STUDIES ON DOWNWARD SWIRLING FLOW IN VERTICAL PIPES

A DISSERTATION
submitted in partial fulfilment of the
requirements for the award of the Degree
of
MASTER OF ENGINEERING
in
CHEMICAL ENGINEERING
(Equipment & Plant Design)

By

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C E R T I F I C A T E

Certified that the thesis entitled "STUDIES ON DOWNWARD SWIRLING FLOW IN VERTICAL PIPES" which is being submitted by Sri Yogesh Chandra in partial fulfilment of the requirements for the award of the Degree of MASTER OF ENGINEERING in CHEMICAL ENGINEERING (Equipment and Plant Design) of University of Roorkee is a record of candidate's own work carried out by him under the supervision and guidance of the undersigned. The matter embodied in this thesis has not been submitted for the award of any other degree or diploma.

This is further certified that he has worked for a period of seven months for preparing this thesis.

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ABSTRACT

Studies on the downward swirling flow in vertical tubes with tangential liquid entries have been conducted.

In swirling flow, the pressure drop across the entry head and the tube through which the liquid is flowing, is the summation of the friction loss due to sudden expansion of cross section of the pipe, the radial pressure drop at the entry head, the pressure drop due to the swirling flow inside the tube and the pressure drop due to friction in the entry pipes. The various parameters involved are not easily amenable for measurement and in view of this difficulty, using dimensional analysis, following correlation has been proposed to predict the pressure drop.

$$(Eu)=2.05\times10^{3}(Re)^{-0.41}(Fr)^{0.01}(D_i/D_t)^{-0.03}(L/D_t)^{-0.85}$$

The computed values of the pressure drop from theoretical considerations have been found to lie within $\pm$ 30% deviation of the experimental values while the values of pressure drop computed from correlation lie within $\pm$ 15% of the experimental values.

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Yogesh Chandra

C O N T E N T S

Contents (Contd..)

NOMENCLATURE

D_i	Inlet nozzle diameter,	cm
D_t	Tube diameter ,	cm
f	Fanning friction factor,	
g	Acceleration due to gravity,	cm/sec^2
g_c	Conversion factor,	$\frac{gm}{gmf}\ \frac{cm}{sec^2}$
L	Air core length ,	cm
ΔP	Total pressure drop,	kg/cm^2
ΔP_1	Pressure drop due to sudden expansion of cross section ;	Kg/cm^2
ΔP_2	Radial pressure drop at the entry head.,	kg/cm^2
ΔP_3	Pressure drop due to friction in swirl flow	kg/cm^2
ΔP_4	Pressure drop due to friction in the tangential entry pipe,	kg/cm^2
r	Radius of air core ,	cm
R	Radius of swirls ,	cm
v_1	Linear velocity at smaller cross section,	cm/sec
v_2	Linear velocity at t larger cross section,	cm/sec
V	Average velocity ,	cm/sec
Eu	Euler number	
Re	Reynolds mumber	
Fr	Froude number	
ρ	Liquid density ,	gm/cm^3
Ω	Circulation constant	
μ	Liquid viscosity ,	gm/cm.sec.

Chapter I

INTRODUCTION

Swirling motion in a conduit increases the point velocity of liquid as compared to the linear flow for the same throughput. The swirl in a flowing stream can be achieved by

(i) mechanical rotation of the pipe through which the liquid is flowing,

(ii) putting twisted tapes inside the pipes through which the liquid is flowing,

(iii) forcing the liquid into the stationary pipe by injecting it through tangential entry system.

The relative merits and demerits of various methods of producing swirling flow have been discussed by Sharma et al (14). It has been pointed out that it is most economical to produce swirling flow in long tubes by tangential entry technique.

In this system the liquid after entering through a tangential inlet takes a swirling motion and as it meets the liquid from the second tangential inlet it is pushed forward towards the centre of the tube. Thus a uniform swirling motion is established. The rotary gas burner flow, trailing vortices from air craft wings, gaseous nuclear rocket swirling flows and flows with prominent circumferential wall effects are some of the examples where the studies have been made. The phenomenon of reversing axial flow in swirling motion through long tubes and the stability of swirling flows have been the subject of interest. A large number of papers have appeared concerning the studies of flow characteristics and heat transfer in horizontal pipes. Quite a few papers have been reported on the studies of vertical pipes using upward flows. However, a little information (4) in the field of downward swirling flow in vertical pipes is available. The present work is intended to study the same with an aim for using the information in future for design of chemical Engineering Equipments.

Chapter II

LITERATURE REVIEW

A large number of experimental and analytical studies on different types of swirling flows have been conducted. These studies may be broadly classified (12) as

(1) Unconfined swirling flows which include swirling within boundaries but with negligible wall effect. Flows falling into this category include rotary gas burner flows, trailing vortices from aircraft wings, and swirling compressible nozzle flows where boundary layer effects are negligible.

(2) Swirling flows in short, large diameter chambers where end-wall effects interact with the swirling flow to produce strong secondary flow effect. This includes studies of the gaseous nuclear rocket swirling flow.

(3) Swirling flows in large L/D tubes where circumferential wall effects interact strongly with the vortex flow.

Considerable studies have been conducted in swirling flows through atomizers (1) which are used in drying and combustion.

Work has been conducted on compressible flows in tubes (6,7) to some extent.

The swirls inside the long tubes may be produced by using either of the following:

(i) Rotating the tube through which the fluid is to flow.

(ii) Using guided vanes in the tubes through which the fluid will be injected.

(iii) Inserting twisted tape in the tube.

(iv) Injecting the fluid into the tube through tangential entries.

2.1 Talbot (2) investigated the aqueous laminar swirling flow by perturbation analysis but the swirl being of insufficient strength the phenomenon of flow reversal could not be observed. However a dimpling of axial velocity at the centre of the tube was predicted.

2.2 Binnie and Teare (3) carried out investigations in upward flow and observed that vertical velocity component would reverse itself in the upper section of the nozzle.

2.3 Nuttal (4) investigated in right circular $2\frac{7}{8}$ inch. I.D., 56 inch long perspex tube. This was surmounted by a cylindrical overhead tank. The swirling flow was produced by putting ring guide vanes and the discharge was controlled by throttling devices at the bottom of the tube. His observations are

(a) at low flow rates the centre axial velocity was less than the expected maximum velocity.

(b) as average axial velocity was increased, the centre-line velocity decreased to a point where it reversed the direction of flow,

(c) as the average axial velocity was further increased, the centre-line velocity started increasing upto a point where the velocity again reversed itself. No quantitative data were taken in this work.

2.4 Binnie (5) studied the flow characteristics when swirling water was fed through a long transparent horizontal tube made of 2.0 inch I.D. perspex. The water was passed under gravity through a number of holes. The flow rate was controlled by varying the heights of constant level tank. The same observations as that of Nuttal were obtained and the various regions a,b,c were termed as Regimes I, II and III respectively. Binnie however developed the swirling motion by rotating the cylinder wall. It was revealed that the surface of the core may be continuously disturbed by progressive waves. The motion is analogus to that of waves moving under gravity and surface tension on the surface of a canal. The cross section of the core remains circular and sometimes it gives the shape of a multithreaded screw.

2.5 Place et al (8) employed the tracer technique to study the behaviour of air flowing through a spray drier. They observed a region of downward vertical velocity located between an upward central core and an upward velocity region. For these investigations a transparent model was used and water was injected through various ports to produce a swirling flow.

2.6 Kreith and Sonju (9) studied the decay of a liquid turbulent swirl which was induced by a twisted metallic tape along the centre line of a 1.0 inch tube, The turbulent swirls were found to decay about 10-20 per cent of its initial intensity over a distance of about 50 pipe diameters. The results were correlated with a linearised model. The swirl however were not sufficiently strong and no flow reversal could be observed.

2.7 Smithberg and Landis (10) reported experimental results of velocity and pressure measurements in the exit plane of the fully developed turbulent swirl flow of air induced by a twisted tape having a width equal to the inside diameter of the pipe. The flow fields were characterised by two main regions:

(1) a helicoidal core flow modified by secondary circulation effects. and

(2) a twisting boundary layer flow.

They explained that the twists were responsible for the double vortex flow patterns which lead to high velocity 'islands' of the contour map. The vortex flow will continuously mix the boundary layer with the core flow resulting in increased frictional losses.

2.8 Bresan et al (11) observed that the presence of vortex motion in a vertical cylinder in which the liquid was passed upwards could result in three types of velocity profiles, which are functions of three factors :

(i) the tangential velocity
(ii) the manner of decay of the tangential velocity
(iii) the wall pressure drop.

They proposed a fourth factor of the boundary layer growth. Studies were conducted for swirling incompressible flow of water in a perspex tube of diameters 2.0 inch and 2.5 inch. I.D. and the test section was made 100 inch long. The swirling motion was produced by tangential entry of the water into the test section. The entry section consisted of two tangential inlet pipes placed diametrically opposite to each other. Water was pumped upwards through the vertical tube. The studies were conducted for Reynolds number ranging from 5,000 to 25,000 based on the diameters of the tubes and the average vertical velocity in the tube. The following conclusions were made -

i. The swirl which was produced by injecting water at constant rate and tangentially into the cylinder through two holes situated diametrically opposite to each other was quite steady and symmetrical to the axis of the cylinder. However, when injection of water restricted through one inlet only, a spiral core was produced and the axial symmetry subsided.

ii. The radial velocities in the cylinder were found to be lower than the tangential and axial velocities except in the regions near the inlet and outlet of the cylinder.

iii. The mean tangential velocity, averaged across a diameter steadily decreased downstream.

iv. The vertical axial velocity at low flow rates, remained upwards throughout the cylinder.

v. At higher flow rates, flow reversal was observed such that the water flowed downwards at the centre, reversed direction at the inlet and near the walls the flow was upwards.

2.9 King et al (12) investigated experimentally the phenomenon of reversing axial flow in swirling incompressible flow through a tube of 2.0 inch I.D., 10 feet, long plexiglass. The swirl was induced by injecting the fluid stream through two 1/2 inch diameter tangential inlets placed perpendicular to the tube. To ensure axis symmetry, flow rates from both of the inlets, were kept equal. Reynolds number ranging from 10,000 to 25,000 based on the tube diameter and the axial velocity were maintained. The following conclusions were made :

i. Swirl decay rate was characterised by a plot of weighted tangential velocity/inlet velocity versus distance along the test section from the inlet.

ii. Dye injection was used to identify the region of reverse axial flow near the centre of the tube.

2.10 Shrivastava et al (13) carried out the pressure studies in two phase flow using swirl generator metallic strips. They studied the effect of twisted tape and liquid phase viscosity in the two phase flow in horizontal pipes. Water and Glycerine-water mixtures were employed.

2.11 Sharma et al (14) carried out studies on the stability of swirling flow in long horizontal tubes and have shown by photographic studies the onset and complete development of air core in swirling flow in long tubes. They observed that induced and forced airflow in the axis of swirling flow in long tubes improves the length , diameter and uniformity of the air core.

