THE PERFORMANCE OF ORIFICE METER HANDLING TWO-PHASE NON-NEWTONIAN FLOW

BY

M.M. Awad, H. Mansour and A.B. Tolba
Mechanical Engineering Department
Mansoura University
Mansoura, Egypt

ABSTRACT

The presented study in this paper is concerned with the performance of an orifice meter handling water-polymer solution, water-sand mixture (two-phase flow), and water-sand mixture with polymer additives (two-phase non-Newtonian flow). An ASME recommendation orifice meter was constructed and installed in a hydraulic circuit. Sand of different grain sizes (0.063-0.125 , 0.125-0.25 and 0.25-0.5 mm) with concentrations 0.25%, 0.5%, 1.0% and 1.5% by weight was tested. One type of polymers (polyacrylamid) was used with an average concentrations of 20, 30 and 40 wppm.

The results show that both polymer and sand concentrations affects the coefficient of discharge of the orifice meter. The coefficient of discharge was found to be increased with increasing polymer concentration, while increasing sand concentration decreases the coefficient of discharge. The used sand grain sizes has no effect on the coefficient of discharge.

INTRODUCTION

Several types of flowmeters fall under the category of obstruction devices. Such devices are sometimes called head meters because a head loss or pressure drop measurement is taken as an indication of the flow rate. The orifice meters represent one type of such flowmeters. They are widely used due to its simplicity either in construction or in measuring. The orifice meters serve in several engineering applications, therefore it is expected to be exposed to different working conditions regarding to the type of the flowing fluid.

When an orifice meter is subjected to measure the flow rate of a two-phase flow, the flow equations do not apply [9]. Several compensating equations has been proposed, to permit the use of the basic equation. Among these are the James density equation [6], Murdock modified Single-Phase flow rate equation [10], and the Smith-Leang blockage factor equation [12]. Murdock equation is the easist to apply if certain simplifying assumptions are made. These equations are applicable to both two-phase and two components liquid-gas flows. The effect of two-phase (solid-liquid) flow on the performance of orifice meter is not quite enough studied. But a similar study on the performance of turbine flow meter in two-phase flow [11] showed that the concentration of the solid phase and the particles size have a noticeable influence on the flow meter performance.

The effect of non-Newtonian (polymer solution) flow on the performance of orifice meter was not a purpose of study. As the fluid passes through orifice meter it flows in converging diverging flow. The behaviour of polymer solution in converging diverging flow was studied by Kato and Shibanuma [7]. They found that in a converging flow a remarkable drag reduction is not recognized. But in a diverging flow the pressure recovery was found to be about 30% larger than that in the case of solvent alone. These results also were concluded by EL-Haroun [1], who added that the pressure recovery in diverging flow increases with flow rate and with polymer concentration up to a certain value.

It is clear that the previous studies are not quite enough to predict the performance of the orifice meter neither in two-phase flow nor when handling non-Newtonian fluid. Therefore, the objective of the presented study is to investigate the performance of orifice meter handling water-polymer solution (non-Newtonian flow), water-sand mixture (two-phase flow) and water-sand mixture with polymer additives (two-phase non-Newtonian flow).

EXPERIMENTAL APPARATUS

A suitable hydraulic circuit was constructed as shown in Fig. (1). The test fluid is sucked from the supply tank through a flexible hose to the orifice meter by a cenrifugal pump. the pump delivery side is connected to a calibrated tank. the flow rate can be changed using a control valve,which is installed at the pump delivery side.

The orifice meter was constructed and installed according to ASME recommendation [5,9]. The detailed construction of the orifice meter is shown in Fig. (2). The orifice is made of thin copper disc with 3 mm thickness having a circuler hole of 0.5 inch diameter and installed concenterically in a horizontal pipe with one inch diameter. A U tube mercury manometer is equipped to the pressure taps, which are located across the orifice as recommended by [5,9].

An individual tank is used for polymer master solution. The tank is connected to a small tube, which is inserted into the suction side of the hydraulic circuit as shown in Fig.(1). A control valve is installed to a small tube to change the polymer master solution flow rate. This arrangement allow for the polymer solution to be sucked and circulated with the test fluid. As it will be discussed later, the flow rate of the polymer master solution was always proportional to the test fluid flow rate. A sight gauge is connected to the polymer tank to indicate the volume of the injected polymer solution during each experiment.

