EXPERIMENTAL STUDY OF THE EFFECTIVENESS OF SOME COAGULANT AIDS AS DRAG REDUCING AGENTS

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Abstract

The objective of the present experimental study is to investigate the effect of the addition of very small concentrations of high molecular weight, non-toxic polymers, on the pressure distribution and consequently on the turbulent frictional drag of the water in which they are solved. This work was motivated by the fact that some polymers, which are used as coagulant aids in water treatment plants, proved to be effective as drag reducing agents. The effect of four polymers which are frequently used, in water treatment plants, namely Magnafloc LT 24, floculate 600, Catfloc, and TFL 1761 was investigated at different concentrations and Reynolds numbers. The economical feasibility of using these polymers as drag reducing agents have also been evaluated.

INTRODUCTION

One of the major problems encountered in Alexandria water distribution network is the tremendous increase of energy estimated to compensate for the increasing demand of water supply, escalated by the growth in number of population and related service utilities, and the expansion of industrial programs. Also, the low pressures in the network, due to the increased demand, involve health problems, partly due to subpressures leading to pollutents seeping into the drinking water. One method of increasing pressures in the network and reducing power consumption is to use non-toxic polymer additives as a means of drag reduction in pipes and hydraulic equipments.

Under certain conditions of turbulent flow in pipes, dilute polymer solutions require a smaller specific energy expenditure than the pure solvent. Thus, with the polymer solution, a lower pressure gradient is needed to maintain the same flow rate, or a higher flow rate can be attained for the same pressure gradient as solvent. This specific energy or drag reduction is termed the Toms phenomenon, after Toms [1], who was the first to recognize it [2]. Drag reduction by polymer additives depends upon the presence of the right type of polymer molecules, at the right concentration, in the correct place and under the correct flow conditions. A thorough review of the drag reduction by additives followed by the bibliography of over 1000 references was given by White and Hemmings [3].

Recently, a state of the art review of the effect of drag reducing additives on fluid flows and their industrial applications was given by Sellin et al. [4,5].

From the review of literature, it appears that the applications of using polymer additives as a means of saving energy expenditure in potable water networks has not received the attention accorded to other applications

The aim of the present work, therefore, was to carry an experimental investigation to study the effect of some non-toxic polymers, specially those already used as coagulent aids in water treatment plants to study their effectiveness as drag reducing agents. An economic study was then attempted to evaluate the economical feasibility of using these polymers to save energy expenditure.

THE EXPERIMENTAL SET-UP

From preliminary investigation, it is proved that recirculation of the polymer solution by means of a centrifugal pump should be avoided. This is due to the severe mechanical degradation of polymers, causing chain rupture during servicing. To avoid degradation the polymer was introduced into the system after the centrifugal pump ,and closed loop operation was only used in case of zero concentration .

The experimental block is shown in Figs.(1,2) where a continuous water flow from the main city network was introduced into the system. The polymer solution was injected via a positive displacement dosing pump. The point of addition was selected so that the natural

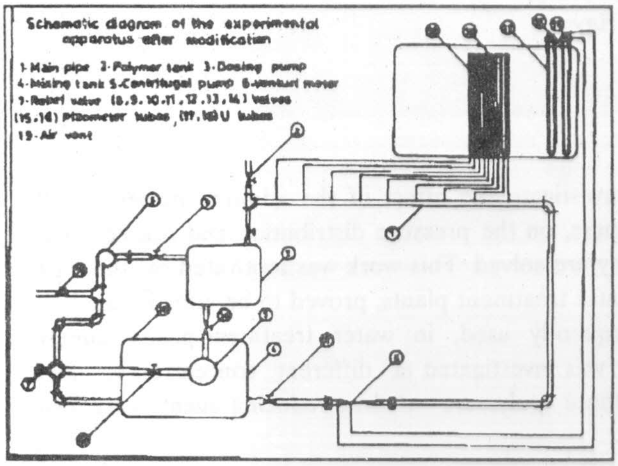

Figure 1. A schematic diagram of the experimental apparatus.

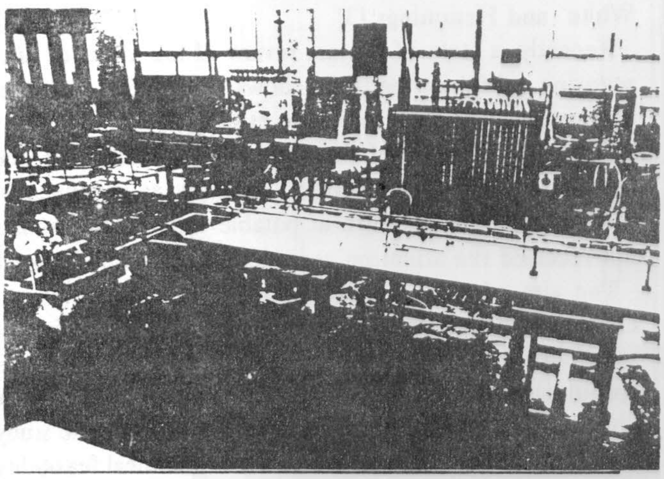

Figure 2. A general viwe of the apparatus.

turbulence in the system will adequately distribute the polymer. The dilute solution was directed after its passage in the test section to the drain and was not recirculated in the loop .

