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Potential Energy Conservation Technique for Fluid Transportation Through Pipeline: Water Soluble Polymer Drag Reduction Technology

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Abstract. In various industrial applications involving fluid transportation through pipelines, such as water, crude oil and hydrocarbons, turbulent friction causes significant reduction in flow rate, resulting enormous head loss. One of the potential techniques to prevent these losses without altering the pumping system is polymer drag reduction technology. Injection of parts per million (ppm) of polymer solutions can enhance the throughput of fluid up to 40%. Due to undefined nature of turbulent flow and limitations of industrial need, effectiveness of polymer solution depends on several parameters such as structure of polymer, polymer concentration, its molecular weight, temperature, Reynolds Number, solution preparation method, method of injection of polymer in the pipeline, solvent-polymer interaction, polymer stability in term of chemical and mechanical degradation and roughness and diameter of the pipeline. In this study, effectiveness of drag reduction using water soluble polymer solution (Poly-(Acryl Amide) depends on method of injection in a single phage water pipeline with 10.5 meter long and 2.54 cm ID was investigated. The percentage drag reduction (% DR) was calculated using obtained experimental data. The results showed that design of nozzle of polymer injection system influence the efficiency of % DR. Similar kind of result observed in two phage pipeline (air combined with water) by Williams et al., (1996) supports optimization of injecting system may increases the efficiency of polymer drag reduction. Present study also showed optimization of pressure of polymer solution vessel significantly influences the drag reduction efficiency.

Keywords: drag reduction; water soluble polymer; injection method

1. Introduction

High energy requirements for industrial application directly influence not only economy but also environment. During actual fluid flow condition in pipeline, skin friction occurs in the boundary layer near solid surfaces and the turbulence friction occurs to the bulk flow of the fluid significantly reduces the flow rate. At higher flow velocity, these frictions are of large magnitude, which causes high energy requirements of transporting fluid [1]. In 1948, Toms recognized the tremendous reduction in operating pressure for turbulent flow by the addition of small concentrations of polymer [2]. Drag reduction (DR) phenomena is the increase in pumping capacity of a fluid, or a decrease in the pressure drop per unit length of transporting pipeline, which is achieved by the addition of small amounts (ppm) of polymer solution to the fluid, when it is flowing under turbulent conditions. It provides a significant reduction in energy requirements and offers several operational and tactical advantages. According to the systems, their use is economically attractive for numerous commercial, defense and research applications [3]. After the innovation of DR phenomena, it seems to be too early to expect this effect to be put into of practical value [1]. DR phenomena have major successful applications for transportation of water, crude oil and hydrocarbons, suspensions and slurries through pipelines. Other major applications are in the field of oil well operations, fire fighting, airplane tank

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filling, field irrigation, ship industry, marine systems (ocean thermal energy conversion systems) and many more [1,3 4]. The energy required during the oil well operation could be reduced by a factor of over five as compared with the use of water alone [5]. It has been found that an irrigation pump can cover twice as much area with the presence of drag reducing polymer in the supply system [6]. Every major airport around the world, uses polymer drag reducer, otherwise filling fuel in the tanks of passenger planes would take approximately twice the time, to when no drag reducing polymers are used [7]. One of the brilliant applications of drag reduction has been found to be in fire-fighting operations. Polymer drag reducer causes a considerable reduction in the pressure drop through the hose, and increases the volume of flow and enhances the range of water stream [8]. In an emergency, due to sudden increase in the system capacity of sewage systems, use of drag resistant polymers can help to meet the high demand. Large urban agglomerations in India and China, find their sewer systems insufficient in the face of doubled or tripled populations. An alternative to digging out the entire municipal sewer system and replacing it by conduits with larger diameters is the use of DR technique can continues to keep the sewage situation under control [4].

Efficiency of % DR depends on limitations of system and understanding of suitable methodology according to the need for effective application. Since effectiveness of % DR of water soluble polymer solution depends on several parameters such as structure of polymer, polymer concentration, its molecular weight, temperature, Reynolds Number (Re), solution preparation method, method of injection of polymer in the pipeline, solvent-polymer interaction, polymer stability in term of chemical and mechanical degradation and roughness and diameter of the pipeline [9]. There are no generalized guidelines for the selection of drag reduction water soluble polymers [10]. But understanding of technical challenges, limitations of DR system and analysis of DR phenomena according to application may enhance the efficiency of drag reduction. Several study for two phase pipeline have been previously investigated but very little work has been reported for single phase, once through horizontal pipeline flow system. In the present work, design of polymer injection system was studied and found optimization of design of polymer injection system can modify the turbulent flow pattern for low pumping energy requirements which increases the throughput of transporting fluid in pipeline.

