra mucilage. The reasons of choosing okra mucilage are abundant production in Malaysia, easily found, biodegradable and cheap. Details of okra can be found in methodology.

The aim of this study is to test the efficiency of new natural polymer which is okra mucilage as drag reduction agent on transporting water in pipes. Different concentration (100, 200, 300, 400 and 500 ppm) and certain range of fluid velocity of polymer where used. Two pipe diameter and four length section within 5 min of flow being tested for the efficiency.

MATERIALS AND METHODS

This research has been carried out at circulation Clean Room and Open Laboratory, Faculty of Chemical Engineering and Natural Resources, University Malaysia Pahang, Malaysia. For closed loop liquid circulation system, the experiment has been done at Open Laboratory. For rheological test, the analysis has been conducted in Clean Room. This research has been supported by grant from University Malaysia Pahang, RDU 070110. This research was conducted in two years starting from February 2010.

Liquid circulation system: Liquid circulation system was build 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 flow from reservoir tank directly into testing pipes before flow back into reservoir tank.

Two visible PVC pipes connected to galvanized iron pipes of various inside diameters 0.0254 and 0.0381 m ID were used in constructing the flow system. A complete closed loop piping system was build. Flow starts from the reservoir tank through the pump reaching a split connected with three different pipes diameter with testing section. The testing sections were 0.5, 1.5 and 2.0 m long.

First testing point was located about 50 times of pipe diameter to ensure the turbulent flows are fully developed before the testing process run. Five sets of build up pressure sensors especially design for industry were used to detect the pressure drop in pipelines. In order to measure the flow rate of fluid in pipelines, Ultraflux Minisonic Portable Flow Meter has been used.

Equipment used: Ultrasonic portable flow meter measurer has used in this present research. The principal used in using this equipment is time transit principal. The measurement was sensitive with small changes in flow rate as low as 0.001 m sec^{-1} can be detected. There are two operations provided by Ultraflux ultrasonic portable flow meter which are velocity measurement from one or several chord and flow rate from several velocity calculation. The measurement of flow rate depends on length and diameter of pipe. The advantages of using ultrasonic portable flow meter are it is independent of sound velocity inside the fluid, the reading are average taken along the testing points. However, ultrasonic portable flow meter do not provides any pressure drop reading. Details of this equipment can be found in Ultraflux: Ultrasonic flow measuring by time transmit principle.

Material used: Raw material used in this study, is okra mucilage. The okra mucilage obtains immersed okra in clear water for overnight and sieved. The ratio for okra to water is 1:2. The scientific name of okra is *Abelmoschus esculentus* and occasionally referred to as *Hibiscus esculentus* L. The type of okra used is Clemson Spineless okra which is usually found in Malaysia or other equatorial climates countries. Okra mucilage is polysaccharide that derived from plant exudates that give gelling and adhesive effect. Ganji *et al.* (2008) reported that okra mucilage is water soluble which consist of 1.7 million molecular weight of glycoprotein which produces viscous, shear thinning and visco-elastic solutions in water.

Transported liquid: The transported liquid used in the present investigation was water. The physical properties of water are shown in Table 1.

Experiment progress:

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

- Fluid Velocity (m^3 h^{-1})
- Pipe Length (0.5, 1.5 and 2.0 m)
- Pipe Diameter (0.0127, 0.0254, and 0.0381 m DI)
- Time (1, 2, 3, 4, and 5 min)

The experimental procedure starts by testing every pipe length and pipe diameter, the operation begins when the pump starts delivering the solution through the

Table 1: Physical properties of water

Water properties at 27°C	Value
Viscosity ($\mu_{\text{water at 25°C}}$)	0.852×10^{-3} Pa.s
Density ($\rho_{\text{water at 25°C}}$)	996.59 kg m^3

