MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

NON-NEWTONIAN FLUIDS FLOW THROUGH DIFFUSERS

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ABSTRACT

This paper presents an experimental study of the characteristics of Non-Newtonian fluids flow thorugh different diffuser geometries. The main geometrical studies were ; the diffuser expansion angle and the diffuser length. The overall area ratio for all diffusers tested was kept constant during the experiments. A capillary tube viscometer was used for measuring the rheological properties of the Non-Newtonian C.M.C. solutions. These properties are; the flow behaviour index and the consistency coefficient. The effect of these rheological properties on the static pressure rise coefficient, for different values of the diffuser inlet Reynolds number, was investigated. The results indicate that the concentration of the polymer solution, the flow Reynolds number, and the diffuser geometry have an effect on the diffuser performance.

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1. INTRODUCTION

The study of Non-Newtonian fluid flow through pipes with variable cross-section is of paramount importance in numerous engineering applications. Especially those fluids which are handled on a large scale in many industries such as; petroleum; paints, paper and polymer conversion.

The behaviour of Non-Newtonian fluid flow through pipes with constant cross-section has previously been studied by [1,2,3]. Experimental studies [4] have been made for determining the discharge coefficient of orifice Non-Newtonian flow meter mounted in a straight circular pipe. Astarita and Peluso [5] measured excess pressure drops for laminar flow of Non-Newtonian liquids, both weakly and highly elastic. Their results show that, the dimensionless pressure drop is inversely proportional to the Reynolds number, the constant of proportionality being a function of the flow index. Kato and Shibanuma [6] made an expeimental study on diverging and converging flow of dilute polymer solutions. They used polyethylene oxide (PEO-18) and polyacrylamide (AP-30) in water as polymer solutions. The main objective of their experiments was to investigate the drag reduction phenomenon in three tapered tubes. They found that in a converging flow, a remarkable drag reduction such as a pipe flow is not recognized. In a diverging flows they found also that with an increase in the concentration to 100 ppm pressure recovery becomes smaller than water flow alone. The effect of drag reducing additives upon the flowwith pressure gradient (positive and negative) has been studied by El-haroun [7] .

From the above literature review, it is clear that the behaviour of Non-Newtonian fluid flow through diffusers needs further analysis. The main object of the present investigation is to determine the effect of polymer concentration, the flow Reynolds number and the diffuser gecmetry on the behaviour of Non-Newtonian fluids flow through difrusers.

NOMENCLATURE

C_p: Static pressure loss coefficient ($\Delta P / \rho_1 V_1^2$)
d : Diffuser diameter.
K : Consistency coefficient.
L : Diffuser length
n : Flow behaviour index
Q : Volume flow rate
R_e : Reynolds number
V : Fluid velocity
Δh: Pressure head difference between the inlet and outlet cross-sections of the diffuser.
ΔP: Pressure difference between the inlet and outlet cross-sections of the diffuser.
θ : Half angle of diffuser
ρ : Fluid density.

SUBSCRIPTS

1 : Conditions at diffuser inlet.
2 : Conditions at diffuser outlet.

2. APPARATUS AND MEASURING TECHNIQUES

A schematic diagram of the test rig is shown in Fig. (1).The test fluid

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flows from the upper main tank (1), (1x1x1m). to the overflow tank (2), (0.5 x 0.3 x 0.4 m) which is used to ensure a constant head allover the expeiments. The test fluid flows from the overflow tank (2), through the test section, to the collecting tank (5), (1.5 x 1.5 x 0.5 m). The flow rate is changed by using the control valve after the test section. A centrifugal pump (6) is used for lifting the testing fluid to the upper tank.

2.1 Test Section:

Five circular diffusers, Fig. (2), are used as a test section. The detailed dimensions of these diffusers are indicated in this figure.

The pressure difference between inlet and outlet cross sections of diffusers was measured, using U tube manometer (4); Fig. (1), at different flow rates and for different values of C.M.C. concentrations.

