[Mansoura Engineering Journal](https://mej.researchcommons.org/home)

Volume 10 | Issue 1 Article 11

6-1-2021

An Experimental Study for the Flow of Dilute Polymer Solutions in Nozzles and Diffusers.

Lotfi Rabie
Assistant Professor., Mechanical Power Engineering Department., Faculty of Engineering., El-Mansoura University., Mansoura., Egypt.

B. Khalifa
Faculty of Engineering and Technology., Menofia University., Shebeen El-Koum., Egypt.

A. El-Haroun
Faculty of Engineering and Technology., Menofia University., Shebeen El-Koum., Egypt.

Recommended Citation

Rabie, Lotfi; Khalifa, B.; and El-Haroun, A. (2021) "An Experimental Study for the Flow of Dilute Polymer Solutions in Nozzles and Diffusers.," *Mansoura Engineering Journal*: Vol. 10 : Iss. 1 , Article 11.
Available at: https://doi.org/10.21608/bfemu.1985.177190

Mansoura Bulletin Vol. 10, No. 1, June 1985 M. 21

AN EXPERIMENTAL STUDY FOR THE FLOW OF DILUTE POLYMER SOLUTIONS IN NOZZLES AND DIFFUSERS

L. H. RABIE *, B. A. KHALIFA, and A. A. EL-HAROUN
Faculty of Engineering and Technology, Menofia University, Shebeen El-Koum, EGYPT.

ABSTRACT:

This work presents an experimental study for the effect of drag reducing polymer additives upon a water flow in nozzles and diffusers. Five circular nozzles and diffusers of constant area ratio of 4 and half angle $\alpha = 4^o, 6^o, 8^o, 10^o$, and 12^o respectively are used. Two polymer types; Polyox coagulant and polyacrylamide are used at diffrent concentrations.

The results show that both polyacrylamide and polyox have no effect on the flow through nozzles at any flow rate and polymer concentrations. However, for diffuser flow, polymer additives results in a substantial increase in the pressure recovery of the diffuser. This effect increases with the flow rate and polymer concentration up to 10 wppm. For higher concentrations as 50 wppm, the effect is complicated and more interesting especially with polyacrylamide additives. The pressure recovery of the diffuser begins to decrease at some value of the flow rate. The decrease becomes more pronounced as the diffuser half angle increases. This is thought to be due to the increase of the viscoelastic properties with concentration and the elongation strains with the flow rate and diffuser half angle. The results also show that the pressure recovery increases with the diffuser half angle. They also show that polymer effect starts at a certain flow rate similar to the onset of drag reduction in pipe flow.

1. INTRODUCTION:

In most of flow systems, sections of converging and diverging flows are almost found. In fact the flow in these sections, especially diffusers, greatly affects the performance of the whole flow system. Many engineering problems

---

*Correspondences should be addressed to Dr. L. H. Rabie, Mechanical Engineering Dept., Faculty of Engineering, Mansoura University, Mansoura, EGYPT.

such as flow separation and the defficiency of pressure recovery are associated with such flow type. Hence, many investigations have been carried out to study the flow characteristics and the optimum design of the nozzles and diffusers in Newtonian fluid flows [1-3] .

It is well known now that the addition of few parts per million of high molecular weight , long chain , flexable molecule polymers to turbulent flow can reduce the frictional loss drastically. This phenomenon is known as Tom's phenomenon or drag reduction [4] . It receives much of the attention of the fluid mechanics researchers since early sixties for its important promissing practical applications. These include ; increasing capacities for crude oil transportation and brine disposal, faster ships especially for millitary purpose , fire fighting and sprinkler irrigation. Most of,the available research were carried out on pipe flow systems. Very little investigations have been done , so far, to study the effect of these drag reducing additives upon flows with pressure gradients. Even most of these very little were carried out on external flow systems as those arround cylinders , bodies of revolutions and hydrofoils [5-7]. To our knowlage, the available investigations for the flow of drag reducing polymer additive fluids in tapered tubes are those of Tomita et al [8] and Kato et al [9&10]. However the work of Kato et al was more systamatic. They measured the pressure distribution and the velocity profile in both diverging and converging tube flow of water and dilute polymer solutions. Their results show that no drag reduction is recognized for the converging flow. They show also that an increase in the pressure recovery of the diffuser is achieved by polymer additives. They also reported that polymer additives promote the occurance of separation. However some of these results are in contradiction with those of Rabie[11] which showed that polymer additives resulted in larger drag reduction level in converging than the pipe flow one. It is also shows that suppresion in the turbulent boundary layer separation is expected with drag reducing polymer additives.

It is obvious that,due to the unsufficient availabe investigations , the effect of drag reducing polymer additives upon the flow in nozzles and diffusers is not clear and more systematic studies are greatly needed. In this work, an experimental study for the effect of two polymer types , Polyox and polyacrylamide upon the flow in nozzles and diffusers for different polymer concentrations is investigated. Five different tapered angles are used for both converging and deverging test sections.

2. EXPERIMENTAL TECHNIQUE.

The experiments were carried out in an open flow system rig. In which the fluid flows under the action of gravity from an overflow constant head tank through the test section to the

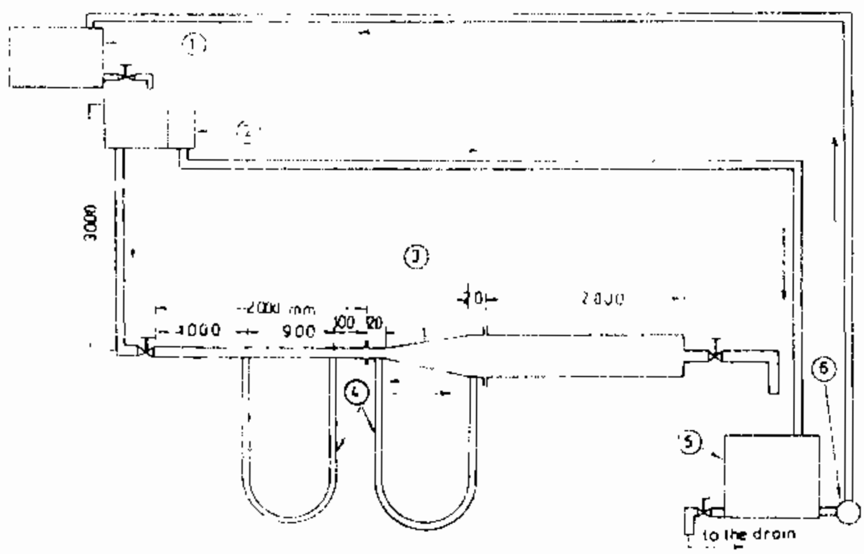


Figure (1)
Schematic diagram of the test rig

(1) main tank (2) over flow tank
(3) test section (4) U tube manometer
(5) collecting tank (6) pump

