International Journal of Research in Applied Sciences & Engineering (IJRASE)
Online ISSN: 2456-2920; Volume 1, Issue 1; January 2016 pp. 11-18

Drag Reduction Characteristics of Flopaam

S. Murthy Shekhar[1+], Shivananda Moolya[2]

[1]*Department of Chemical Engineering, Dayananda Sagar College of Engineering, Bengaluru-78*
[2]*Mechanical Engineering Section, Higher College of Technology, Muscat, Sultanate of Oman*
[+]*Author for correspondence*
murthyshekhar2009@gmail.com

Abstract: In oil and gas industry, Drag Reducing Agents (DRA) are added to flowing fluid, to reduce the drag experienced by the flowing fluid leading to enhanced performance of the existing system. With achievable drag reduction fluid and concentration specific no single species can meet all the needs of industry. A study with laboratory model experimental set-up consisting of galvanized iron, copper tube and Polyvinylchloride (PVC) pipe of 0.016 to 0.021 m diameter as materials of construction has been completed to estimate the percentage drag reduction achievable with dilute concentration of Flopaam as DRA with water. The obtained results indicate that, friction factor decreases with Reynolds number for various pipe material and the concentration of Flopaam has varying effect on drag reduction, indicating only a specific concentration of Flopaam providing higher drag reduction for a given pipe and Re.

Keywords: Drag Reducing Agent, Flopaam, friction factor, Drag Reduction, piping system

1. INTRODUCTION

Fluid flow plays an important part in daily life of plant and animal species, environment, climate change, movement of automobiles, aero planes, and through piping systems. The transportation of fluid from one location to another viz., water distribution lines in cities and towns, conveying oil and gas within industry, to refineries and across countries is carried out mainly using pipelines. The piping systems offer, ease, low cost, assured supply and safety for transfer of fluids.

The pipe line transfer system, depends on nature of fluid, terrain or geographical zone, flow type and forces acting on the fluid. In conveying fluid from one location to another location, the energy loss fluid encounters increases with distance between stations and viscosity of fluid. To overcome these huge losses in oil transportation lines in oil pipe lines, pumping systems are used to achieve required pressure in the pipe lines. These pumps enhance the operational cost based on the energy consumed, depending on the size of pump and the attached motor and other accessories attached to the system.

With increased demand for higher production from the existing facilities, oil and gas industry frequently encounters a need to optimize the piping system to meet the higher throughput needs, which seek replacement of existing lines by new lines of higher diameter, which calls for higher capital investment and longer time duration for facility creation. To overcome the above challenge, oils and gas industry widely accepts the application of Drag Reducing Agents (DRA) to piping systems, which would reduce the drag force acting on the fluid, thereby minimizing the pressure loss per unit length leading to enhanced crude oil through the existing system. This reduction in drag will lead to decrease in pressure drop which lead to reduction in electrical power consumption by the pumping devices or can permit higher flow rate of fluid through a smaller diameter pipe, which can reduce the material cost or initial cost involved in the piping system installation. Hence in oil and gas industries they are very widely popular and are used extensively, where very low percentage of contamination of product can be permitted.

The DRA's are found to increase the performance by reducing turbulence at high Reynolds numbers, thus reducing the amount of turbulent flow friction. Typical drag reduction effect of 25-50% are normally achieved.

2. DRAG REDUCING AGENTS

Bird et al., (1987) define Drag Reduction as the diminution in pressure drop in the polymer solution relative to the pure solvent alone at the same rate, which strictly occurs under turbulent flow conditions. It has been observed that adding a small amount of specific high molecular weight polymer known as "Drag Reducers" under turbulent pipe flow condition can drastically decrease the friction pressure gradient and thus, increase pumping capacity.

The DRA's used in petroleum industry belong either to polymers, surfactants and fibers category, which can lower the friction pressure losses up to 80% over solvent. The widely used polymers, are synthetically prepared high molecular weight chemical compounds which are usually available in granular form, which get hydrolyzed in aqueous systems. The addition of these DRAs in very small concentration in the range of 0.001% to 0.1% concentration where the viscosity of the fluid is high can reduce the drag exerted by the fluid when fluid flows through closed conduit. In their extended configuration, polymers have a size which is much smaller than the smallest length scale of turbulence. A well known effect is the increase of the shear viscosity of a fluid due to polymers, which gives reason to suspect that polymers can at the most affect the micro scale of the turbulence. The polymers affect the macrostructure of the turbulence, which is responsible for the transport of momentum that results in drag, seems unlikely. However, the story is completely different. Polymers are primarily active on the micro scale of the turbulence but also influence the macro scale of the turbulence. Accurate determination of friction pressure losses of drag reducing polymer solutions remains to be a challenge because the mechanism causing drag reduction itself has not yet been satisfactorily identified and explained. Kostic et al. (1994) report, factors such as shear thinning, viscoelasticity, molecular stretching and decreased turbulence production, among others as possible schemes for drag reduction.