The test section was made of Plexiglas pipe (three identical parts) of inside diameter, d = 2.54 cm (1 inch) and total length, L = 270 cm. The wall static pressure drop through the test section was measured using nine pressure taps connected to piezometer tubes. Each two taps are 30 cms apart .

For a drag reducer to be wholly effective it is important that it is highly soluble in the solvent .The polymer was premixed with water and stired properly for 20 to 30 minutes. Each concentration was prepared one day before use to allow for homogeneous concentration [5]. A period of 5 to 10 minutes of stirring was enough before the direct use. Since the concentration of the solution was in all cases very low, the rheological properties of the solution were hardly influenced by the addition of polymers. Therefore, all the measuring equipments were checked and calibrated with water only before conducting the experimental work .

RESULTS AND DISCUSSION

The global effectiveness of the polymers as drag reducing agents was first investigated. This was performed, simply, by measuring the solution throughput in a vertical cast-iron pipe 1/2 inch diameter and 5 mt. long. Four polymers solved in water were initially tested for the same input head in an elevated supply tank of volume 45 Lit.. The polymers are Magnafloc LT 24 , Catfloc, Floculate 600, and TFL 1761.The results are shown in table (1). From the table it is clear that for all polymers the time taken to empty the elevated tank decreases as the polymer concentration increases, i.e. the throughput and Reynolds number, for the same available head, are increased. However, It is apparant from the table that Magnafloc and TFL 1761 are more effective at low concentrations, while Catfloc has almost no effect. Floculate 600 starts to be effective only at relatively high concentrations. Therefore it was decided to investigate, more thoroughly, the effect of the former two polymers on the extent of pressure drop.

For steady fully developed turbulent pipe flow, the static pressure drop is balanced only by shear stress at the pipe wall. This can be seen by applying the momentum equation to a cylinderical control volume in the flow [6,7]. Therefore, the wall shear stress, τ_w , can be calculated directly by measuring the wall static pressure drop, Δp, along the pipe axis (x - direction)

$$\tau_w = -\frac{R}{2}\frac{\Delta P}{\Delta x} \quad \text{where R is the pipe radius}$$

There are several ways of setting criteria for fully developed flow. For example, one may define fully developed flow on the basis of pressure drop, mean velocity distribution or turbulence quantities. The actual

Table 1. Elevated tank results

	a. *Floculate 600*			b. *Magnafloc LT 24*		
Concentration [WPPM]	Time [sec]	Q_{ava} [lit/sec]	RN_{ava}	Time [sec]	Q_{ava} [lit/sec]	RN_{ava}
0	66.4	0.677	67940	66.4	0.677	67940
10	65.0	0.692	69373	62.8	0.716	71779
20	58.0	0.775	77693	60.9	0.739	74084
30	52.4	0.858	86014	58.3	0.771	77242
40	53.2	0.845	84711	54.8	0.821	82305
50	50.2	0.896	89865	52.9	0.850	85204

	c. *Catfloc*			d. *TFL 1761*		
Concentration [WPPM]	Time [sec]	Q_{ava} [lit/sec]	RN_{ava}	Time [sec]	Q_{ava} [lit/sec]	RN_{ava}
0	66.4	0.677	67940	66.4	0.677	67940
10	66.0	0.681	68270	58.8	0.765	76722
20	66.6	0.676	67769	49.0	0.918	92066
30	58.3	0.771	77242	47.4	0.949	95167
40	54.8	0.821	82305	47.2	0.953	95577
50	52.9	0.850	85204	47.4	0.949	95167

lengths for these are substantially different. The pressure gradient generally takes on the fully developed values after three or four diameters of entrance length. The mean velocity requires from 30 to 60 diameters at entrance length before it becomes fully developed. The turbulence quantities require a much greater length [8]. For the present study, the linearity of the wall static pressure drop were checked at the beginning using water only (zero concentration). A sample of the results are shown in Fig.(3) for the range of Reynolds numbers (40421-51527). From this figure, it is clear that for all Reynolds numbers the static pressure drop along the pipe wall is linear and consequently the flow is fully developed.

