# STUDIES ON THE SUPERIMPOSITION OF AXIAL FLOW ON SWIRLING FLOW IN HORIZONTAL TUBES

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



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# CERTIFICATE

Certified that the thesis entitled "STUDIES ON THE SUPERIMPOSITION OF AXIAL FLOW ON THE SWIRLING FLOW IN HORIZONTAL TUBES" which is being submitted by Sri Vinod Raj Singh Mudda 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, 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 at this University.

October 18 , 1976.

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## ABSTRACT

The present work deals with the swirling flow in horizontal tubes achieved by using swirl chamber, where the liquid is forced into the swirl chamber, through two tangential entries located diagonally opposite to each other. Earlier workers have found that the flow reversal in swirling flow can be removed by giving air input at the axis of the tube. The same technique has been used in the present study also. Uptill now no study seems to have been carried out on the superimposition of axial flows on the tangential flows.

Therefore axial flow has been superimposed on the tangential flow and its effects on the air core diameter and length have been studied along with the air input rates. The studies have been carried out in two perspex tubes of diameter 3.810 cms and 5.720 cms. It has been found within the range of the experimental conditions used, it is possible to superimpose axial flows on tangential flows without much disturbing the stability of the aircore. It has been found that in such cases much higher input rates are to be taken while superimposing axial flows as compared to air rates used without any axial superimposition.

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Budda

(V.R.S.Budda)

# CONTENTS

## NOMENCLATURE

| | | |
|---|---|---|
| $D_a$ | Average diameter of air-core | Cm |
| $D_i$ | Internal diameter of tangential entry | Cm |
| $D_o$ | Internal diameter of swirl chamber | Cm |
| $D_T$ | Inside diameter of tube (test section) | Cm |
| $G$ | Gravitation Acceleration | $Cm/Sec^2$ |
| $G_c$ | Gravitation (Newtons) conversion factor | |
| $L$ | Length of stable air core | Cm |
| $\Delta P$ | Pressure drop of liquid measured at tangential inlets | $Kg/cm^2$ |
| $R$ | Radius at any point | Cm |
| $R_o$ | Tube radius test section | Cm |
| $V_i$ | Velocity of liquid at tangential inlets | Cm/sec. |
| $V_T$ | Tangential component of the velocity at any point | Cm/sec. |
| $Z$ | Axial distance down main tube referred from inlet plane | Cm |
| $\rho$ | Density of liquid | $Gm/cm^3$ |
| $\nu$ | Kinematic viscosity | $cm^2/sec$ |
| $C$ | Circulation constant | |

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# CHAPTER I

# INTRODUCTION AND LITERATURE REVIEW

## 1.1 INTRODUCTION

The flow characteristics of rotating systems are of great theoretical and practical importance and have been a subject of active interest for long time. Review of literature reveals that a paper was published(1) as early as 1880 on the gravitational oscillations of rotating water by Kelvin. The flow characteristics of rotating systems are complex and in addition most of the systems reveal novel and unexpected flow characteristics when put to a complete stability analysis.

Considerable work has been done in swirling flow through atomisers, fluid flow between rotating cylinders and in curved channels. Attention of various workers have been drawn on compressible swirling flow in tubes since 1950, however, relatively little work is available in literature regarding swirling incompressible flow in long tubes. The swirling flow inside long tubes can be generated by any one of the following methods:

(1) By rotating the tube through which the fluid is pumped.

(2) By introducing fluid into the tube with the help of guided vanes.

(3) By inserting twisted tape in the tube through which the fluid is pumped.

(4) By forcing liquid into the tube through tangential inlets at the inner surface of the tube.

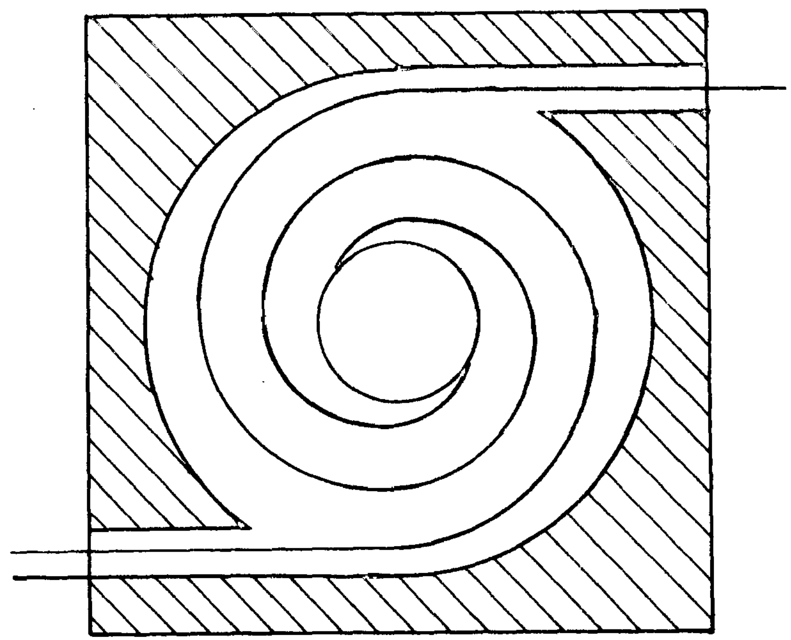



FIG. 1

PRODUCTION OF SWIRLING FLOW BY TANGENTIAL INJECTION OF LIQUID

GENERAL PRINCIPLE :

Principle of swirl flow generation can be understood by the help of fig. 1. showing formation of swirling flow by two tangential inlets. As the liquid enters through a tangential inlet No. 1 it takes a swirling motion and as it meets the liquid from the tangential inlet No. 2 it is pushed towards the centre of the tube. Thus a swirling motion is established. This swirling motion can be of two types

(1) Forced vortex flow in which angular velocity is constt and

(2) Free vortex motion in which the moment of momentum is radially converved such that the product of the tangential velocity component and radius at any point within the main body of the liquid is constt i.e.

$$V_T \times R = \Gamma \qquad (1.1)$$

where $\Gamma$ is generally referred to as circulation constant.

Swirling flow produced in tubes is generally more of free vortex in nature. In this type of flow we have already seen that the moment of the momentum is radially conserved ie product of tangential velocity component and radius at any point with in the main body of the fluid remains constant. This will predict creation of vacuum at the centre and hence reversal of axial flow is predicted even at lower strength of swirl.

From equation 1.1 it is apparent that as R approaches zero $V_T$ approaches infinite which is hydrodynamically impossible. The axial velocity component has been reported to cavitate near the central axis if the swirl strength is low. At higher values of swirl strength a complete reversal of axial component was reported still higher swirl strength give-rise to vacuum of such a degree that a central air-core is produced if the system is able to suck air at the axis of swirl from some source. If this air passage is sealed the liquid itself vapourises to give rise to vapour core.

## 1.2 LITERATURE REVIEW

Talbot(2) studied the swirling flow of water in a tube and employed a long unperforated tube in which swirl was induced by the rotation of tube situated at some distance from the entry. The swirl strength was insufficient to produce flow reversal but a dimpling of the axial velocity profile at the centre of the tube was reported.

Binnie and Teare(3) carried out experiments on the flow of swirling water through a pressure nozzle and recorded observations when the swirling water was discharged downwards under pressure through a large perspex conical nozzle. It was discovered that a boundary layer of forced vortex motion existed around the free surface of the aircore. The results were confirmed by measurement of tangential and axial velocities close to the free surface. Further when the swirl was sufficiently strong compared with the supply pressure the axial component of the velocity was reversed in the upper part of the nozzle close to the forced vortex zone.