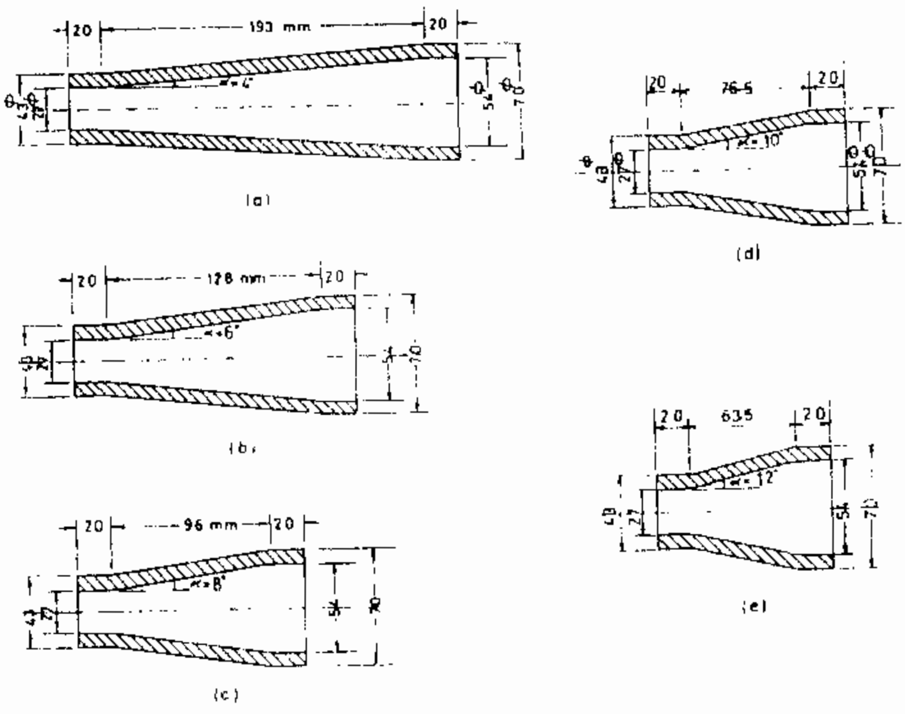


Figure (2)
Detailed dimensions of the test sections

collecting tank as shown in figure (1). Since the flow is a gravitational one , the use of the overflow constant head tank is necessary to keep the fluid head constant during the experiment. The water level of the constant head tank is kept at 300 cm higher than that of the test section. The overflow tank is 50 x 50 x 40 cm in dimension with a baffle plate of 20 cm hight inside. It is fed continously by an overhead tank of capacity 1 m^3. The flooded flow from the overflow tank is directly drained to the collecting tank which is 150 x 150 x 50 cm in dimension.

The test section is a tapered circular brass tube of 27 and 54 mm diameters, and constant area ratio of 4 . Five different test sections are used with half angle α of 4° , 6°, 8°, 10° and 12° respectively, and length "L" of 193, 128, 96, 76.5 , and 63.5 mm respectively. Each test section is provided with two wall pressure taps of 1 mm diameter at the inlet and outlet cross sections for static pressure measurements. Figure (2) shows details of the test section. The five test sections are used for both nozzle and diffuser flow experiments. For nozzle flow experiments ; the test section is arranged such that the inlet diameter is the 54 mm. While for diffuser flow experiments ; it is reversed such that the inlet diameter is that of 27 mm. The test section is flanged in between two commercial steel pipe tubes of 27 and 54 mm diameters and 200 mm length each. This ensures an entrance length of about 40 and 80 pipe diameters for the nozzle and diffuser test sections respectively.

The pressure differance between the inlet and outlet of the test section is measured using a U tube manometer connected to the two pressure taps. In order to monitor the behaviour of drag reducing polymer additives, the pressure drop across the 27 mm diameter pipe is measured. For this purpose two wall pressure taps are made 90 cm. apart and connected to another U tube manometer. Carbon tetracholoride (CCl_4) of specific gravity 1.595 is used as manometer liquid. It has been coloured red by dissolving some Iodine grains.

The fluid flow rate is controlled using a gate valve at the end of the downstream tube as shown in figure (1). The flow rate is measured using a weighting tank and stop watch. The experiments are carried out at a temperature 15 - 18°C. The temperature of the flowing fluid is measured at the exit by a thermometer.

To study the effect of drag reducing polymer additives upon the flow through nozzles and diffusers , the pressure difference between inlet and outlet cross sections is measured at different flow rates for water and dilute polymer solutions flows. Two polymer types are used , polyox coagulant and polyacrylamide both of molecular weight of 5 x 10^6 and produced by BDH laboratory chemicals, England. Different polymer concentrations of 2, 5, 10 and 50 wppm are used through out

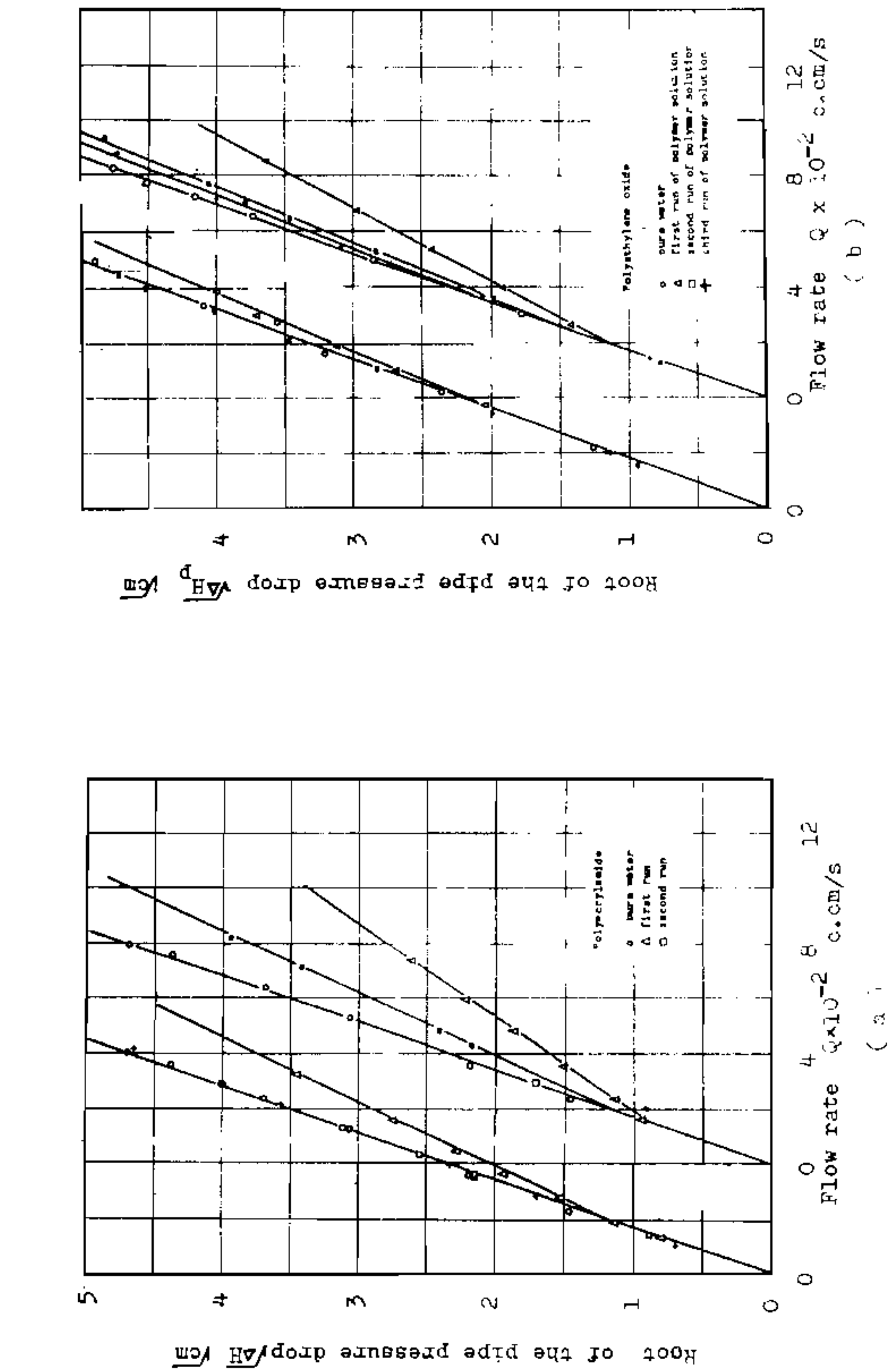


Figure (3)