2.2 Measurement of Rheclogical Properties of The Non-Newtonian Fluid:

To measure the rheological properties (consistency coefficient "K" and the flow index "n") of the carboxymethyl cellulose (C.M.C) solution, a capillary tube viscometer was used.

3. RESULTS AND DISCUSSION

The working fluids used in the experimental work were water as the Newtonian fluid and different concentrations of carboxy-methyl-cellulose (C.M.C) solutions (10000, 20000, 30000 and 50000 P.P.m) as the dilatant Non-Newtonian fluids. Degradation of polymer solutions and time effects were not determined as effective parameters due to high stability of the polymer solutions.

3.1 Effect of Flow Behaviour Index "n"

Figs (3 and 4) show a representative selection of the measurements of the pressure difference between inlet and outlet cross-sections at different flow rates. The measurements were taken for water (n=1) and for different concentrations of C.M.C. (different values of n). The effect of flow behaviour index "n" on the root of pressure difference head is shown in these figures. From these figures it can be seen that the total pressure difference increases with the increase of polymer concentration (increase the value of n) and volume flow rate. This means that the diffuser losses decreases when the polymer concentration increases. From Fig. (3) it is clear that after n= 1.104 (concentration 20 000 p.p.m.) , there is a reduction of diffuser pressure defference. This is due to an increase in the fluid viscosity and consequenly the risistance to the flow increases. Shibanuma and Kato [6] found that the polymer reduces the skin friction and in the same time enhances the separation and makes it occur at early cross-section of the diffuser. As the separation increases the diffuser losses are increased. Fig. (5) shows a result for the diffuser No.1, which has a big angle and small length as it is compared with the other diffusers. For this reason, it is clear from this figure that, there is a reduction in the pressure difference between the inlet and outlet cross-sections. This is due to the separation which takes place early ($\theta = 12^\circ$ in this case). These results are confirmed by El-haroun [7], who studied the effect of drag reducing additives on the flow with positive or negative pressure gradient.

3.2 Effect of Volume Flow Rate

The effect of changing the volume flow rate (Raynolds number) on the pressure difference between the inlet and outlet cross-sections of the tested diffusers is shown in Figs (3-7). Higher values of pressure difference are obtained with higher flow rate which was expected due to the increase of the fluid velocity. Also it is clear from these figures that the value of $\sqrt{\Delta h}$ or C_p increases with the increase of volume flow rate.

3.3 Effect of Diffuser Geometry

The main geometrical parameters tested here were; the diffuser expansion angle and the diffuser length, see Fig. (2). The overall area ratio is equal to 2 for all diffusers. Figs (6 and 7) illustrate a selection of the experimental results showing the variation of static pressure rise coefficient Cp with the diffuser inlet flow Reynolds number (Re_1). The values of Reynolds number, for the case of Non-Newtonian flow, were calculated according to the following relation;

$$Re_1 = \frac{\rho_1 \cdot V_1 \cdot d_1}{K(8.V_1/d_1)^{n-1}}$$

The measurements were taken for $n = 1.104$ and $n = 1.303$. It is clear that the static pressure rise coefficient increases as the inlet Reynolds number increases. This is due to the increase of volume flow rate. The curves have the same trend for all tested diffusers. From these figures and with the help of Fig. (2), it is noticed for each value of Q and n that the pressure rise coefficient decreases as the diffuser expansion angle increases. This is due to the separation which takes place at early cross-section of the diffuser, as was discussed in subsection 3.1. In general , from these figures it can be seen that, the poor performance of the 12° half angle diffuser (diffuser No.1) is attributed to the fact that the diffuser separates badly at this range of Reynolds number. For all the configurations tested, the 4° half angle diffuser (diffuser No.5) has the greatest pressure rise coefficient, whilst the 12° half angle diffuser (diffuser No.1) has the lowest pressure rise coefficient.