The orifice meter was installed at a distance quite enough to ensure that the flowing fluid at the orifice is fully developed turbulent. For practical purposes a value of 40 pipe diameter was recommended by Hinze [4]. When polymer is injected at the centerline of a pipe, the local drag reduction attains its constant value at a distance of 100 times pipe diameter [8]. Therefore the orifice was installed at a distance more than 350 times pipe diameter. The minimum allowed velocity of the test fluid in the hydraulic circuit was checked by that obtained by Spells [13] to avoid settling of sand and to ensure homogeneous fluid flow.

Three types of sand according to their grain size are used (0.063-0.125), (0.125-0.25) and (0.25-0.5) mm at different concentrations of 0.25%, 0.5%, 1.0% and 1.5% by weight. One type of polymers (polyacrylamide) is used by injection of master solutions at concentrations 1000,1500 and 2000 wppm, which correspond to an average concentration of 20,30 and 40 wppm, resectively.

According to the type of flowing fluid, a different groups of experiments are considered to study the following :

a- Performance of the orifice meter handling water only.
b- Performance of the orifice meter handling water polymer solution (non-Newtonian fluid) at different polymer concentrations.
c- Performance of the orifice meter handling water-sand mixture (two-phase flow) at different sand concentrations and grain sizes.
d- Performance of the orifice meter handling water-sand mixture with polymer additives (two-phase non-Newtonian fluid) at different sand and polymer concentrations.

The coefficient of discharge of the orifice meter was obtained in these experiments as a function of the flow rate (Reynolds number). The discharge was measured by primary measurements. This can be achieved by measuring a quantity of liquid in a tank and then recording the time taken for the liquid to flow through the meter. The calibrated tank was used for this purpose. The collected test fluid was added again to that in the supply tank.

The uncertainty in measuring the different involved parameters were studied and the following values were obtained. The uncertainty in measuring the flow rate of the test fluid is 1.2%, the uncertainty in calculating both sand and polymer concentrations are 0.7% and 0.6%, respectively. The uncertainty in measuring the pressure drop across the orifice meter is 1.5% .

The hydraulic circuit must be completely evacuated and flushed with pure water after each experiment to avoid the effect of the previous injected polymer and sand.

The coefficient of discharge is performed from the following equation :

$$Q_{ac} = C_d \frac{\pi}{4} d_o^2 \sqrt{\frac{2g \, \Delta H_o}{1 - \left(\frac{d_o}{D}\right)^4}} \qquad \ldots (1)$$

The average polymer concentration can be calculated as follows :

$$C_{pav} = \left(\frac{Q_p}{Q_p + Q_w} \right) . C_{pi} \qquad \ldots (2)$$

The sand concentration and the density of water-sand mixture are calculated from the following expressions :

$$C_s \; \% = \left(\frac{m_s}{m_m} \right) \qquad \ldots (3)$$

$$\rho_m = \frac{\rho_w}{1 - C_s \left(\frac{\rho_s - \rho_w}{\rho_s} \right)} \qquad \ldots (4)$$

RESULTS AND DISCUSSIONS

A special experiments were carried out to show the relation between the injected polymer master solution flow rate and the test fluid flow rate. A sample of these results is shown in Fig.(3), from which it is clear that the relation seems to be linear and the following relation can be deduced :

$$Q_p / Q_m = \text{constant} = 0.02 \qquad \ldots (5)$$

Figure (4a) shows the orifice pressure drop against flow rate for water and water polymer solution with different concentrations. From this Fig. it is clear that the orifice pressure drop decreases with increasing polymer concentration. A noticeable decrease was obtained even at low concentration (20 wppm average concentration). The rate of decreament does not increase with rate of increament of polymer concentration. The coefficient of discharge of the orifice meter was calculated from Eq . I and plotted against Reynolds number as shown in Fig.(4b). It is clear also from this figure that the coefficient of discharge increases with polymer concentration and in general the rate of increament increases with increasing Reynolds number. These results can be explained due to the decrease of the sudden contractions losses at the orifice plate. The mechanism of polymer in this region was suggested by Gadd [2], who assumed that the polymer molecules increase the stretching resistance of the vortices in the wall region,which reduce the mixing length of turbulence and dampen the turbulence eddies.

The results of the two-phase (water-sand) flow are shown in Fig. (5). The coefficient of discharge of the orifice meter is indicated against Reynolds number for different sand grain sizes at sand concentration of 0.5%. From this figure it is difficult to provide a conclusion,as the experimental points are dispersed. thus it can be considered that the used grain sizes has no effect on the coefficient of discgarge. For this reason a homogeneous mixture was prepared from equal weights of the tested sand grain sizes and the other experiments were carried out using different concentrations of the mixture.