2.12 Sharma (15) has carried out investigations in swirling flow in horizontal tubes by taking different diameters ranging from 18 mm to 56 mm perspex tubes. He has described the technique of breaking the flow reversal observed in swirling flow by previous workers (1,3,4,5,8,11,12,14) . Further, he has carried out the studies on the effect of various parameters such as tube diameter, tangential entry diameters, flow rates and viscosity on the stability of swirling flow in horizontal tubes. Correlation for pressure drop , air core length and diameter and flow rates has been proposed. His studies on the decay of swirling flow are in agreement with the observations made by other workers (11,12).

2.13 The introduction of spiral promoters was shown to increase the convective heat transfer coefficients to a higher value than is possible with an empty tube for the same pressure drop. On the basis of the assumption that the flow imparted to the fluid stream is of spiral pattern causing a thorough mixing by eddy streams some correlations were presented for single phase flows (16).

Investigations were carried out on the studies of heat transfer characteristics of fluids in rotating cylinders and correlations were proposed (16 -20)

2.14 Sharma et al (21) have made observations on the overall heat transfer coefficient in horizontal double pipe heat exchanger using water and steam as the heating medium and have reported an increase in the overall heat transfer coefficient substantially at a nominal power expense in creating the swirling flow.

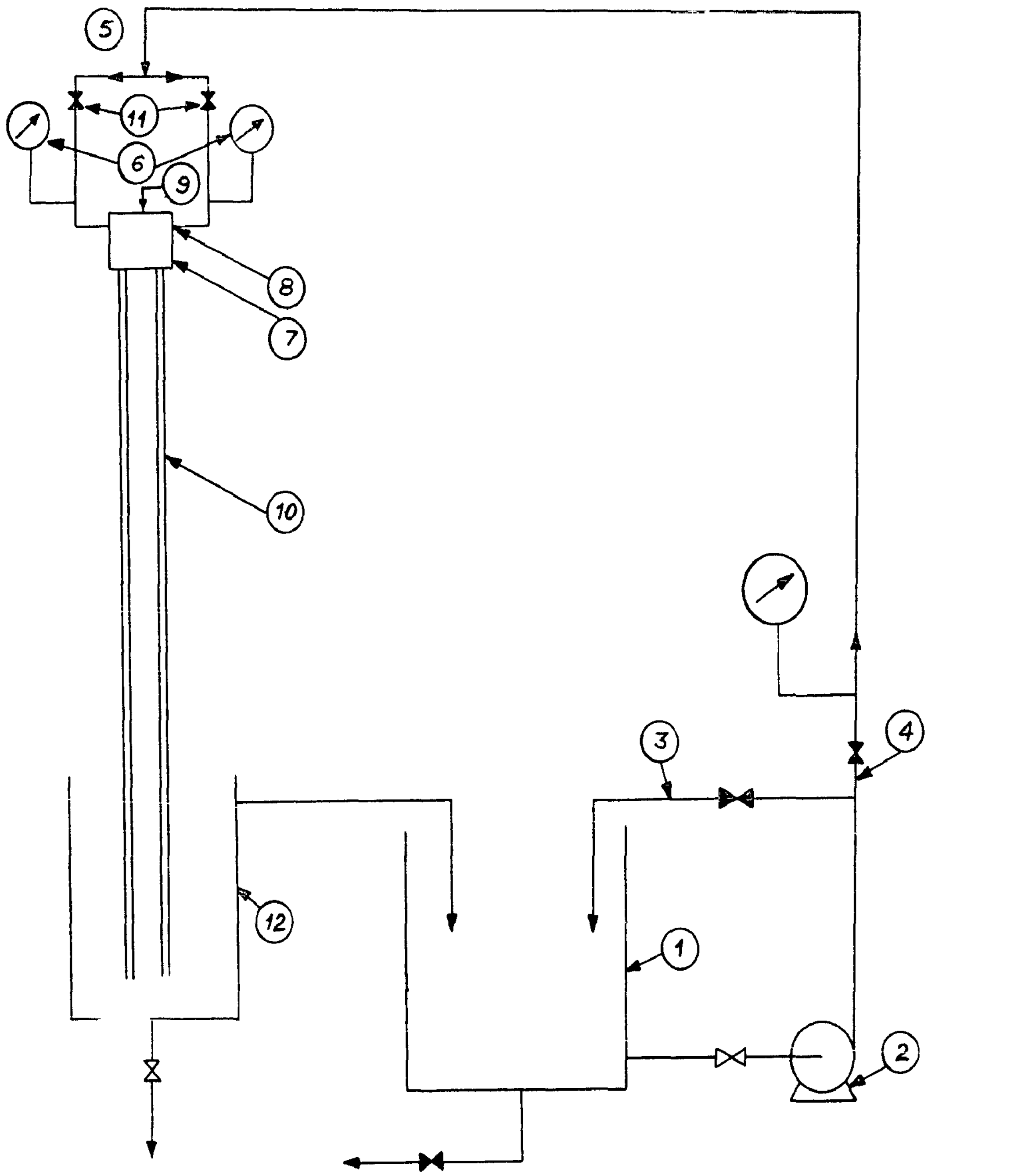
Chapter III

EXPERIMENTAL SET UP AND PROCEDURE

3.1 EXPERIMENTAL SET UP

Experimental set up used for this study has been shown schematically in figure 3.01 and also presented in plate 3.01.

It consists of a feed tank (1) which is connected to the inlet of rubber lined centrifugal pump (2). The outlet of the pump is divided into two parts. One called bypass line (3) goes to tank (1) itself and the other line called feed line (4) is connected to the two-pronged inlet line(5). This is then connected to the entry head (7) fixed on a support stand. The entry head consists of two tangential inlets (8) placed symmetrically along the diameter of the entry head and one axial inlet for air (9). Just before the entry head, two inlet pressure gauges (6) are provided in the feed line to record inlet pressure. The liquid is fed by the pump (2). The tubes (10) employed were of perspex (ranging from 18 to 56 mm I.D. and lengths 1300 mm). The one end of the tube is screwed in the entry head(7) The inlet pressure is controlled by two control valves (11) and also by the bypass valve (3). The liquid discharging from the tube (10) is taken in a collecting



1. FEED TANK 2. CENTRIFUGAL PUMP 3. BY PASS LINE
4. FEED LINE 5. TWO PRONGED INLET LINE 6. PRESSURE GAUGES
7. ENTRY HEAD 8. TANGENTIAL INLETS 9. AXIAL INLETS

FIG. 3·01 EXPERIMENTAL SET UP.

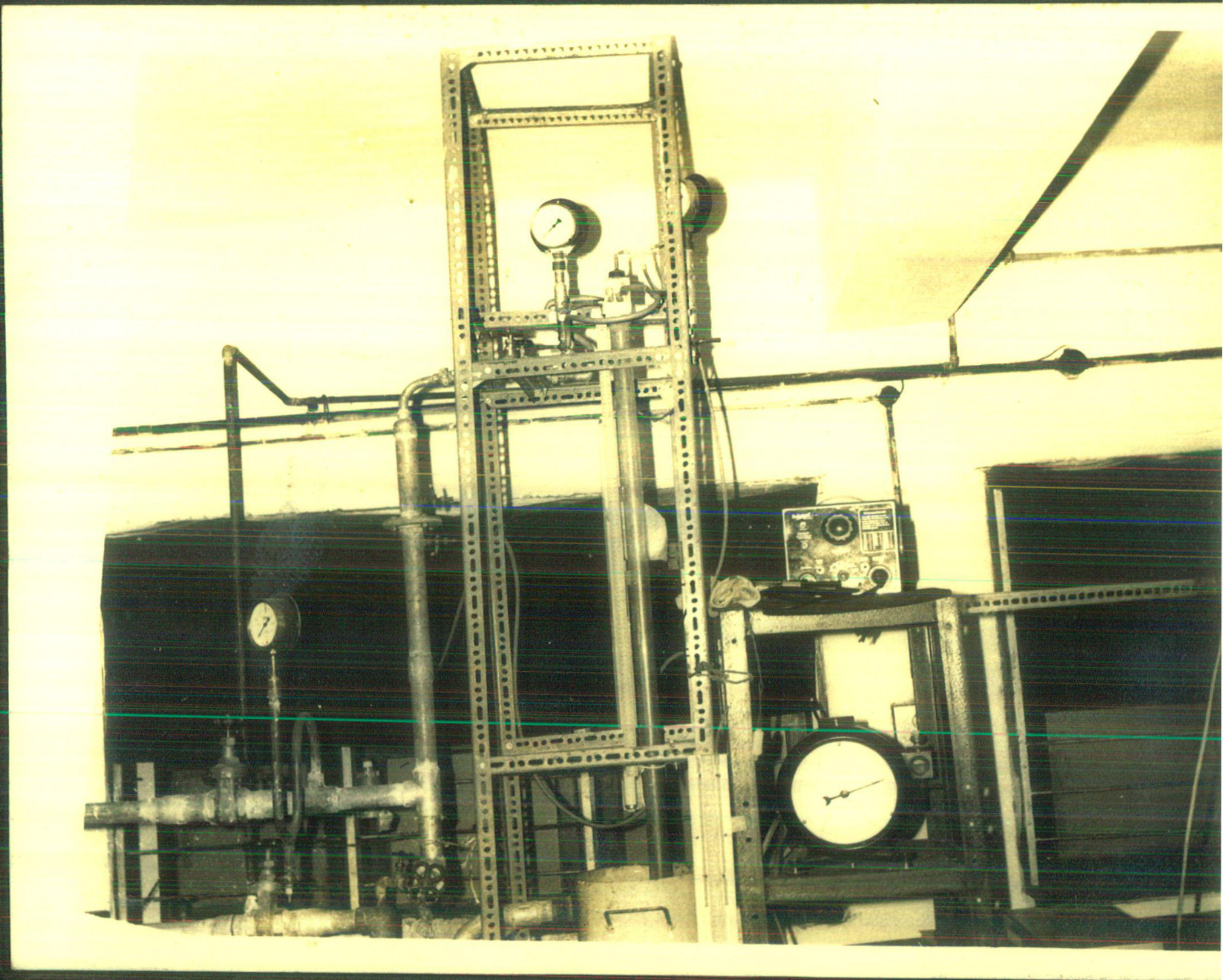


PLATE 3.01 EXPERIMENTAL SET-UP

tank (12). The lower end of the tube (10) is dipped in the liquid in this tank (12) and the overflow liquid is directed into the feedtank (1).

3.1.1. Specifications of Centrifugal Pump

Horse Power (H.P)	5.0
Maximum head developed	90 ft
Capacity	20 GPM
R.P.M.	2880

3.2 PROCEDURE

Stepwise procedure is as follows.

3.2.1 The liquid is taken in the feed tank. Keeping bypass line valve open, pump is started. Now the control valve in feed line is opened gradually. As soon as desired pressure is obtained, the control valves just before the tangential inlets are controlled to adjust the inlet pressure in the inlet pressure gauges.