4. CONCLUSIONS

The Non-Newtonian fluid flow through diffuser with different geometries has been studied experimentally, for fluid flow Reynolds number range from 5000 to 21000 and polymer concentration from 10000 to 50000 p.p.m. The major conclusions and the results of this study are summarized below:

1. For diffusers having an expansion half angle less than or equal to 10°, the pressure difference between the inlet and outlet cross-sections of the diffuser increases with the increase of polymer concentration. On the other hand for 12° half angle diffuser, this pressure difference was found to decrease with the increase of polymer concentration.

2. Higher values of total pressure rise through diffusers are obtained, for all values of polymer concentrations, with higher values of volume flow rate.

3. The static pressure rise coefficient increases as the Reynolds number increases. Also for all values of Q and n tested, the static pressure

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rise coefficient decreases as the diffuser expansion angle increases. For all the configurations tested, the 4^{o} half angle diffuser has the greatest pressure rise coefficient, whilst the 12^{o} half angle diffuser has the lowest pressure rise coefficient.

4. For the Reynolds number range ($12000 \leq Re_1 \leq 21000$) considered, the diffuser performance deteriorates with an increase in the inlet flow Reynolds number. In Fig. (6), for example, taking the case of n= 1.104, k = 0.0084 and area ratio 2, by varying Re_1 from 12000 to 21000, the following variations in Cp occur :

(a) For the 4^{o} half angle diffuser, Cp increases from 0.65 to 0.68.

(b) For the 6^{o} half angle diffuser, Cp increases from 0.6 to 0.65.

(c) For the 8^{o} half angle diffuser, Cp increases from 0.56 to 0.6.

(d) For the 10^{o} half angle diffuser, Cp increases from 0.315 to 0.34.

(e) For the 12^{o} half angle diffuser, Cp increases from 0.23 to 0.26 .

It should be mentioned that there is no unique relation-ship between the Reynolds number and $Cp = \Delta P/ \rho_1 V_1^2)$ and those values given above are merely for illustration . This conclusion has been previously achieved by Livesey, et.al [8] , for air flow through conical diffusers. The present investigation proves this conclusion in the case of incompressible Non-Newtonian fluids flow through diffusers.

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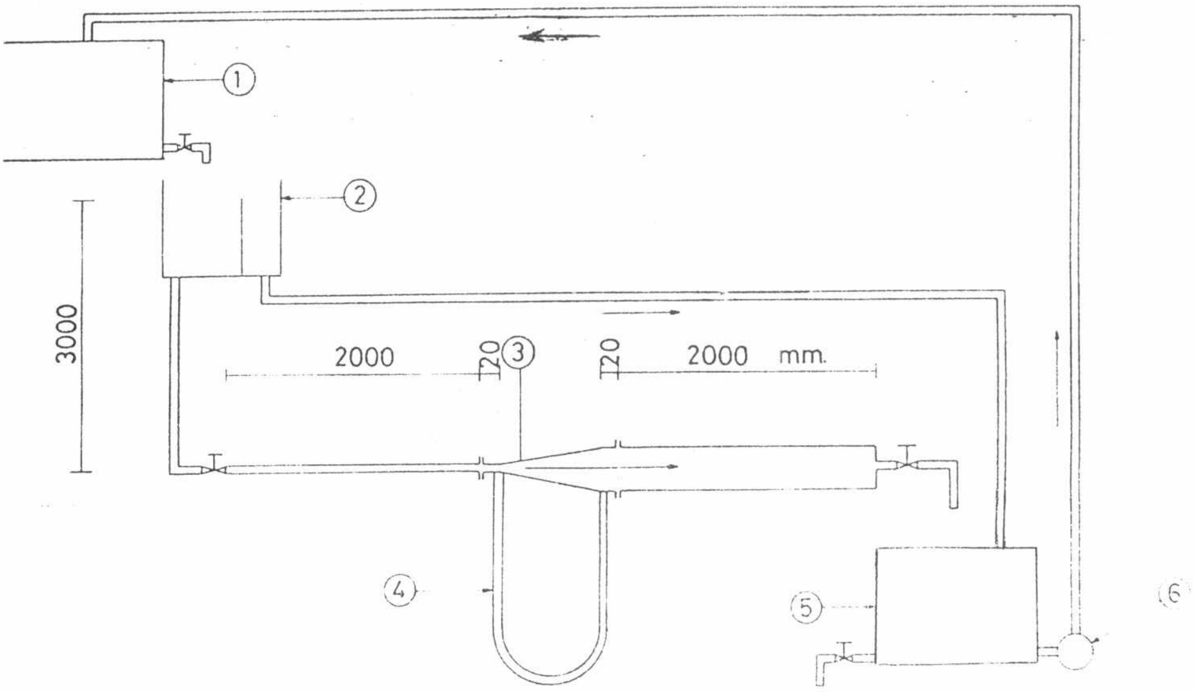
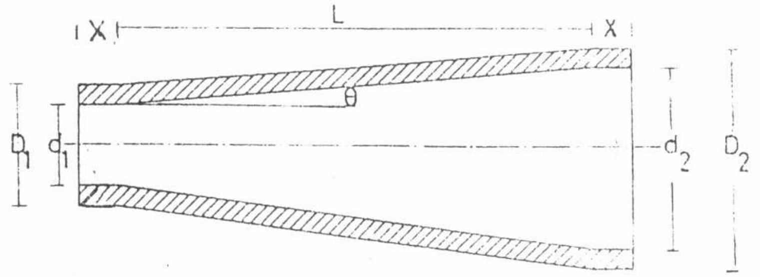


