NON-NEWTONIAN TWO-PHASE FLOW IN A TURBULENT PIPE

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ABSTRACT

An experimental investigation on the effect of drag reducing additives (polymers) upon the two-phase (water-sand) flow in a turbulent pipe is presented in this paper. Three types of sand grain size, (0.063-0.125), (0.125-0.25) and (0.25-0.5) mm were tested at different consentrations of 0.25%, 0.50%, 1.0% and 1.5% by weight. One type of polymers (poly-acrylamide) was used at different concentrations of 20, 30 and 40 wppm. The desired concentrations are made by injection of concentrated master polymer solutions of 1000, 1500 and 2000 wppm.

The experimental results show that the polymer additives have a drag reduction effect on the turbulent pipe flow in both water and water-sand mixture. This effect increases with the flow rate (Reynolds number) and the polymer concentration. It was found also that the coefficient of friction, drag reduction and the onset of drag reduction depend on sand concentration, sand grain size, and the Reynolds number of the folwing fluid.

INTRODUCTION

The reduction of the frictional head losses in pipe flow systems is an important purpose in many industrial applications to save energy. It was found that the addition of a few parts per million of high molecular weight polymers reduce the skin friction in a turbulent pipe flow to one-half or less than that of pure solvent alone [5]. Drag reduction phenomena has been subjected to an extensive experimental and theoritical investigations in order to achieve a deeper understanding of the nature of turbulent and mechanism of drag reduction, which may lead to great improvement in many technical applications.

It was found that the polymer solution at low flow rate obeys the laminar friction low, while at higher flow rates the flow is similar to the non-Newtonian fluid flow [11]. The maximum drag reduction for any drag reducing additives and at any Reynolds number is described by a unique asymptote which is independent of polymeric partameters[12].

The presence of solid particles is unavoidable in many industrial processes even at low concentrations. Some of these applications are mineral washing operations, sprinkler irrigation, thermal power stations and hydrotransport. An emperical relation for the pressure drop in water-sand flow was obtained by Blatch [2]. The pressure drop depends on the particles concentration and size with respect to the scale of turbulence

Designing the hydraulic circuit, the test section pipe was installed to be 7.5 m apart from the entrance pipe (300 pipe diameter). This distance is quite enough to ensure fully developed turbulent flow in the test pipe. For practical purposes a value of 40 times pipe diameter was recommonded by Hinze [3]. The position of the test section was chosen to be at a distance more than 100 times pipe diameter. Since 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]. The minimum allowed velocity of the test fluid was checked by that obtained by Spells [10] to avoid settling of sand.

The uncertainty in measuring the different involved parameters were studied and the following values were obtained. The uncertainty in measuring the flow rate of test fluid is 1.9%, 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 and the test section 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 calculation of the friction loss is performed from the following expression:

$$\Delta H_f = \Delta H_t \quad (S_t - 1) \qquad \ldots\ldots \qquad (1)$$

The flow rate can be known using the calibration charts obtained in [1]. A sample of these charts is indicated in Fig.(2), from which the discharge is directly obtained knowing the pressure head loss across the test section.

The friction factor (λ) is calculated from Darcy-Weisbach equation:

$$\lambda = 4f = D \frac{2g}{V^2} \cdot \frac{\Delta H_f}{L} \qquad \ldots\ldots \qquad (2)$$

The definition of percentage drag reduction is adopted by a number of previous investigators [5,7] in the following form:

$$DR\ \% = 1 - \left(\frac{\Delta P_p}{\Delta P_s} \right)_Q \times 100 \qquad \ldots\ldots \qquad (3)$$

The subscript Q indicates that the polymer solution is compared to the solvent at the same flow rate.

The average polymer concentration in the test section can be calculated as follows:

$$C_{pav} = \left(\frac{Q_p}{Q_p + Q_w} \right) C_{pi} \qquad \ldots\ldots\ (4)$$

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

$$C_s \% = \frac{m_s}{m_m} \times 100 \qquad \ldots\ldots\ (5)$$

$$\rho_m = \frac{\rho}{1 - C_s \left(\frac{\rho_s - \rho}{\rho_s} \right)} \qquad \ldots\ldots\ (6)$$

RESULTS AND DISCUSSIONS

A set of preliminary experiments were carried out to ensure that the sucked polymer master solution is always proportional to the test fluid flow rate. A sample of the results of these experiments is indicated in Fig. (3). From which it is clear that the relation seems to be linear. The other experiments gave the same result and thus the following relation can be deduced:

$$(Q_p / Q_m) = \text{constant} = 0.02 \qquad \ldots\ldots\ (7)$$

Fig. (4a) shows the pipe pressure drop against the flow rate for different polymer concentrations. From this figure it is clear that the pipe pressure drop decreases with increasing polymer concentration. The percentage drag reduction can be deduced from this figure (using Eq.3) and plotted against flow rate as shown in Fig. (4b). It is clear from Fig. (4b) that the percentage drag reduction is increased with increasing polymer concentration at the same flow rate, and also increases with increasing flow rate at the same polymer concentration. The results indicate that the onset of drag reduction depends on the polymer concentration in such a manner that increasing polymer concentration decreases the onset of the drag reducion. These results agree with that obtained by [8,12]. The obtained results are plotted on Prandtl-Karman coordinates, which is a linear plot of $1/\sqrt{f}$ against the logarithm of $Re\sqrt{f}$ as shown in Fig.(5). It is evident from this figure that the obtained data for Newtonian flow (water) are in good agreement with Prandtl-Karman law. For water-polymer solution the results describe straight lines with slope increasing progressively with the polymer concentration until the maximum drag reduction is reached. Thus the obtained results are bounded by two extreems, which are Prandtl-Karman law and Virk asymptotic [12].

Figures (6a,6b,6c) show the relation between the coefficient of fraction (λ) and Reynolds number when water-sand mixture is tested. The results are plotted for different sand grain sizes. It is clear from these results that the coefficient of friction increases with increasing sand concentration when water-sand mixture flow is homogeneous, which is characterised by a minimum velocity to avoid settling of the sand [10]. These results can be explained from the nature of motion of solid particles in turbulent flow. The behaviour of solid particles in a turbulent fluid depends largly on the concentration of particles and its grain size with respect to the scale of turbulence of the fluid. The rapid motion of the particles with respect to the fluid may cause a creation of additional turbulence and increase the generated eddies which tend to increase friction head, so it increases the coefficient of friction.

Figure (7) represents the coefficient of friction against Reynolds number for grain sizes (0.063-0.125) and (0.25-0.5) mm at the same sand concentration (0.25% by weight). This figure shows that the sand of fine particles has more effect on the coefficient of friction than that of large particles. This result may be explained due to rapidly spread of fine particles than large particles, this spread may generate large number of more additionel eddies and increase the wave number of turbulence.

Figures (8a,8b and 8c) show a sample of the obtained results for the pressure drop against the flow rate. From such curves the percentage drag reduction were deduced and plotted against the flow rate. from these results it is clear that the polymer has also an effect on the two-phase water-sand mixture in a turbulent pipe.

