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Experimental Study of the Reduction of Pressure Drop of Flowing Silt in Horizontal Pipes

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Abstract: Experimental studies have been conducted in the laboratory in order to test various polymers in the transport of silt, taken from the Fergoug reservoir situated in the north western region of Algeria. To study the effect of size, two pipe diameters have been used. The pressure drop, pipe friction factor and drag reduction were measured in the flow varying concentrations of polymers (Carboxymethyl cellulose called CMC and Polyethylene oxide called Polyox (WSR-301)) and silt. Adding the polymers (CMC and Polyox) to the mixture water/sediments, the results have shown that the drag reduction rate is round 15%. The results have shown that the polymers (Polyox, CMC) have an effect on the drop pressure. In addition to this we point out that the polyox has more effect than CMC.

Key words: Drag reduction, turbulent pipe flow, Toms effect, reduction of pressure, CMC

INTRODUCTION

In Algeria, silting of reservoirs has become a major problem for all existing dams and their dredging has become a major preoccupation. In recent years, a hydraulic dredging operation has been initiated at the Fergoug reservoir situated in the north west of Algeria. It is intended that this operation will be extended to the other dams too. The dredging of silt with a strong concentration in solid particles involves significant pressure losses. To reduce these pressure losses, friction reducing polymers are used. The reduction of friction by adding polymers was highlighted accidentally in 1948 by Toms. The first systematic work on the reduction of friction by the macromolecular compounds and other additives began in the United States. The first results were published by Toms (1949), which justifies sometimes the denomination of Toms effect attributed to the phenomenon of drag reduction. Tom's phenomenon has been well confirmed by many workers and drag reduction has been applied to many flow situations with varying degrees of success: hydraulics machinery, flow over submerged bodies, heating systems, jets. Sellin *et al.* (1982a, 1982b) present an extensive state of the art review on work done on drag reduction aspects and applications. This mode of reduction has been used in pipe flows (Sellin and Ollis, 1983), Couette-Taylor systems (Crumeyrolle *et al.*, 2005) and flat plate (Larsan, 2003).

Herod *et al.* (1974), in their experimental study explored the possibility of using drag reducing polymers to reduce the power consumption required by pump slurries as well as the possibility of increasing the solids content without causing pipeline blocking. They used 100 wppm concentrations of the Polyacrylamide (Separan AP-273). Flow rate pressure drop tests were carried out using fresh water, 6 dredge spoil samples, two clay slurries and two concentrations of silt water both with and without polymer. Drag reduction tests were carried out, using a flow loop. Such a fluid could be discharged after passing through the pump section. To minimize the polymer degradation, the polymer is injected into the flow at the pump discharge. Up to 70% drag reduction was achieved and for a given pressure drop the flow rate of the spoil could be increased.

Poreh *et al.* (1970), used 0.15% of a complex soap (CTAB, 1-Naphtol) to measure drag reduction of the transport of 20% (by volume) slurry of quartz sand in water. Their results show that up to 30% in energy could be saved in pumping the slurry. They also found that polymer additives were not so effective in this respect. Our interest in this mode of reduction of friction is due mainly to the small quantities of polymers necessary to obtain a considerable effect.

Different explanations of the mechanism of this friction reduction mode were published. These theories take into account the wall effects (decrease of the shear

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stress), the existence of normal stress, the flow extend gradient and some more the decrease of turbulence production.

The aim of this study, is to test the efficiency of friction reduces polymers on transport of silt in pipes; two silt concentrations (2.3 and 10%) were used. The polymers added were carboxymethyl cellulose named as (CMC) and the Polyethylene oxide (WSR-301) named as Polyox (WSR-301). Two pipe diameters were used in the purpose to investigate the diameter effect. The efficiency of each polymer was tested using clear water followed by other tests using silt.