FIG(1) A SCHEMATIC DIAGRAM OF THE TEST RIG.



DIFFUSER NO.	L_1 mm.	D_1 mm.	d_1 mm.	D_2 mm.	d_2 mm.	θ	X min
1	63.5	43	27	70	54	12°	20
2	76.5	43	27	70	54	10°	20
3	96	43	27	70	54	8°	20
4	128	43	27	70	54	6°	20
5	193	43	27	70	54	4°	20

FIG (2) DIFFUSER GEOMETRY

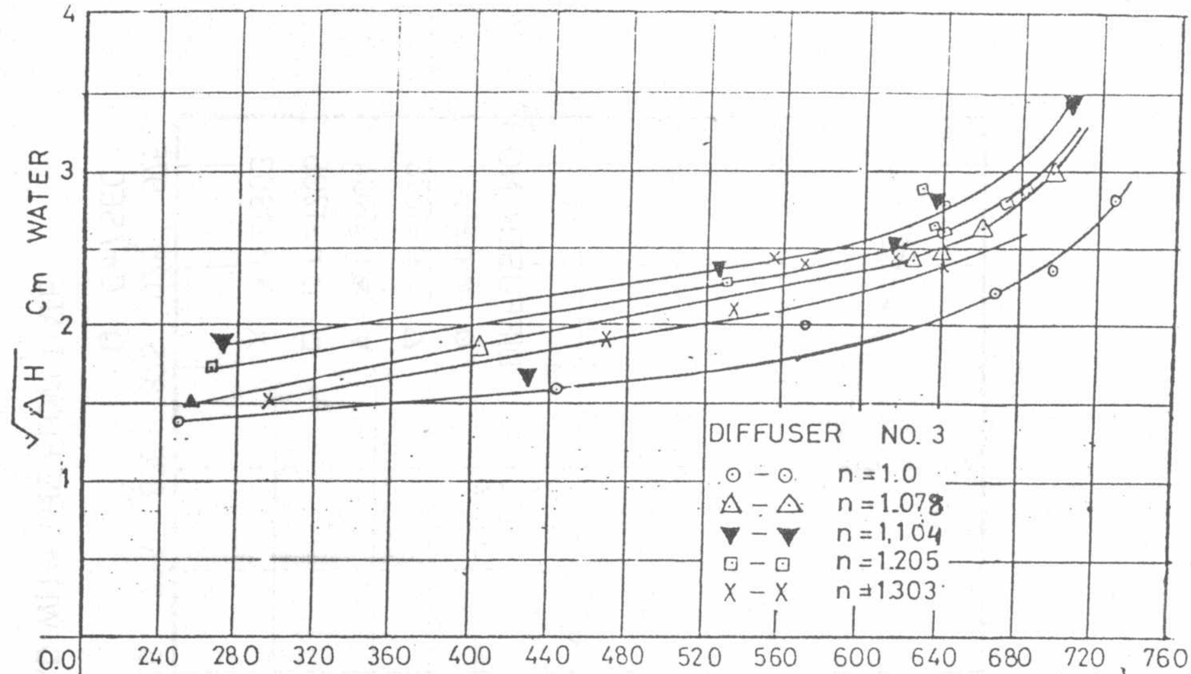


FIG.(3) VARIATION OF TOTAL PRESS. HEAD WITH THE FLOW RATE Q Cm³/Sec

(EFFECT OF FLOW BEHAVIOUR INDEX)

