EFFECT OF DRAG REDUCING POLYMER ADDITIVES ON FLOW THROUGH COMMERCIAL BENDS AND TEES.

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ABSTRACT

Experimental studies of the total loss coefficient and pressure distribution, for turbulent Newtonian and drag reduction flows in bends and tees are presented. Dilute solutions of polyethylene glycol in water were used as the drag reducing fluids. Drag reduction was deduced from plots of experimental pipe flow data, on Prandtl-Karman coordinates. Two main test sections were studied. The first test section was a commercial 90° bend,while the second was a commercial tee section. The later test section was studied in different situations such as a distributer , a collector, a by-pass and a bend. Estimation of the total loss coefficient required an evaluation of a kinetic energy correction factor. Based on previous theoretical and experimental verifications, this factor was determined from the friction factor Reynolds number pipe flow data, for the different flowing fluids. Thus, a reasonally accurate evaluation of the total loss coefficient could be obtained. The results showed that drag reducing polymer additives cause a reduction in the total loss coefficient for all flow situations studied. Pressure distributions along the different sections were presented both with physical interpretations and discussion of some flow separation aspects. The results showed that the pressure distributions along the studied sections had the same trend for both Newtonian and drag reduction flows.

1. INTRODUCTION

It is well known that a fluid stream flowing through a bend or a tee section develops secondary flow depending on the flow rate and the dimension of each element. In long pipelines these are distinctly "minor" losses and can often be neglected without serious error. However, in shorter pipelines an accurate knowledge of the effects of these losses must be known for correct engineering calculations.

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Review of previous work on bends and tees may help understanding the objective of the present research. Studies concerned with pressure and power loss along bends and tees in case of turbulent Newtenian flow, are numerous. Correlations of the static pressure loss along bends and tees, in terms of kinetic energy head, have been presented in many text books [1]. Ito [2] made experiments on smooth curved pipes with circular cross section. He gave an empirical formula for the total loss coefficient in terms of Reynolds number, bend curvature ratio and deflection angle. Tukimaru, et.al [3] found experimentally, that the hydraulic losses in the wavy bend pipes are larger than those in quasi-coil pipes. Villemonte [4] gave an explanation of the phenomena associated with minor losses and defined an energy loss coefficient-for the fitting-based on momentum and energy balances. They suggested a correlation of the experimental data, of the flow in fitting, using a loss coefficient-Reynolds number correlation similar to that used in case of straight pipe flow. Ito, et.al. [5] carried out experiments on both smooth and screwed symmetrical 90° Y-junction. They found that the power loss coefficient in case of screwed Y-junction was higher due to the effect of the internal threads exposed to the flowing fluid. Also, they introduced empirical correlations for loss coefficients in case of smooth symmetrical 90° Y-junction of different flow configurations.

Measurements, on velocity profiles and turbulence quantities of turbulent Newtonian-boundary layers on curved walls, had been carried out by many authors [6-7]. These measurements showed that turbulence tends to be suppressed on the convex wall and amplified on the concave wall. Some authors [8-9] introduced theoretical approaches for the problem of turbulent-Newtonian-flow in curved channels. Losses due to two-phase flow in bends and tees had been studied by many authors. Reference [10] includes a wide review in this field. Empirical correlations of pressure loss along bends and tees, in case of turbulent two-phase flows, were presented in details.

The above review shows that most of previous studies were concerned with Newtonian fluid flow through bends and tees. Similar studies, for drag reducing fluid flow, seem not to be available. On the other hand, the flow of drag reducing fluids through pipes has been widly studied [11]. Studies on drag reducing polymer solution flow in straight pipes indicated that: i) drag reduction occures only in turbulent flow, ii) there is a distinct onset of drag reduction and iii) as polymer concentration increases drag reduction increases until the maximum drag reduction asymptote which is independent of concentration.

The objective of the present paper is to present a study of the effects of polymer additives on the losses due to flow through pipes, bends and tees. In addition, the study includes the effect of flow configuration in the tee section on its loss coefficient.

