Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 11 (6): 1039-1043, 2011
ISSN 1812-5654 / DOI: 10.3923/jas.2011.1039.1043

Drag Reduction Characteristics Using Aloe Vera Natural Mucilage: An Experimental Study

Hayder A. Abdul Bari, Kumaran Letchmanan and Rosli Mohd. Yunus
Faculty of Chemical and Natural Resources Engineering, University Malaysia Pahang,
Gambang, 26300, Kuantan, Pahang, Malaysia

Abstract: In the present study, a new natural and environmentally friendly drag reducing agent is introduced as a flow improver in pipelines carrying liquids in turbulent flow mode. The new drag reducing agent is extracted from the Aloe Vera leaves. The extracted mucilage drag reduction performance was tested using a closed loop liquid circulation system. The experimental work was carried out in 0.0254 m I.D. pipe with 100 to 400 ppm addition concentrations, four testing sections lengths and five different flow rates. It was found that the Aloe Vera mucilage was an effective drag reducing agent. A maximum drag reduction percentage of 63% could be achieved by adding 400 ppm of mucilage to the main flow. Drag reduction was found to increase with increasing Reynolds Numbers, additive concentrations and pipe lengths. Finally, a new correlation equation representing the experimental data is introduced.

Key words: Flow improvement, natural mucilage, pump cost, polymer, reynolds number, turbulent flow

INTRODUCTION

Liquids, especially crude oils, refinery products and raw water, are always transported under turbulent conditions in strategic pipelines. Massive amounts of pumping power are lost during transportation due to the power dissipation, which is caused by the turbulent structures that are formed in the flow media. Due to the velocity difference between the laminar sub layer and the core of the turbulent flow system, eddies are formed. Their shapes result from energy absorptions from the main flow. Such energy absorptions lead to losses in the pumping power that can be sensed as pressure drops across the piping system.

A solution to pumping power losses during transportation through pipelines is the addition of certain soluble chemicals to the main flow. These chemicals, which have viscoelastic properties, interfere with turbulent structures and eventually suppress eddies. More specifically, they prevent eddies from absorbing more energy from the main flow to reach their final shapes.

The drag reduction phenomenon is a combination of effects of various factors that happen at a same time and at a given position. Examples of such factors include pipe geometry, transported liquid properties and the degree of turbulence inside the pipe. It is known that none of the above-mentioned factors act individually but that many variables and factors may interact at a given moment to develop certain turbulent flow structures inside the pipe. The mission of the additive is to overcome the effect of turbulent flow structures and stop pumping power dissipation.

Toms (1949) was the first to report the drag reduction phenomenon and observed that the addition of few parts per million of long-chain polymers in a turbulent flow produces a dramatic reduction of the friction drag. This phenomenon has been the subject of extensive reviews by Mowla and Nadari (2006), Ling and Hassan (2006), Li *et al.* (2007), Wan *et al.* (2008), Safri and Bouhadef (2008), Riccoa and Quadrio (2008), Bari and Yunus (2009) Kamela and Shah (2009), Al-Sarkhi (2010) and many others.

Drag Reducing Agents (DRAs) can be classified into three major categories: polymers, surfactants and suspended solids (fibres). In general, polymers are most effective from the industrial point of view and the most usable in the industrial applications. It is known that, polymers are divided into two categories: synthetic polymers and natural polymers. Synthetic polymers are derived from petroleum oil, while natural polymers can be extracted from resources in nature. Although synthetic polymers possess good mechanical properties and thermal stability when used as flow improvers in pipelines, these materials biodegrade very slowly, which is an environmental concern. Moreover, for similar molecular weights, synthetic polymers are more expensive than

Corresponding Author: Hhayder A. Abdul Bari, Faculty of Chemical and Natural Resources Engineering, University Malaysia Pahang, Gambang, 26300, Kuantan, Pahang, Malaysia
Tel: 0060123495130 Fax: 006095492889

natural polymers. On the other hand, natural polymers are biodegradable and easily obtained. Indeed, these materials are produced in the form of polysaccharides by microorganisms and plants.