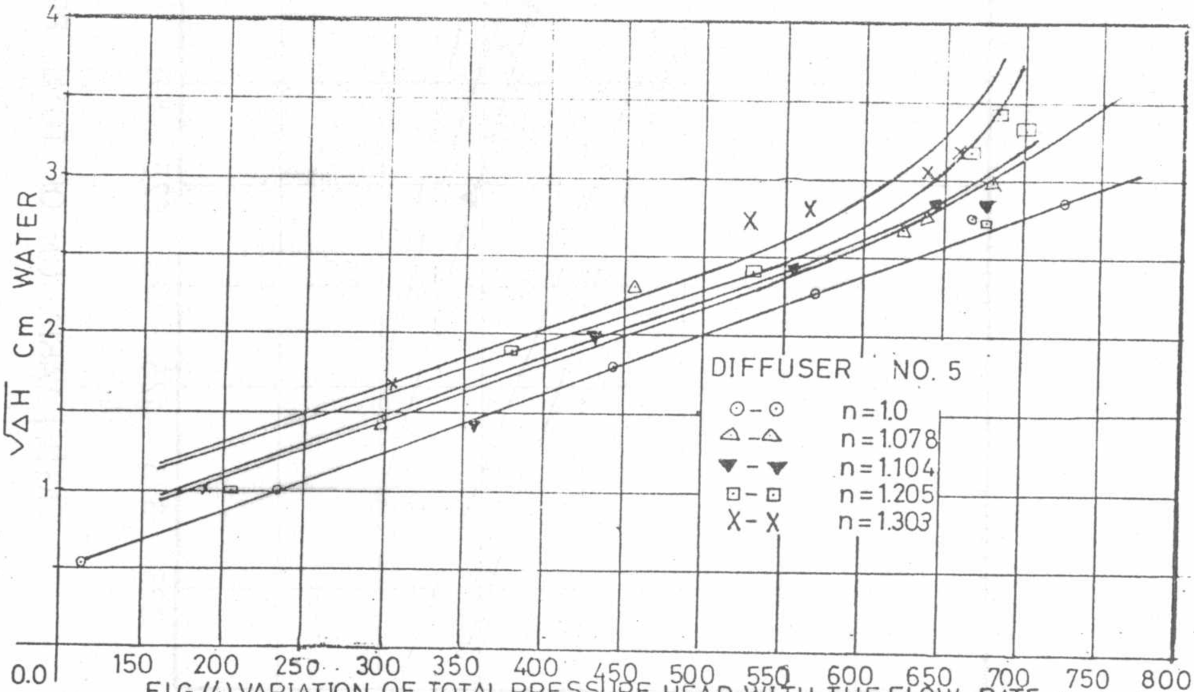
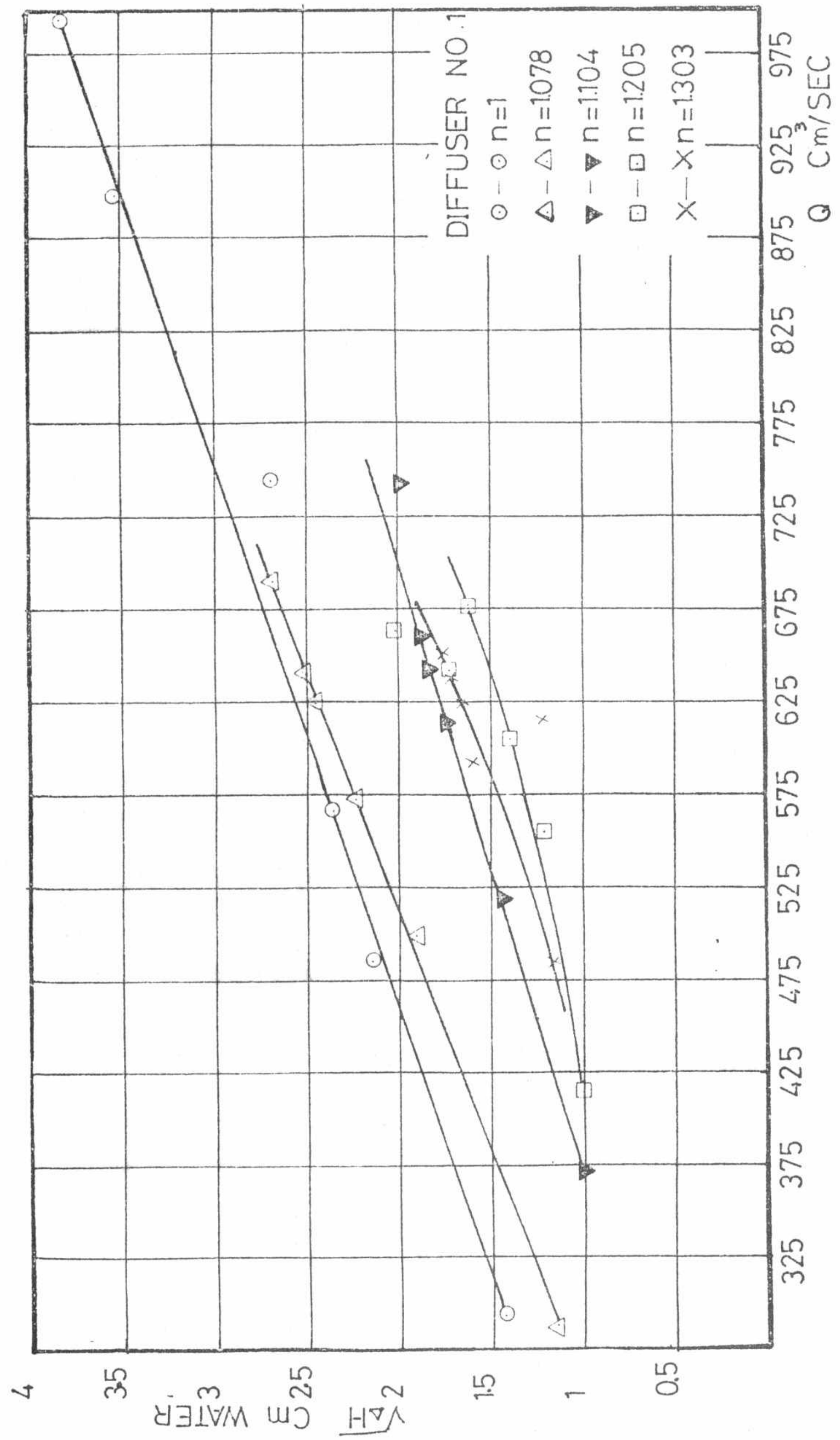


FIG.(4) VARIATION OF TOTAL PRESSURE HEAD WITH THE FLOW RATE Q Cm³/Sec

(EFFECT OF FLOW BEHAVIOUR INDEX)