On the other hand, Surfactants can reduce the surface tension of a liquid, while Fibers are long cylinder-like objects with high length to width ratio, which orient themselves in the main direction of the flow to reduce drag.

The factors which affect the selection of DRA is its ease of solubility in the liquid, high molecular weight, shear degradation resistance, heat, light, chemical and biological degradation resistance.

2.1 Application of Drag Reducing Agents

In petroleum industry, fluids are pumped through straight pipes during operations such as hydraulic fracturing, acidizing, wellbore cleanup, cementing and drilling. These operations are usually executed under turbulent flow conditions. In a oil field, the amount of water injected into a reservoir for sweep efficiency, pressure maintenance and void age replacement are severely limited by existing water injection facilities. Once this limitation is reached, injection facilities must be upgraded to increase injection capacity. If not, ultimate oil recovery could be reduced. Upgradation of facilities require significant capital investment and may not be feasible due to logistics or platform loading. Hence, use of Drag Reducing Agents to the injection system continuously at low concentration requires minimum capital costs to increase the performance of the system.

Apart from above DRA’s have much higher role to play in transportation of crude oil. With characteristics of crude oil varying from light, heavy to extra heavy and Degree API varying from 30 to below 10 the viscosities of crude can go upto 800-1000cP. With desired viscosity of crude for pipe line transport to be below 400 cP, various methods like dilution, thermal heating and addition of DRA’s have been looked as alternative to ease the problems encountered during transportation. With depletion of light crudes, and costlier thermal methods, application of DRA’s has become natural choice by the oil and gas industry. The drag reducing agents apart from reducing the drag on the surface and turbulence frictional factor, they are found to improve the performance of system upstream operations of petroleum engineering in the following ways:

- Increase water flow rate into injections wells
- Increase bottom hole pressure.
- Reduce operating costs in water injection facilities.
- Operate injection pumps at lower speed to increase operating life.
- Operate injection pumps at lower speed to increase operating life.
- Reduce the level of corrosion.
- Temporarily used to increase the injection rate in parts or whole fields to make up voidage ratio lost during downtime or high production rates.
- Used from the beginning of injection to minimize capital expenses by allowing design of smaller pipelines or tubing.
- Production wells with high water cut.

With changing characteristics of crude oil with discovery of new wells, attempts are being made to find out an appropriate DRA for each application and fluid. Hence, in the present study an attempt has been made to understand the effect of DRAs on flow of water through a laboratory model fitted with pipes of various material of construction by estimation of frictional losses and percentage of drag reduction achievable for flow of water with and without DRA viz., Flopaam (polyacrylamide) supplied by PDO Oman

3. LITERATURE REVIEW

A good number of literatures are available on the effect of drag reduction due to the addition of DRAs to flowing fluid in various applications. The wide variety of polymers availability, enable different researchers to attempt to find application of each DRA and their behavior under various flow geometries and fluids. Selected literature from Smith R., Subash N. Shat are highlight which have relevance to the present work.

Smith, R., and M.F. Edwards (1982) had conducted studies on estimation of pressure drop in aqueous solution using Polyox (Polyethylene oxide) in a turbulent pipe flow. They found that pumping Polyox solution with a centrifugal pump caused rapid irreversible shear degradation which considerabley reduced the drag reducing properties of the solutions, decreased viscosities. They also found that presence of electrolyte in the solution decreased the drag reduction property of the solution.