3.2.2 The diameter of the air core formed is measured at different heights of the tube by adjusting the Cathetometer.

3.2.3 The flow rate of the liquid is then directly measured. The length of the liquid column built up in the tube is measured.

3.2.4 The R.P.M. of the swirling liquid is determined by using Infra- Red rays stroboscope.

3.2.5 The axial inlet to the tube is opened. The changes taking place are noted. Air is then forced from a compressor.

Chapter IV

THEORETICAL METHOD FOR COMPUTING PRESSURE DROP

The pressure measured with calibrated pressure gauges during the course of the investigations, represents the pressure drop across the entry head and the tube through which the liquid is flowing.

It may further be envisaged that the pressure drop will include :

i. The friction loss due to sudden expansion of cross section.

ii. Radial pressure drop at the entry head.

iii. Pressure drop due to friction in swirl flow.

iv. Pressure drop due to friction in the tangential entry pipes.

Total pressure drop observed experimentally will thus be equal to the sum of all the pressure drops as mentioned above.

$$\Delta P = (\Delta P_1 + \Delta P_2 + \Delta P_3 + \Delta P_4) \qquad (4.01)$$

The various pressure drops are as detailed below:

4.1 PRESSURE DROP DUE TO SUDDEN EXPANSION OF CROSS SECTION

If the cross section of the conduit is suddenly enlarged, the fluid stream separates from the wall and issues as a jet into the enlarged section. The jet then expands to fill the entire cross section of the larger conduit. The space between the expanding jet and the conduit wall is filled with fluid in vortex motion and considerable friction is generated within this space . If the velocities at two cross sections are known then,

$$\frac{\Delta P_1}{\rho} = \frac{(V_1 - V_2)^2}{2g_c} \qquad (4.02)$$

4.2 RADIAL PRESSURE DROP AT THE ENTRY HEAD

The radial pressure drop can be computed by

$$\frac{\Delta P_2}{\rho} = \frac{\Omega^2}{2\, g_c}\left[\frac{1}{r^2} - \frac{1}{R^2}\right] \qquad (4.03)$$

which may be derived using Navier Stoke's equation(25)

4.3 PRESSURE DROP DUE TO FRICTION IN SWIRL FLOW

$$\frac{\Delta P_3}{\rho} = \frac{4.\, f\, L.\, v^2}{2\, g_c\, D} \qquad (4.04)$$

Fanning friction factor 'f' may be computed from

$$f = 0.0791/ (Re)^{0.25} \quad \text{for} \quad 2.1 \times 10^3 < Re < 10^5 \qquad (4.05)$$

4.4 PRESSURE DROP DUE TO FRICTION IN THE TANGENTIAL ENTRY PIPES

Some pressure drop may be expected in the approach pipes to the entry head. To minimise this frictionloss, the lengths of the pipes leading from pressure gauges to the two tangential entries have been made very small (10 cm) . Though the pressure drop will be quite small , it may be computed using the equation (4.04).

Chapter V

O B S E R V A T I O N S

5.1 ANALYTICAL OBSERVATIONS

5.1.1 Flow Pattern

For a downward swirling flow in vertical pipes the introduction of a liquid tangentially into a cylinder leads to a complex flow phenomenon and the velocity profile is a function of three factors: the tangential velocity, the manner of decay of the tangential velocity and the wall pressure drop.

When the liquid enters through a tangential inlet, it takes a rotating motion and as it meets the liquid from the second tangential inlet, the liquid is pushed towards the centre of the tube. Thus, a swirling motion is established Figure 5.01. The liquid cavitates giving rise to a central air core. The swirling motion is of two types :

i. Forced vortex flow in which angular velocity is constant, and

ii. Free vortex motion in which the angular momentum that is the product of the tangential velocity component and radius at any point in the liquid is constant, i.e. V.R. = constant.

The forced vortex type flow could neither originate nor survive on its own and as such they are to be created artificially. In the free vortex motion it is apparent that as R approaches zero, V approaches infinity which is hydrodynamically impossible. However, the liquid gives rise to the air core well before this stage occurs.

5.1.2 Flow Reversal

The existence of a swirl near the end of the tube, leads to a large pressure differential across the tube cross section, Centre line static pressure being considerably lower than the static pressure at the wall. This creates a vacuum near the axis.

5.2 EXPERIMENTAL OBSERVATIONS

On injecting the liquid through the two tangential inlets in the tube, the liquid starts swirling. As the flow rate is increased gradually (From 13 LPM to 26 LPM) the swirling motion becomes more pronounced. The liquid has a tendency to build a column in the tube by climbing towards the feed end of the tube (Plate 5.01 and Plate 5.02) corresponding to tube I.D. 38 mm). One drop of dye is injected at this stage. The dye does not fall down immediately but

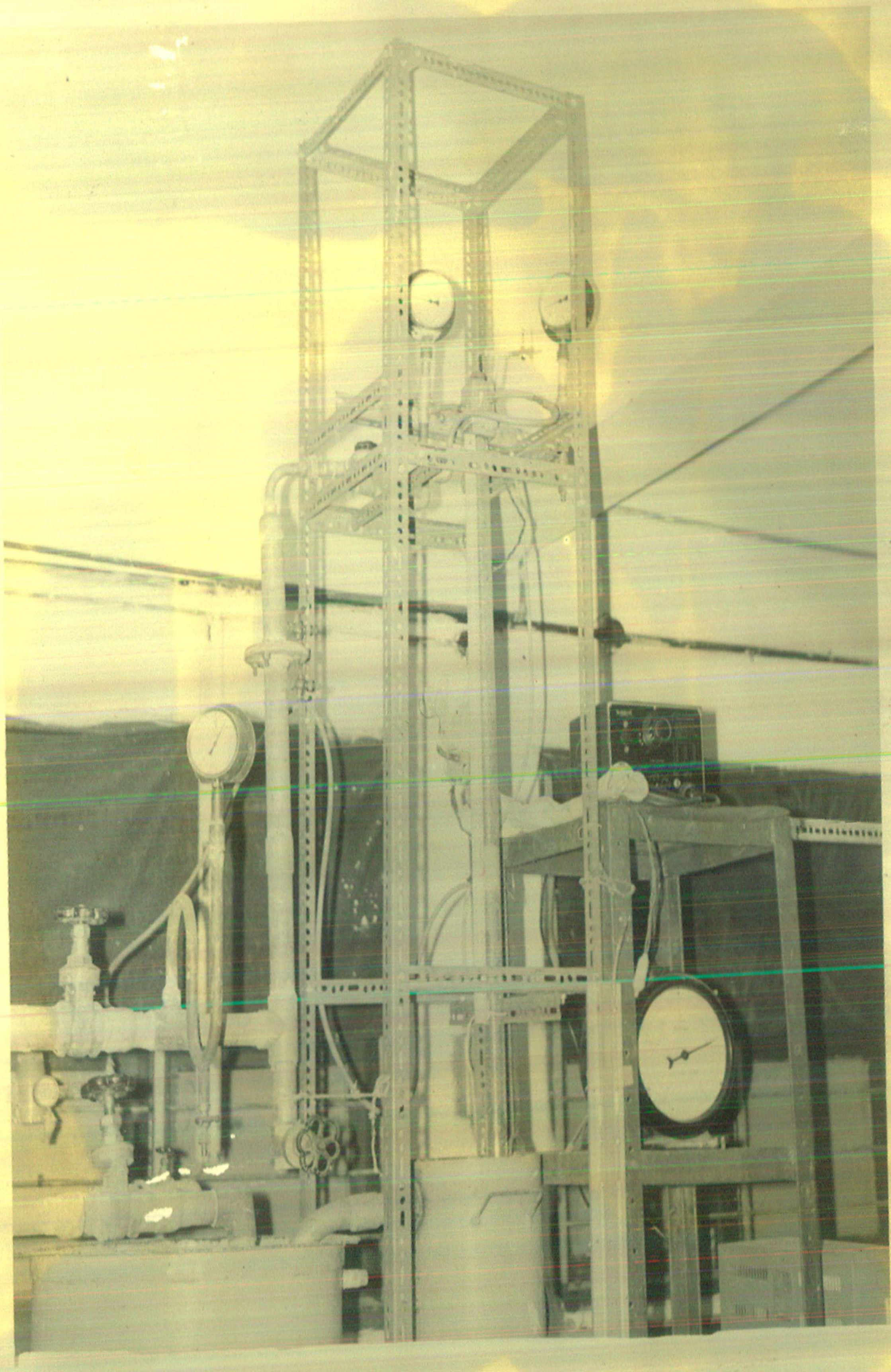


PLATE 5.01 FLOW REVERSAL
(TUBE I.D. 38 M.M.)