2. Experimentation

2.1. Materials

The chemical used in this study was water soluble polymer Poly-acrylamide (PAM), molecular weight $4x10^6$ g/mol). Polymer solution was made in tap water. The main transporting fluid, used for pipeline was tap water from Bombay Municipality Corporation (BMC), India.

2.2. Instrumentation

All experiments reported in this investigation were conducted on single phase, once through, horizontal flow system. The test section consists of a 10.2 meter long acrylic (to allow visual observation) horizontal pipe with 25.4 mm internal diameter. Pressure drop between two points along the pipe which was 2 meter apart from each other was monitored using differential pressure gauge. The first pressure tap was located at 4 meter from the polymer injection point to make sure that the flow is fully developed. Water outlet was located at 1.5 meter from the second pressure tap and free fall in drainage tank to minimize the end effects. Injection system consist of polymer solution tank (50 liters) connected with air compressor to maintain a constant pressure in polymer tank. Polymer solution (1000 Wppm) was injected (downstream, 2 meter apart from pump) from the polymer solution tank into the pipeline controlled by flow meter using modified injection nozzle 2 meter apart from the . The first polymer injection nozzle involved the use of three holes with diameter of 3 mm that oriented in the vertical and plus minus 15^0 from the vertical. Second polymer injection nozzle involved the use of single hole with diameter of 3 mm. The flow meter, injection system, and differential pressure gauge were calibrated before every experiment.

2.3. Measurements

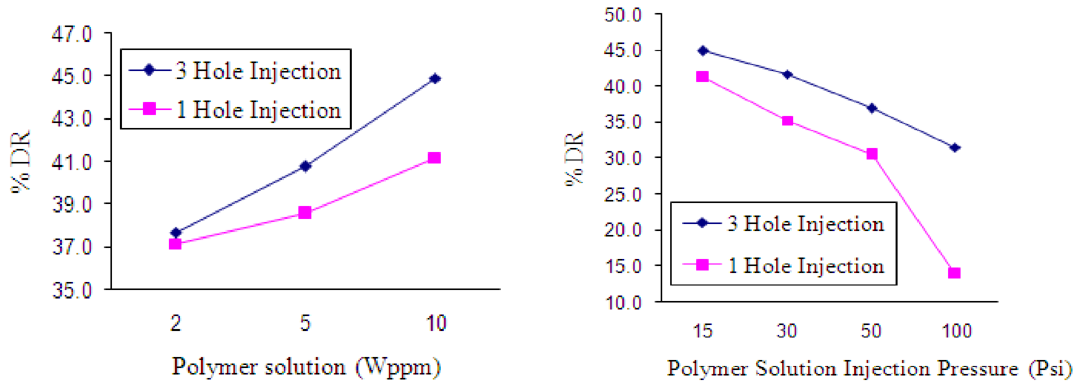
A measure for the amount of drag reduction at constant Re is defined as equation 1. Where Δp is the pressure drop in the absence and Δp_{dra} is the pressure drop in the presence of drag reducing polymer. The change in fraction by polymer drag reduction can be characterized by friction factor as equation 2. Where d is pipe dimeter, Δx is the distance between two points at which presser drop was recorded for each experiment and ρ is the density of test fluid. *U* is the observed flow rate and Δ*p* is the observed pressure drop at distance Δx.

$$\%DR = \frac{(\Delta p - \Delta p_{dra})}{\Delta p} * 100 \qquad \text{eq.1}$$

$$f = \frac{d}{2\rho U^2}\frac{\Delta p}{\Delta x} \qquad \text{eq.2}$$

3. Results and Discussion

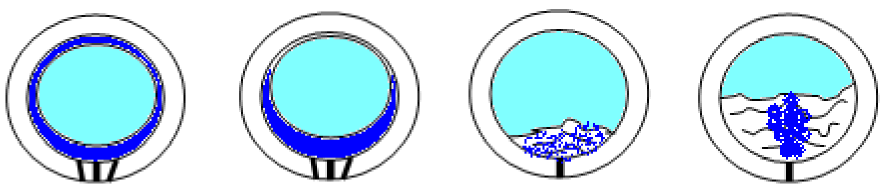
The drag reduction results (injection pressure at 15 psi) of Poly-acryl amide (PAM) solutions are presented in Fig. 1(a). As concentration increases % DR increases shows that high concentration reduces more turbulent frictional force. Fig.1 (a) indicated that three holes polymer injection nozzle showing higher efficiency of % DR (44.9 % at 10 wppm) then single holes