Subash N. Shah et al. (2006) carried out experimental study of drag reduction performance of commonly used drag reducing ageny viz., Nalco ASP-820 in straight and coiled tubing. The measurements were made in 0.0125 m OD coil and 0.0125 m straight pipe. They have reported that drag reduction in coiled tubings were significantly lower than in straight tubing. They have also proposed a correlation for estimation of friction factor with DRA's as a function of Solvent Reynolds number for straight and coiled tubing. The correlation proposed for straight tubing are as follows:

$$f_t = A - [B/\ln(Re_s)] + [C/Re_s^{0.5}]$$

where, A, B and C are constant , f_t – friction factor with DRA in solvent; Re_s – Reynolds number of solvent

Felipe Gallego and Subash N. Shah (2009) have reported mechanism of drag reduction for flow of fluid with DRAs in a coiled tubing. They report energy dissipation by eddies in turbulent flow of viscoelastic fluids as the mechanism of drag reduction. They also report about reduction in drag reduction with increase in temperature. Further correlations have been reported for the prediction of drag reduction in dilute polymer solutions flowing in straight and coiled tubings.

Ahmed Kamel and Subash N. Shah (2009) report about the effect of salinity and temperature on drag reduction characteristics of polymers in straight circular pipes. They report decrease in drag reduction with increase in salinity and temperature for two DRAs viz., ASP -700 and ASP-820 polymer solutions.

4. EXPERIMENTAL SET-UP

The study has been conducted on the laboratory model of Hydrodynamic Trainer at Higher College of Technology, Muscat, Sultanate of Oman and supplied by GUNT Germany. It consisted of pipes made of different material of construction viz., Galavanized Steel, Copper and PVC pipe whose specifications are shown in Table-1. The stand alone system consists of a closed loop fluid circulation system with water tank capacity of 55 liters fitted with a pump of maximum capacity and heat 230 l/min and 11 m. The flow rate was measured with help of variable flow meter (DN50) with measuring range 0.4- 4.0 m^3/h. The pressure drop across the pipe line was measured using a double tube manometer with water as manometric fluid.

TABLE 1: Details of pipe sections

Type of Pipe	Dimension
Straight pipe section Galvanized	12 mm, 1 m long Surface: Galvanized Wall roughness (k): 0.1 mm
Straight pipe section – Copper	18 x 1 , 1m long Surface: Technically smooth Wall roughness (k): 0.001 mm
Straight pipe – PVC	20 x 1.5, 1 m long Surface: Technically smooth Wall roughness (k): 0.001 mm

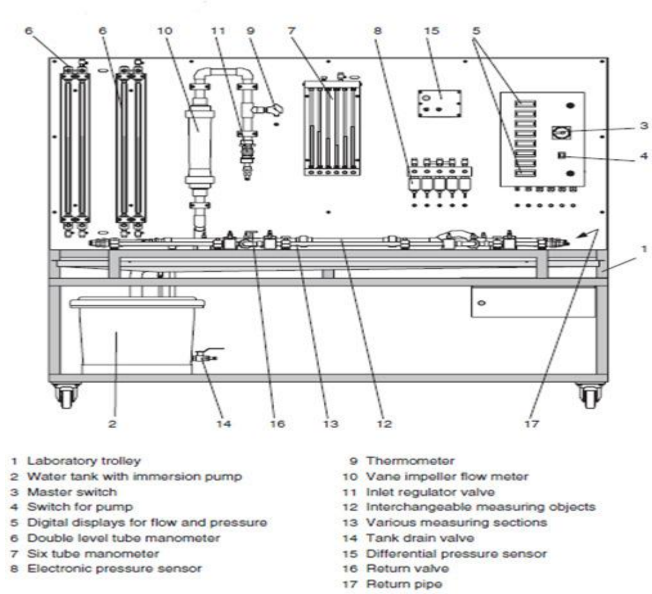

Fig. 1. Hydraulic Trainer, GUNT, Germany

4.1 Experimental Methodology

The experimental methodology adopted for study comprised of Preparation of stock solution, Preparation of Flopaam solution of desired concentration, Determination of Viscosity of the solution followed by Pipe flow studies for estimation of friction factor and drag reduction.

1. **Preparation of Stock Solution:** The Stock solution was prepared by using a well known polymeric DRA provided by Petroleum Development Oman following the published literature guidelines. Flopaam, a white crystalline dry powder is found to have a free flowing characteristics. A measured quantity of dry Flopaam powder was carefully transferred to known volume of water to obtain a stock solution of required concentration. i.e., 1 g Flopaam in 1 liter water to achieve a stock solution of 1% concentration w/w. Care

was exercised during addition in short interval to avoid lump formation. After complete addition of powder, the solution was stirred continuously for 2 hours to enhance the hydrolysation of the polymer. Further, the stock solution was left undisturbed for 24 hours for completion of hydrolysation and was later verified for absence of fish eyes in the solution for usage.