The minimum Reynolds number required to ensure fully turbulent flow was investigated thoroughly for the case of pipe and channel flows by Patel and Head [9]. Their three criteria, namely, skin friction-Reynolds number relation, log law with universal constants, and disappearance of intermittency, did not lead to a unique minimum value of Reynolds number above which fully turbulent flow can be established. But Figs.(13,14) and table (1) in their paper show that this Reynolds number should be greater than 10^4 . In the present study the minimum Reynolds number was 25900 , i.e. the present pipe flow satisfies this

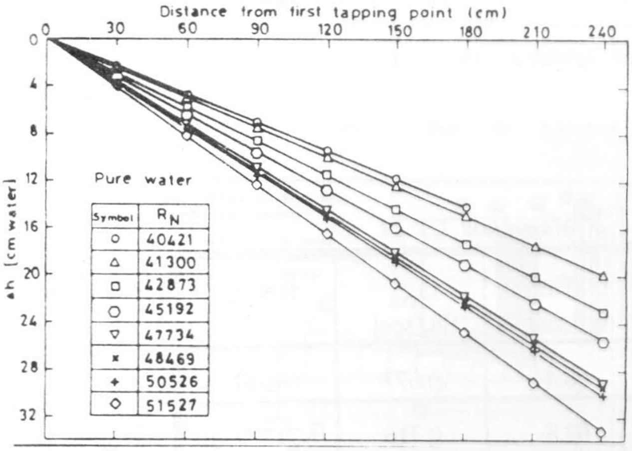

Figure 3. Pressure distribution of pure water at different RN.

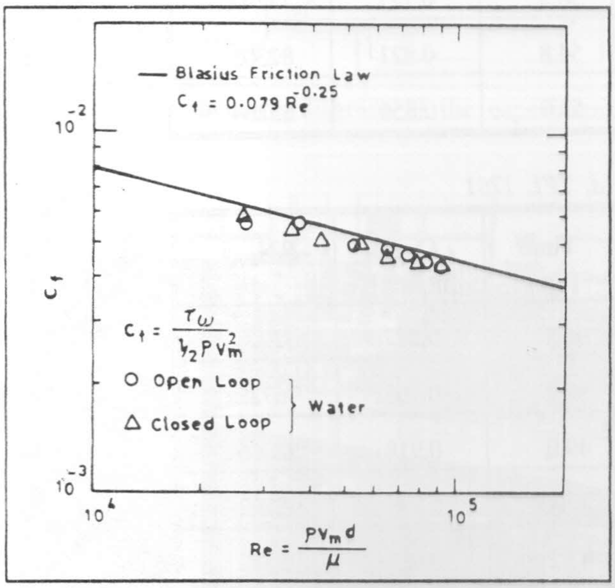

Figure. skin friction coefficient versus RN.

requirement. Further, the coefficient of friction

$$C_f = \frac{\tau_w}{\frac{1}{2} \rho V_m^2}$$

(where τ_w is the wall shear stress, ρ is the fluid density, and V_m is the bulk or mean velocity at a cross-section of the pipe in the longitudinal direction) is shown in Fig.(4). The present results are in agreement with the well known Blasius friction law

$$C_f = 0.079\ Re^{-0.25}$$

As was mentioned previously two polymers were selected f2or this set of experiments. Results of only one Reynolds number are presented here. However, the same trend was observed for other Reynolds numbers.

Fig. (5) shows the pressure distribution for the two polymers . It is clearly shown that the effect of polymer addition is to reduce the friction loss in pipes, but with different effectiveness that can be summarised as follows :

The percentage drag reduction in pipes can be determined as a function of the reduction in the friction coefficient 'S',

$$S = [(F_w - F_p) / Fw] \times 100 \quad \text{, where,}$$

S = % drag reduction.
F_w = Friction coefficient for pure water.
F_p = Friction coefficient for a polymer solution.

From the pressure measurements, the percentage reduction in the friction coefficient can be determined for the two polymers under consideration. A concentration of 10 and 15 weight part per million (w.p.p.m.) of Magnafloc resulted in a drag reduction of only 2 % and 7.8 % respectively. On the other hand TFL 1761 gave good results at 5, 10 and 15 w.p.p.m.. A concentration of about 5 w.p.p.m. results in a drag reduction of about 5.88 %, while at a concentration of 10 w.p.p.m. a reduction of 9.8 % was obtained. Meanwhile, a concentration of 15 w.p.p.m. of TFL 1761 results in a drag reduction of about 13.7 %. From the above results it is apparant that TFL 1761 is the most effective polymer as a drag reducer. Since this polymer is already used as a coagulant aid in water treatement plants, its usage can be further extended as a drag reducing agent. However, it can only be used at low concentrations, no more than 5 w.p.p.m., which is the same concentration used practically in clarifiers in water treatement plants.