MATERIALS AND METHODS

Figure 1 shows a schematic description of the test rig used. The solid-fluid mixture is pumped from the mixing tank into one of the two horizontal pipes. Valves at inlet and outlet of each pipe allow to direct the flow through the pipe where pressure loss measurements are made. The mixture discharges into a volumetric upper tank where volume flow rate measurement may be made. This tank is composed of two parts separated by a plate which might pivoted by a lever. One part is open to the lower tank and the second is closed. The closed part of the upper tank is calibrated allowing the measurement of an accumulated volume of mixture for a given time. When the measurement is completed the tank is emptied by opening a valve situated at its base. The flow is then directed in the open part of the tank by using the lever.

Pressure loss measurements are made using U tube manometers. Pressure drops less than one meter H_2O are measured using an inverted U tube water manometer. Higher pressure drops are measured using a mercury manometer. The pressure taps were set up at $l_1 = 3.727$ m and $l_2 = 6.310$ m along the pipe. The pipe diameters used were 36 and 53 mm with a roughness of 0.18 and 0.05 mm, respectively. The whole experiments were run at ambient temperature (T≈22°C).

Rheological characteristics of the mixtures used are determined using either an Engler type viscometer for Newtonian fluids or a coaxial viscometer for non-Newtonian fluids.

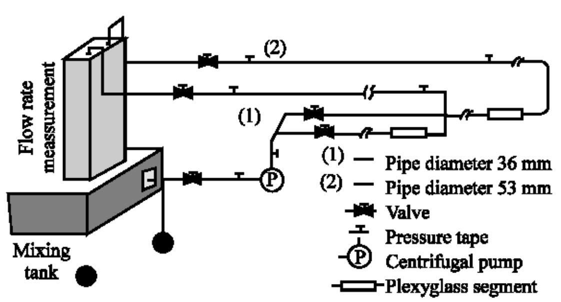

Fig. 1: Schematic description of the test rig

RESULTS AND DISCUSSION

The silt deposited along the Fergoug dam consists of materials of different grain sizes and geotechnical characteristics, which means, the silt has a $d_{50} = 6$ μm, the percentage of diameter of solid particles less than 75 μm is 97% in natural state and these values change in characteristics, which means d50 = 1.4 μm and the percentage of diameter less than 75 μm is 100% in its deflocculated state. The liquid and plastic limits of the silt are: 63.8 and 34.5%, respectively.

The concentrations in volume of sediments used are Cv = 2.3 and 10%. This parameter was determined using the following equation:

$$\rho_m = \rho_{solid} C_v + \rho_{water}(1 - C_v) \quad (1)$$

Where:

ρ_{Solid} : Particles density.
ρ_m : Mixture density.
ρ_{water} : Water density.

The polymers used in this investigation are Polyethylene oxide Polyox (WSR-301) and Carboxymethyl cellulose (CMC). These polymers reduce the friction and are characterized by the linearity of the macromolecular chains, the solubility in solvent and the high molecular weight. His concentration is expressed as part per million per weight (wppm).

The head loss between 2 sections of a horizontal pipe, J, induces a loss of pressure ΔH (Eq. 2) and the pressure drop, ΔP, is expressed in height of water per meter of pipe (Eq. 3).

$$J = \Delta H / L \quad (2)$$

With

$$\Delta H = \Delta P / \rho_m g \quad (3)$$

ρ_m : Density of the mixture.

In the first stage, we studied the variation of pressure drop with the average velocity for three various concentrations of silt (0; 2.3%; 10%). The relationship between the pressure drop and the average velocity of the mixture silt for both diameters 36 mm and 53 mm are presented in Fig. 2. At Cv = 2.3%, the mixture may be regarded as homogeneous or pseudo-homogeneous and behaves as a Newtonian fluid. In fact this concentration is lower than the limiting concentration value Cv_{lim} at which the fluid becomes non-Newtonian. Cv_{lim} was found to be equal to 3.12%. At Cv = 10%, the silt follow a non-Newtonian fluid behaviour. It is noted that the addition of polymers changes viscosity but the rheological behaviour remains the same one.