2. **Preparation of Flopaam of desired concentration:** A measured quantity of stock solution was used to prepare solutions of Flopaan in the range of 0.001% to 3% .

3. **Determination of Viscosity:** The viscosity of the prepared Flopaam solution was estimated using Ostwald Viscometer of Grade A. The kinematic viscosity of the fluid was measured using the relation $\nu = K*t$. The capillary viscometer constant K was 7.74 E-09 for pure water. The estimated values of viscosities of 0.01% to 3% Flopaam solution in water are as shown in Table-2

TABLE 2: Viscosities of solution for different concentration of Flopaam in the fluid

Concentration of Flopaam	Kinematic Viscosity (m^2/s)
0.01%	1.12e-06
0.025%	9.11e-07
0.05%	7.70e-07
0.2%	7.70e-07
0.5%	8.59e-07
1%	8.17e-07
3%	1.11e-06
5%	1.05e-06

iv. Pipe Flow studies: Pipe flow studies were carried out in the hydrodynamic trainer after verifying the equipment following the guidelines of preliminary check and precautions in operation, leak test and operations procedure. Initial studies were completed with pure water as the flowing medium and later studies were completed with flopaam of desired concentration in the storage tank. The flow rate, differential manometer readings were recorded for estimation of Reynolds number, pressure drop and friction factor across the pipeline.

Further the differential pressure head readings of the manometer were converted to pressure drop (ΔP) using the relation

$$\Delta P = \rho g \Delta h \quad (2)$$

The friction factor (f) which depends on Reynolds number (Re) and relative roughness factor (ε/D) were estimated for the given flow rate by the relation

$$Re = \rho Q d / \mu A \quad (3)$$

and

$f = 64/Re$ for $Re < 2000$ & laminar flow (4)

and by famous Cole-brook-White equation

$$1/\sqrt{f} = -2\log_{10}\left[(e/3.7D) + 2.51/(Re\sqrt{f})\right] \quad Re > 40000 \text{ \& turbulent flow} \quad (5)$$

The equation (3) above is valid for laminar flow i.e., Re <2000 and equation (4) above is valid for turbulent flow Re > 4000. The calculations of ‘f’ based on equation (5) needs a trial and error approach.

In comparison to the above implicit equation, large attempts are being made to estimate friction factors by explicit schemes. In this group the more popular are the Churchill equation and Swamee-Jain equation

$$f = 0.25/[\log(1/3.7(D/\varepsilon) + 5.74/Re^{0.9})]^2 \quad (6)$$

The above equation predicts the values of f that are within ± 1.0 percent within the range of relative roughness D/ε from 100 to 1 x 10^6 and for Reynolds numbers from 5 x 10^3 to 1 x 10^8, which is virtually the entire turbulent zone of the Moody diagram.

Based on the value of pressure loss (ΔP) across the pipe for different concentration of flopaam recorded, values of f were determined using Darcy-Weisbach equation given in equation

$$h = f\,(L/D)\,(V^2/2g) \quad (7)$$

Further, an estimation of percentage drag reduction (%DR) achieved by introduction of flopaam into the system has been estimated by the relation,

$$\%\,DR = [1 - (f_t/f_s)] * 100 \quad (8)$$

5. RESULTS AND DISCUSSION

5.1 Estimation of friction factor with water

Initial studies on variation of friction factor for Galvanized Iron, Copper tube and PVC for varying flow rate of water from 0.2 to 1.2 m^3/h was undertaken. The obtained results plotted as f vs. Re is shown in Fig. 2. The obtained results indicate higher values of friction factor for Galavanized iron pipe and reasonably agreeable values for copper tube and PVC with literature. The likely agreement would be due to the smooth pipe configuration represented by Copper and PVC piping systems.

Further development of power-law correlation of the form f = A (Re)^B. based on least square technique for the values plotted in Fig. 2 are shown in Table-3. The results in Table-3 indicate excellent agreement with power-law correlations with higher values of constant A for Galavanized Iron Pipe in comparison to copper and PVC tube. The above values further justify the hypothesis that copper tube and PVC pipe belongs to smooth pipe category.