2. THEORETICAL ANALYSIS

The following analysis is based on the work given by Villemonte [4]. The assumption of steady, isothermal turbulent incompressible

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3.3. EXPERIMENTAL APPARATUS AND MEASUREMENTS

The experimental apparatus is shown in Fig. 2. The test fluid flows from the upper main tank (1), (1 x 1 x 1 m) to the overflow tank (2), (0.5 x 0.3 x 0.4 m) which ensures a constant head all-over the experiments. The test fluid flows from the over flow tank, through the test section, to the flow rate measuring tank and then to the drain valve. A centrifugal pump (10) was used to pump the water from the collecting tank (7) to the upper tank. Two test sections were studied, Fig.3-a. The first section was a commercial 90° bend, while the second was a commercial tee section. The tee section is studied in different flow situations, as seen in Fig.3-b. The test sections were provided with static pressure taps as seen in Fig. 2. Static pressure measurements were carried out using multitube manometer (9) and flow rates were measured using calibrated measuring tanks (8). Dilute solutions of Polyethylene glycol (MW = 3.9 x 10^5) in water were used as drag reducing fluids. The solutions were prepared in the upper tank (1) and were not recirculated to avoid degradation effects.

4. RESULTS AND DISCUSSION

The following discussion concerns with the effects of both Reynolds number "Re" and polymer concentration "C" on pressure distribution and losses in pipes, bends and tees. Also, the effect of arranging the tee section, in different situations, on its losses is discussed.

4.1. Flow in Pipes:

Figure (4) shows the variation of the friction coefficient (λ) with the flow Reynolds number (Re) , for different polymer concentrations. Drag reduction is depicted from this figure. These results were used to get the (λ) values, and consequently the corresponding (α) values required to calculate the total loss coefficient (KF) for bends and tees, see Eqs. (2-7).

4.2. Flow in Bends:

4.2.1. Pressure distribution:

Pressure distributions along bends and tees showed the same trends in all experiments. Samples of pressure distributions along the bend sections are shown in Figs. 5 & 6. It is shown that at a distance $L/D \simeq 3$ the pressure begins to rise due to increasing stream tube area, while at a distance L/D = 4, the effect of flow separation, due to the positive pressure gradient and stream tube deflection, is dominate and this will give a steep in pressure drop. Finally, at a distance $L/D \simeq 7$, the flow recovers from separation effects and the static pressure drop is mainly due to straight pipe friction. Fig. 5 shows the effect of (Re) on the pressure distribution. It is shown that as Re increases the pressure drop due to flow along the distance, L/D = 3 to L/D = 7, of the test section increases. Fig. 6 shows the effect of polymer concentration (C) on pressure distribution. It is seen that the increase in the value of flow is adopted. Fig. 1 shows the control volumes for combining and dividing flow situations. Pipe (m) contains the total volumetric flow rate Q_m. The side pipe could serve as the main pipe in both situations. Also, one of the side pipes could be closed. However, the analytical concepts for all of these physical arrangements would be the same. It is assumed that the fitting effect begins downstream section "m" and vanishes upstream the other sections.

Considering the case of combining flow, Fig. 1-a, continuity requirements yields:

$$Q_m = Q_1 + Q_2 \tag{1}$$

Using this equation, an energy balance on the control volume results in a total loss head hF as:

$$hF = \left(\frac{P}{\rho g} + \alpha \frac{V^2}{2g}\right)_1 \frac{Q_1}{Q_m} + \left(\frac{P}{\rho g} + \alpha \frac{V^2}{2g}\right)_2 \frac{Q_2}{Q_m} - \left(\frac{P}{\rho g} + \alpha \frac{V^2}{2g}\right)_m - h_{f1}\left(\frac{Q_1}{Q_m}\right) - h_{f2}\left(\frac{Q_2}{Q_m}\right) - h_{fm} \tag{2}$$

where $h_f = \lambda.(LV^2/2gD)$. In Eq.(2) values of Q and P were measured experimentally. Also, the friction coefficients λ's were determined from measurements on stright pipe flow. The kinetic energy correction factors α's could be determined in terms of the measured friction coefficients as follows.