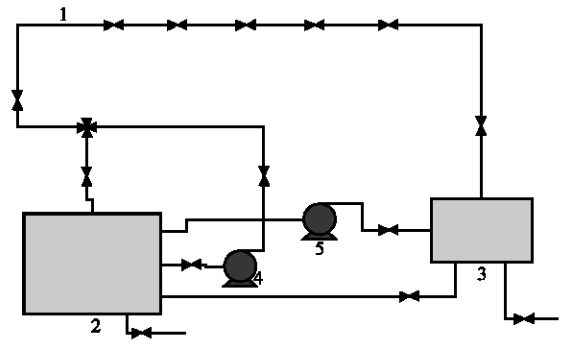
Aloe Vera is an example of plant that contains a high amount of natural polymers. It is often assumed that Aloe Vera belongs to the cactus family because of the rosette-like arrangement of the long spiked leaves on the central stem. In fact, Aloe Vera is a perennial plant from the lily family (Liliaceae), not the cactus family. There are over 300 species of Aloe known and Aloe Vera L. is known as the true Aloe Vera and is famous for its various applications and purported healing virtues. Aloe Vera gel is the commercial name given to the fibre-free, mucilaginous exudates that are extracted from the hydroparenchyma of the succulent leaves of Aloe Vera. The viscous, pseudo plastic nature of Aloe Vera gel is mainly due to the presence of polysaccharides. These polysaccharides are a mixture of acetylated glucomannans that are lost shortly after extraction, apparently due to enzymatic degradation.

MATERIALS AND MATHODS

A build-up system consisting of a horizontal test section and instrumentations was used to fulfil the investigation requirements. The system included a pipe made of transparent PVC. The pipe had a 0.0254 m Internal Diameter (ID) and a length of 2 m to permit visual observation of the flow pattern. Each pipe was divided into four pressure testing sections. The distance between two sections was 0.5 m. The first pressure testing point for each pipe was located at a distance corresponding to about 50 times the pipe diameter (50D) as shown in Fig. 1. This test was performed to ensure that the turbulent flows were fully developed before the testing point.

The fluid flow rate in pipelines was measured by a Ultraflux Portable Flow meter, Minisonic P, in which the ultrasonic flow measurement is sensitive to changes in flow rate as low as 0.001 m sec^{-1}. This exterior portable ultrasonic measurement was used to avoid any disturbance in the flow pattern. Baumer Differential Pressure Gauges were used to detect pressure drops in pipelines with maximum differential pressure readings of up to 0.16 bar.

Experimental procedures: The experimental work was carried out in a pipe having a length of 2.0 m and a diameter of 0.0254 m. Before the addition of polymers in the tank, pressure drop was measured as a function of water flow rate. The results were used in drag reduction calculations in which the drag reduction in pipes is defined as:



No.	Equipments	Capacity
1	Pipe 1	I.D = 0.0254 m
2	Tank 1	V = 420 m^3
3	Tank 2	V = 210 m^3
4	Pump 1	P = 6 horse power
5	Pump 2	P = 6 horse power

Fig. 1: Closed loop circulation system

$$\%DR = \frac{\Delta P1 - \Delta P2}{\Delta P1} \quad (1)$$

where, $\Delta P1$ is the pressure drop before the addition of drag reducers and $\Delta P2$ is the pressure drop after the addition of drag reducers. Aloe Vera mucilage was tested at different concentrations. The concentrations were 100, 200, 300 and 400 ppm. For each concentration, different flow rates and different testing lengths were tested and the pressure drop readings were taken and compared with the readings for pure water.

In this study, the Reynolds number is defined as:

$$NRe = \frac{\rho VD}{\mu} \quad (2)$$

The fanning friction factor was calculated from the equation of Yunus and Cimbala (2006):

$$f = \frac{\Delta P.D/4L}{\rho.V^2/2} \quad (3)$$

where, ρ, V and μ are the density, velocity and viscosity of water, respectively, D is the internal diameter of the pipe and L is the length of the pipe.