Binnie(4) investigated the nature of the flow patterns when swirling water was passed through a long transparent horizontal straight tube. A portion of the tube (perspex tube of I.D. 2.0" ) was rotated and water was admitted by gravity into the tube through a large number of holes. The flow through the apparatus was controlled by altering the heights of the constant level tank, from which the water was fed. The maximum speed was about 40 revolutions per minute. Coloured liquid was injected and following three regimes were observed :-

(1) Down stream over entire cross section..

(2) Upstream near the axis and down stream near the tube wall.

(3) Down stream near the axis and the wall and upstream in the intermediate region.

Nuttal(5) carried out the study of swirling fluid flow in circular pipe. His experimental apparatus consisted of 2.875" I.D. 33" long perspex pipe set vertically and mounted by cylindrical tank containing a ring of guided vanes when produced the swirl ( free vortex ). The rate of discharge was controlled by throttling the lower end of the pipe by using several throttling devices. Dye injection technique was used for observing fluid path lines

No quantitative velocity measurements were made in his study. His observations were as follows:

(1) At low rates of swirl the axial velocity at the pipe centre was less than the expected maximum velocity.

(2) As average axialvelocity increased, centre line velocity decreased to a point where it reversed in direction.

(3) Finally upon further increase of the average vertical velocity, centre line axial velocity was positive at the centre but negative in a narrow region between the axis and the wall of the pipe.

His qualitative observations confirmed that flow reversal occurs in the centre of the pipe for some ratio of swirl and discharge. Similar observations were observed by Binnie (4) and were called regions, I II and III respectively. Although Binnie's method of producing swirl was different than that of Nuttal's.

Place et al (6) recorded investigations on the behaviour of the air flowing through large spray drier by making use of tracer technique and found the existence of the swirl flow pattern in spray drier. While studying the flow pattern of the spray drier in a model they found a region within their experimental equipment there a core of velocity opposite in direction to the primary flow existed. A transparent 1/80th scale model was used in which the fluid used was water and the same entered the model through 12 ports placed at appropriate angles to generate the swirl. Coloured solutions were injected into the model through these inlets.

The experiments conducted as above revealed the presence of a zone of reversed flow and they could observe a region of downward vertical velocity located between an upward central core and an upward velocity region adjacent to the wall. Values were not ascribed to the velocities but it was described as a "region III type of flow".

Kreith and Sonju (7) studied the decay of a liquid swirl which was induced by twisted metal strips along the centre line. Of a tube in an one inch pipe. It was observed that the swirl decay to about 10-20%. Of its initial intensity in a distance of about 50 pipe diameters the decay being more rapid at small than at large Reynolds numbers. In this work the swirl was not sufficiently. strong to produce flow reversal. The theoretical swirl velocity distribution agreed qualitatively with experimental measurements at distance less than 20 diameter down stream from the outlet, of the swirl inducer, but deviated from the experimental results further down stream.

Smithberg and Landis (8) while studying the convection heat transfer characteristics in tubes with twisted tape swirl generators also studied the velocity distribution and made the following conclusions.

(1) The axial velocity is nearly constant over most of the cross section while the inplane component appears to be tangential and increase linearly with radius.

(2) The velocity field is helicoidal and corresponds to a forced vortex in the core superimposed on an essentially uniform axial flow.

The author claims that a helicoidal flow with a uniform axial velocity with its total velocity vector tangent at every point to an helix defined by the pitch of the twisted strip and the radial distance from the tube centre line will result in a forced vortex motion in the tube cross section. This predicted vortex pattern was found to be in excellent agreement with the experimental results.

Brocan et al (9) studied the swirling incompressible flow of water in a tube held vertically with the swirl induced by tangential injection of the water into the test section from bottom of the tube. The inlet section consisted of 2 tangential inlet pipes which were parallel and 180° apart and flush with the baseplate. Inlet diameters were equal to D/4. Two tube diameters

2" and 2.5" I.D. were used for the 100" long test section. Water was pumped upwards through the vertical tubes. Lucite plastic tube were used for the test section so that visual observations could be made. In this investigation a study of pressure and velocity profile was made in an attempt to elucidate some of the factors governing the phenomenon of reversed flow. Profiles were studied at four lengths of pipe and for Reynolds numbers ranging from 5,000 to 25,000 with the help of two pressure probes (used separately to measure total and static pressures respectively) Reynolds numbers were measured based on the diameter of the tube and average vertical velocity in the tube. Their conclusions regarding velocity profiles were as under:

(1) Swirling flow produced by injecting water at constant rate and tangentially into a cylinder through two ports situated diametrically opposite to each other is found to be steady and approximately cylindrical and coaxial to the tube. Injection of water through a single port gave a spiral core and destroyed the cylindrical symmetry.

(2) Except in narrow regions near inlets and outlets of the cylinder radial velocities were always small compared to the tangential and axial velocities.

(3) The tangential velocity profile across a radius showed the velocity to increase from zero at the centre to a maximum at a radius usually less than half the tube radius to keep steady for the further distance and then to fall to zero again at the wall indicating that the flow was essentially forced vortex in nature.

(4) The mean tangential velocity, averaged across a diameter steady decreased down stream from the inlet.

(5) The axial referred to as vertical in their experiments showed the most interesting variations. For an overall upward flow along the tube they observed

(a) At low rates of flow the vertical velocity was upward throughout the cylinder

(b) At higher rates of flow there was reversal of flow at the axis of the tube so that water flowed downwards at the centre, reversed direction near the inlet and upward near the wall.

King et al (10) in their investigations in swirling incompressible tube flow took a system similar to Dresen et al . Their studies was carried out in 2" I.D. test section of plexi glass tube 10' long held horizontally. The wirl was introduced by injection of the total fluid stream through two symmetric tangential inlets 1/2" diameter perpendicular to the tube with equal flow rates to ensure axisymmetric flow. They also obtained static pressure and velocity profile by using probe technique. These profiles were determined for test section axial flow Reynolds numbers of 10,000 , 15,000 , 20,000 and 25,000. They concluded the following observations regarding the velocity profiles.

(1) The flow rate could be roughly divided into free and forced vortex regions.

(2) A region of reverse axial flow was noted in the tube centre, the radius of this region decreasing with increasing $Z/R_o$ to zero (Z = axial axial distance from the inlet of the main tube, $R_o$ is tube radius of test section.

(3) Also cumces of the tangential velocity/inlet velocity versus $Z/R_o$ were developed as a form of representation of swirl decay.

Pressure drop studies in swirling flow created by guided vanes, by rotation of the tube apparently has not been reported in the literature.

Smithberg et al (8) in their studies have concluded that the friction losses may be predicted from the combined effect of the axial and the tangential boundary layer flows coupled with an additional "Vortex mixing effect". They have also proposed an equation for predicting the total vortex mixing loss with satisfactory acuracy for tube with twisted tape turbulence generators. The range is applicable for Reynolds number in the range from 2,000 to 100,000.

Lopina et al (11) have made studies for the pressure drop in tape generated swirl flow of single phase water. The studies were carried out for electrically heated tubular test sections with tight fitting full length takes with twist rotation from 2.5 to 9.2. They have also reviewed the work of earlier investigators on this subject for various systems like air, other gases, water, liquid metals in generated swirl flow studies. These workers have suggested a simpler equation for predicting the isothermal friction factor for swirl flow. They also observed that the difference between the isothermal and heated friction factors for the swirl flow data was substantially less than the corresponding difference for the empty tube.

This investigation was carried out at the same times that of Thorsen and Landis who studied the friction; and heat transfer characteristics in turbulent swirl flow subjected to large transverse temperature gradient.

Bergles et al (12) carried out studies in rough tube with tape generated swirl flow. Pressure drop data for a variety of tubular test sections with low pressure water system was taken and also various combinations of the tube roughness and swirl flow were tried and utilized. They have proposed an expression for the isothermal swirl flow friction factor.