Effect of pumping upon the effectiveness of polymer additives; o pure water, Δ first run, □ second run.
(a) polyacrylamide (b) polyethylene oxide

this investigation. Polymer solutions of the desired concentrations are made by diluting concentrated master solution of 7000 wppm. Details of the experimental set up and technique are found in El-Haroun (1983) [12].

3. RESULTS AND DISCUSSION.

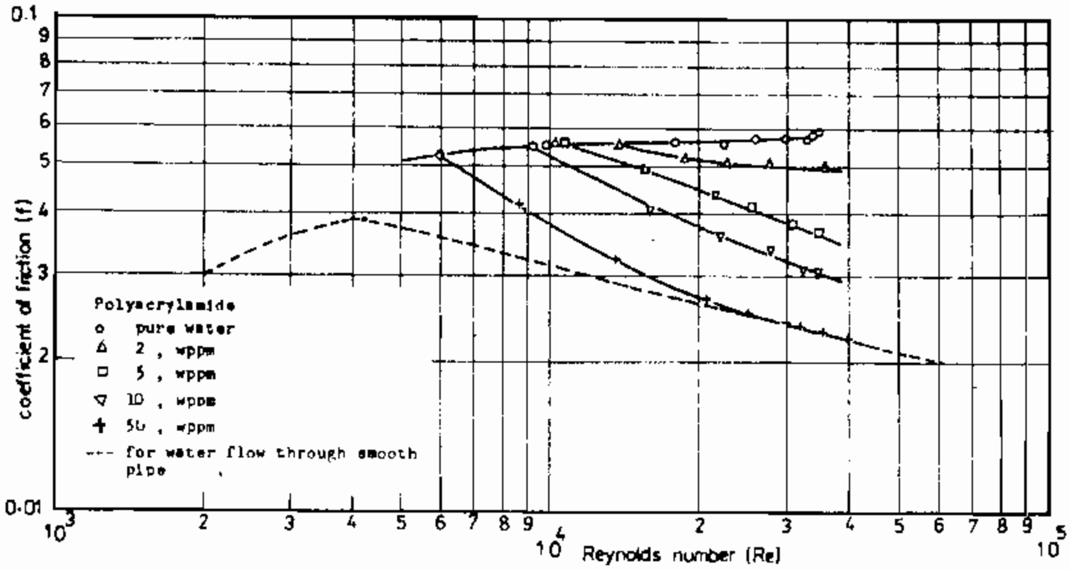
The experiments are carried out first on pure water alone and , then , on polymer solutions. They can be divided mainly into four groups. The first one is concerned with the effect of mechanical degradation due to pumping on the effectiveness of the polymer solutions. The second group deals with the effect of polymer additives upon the flow through commercial steel rough pipe. The third and fourth groups are devoted to study the effect of these additives upon the flow through nozzles and diffusers respectively which are the main aim of this work.

3.1. Pumping Effect Upon Drag Reduction.

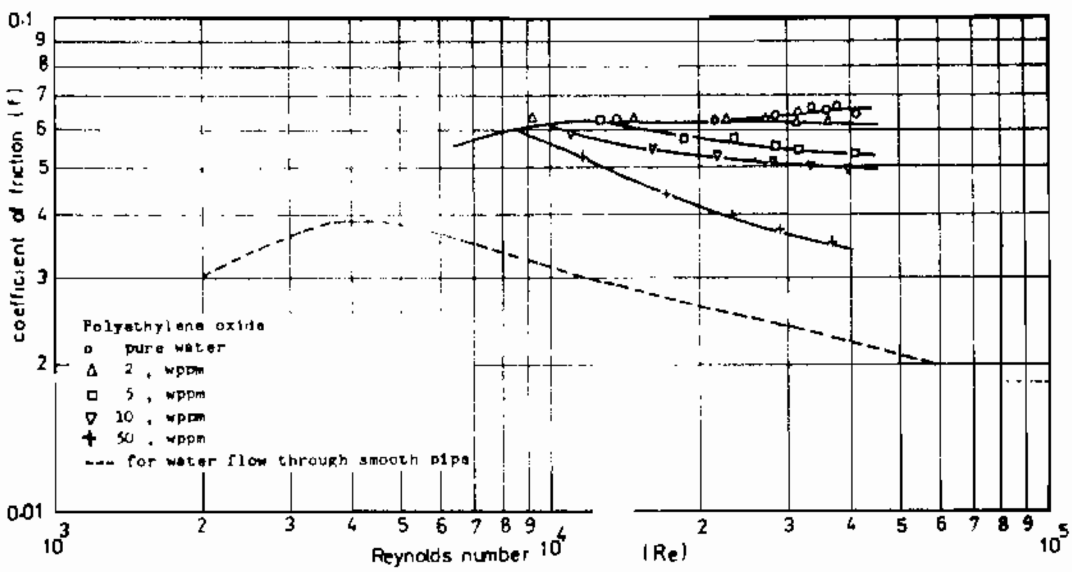
Fresh polymer solutions are allowed to flow through the system for the first run from the upper tank to the collecting one and the pressure drop through the 27 mm diameter pipe is measured. Then the collected polymer solutions are pumped back to the upper tank by a centrifugal pump to flow for the second run and repeated for the third one. The square root of the pressure drop as a function of the flow rate for the two polymer types at different concentrations are plotted in figures (3-a) and (3-b) respectively. The results show that the effectiveness of both polyacrylamide and polyox solutions decrease as they pass through the pump. Polyacrylamide shows more resistance to mechanical degradation than polyox solutions. The increase in polymer concentration increases its resistance to mechanical degradation. From these results one can see that polymer solutions must be used once from the main tank through the system to the drain.