RESULTS AND DISCUSSION

Figure 2 shows the relationship between drag reduction and Reynolds number (NRe) with various polymer concentrations in a pipe having an inner diameter of 0.0254 m and a length of 2.0 m. It can be noticed that the %Dr generally increases with increasing NRe. Different patterns can be observed depending on the factors that were tested in the experiments

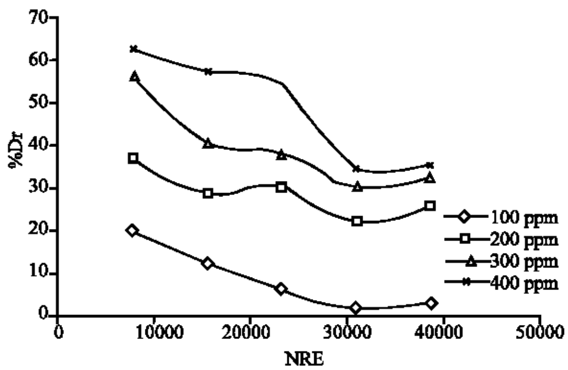


Fig. 2: Effect of the Reynolds number on the drag reduction percentage for various additive concentrations, with D = 0.0245 m and L = 2.0 m

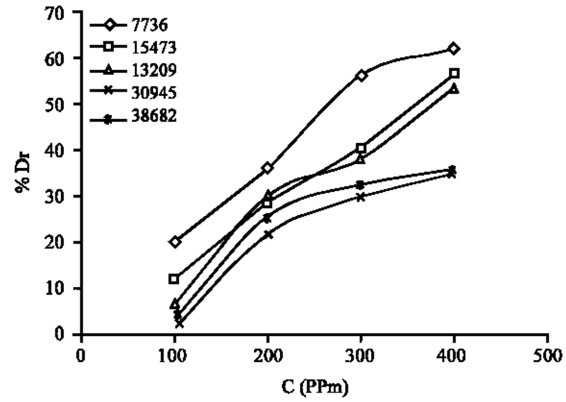


Fig. 3: Effect of the additive concentration on the drag reduction percentage for various Reynolds numbers, with D = 0.0245 m and L = 2.0 m

(e.g., additive concentration and pipe geometry). In most cases, the %Dr increases with increasing NRe until a certain value is reached. The %Dr then decreases, which can be clearly seen for each concentration (i.e., 100 to 400 ppm) in Fig. 2. The maximum value for the %Dr was between 60 and 65% for the highest concentration (i.e., 400 ppm) and for a NRe between 7000 and 10000. The minimum value for the %Dr was 1% and was observed for a concentration of 100 ppm. Further, it can be observed that an increase in the Re results in a gradual decrease in the %Dr.

When the NRe increases from 7000 to 10000, the degree of turbulence increases. As the number of collisions between eddies is also increased, smaller eddies are obtained. It is easier to suppress smaller eddies with polymer additives than larger eddies as the amount of energy absorbed by smaller eddies is lower. The decrease in %Dr after it has reached a maximum value at a NRe of 10000 is due to a low ratio between additive concentration and degree of turbulence. For a low ratio, the polymeric structure of polysaccharides is easy to break. This results in a drastic reduction in the %Dr value. These results agrees well with most of the published results for all the drag reducing agents introduced where it agrees well with the results published by Virk (1975), Ptasinski *et al.*, (2001), Escudier *et al.* (2009), Suali *et al.* (2010) and Japper-Jaafar *et al.* (2009).

The results of the drag reduction experiment for Aloe Vera as a function of additive concentration and NRe are shown in Fig. 3. It can be seen that the drag reduction continuously increases until it reaches the maximum concentration of 40 ppm. It can also be seen that for each concentration, the highest drag reduction percentage was obtained for a NRe of 7736. The highest drag reduction was obtained for a concentration of 400 ppm and a NRe between 7000 and 10000. The highest value was 62% and the lowest value was 2%, which was obtained for a NRe of 30945.

These results indicate that increasing the additive concentration means increasing the turbulence spectrum that is under the drag reducer effect. This may be due to the increase in the number of polymeric molecules that influences the strength of the degree of turbulence which will lead to the increase in the drag reduction efficiency. These results agrees well with the results published by Virk (1975), Japper-Jaafar *et al.* (2009), Cho *et al.* (2007), Wei *et al.* (2009) and Bari *et al.* (2008).

Figure 4 represents the %Dr as a function of the pipe length. Thus, it is a representation of the relation between the stability of the extracted polymer against the shear forces and the degree of turbulence inside the pipe. It is clear that the efficiency of the additive reaches maximum operating values after a certain distance. The optimum drag reduction (%Dr is 30%) was observed at a pipe length of 1.0 m. The %Dr decreased for longer distances and the effect of shear degradation started to appear. Indeed, the polymer molecules were subjected to shear forces for a longer period of time, resulting in a loss of efficiency.