Assuming the velocity profiles at the different terminal sections are represented by the wall law as [11]:

$$u^+ = 2.5 \ln y^+ + B \tag{3}$$

where $u^+ = u/u^*$, $y^+ = yu^*/\nu$ and $u^* = \sqrt{\tau w/\rho}$.

Integration of this profile across pipe area gives the mean velocity V. The following velocity distribution can be obtained

$$u/V = \psi \ln \xi + \emptyset \tag{4}$$

where:

$$\xi = r/R, \quad \psi = 2.5\sqrt{f/2}, \quad \emptyset = 3.75\sqrt{f/2} + 1 \text{ and}$$

$$f = \tau_w / 0.5 \rho V^2 = \lambda/4 \tag{5}$$

The kinetic energy correction factor α and the total loss coefficient KF are obtained from the following relations:-

$$\alpha = 2\int_0^1 (u/V)^3 \xi d\xi = \emptyset^3 - \frac{3}{2}\emptyset^2\psi + \frac{3}{2}\emptyset\psi^2 - \frac{3}{4}\psi^3 \tag{6}$$

$$KF = hF/(V_m^2/2g) \tag{7}$$

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polymer concentration causes a reduction in the pressure drop. Fig. 7 shows a representative selection of pressure distribution along the tee section as a distributor. The effect of Reynolds number is clear whereas its effect is opposite to that obtained for the bend section.

4.2.2. Total loss coefficient (KF):

Fig. 8 shows the variation of KF with Re at different polymer concentrations for flow through bend. For a certain concentration, as Re increases the loss coefficient KF increases. The increase in Re results in a decrease in the friction factor and, at the same time, an increase in eddies due to separation. Thus, the increase in KF due to Re increase means that eddies effect dominates over friction effect in case of flow in bends. The rate of KF increase, decreases as Re increases. At high Re, KF attains a constant value where losses are related to the flow inertia only.

The effect of polymer concentration is quite clear in Fig. 8. At a certain Re, as polymer concentration (C) increases KF decreases. This means that polymer additives cause damping of the eddies associated with separation in the bend. It is interesting to note that the maximum achieved loss reduction is about 75% at $Re = 5 \times 10^4$ and C = 10 ppm, while pipe flow drag reduction at the same conditions - is about 20%. This means that the effect of polymer is more apparent in bend flow.

4.3. Flow in Tees:

Fig. 9 shows the variation of KF with Re at different polymer concentrations for flow through a tee section which was used as a distributer. For a certain concentration, it is clear that KF decreases as Re increases. This means that, unlike the case of bend, the friction effect dominates over eddies effect in case of the tee section. For higher values of Re, KF approaches constant value where the losses are related to the inertia of flow only. The effect of polymer concentration is also quite clear in Fig. 9. Like the case of bend flow, polymer additives reduce loss coefficients. At a certain Re, loss reduction increases as concentration increases. Also, it can be seen that the effect of polymer additives on loss reduction in tees is more apparent than that in pipe flow drag reduction. A comparison between loss coefficients for the bend and the tee section when used as a bend is shown in Fig. 9. It is seen that the curves of the variation of KF with Re have the same trend in both cases. On the other hand, for a certain concentration, the curves obtained for the two cases intersect at a certain point. Below this point KF of the tee as a bend section is less than that of the bend at the same Re. This intersecting result means that the dead zone in the tee as a bend section may act as eddies damper leading to loss reduction under certain flow conditions. Figs. 11 & 12 show a comparison of the loss coefficients, obtained for different flow situations of tee section. It is seen that at a certain Re, the maximum loss occures when the tee is used as a collector. On the other hand, the minimum loss occures where the tee is used as a bend. These results are expected since the losses in the former case are due to separation in both branches and the deflection of the main stream in two opposite directions. The previously discussed trends prevail in case of polymer solution flow in tee section at different situations. For example, Fig. 12 shows those trends for C = 10 p.p.m.