The effect of polymer additives upon the mixture of water-sand flow is shown in Fig. (9,10 and 11). Fig. (9a,9b,9c and 9d) show the drag reduction percentage against the flow rate for grain size (0.063-0.125) mm at different concentrations of polymer. The results of the other two grain sizes (0.125-0.25) and (0.25-0.5) mm are shown in Fig.(10, 11) respectively. From these figures it is clear that the percentage of drag reduction depends on sand concentration, sand particle size, and polymer concentration. The polymer concentration has the same effect on drag reduction as in pure solvent. The percentage drag reduction is increased with increasing polymer concentration at the same flow rate, but in this case (two-phase flow) the polymer effect is relatively lower than that in water polymer solution. This can be explained as the presence of solid particles may cause a creation of additional turbulence and increase the generated eddies, while the main influence of the polymer additives is to reduce the generation of turbulence through the suppression of streak formation and the eruption of bursts. Thus the polymer has an opposite effect to that of the sand. The results show that the onset of drag reduction is lagged due to sand suspension compared with that inpure water. This may be due to the behaviour of solid particles in the flow, which discussed before.

The effect of sand grain size can be noticed from Fig. (12), where the percentage drag reduction is plotted against the flow rate for different sand grain sizes at 1 % by weight sand concentration with average polymer concentration of 30 wppm. From this figure it is evident that sand grain size has a noticeable effect on the drag reduction. Increasing the sand grain size increases the percentage drag reduction. This can be explained as discussed before due to the rapidly spread of the fine particles which may generate additional eddies and increase turbulence.

Figure (13) presents a sample of results, where the friction factor is plotted against Reynolds number for grain size of (0.063-0.125) mm with 1 % sand concentration at different polymer concentrations. From this figure it is evident that the experimental results are bounded by two extreems (Prandtl-Karman law and Virk law). This result agrees with that obtained by Virk [12] in case of water polymer solution.

CONCLUSIONS

Based on this investigation, the following conclusions are offered:

1- Drag reduction additives (polymers) has a drag reducing effect on turbulent pipe flow in both water and water-sand mixture. The effect has relatively higher values in case of water flow.
2- The drag reduction increases with increasing polymer concentration at the same flow rate and with increasing flow rate of the same concentration. The onset of drag reduction decreases with increasing polymer concentration.
3- The coefficient of friction increases with increasing sand concentration at the same Reynolds number. At the same concentration and Reynolds number, the coefficient of friction decreases at large grain sizes of sand.
4- The drag reduction in two-phse (water-sand) flow in turbulent pipe increases with polymer concentration and flow rate. Also the drag reduction increases with increasing the grain size of the sand at the same polymer and sand concentration.
5- The onset of drag reduction is lagged due to sand suspension compared with that at water polymer solution.

ACKNOWLEDGEMENT

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NOMENCLATURE

C	Concentration
C_d	Coefficient of discharge
D	Test pipe diameter (cm)
d_s	Solid patrticle diameter (mm)
DR%	Drag reduction percentage
f	Friction factor
g	Gravitational acceleration (m/sec^2)

ΔH_f Friction head loss (cm water)
ΔH Pressure difference (cm water)
L Pipe length of test section (m)
m Mass (kg)
Q Flow rate (cm^3/sec)
Re Reynolds number
S Specific gravity
t Time (sec)
V Volume (cm^3)
U Mean velocity (cm/sec)
wppm Weight part per million
w water

Greek Letters

Δ Incremental change
λ Coefficient of friction, $\lambda = 4f$
ρ Density

Subscripts

av Average value
m Mixture of sand and water
p Polymer
Pav Average polymer
Pi Injected polymer
S Sand
t Carbon tetra cholori de

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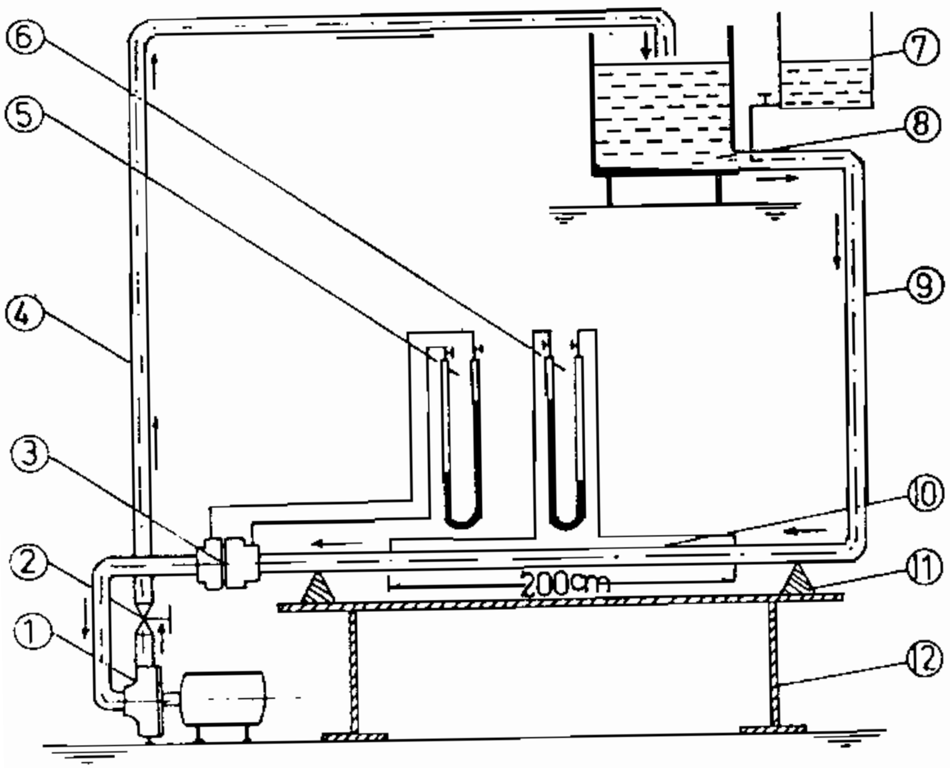


Fig.(1) Experimental set-up

1- Centrifugal pump	7- Polymer tank.
2- Control vaive	8- Supply tank.
3- Orifice meter	9- Suction side tube
4- Delivery side tube	10- Test section.
5- Mercury manometer	11- Wood support.
6 Tetro manometer	12- Horizontal table.