The effect of sand concentration in two-phase (water-sand) flow is shown in Fig.(6). The coefficient of discharge is indicated against Reynolds number for sand concentrations of 0.25%, 0.5%. 1.0% and 1.5% by weight. From this figure it is evident that the coefficient of discharge decreases with increasing sand concentration at the same flow rate, and also decreases with increasing Reynolds number at the same sand concentration. This can be explained due to the generated eddies in the flow from sand suspension and the interaction of sand particles during the motion. At higher sand concentration the ability of sand suspensions to change its direction and flow through the orifice are connected with higher generation of eddies. In addition at higher sand concentration, solid particles may settle at the pipe bottom near the orifice, which may increase the friction losses at this region and decrease the coefficient of discharge.

The orifice pressure drop against the flow rate for different sand and polymer concentrations is shown in Figs.(7a, 7b, 7c and 7d). These figures can be used as a calibration charts, from which the fluid flow rate can be easily obtained by knowing the pressure difference across the orifice and the type of the flowing fluid.

Figures (8a, 8b, 8c and 8d) show the coefficient of discharge against Reynolds number at different sand and polymer concentrations. From these figures it is clear that the polymer additives increase the coefficient of discharge of the orifice meter. The coefficient of discharge increases with increasing polymer concentration at the same flow rate comparing with that in two-phase (water-sand) flow. This can be explained due to the presence of polymer, which help sand particles to suspend in the turbulent flow and suppress the production of turbulence in the flow.

CONCLUSIONS

1- Both polymer additives and sand suspension affect the performance of the orifice meter.

2- The coefficient of discharge increases with increasing polymer solution concentration at the same flow rate.

3- The tested sand grain sizes has no effect on the coefficient of discharge of the orifice meter, while the coefficient of discharge decreases with increasing sand concentration.

4- The polymer additives improves the coefficient of discharge of the orifice meter in two-phase (water-sand) flow. The coefficient of discharge is relatively higher in water polymer solution than that in water-sand mixture and water-sand mixture with polymer additives.

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NOMENCLATURE

c	Concentration
c_d	Coefficient of discharge
D	Test pipe diameter (cm)
d_o	Orifice meter diameter (cm)
G_s	Grain size diameter (mm)
g	Gravitational acceleration (m/sec^2)
ΔH_o	Orifice pressure drop (cm mercury)
m	Mass (kg)
Q	Flow rate (cm^3/sec)
Re	Reynolds number
wppm	weight part per million
ρ	Density (kg/m^3)

Subscripts

ac	Actual value
av	Average value
m	Mixture
p	Polymer
pav	Average polymer
pi	Injected polymer
s	Sand
w	Water