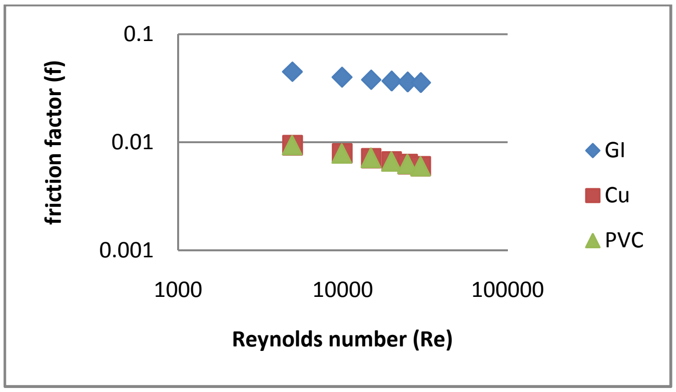

Fig. 2. Friction factor values for varying flow rate of water through Galvanized Iron Pipe, Copper and PVC tubes

TABLE 3: Correlation for estimation of friction factor for varying Reynolds numbers

Pipe	A	B	R^2
Galvanized Iron pipe	0.135	-0.13	0.977
Copper tube	0.079	-0.25	1
PVC	0.079	-0.25	1

5.2 Estimation of f and %DR for flow through Galvanized Pipe

The studies on Galvanized pipe of 16mm diameter of unit length with flowing fluid as water and different concentrations of Flopaam as the DRA in water had been undertaken for fluid flow rate from 0 -1.2 m^3/h and concentration of Flopaam from 0.01% to 5%. A plot of friction factor vs. Reynolds number is shown in Fig.3. From the figure it can be seen that friction factor values decrease with increase in Reynolds number for flow of water in accordance with the literature. Further it can be seen that value of friction factor also decreases with increase in Re for different concentration of Flopaam. But marginal variation exists in the estimated values of friction factor with respect to friction factor of pure solvent depending on the concentration of Flopaam.

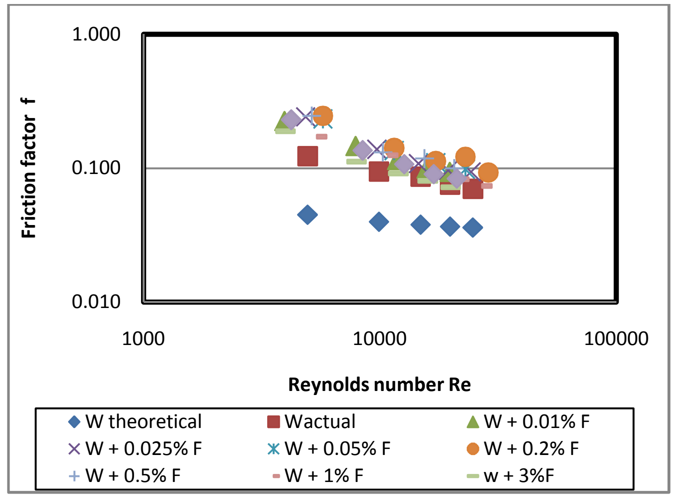

Fig. 3. Friction factor value for flow of water with varying concentration of Flopaam inside Galvanized pipe

The application of DRA's into the fluid is to reduce the drag leading to reduction in energy consumption. Further a plot of Percentage drag reduction (%DR) Vs. Reynolds number for different concentration of Flopaam is shown in Fig. 4.3. The graph indicates increase in drag in comparison to the drag with pure solvent at low concentrations viz., 0.01% and 0.025% concentration of Flopaam in the flowing fluid. Further graph indicates that maximum drag reduction at 0.05% F. Further increase in concentration of Flopaam also shows negative impact leading to reduction in percentage drag reduction upto 3% Flopaam and shown increase in drag for 5% Flopaam in the fluid. The above results indicate that, drag inside galvanized iron pipe is very sensitive to Reynolds number and concentration of Flopaam in the fluid. The results also indicate that for a given pipe material the concentration of Flopaam is very vital and best reduction in drag can be achieved with 0.05% Flopaam.