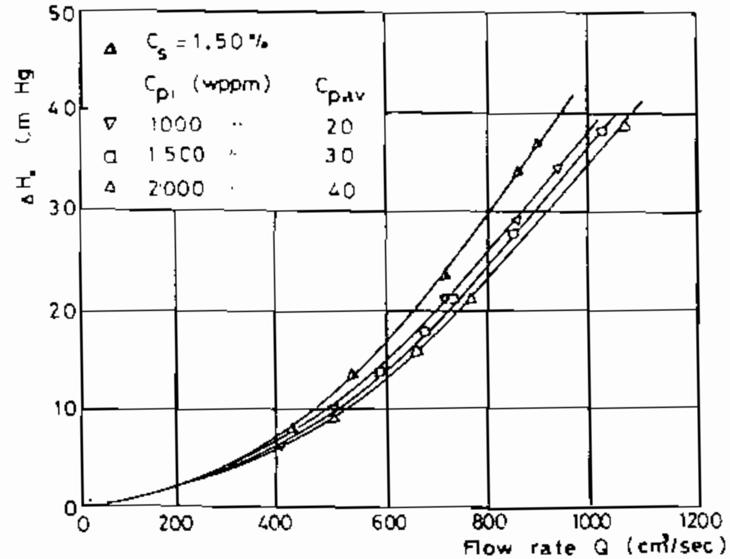
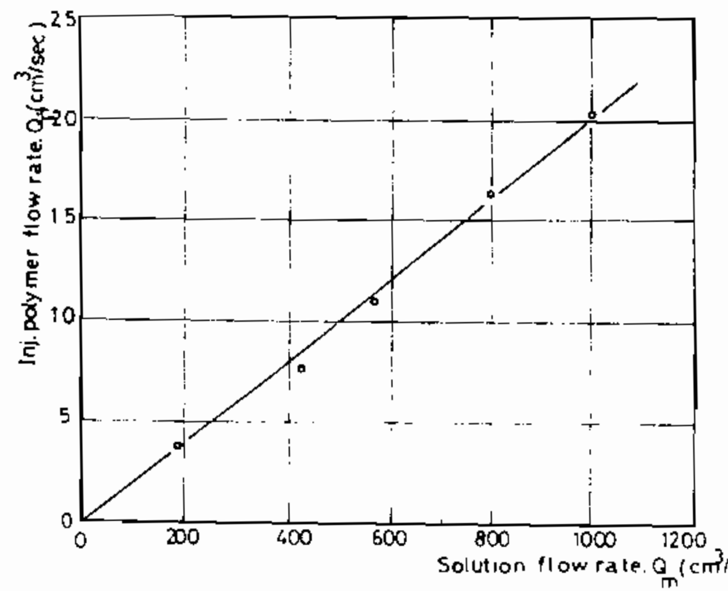


Fig.(2) Orifice pressure drop against flow rare for C_s=1.50 % at different polymer concentrations



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

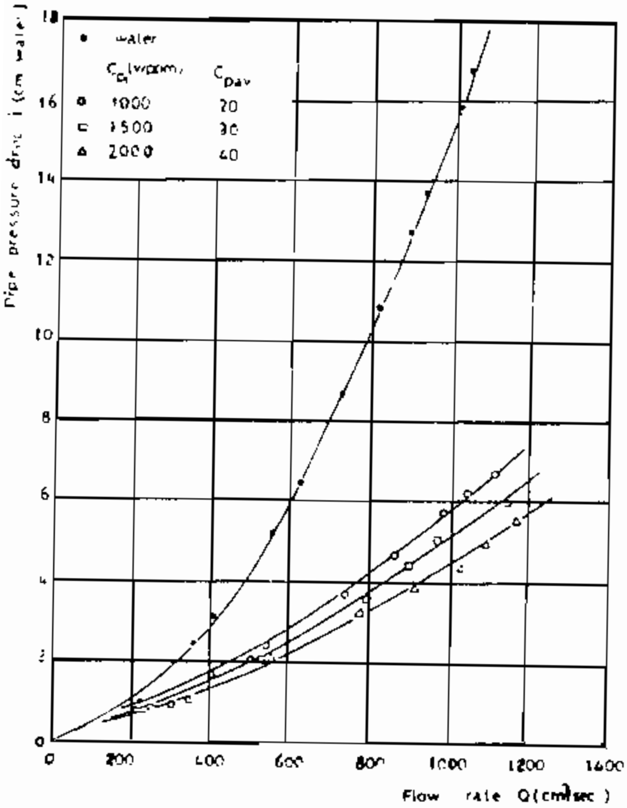


Fig (4 a) Pipe pressure drop against flow rate for different polymer concentrations

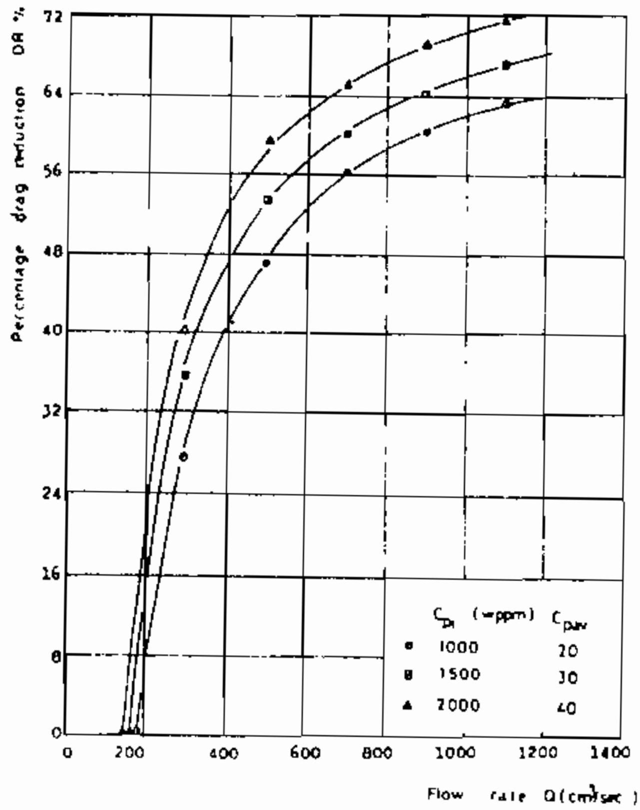


Fig (4 b) Drag reduction against flow rate at different polymer cocentrations

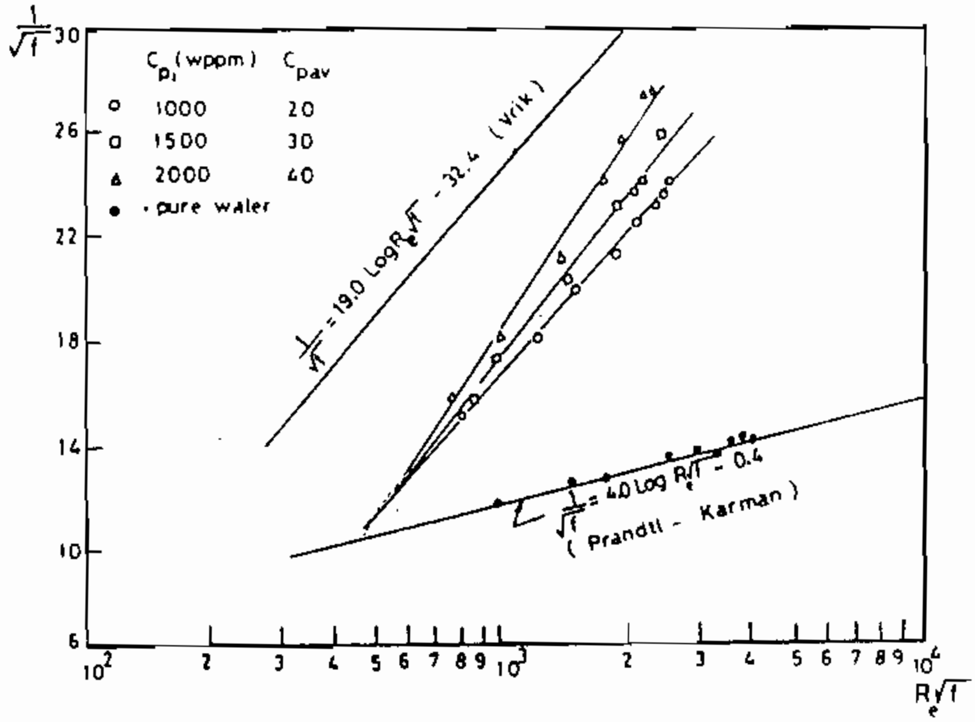


Fig.(5) prandtl-Karman plot of $\frac{1}{\sqrt{f}}$ against $R_e\sqrt{f}$ for pure water with polymer at different concentrations.