Brosan et al (9) recorded observations regarding the pressure profiles while studying the swirling incompressible flow of water in a tube held vertically with the swirl induced by tangential injection of water into the test section from bottom of the tube. Their conclusions were:

(1) Profiles of the static pressure along any radius of the tube always showed a minimum at the centre with a more or less steady increase towards the wall.

(2) The static pressure profile as well as patterns of flow established by the axial velocities were primarily controlled by the variations of tangential velocity along the radius of tube and its decay along the axial direction. Boundary layer growth appears to offer an explanation for the doubly reversed flow described as above.

(3) The static pressure measured at the wall decreased steadily down stream from the inlet.

King et al (10) who conducted the studies in swirling incompressible horizontal tube flow, with the swirl induced by tangential injection of the water into the test section made observations regarding pressure profiles and concluded that the static pressure $Z/R_o$ increases monotically from the centre line to the wall with increasing $Z/R_o$, the magnitude of this gradient decreases as the gradient producing swirl decays. In addition it is particularly interesting to note that at, and near, the centre line the axial pressure gradient is positive for considerable distance from the tube

1.3 WORK CARRIED OUT IN OUR DEPARTMENT

Considerable studies have also been conducted in our department in the field of swirling flow in horizontal and vertical tubes.

Studies in swirling flow in vertical tubes have been conducted by Shri Goel (16) and Shri Chandra (15). Mr. Goel (16) produced the swirling flow by injecting water through the tangential inlets at the bottom of the tube. He employed a 3.80 cm internal diameter and about 2.0 meters long perspex tube for his studies. In his studies he has confirmed the existence o the flow reversal and also shown that the flow reversal can be removed by injecting air at the axis of the vertical tube. Further

Sri Gool has carried out a photographic study for the above phenomenon of flow reversal and its removal. Flow pattern studies were done with the help of dye injection technique. Effects of various geometrical and flow dynamic parameters on pressure drop in such a flow have been studied. Theoretical method has been proposed to compute the pressure drop in this type of flow. His studies contains the production of swirling flow by using a tangential entry block as well as by using a swirl chamber.

Mr. Chandra (15) has carried out the swirling flow studies in vertical tubes by injecting liquid through tangential inlets from the top of the tube and allowing the water to flow downwards. The tubes employed by Sri Chandra were of perspex ranging from 1.80 to 5.60 cms in internal diameter and 130.- cms in length. The upper end of the tube was screwed in the tangential entry head. Shri Chandra has also confirmed the existence of flow reversal and its removal by the technique used by Sharma (15). I" swirling flow the pressure drop across the e ntry head and the tube through which the liquid is flowing is the summation of the friction is due to sudden expansion of cross section of the pipe, the radial pressure drop at the entry head, the pressure drop due to swirling flow inside the tube and the pressure drop due to friction in the entry pipes. As the various parameters involved were not easily amendable for measurement and in view of the difficulty he has proposed the following dimensionless correlation

$$Eu = (Re)^{-0.41} (Fr)^{0.01} (D_1/DT)^{-0.03} (L/DT)^{-0.85}$$

Sharma et al (13,153) have developed a new method for generating swirling flow by use of separate swirl chamber and exposing the axis of the swirl to atmosphere or injecting air thereby breaking he flow reversal. In the studies carried out in our laborato ies in this depth they have studied the incompressible rotating liquids without flow reversal in horizontal tubes of four different diameters and lengths for 2.0 metres to 4.0 metres approximately. They have carried out experiments and developed various correlation for predicting pressure drop, air core diameter and length as stated below.

Sharma has also revealed the existence of flow reversal in such systems and its removal with the technique proposed and confirmation of the same work with the help of dye injection and photographic studies.

CORRELATION FOR PRESSURE DROP:

$$\frac{\Delta P\, g_c}{V_1^2 \rho} = 2.57 \times 10^{-2} \left[\frac{D_T V_1}{\nu}\right]^{-0.15} \left[\frac{V_1}{g\, D_T}\right]^{-0.065} \left[\frac{D_a}{D_T}\right]^{4.18} \left[\frac{D_T}{D_1}\right]^{2.6}$$

CORRELATION FOR DIAMETER OF CORE

$$\frac{D_a}{D_T} = 0.94 \left[\frac{D_a}{D_T}\right]^{-0.50} \left[\frac{D_T}{D_i}\right]^{0.16}$$

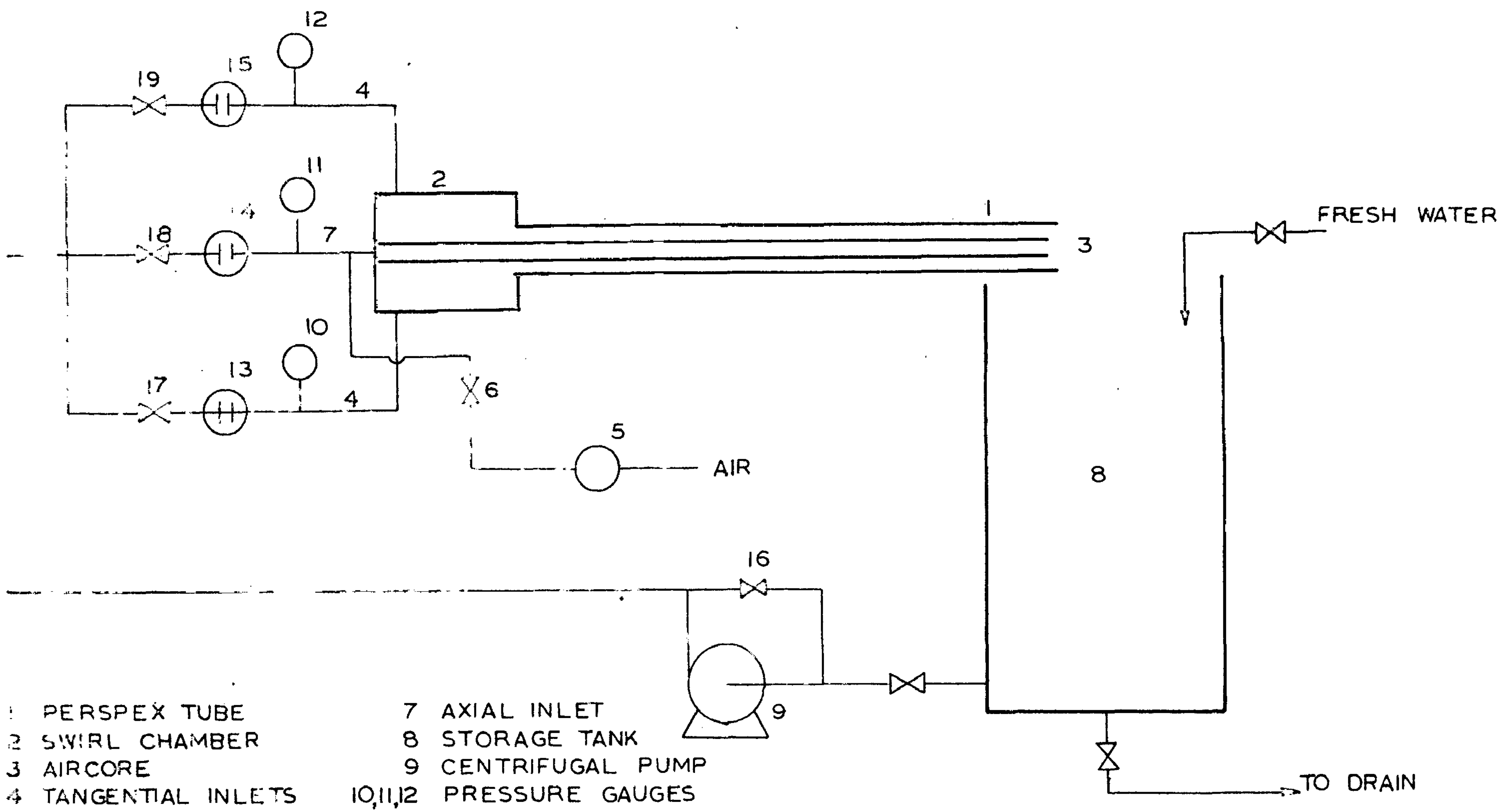
CORRELATION FOR LENGTH OF CORE

$$\frac{L}{D_T} = 2.72 \left[\frac{D_T\, V_i}{\nu}\right]^{0.41} \left[\frac{V_i}{g\, D_T}\right]^{0.17} \left[\frac{D_T}{D_o}\right]^{1.05} \left[\frac{D_i}{D_T}\right]^{1.58}$$