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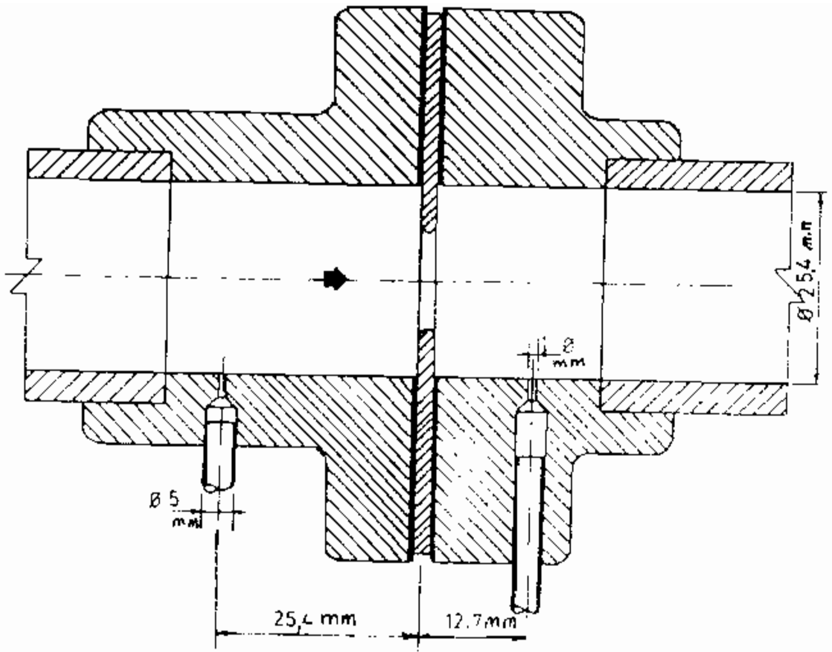
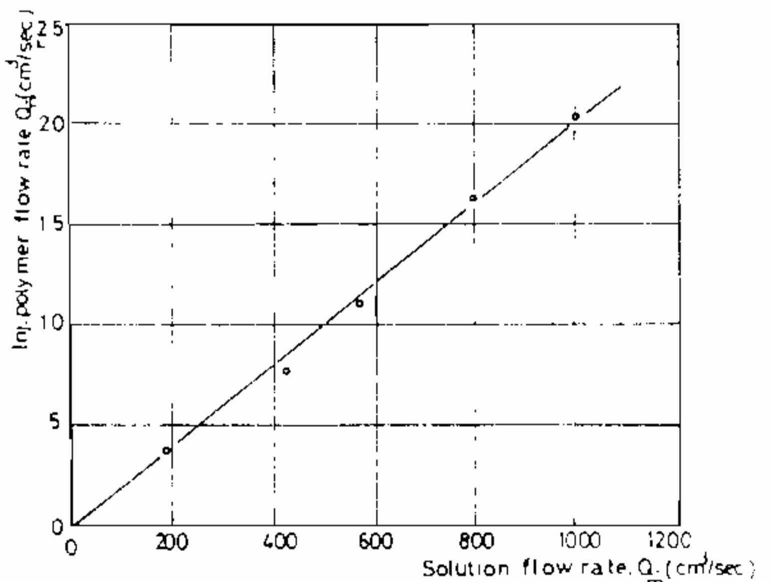
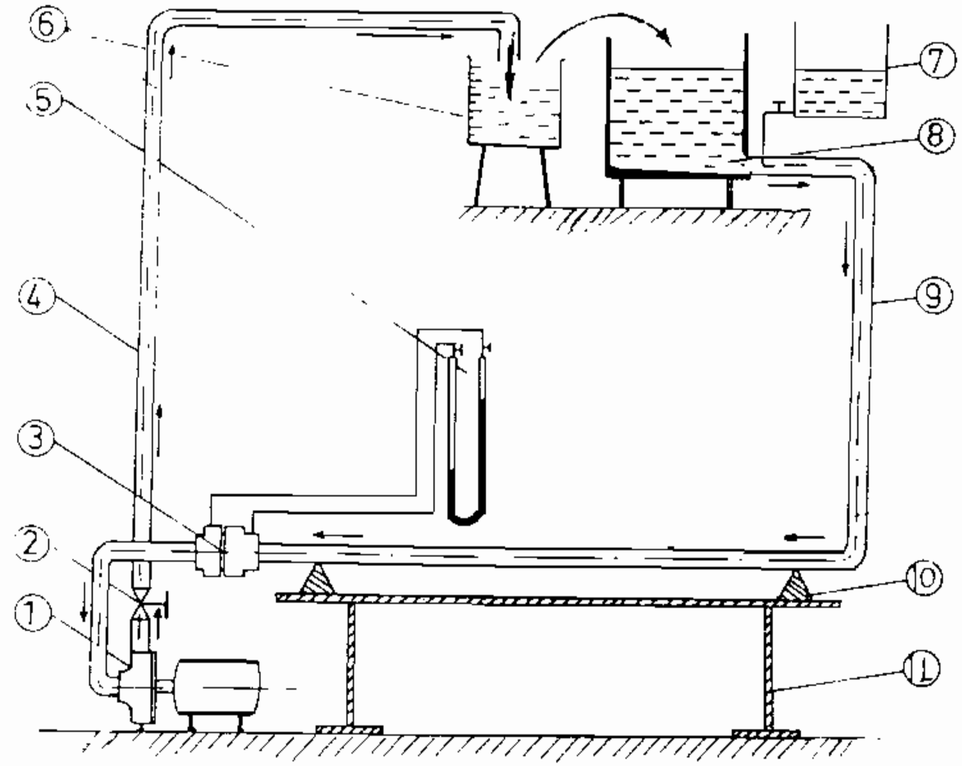


Fig.(2) Orifice meter



Fig(3) Injected polymer flow rate against solution flow rate



Fig(1) Experimental set-up.