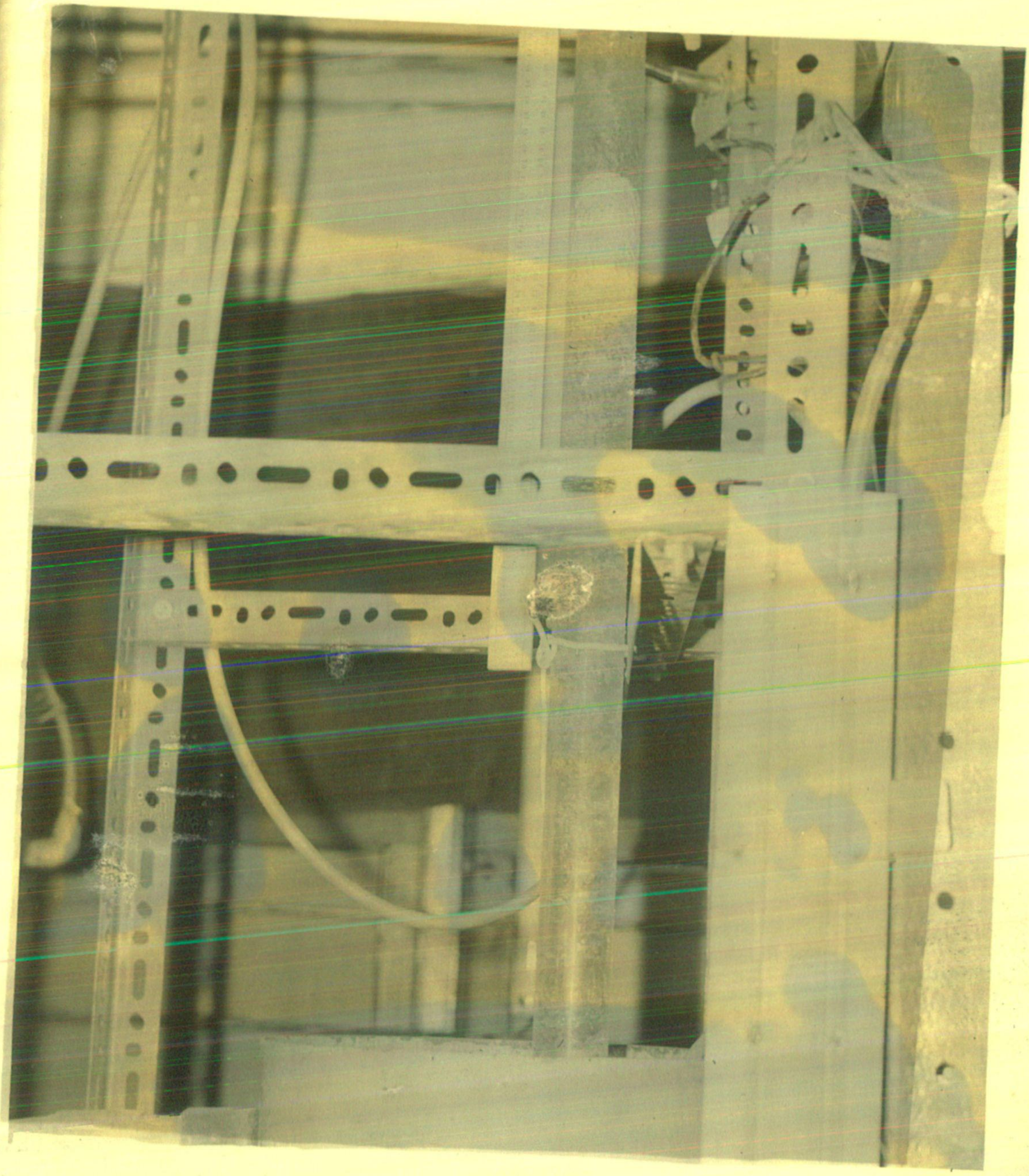


PLATE 5.02 ENLARGED VIEW SHOWING REVERSAL

it oscillates for sometime and then finally it diffuses outwardly along the tube wall. This is suggestive of the flow reversal phenomenon. when axial inlet in the test section is opened to atmosphere the liquid column built up because of the flow reversal is fully removed and an uniform air core prevails throughout the section, indicating that the reversal has been overcome. By careful study of the air core it is observed that the swirls decay downstream of the test section gradually right from the point of onset of the swirls in the test section.

Chapter VI

EXPERIMENTAL DATA, RESULT AND DISCUSSION

6.1 EXPERIMENTAL DATA

All experimental data are taken for water at room temperature.

Table 6.01 to 6.04 give the pressure drop data for various inlet velocities for tube diameters 18 mm, 25 mm , 38 mm and 56 mm. The entry heads of the same size as that of the tube were used, having tangential entry diameters of 6 mm. Figures 6.01 to 6.04 depict the effect of water flow rates on pressure drop.

Data for RPM of swirl for different flow rates through the tube diameters 18 mm, 25 mm, 38 mm and 56 mm with tangential entry diameter 6 mm have been tabulated in Tables 6.01 to 6.04.

Data for air-core lengths for various liquid velocities in the tube diameter 18 mm, 25 mm, 38 mm and 56 mm are given in Tables 6.01 to 6.04

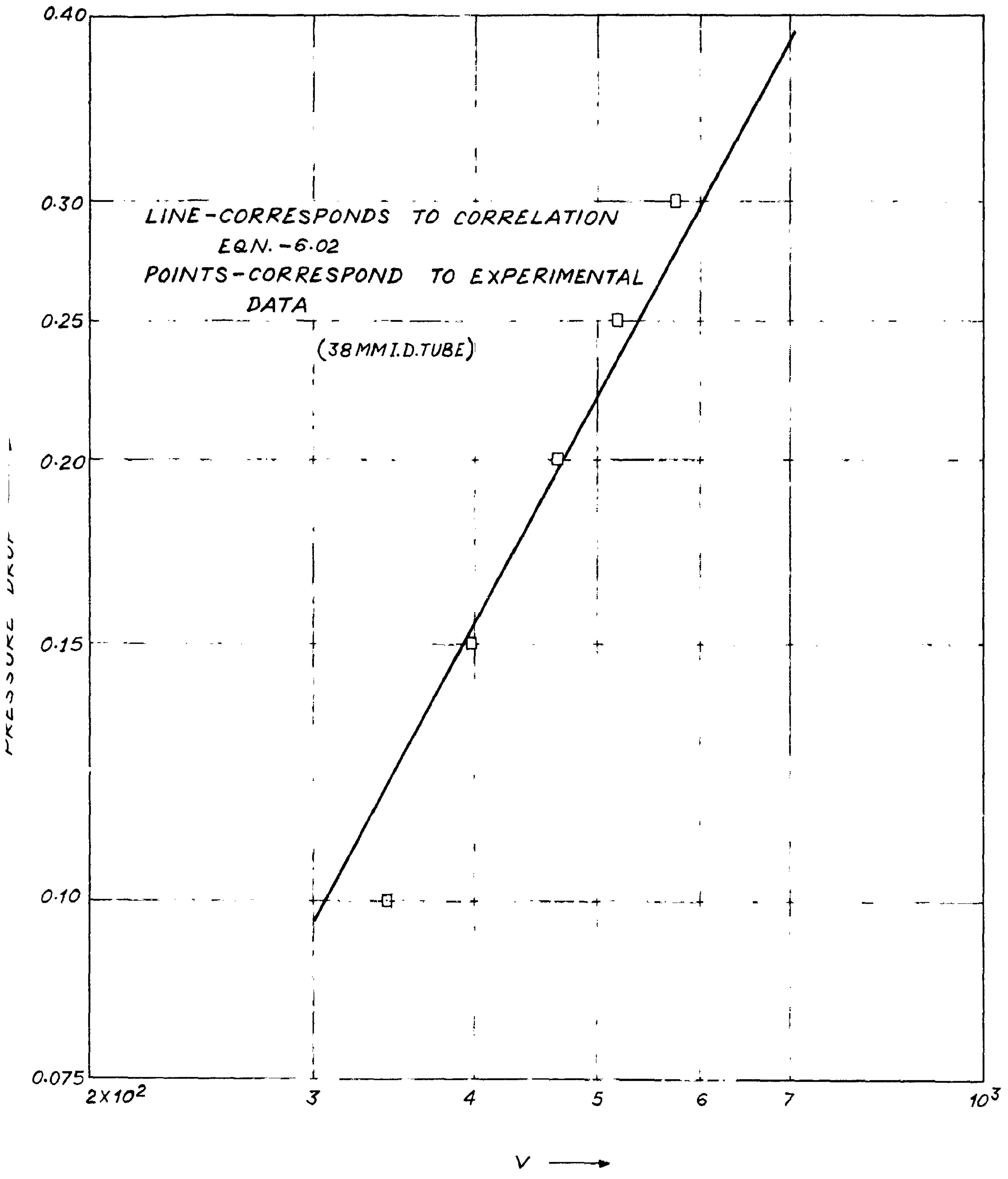


FIG. 6·03 EFFECT OF VELOCITY ON PRESSURE DROP.

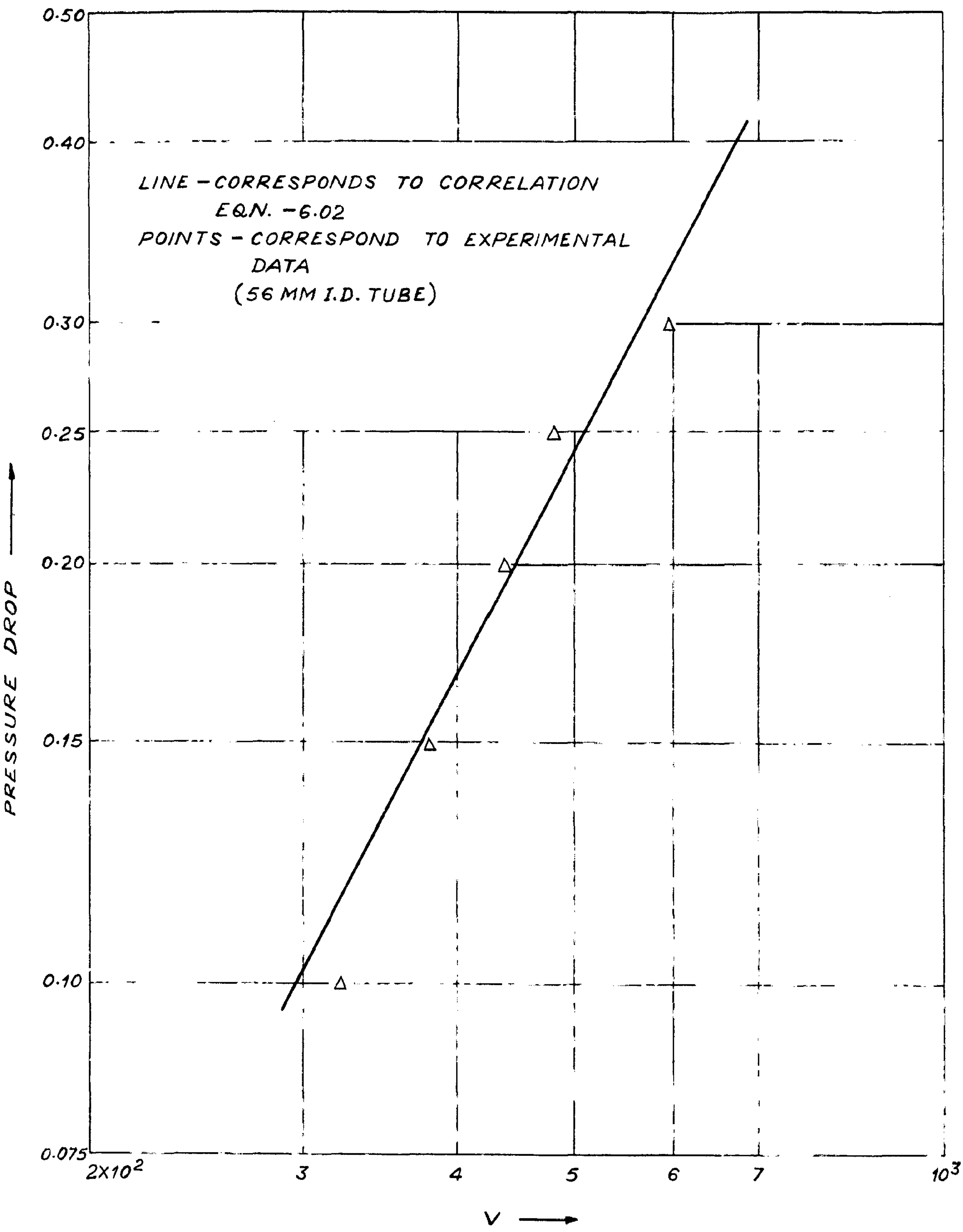


FIG. 6·04 EFFECT OF VELOCITY ON PRESSURE DROP.