CONCLUSION

Polymer additives, which reduce friction in case of flow in pipes, reduce losses in case of flow in bends and tees also. In the latter case, the effect of the polymer is more apparent. For a certain polymer concentration, as the Reynolds number increases the total loss coefficient of bend increases, while for flow through tee section it decreases. At high Reynolds number the total loss coefficient approaches a constant values in both cases of tested elements. For a certain Reynolds number, the total loss coefficient decreases as polymer concentration increases in case of flow through bends and tees. Under certain flow conditions the total loss coefficient of tee as a bend section is less than that obtained for the conventional bend. The results are also indicate that the total loss coefficient in the tee section depends mainly on the flow situation through it.

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NOMENCLATURE

B	Polymer concentration dependent parameter, Eq. (3).
C	Polymer concentration, by weight, p.p.m.
D	Diameter.
f	Friction factor
g	Gravitational acceleration.
hF	Total head loss due to fitting over and above that due to straight pipe friction.
h_f	Head loss due to straight pipe friction.
KF	Total loss coefficient.
L	Length
P	Static pressure.
Δp	Static pressure coefficient $=(P-P_o)/(0.5\rho V_m^2)$
Q	Volume flow rate
R	Radius
Re	Reynolds number = ρ.Vm.D/μ
u	Local velocity
u*	Shear velocity.
V	Mean velocity.
y	Distance from the pipe wall.
α	Kinetic energy correction factor.
ξ	dimensionless radial distance = r/R.
λ	Coefficient of friction, λ =4f.
μ	Solvent (water) viscosity.
ρ	Water density.
τ	Shear stress.
Ø, ψ	Friction factor dependent parameters.

Subscripts

1, 2, and m	Evaluated at section (1), (2) and m, respectively.
w	Evaluated at the wall.
o	Evaluated at the first measuring station.