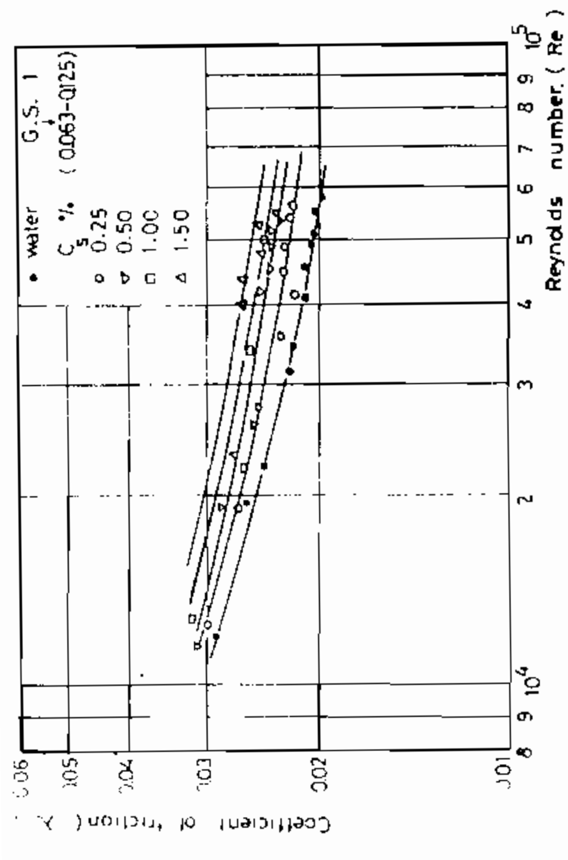


Fig. (6 a) Coefficient of friction against Reynolds number for G.S.(1) at different sand concentrations.

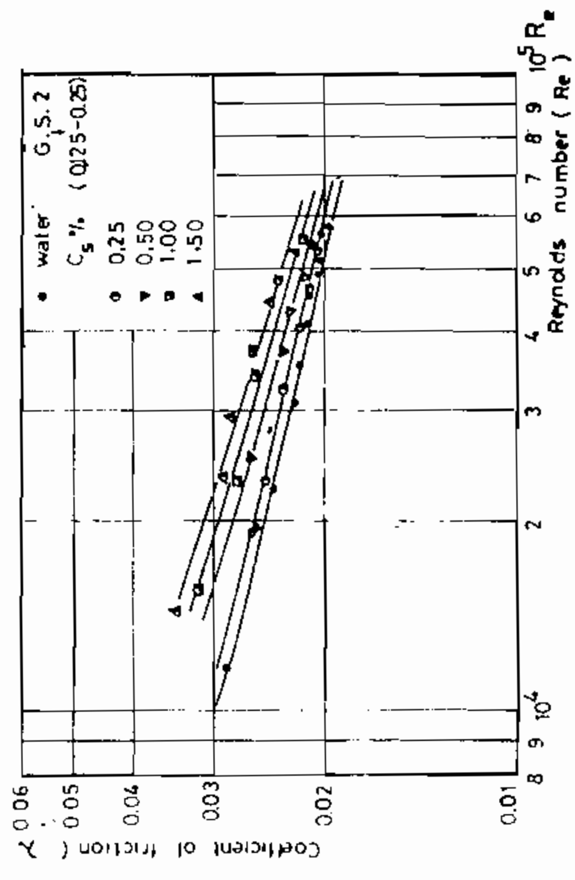


Fig (6 b) Coefficient of friction against Reynolds number for G.S.(2) at different sand concentrations.

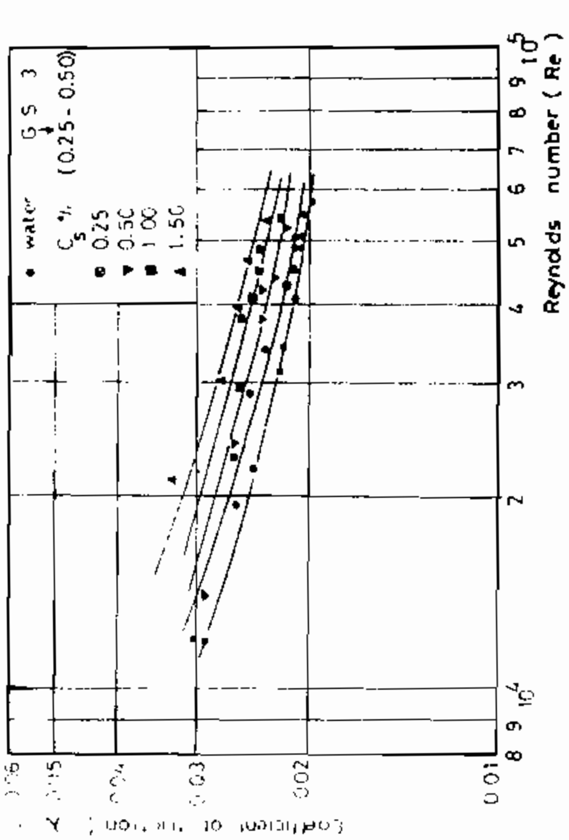


Fig. (6 c) Coefficient of friction against Reynolds number for G.S.(3) at different sand concentrations.

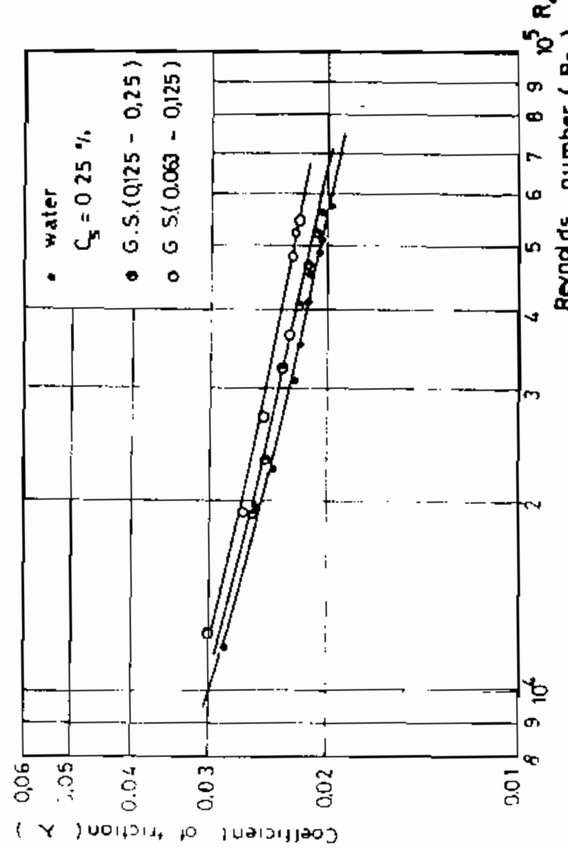


Fig. (7) Coefficient of friction against Reynolds number for C_s = 0,25 % at different grain sizes.