1- Centrifugal pump.
2- Control valve.
3- Orifice meter
4- Delivery side tube
5- Mercury manometer.
6- Calibrated tank
7- Polymer. tank.
8- Supply tank.
9- Suction side tube
10- Wood support.
11- Horizontal table.

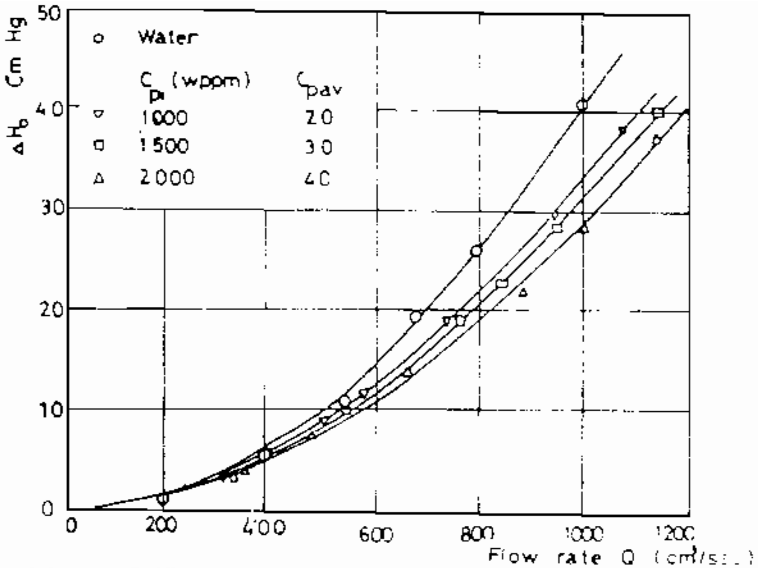


Fig (4 a) Orifice pressure drop against flow rate for different polymer concentrations

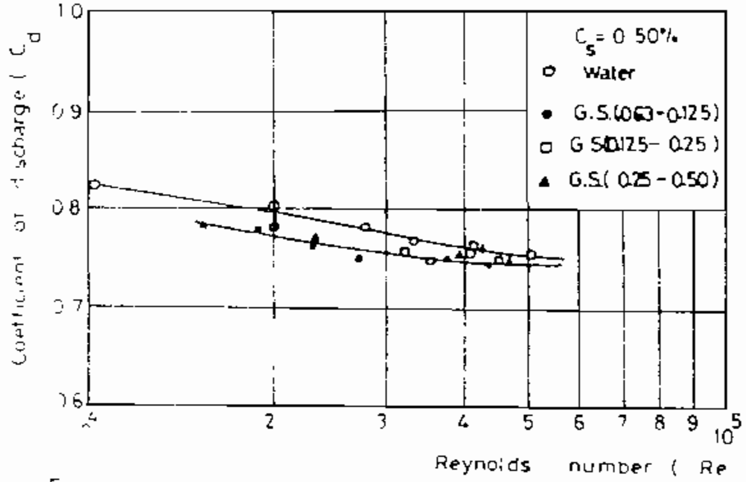


Fig. 5) Coefficient of discharge of the orifice meter against Reynolds number at different grain sizes and sand concentrations of $C_s = 0,50\%$

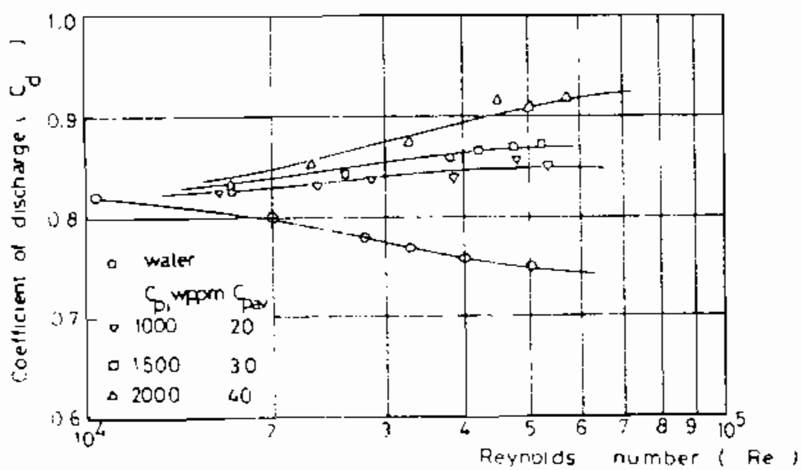


Fig (4 b) Coefficient of discharge of the orifice meter against Reynolds number at different polymer concentrations