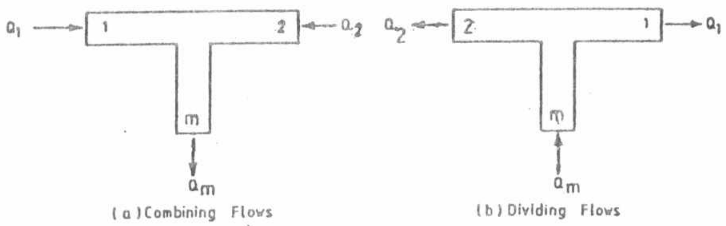


Figure (1) Control Volume

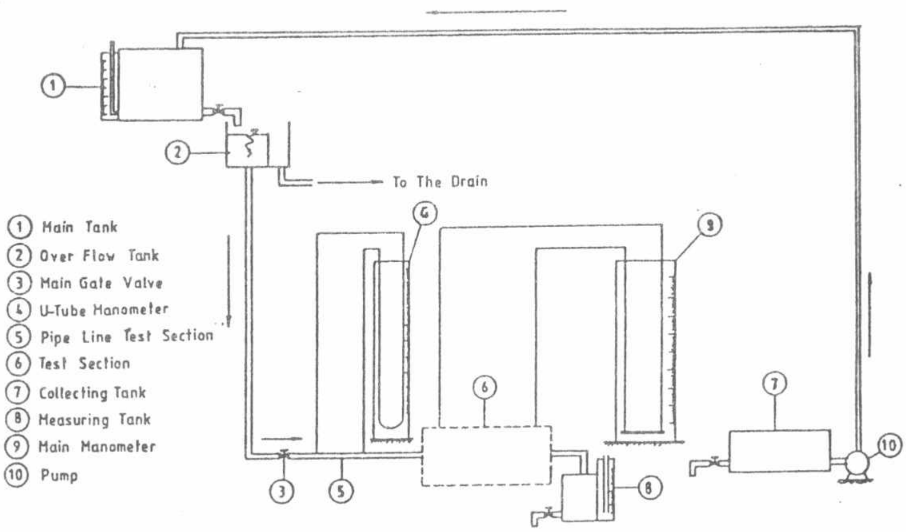


Fig.(2) The Schematic Diagram of The Experimental Apparatus

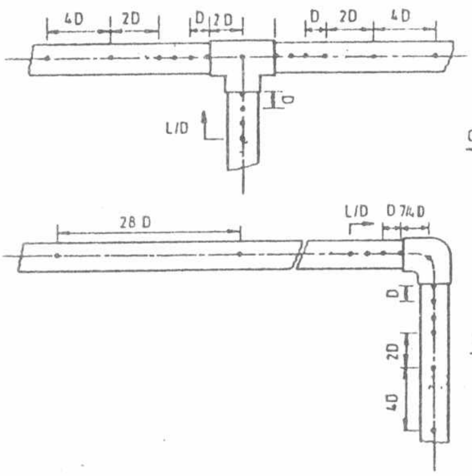
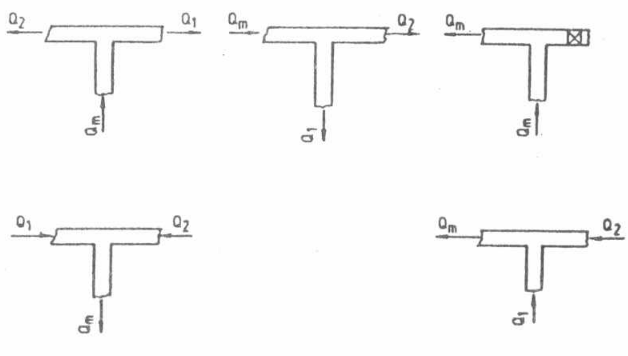


Fig (3_a) Static Pressure Hole Distribution on test Sections



Fig(3_b) Tee Test Section Situations

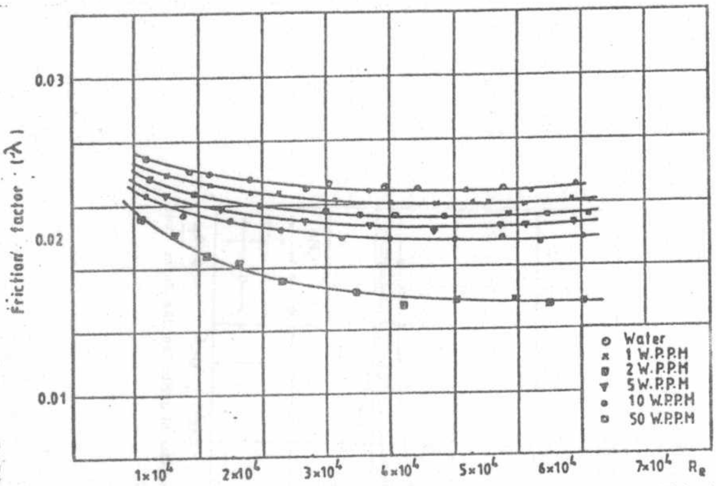
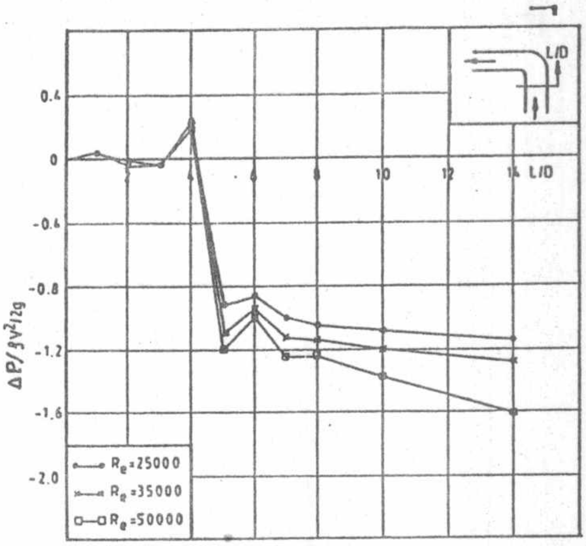
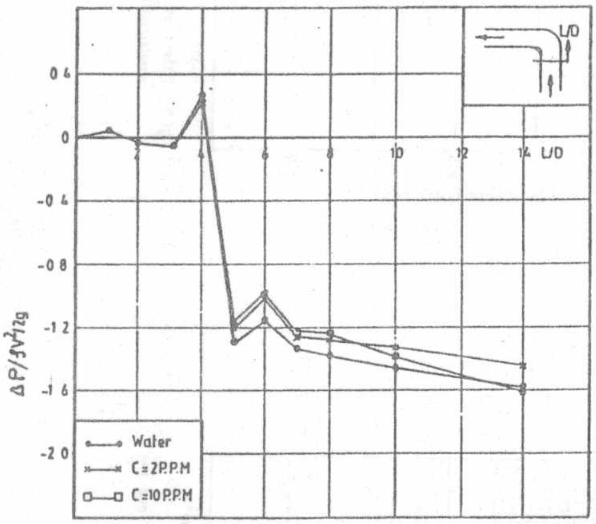