To explain this behaviour, it is very important to understand the relation between the degree of turbulence, the pipe length, the additive concentration and the additive type. It is believed that the degree of turbulence increases by increasing the length due to the increase in eddy collisions inside the pipe. That will lead to increase the effectiveness of the additives as mentioned earlier. At this point, the concentration and type of the drag reducing agent will interfere in deciding the effect of pipe length on the drag reduction behaviour. The combination between all the factors mentioned above will lead to

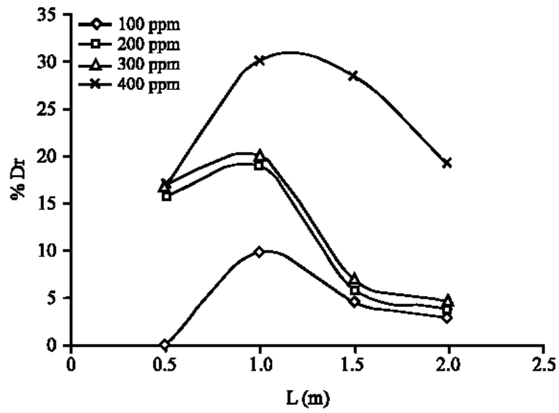


Fig. 4: Effect of the pipe length on the drag reduction percentage for various additive concentrations, with D = 0.0254 m and NRe = 41260.546

improve the flow in pipelines, that, it is believed that all the factors will reach its optimum integrated effect after 1 m length in the testing section where the concentration, NRe and pipe diameter will show optimum conjugation. That does not mean that this must be the optimum condition for the maximum %Dr and it must be an indication about how important controlling more than one variable in the same time for better drag reduction performance.

Correlation: In the present investigation, a dimensional analysis was performed to assemble significant quantities in a dimensionless group and reduce the number of variables. It is rather difficult to choose the appropriate variables that influence the friction factor (f) in the case of drag reduction. As this factor is influenced by the solvent physical and flow properties, we started with the following relation:

$$\Delta P = .f\,(D, \mu, \rho, V, C, L) \quad (4)$$

By applying the dimensional analysis using the Buckingham π theorem, the following non-dimensional relation was proposed:

$$f = f\,(Re, C) \quad (5)$$

Or:

$$f = a\,Re^{b} \quad (6)$$

The values of the constants a, b and k that give the best fitting of the experimental data were then determined with the least square method and a computer program STATISTICA 5.5.

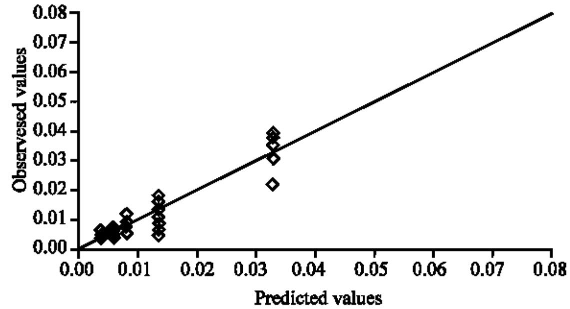


Fig. 5: Predicted versus observed values for the friction factor

The following equation was obtained:

$$f = 3115\,(Re)^{-1.28} \quad (7)$$

Figure 5 represents the relation between the values for the friction factor that were experimentally observed and those that were predicted by mathematical correlation. It can be seen that most points are on or close to the straight line, thereby indicating a good agreement between theoretical and experimental data.

CONCLUSION

- Aloe Vera mucilage is introduced for the first time as natural drag reducing agent in pipelines carrying aqueous media in turbulent flow
- The maximum drag reduction percentage that was achieved was 63%, indicating that a power savings of up to 63% can be achieved by the addition of Aloe Vera mucilage at a concentration as low as 400 ppm
- The %Dr was found to increase by increasing the liquid velocity to certain extent when the degree of turbulence balances the effect of the additives in the main flow and any further increase in the flow will reduce the effect of the additive in the same concentration
- Generally, the %Dr was found to increase by increasing the addition concentrations and pipe length

ACKNOWLEDGMENT

The University Malaysia Pahang is gratefully acknowledged for providing materials and chemicals.