3.2. Effect Of Polymer Additives Upon The Flow Through Commercial Rough Pipe.

The pressure drop across 90 cm of 2 m length, 27 mm diameter commercial steel rough pipe is measured at different flow rates and polymer concentrations. The results are plotted as the friction factor "f" againest the Reynolds number "Re" and shown in figure (4-a) and (4-b) for polyacrylamide and polyox respectively.They show that polymer additives resulted in lower friction factor than water flow. This reduction in frictional drag increases with the polymer concentration and Reynolds number. The results also show that drag reduction starts at certain Reynolds number which is known as the onset point. This onset point shows a dependence on polymer concentration in contrast to that reported by Rabie (1978)[13]. The results also show that polyacrylamide has



(a)



(b)

Figure (4)

Effect of polymer additives upon the flow in commercial rough pipe;
(a) polyacrylamide (b) polyethylene oxide

higher drag reduction values than polyethylene oxide. More than 60% drag reduction is reported for polyacrylomide solution of 50 wppm at 35000 Reynolds number and 47% for polyox of the same concentration at 39000 Raynolds number.

3.3 Effect Of Polymer Additives On The Flow Through Nozzles.

The pressure difference between the inlet and outlet cross sections of five nozzles with half angle $\alpha = 4°, 6°, 8°, 10°$ and $12°$ respectively are measured, at different flow rates and polymer concentrations. The results are plotted as a relation between the square root of the pressure difference $\sqrt{Hn}$ and the flow rate and shown in figures (5-a) and (5-b) for polyacrylamide and polyox respectively.

Figures (5-a) and (5-b) show that it is very difficult to find any difference between water and polymer flow results at any nozzle half angle or polymer concentration for both polymer types. This agrees with that of kato et al [9] who mentioned that the difference in pressure distribution between polyox and pure water is not clear for converging flow and there is no remarkable drag reduction as that of the pipe flow. It is beleived that the effect of polymer additives as drag reducer does not appear in converging flows due to the fact that it is small compared with the large pressure drop with the area contraction of the nozzle.

3.4. Effect Of Polymer Additives Upon The Flow In Diffusers.

Five circular diffusers of constant area ratio 4 and with half angles $\alpha = 4°, 6°, 8°, 10°$ and $12°$ are used respectively to study the effect of drag reducing polymer additives upon diffuser flows. The pressure difference between the inlet and and outlet cross sections "H_d" is measured at different flow rates for water and polymer solutions at different concentrations. The results are shown in figures (6-a) and (6-b) as the root of the pressure recovery of the diffuser $\sqrt{Hd}$ as function of the flow rate at different polymer concentration of 2, 5, 10 and 50 wppm and for the five test sections in comparison with that of pure water. The results show that polymer additives causes drastic changes to the turbulent flow through diffusers. It shows an increase in the pressure recovery of the diffuser with polymer additives over that of pure water.

Figures (7) and (8) present the percentage increase in the pressure recovery of the diffuser with polymer additives as function of the flow rate and polymer concentrations. The results show that polymer additives resulted in an increase in the pressure recovery of the diffuser. This effect starts at a certain flow rate similar to the onset point for drag reduction in pipe flow. After the onset point the effect of polymer additives increases with the flow rate to an asymptotic value. Over 30% gain in the pressure recovery of the diffuser is achieved with

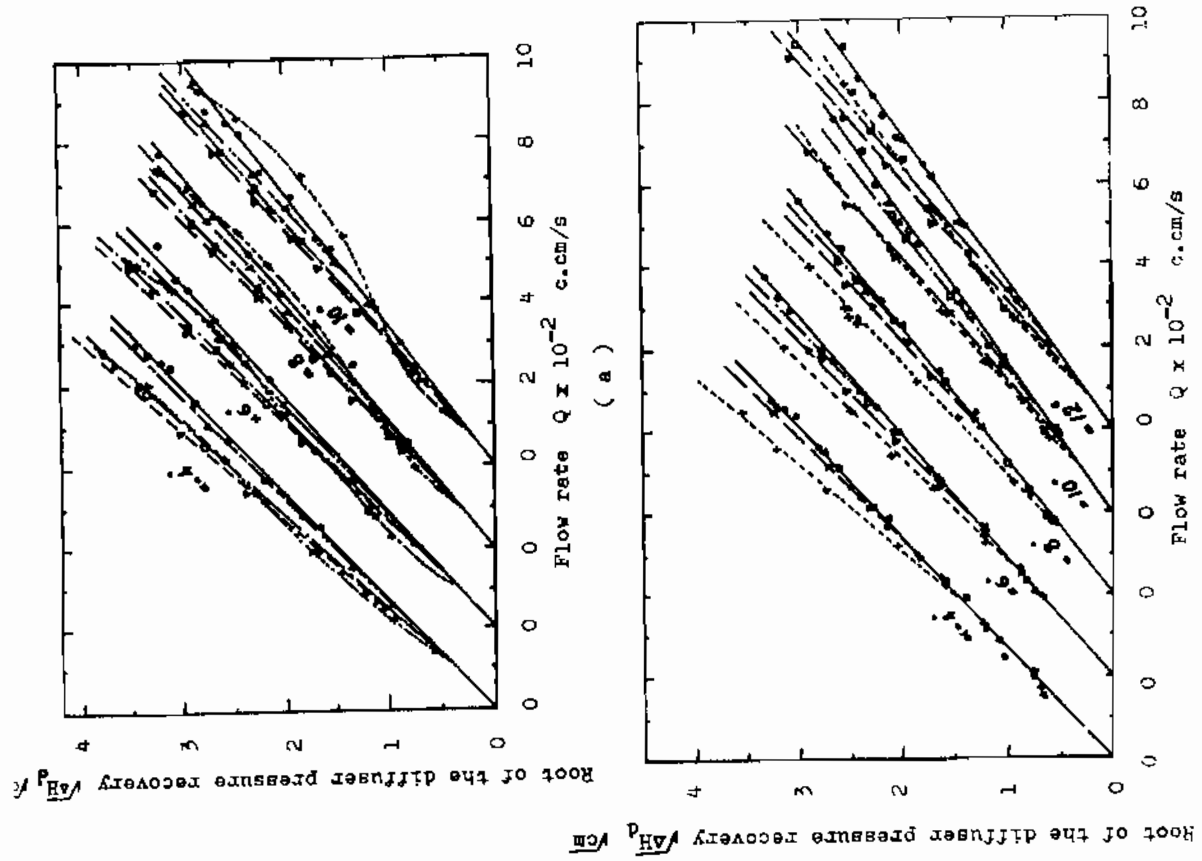


Figure (6)
Flow of drag reducing polymer additive fluids through diffusers; o pure water, Δ 2 wppm, □ 5 wppm, ▽ 10 wppm, + 50 wppm.
(a) polyacrylamide (b) polyethylene oxide