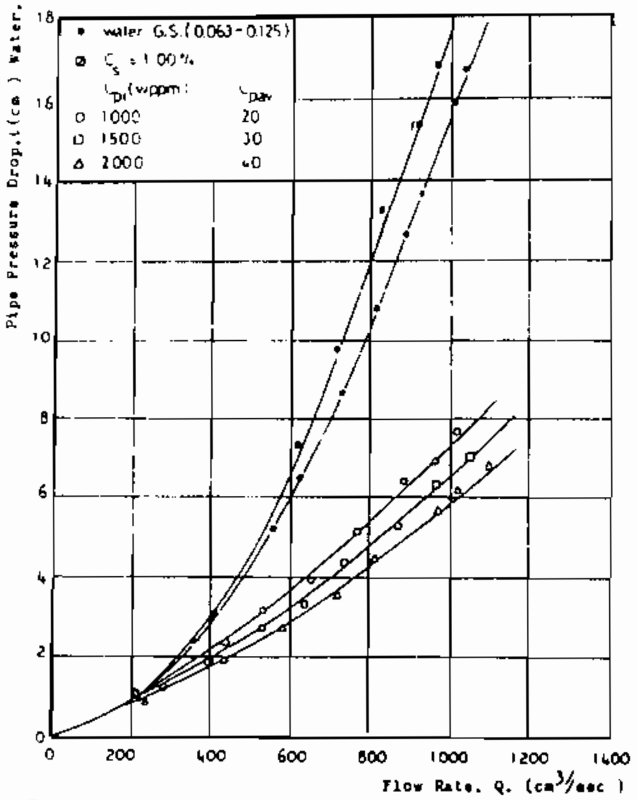


Fig (8 a) Pipe pressure drop against flow rate for grain size (1), C_s=1.00 % at different polymer concentrations

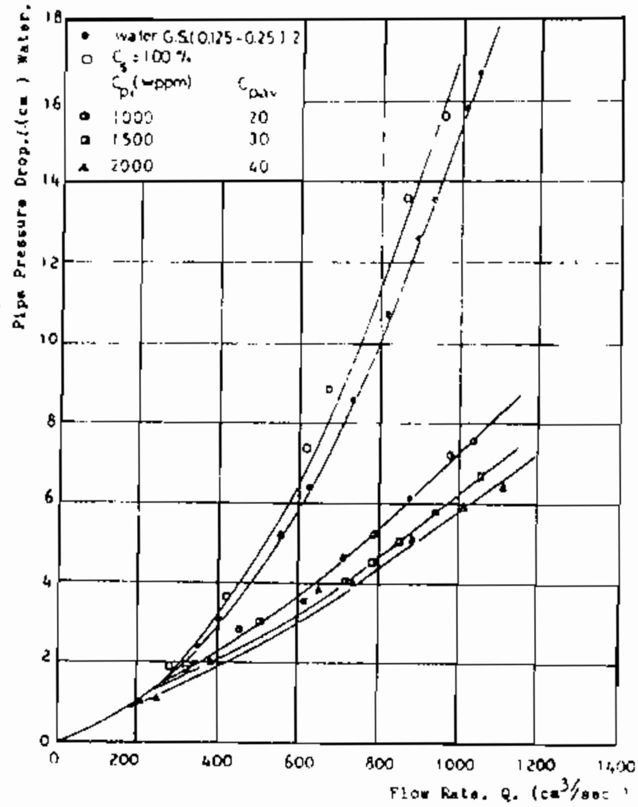


Fig (8 b) Pipe pressure drop against flow rate for grain size (2), C_s=1.00 % at different polymer concentrations

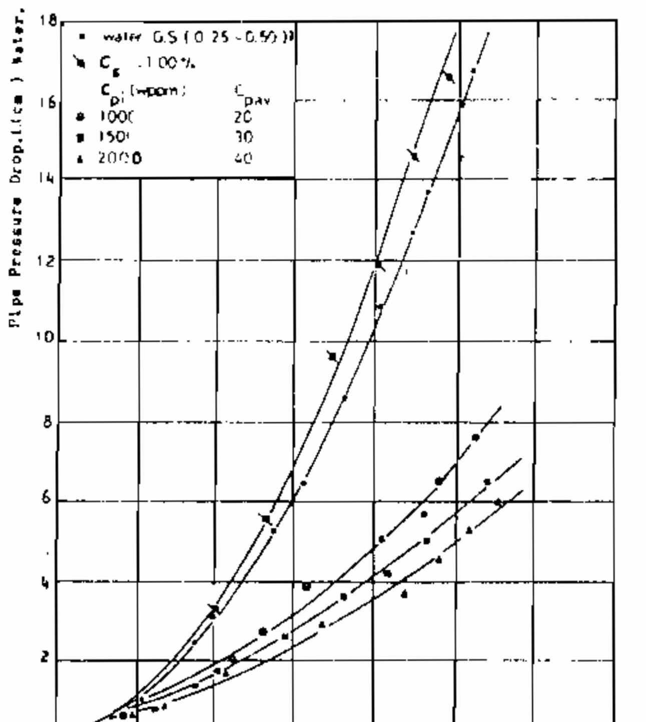


Fig (8 C) Pipe pressure drop against flow rate for grain size (3), C_s=1.00 % at different polymer concentrations

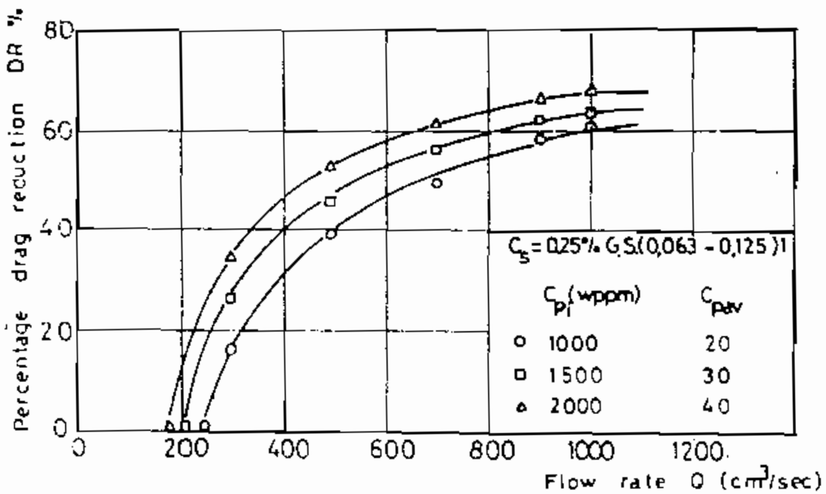


Fig.(9 a) Drag reduction against flow rate for grain size (1) C_s=0,25 %. at different polymer concentrations