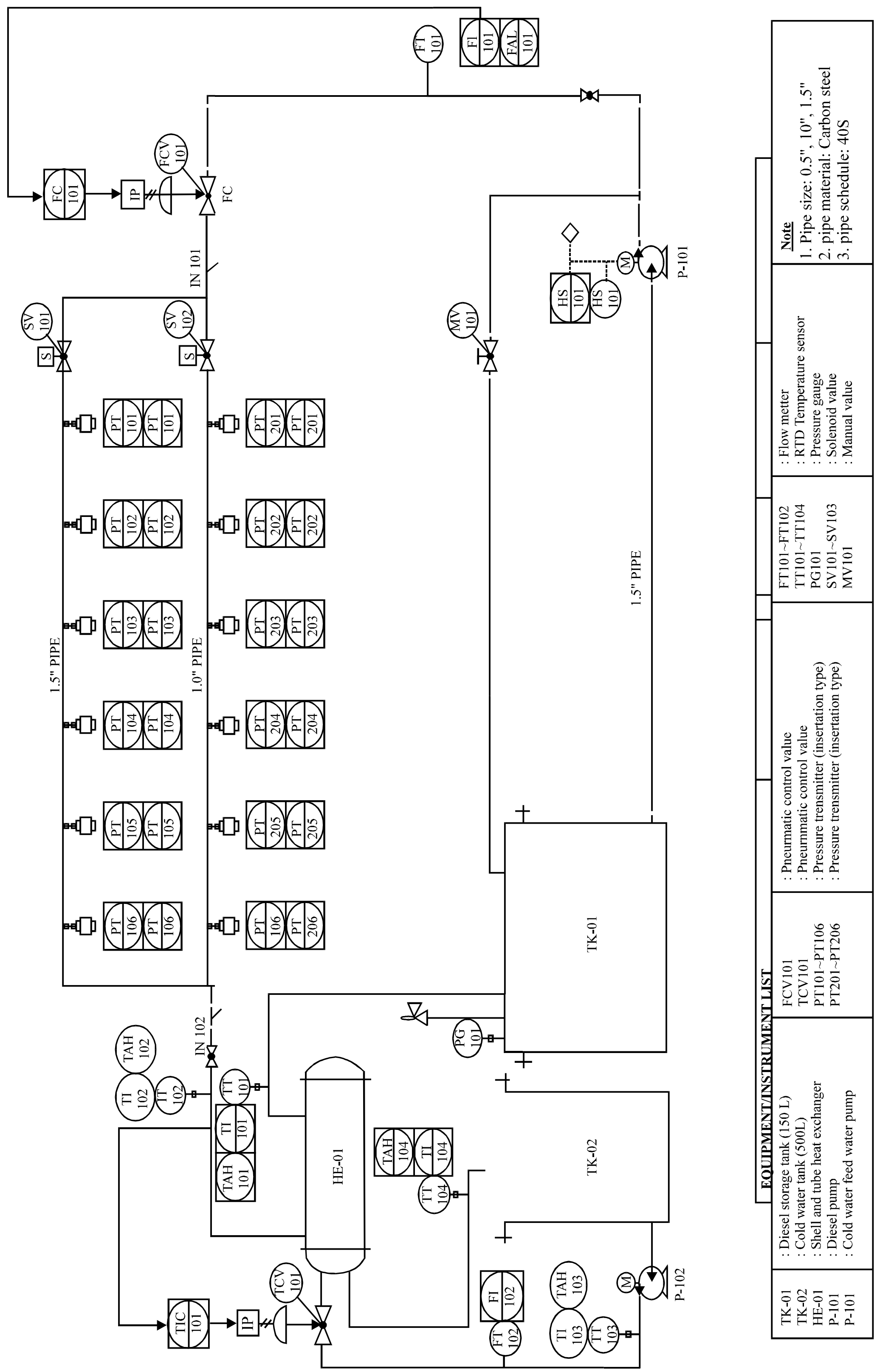

Fig. 1: Schematic of the flow system

testing section. The solution flow rate is fixed at the certain value by controlling it from the bypass section. Pressure readings are taken according to testing section. Changing the solution flow rate to another fixed point, pressure readings are taken again until certain pressure limit. This procedure is repeated for each pipe diameter and concentration to test its effect on the drag reduction operation.