(a) (b)

Fig. 1: (a) Variation of % DR versus concentration of water soluble polymer solution in pipeline, (b) variation of %DR versus pressure (psi) of polymer injection systems

Polymer injection nozzle system (41.2%). These results may be interpreted as the formation of symmetrical polymer film around the whole pipe circumference in the 3 hole injection nozzle at low pressure as shown in Fig.2 (a). It may reduce the skin friction with greater extent which promotes modified turbulent flow having low friction factor (f). Results showed that the f of 3 hole and single hole injection nozzle system at15 psi of 10 wppp of PAM solution was 0.00259 and 0.00277 respectively. High value of f in the case of single hole injection nozzle may be due to creation of disturbance wave during polymer injection as shown in Fig.2 (c). Fig.1 (b) indicated that high injection pressure reduces the efficiency of % drag reduction in both injection systems. It may be due to formation of asymmetrical polymer film around the whole pipe circumference as shown in Fig.2 (b) in the case of 3 hole injection nozzle. Whereas single hole injection nozzle having more disturbances wave as shown in Fig.2 (d) causes ineffective mixing of polymer retarded the improvement of improving velocity profile. Williams et al., (1996) also reported optimization of injecting system may increases the efficiency of DR [11].



(a) (b) (c) (d)

Fig. 2: Polymer film distribution in pipeline (a) 3 hole nozzle at low pressure, (b) 3 hole nozzle at high pressure, (c) single hole nozzle at low pressure, (d) single hole nozzle at high pressure

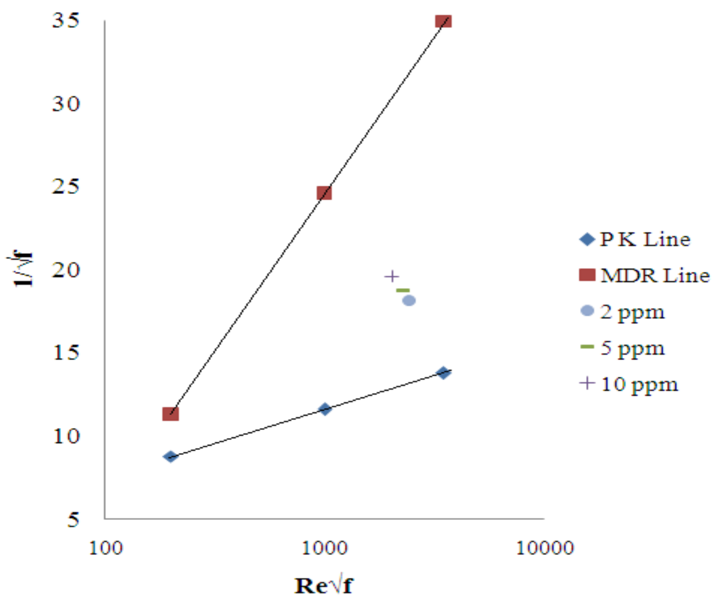


Fig. 3: PK plot for drag reduction asymptote of 10 wppm at 15 psi of PAM (MW $4x10^6$ g/mol)

Essential characteristics of polymer drag reduction of PAM can be verified by a universal maximum drag reduction (MDR) asymptote (PK plots). PK coordinates are a natural way of presenting drag reduction in pipe flow as the ordinate represents the ratio of bulk fluid velocity to the turbulent friction velocity, and the abscissa is a ratio of pipe to turbulent length scales [12]. The drag reduction results obtained with the PAM solutions are presented in Fig.3 in PK coordinates and illustrate important observations. All polymer drag reduction results fall between the Newtonian (PK line) and the MDR asymptote (MDR line) friction relationships. At higher concentration fluid velocity profile (1/√f) was improved. It shows that PAM solution follow the characteristic of polymer drag reduction phenomena correctly with the limitations of experimental parameters.

4. Conclusions

The effect of concentration for a PAM (MW $4x10^6$ g/mol) on DR was investigated in a single phase, once through, horizontal flow system. Increases in the % DR of polymer solutions were obtained by incremental increases of concentration. Optimization of injecting system may increases the efficiency of DR. 3 hole polymer injection nozzle at low pressure improves fluid velocity profile with greater extant due to symmetrical polymer film around the whole pipe circumference. High pressure polymer injection in the pipeline reduces the efficiency of DR.

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