NOMENCLATURE

A = Pipe cross section area (m^2)
(%Dr) = Drag reduction percentage (%)

I.D = Pipe internal diameter (m)
Q = Volumetric flow rate ($m^3\ sec^{-1}$)
Nre = Reynolds number
V = Average velocity ($m\ sec^{-1}$)
ΔP = Pressure drop (bar)
Greek symbols
ρ = Density ($kg\ m^{-3}$)
μ = Viscosity ($kg\ m^1\ sec^{-1}$)

REFERENCES

Al-Sarkhi, A., 2010. Drag reduction with polymers in gas-liquid/liquid-liquid flows in pipes: A literature review. J. Natural Gas Sci. Eng., 2: 41-48.

Bari, H.A.A., E. Suali and Z. Hassan, 2008. Glycolic acid ethoxylate lauryl ether performance as drag reducing agent in aqueous media flow in pipelines. J. Applied Sci., 8: 4410-4415.

Bari, H.A.A. and R.B.M. Yunus, 2009. Drag reduction improvement in two phase flow system using traces of SLES surfactant. Asian J. Ind. Eng., 1: 1-11.

Cho, S.H., C.S. Tae and M. Zaheeruddin, 2007. Effect of fluid velocity, temperature and concentration of non-ionic surfactants on drag reduction. Energy Convers. Manage., 48: 913-918.

Escudier, M.P., A.K. Nickson and R.J. Poole, 2009. Turbulent flow of viscoelastic shear- thinning liquids through a rectangular duct: Quantification of turbulence anisotropy. J. Non-Newtonian Fluid Mechanics, 160: 2-10.

Japper-Jaafar, A., M.P. Escudier and R.J. Poole, 2009. Turbulent pipe flow of a drag-reducing rigid rod-like polymer solution. J. Non-Newtonian Fluid Mechanics, 161: 86-89.

Kamela, A. and S.N. Shah, 2009. Effects of salinity and temperature on drag reduction characteristics of polymers in straight circular pipes. J. Petroleum Sci. Eng., 67: 23-33.

Li, C.F., R. Sureshkumara and B. Khomami, 2007. Influence of rheological parameters on polymer induced turbulent drag reduction. J. Non-Newtonian Fluid Mechanics, 140: 23-40.

Ling, Z. and Y.A. Hassan, 2006. Wavelet autocorrelation identification of the turbulent flow multi-scales for drag reduction process in microbubbly flows. Chem. Eng. Sci., 61: 7107-7114.

Mowla, D. and A. Naderi, 2006. Experimental study of drag reduction by a polymeric additive in slug two-phase flow of crude oil and air in horizontal pipes. Chem. Eng. Sci., 61: 1549-1554.

Ptasinski, P.K., F.T.M. Nieuwstadt, B.H.A.A. Van Den Brule and M.A. Hulsen, 2001. Experiments in turbulent pipe flow with polymer additives at maximum drag reduction. Flow Turbul. Combust., 66: 159-182.

Riccoa, P. and M. Quadrio, 2008. Wall-oscillation conditions for drag reduction in turbulent channel flow. Int. J. Heat Fluid Flow, 29: 891-902.

Safri, A. and M. Bouhadef, 2008. Experimental study of the reduction of pressure drop of flowing silt in horizontal pipes. J. Eng. Applied Sci., 3: 476-481.

Suali, E., H.A.A. Bari, Z. Hassan and M.M. Rahman, 2010. The study of glycolic acid ethoxylate 4-nonylphenyl ether on drag reduction. J. Applied Sci., 10: 2683-2687.

Toms, B.A., 1949. Observation on the flow of linear polymer solutions through straight tubes at large Reynold numbers. Proc. Int. Rheological Cong. Holland, 2: 135-141.

Virk, P.S., 1975. Drag reduction fundamentals. AICHE. J., 21: 625-656.

Wan, Z., J. Lin and H. Xiong, 2008. On the non-linear instability of fiber suspensions in a poiseuille flow. Int. J. Non-linear Mech., 43: 897-907.

Wei, J.J., Y. Kawaguchi, F.C. Li, B. Yu, J.L. Zakin D.J. Hart and Y. Zhang, 2009. Drag-reducing and heat transfer characteristics of a novel zwitterionic surfactant solution. Int. J. Heat Mass Transfer, 52: 3547-3554.