They have also mentioned that it is expected that probably the air core diameter and length of swirling flow in horizontal tubes will increase by super-imposing some horizontal axial flow on the tangential flow without much disturbing the stability of the aircore in the tangential flow. No work seems to have been done in this respect in the study of swirling flow proposed by tangential inlets in horizontal tubes. Therefore, it was proposed to study the effect of super-imposition of axial flow on the stability of swirling flow in horizontal tubes and its effect on the stability so that swirling flow system can be better utilised in industries.

# CHAPTER II

## EXPERIMENTAL SET UP



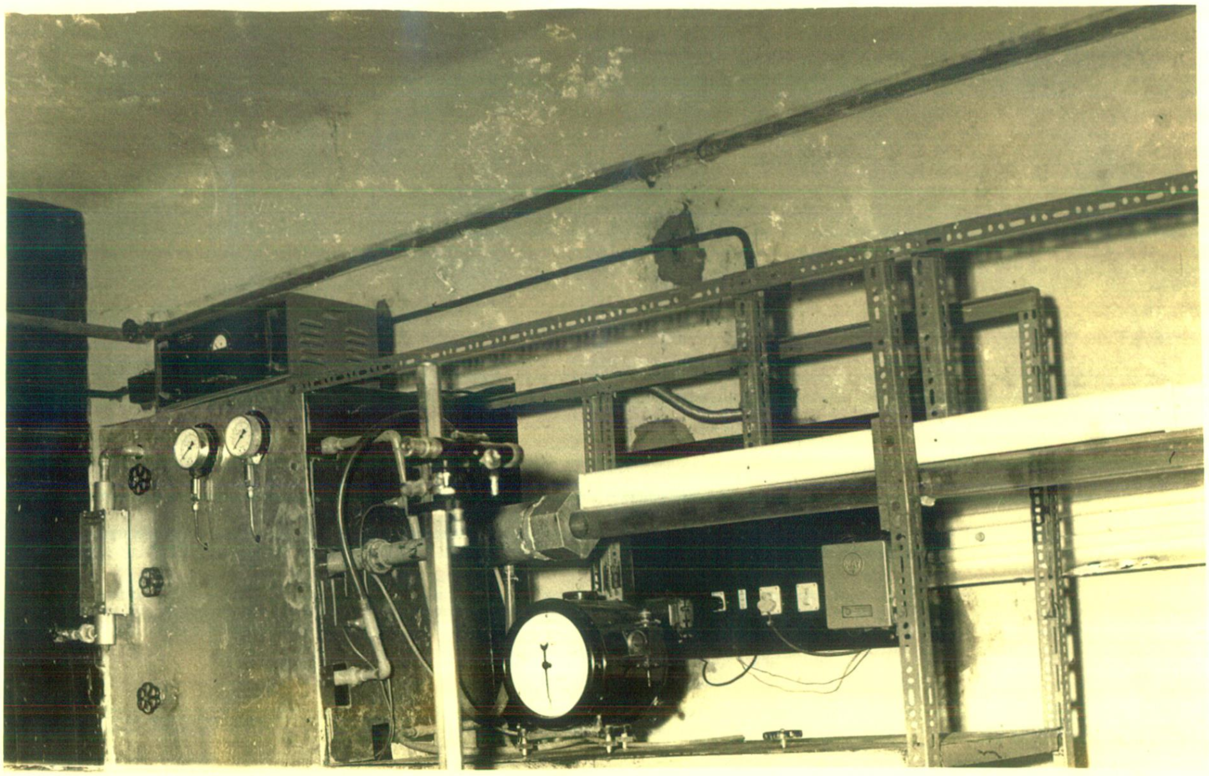

1 PERSPEX TUBE
2 SWIRL CHAMBER
3 AIRCORE
4 TANGENTIAL INLETS
5 WET GAS METER
6 AIR INLET
7 AXIAL INLET
8 STORAGE TANK
9 CENTRIFUGAL PUMP
10,11,12 PRESSURE GAUGES
13,14,15 ORIFICE METERS
16,17,18,19 GLOBE VALVES

FIG. 2 EXPERIMENTAL SET UP

## CHAPTER II

## EXPERIMENTAL SETUP.

The proposed experimental set up is shown in the Fig. (2) attached herewith. It consists of a long perspex tube (1) Tubes of different inside diameter can be used as required. Tubes of different lengths are used. A separate mild steel swirl chamber (2) is fitted to one end of the tube by stuffing box arrangement. The swirl chamber consists of one axial (7) and two symmetrically located tangential inlets (4) for feeding liquid to the swirl chamber. An air inlet (6) is provided for sucking or pumping air at the centre of axis of swirl. When the tangential inlet velocity is high enough to give rise to a free vortex type of motion a central air core 3 coaxial to the tube is obtained to a long distance inside the tube by allowing the air at the axis, measured by a calibrated wet gas meter (5). Water from a storage tank (8) is drawn by 3 H.P. centrifugal pump (9) and fed into both the tangential inlets at equal pressures, to obtain a stabilised swirling flow in the s swirl chamber. The inlet pressures are recorded by calibrated pressure gauges (10,11,12). The flow of water was measured by calibrated orificemeters (13,14,15) and also verified by direct measurements. Globe values (16,17,18, 19) are used for controlling flow of water. The experimental set up is shown in Fig. 2 for the studies of superimposition