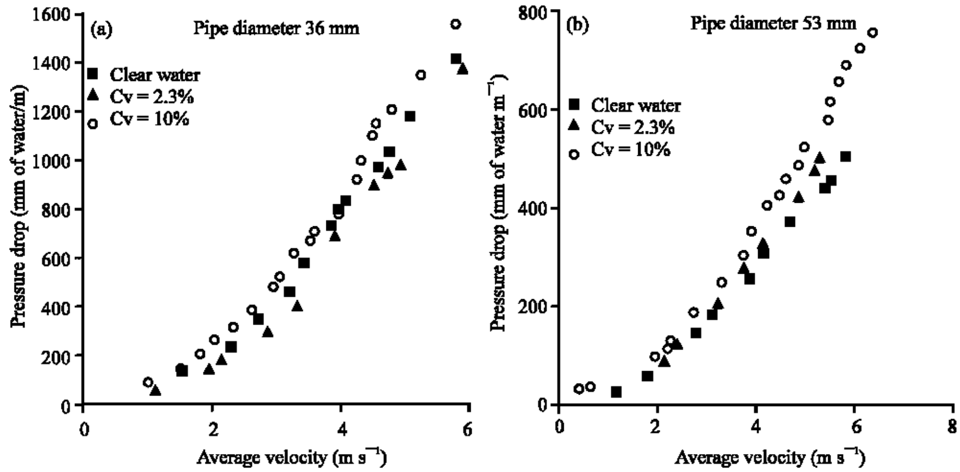

Fig. 2: Pressure drop vs. average velocity: effect of silt concentration

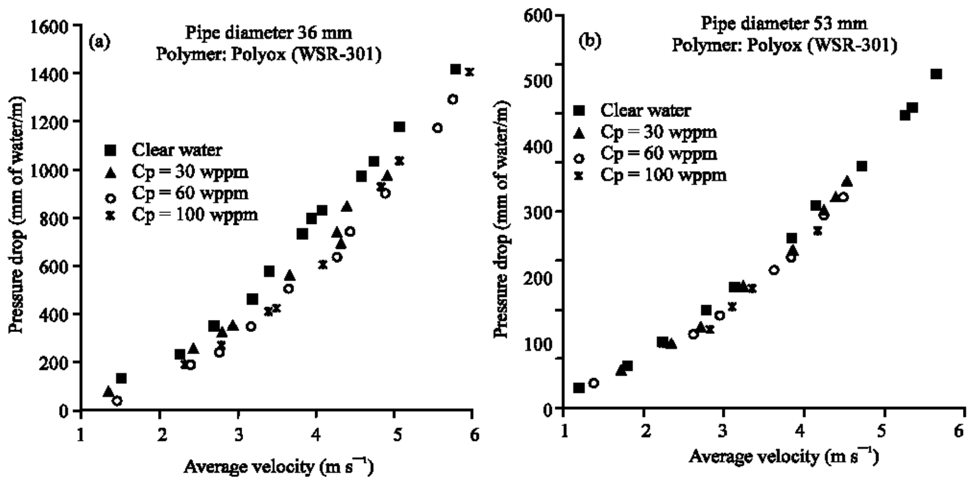

Fig. 3: Pressure drop vs average velocity: Effect of the polyox (WSR-301) in clear water

According to Fig. 2, the curve representing Cv = 10% is above the curve of clear water, whereas, the curve representing Cv = 2.3% is bellow the same curve. They reported that the mixture of water/sediment containing fine particles is characterised by reduction of pressure drop. The mixture with a concentration of 10% has a non-Newtonian behaviour. This means that, there is slight increase in pressure drop in comparison with clear water. The area between the curves representing Cv = 0% and Cv = 10% increased with average velocity. This phenomenon was explained by Newitt *et al.* (1961).

The effect of these polymers was tested using clear water. The curves in Fig. 3, show clearly the pressure drop reduction in the case of 36 mm diameter. Whereas, this effect is less in the case of the second diameter (53 mm), this effect could be attributed to the effect of pipe diameter; these findings are supported by Sellin and Ollis (1983). The results found in our investigation, prove the effect of the used polymers and the qualification of the used installation to detect a possible reduction of pressure drop.