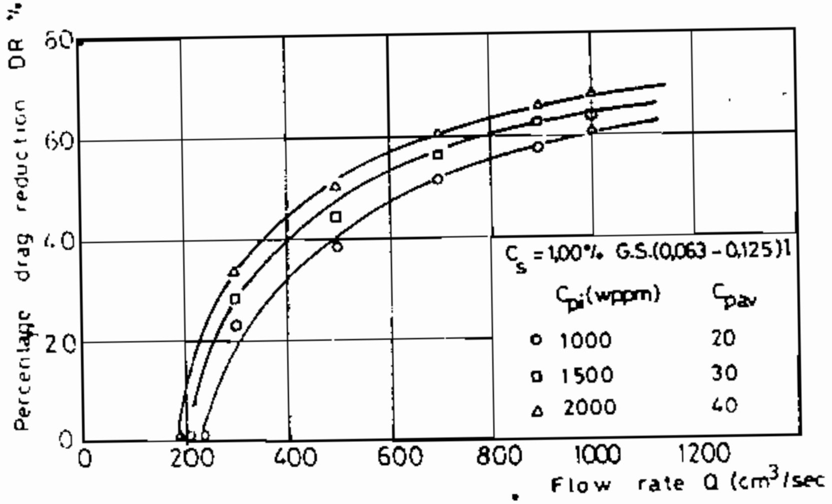


Fig.(9 c) Drag reduction against flow rate for grain size (1) C_s=1.00 %. at different polymer concentrations

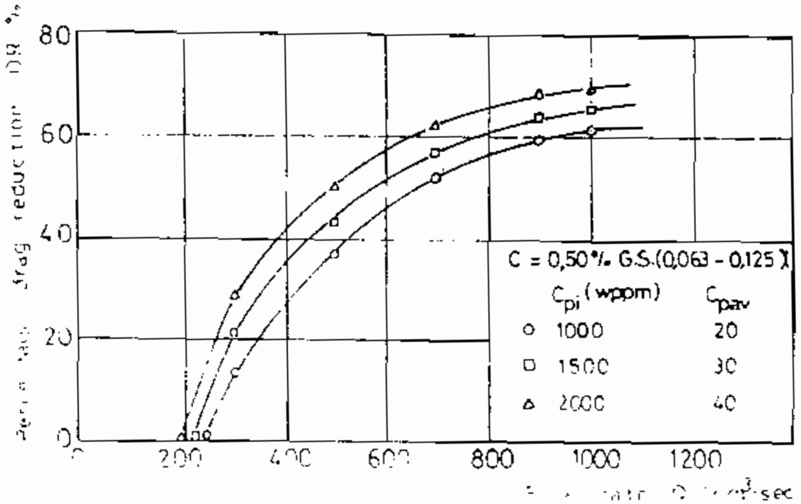


Fig 9 b Drag reduction against flow rate for grain size C_s=0.50 %. at different polymer concentrations

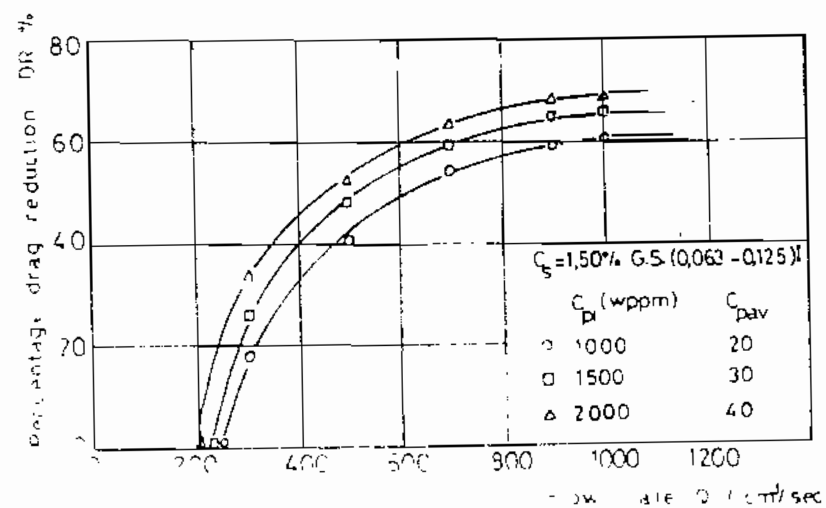


Fig 9 d Drag reduction against flow rate for grain size C_s=1.50 %. at different polymer concentrations

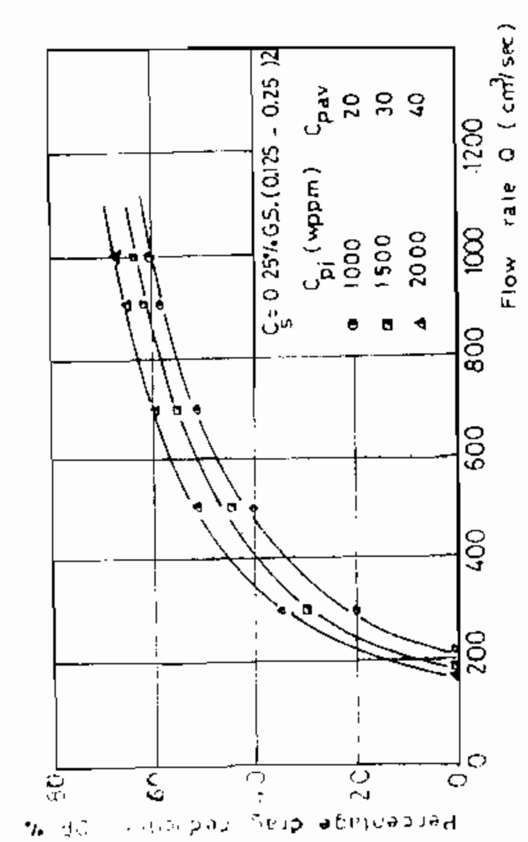


Fig. (10 a) Drag reduction against flow rate for grain size (2), C_s=0,25 % at different polymer concentrations

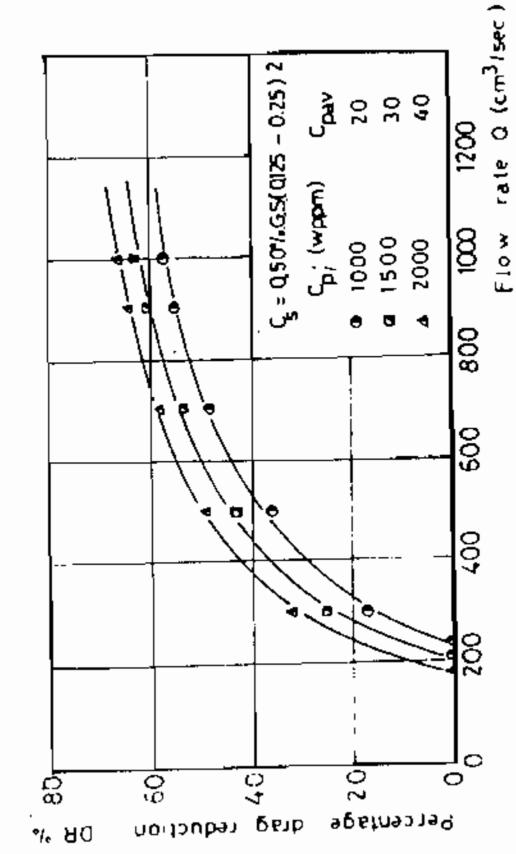


Fig. (10 b) Drag reduction against flow rate for grain size (2), C_s=0,50 % at different polymer concentrations.