Experimental calculation

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:

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

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 *et al*., 1967):

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

Rheology test

Density: Density of polymer-water solution has been determined by gas pycnometer. Micromeritics AccuPyc II 1340 has been used in this present investigation. This equipment consist of sample cup, chamber cap ring, filtered cup, gas regulator and control panel with display. This instrument used to detect volume and density measurement of phases such as slurry, liquid, powder and solid. For this research purpose, specific gravity of solution with concentration 100, 200, 300, 400 and 500 ppm. Density of water used is 1 g cm^3. Accuracy level of this equipment is 0.03% of reading accuracy and 0.03% maximum sample size accuracy.

Viscosity: Viscosity of water-polymer solution has been investigated by using Brookfield DV-III Ultra Programmable Rheometer. This equipment consists of rotor base, water jacket, straight bar, helipath spindle set, ballast and closed assembly. This instrument can predict the material flow, spray and pumping characteristic by studying shear rate. The advantage of using this equipment is it continuous displays the viscosity, temperature, shear stress and torque percentage.

Surface tension: Surface tension of water-polymer solution has been investigated by using Surface Electro Opties DST 60 M Surface Tension Analyzer. This equipment consists of Nu Douy Ring, automatic/manual lift system, glass container and display. It operated by immersing Do Nuoy ring into solution and pull back. The automatic calculation for surface tension gives readings at LCD display. This equipment is 1% accuracy level, auto-calculation of surface tension and simple to operate.

RESULTS AND DISCUSSION

Entire experiment has been done to confirm and embrace the potential of okra mucilage as new natural DRA. As seen in Fig. 2, the performance of DRA by addition of additive gives positive effects. Addition of DRA seems to enhance %Dr. As shown, highest %Dr is 34% at 500 ppm of addition concentration flowing trough 2.0 meter pipe length and 0.0254 m I.D at Reynold Number range of 100004. Referring to Fig. 2, samples are taken from selection of all data that represent %Dr in certain condition (Mowla and Naderi, 2006; Choi *et al*., 2000; Shetty and Solomon, 2009; Bari *et al*., 2008, 2010; Dubief *et al*., 2004) and most of the previous experiment related to drag reduction concluded that higher concentration give better effect of drag reduction.

For instant, (Mowla and Naderi, 2006) given range of 40 % drag reduction obtained from polyalpha-olefin DRA with mixture of air and crude oil as the solvent. Shetty and Solomon (2009) explaining aggregation of polymer as DRA mention that increment of %Dr by addition of polymer additive. Choi *et al*. (2000) who explaining degradation factors of turbulent also mentioned the influence of concentration towards degradation which is higher concentration of polymer additive will lowering degradation rate.

Complied with previous study, higher concentration give wider possibility of polymer chain in solution to

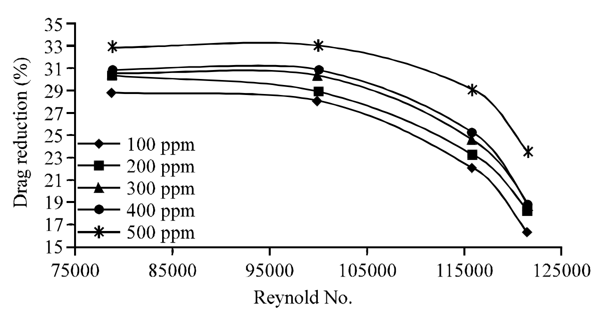

Fig. 2: Effect of concentration (ppm) on %Dr by increasing Reynold Number with water flowing trough 0.0254 m D.I and 2.0 m pipe length

suppress eddies. Elastic energy of polymer is proportional to concentration of polymer. Higher elastic energy will widen the coverage of wall bounded flow which decreased losing of energy due to wall friction. Elastic energy will ensure polymer is fully stretch to perform %Dr Process. Dragging eddies by polymer chain to flow trough closed channel will conserve the energy in main flow rather to be used as eddies formation. Continuum addition of polymer significantly effect %Dr since its mainly manipulated extensional viscosity. Drastic change in flow structure take to account which prominently as viscous mechanism proposed by Lumley (1969) and elastic mechanism proposed by De Gennes (1990). Higher concentration of polymeric DRA gives longer effective time for polymer to take control. High polymer content in solvent also gives the possibility that more polymer can enter into turbulent region hence giving drag reduction effect.