Different concentrations of polyethylene oxide and CMC have been tested in the silt (Cv = 2.3%). The results found and plotted in Fig. 4 and 5 (pipe diameter 36 mm), show that the graph represents three zones. The first zone representing the small values of the mean velocity, the reduction of pressure drop evolve slowly, second zone, this pressure drop increases and then it is reduced in a third zone. These results are in conformity with those found by Virk (1975) and Larsan (2003). Indeed, the efficiency of polymers depends on the shearing force

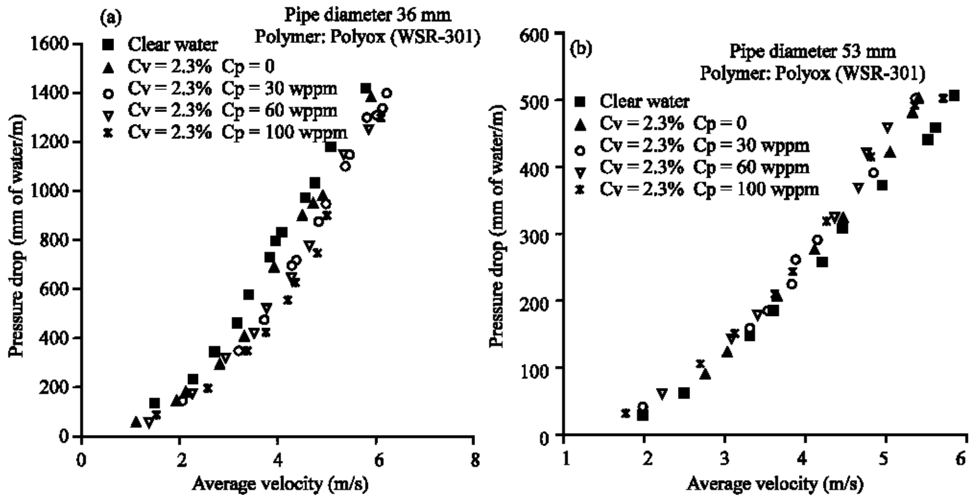

Fig. 4: Pressure drop vs. average velocity: Effect of the polyox (WSR-301) in the mixture Cv = 2.3%

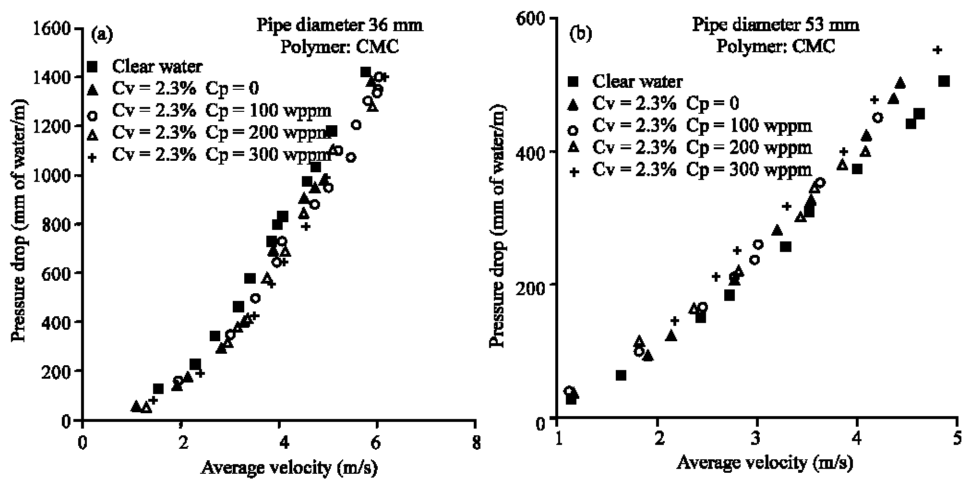

Fig. 5: Pressure drop vs. average velocity: Effect of the CMC in the mixture Cv = 2.3%

applied to the macromolecular. The absence of the effect of reduction of both polymers on the mixture in the second pipe (53 mm), could be the effect of the diameter, as showed by the work of Sellin and Ollis (1983). However, we note an increase of the pressure drop in this pipe when the velocity becomes important. The results analysis of Fig. 5, show that the carboxymethyl cellulose is less efficient than polyethylene oxide in the case of the mixture of Cv = 2.3%.