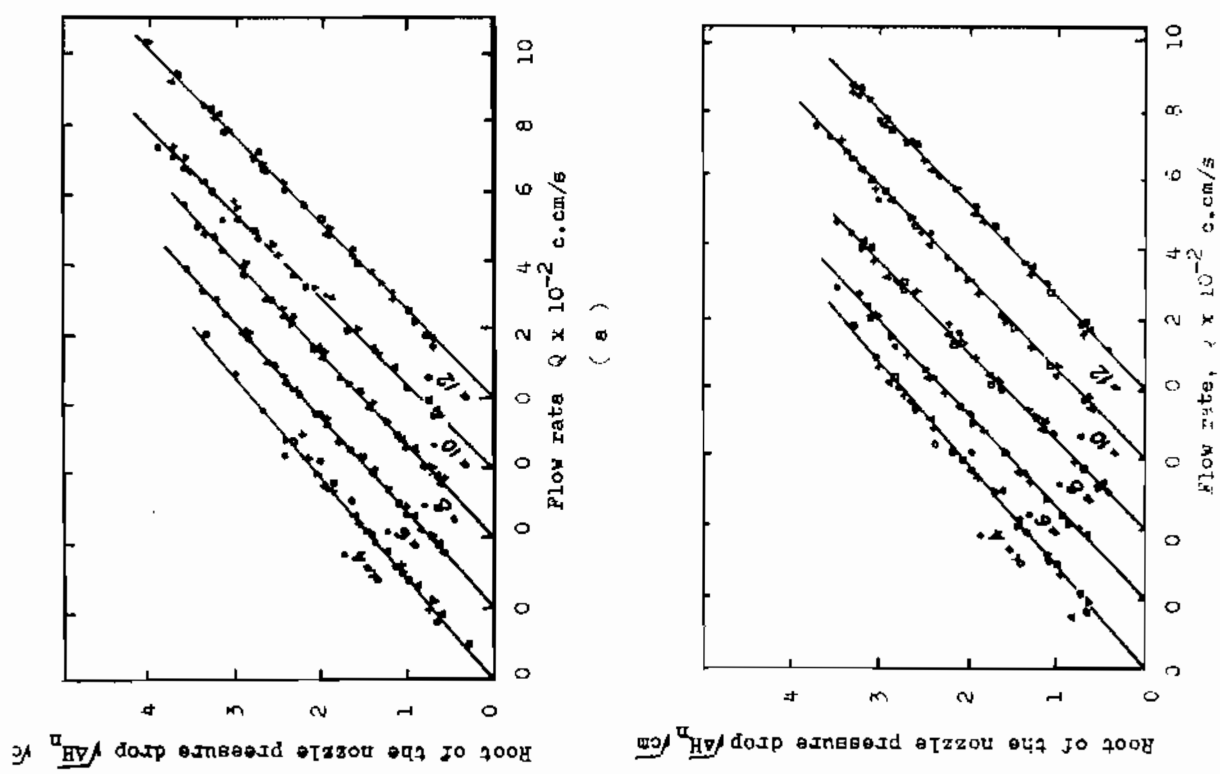


Figure [illegible]
Flow of drag reducing polymer additive fluids through nozzles; o pure water, Δ 2 wppm, □ 5 wppm, ▽ 10 wppm, + 50 wppm.
(a) polyacrylamid (b) polyethylene oxide

polyacrylamide and 40% with polyox additives at 10 wppm. The results show also that the onset flow rate decreases with the concentration of the polymer additives , which is similar to pipe flow results.

From the above results one can see that the increase in the pressure recovery of the diffuser with polymer additives increases with polymer concentration up to 10 wppm. However, for higher concentrations such as 50 wppm, the results have complicated behaviour. At low flow rates, the percentage rise of the diffuser pressure recovery increases with the increase of the flow rate till a certain limit, then it begins to decrease. Polyacrylamide results show that further increase in flow rate results in a reincrease of the pressure gain. This complicated behaviour becomes more and more pronounced as the half angle of the diffuser increases as shown in figure (7). In case of $\alpha = 8°$, $10°$ and $12°$, 50 wppm polyacrylamide concentration results in lower pressure gain than that of water at flow rate around 600 cm^3/sec. Such strange behaviour is thought to be due to a combined effects of the drag reduction and the viscoelastic properties of the polymers. The effect of drag reduction is to reduce friction losses, delay the development and the separation of the boundary layer [11] reducing the boundary layer thickness and the blockage factor. This results in an increase in the diffuser pressure recovery . On the other hand with the increase of polymer concentration its viscoelastic properties which increases the flow resistance in elongational flows as that in diffusers. This results in a decrease of the pressure recovery of the diffuser. At low flow rate , the effect of drag reduction is more pronounced due to small values of elongational strains and consequently elongational stresses. But with the increase of the flow rate the effect of the viscoelastic properties appears and becomes more and more pronounced. Comparing figures (7) and (8) show that polyacrylamide is more effective than polyox. It produces higher increase in the pressure recovery of the diffuser than that of polyox at the same concentration and flow rate. It also has lower values for onset flow rate (Reynolds number) for the increase in pressure recovery than those of polyox.

Figure (9) presents the increase of pressure recovery of the diffuser as function of the flow rate for different α at 10 wppm polyacrylamide and polyox respectively , while figure (10) shows the results at 50 wppm. For 10 wppm , polyacrylamide results show insensitivety to the change of the diffuser half angle α . However, polyox results show that the increase of the pressure recovery increases with the half angle α. For 50 wppm both polyacrylamide and polyox results show great dependence upon the diffuser half angle. As shown in figure (10), the increase in pressure recovery with polyox increases with the flow rate for $\alpha = 4$, 6 and 8. For $\alpha = 10$ it starts to decrease after reaching a maximum value, but for $\alpha = 12$ it decreases with the flow rate. Polyacrylamide results show a decrease in the gain of the diffuser pressure recovery with the flow rate to reach a minimum , then , it starts to increase again .