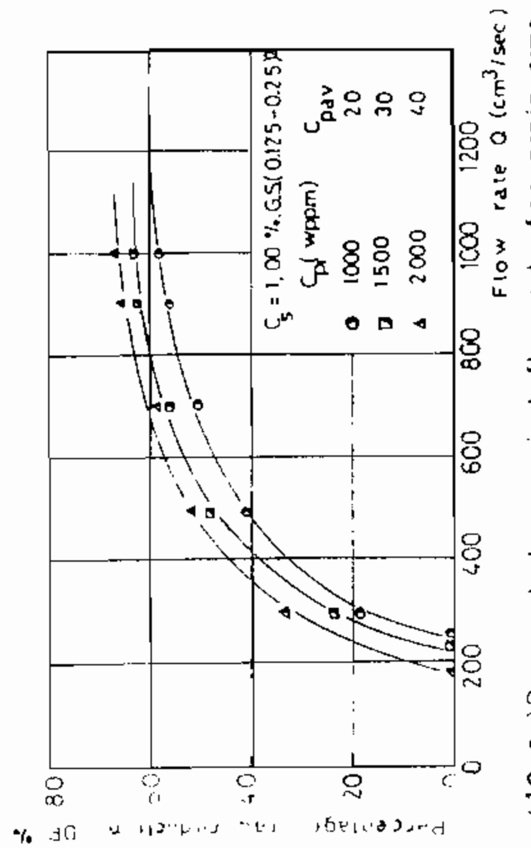


Fig (10 c) Drag reduction against flow rate for grain size (2), C_s=1,00 % at different polymer concentrations

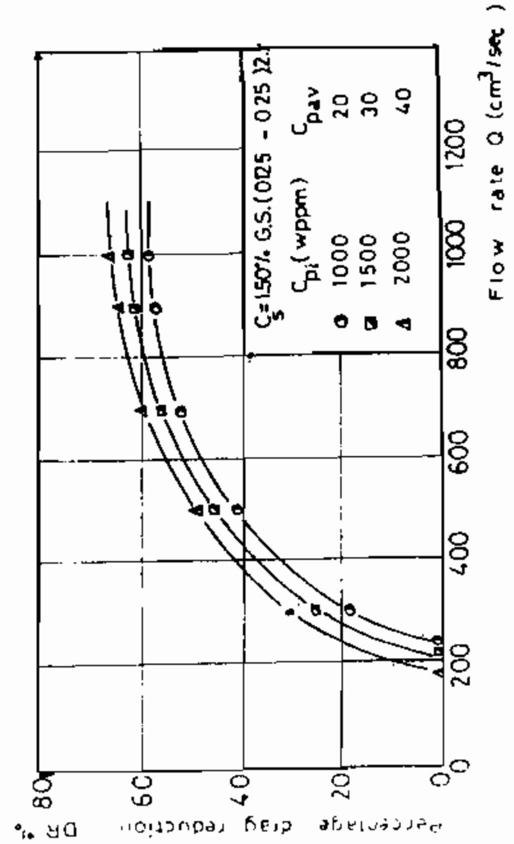


Fig (10 d) Drag reduction against flow rate for grain size (2), C_s=1,50 % at different polymer concentrations.

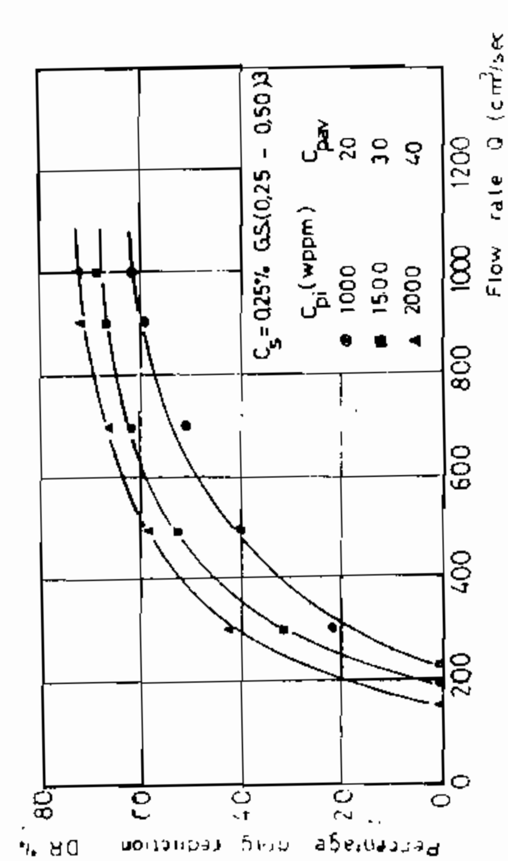


Fig.(11 a) Drag reduction against flow rate for grain size (3) C_s=0.25 %.at different polymer concentrations

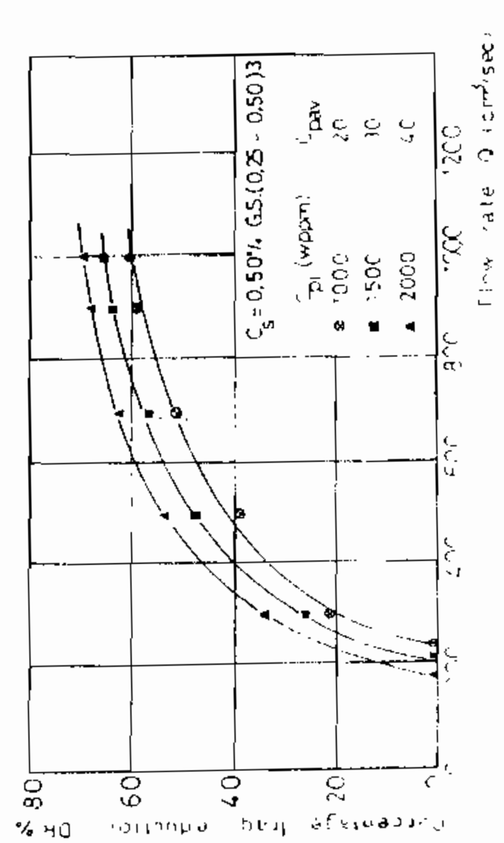


Fig. 11 b Drag reduction against flow rate for grain size ( ) C_s=0.5 % at different polymer concentrations