In the case of the polymeric mixtures with Cv = 10%, Fig. 6 show a slight increase in the pressure loss for 36 mm diameter. Whereas, in the case of 53 mm diameter a significant increase in the pressure drop is noted, this increase is mainly attributed to the degradation of the macromolecular chains of the polymers (Yu *et al*., 1979; Kalashnikov, 2002) and consequently the viscosity of the mixture increased. This phenomenon occurs during recycling of the solutions and mixtures polymerized by the pump and during the preparation by either manual or propeller agitations. This degradation phenomenon is due primarily to a macromolecular chain breakage and constitutes a major obstacle to the extension of this mode of drag reduction. For the polymers used, it is noted that the drag reduction is definitely higher in the case of the 36 mm pipe diameter than for the 53 mm one.

The curves representing the friction factor versus Reynolds number in Fig. 7 show a threshold point. From this point we observed a clear reduction in the friction factor and this corresponds to a shear threshold point

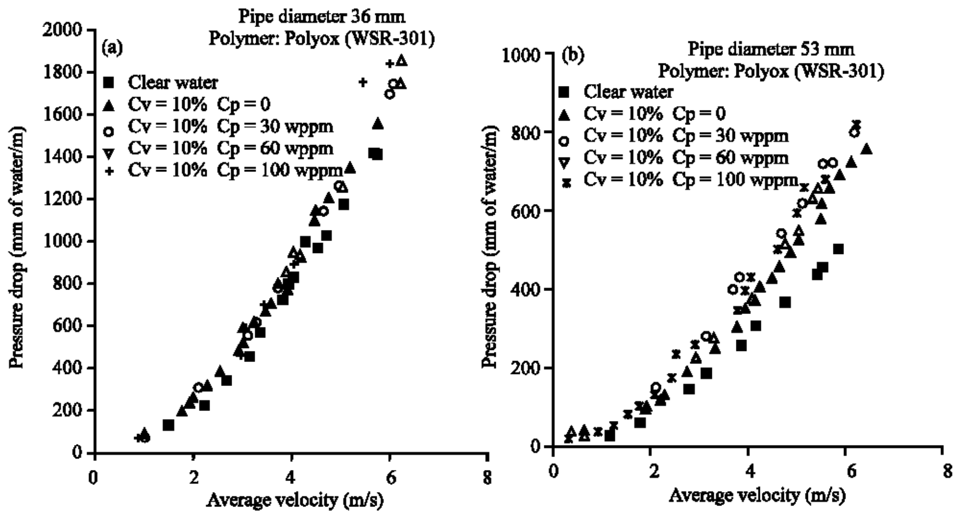

Fig. 6: Pressure drop vs. average velocity: Effect of the polyox (WSR-301) in the mixture Cv = 10%