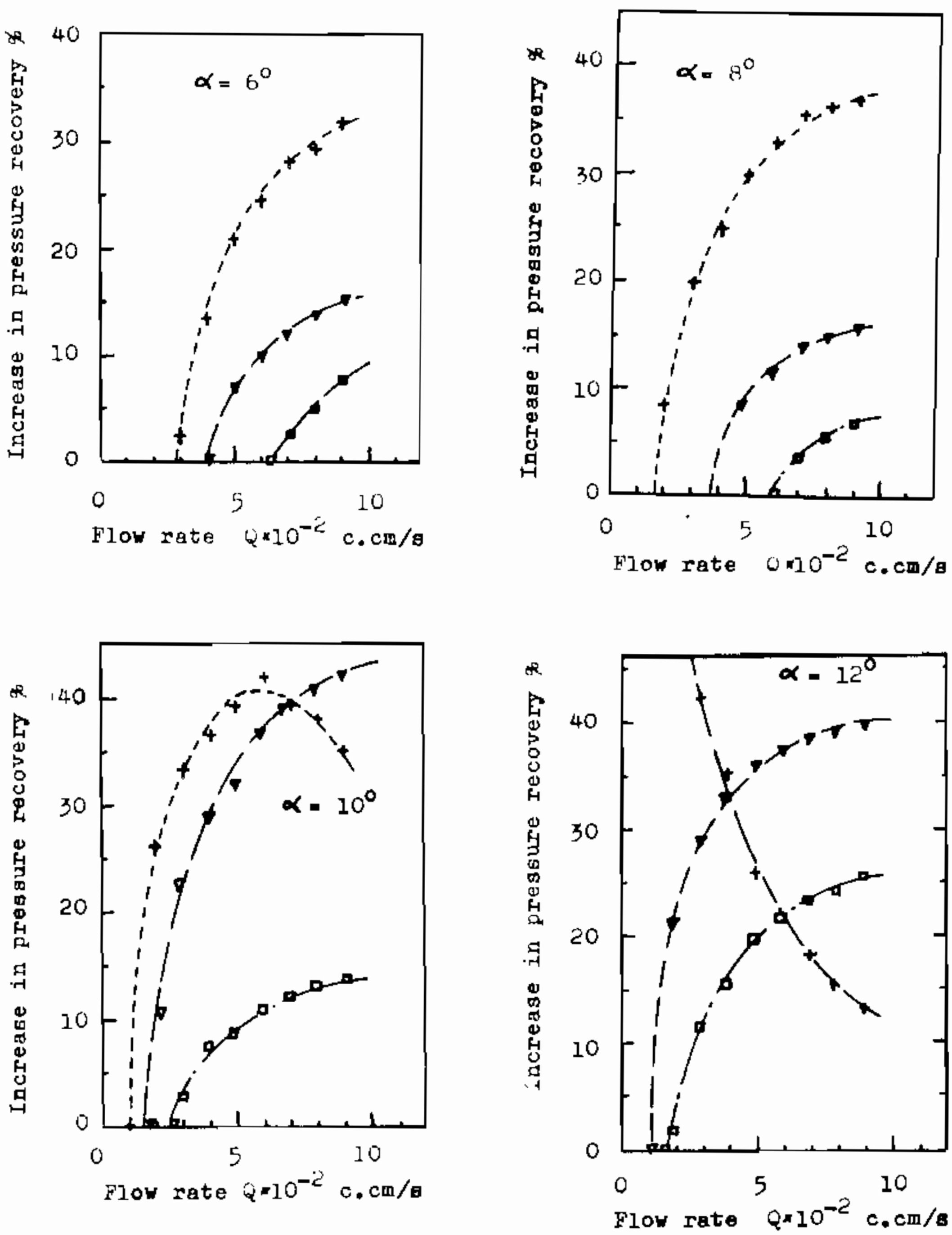


Figure (8)

Effect of flow rate and polymer concentration on the increase in the diffuser pressure recovery of polyethylene oxide additive fluid flow; Δ 2 wppm, □ 5 wppm, ∇ 10 wppm, + 50 wppm.

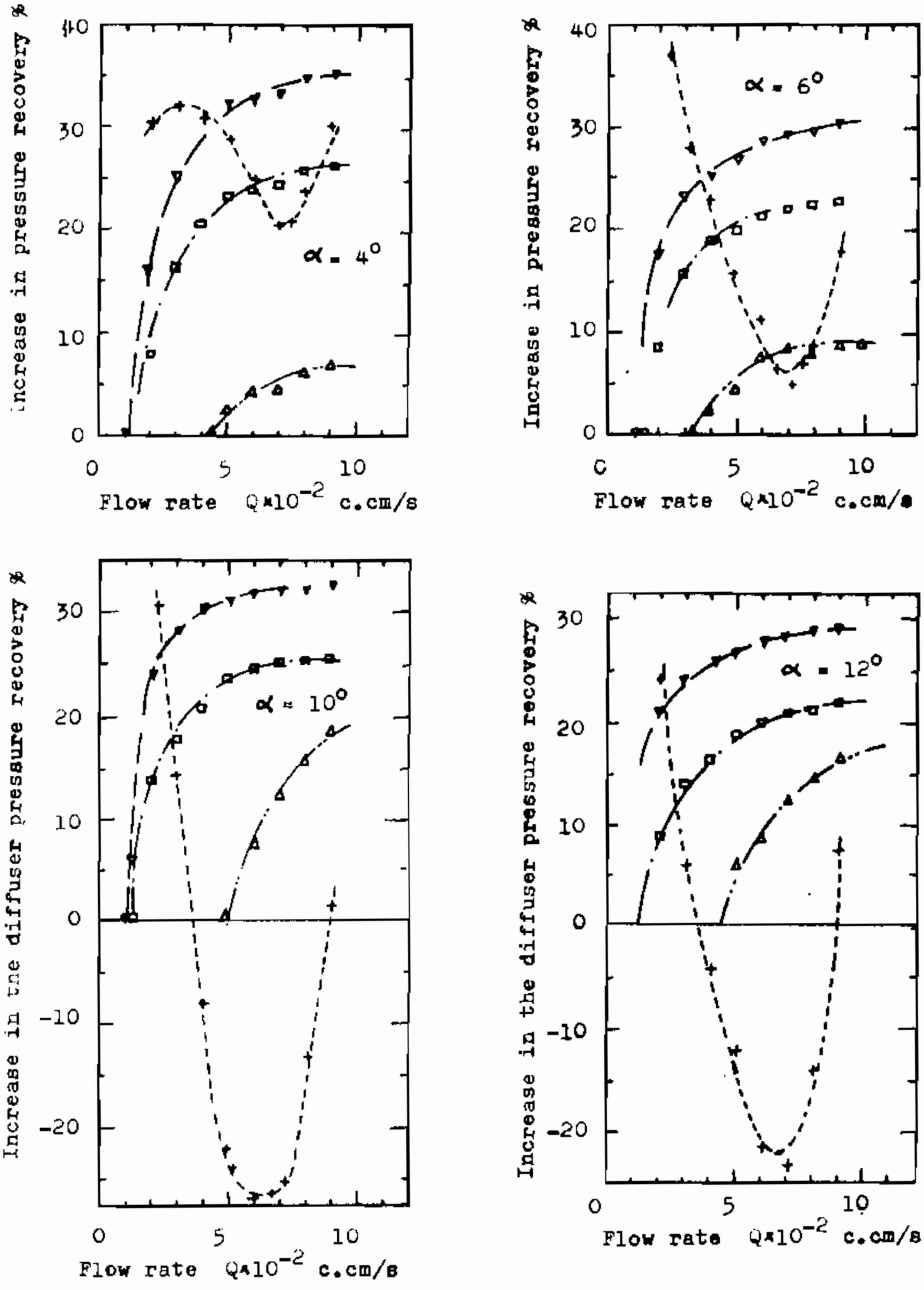


Figure (7)

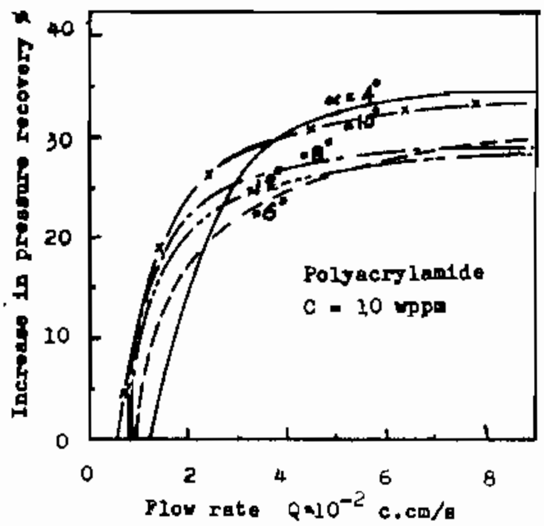
Effect of flow rate and polymer concentration upon the increase in the diffuser pressure recovery of polyacrylamide additive fluid flow; Δ 2 wppm, □ 5 wppm, ▽ 10 wppm, + 50 wppm.