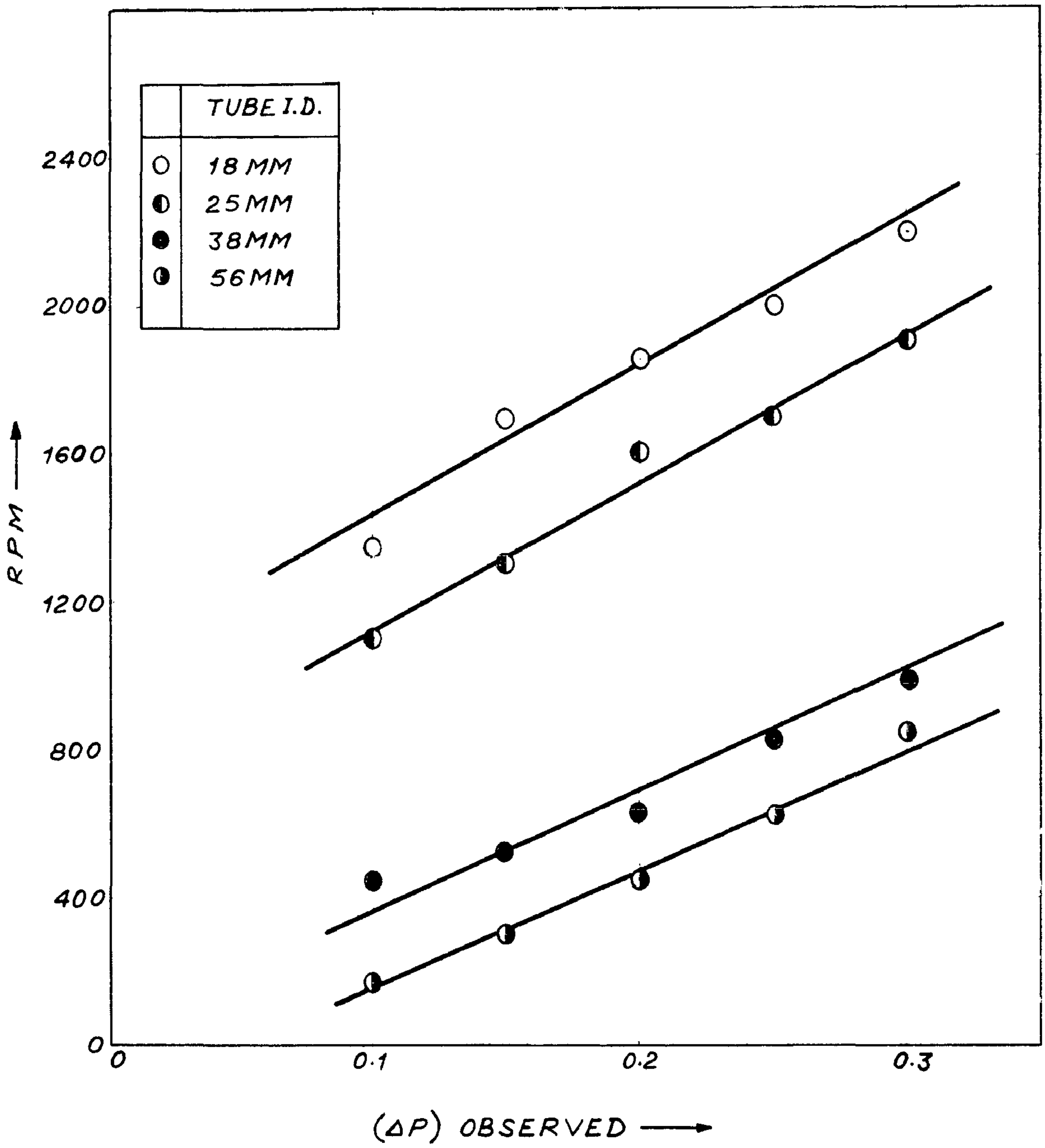


FIG. 6·05 VARIATION OF RPM WITH (ΔP)

Figure 6.05 represents the variation of the swirl strength with pressure drop for various tubes under study.

Figure 6.06 shows the effect of pressure drop across the liquid entry head and the tube on air core lengths of swirling liquid for various tubes.

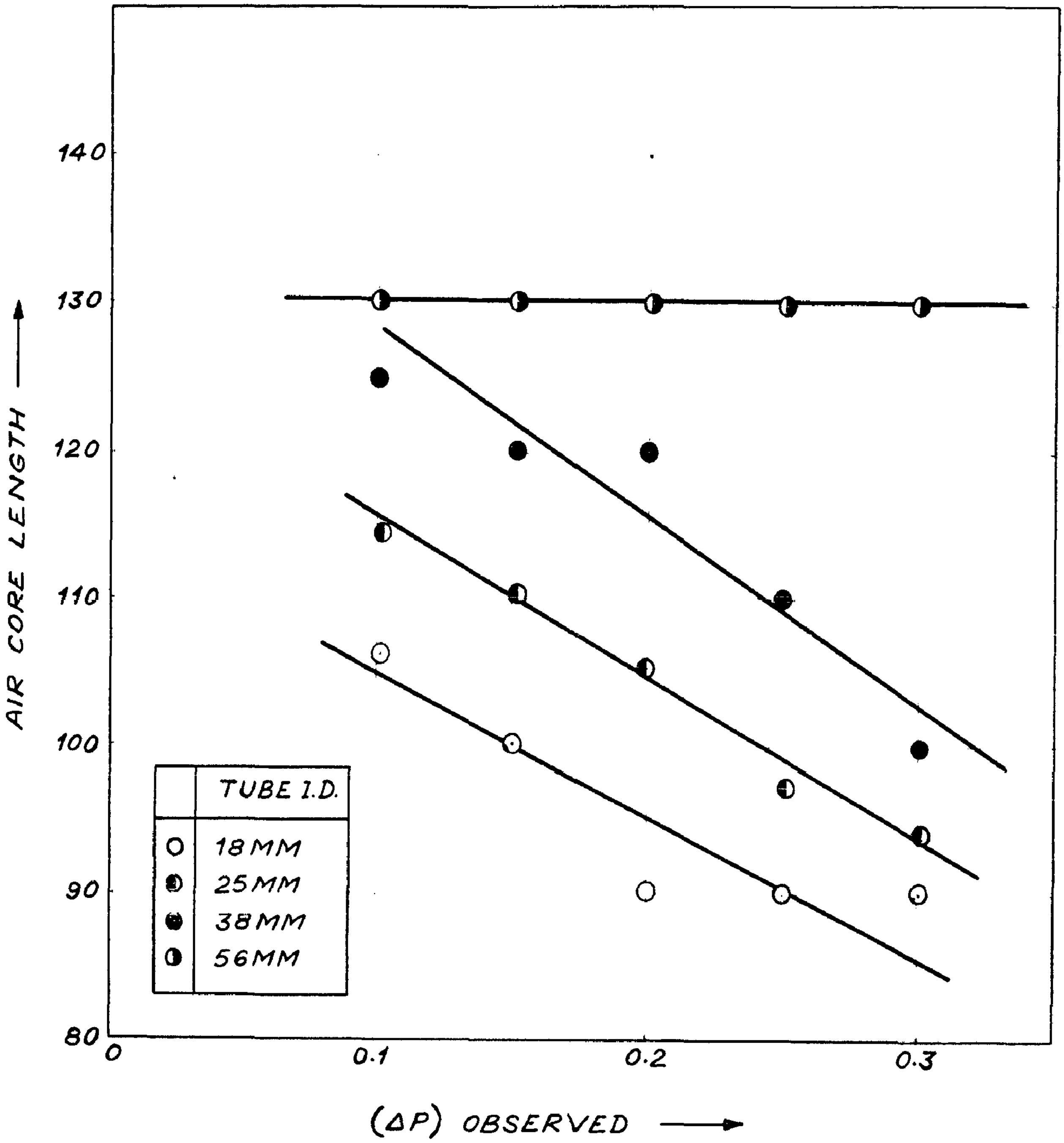


FIG.6.06 EFFECT OF (ΔP) ON AIR CORE LENGTH.

TABLE No. 6.01

RUN No. 1

Sl. No.	Diameter of Tube on which Run is taken 18 mm			Air Inlet closed	
	Pressure drop ΔP kg/cm^2	Air core diameter cm	Air core length cm	Time for collecting 13 litres of water secs.	R.P.M.
1	0.10	1.44	106.0	53.7	1350
2	0.15	1.44	100.0	47.0	1700
3	0.20	1.445	90.0	40.2	1850
4	0.25	1.445	90.0	34.5	2000
5	0.30	1.445	90.0	28.8	2200

TABLE No. 6.02

RUN No. 2

Sl No	Diameter of Tube on which Tun is taken 25 mm			Air Inlet closed	
	Pressure drop ΔP kg/cm^2	Air core diameter cm	Air core length cm	Time for collecting 13 litres of water secs.	R.P.M.
1	0.10	1.48	114.0	58.0	1100
2	0.15	1.48	110.0	50.3	1300
3	0.20	1.48	105.0	42.8	1600
4	0.25	1.48	97.0	38.5	1700
5	0.30	1.48	94.0	32.4	1900

TABLE 6.03

RUN No. 3

Sl. No.	Diameter of Tube on which Run is taken 38 mm			Air Inlet closed	
	Pressure drop ΔP kg/cm^2	Air core diameter cm	Air core length cm	Time for collecting 1? litres of water secs.	R.P.M.
1	0.10	3.05	125.0	59.7	450
2	0.15	3.05	120.0	51.7	525
3	0.20	3.055	120.0	44.5	630
4	0.25	3.06	110.0	39.8	830
5	0.30	3.06	100.0	36.0	890

TABLE No. 6.04

RUN No. 4

Sl No	Diameter of Tube on which Run is taken 56 mm			Air Inlet closed	
	Pressure drop ΔP kg/cm^2	Air core diameter cm	Air core length cm	Time for collecting 13 litres of water secs.	R.P.M.
1	0.10	4.35	130.0	62.0	180
2	0.15	4.35	130.0	54.1	360
3	0.20	4.40	130.0	47.5	450
4	0.25	4.40	130.0	47.5	450
5	0.30	4.40	130.0	38.2	850

6.2 RESULTS AND DISCUSSIONS

Figure 6.05 reveals that with the increase in pressure of the inflowing liquid, the swirl strength increases for all the tubes under study.

From figure 6.06 it is observed that for tubes of diameter 18 mm, 25 mm and 38 mm , as the pressure is increased from 0.10 kg/cm^2 to 0.30 kg/cm^2 , the air core length decreases or in other words the reversal becomes greater. As the swirls become more pronounced with the increase in pressure the static pressure at the wall also increases with the result that more vacuum is created at the centre line, thus giving rise to more reversal. The air core length is reduced. A simple opening of the axial air inlet to the atmosphere, however, is capable of breaking this reversal and the air core prevails throughout the length of the test section without disturbing the swirl strength. For the tube of 56 mm diameter, however, the air core length is not affected by increase in pressure.