Trifling change of solvent characteristic suggested by Lumley (1969) including slightly increase in density, surface tension and viscosity which help to perform drag reduction. In addition, high molecular weight polymers that can be dispersing in solvent also have give positive values of %Dr. As seen in Fig. 3-5 are the data collected from increment of polymer concentration. Addition of polymer concentration does give significant %Dr and yet still did not show significant effect in density change (Fig. 3). The range of density is still in range of water itself.

Higher concentration also gives higher kinematic viscosity of the solvent (Fig. 4). Even though the change just in range of water viscosity itself. Viscous solution contains more polymers. This high molecular weight polymer are effective to suppress eddies formation. This viscous solution also can well coat pipe wall to reduce friction effects hence increased %Dr. Addition minutes quantity of polymers that give change in viscosity seem to well coat the pipe wall and drag eddies reported by (Shetty and Solomon, 2009) which explaining the correlation of concentration and viscosity by using different modelling and DRA.

Surface tension is the ability of liquid molecules to hold force or pressure on its surface. Based on Fig. 5, water surface tension is higher compare to polymer. This is because interactions between water molecules with solid wall are higher compare to mucilage. Mucilage molecules are tending to interact with each other in bulk quantity. However, by adding certain amount of polymer into solvent it shows that the surface tension is increase. The possibility of this situation is adhesive effect of polymer. As mentioned by Ganji *et al.* (2008) as gluey

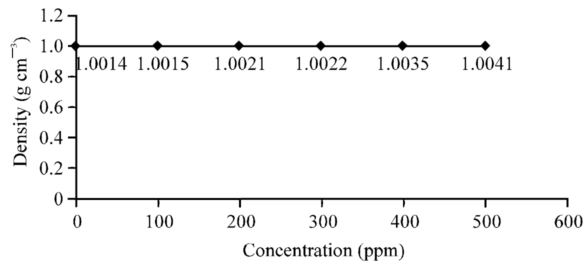

Fig. 3: Effect of density on DRA concentration

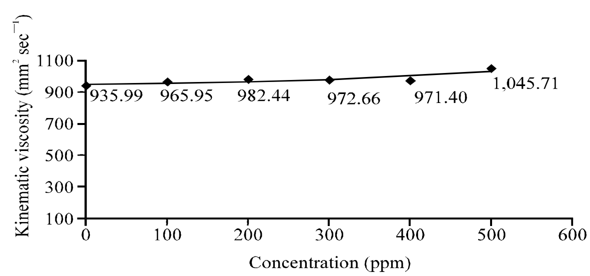

Fig. 4: Effect of Kinematic viscosity on DRA concentration

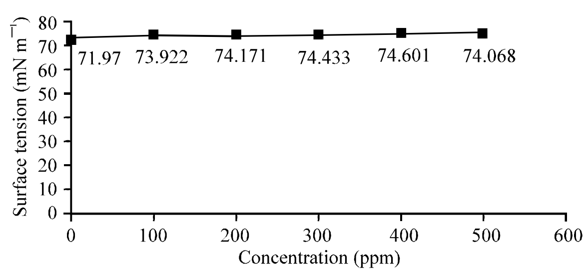

Fig. 5: Effect of Surface Tension on DRA concentration

material which give stickiness effect that coated the pipe wall to reduce friction hence increased %Dr. Lower surface tension samples can penetrate easily into higher surface tension liquid. Due to this statement, this polymer is a good application of water soluble DRA since it can disperses easily in the solvent. Opposition, adding natural polymer in certain point will decrease the surface tension. This may explained that at this point, the interaction between polymers molecules are higher compare to polymer-water molecules.

Individually sample of experimental data taken from 200 ppm DRA addition in 0.0254 m D.I, 2.0 m pipe length and Re = 121503.7 for 400 sec. Figure 6 have shows the data on pressure drop before and after addition of polymer as DRA. Frequency and pressure drop of the data become lower in same period of time when adding minute's quantity of polymer.