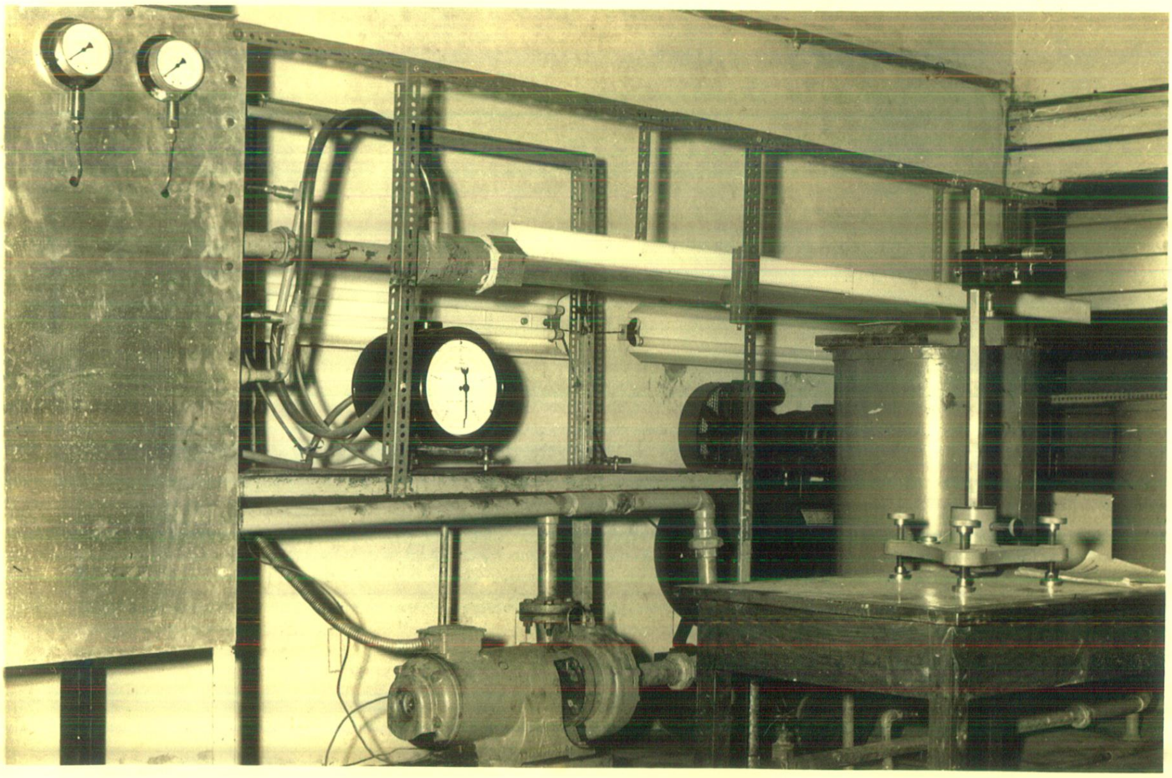


PLATE No. 1 AND 2

EXPERIMENTAL SET UP

of axial flow on tangential flow. A photograph of the same is shown in Plate No.1.

AIR-CORE MEASUREMENT

(a) Diameter:

The aircore diameter was measured with the help of a calibrated cathetometer having an eye piece calibrated for distance and refraction. The diameter of aircore was measured along the entire lngth of the tube. The average diameter was then computed. Care should always be taken to maintain reasonably straight and uniform air core throughout the length of the tube.

(b) Length:

A scale graduated in centimeters is kept fixed along the entire length of the perspex tube and the length of the aircore can be directly noted on this scale.

MEASUREMENT OF AIR RATE:

The quantity of air is to be measured with the help of a calibrated wet gas meter. The inlet pressure of air is to be recorded by a manometer.

# CHAPTER III

# OBSERVATIONS

## Table No. 1

Tube Diameter = 3.81 cms. Tangential flow rate = 3700 LPH

Air flow rate = 280 LPH. Correction factor for refraction=0.87

| Sr. No. | Distance along the length of tube (Cms.) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 2.435 | 2.580 | 2.364 | 2.297 | 2.373 | 2.306 |
| 2 | 10 | 2.371 | 2.673 | 2.445 | 2.388 | 2.343 | 2.223 |
| 3 | 20 | 2.351 | 2.551 | 2.565 | 2.413 | 2.300 | 2.325 |
| 4 | 30 | 2.507 | 2.518 | 2.377 | 2.372 | 2.375 | 2.279 |
| 5 | 40 | 2.516 | 2.462 | 2.355 | 2.326 | 2.262 | 2.288 |
| 6 | 50 | 2.480 | 2.466 | 2.323 | 2.311 | 2.366 | 2.306 |
| 7 | 60 | 2.459 | 2.419 | 2.393 | 2.284 | 2.268 | 2.227 |
| 8 | 70 | 2.393 | 2.359 | 2.292 | 2.271 | 2.339 | 2.245 |
| 9 | 80 | 2.352 | 2.314 | 2.350 | 2.194 | 2.253 | 2.185 |
| 10 | 90 | 2.245 | 2.266 | 2.187 | 2.122 | 2.172 | 2.219 |
| 11 | 100 | 2.198 | 2.137 | 2.158 | 2.038 | 2.093 | 1.968 |
| 12 | 110 | 2.158 | 2.248 | 2.138 | 1.934 | 2.114 | 1.956 |
| 13 | 120 | 2.137 | 2.144 | 2.114 | 1.888 | 2.003 | 1.917 |
| 14 | 130 | 2.074 | 2.057 | 1.960 | 1.884 | 2.060 | 1.844 |
| 15 | 140 | 2.057 | 2.067 | 1.958 | 1.949 | 2.058 | 1.890 |
| 16 | 150 | 2.005 | 1.843 | 1.836 | 1.815 | 1.985 | 1.871 |
| 17 | 160 | 1.937 | 1.897 | 1.844 | 1.827 | 1.764 | 1.740 |

## Table No. 3

Tube Diameter = 3.01 cms Tangential flow rate = 5700 LPH

Air flow rate = 200 LPH . Correction factor for refraction=0.87

| Sr. No. | Distance along the length of the tube (cms) | Corrected air core diameter (in cms) for superimposed axial flows (in LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 2.473 | 2.466 | 2.373 | 2.406 | 2.327 | 2.269 |
| 2 | 10 | 2.428 | 2.563 | 2.347 | 2.464 | 2.309 | 2.232 |
| 3 | 20 | 2.393 | 2.532 | 2.475 | 2.422 | 2.348 | 2.263 |
| 4 | 30 | 2.376 | 2.513 | 2.417 | 2.429 | 2.311 | 2.333 |
| 5 | 40 | 2.349 | 2.455 | 2.395 | 2.332 | 2.321 | 2.275 |
| 6 | 50 | 2.333 | 2.436 | 2.232 | 2.315 | 2.294 | 2.238 |
| 7 | 60 | 2.311 | 2.434 | 2.363 | 2.263 | 2.317 | 2.307 |
| 8 | 70 | 2.304 | 2.455 | 2.314 | 2.302 | 2.293 | 2.304 |
| 9 | 80 | 2.295 | 2.319 | 2.273 | 2.067 | 2.250 | 2.152 |
| 10 | 90 | 2.266 | 2.272 | 2.162 | 2.251 | 2.127 | 2.204 |
| 11 | 100 | 2.201 | 2.169 | 2.182 | 2.132 | 1.983 | 2.091 |
| 12 | 110 | 2.163 | 2.112 | 2.125 | 2.101 | 2.013 | 1.953 |
| 13 | 120 | 2.114 | 2.192 | 2.255 | 2.045 | 2.093 | 1.950 |
| 14 | 130 | 2.692 | 2.033 | 2.105 | 2.070 | 1.888 | 1.924 |
| 15 | 140 | 2.077 | 2.696 | 2.110 | 1.045 | 1.924 | 1.924 |
| 16 | 150 | 2.001 | 1.837 | 1.827 | 2.001 | 1.923 | [illegible] |
| 17 | 160 | 1.934 | 1.829 | 1.810 | 2.001 | 1.762 | [illegible] |

Table No. 3

...r = 3.81 cms Tangential flow rate = 8700 LPH

...te = 650 LPH Correction factor for refraction 0.87

| ...e along ...gth of ...ube ...) | Corrected air core diameter (in cms) for ... imposed axial flows (in LPH) | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 100 | 200 | 300 | 400 | 500 |
| ) | 2.574 | 2.364 | 2.376 | 2.342 | 2.326 | 2.35 |
| ) | 2.571 | 2.504 | 2.440 | 2.445 | 2.429 | 2.34 |
| ) | 2.580 | 2.471 | 2.453 | 2.451 | 2.423 | 2.23 |
| ) | 2.519 | 2.423 | 2.416 | 2.399 | 2.338 | 2.39 |
| ) | 2.513 | 2.425 | 2.420 | 2.382 | 2.352 | 2.34 |
| ) | 2.363 | 2.381 | 2.[illegible] | 2.362 | 2.349 | 2.37 |
| ) | 2.436 | 2.433 | 2.370 | 2.351 | 2.327 | 2.3 |
| ) | 2.433 | 2.379 | 2.393 | 2.338 | 2.363 | 2.2 |
| ) | 2.373 | 2.349 | 2.293 | 2.299 | 2.239 | 2.2 |
| ) | 2.394 | 2.333 | 2.210 | 2.290 | 2.230 | 2.2 |
| ) | 2.236 | 2.239 | 2.253 | 2.137 | 2.169 | 2.1 |
| ) | 2.170 | 2.217 | 2.175 | 2.096 | 2.152 | 2.1 |
| ) | 2.093 | 2.213 | 2.201 | 2.045 | 2.035 | 2.0 |
| ) | 2.045 | 2.193 | 2.201 | 2.023 | 2.026 | 2.0 |
| ) | 2.001 | 2.171 | 2.102 | 1.999 | 1.970 | 1.9 |
| ) | 1.953 | 2.049 | 2.020 | 1.940 | 1.940 | 1.8 |
| ) | 1.949 | 1.971 | 1.953 | 1.853 | 1.857 | 1.8 |