FIG(5) VARIATION OF TOTAL PRESSURE HEAD WITH THE FLOW RATE

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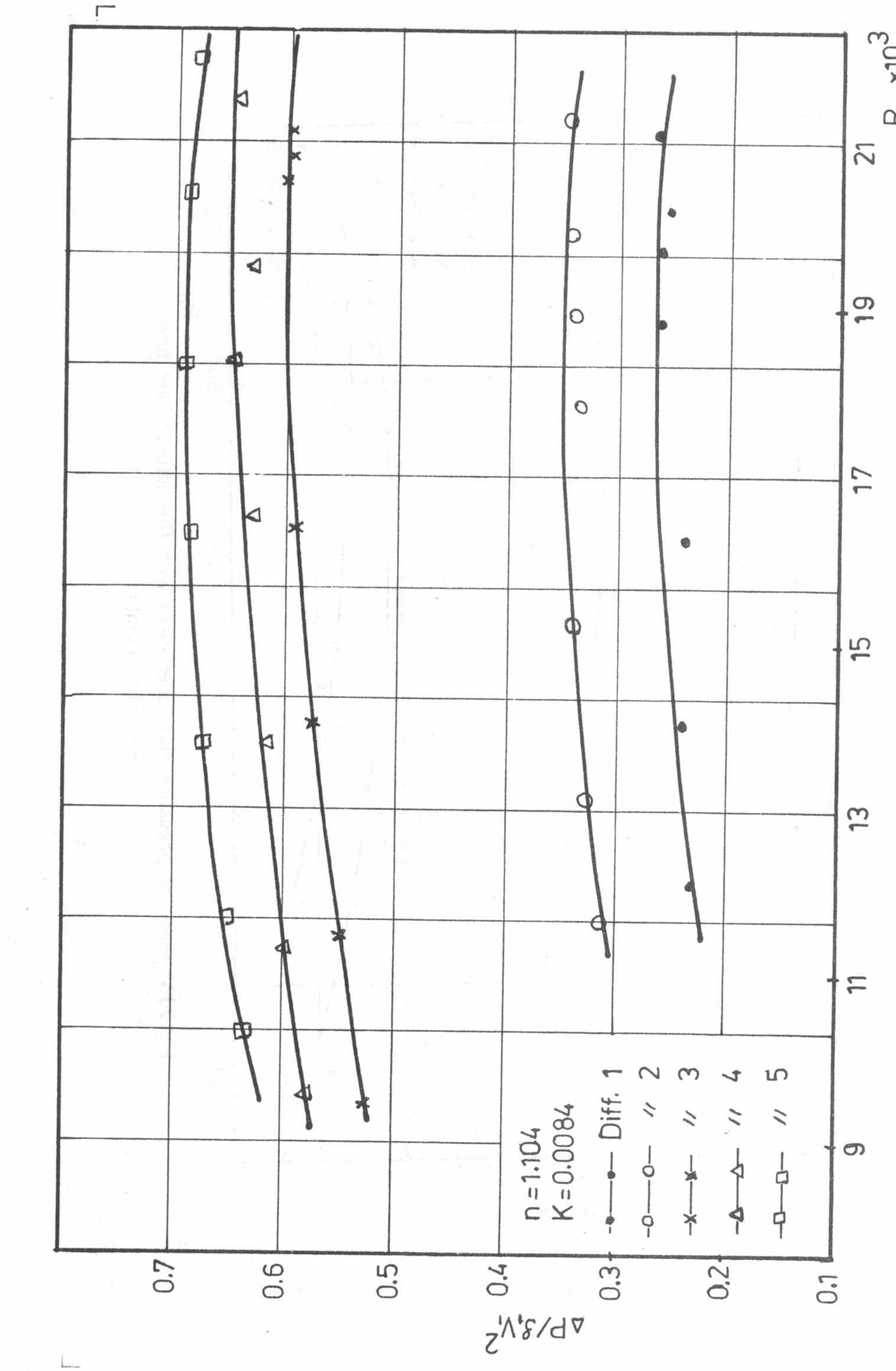