This minimum value decreases with α such that the pressure recovery of polyacrylamide solution is lower than that of water for $\alpha = 8°$, $10°$ and $12°$. This can be clearly understood by knowing that drag reducing polymer additives affects the development and separation of the boundary layer [11]. They decrease the displacement and momentum thickness, reduce the shear stresses and the blockage factor and delay the boundary layer separation. These contribute in increasing the diffuser pressure recovery. On the other hand polymer solutions are characterized by the very high extensional viscosity which increases with polymer concentration. The increase of elongational strain rate produced by the increase of the diffuser half angle and the flow rate resulted in increase in the flow rèsistance. Hence a decrease in the pressure gain is expected. It is also thought that the increase of the viscoelastic properties can enhance the development of the boundary layer resulting in earlier separation [10] and lower pressure recovery. The combined effect of both drag reduction and extensional viscosity produce the observed behaviour of the results.

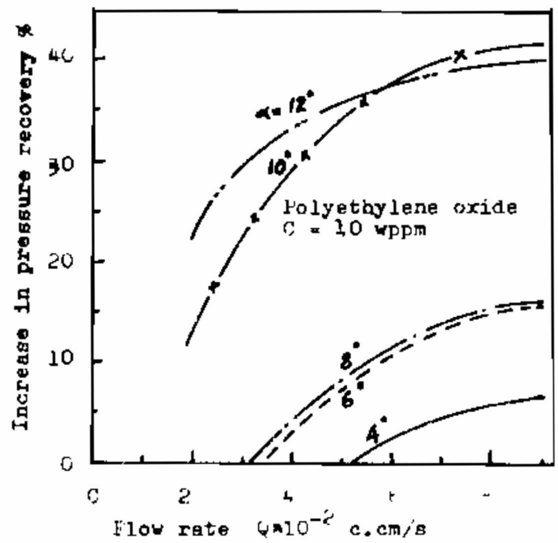
In order to have better understanding for the effect of the angle of divergence of the diffuser, the increase in the diffuser pressure recovery results are plotted as function of the half angle α for different polymer concentration at constant Reynolds number of 25000 and 38000 respectively. Polyacrylamide results are shown in figure (11) while those of polyox are in figure (12). Polyacrylamide results at low concentrations are independent upon α while at 50 wppm the increase in pressure recovery decreases with α due to the increased influence of viscoelastic properties. Polyox results show that the increase in pressure recovery increases with α to reach a maximum then decreases. This is more pronounced at higher concentrations as 50 wppm. The increase in α increases the strain rate. This in turn increases the effectiveness of the polymer as drag reducer untill the influence of the viscoelastic properties to increase the flow resistance becomes appreciable.

4. CONCLUSIONS.

This work presents an experimental investigation for the effect of drag reducing polymer additives upon the flow through nozzles and diffusers. The results show that polymer additives has no effect upon the pressure difference of nozzles at all conditions. However, these additives have drastic influence upon the flow through diffusers. For constant area ratio diffusers, polyacrylamide and polyox additives produces an increase in the pressure recovery. This effect increases with the flow rate up to Renolds number 40000 and polymer concentration up to 10 wppm. Further increase in polymer concentration or flow rate results in a maximum increase in pressure recovery followed by a decrease may be to a minimum followed by another increase. This behaviour is more pronounced with polyacrylamide. Polyacrylamide results show negligable effect for the angle of divergence at low concentrations while, at higher concentrations the increase in pressure recovery decreases with α. For polyox, the increase in α results in increase in the rise of pressure recovery until it reachs maximum value followed by a decrease. This feature becomes pronounced with the increase of polymer concentration.



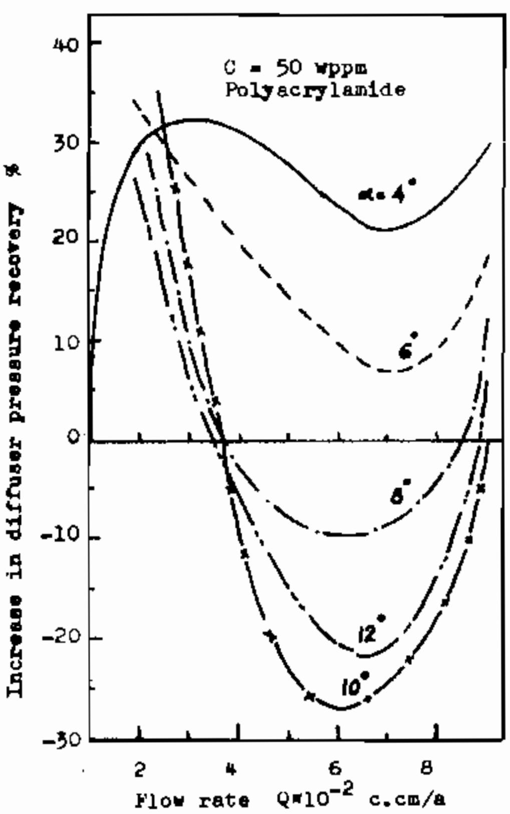
(a)



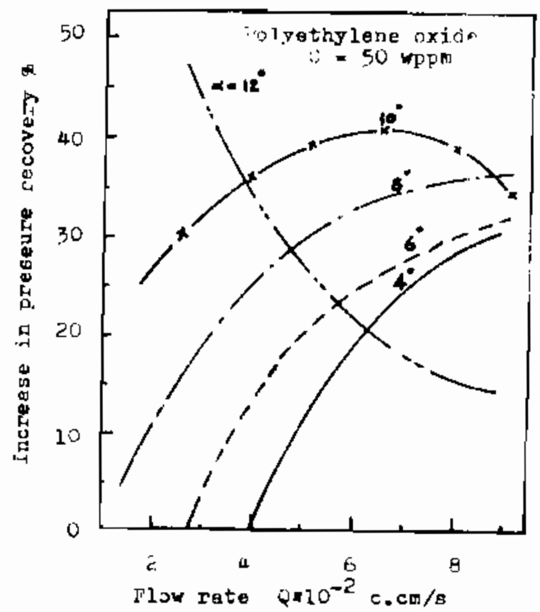
(b)

Figure (9)

Percentage increase in the diffuser pressure recovery due to polymers as function of the flow rete for different diffuser half angle at 10 wppm concentration; ———— α=4°, - - - - - - α=6°, —— - —— α=8°, ——x—— α=10°, ——-- —— α=12°,
(a) Polyacrylamide (b) Polyethylene oxide



(a)



(b)

Figure (10)

Percentage increase in the diffuser pressure recovery as function of the flow rate for different diffuser half angle at 50 wppm;
———— α=4°, - - - - α=6°, —— - —— α=8°,
——x—— α=10°, ——-- —— α=12°.
(a) Polyacrylamide (b) Polyethylene oxide