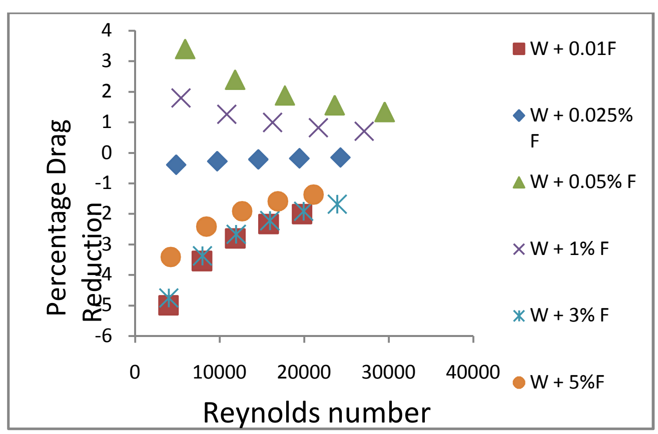

Fig. 4. Percentage Drag Reduction for flow of water with varying concentation of Flopaam through Galvanized Iron pipe

5.3 Estimation of f and %DR for flow through Copper tube

The copper tubes represent flow through a smooth pipe as they are drawn through in their manufacturing process. In the present study, experiments have been carried out on pipe of 16mm diameter of unit length with pure water as flowing fluid and also with addition of different concentrations of Flopaam to act as the Drag Reducing agent. The flow rate has been varied from 0 - 1.2 m^3/h and concentration of Flopaam from 0.01% to 5% concentration.

A plot of f vs. Re for flow through copper tube is shown in Fig. 4.3. The plot indicates that influence of DRA on for flow of pure water at different concentration of DRA. The friction factor values are nearly one order of magnitude lower than the friction factor of galvanized iron pipe and are due to the smooth surface behavior of copper tube. The values of friction factor for different concentrations of Flopaam vary marginally with that of pure solvent.

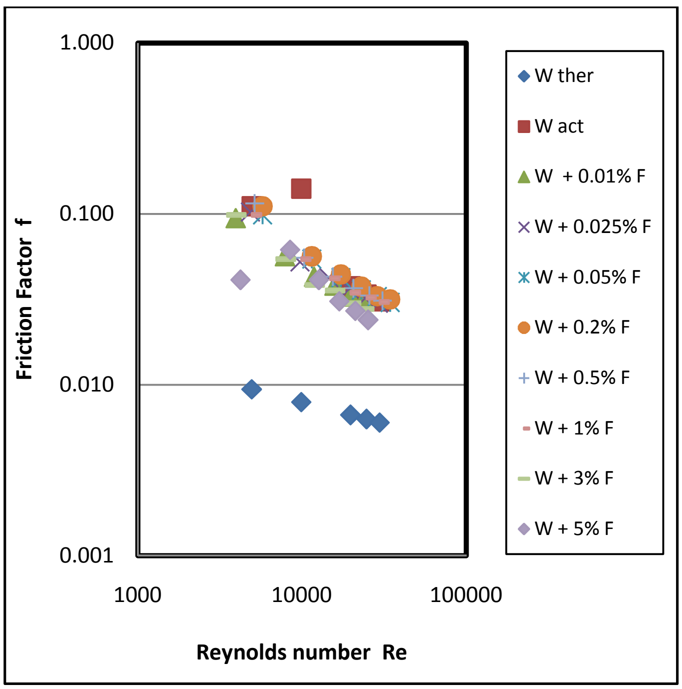

Fig. 5. Friction factors values for flow of water with different concentration of Flopaam through copper tube

A plot of percentage drag reduction Vs. Reynolds number for different concentrations of Flopaam is shown in Fig. 4.5. The Drag reduction plot shows that very low concentration of Flopaam or high concentration of Flopaam are not able to bring down the drag reduction. A nominal decrease in drag reduction can be observed for Flopaam concentration of 0.05%-0.2%. This again substantiate that for a given fluid and pipe material a specific concentration of Flopaam needs to be added to bring about drag reduction. The results at 0.5% Flopaam concentration and 1% concentration needs to be further verified.