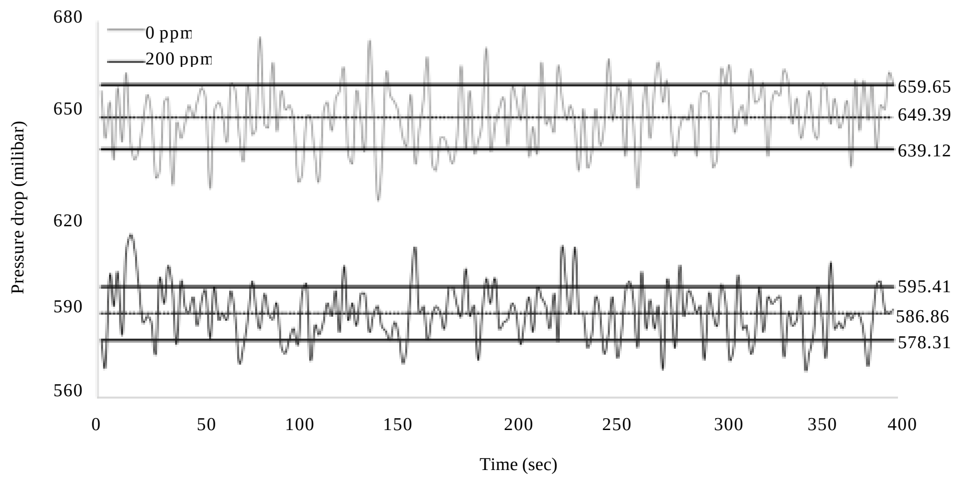

Fig. 6: Effect of time on pressure drop in transporting water with 200ppm DRA addition in 0.0254 m D.I, 2.0 m pipe length and Re = 121503.7

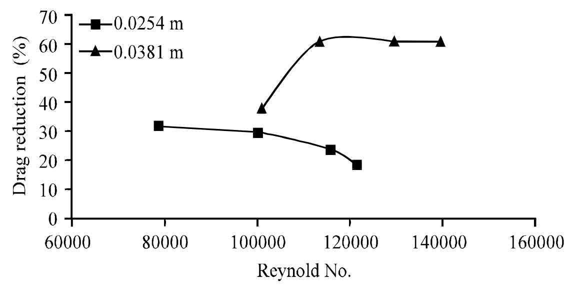

Fig. 7: Effect of Re on Dr% for transported water with DRA addition with different internal pipe diameter in 200ppm concentration

Lowering pressure drop is an essential reason of doing this research. It proves that okra mucilage is a good pressure drop reducer hence increased %Dr. The frequency of cycle also can be seen by addition of polymer, it's become lower. Frequency is the fluctuation data obtained along 400 second. The variance shows the frequency been reduced from 10.26 to 8.55. Usually turbulent are associated with unstable flow which fluctuating the pressure drop. As known, pressure drop can similarly represent eddies formation by losing the main flow energy. By addition of polymer, it's proved that the flow become smoother which can maintain the energy inside pipe and the turbulent can be smoother and laminarize.

On the other hand, this can prove that this natural polymer can maintain the effectiveness as DRA in certain period of time and pump cycles. This is one important factor to be considered because its show degradation rate of polymer as DRA when injecting into pipeline system. The possibility of polymer degrade due to pump circulation is low within time. As know, pump shear stress due to the rotation is high. It can cause the polymer to be break into shorter polymer. This is the major factor why pressure drop is slightly increased by time. These factors proven the findings of Choi *et al*. (2000) has prove polymer will be degrade within time and pump cycles.