Fig (4) Effect of polymer concentration on the pipe friction coefficient



Fig(5) Pressure Distribution along the bend at different Reynolds number (10 P.P.M)



Fig(6) Effect of polymer concentration on pressure distribution along the bend at constant Reynols number (R_e=50000)

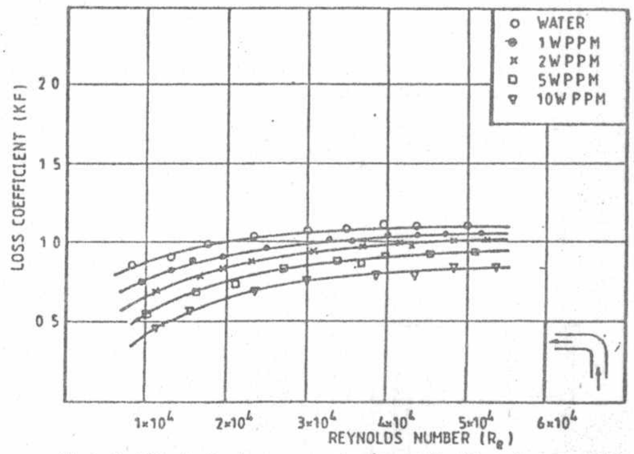


Fig (8) Effect of polymer concentration on the total loss coefficient of the bend.

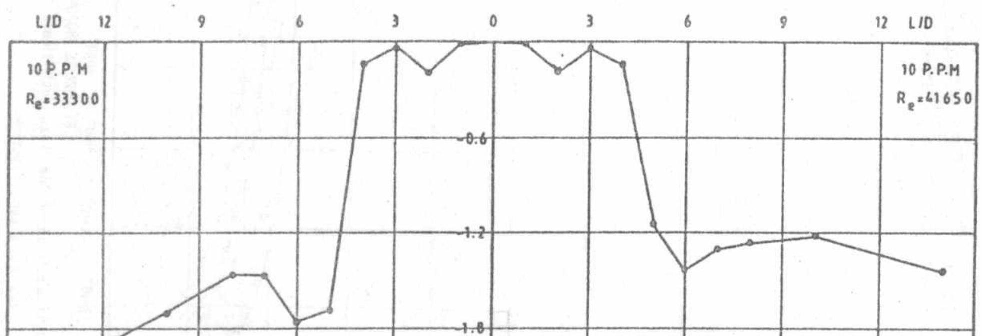
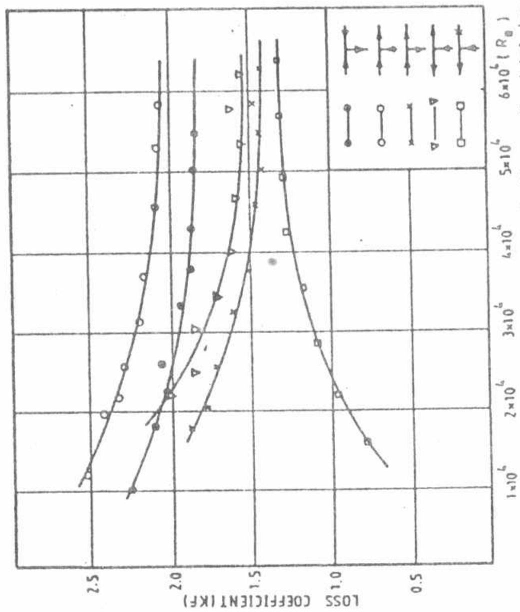
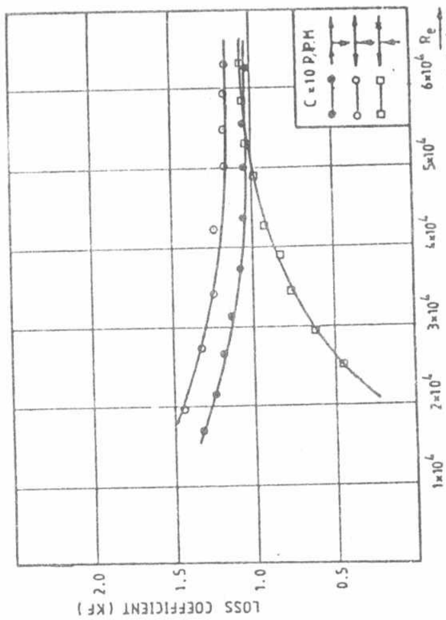