## Table No. 4

Tube Diameter = 3.81 cms., Tangential flow rate = 4870 LPH

Air flow rate = 490 LPH Correction factor for refraction = 9.87

| Sr. No. | Distance along the length of tube (Cms.) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 2.333 | 2.366 | 2.449 | 2.416 | 2.228 | 2.218 |
| 2 | 10 | 2.337 | 2.384 | 2.393 | 2.418 | 2.340 | 2.244 |
| 3 | 20 | 2.443 | 2.324 | 2.439 | 2.364 | 2.289 | 2.296 |
| 4 | 30 | 2.486 | 2.448 | 2.499 | 2.395 | 2.376 | 2.221 |
| 5 | 40 | 2.470 | 2.423 | 2.423 | 2.359 | 2.31246 | 2.225 |
| 6 | 50 | 2.450 | 2.450 | 2.433 | 2.320 | 2.209 | 2.208 |
| 7 | 60 | 2.425 | 2.343 | 2.349 | 2.324 | 2.229 | 2.181 |
| 8 | 70 | 2.431 | 2.333 | 2.339 | 2.298 | 2.241 | 2.133 |
| 9 | 80 | 2.346 | 2.219 | 2.255 | 2.218 | 2.100 | 2.144 |
| 10 | 90 | 2.238 | 2.245 | 2.260 | 2.121 | 2.110 | 2.058 |
| 11 | 100 | 2.125 | 2.109 | 2.112 | 2.071 | 2.077 | 2.013 |
| 12 | 110 | 2.113 | 2.009 | 2.022 | 2.031 | 2.058 | 1.981 |
| 13 | 120 | 1.973 | 2.045 | 2.009 | 2.001 | 1.922 | 1.945 |
| 14 | 130 | 1.905 | 1.998 | 2.001 | 1.938 | 1.853 | 1.882 |
| 15 | 140 | 1.898 | 1.996 | 1.931 | 1.940 | 1.827 | 1.806 |
| 16 | 150 | 1.871 | 1.941 | 1.970 | 1.879 | 1.847 | 1.869 |
| 17 | 160 | 1.938 | 1.880 | 1.900 | 1.871 | 1.842 | 1.749 |

## Table No. 5

Tube diameter = 3.81 cms ; Tangential flow rate = 4870 LPH

Air flow rate = 835 LPH ; Correction factor for refraction = 0.87

| Sr. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 2.564 | 2.449 | 2.428 | 2.408 | 2.415 | 2.324 |
| 2 | 10 | 2.597 | 2.449 | 2.471 | 2.470 | 2.540 | 2.265 |
| 3 | 20 | 2.564 | 2.524 | 2.400 | 2.437 | 2.449 | 2.326 |
| 4 | 30 | 2.541 | 2.495 | 2.481 | 2.413 | 2.418 | 2.350 |
| 5 | 40 | 2.523 | 2.486 | 2.403 | 2.362 | 2.366 | 2.275 |
| 6 | 50 | 2.503 | 2.472 | 2.432 | 2.365 | 2.357 | 2.263 |
| 7 | 60 | 2.461 | 2.467 | 2.365 | 2.363 | 2.334 | 2.227 |
| 8 | 70 | 2.436 | 2.403 | 2.352 | 2.265 | 2.305 | 2.188 |
| 9 | 80 | 2.380 | 2.344 | 2.331 | 2.197 | 2.211 | 2.171 |
| 10 | 90 | 2.331 | 2.301 | 2.279 | 2.169 | 2.204 | 2.114 |
| 11 | 100 | 2.321 | 2.225 | 2.180 | 2.063 | 2.123 | 2.057 |
| 12 | 110 | 2.231 | 2.173 | 2.094 | 2.043 | 2.101 | 2.054 |
| 13 | 120 | 2.161 | 2.152 | 2.122 | 2.035 | 2.082 | 1.993 |
| 14 | 130 | 2.114 | 2.113 | 2.092 | 2.020 | 2.034 | 1.973 |
| 15 | 140 | 2.096 | 2.027 | 2.015 | 1.934 | 1.996 | 1.917 |
| 16 | 150 | 2.008 | 1.935 | 1.962 | 1.899 | 1.941 | 1.867 |
| 17 | 160 | 1.940 | 1.920 | 1.907 | 1.920 | 1.887 | 1.809 |

## Table No. 6

Tube diameter = 3.81 cms. Tangential flow rate = 4070 LPH

Air flow rate = 1310 LPH ; Correction factor for refraction=0.87

| Sr. No. | Distance along the length of tube (Cms). | Corrected air core diameter (in cms) for super-imposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 2.575 | 2.484 | 2.462 | 2.479 | 2.436 | 2.394 |
| 2 | 10 | 2.637 | 2.524 | 2.474 | 2.489 | 2.518 | 2.420 |
| 3 | 20 | 2.606 | 2.540 | 2.522 | 2.509 | 2.461 | 2.331 |
| 4 | 30 | 2.597 | 2.523 | 2.457 | 2.441 | 2.492 | 2.450 |
| 5 | 40 | 2.578 | 2.491 | 2.411 | 2.401 | 2.395 | 2.318 |
| 6 | 50 | 2.514 | 2.477 | 2.354 | 2.438 | 2.347 | 2.370 |
| 7 | 60 | 2.470 | 2.430 | 2.340 | 2.347 | 2.296 | 2.291 |
| 8 | 70 | 2.469 | 2.426 | 2.326 | 2.321 | 2.303 | 2.282 |
| 9 | 80 | 2.396 | 2.305 | 2.279 | 2.268 | 2.249 | 2.267 |
| 10 | 90 | 2.339 | 2.276 | 2.266 | 2.305 | 2.288 | 2.249 |
| 11 | 100 | 2.132 | 2.268 | 2.248 | 2.199 | 2.179 | 2.213 |
| 12 | 110 | 2.270 | 2.249 | 2.228 | 2.242 | 2.181 | 2.125 |
| 13 | 120 | 2.215 | 2.209 | 2.166 | 2.202 | 2.175 | 2.103 |
| 14 | 130 | 2.201 | 2.133 | 2.119 | 2.107 | 2.122 | 2.103 |
| 15 | 140 | 2.117 | 2.150 | 2.070 | 2.042 | 2.089 | 2.060 |
| 16 | 150 | 2.083 | 2.053 | 2.037 | 2.034 | 2.009 | 1.997 |
| 17 | 160 | 2.068 | 2.023 | 1.992 | 1.957 | 1.922 | 1.865 |