Fig(6) Variation of pressure rise coefficient with the diffuser inlet flow Reynolds number

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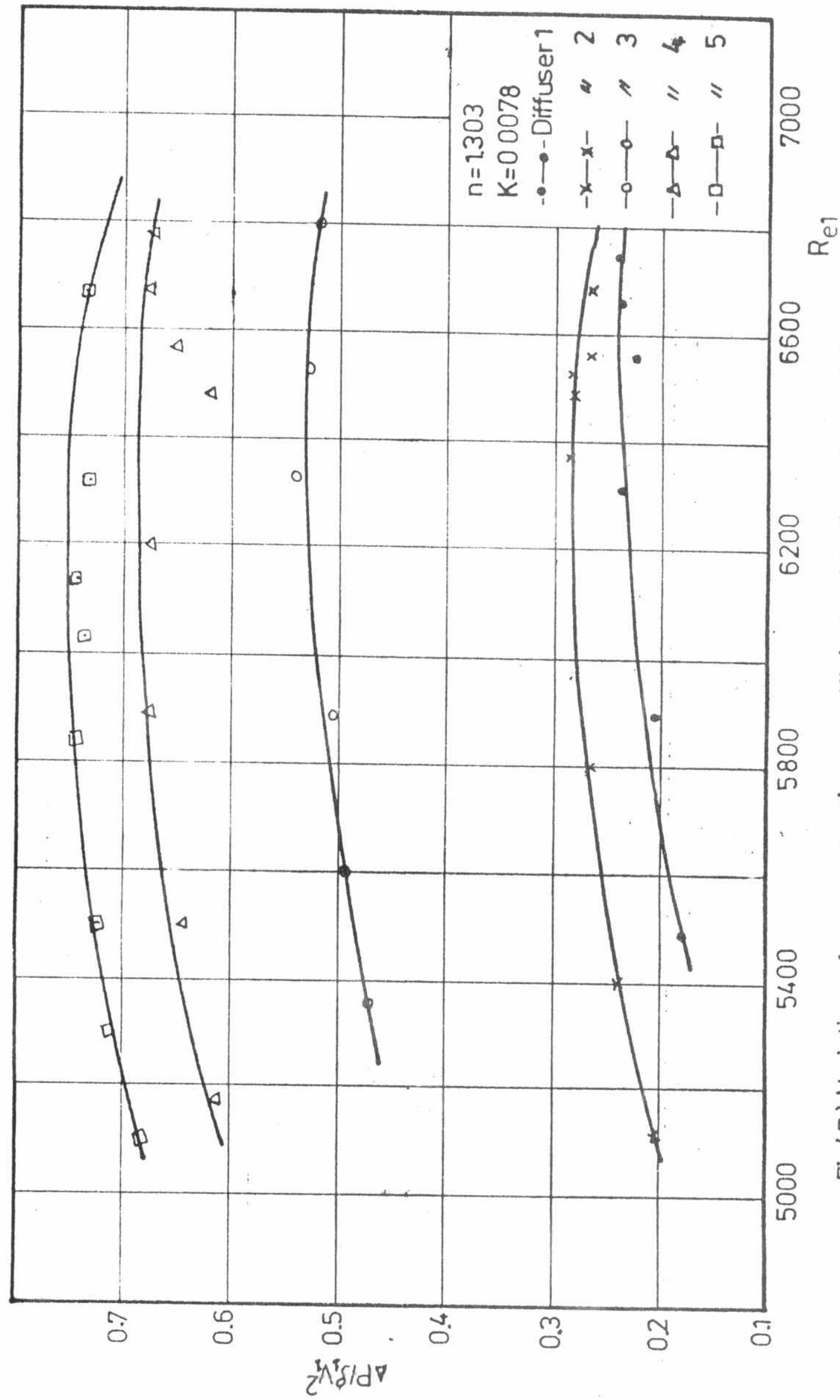

Fig(7) Variation of pressure rise coefficient with the diffuser inlet flow Reynolds number