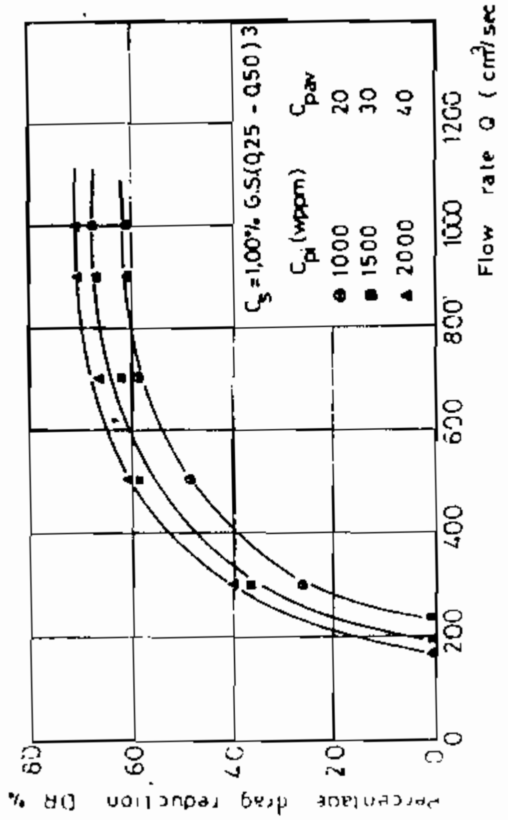


Fig (11 c)Drag reduction against flow rate for grain size (3), C_s=1,00 %.at different polymer concentrations

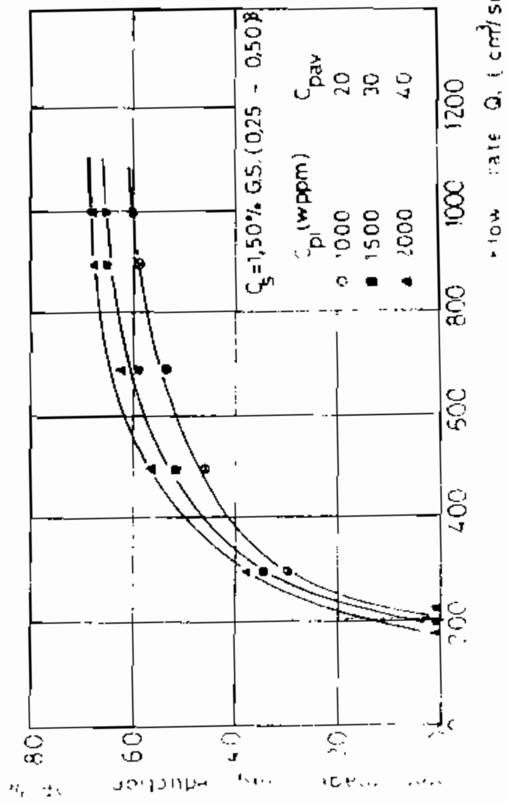


Fig. 11 d Drag reduction against flow rate for grain size ( ) C_s=1,50 % at different polymer concentrations

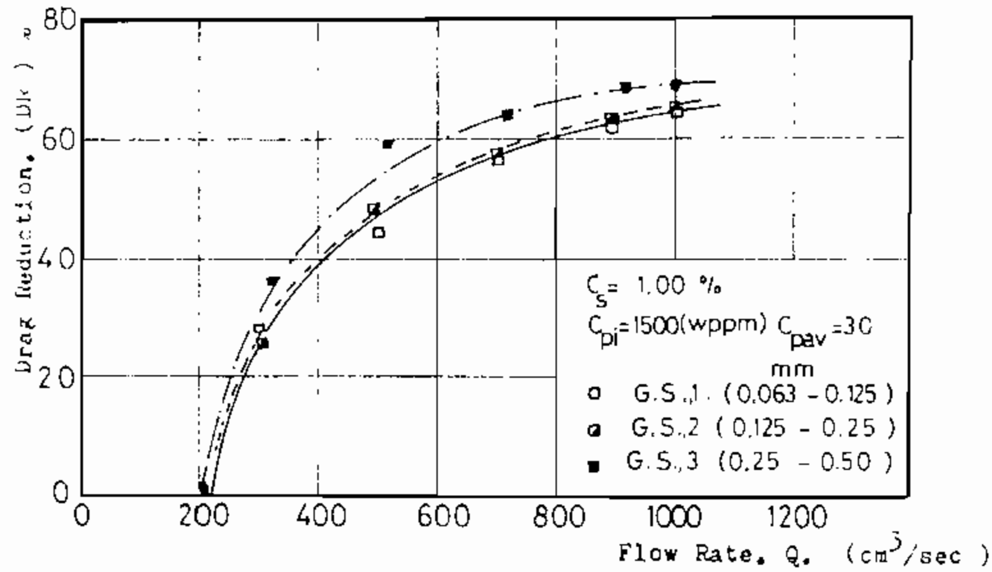


Fig (12)Drag reduction against flow rate for C_s=1.0 %, C_{pav}=30 (wppm) at different grain sizes

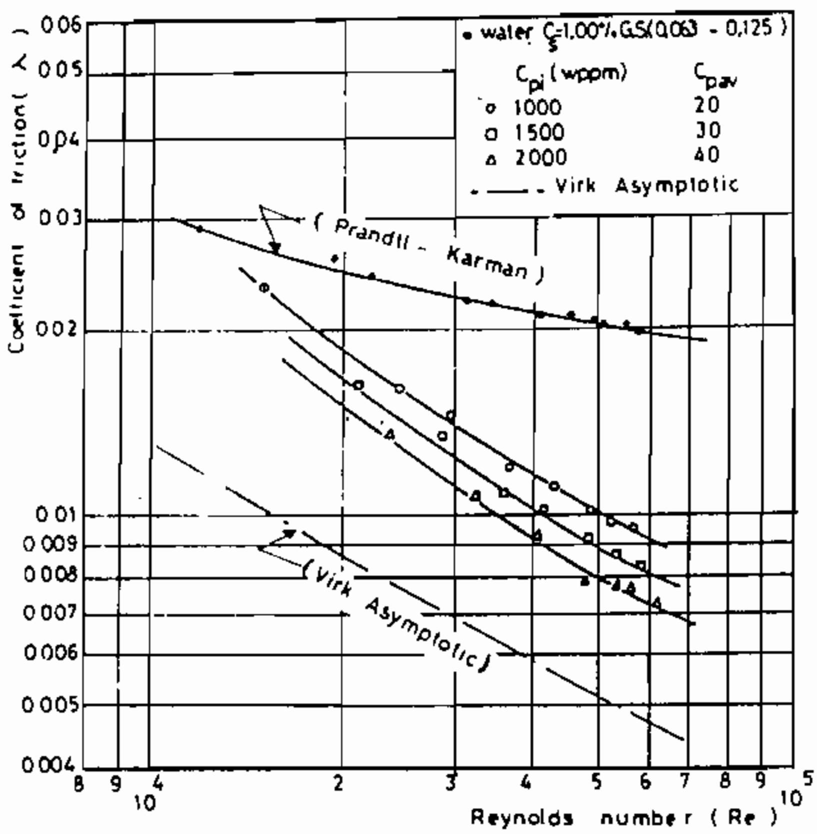


Fig (13) Coefficient of friction against Reynolds number for G.S.(1).C_s = 1,00 % at different polymer conentrations in comparison with Virk (12)