## Table No. 7

Tube Diameter = 3.81 cms; Tangential flow rate = 4040 LPH

Air flow rate = 365 LPH ; Correction factor for refraction=0.8

| Sr. No. | Distance along the length of tube (Cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 2.436 | 2.379 | 2.375 | 2.374 | 2.249 | 2.163 |
| 2 | 10 | 2.653 | 2.502 | 2.428 | 2.349 | 2.386 | 2.293 |
| 3 | 20 | 2.502 | 2.457 | 2.367 | 2.347 | 2.333 | 2.257 |
| 4 | 30 | 2.499 | 2.432 | 2.363 | 2.299 | 2.293 | 2.228 |
| 5 | 40 | 2.434 | 2.416 | 2.356 | 2.316 | 2.261 | 2.210 |
| 6 | 50 | 2.410 | 2.385 | 2.393 | 2.311 | 2.246 | 2.215 |
| 7 | 60 | 2.312 | 2.365 | 2.319 | 2.286 | 2.230 | 2.204 |
| 8 | 70 | 2.363 | 2.369 | 2.279 | 2.262 | 2.212 | 2.185 |
| 9 | 80 | 2.282 | 2.316 | 2.230 | 2.204 | 2.197 | 2.175 |
| 10 | 90 | 2.257 | 2.267 | 2.227 | 2.203 | 2.170 | 2.140 |
| 11 | 100 | 2.163 | 2.186 | 2.192 | 2.098 | 2.088 | 2.071 |
| 12 | 110 | 2.148 | 2.131 | 2.175 | 2.094 | 2.056 | 2.054 |
| 13 | 120 | 2.088 | 2.032 | 2.056 | 2.025 | 2.006 | 2.015 |
| 14 | 130 | 2.061 | 2.035 | 2.021 | 2.013 | 2.004 | 1.998 |

Table No. 8

Tube diameter = 4.01 cms  Tangential flow rate = 4040 LPH

Air flow rate = 600 LPH ; Correction factor for refraction=0.07

| Sr. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axialflow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 2.498 | 2.432 | 2.463 | 2.305 | 2.403 | 2.334 |
| 2 | 10 | 2.532 | 2.571 | 2.422 | 2.426 | 2.366 | 2.422 |
| 3 | 20 | 2.528 | 2.562 | 2.422 | 2.415 | 2.333 | 2.391 |
| 4 | 30 | 2.524 | 2.508 | 2.424 | 2.388 | 2.388 | 2.320 |
| 5 | 40 | 2.488 | 2.455 | 2.409 | 2.363 | 2.326 | 2.277 |
| 6 | 50 | 2.453 | 2.496 | 2.337 | 2.349 | 2.321 | 2.277 |
| 7 | 60 | 2.432 | 2.458 | 2.362 | 2.349 | 2.329 | 2.240 |
| 8 | 70 | 2.399 | 2.245 | 2.325 | 2.346 | 2.312 | 2.237 |
| 9 | 80 | 2.366 | 2.364 | 2.273 | 2.338 | 2.303 | 2.219 |
| 10 | 90 | 2.340 | 2.344 | 2.262 | 2.322 | 2.232 | 2.203 |
| 11 | 100 | 2.325 | 2.307 | 2.250 | 2.307 | 2.262 | 2.175 |
| 12 | 110 | 2.325 | 2.253 | 2.186 | 2.302 | 2.229 | 2.151 |
| 13 | 120 | 2.305 | 2.223 | 2.164 | 2.232 | 2.203 | 2.129 |
| 14 | 130 | 2.262 | 2.227 | 2.183 | 2.224 | 2.212 | 2.095 |
| 15 | 140 | 2.245 | 2.224 | 2.153 | 2.175 | 2.112 | 2.035 |

Table No. 9

Tube diameter = 3.81 cms. , Tangential flow rate = 4040 LPH

Air flow rate =300 LPH , Correction factor refraction = 0.87

| Sr No. | Distance along the length of tube(cms) | Corrected air core diameter (in cms) for super-imposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 2.550 | 2.526 | 2.493 | 2.497 | 2.375 | 2.372 |
| 2 | 10 | 2.573 | 2.599 | 2.493 | 2.495 | 2.450 | 2.530 |
| 3 | 20 | 2.610 | 2.587 | 2.520 | 2.405 | 2.330 | 2.270 |
| 4 | 30 | 2.585 | 2.553 | 2.549 | 2.447 | 2.93 | 2.343 |
| 5 | 40 | 2.589 | 2.456 | 2.307 | 2.368 | 2.326 | 2.319 |
| 6 | 50 | 2.501 | 2.556 | 2.393 | 2.332 | 2.309 | 2.224 |
| 7 | 60 | 2.469 | 2.446 | 2.426 | 2.448 | 2.300 | 2.276 |
| 8 | 70 | 2.441 | 2.499 | 2.399 | 2.356 | 2.320 | 2.194 |
| 9 | 80 | 2.455 | 2.317 | 2.305 | 2.306 | 2.256 | 2.132 |
| 10 | 90 | 2.338 | 2.331 | 2.314 | 2.297 | 2.220 | 2.157 |
| 11 | 100 | 2.301 | 2.224 | 2.194 | 2.170 | 2.152 | 2.005 |
| 12 | 110 | 2.299 | 2.188 | 2.203 | 2.166 | 2.104 | 1.984 |
| 13 | 120 | 2.231 | 2.248 | 2.125 | 2.155 | 2.152 | 2.690 |
| 14 | 130 | 2.276 | 2.178 | 2.134 | 2.165 | 2.134 | 1.978 |
| 15 | 140 | 2.223 | 2.219 | 2.263 | 2.166 | 2.142 | 2.029 |

## Table No. 10

Tube Diameter = 3.81 cms. Tangential flow rate = 3344 LPH

Air flow rate = 400 LPH , Correction factor for refraction = 0.87

| Sr. No. | Distance along the length of tube(cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 2.440 | 2.362 | 2.318 | 2.311 | 2.278 | 2.145 |
| 2 | 10 | 2.445 | 2.484 | 2.459 | 2.318 | 2.242 | 2.219 |
| 3 | 20 | 2.573 | 2.339 | 2.403 | 2.418 | 2.292 | 2.309 |
| 4 | 30 | 2.900 | 2.400 | 2.451 | 2.306 | 2.235 | 2.152 |
| 5 | 40 | 2.419 | 2.401 | 2.341 | 2.262 | 2.193 | 2.175 |
| 6 | 50 | 2.360 | 2.424 | 2.378 | 2.271 | 2.205 | 2.149 |
| 7 | 60 | 2.401 | 2.302 | 2.396 | 2.246 | 2.181 | 2.166 |
| 8 | 70 | 2.394 | 2.353 | 2.341 | 2.304 | 2.223 | 2.145 |
| 9 | 80 | 2.309 | 2.243 | 2.283 | 2.227 | 2.185 | 2.169 |
| 10 | 90 | 2.172 | 2.177 | 2.240 | 2.217 | 2.136 | 2.105 |
| 11 | 100 | 2.159 | 2.175 | 2.118 | 2.106 | 2.106 | 2.105 |

## Table No. 11

Tube Diameter = 3.81 cms. Tangential flow rate = 3344 LPH

Air flow rate = 900 LPH .Correction factor for refraction=0.87

| Sr. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for super-imposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 2.422 | 2.431 | 2.393 | 2.139 | 2.358 | 2.187 |
| 2 | 10 | 2.551 | 2.492 | 2.437 | 2.318 | 2.339 | 2.329 |
| 3 | 20 | 2.549 | 2.502 | 2.426 | 2.456 | 2.311 | 2.265 |
| 4 | 30 | 2.543 | 2.457 | 2.405 | 2.317 | 2.276 | 2.265 |
| 5 | 40 | 2.509 | 2.459 | 2.393 | 2.310 | 2.273 | 2.225 |
| 6 | 50 | 2.468 | 2.419 | 2.380 | 2.331 | 2.294 | 2.219 |
| 7 | 60 | 2.443 | 2.426 | 2.412 | 2.256 | 2.239 | 2.224 |
| 8 | 70 | 2.399 | 2.407 | [illegible] | 2.293 | 2.271 | 2.214 |
| 9 | 80 | 2.365 | 2.353 | 2.306 | 2.253 | 2.261 | 2.145 |
| 10 | 90 | 2.315 | 2.347 | [illegible] | 2.239 | 2.212 | 2.1001 |
| 11 | 100 | 2.222 | 2.184 | 2.139 | 2.166 | 2.123 | 2.065 |