The pressure drop across the liquid entry head and the tube based on various theoretical factors was programmed on computer IBM 1620. The computed values of pressure drops against the observed pressure drop are listed in Appendix I.

From the computed values, it is noted that though most of the data lie within ± 25 % but some data show a deviation of about ± 30%. This method of computing the pressure drop is tedious in the sense that further correction for friction loss through other factors viz the hydrostatic pressure of liquid column present in the tube, need be made. Some of the data needed are not amenable to easy measurement.

A correlation based on the dimensional analysis for predicting the pressure drop has therefore been proposed (Appendix II)

$$Eu = K\,(Re)^{a}\,(Fr)^{b}\,(D_i/D_t)^{c}\,(L/D_t)^{d} \qquad (6.01)$$

The details of the method of regression analysis employed for determining the exponents of the different dimensionless groups in the correlation have been given (Appendix III). The programme for the same was run on IBM 1620 and is listed in Appendix IV alongwith the results. Based on the experimental data, the exponents were determined and the correlation may be written in the form-

$$(Eu) = 2.05\times10^{3}(Re)^{-0.41}\,(Fr)^{0.01}\,(D_i/D_t)^{-0.03}\,(L/D_t)^{-0.85} \qquad (6.02)$$

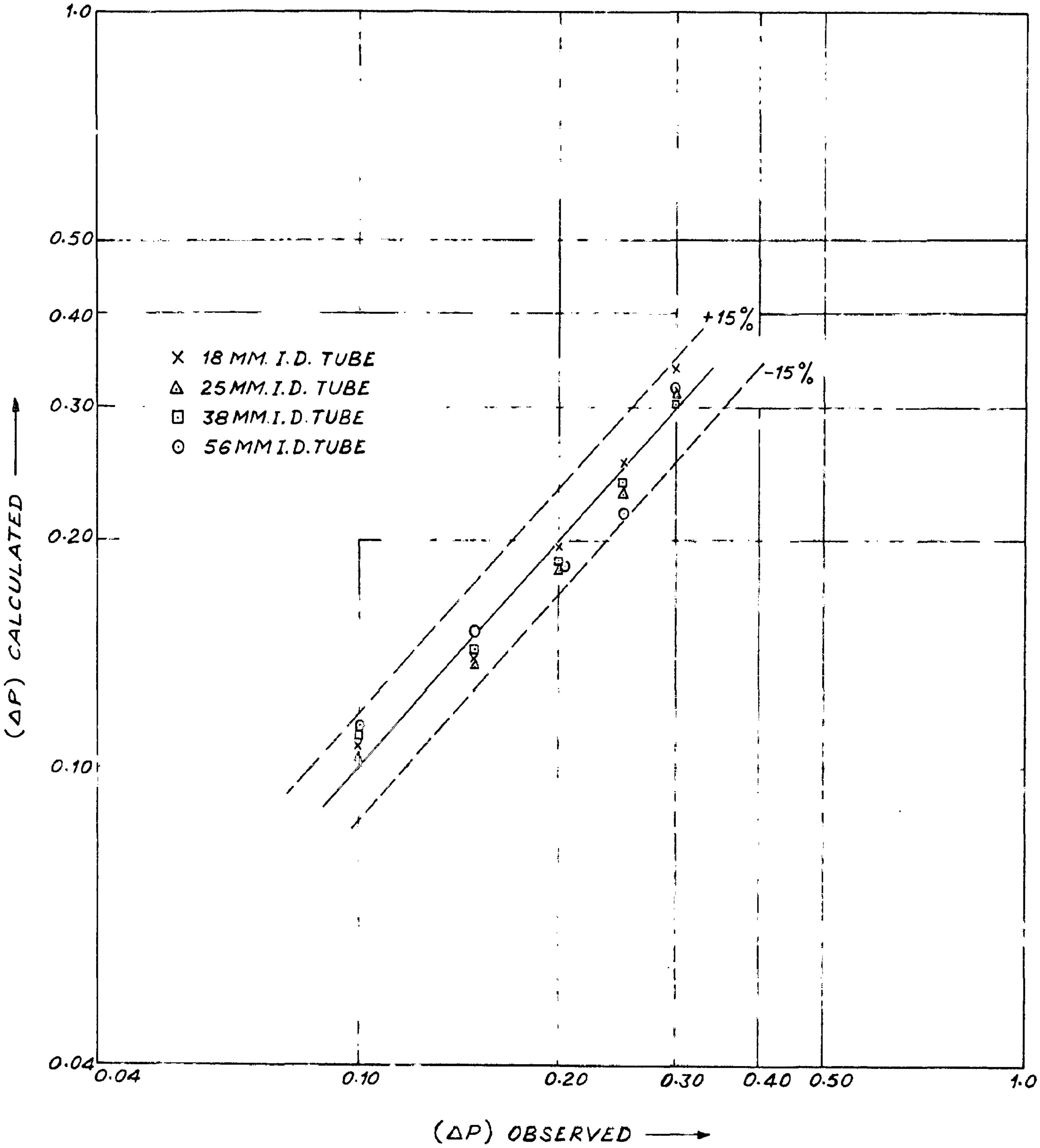


FIG. 6.07 VARIATION OF PRESSURE DROP OBSERVED AND CALCULATED FROM CORRELATION.

$$\left[Eu = (Re)^{-0.41} (Fr)^{0.01} (Di/Dt)^{-0.03} (L/Dt)^{-0.85}\right]$$

The value of the linear slope obtained from Figure 6.01 to 6.04 is in accordance with the value of the power of the velocity term obtained from the correlation.

Figure 6.07 is a plot between (ΔP) observed and (ΔP) calculated from the proposed correlation. The deviation between the values of the (ΔP) calculated is within $\pm$ 15% of the values of (ΔP) observed. The proposed correlation therefore makes it possible the determination of the pressure drop across the liquid entry head and the tube through which the swirling is taking place.

Chapter VII

CONCLUSION AND RECOMMENDATIONS

7.1 Studies on Downward Swirling flow in vertical pipes have been conducted and the pressure drop across the liquid entry head and the tube through which swirling is taking place has been computed based on theoretical considerations. In swirling flow the pressure drop across the liquid entry head and the tube through which the liquid is flowing is the summation of the pressure drops due to :

i. Sudden expansion of the cross section

ii. Radial flow at the entry head

iii. Swirling flow ., and

iv. Friction in the entry pipes

Since some of the parameters viz swirl strength and the rate of decay of swirls are not easily amenable to experimental evaluation, therefore the dimensional analysis of the variables involved has been approached. A correlation incorporating various experimental factors has been obtained.

$$Eu = 2.05 \times 10^3 (Re)^{-0.41} (Fr)^{0.01} (D_i/D_t)^{-0.03} (L/D_t)^{-0.85}$$

The computed values of the pressure drop through theoretical considerations show a deviation of $\pm$ 25 % with the experimental values while the pressure drop computed from correlation lies within $\pm$ 15% of the experimental values. A critical observation of the flow characteristics reveals the following points :

1. The swirls are produced by tangentially injecting water at constant rate into the tube through two inlets placed diameterically opposite to each other.

2. The vertical axial velocity at low pressures remained downwards throughout the tube.

3. The swirls decay steadily downwards starting from the onset of swirling.

4. At higher pressures, the flow reversal is more pronounced.

5. Induced air through the axial inlet breaks up the reversal and a uniform air core is obtained.

7.2 It is felt that the effect of viscosity of the liquid on swirling may be studied by taking liquids other than water, to make the studies generalised.

The overall heat transfer coefficient in horizontal double pipe heat exchanger using water and steam has been reported to increase substantially by Sharma et al (21). In the design of an equipment, pressure drop is a vital factor. These studies will be helpful in the calculation of the pressure drop in the design of vertical swirl flow heat exchangers.

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APPENDIX I — COMPUTER PROGRAM AND RESULTS FOR PRESSURE DROP BALANCE

```
C   C   THESIS  PRESSURE DROP BALANCE  YOGESH CHANDRA
C       PL IS THE OBSERVED PRESSURE
C       CD IS THE AIRCORE DIAMETER
C       TD IS THE TUBE DIAMETER, AN IS THE R.P.M.
C       VTA IS THE TANGENTIAL VELOCITY,VTTIS TANGENTIAL VELOCITY ALONG THE WALL
C       VAX IS THE AXIAL VELOCITY
C       OMEGA IS THE CIRCULATION CONSTANT
C       TL IS THE AIRCORE LENGTH
C       REN AND REN1ARE THE REYNOLDS NUMBERS
C       F AND FF ARE FRICTION FACTORS
        PUNCH25
     25 FORMAT(/3X,2HPL,9X,2HTD,6X,5HDELP1,5X,5HDELP2,5X,5HDELP3,3X,5HDELP
       14,3X,4HDELP//)
        IT = 1
     10 READ20,PL,TL,CD,AN,TD,T
     20 FORMAT(6F10.4)
        CR = CD/2.0  $  TR = TD/2.0
        Z = 2.0*981.0*1000.0
        VTA = (3.14*CD*AN)/60.0
        VTT = (VTA*CD)/TD
        VTAV = (VTA+VTT)/2.0
        AA = (3.14/4.0)*(TD**2-CD**2)
        VAX = 13000.0/(T*AA)
        VV = VAX**2+VTAV**2
        VAV = SQRTF(VV)
        HD = (4.0*AA)/(3.14*TD)
        REN = 100.0*HD*VAV
        FF = 0.079/(REN**0.25)
        EQF = VAV/VAX
        DELP1 = (2.0*FF*TL*EQF*(VAV**2))/(Z*TR)
        OMEGA = VTA*CR
        DELP2 = (OMEGA**2)*(1.0/CR**2-1.0/TR**2)/Z
        V = 13000.0/(T*0.63)
        REN1= 1300000.0/T
        F = 0.079/(REN1**0.25)
        DELP3 = (40.0*F*(V**2))/(Z*TR)
        DELP4 = 2.0*(V-VAV)**2/Z
        DELP = DELP1+DELP2+DELP3+DELP4
        PUNCH 30,PL,TD,DELP1,DELP2,DELP3,DELP4,DELP
     30 FORMAT(7E10.3)
        IT =IT + 1
        IF(IT-100)10,10,40
     40 STOP
        END
```

0.10	106.0	1.44	1400.0	1.8	53.5
0.15	100.0	1.44	1700.0	1.8	47.0
0.20	90.0	1.445	1850.0	1.8	40.2
0.25	90.0	1.445	2000.0	1.8	34.5
0.30	90.0	1.445	2200.0	1.8	28.8
0.10	114.0	1.48	1100.0	2.5	58.0
0.15	110.0	1.48	1300.0	2.5	51.8
0.20	105.0	1.48	1600.0	2.5	42.6
0.25	97.0	1.48	1700.0	2.5	36.5
0.30	94.0	1.48	1900.0	2.5	32.4
0.10	125.0	3.05	450.0	3.8	59.7
0.15	120.0	3.05	525.0	3.8	50.7
0.20	120.0	3.055	630.0	3.8	44.5
0.25	110.0	3.06	830.0	3.8	39.8
0.30	100.0	3.06	890.0	3.8	36.0
0.10	130.0	4.35	180.0	5.6	62.0
0.15	130.0	4.35	300.0	5.6	54.1
0.20	130.0	4.40	450.0	5.6	46.0
0.25	130.0	4.40	625.0	5.6	43.0
0.30	130.0	4.40	850.0	5.6	34.5