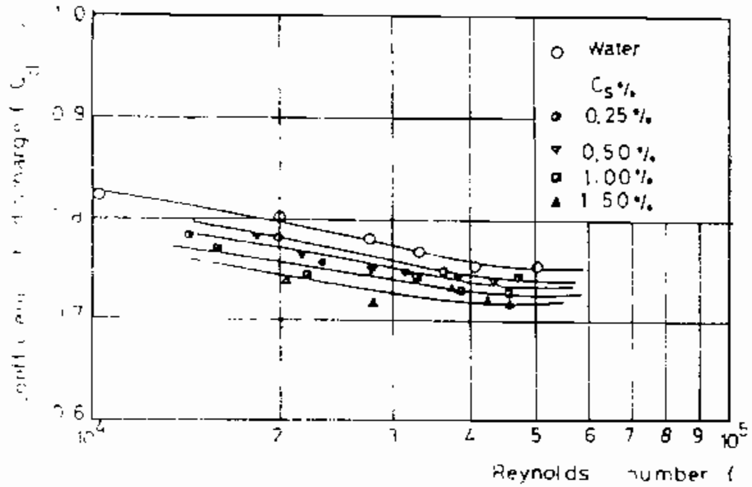


Fig. 6) Coefficient of discharge of the orifice meter against Reynolds number at different sand concentrations

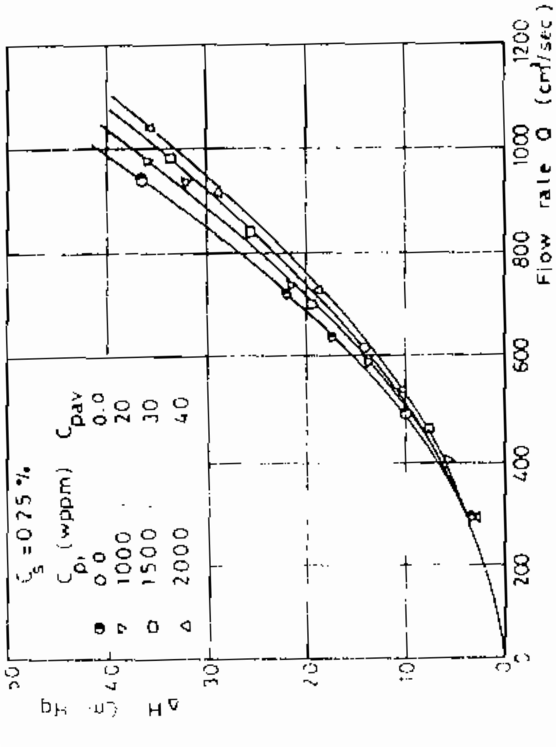


Fig (7 a) Orifice pressure drop against flow rate for C_s=0,25 % at different polymer concentrations

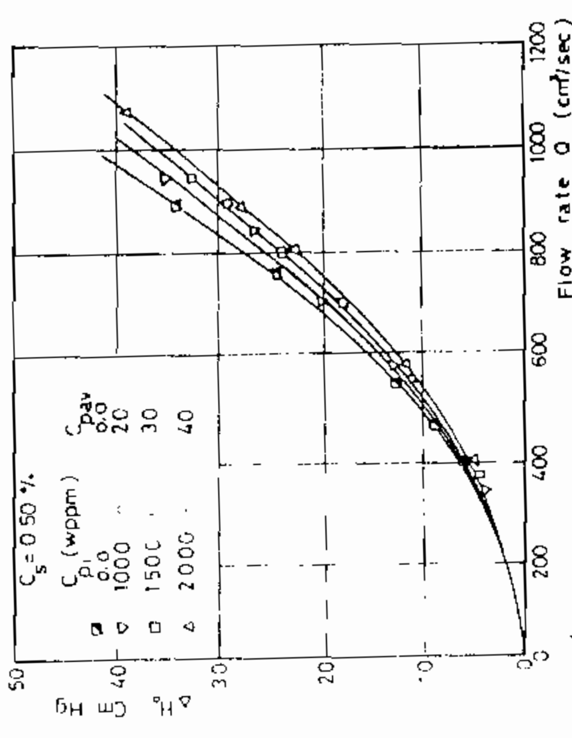


Fig (7 b) Orifice pressure drop against flow rate for C_s=0,50 % at different polymer concentrations