Fig (7) Pressur distribution along the tee section as a distibutar



Fig(11)Effect of the tee section flow situation on the total loss coefficient (water ; C=0.0 P.P.M)



Fig(12)Effect of the tee section flow situation on the total loss coefficient (C=10 P.P.M)

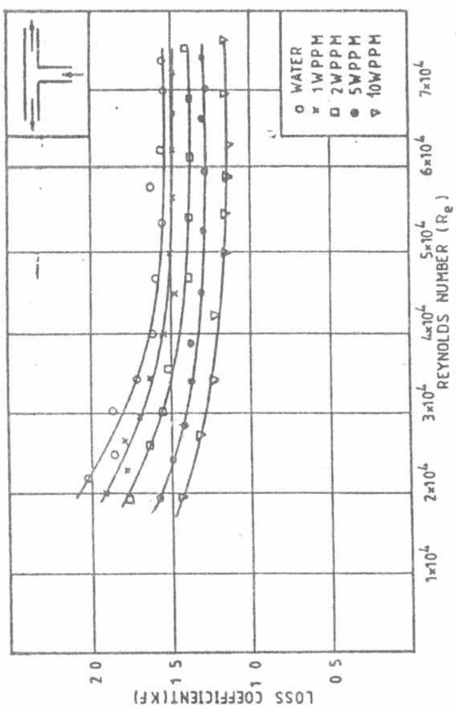
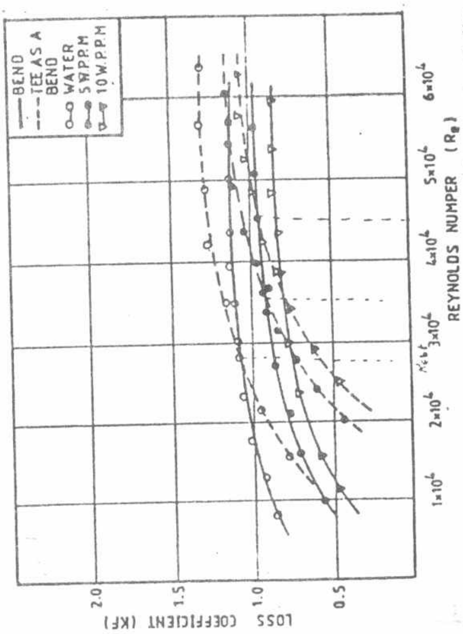


Fig (9)Effect Of Polymer Concentration On The Total Loss Coefficient Of The Tee



Fig(10) Comparison of the loss coefficients for the bend and the tee as a bend section.