ECONOMICAL EVALUATION

In order to test the feasibility of using the polymer as a drag reducing agent, it was necessary to study the economical feasibility , i.e. whether the saving in energy expenditure in the pumping power of the water treatment plants outweights the cost of the raw polymer material. Therefore, a computer program for the water network simulation that was developed by the Water Research Engineering, Swindon, United Kingdom, (available at the Alexandria Water General Authòrity) was used to simulate the Alexandria water distribution networks .

Table 2. Daily production and energy consumption of each treatment plant.

Treatment Plant	Total water prod. cu. mt	Total power cons. K.W.H.	Water prod. cu. mt/K.W.H.
Rond point	10092770	2018554	5.000
Siouf	7050941	1588209	4.115
Manshia	3850150	734400	5.243
F. Elgeraya	1637850	259970	6.300
Mamoura	634200	154790	4.097
Mariout	1839996	682260	2.697

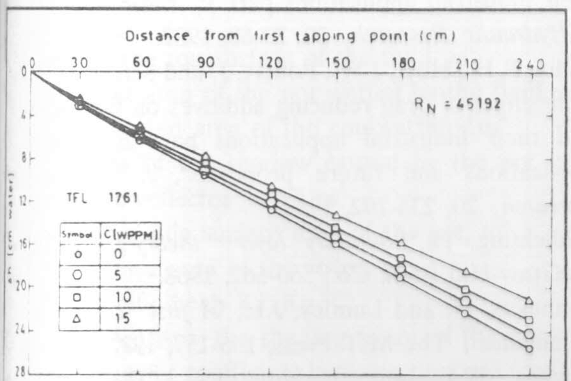

Figure 5a. Pressure distribution of polymer solution at RN-45192 and different concentrations of TFL 24.

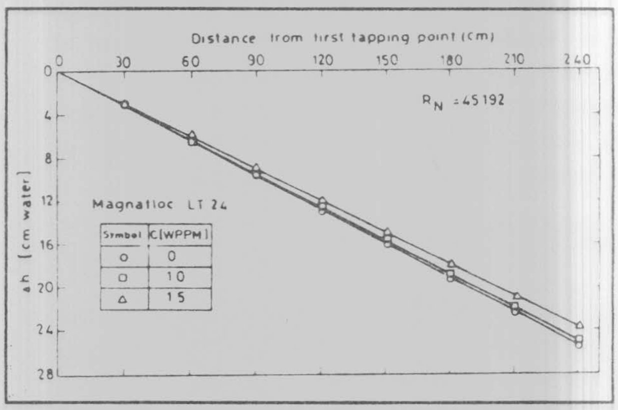

Figure 5b. Pressure distribution of polymer solution at RN-45192 and different concentrations of Magnaflock LT 24.

From the computer output the necessar pumping power of all six water treatment plants of Alexandria were obtained. The production and energy consumption for each station are shown in table (2) . From the results, the average water production in cubic meter per K.W.H. average is 4.792. Therefore, the amount of coagulant aid, TFL 1761(the most effective) necessary to produce 5.88 % drag reduction is, 500 gm./ 100 cu.mt.

The price of the TFL 1761 = 2000 EL/ton.

The price of one gram = 2 ml.

The total price of polymer per 100 cu.mt production = 1000 ml.

The price of one K.W.H. = 24 ml.

Therefore the saving price of electrical energy = 29.5 ml./100 cu.mt.

From the above results, it may be concluded that using polymers as a drag reducing agent, although it may be feasible in other industrial applications, it is not economical in this application since the cost of extra coagulant aid outweights the cost of energy saving. This is primarily due to the high cost of coagulant aids, and secondly due to the relatively high polymer concentrations necessary to produce significant drag reduction.

However, the price of coagulant aids is based on local prices which are higher than the international market price. On the other hand, the price of energy in Egypt is highly subsidised. Therefore, if the study is based on international prices, the situation might be worth considering.

CONCLUSION

The following concluding remarks are based on the experimental results obtained using four polymers namely, Magnafloc LT 24, Floculate 600, Catfloc, and TFL 1761 at different concentrations and Reynolds numbers.

1. TFL 1761 is the most effective polymer as a drag reducer at low concentrations (< 10 w.p.p.m.) followed by Magnafloc.
2. Catfloc has almost no effect .
3. Floculate 600 is effective at relatively high concentrations (> 10 w.p.p.m.) .
4. The use of TFL 1761 polymer at low concentration in water supply plants, even though effective, is not economically feasible. This is primarily due to the high cost of coagulant aids which outweight the cost of energy saving. However, if a cheaper coagulent aid of an equivalent effect to TFL 1761 or can be used at lower concentrations can be obtained, the usage of such polymer might be economically feasible.

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