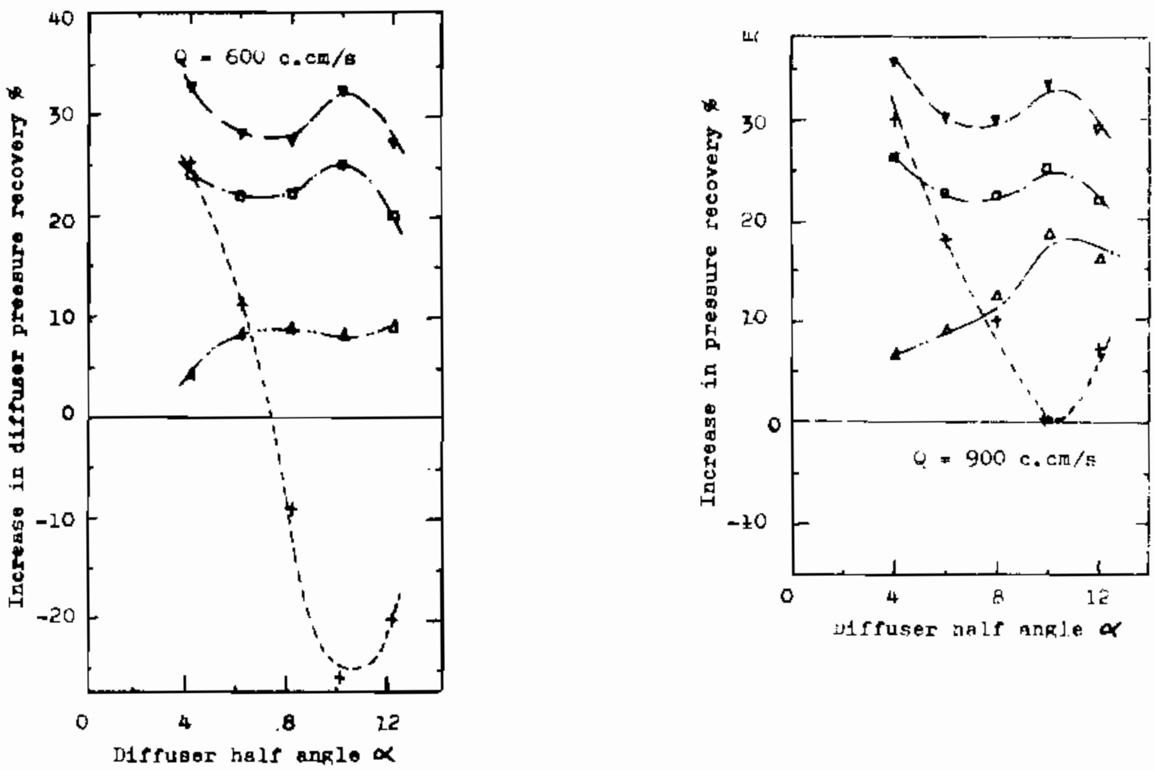


Figure (11)

Effect of the diffuser half angle α upon the increase in the diffuser pressure recovery due to polyacrylamide at constant flow rate; Δ 2 wppm, □ 5 wppm, ▽ 10 wppm, + 50 wppm

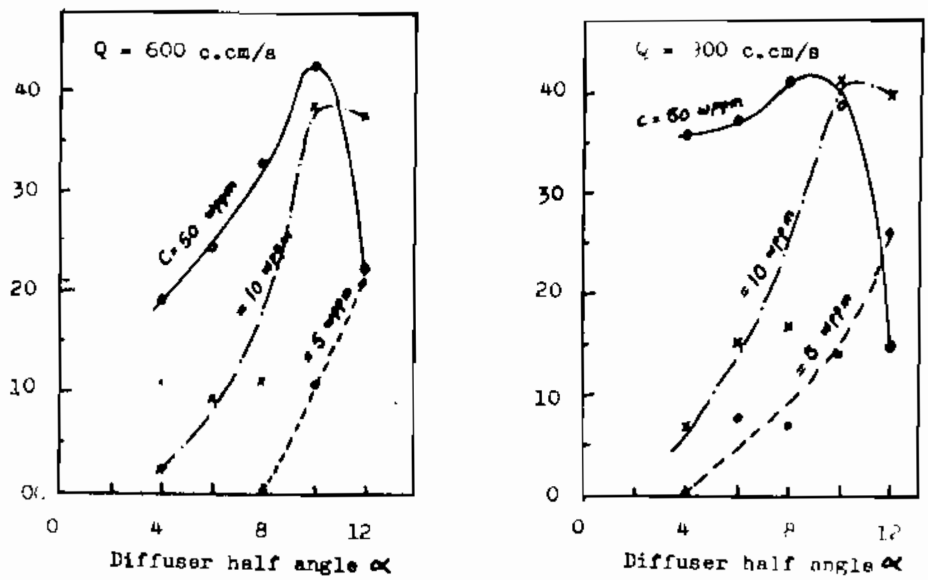


Figure (12)

Effect of diffuser half angle α upon the increase in the diffuser pressure recovery due to polyethylene oxide at constant flow rate; • 5 wppm, X 10 wppm, ● 50 wppm

REFERENCES

1. Fox, R. W. and Kline, S.J., "Flow Regime Data and Design Methods for Curved Subsonic Diffusers", ASME J. of Basic Engineering, 84, 303, (1962).

2. Reneau, L. R., Johnston,J. P., and Kline, S. J., "Performance and Design of Straight Two Dimentional Diffusers", Rept. PD-8, Thermosciences Div., M. E. Dept., Stanford Univ., Sept. (1964)

3. Ghose, S., and Kline, S. J., "The Computation of Optimum Pressure Recovery in Two Dimentional Diffusers", Trans. ASME, J. Fluids Engineering, 100, 419, (1978).

4. Hoyt, J. W., "Effect of Additives on Fluid Friction", ASME J. of Basic Engineering, 94, 258, (1972).

5. Sarpkaya, T., "On the Performance of Hydrofoils in Dilute Polymer Solutions", Proc. of the Int. Conf. on Drag Reduction, BHRA fluid Engineering, Cranfield, Paper E-1, (1974).

6. Fruman, D. M., "Lift Effects Associated with Drag Reducing Polymer Injection on Two Dimentional Hydrofoils", J. Ship Research, 20, 145, (1975).

7. Sarpkaya, T., Rainey, P.G., and Kell, R. E., "Flow of Dilute Polymer Solutions About Circular Cylinders", J. Fluid Mech., 57, 177, (1973).

8. Tomita, Y. and Mochimaru, Y., Colloques Internationux du C.N.R.S., Polymeres et Lubrification, No. 233, 305, (1975).

9. Kato, H., and Shibanuma, H., "Diverging and Converging Flow of Dilute Polymer Solutions; Pressure Distribution and Velocity Profiles", Bulletin of the JSME, 23,1140, (1980).

10. Shibanuma, H., and Kato, H., "Diverging and Converging Flow of Dilute Polymer Solutions; Universal Velocity Profiles of Turbulent Diverging Flow", Bulletin of the JSME, 23, 1148, (1980).

11. Rabie, L. H., "Effect of Drag Reducing Additives Upon the Development and Separation of Turbulent Boundary Layer with Adverse Pressure Gradients", ASME Symposium on Laminar/ Turbulent Boundary Layers Control, Modification and Marine Applications, ETCE conference, New Orleans, Feb. 13 - 17, (1984).

12. El-Haroun, A. A., " The Effect of Drag Reducing Additives Upon the Flow in Nozzels and Diffusers", M.Sc. Thesis, Menofia University, EGYPT, (1983)

13. Rabie, L. H., "Drag Reduction in Turbulent Shear Flow Due to Injected Polymer Solutions", Ph.D. Thesis, Edinburgh University, U. K., (1978).