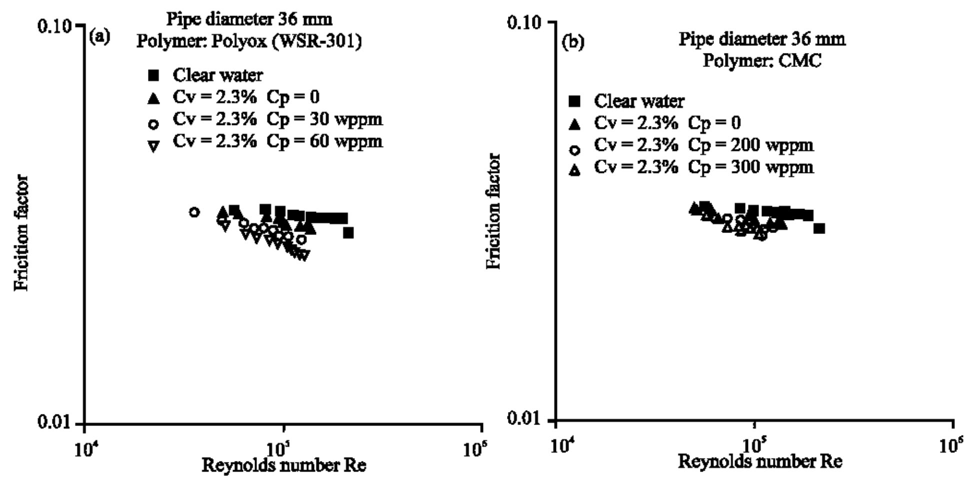

Fig. 7: Friction factor vs. Reynolds number, effect of polyox (WSR-301) and CMC in the mixture Cv = 2.3%

which is called "Onset". Onset is already mentioned by (Elata *et al.*, 1966; Virk and Baher, 1970). The same figure shows that the Onset depends on the polymer nature and pipe diameter.

Drag reduction, at constant Re value, is defined by:

$$DR(\%) = \frac{\lambda_0 - \lambda_P}{\lambda_0} \times 100$$

Where, λ_p is the friction factor for the polymer mixture and λ_0 is that for the solvent in the same pipe and at the same Reynolds value. Reduction degree presented has been calculated in relation to the mixture of the volumetric concentration 2.3%. Maximum reduction obtained for Polyox (WSR-301) was 12.6% meanwhile it was 6.76% for CMC. These reduction percentages are less in comparison with those obtained with the same installation when clear water transported. This difference of percentage is probably due to the presence of solid particles in the silt mixture. Drag reduction rate against Reynolds number presented in Fig. 8 shows that, the effectiveness of polymers depends on both the polymer and the nature of the transported fluid. Thus for the same Polyethylene oxide concentration, the reduction ratio obtained is more important in the case of clear water than in the case of the mixtures of silt. This can be attributed to the mechanical degradation that the macromolecular chains undergo following the deformation resulting from the gradient velocity.

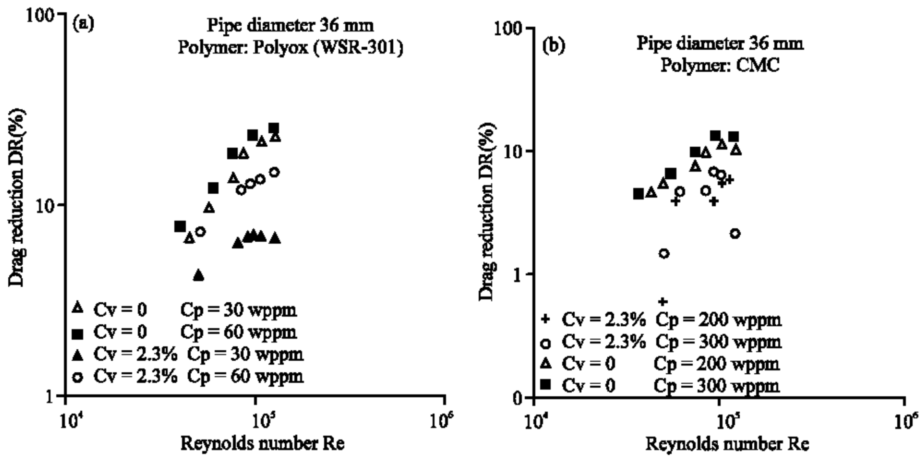

Fig. 8: Drag reduction versus reynolds number, effect of polyox (WSR-301) and CMC in the mixture Cv = 2.3%

CONCLUSION

In this study the following conclusions have been reached:

- Drag reduction appeared only in the turbulent regime.
- Effect of drag reduction depends on polymer type and on its concentration.
- Polymer effect depends on the fluid nature (clear water, silt ...).
- Drag reduction depends on the pipe diameter.
- Solid particles contribute significantly to mechanical degradation of the macromolecular chains.

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