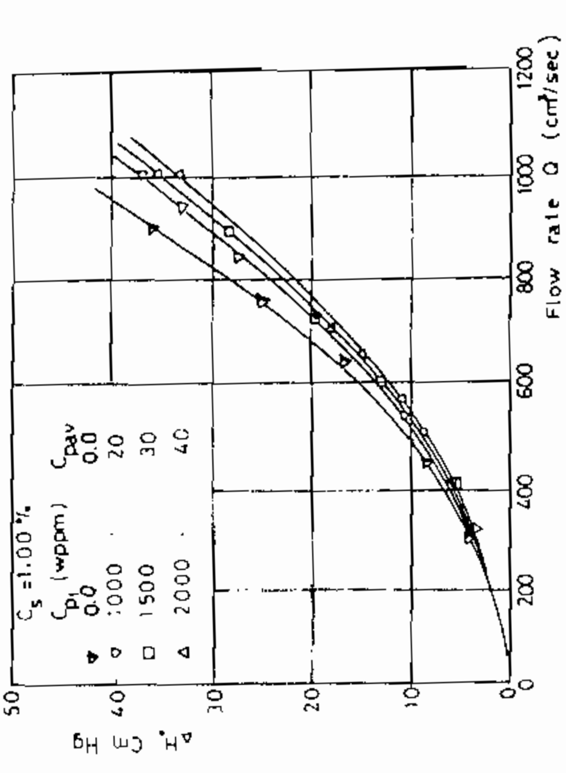


Fig.(7 c) Orifice pressure drop against flow rate for C_s=1,00 % at different polymer concentrations

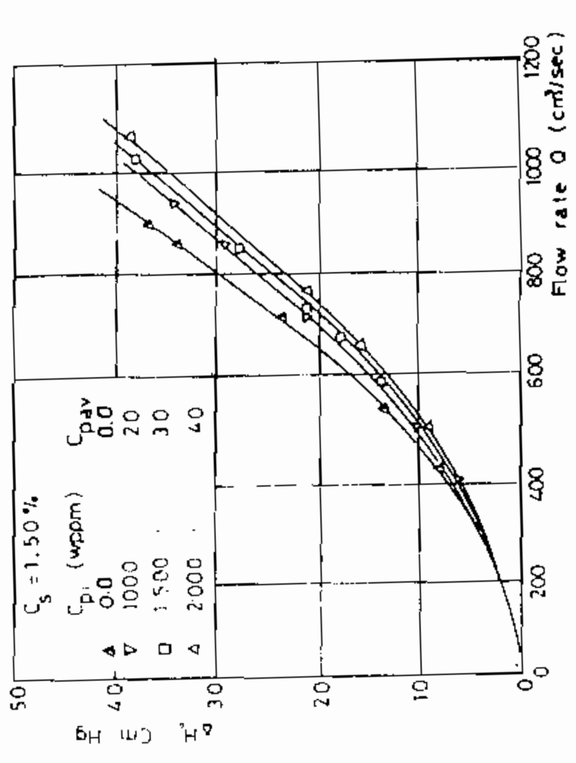


Fig (7 d) Orifice pressure drop against flow rate for C_s=1.50 % at different polymer concentrations

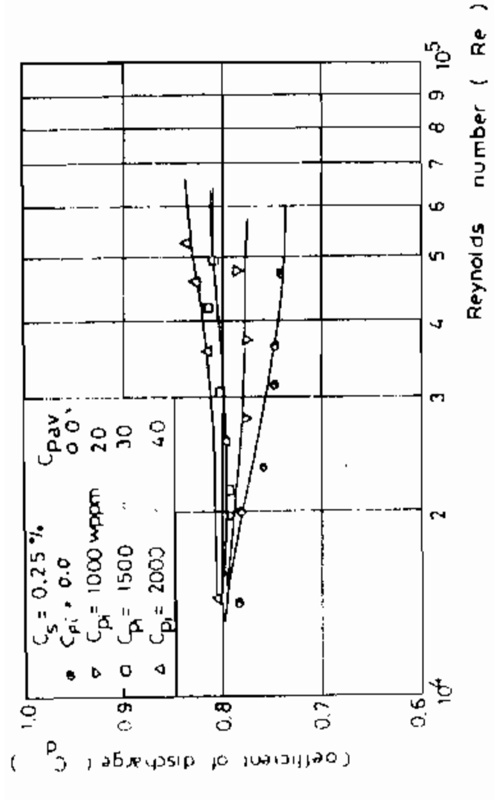


Fig. (8 a) Coefficient of discharge of the orifice meter against Reynolds number for C_s=0,25 % at different polymer concentrations