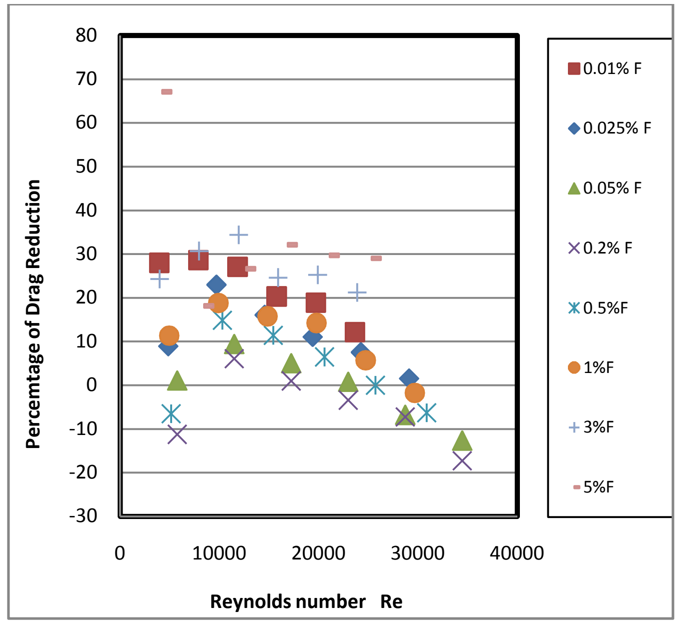

Fig. 6. Percentage Drag Reduction achieved for flow of water with different concentration of Flopaam through copper tube

A comparison of the copper tube results with galvanized iron pipe indicates, that drag reduction is independent of Reynolds number for copper tube, while it is dependent on Reynolds number and concentration of Flopaam for Galvanized pipe . This indicates that mechanism of drag reduction is different in copper tube and galvanized iron pipe. The change in mechanism can be attributed to surface roughness.

5.4 Estimation of f and % DR for flow through PVC pipe

In the present study, experiments have been carried out on pipe of 16mm diameter with unit length for pure water as the flowing fluid and with different concentrations of Floppam as the Drag Reducing agent. The flow rate has been varied from 0 -1.2 m^3/h and concentration of Flopaam from 0.01% to 5% concentration. A plot of friction factor vs. Reynolds number is shown in Fig. 4.4. From the figure it can be seen that friction factor values decrease with increase in Reynolds number for flow of pure solvent (water) in accordance with the literature. Further it can be seen that value of friction factor with different concentration of Floppam oscillating marginally with respect to friction factor of pure solvent. The friction factor values are larger for concentration between 3% and 5%. It also indicates that increase in concentration of Flopaam, increases the friction factor values to maximum at 3% and further decrease the friction factor for 5% concentration. It indicates addition of Floppam adversely affect the flow in the PVC pipe.

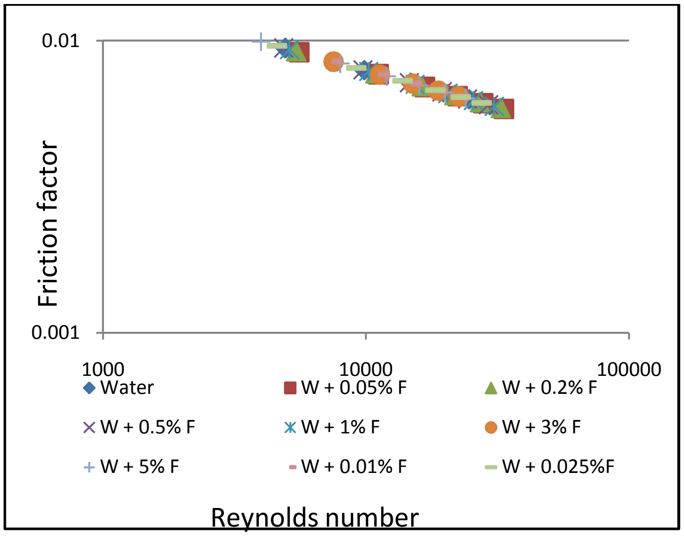

Fig. 7. Friction factor variation for flow of water with different concentration of Flopaam through PVC Pipe

Further analysis of percentage drag reduction indicates negative results for Flopaam concentration in the range of 0.01% to 0.025%. But indicate positive results for Flopaam concentration of 0.05% and 0.2%. Again a negative trend has been observed for 0.5% Flopaam indicating the concentration of Flopaam is higher is not suitable for drag reduction. But at higher concentration of Flopaam, the drag reduction factor is showing a negative trend.