C C THESIS PRESSURE DROP BALANCE YOGESH CHANDRA

PL	TD	DELP1	DELP2	DELP3	DELP4	DELP
0.100	0.180E+01	0.688E-01	0.204E-02	0.213E-01	0.110E-01	0.103
0.150	0.180E+01	0.832E-01	0.301E-02	0.267E-01	0.136E-01	0.127
0.200	0.180E+01	0.984E-01	0.355E-02	0.352E-01	0.183E-01	0.155
0.250	0.180E+01	0.126	0.415E-02	0.459E-01	0.260E-01	0.202
0.300	0.180E+01	0.169	0.502E-02	0.630E-01	0.389E-01	0.276
0.100	0.250E+01	0.868E-02	0.240E-02	0.133E-01	0.679E-01	0.923E-01
0.150	0.250E+01	0.110E-01	0.336E-02	0.162E-01	0.834E-01	0.114
0.200	0.250E+01	0.150E-01	0.508E-02	0.229E-01	0.123	0.166
0.250	0.250E+01	0.160E-01	0.574E-02	0.300E-01	0.173	0.225
0.300	0.250E+01	0.189E-01	0.717E-02	0.369E-01	0.220	0.283
0.100	0.380E+01	0.569E-02	0.936E-03	0.834E-02	0.696E-01	0.846E-01
0.150	0.380E+01	0.716E-02	0.127E-02	0.111E-01	0.969E-01	0.116
0.200	0.380E+01	0.986E-02	0.183E-02	0.139E-01	0.123	0.149
0.250	0.380E+01	0.148E-01	0.317E-02	0.169E-01	0.142	0.177
0.300	0.380E+01	0.151E-01	0.364E-02	0.202E-01	0.176	0.215
0.100	0.560E+01	0.134E-02	0.339E-03	0.529E-02	0.861E-01	0.930E-01
0.150	0.560E+01	0.388E-02	0.943E-03	0.672E-02	0.102	0.113
0.200	0.560E+01	0.954E-02	0.209E-02	0.893E-02	0.126	0.146
0.250	0.560E+01	0.209E-01	0.404E-02	0.100E-01	0.123	0.158
0.300	0.560E+01	0.385E-01	0.747E-02	0.148E-01	0.179	0.240

0 ERROR LC-2 IN STATEMENT 0010 + 00 L. L.

APPENDIX II DIMENSIONAL ANALYSIS OF VARIABLES

The pressure exerted by a fluid stream flowing will depend on the physical properties of the fluid, on the velocity of the stream which will, in turn depend upon the core diameter, on tube diameter and on length of the tube. Hence,

$$f\ (\Delta P, D_i, D_t, L, \mu, g, \rho, g_c, v) = 0$$

Fundamental dimensions are F, M, L, T.

The number of numerics are 5

Considering D_t, ρ, g_c, v as primaries

ΔP	D_i	D_t	L	μ	g	ρ	g_c	v
F/L^2	L	L	L	$\frac{M}{LT}$	$\frac{L}{T^2}$	$\frac{M}{L^3}$	$\frac{ML}{FT^2}$	L/T

$$\frac{\Delta P}{(\rho)^a (v)^b (g_c)^c (D_t)^d} : \frac{F/L^2}{\left(\frac{M}{L^3}\right)^a \left(\frac{L}{T}\right)^b \left(\frac{M}{F}\ \frac{L}{T^2}\right)^c (L)^d}$$

a = 1, b = 2, c = -1, d = 0

$$\pi_1 = \frac{\Delta P \cdot g_c}{\rho\ v^2}$$

$$\frac{\mu}{(\rho)^a (v)^b (g_c)^c (D_t)^d} : \frac{M/LT}{\left(\frac{M}{L^3}\right)^a \left(\frac{L}{T}\right)^b \left(\frac{M}{F}\ \frac{L}{T^2}\right)^c (L)^d}$$

a = 1, b = 1, c = 0, d = 1

APPENDIX III METHOD OF REGRESSION ANALYSIS EMPLOYED

In general a dependent variable y may be expressed in terms of several independent variables :

$$\hat{y} = a + bx + cz + dw + \ldots.. \quad (1)$$

An alternative form, in which the independent variables are not necessarily to the first power, can sometimes be modified to give the multiple linearequation . For example, if

$$\hat{y} = ax^b z^c w^d \quad (2)$$

then

$$\log y = \log a + b \log x + c \log z + d \log w + \ldots \quad (3)$$

and, therefore,

$$\hat{Y} = A + bX + cZ + dW + \ldots. \quad (4)$$

If the degree of fit of a multiple linear regression is measured by the sum of the squares of deviation of the observed from the predicted values, $\sum(y_i - \hat{y}_i)^2$, then in a manner directly analogous to that used for a simple linear regression, an expression for the constants of Eq. (1) can be obtained that will give the minimum value ofor $\sum(y_i - \hat{y}_i)^2$.

We shall rewrite Eq (1) to simplify the symbols.

$$y = a + b_1x_1 + b_2x_2 + b_3x_3 + \ldots \quad (5)$$

where b_1 means $b_{1.23\ldots k}$ and indicates the regression coefficient for y upon x_1 when all the other independent

$$\pi_2 = \frac{D\,v\,\rho}{\mu}$$

$$\frac{g}{(\rho)^a (v)^b (g_c)^c (D_t)^d} : \frac{L/T^2}{(\frac{M}{L^3})^a (\frac{L}{T})^b (\frac{M}{F}\ \frac{L}{T^2})^c (L)^d}$$

a = 0 , b = 2 , c = 0 , d = -1

$$\pi_3 = \frac{v^2}{g\,D}$$

$$\frac{D_i}{(\rho)^a (v)^b (g_c)^c (D_t)^d} : \frac{L}{(\frac{M}{L^3})^a (\frac{L}{T})^b (\frac{M}{F}\ \frac{L}{T^2})^c (L)^d}$$

a = 0 , b = 0 , c = 0 , d = 1

$$\pi_4 = D_i / D_t$$

$$\frac{L}{(\rho)^a (v)^b (g_c)^c (D_t)^d} : \frac{L}{(\frac{M}{L^3})^a (\frac{L}{T})^b (\frac{M}{F}\ \frac{L}{T^2})^c (L)^d}$$

a = 0 , b = 0 , c = 0 , d = 1

$$\pi_5 = \frac{L}{D_t}$$

The statement can therefore be expressed as,

$$\frac{\Delta P \cdot g_c}{\rho\ v^2} = f_1\left(\frac{D_t v\ \rho}{\mu}\right) f_2\left(\frac{v^2}{gD}\right)\ f_3\left(\frac{D_i}{D_t}\right)\ f_4\left(\frac{L}{D_t}\right)$$

or

$$Eu = K\ (Re)^a\ (Fr)^b\ (D_i/D_t)^c\ (L/D_t)^d$$

variables, $x_2, x_3, \ldots x_k$ are held constant. $b_1.$ is referred to as the partial regression coefficient. The dot symbol differentiates $b_1.$ from the simple b_1 (without the dot), which is the regression coefficient of y upon x_1 when the other variables are disregarded.

If the sum of squares of deviation between the observed values of the dependent variable y, and those predicted by an equation of the form of Eq (5), is differentiated with respect to each of the constants in the equation, and in each case the derivative is equated to zero, the value of/ constant will be obtained that gives the minimum sum of squares of deviation. This was the method used to obtain the constants for the least - squares line for two variables. For the multivariable case, the equations obtained are those listed as Eqs (6)

$$
\begin{aligned}
Na + b_{1.}\sum x_1 + b_{2.}\sum x_2 + b_{3.}\sum x_3 + \ldots &= \sum y \\
a\sum x_1 + b_{1.}\sum x_1^2 + b_{2.}\sum x_1 x_2 + b_{3.}\sum x_1 x_3 + \ldots &= \sum x_1 y \\
a\sum x_2 + b_{1.}\sum x_2 x_1 + b_{2.}\sum x_2^2 + b_{3.}\sum x_2 x_3 + \ldots &= \sum x_2 y \qquad (6) \\
a\sum x_3 + b_{1.}\sum x_3 x_1 + b_{2.}\sum x_3 x_2 + b_3\sum x_3^2 \ldots &= \sum x_3 y
\end{aligned}
$$

where N is the number of sets of data points.

Equations (6) can be solved by any method for the solution of simultaneous equations for the evaluation of the regression coefficients $b_{1.}, b_{2.}$, and for the intercept a.

However, if the first of the equations listed in the (6) series is solved for a,

$$a = \bar{y} - b_{1.}\bar{x}_1 - b_{2.}\bar{x}_2 - b_{3.}\bar{x}_3 - \ldots$$

and this value substituted for a in the other equations, a second set of equations results which are more amenable to statistical calculations. These equations, listed as Eqs. (7) are in terms of the deviations of each variable from its mean, $\sum' x^2 = \sum (x - \bar{x})^2$, and $\sum' xy = \sum (x-\bar{x})(y - \bar{y})$, etc.

$$\begin{aligned} b_{1.} \textstyle\sum' x_1^2 + b_2 \textstyle\sum' x_1x_2 + b_{3.} \textstyle\sum' x_1x_2 + \ldots &= \textstyle\sum' x_1y \\ b_{1.} \textstyle\sum' x_2x_1 + b_2 \textstyle\sum' x_2^2 + b_{3.} \textstyle\sum' x_2x_3 + \ldots &= \textstyle\sum' x_2y \qquad (7) \\ b_{1.} \textstyle\sum' x_3x_1 + b_{2.} \textstyle\sum' x_3x_2 + b_{3.} \textstyle\sum' x_3^2 + \ldots &= \textstyle\sum' x_3y \end{aligned}$$

These eqns may be solved simultaneously by any method of numerical analysis.