Two pipe diameters, which are 0.0254 and 0.0381 m D.I, have been investigated to study their effects on %Dr. Figure 7 shows maximum %Dr is 60.7% at 200 ppm concentration at 0.0381 m D.I. The results of this study showed that within polymer concentration, %DR highest at largest pipe diameter. The results show that %Dr is increasing by increasing on internal pipe diameter. Opposition to this result data, (Bari *et al*., 2008) and (Bari *et al*., 2010) the pattern of previous experiment is by increasing the pipe diameter, %Dr will be decreased. Increasing internal pipe diameter means increasing flow rate of the liquid. This situation led to the increment of fluid velocity which resulting increment of turbulence. Although all flows in pipes are turbulent but the degree of turbulent are different. Bigger pipe diameter also will create bigger eddies. Big eddies tend to use more energy from main flow to complete its formation. Increasing pipe diameter also will give more space for eddies to form. Hence, when the degree of turbulence becomes higher, the number of collisions between eddies will be higher, which will produce smaller eddies. These collisions provide extra number of eddies absorbing energy from the main flow to complete their shape. By addition of

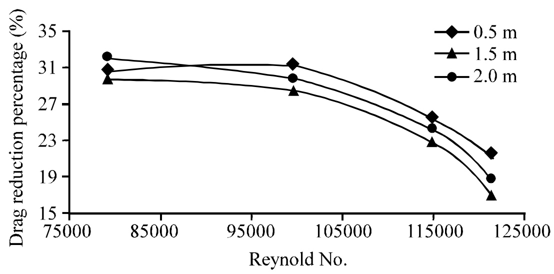

Fig. 8: Effect of Re on Dr% for transported water with DRA addition with different pipe length in 200ppm concentration and 0.0254 m D.I

polymeric DRA, eddies formation will be restricted. This is because polymer have suppressed eddies formation hence saving the energy from main flow. By having larger area, drag reducing process have more space to perform. Both of this factors will retaining the energy and pressure drop will be decrease hence increased %Dr.

Figure 8 shows the effect of pipe length. %Dr is increased by increment of pipe length. Maximum %Dr is 31.81%for 200 ppm was established in the 0.0254 m I.D pipe. The result complies with experimental data obtained by Bari *et al.* (2010) which when fraction of length to diameter is higher it give higher %Dr. %Dr is increased because there are changes in pressure drop by adding polymeric DRA. Before adding DRA, pressure drop from start point is increasing by increasing of pipe length. This is the usual phenomena occurs in transporting liquid. As liquid flowing trough, the pressure drop is increasing by increasing distance. Plus, this is the major problems to be investigated in this DRA field. Then by addition certain amount of DRA, energy can be retain in the flow. For a long distance, this DRA has proved to maintain its efficiency toward energy conservation. This is why the %Dr is greater by increasing the pipe length.

Due to pump rotation, the effectiveness of polymer will be lesser. This is proving by decreasing of %DR by increasing Re, which means by increment of fluid velocity. There are few suggestions on why these conditions happen. First prospect is the breakage of polymer bond will make fluid less viscous than before that cause by mechanical force of pump rotation. Referring to (Lumley, 1969), the suggested that polymer were extending in the fluid elongation flow in order to make drag reduction mechanism happen. Stretched polymer also thickening fluid by dumping small eddies in sub layer regions. Furthermore, assumed that coiled polymer must highly stretch before drag reduction mechanism can be applied. So that, there are possibility polymer will be break into shorter polymer by itself. For the flow prospects, the polymer performance has reach maximum potential due to high degree of turbulent. The polymer no longer effective to higher degree of turbulent due to high shearing force that resists extended performance of polymer. Shetty and Solomon (2009) also mentioning that the relaxation time which related to %Dr as decreased by increasing pipe length due to diffusity of polymer inside pipe length that decreased as it flow trough.

CONCLUSION

It is concluded that okra mucilage is applicable water soluble DRA since it is natural, biodegradable, highly effective in water and cheap in cost. Several effects have been investigated in order to test the natural polymeric DRA and how the drag reducing work. Several effects have been proved that this okra mucilage is increasing %Dr by increasing fluid velocity, pipe length and internal pipe diameter. However, %Dr is decrease with time. There is several limitation of using this polymer. Polymer can be degraded due to mechanical force and polymer extension which will decrease the drag reducing efficiency. The possible used of this polymeric DRA is fire fighting and irrigation which do not consume by living thing. This is because the water quality is a little bit disturbed in order to maintain the energy. However, this polymer is not harmful to living organism and environment since there is no hazardous chemical have been used.

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