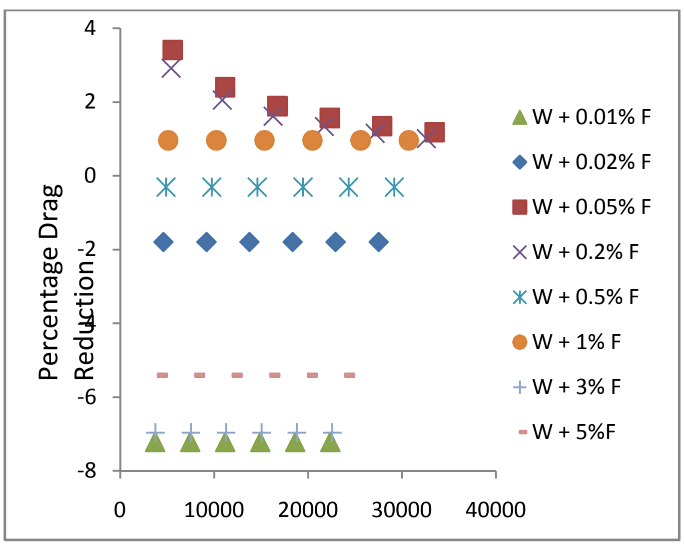

Fig. 8. Percentage Drag Reduction for flow of water with different concentration of Flopaam through PVC Pipe

Further analysis of drag reduction, indicates that drag reduction is function of Reynolds number and concentration of Flopaam at lower concentration and is independent of Reynolds number at higher concentration of Flopaam, clearly indicating the change in the mechanism of drag reduction with change in concentration of the Flopaam.

A comparison of the above results of drag with the results of galvanized pipe and copper tube shows that, the drag mechanism followed by flopaam in PVC pipe lies in between galvanized iron pipe and copper tube.

6. CONCLUSIONS

The experiments carried out using water as flowing fluid and Flopaam as the drag reducing agent has indicated effect of Flopaam concentration on flow through galvanized, copper and PVC pipe. The values of friction factor indicated decreasing trend with increase in Reynolds number and depend on the pipe material and is in accordance with literature findings reported till date. For the same flow rate the dosage of Floppam required to bring about the required reduction in drag depends on nature of pipe and Reynolds number. The frictional loss across the pipe can be varied by small addition of drag reducing agents and quantity of addition needs to be specific, as concentration of drag reducing agent has varying effect on frictional loss. The best drag reduction achievable for a given fluid and pipe needs to be experimentally determined. A good drag reduction has been achieved at 1% Flopaam for Galvanized iron, 0.05% Flopaam for copper tube and 0.05% for PVC pipe. Further analysis with similar nature DRA would confirm the mechanism of drag reduction. Further it would be interesting to extend the study to find the effect of these drag reducing agents on various pipe fittings, which cause larger energy loss across a given cross section.

7. ACKNOWLEDGEMENT

The authors wishes to express their thanks to Petroleum Development Oman and Higher College of Technology, Muscat, Sultanate of Oman for the support extended during this study.

REFERENCES

[1] Ahmed Kamel and Subhash N. Shah (2009) Effect of salinity and temperature on drag reduction characteristics of polymers in straight circular pipes, J. of Petroleum Science and Engineering, Vol.67, 23-33.

[2] Felipe Gallego and Subhash N. Shah (2009) Friction pressure correlations for turbulent flow of drag reducing polymer solutions in straight and coiled tubing, Vol.65, 147-161

[3] Proesfschift, Drag Reduction by polymer additives in a Turbulent pipe flow: Laboratory and numerical experiments, Ph., D. Thesis, Delft University, 1995.

[4] Smith. R., and M. F. Edwards (1982) Pressure drop and mass transfer in dilute polymer solutions in turbulent drag-reducing

pipe flow, Int. J. Heat and Mass Transfer, Vol. 25, No. 12, 1869-1878.

[5] Subash N. Shah et al. (2006) Drag reduction characteristics in straight and coiled tubing – An experimental study, J. of Petroleum Science and Engineering, Vol. 53, 179-188.

[6] Mott R., Applied Fluid Mechanics, 6^{th} Edition, Pearson Education, Singapore, 2003.

Abbreviations

D pipe internal diameter,

E absolute pipe roughness, mm

f Darcy friction factor, dimensionless, usually a number between 0.008 and 0.10

F_s friction factor without DRA (Pure solvent)

F_t friction factor with DRA

g acceleration due to gravity

K capillary viscometer constant

L Length of the pipe (m)

Re Reynolds number of flow, dimensionless

R Hydraulic radius of the flow conduit (m)

S Ratio ($\Delta H/L$)

t time of flow (s)

V Average liquid velocity, m/s

Greek Symbols

ΔH = Head loss across the pipe (m)

ρ = Density of the fluid (kg/m^3)

ν = Kinematic Viscosity (m^2/s)