CONDENSED

APPENDIX IV - COMPUTER PROGRAM FOR DETERMINATION OF EXPONENTS OF CORRELATION

```
C  C  THESIS  CURVE FITTING  YOGESH CHANDRA
      DIMENSION PL(20),TD(20),T(20),V(20),TL(20),XEU(20),XRE(20),XFR(20)
      DIMENSION XD(20),XL(20),Y(20),X1(20),X2(20),X3(20),X4(20)
      DIMENSION CK(20),XNEU(20)
      READ5,N
    5 FORMAT(I5)
      READ10,(PL(I),TD(I),T(I),TL(I),I=1,N)
   10 FORMAT(4E15.3)
      GC=981000.0  $ G=981.0  $ ANU=0.01  $ TDN=0.6
      DO 20 I=1,N
      V(I) = 13000.0/(0.63*T(I))
   20 CONTINUE
      DO 30 I=1,N
C     XEU =EULER NUMBER, XRE =REYNOLDS NUMBER, XFR =FROUDE NUMBER
C     XD = DIMENSIONLESS DIAMETER RATIO,XL = DIMENSIONLESS LENGTH TO DIAMETE(
C     PL=OBSERVED PRESSURE,TD=TUBE DIAMETER, TL=AIRCORE LENGTH
C     T=TIME FOR COLLECTING KNOWN AMOUNT OF WATER.
C     TDN=TANGENTIAL ENTRY NOZZLE DIAMETER
C     ANU=KINEMATIC VISCOSITY
      XEU(I)=PL(I)*GC/(V(I)*V(I))
      XRE(I)=TD(I)*V(I)/ANU
      XFR(I)=V(I)*V(I)/(G*TD(I))
      XD(I)=TDN/TD(I)
      XL(I)=TL(I)/TD(I)
      XR=(1.0/XRE(I))**0.41
      XF = (XFR(I))**0.01
      XB = (1.0/XD(I))**0.03
      XLL = (1.0/XL(I))**0.85
      XNEU(I) = XR*XF*XB*XLL
      CK(I) = XEU(I)/XNEU(I)
   30 CONTINUE
C     Y,X1,X2,X3,X4, ARE LOGARITHMS OF XEU ,XRE,XFR,XD,XL
C     N IS THE NUMBER OF RUNS
C     YM,XM1,XM2,XM3,XM4 ARE THE MEANS OF Y,X1, ETC.
C     SUM7 ETC. ARE SIGMA(Y-XM1)**2 ETC.
       PUNCH35
   35 FORMAT(/5X,3HXEU,12X,3HXRE,12X,3HXFR,11X,2HXD,14X,2HXL//)
      PUNCH 45,(XEU(I),XRE(I),XFR(I),XD(I),XL(I),I=1,N)
   45 FORMAT (5E14.5)
      PUNCH 41
   41 FORMAT(/5X,4HXNEU//)
      PUNCH45,(XNEU(I),I=1,N)
      PUNCH43
   43 FORMAT(/5X,2HCK//)
```

```
      PUNCH45,(CK(I),I=1,N)
      FSUM = 0.0
      DO55I=1,N
      FSUM = FSUM + CK(I)
   55 CONTINUE
      AN = N
      CKAVG = FSUM/AN
      PUNCH42,CKAVG
   42 FORMAT(/10X,7HCKAVG =,F10.3)
      DO 40 I=1,N
      Y(I)=LOGF(XEU(I))
      X1(I)=LOGF(XRE(I))
      X2(I)=LOGF(XFR(I))
      X3(I)=LOGF(XD(I))
      X4(I)=LOGF(XL(I))
   40 CONTINUE
      SUM1=0.0  $  SUM2=0.0  $  SUM3=0.0  $SUM4=0.0  $  SUM5=0.0
      DO 50 I=1,N
      SUM1=SUM1+Y(I)
      SUM2=SUM2+X1(I)
      SUM3=SUM3+X2(I)
      SUM4=SUM4+X3(I)
      SUM5=SUM5+X4(I)
   50 CONTINUE
      AN=N
      YM=SUM1/AN
      XM1=SUM2/AN
      XM2=SUM3/AN
      XM3=SUM4/AN
      XM4=SUM5/AN
      PUNCH49
   49 FORMAT(/11X,2HYM,11X,3HXM1,11X,3HXM2,11X,3HXM3,12X,3HXM4//)
      PUNCH48,YM,XM1,XM2,XM3,XM4
   48 FORMAT(5F14.3)
      SUM7=0.0 $ SUM8=0.0  $ SUM9=0.0  $  SUM10=0.0
      DO 60 I=1,N
      SUM7=SUM7+(X1(I)-XM1)**2
      SUM8=SUM8+(X2(I)-XM2)**2
      SUM9=SUM9+(X3(I)-XM3)**2
      SUM10=SUM10+(X4(I)-XM4)**2
   60 CONTINUE
      S1=0.0 $S2=0.0 $ S3=0.0 $ S4=0.0 $ S5=0.0 $ S6=0.0 $ S7=0.0$S8=0.0
      S9=0.0 $ S10=0.0$S11=0.0$S12=0.0$S13=0.0$S14=0.0$S15=0.0$S16=0.0
      DO70 I=1,N
      A=Y(I)-YM
      A1=X1(I)-XM1
      A2=X2(I)-XM2
      A3=X3(I)-XM3
      A4=X4(I)-XM4
      S1=S1+A1*A2
```

```
      S2=S2+A1*A3
      S3=S3+A1*A4
      S4=S4+A1*A
      S5=S5+A2*A1
      S6=S6+A2*A3
      S7=S7+A2*A4
      S8=S8+A2*A
      S9=S9+A3*A1
      S10=S10+A3*A2
      S11=S11+A3*A4
      S12=S12+A3*A
      S13=S13+A4*A1
      S14=S14+A4*A2
      S15=S15+A4*A3
      S16=S16+A4*A
   70 CONTINUE
      PUNCH80,SUM7,SUM8
   80 FORMAT(2X,5HSUM7=,F10.3,5X,5HSUM8=,F10.3)
      PUNCH81,SUM9,SUM10
   81 FORMAT(2X,5HSUM9=,F10.3,5X,6HSUM10=,F9.3)
      PUNCH82,S1,S2
   82 FORMAT(2X,4HS1 =,F10.3,7X,4HS2 =,F10.3)
      PUNCH83,S3,S4
   83 FORMAT(2X,4HS3 =,F10.3,7X,4HS4 =,F10.3)
      PUNCH84,S5,S6
   84 FORMAT(2X,4HS5 =,F10.3,7X,4HS6 =,F10.3)
      PUNCH85,S7,S8
   85 FORMAT(2X,4HS7 =,F10.3,7X,4HS8 =,F10.3)
      PUNCH86,S9,S10
   86 FORMAT(2X,3HS9=,F10.3,7X,4HS10=,F9.3)
      PUNCH87,S11,S12
   87 FORMAT(2X,4HS11=,F9.3,6X,4HS12=,F9.3)
      PUNCH88,S13,S14
   88 FORMAT(2X,4HS13=,F9.3,6X,4HS14=,F9.3)
      PUNCH89,S15,S16
   89 FORMAT(2X,4HS15=,F9.3,6X,4HS16=,F9.3)
      STOP
      END
   20
      0.10             0.180E+01       0.535E+02       0.106E+03
      0.15             0.180E+01       0.470E+02       0.100E+03
      0.20             0.180E+01       0.402E+02       0.900E+02
      0.25             0.180E+01       0.345E+02       0.900E+02
      0.30             0.180E+01       0.288E+02       0.900E+02
      0.100            0.250E+01       0.580E+02       0.114E+03
      0.150            0.250E+01       0.518E+02       0.110E+03
      0.200            0.250E+01       0.428E+02       0.105E+03
      0.250            0.250E+01       0.385E+02       0.970E+02
      0.300            0.250E+01       0.324E+02       0.940E+02
      0.100            0.380E+01       0.597E+02       0.125E+03
```

0.150	0.380E+01	0.507E+02	0.120E+03
0.200	0.380E+01	0.445E+02	0.120E+03
0.250	0.380E+01	0.398E+02	0.110E+03
0.300	0.380E+01	0.360E+02	0.100E+03
0.100	0.560E+01	0.620E+02	0.130E+03
0.150	0.560E+01	0.541E+02	0.130E+03
0.200	0.560E+01	0.460E+02	0.130E+03
0.250	0.560E+01	0.430E+02	0.130E+03
0.300	0.560E+01	0.345E+02	0.130E+03

C C THESIS CURVE FITTING YOGESH CHANDRA

XEU	XRE	XFR	XD	XL
0.65943	0.69426E+05	0.84247E+02	0.33333	0.58889E+02
0.76340	0.79027E+05	0.10916E+03	0.33333	0.55556E+02
0.74464	0.92395E+05	0.14921E+03	0.33333	0.50000E+02
0.68555	0.10766E+06	0.20259E+03	0.33333	0.50000E+02
0.57328	0.12897E+06	0.29072E+03	0.33333	0.50000E+02
0.77503	0.88944E+05	0.51611E+02	0.24000	0.45600E+02
0.92729	0.99589E+05	0.64705E+02	0.24000	0.44000E+02
0.84407	0.12053E+06	0.94778E+02	0.24000	0.42000E+02
0.85374	0.13399E+06	0.11713E+03	0.24000	0.38800E+02
0.72556	0.15922E+06	0.16539E+03	0.24000	0.37600E+02
0.82113	0.13134E+06	0.32048E+02	0.15789	0.32895E+02
0.88832	0.15466E+06	0.44436E+02	0.15789	0.31579E+02
0.91246	0.17621E+06	0.57681E+02	0.15789	0.31579E+02
0.91237	0.19702E+06	0.72109E+02	0.15789	0.28947E+02
0.89576	0.21781E+06	0.88135E+02	0.15789	0.26316E+02
0.88562	0.18638E+06	0.20163E+02	0.10714	0.23214E+02
0.10115E+01	0.21360E+06	0.26482E+02	0.10714	0.23214E+02
0.97501	0.25121E+06	0.36630E+02	0.10714	0.23214E+02
0.10650E+01	0.26873E+06	0.41919E+02	0.10714	0.23214E+02
0.82266	0.33494E+06	0.65119E+02	0.10714	0.23214E+02

XNEU

0.34996E-03	0.34961E-03	0.35976E-03	0.33893E-03	0.31588E-03
0.39488E-03	0.38949E-03	0.37614E-03	0.38607E-03	0.37072E-03
0.44771E-03	0.43490E-03	0.41333E-03	0.42610E-03	0.44433E-03
0.52528E-03	0.49809E-03	0.46756E-03	0.45542E-03	0.41793E-03

CK

0.18843E+04	0.21835E+04	0.20698E+04	0.20227E+04	0.18149E+04
0.19627E+04	0.23807E+04	0.22441E+04	0.22113E+04	0.19572E+04
0.18341E+04	0.20426E+04	0.22076E+04	0.21412E+04	0.20160E+04
0.16860E+04	0.20307E+04	0.20853E+04	0.23385E+04	0.19684E+04

CKAVG = 2054.080

YM	XM1	XM2	XM3	XM4
-.189	11.898	4.276	-1.651	3.561

SUM7=	3.550	SUM8=	9.231
SUM9=	3.663	SUM10=	2.022
S1 =	-2.384	S2 =	-3.161
S3 =	-2.504	S4 =	.756
S5 =	-2.384	S6 =	4.667
S7 =	2.987	S8 =	-1.499
S9=	-3.161	S10=	4.667
S11=	2.665	S12=	-1.004
S13=	-2.504	S14=	2.987
S15=	2.665	S16=	-.722

0 STOP END AT S. 0089 + 01 L. Z