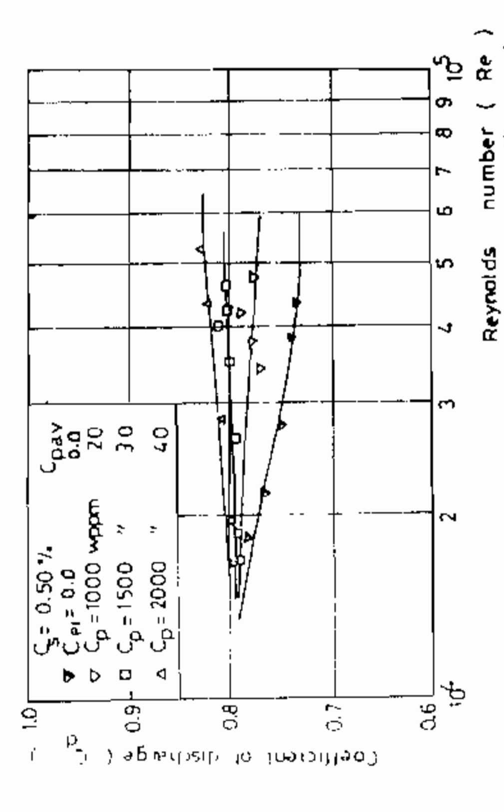


Fig. (8 b) Coefficient of discharge of the orifice meter against Reynolds number for C_s=0,50 % at different polymer concentrations

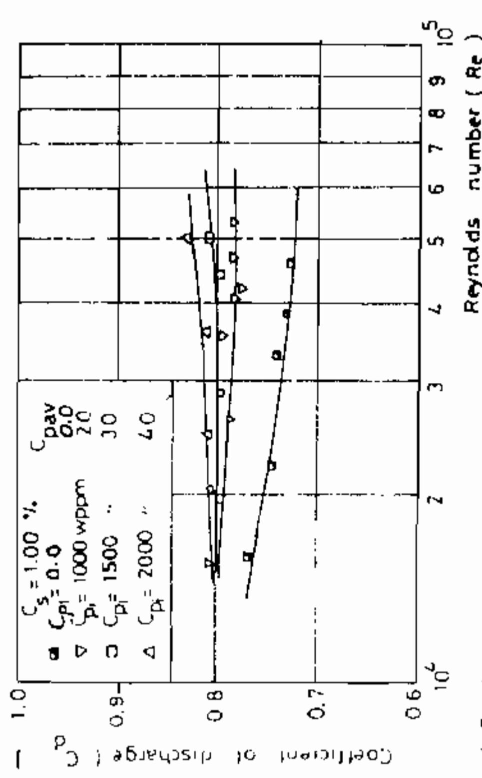


Fig. (8 c) Coefficient of discharge of the orifice meter against Reynolds number for C_s=1,00 % at different polymer concentrations

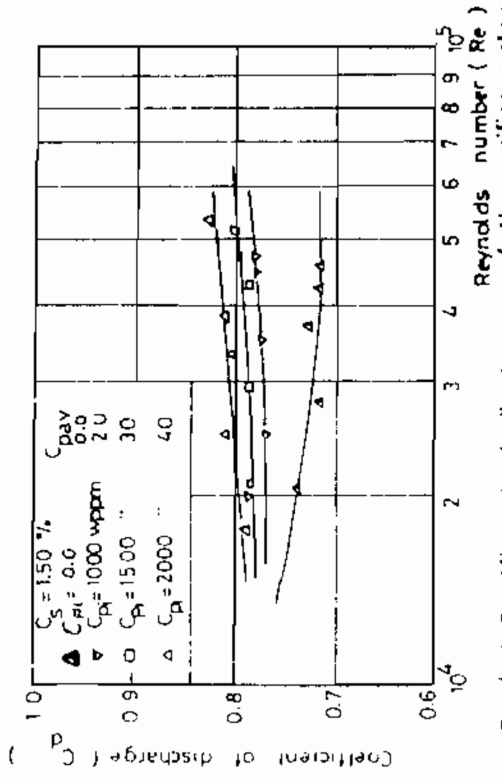


Fig. (8 d) Coefficient of discharge of the orifice meter against Reynolds number for C_s=1,50 % at different polymer concentrations