Table No. 12

Tube diameter = 3.81 cms. Tangential flow rate = 3944 LPH

Air flow rate = 960 LPH , Correction factor for refraction=0.87

| Sr. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 2.512 | 2.356 | 2.332 | 2.339 | 2.366 | 2.293 |
| 2 | 10 | 2.554 | 2.456 | 2.439 | 2.396 | 2.349 | 2.368 |
| 3 | 20 | 2.523 | 2.623 | 2.464 | 2.469 | 2.389 | 2.412 |
| 4 | 30 | 2.511 | 2.546 | 2.454 | 2.412 | 2.346 | 2.292 |
| 5 | 40 | 2.430 | 2.472 | 2.466 | 2.293 | 2.276 | 2.240 |
| 6 | 50 | 2.480 | 2.423 | 2.390 | 2.357 | 2.349 | 2.266 |
| 7 | 60 | 2.450 | 2.375 | 2.355 | 2.278 | 2.260 | 2.199 |
| 8 | 70 | 2.447 | 2.464 | 2.326 | 2.367 | 2.333 | 2.312 |
| 9 | 80 | 2.388 | 2.303 | 2.270 | 2.270 | 2.259 | 2.188 |
| 10 | 90 | 2.342 | 2.310 | 2.212 | 2.331 | 2.253 | 2.163 |
| 11 | 100 | 2.179 | 2.129 | 2.158 | 2.156 | 2.132 | 2.105 |

Table No. 11

Tube Diameter = 3.81 cm. Tangential flow rate = 2240 LPH

Air flow rate = 300 LPH . Correction factor for refraction =0.87

| Sr. No. | Distance along the length of tube (cm) | Corrected air diameter (in cm) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 2.426 | 2.342 | 2.340 | 2.091 | 1.907 | |
| 2 | 10 | 2.514 | 2.444 | 2.383 | 2.109 | 1.905 | |
| 3 | 20 | 2.368 | 2.329 | 2.284 | 2.065 | 1.876 | |
| 4 | 30 | 2.360 | 2.339 | 2.269 | 2.152 | 1.850 | |
| 5 | 40 | 2.296 | 2.257 | 2.246 | 2.024 | 1.847 | |
| 6 | 50 | 2.137 | 2.244 | 2.193 | 2.049 | 1.770 | |
| 7 | 60 | 2.248 | 2.249 | 2.195 | 2.024 | 1.776 | |
| 8 | 70 | 2.306 | 2.241 | 2.175 | 1.970 | 1.764 | |
| 9 | 80 | 2.172 | 2.201 | 2.093 | 1.930 | 1.749 | |
| 10 | 90 | 2.162 | 2.125 | 2.096 | 1.901 | 1.734 | |

## Table No. 14

Tube diameter = 3.81 cm. Tangential flow rate = 2240 LPH

Air flow rate = 600 LPH. Correction factor for refraction = 0.87

| Sr. No. | Distance along the length of tube (cm) | Corrected air core diameter (in cm) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 2.393 | 2.427 | 2.391 | 2.330 | 2.208 | 2.185 |
| 2 | 10 | 2.460 | 2.399 | 2.346 | 2.301 | 2.239 | 2.204 |
| 3 | 20 | 2.587 | 2.393 | 2.296 | 2.272 | 2.261 | 2.218 |
| 4 | 30 | 2.500 | 2.390 | 2.309 | 2.292 | 2.192 | 2.184 |
| 5 | 40 | 2.413 | 2.332 | 2.303 | 2.275 | 2.013 | 2.153 |
| 6 | 50 | 2.427 | 2.346 | 2.313 | 2.312 | 2.149 | 2.132 |
| 7 | 60 | 2.376 | 2.306 | 2.284 | 2.252 | 2.158 | 2.130 |
| 8 | 70 | 2.323 | 2.281 | 2.262 | 2.242 | 2.123 | 2.097 |
| 9 | 80 | 2.312 | 2.230 | 2.216 | 2.134 | 2.080 | 2.053 |
| 10 | 90 | 2.273 | 2.233 | 2.177 | 2.142 | 2.047 | 2.002 |

Table No. 15.

Tube diameter = 3.81 cms. Tangential flow rate = 2240 LPH

Air flow rate=960 LPH , Correction factor for refraction=0.87

| Sr. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 2.458 | 2.415 | 2.352 | 2.308 | 2.299 | 2.201 |
| 2 | 10 | 2.466 | 2.421 | 2.393 | 2.352 | 2.284 | 2.250 |
| 3 | 20 | 2.506 | 2.410 | 2.387 | 2.353 | 2.288 | 2.255 |
| 4 | 30 | 2.483 | 2.403 | 2.347 | 2.323 | 2.279 | 2.245 |
| 5 | 40 | 2.452 | 2.393 | 2.321 | 2.306 | 2.262 | 2.200 |
| 6 | 50 | 2.426 | 2.412 | 2.306 | 2.262 | 2.247 | 2.170 |
| 7 | 60 | 2.362 | 2.354 | 2.353 | 2.240 | 2.198 | 2.163 |
| 8 | 70 | 2.338 | 2.307 | 2.292 | 2.243 | 2.215 | 2.132 |
| 9 | 80 | 2.321 | 2.304 | 2.210 | 2.207 | 2.189 | 2.125 |
| 10 | 90 | 2.297 | 2.281 | 2.219 | 2.196 | 2.178 | 2.133 |

## Table No. 16

Tube Diameter = 5.715 cms.
Tangential flow rate = 6164 LPH
Air flow rate = 350 LPH

Correction factor for refraction = 0.89

| Sr. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 5.1860 | 5.102 | 5.042 | 4.924 | 4.880 | 4.793 |
| 2 | 10 | 5.175 | 5.100 | 4.232 | 4.910 | 4.852 | 4.738 |
| 3 | 20 | 5.148 | 5.050 | 4.950 | 4.880 | 4.821 | 4.775 |
| 4 | 30 | 5.020 | 5.010 | 4.874 | 4.834 | 4.785 | 4.756 |
| 5 | 40 | 4.940 | 4.900 | 4.750 | 4.710 | 4.682 | 4.635 |
| 6 | 50 | 4.880 | 4.802 | 4.702 | 4.648 | 4.584 | 4.520 |
| 7 | 60 | 4.774 | 4.752 | 4.630 | 4.563 | 4.512 | 4.454 |
| 8 | 70 | 4.630 | 4.612 | 4.580 | 4.525 | 4.484 | 4.462 |
| 9 | 80 | 4.620 | 4.602 | 4.500 | 4.452 | 4.410 | 4.410 |
| 10 | 90 | 4.557 | 4.510 | 4.480 | 4.426 | 4.392 | 4.376 |
| 11 | 100 | 4.500 | 4.450 | 4.452 | 4.401 | 4.372 | 4.356 |
| 12 | 110 | 4.510 | 4.448 | 4.402 | 4.389 | 4.366 | 4.342 |
| 13 | 120 | 4.454 | 4.412 | 4.419 | 4.350 | 4.342 | 4.333 |
| 14 | 130 | 4.450 | 4.390 | 4.360 | 4.325 | 4.316 | 4.310 |
| 15 | 140 | 4.442 | 4.390 | 4.342 | 4.318 | 4.299 | 4.392 |
| 16 | 150 | 4.362 | 4.358 | 4.320 | 4.302 | 4.288 | 4.233 |

## Table No. 17

Tube diameter = 5.719
Tangential flow rate = 6254 LPH
Air flow rate = 710 LPH
Correction factor for refraction = 0.85

| Sr. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 5.210 | 5.192 | 5.120 | 5.080 | 4.930 | 4.815 |
| 2 | 10 | 5.175 | 5.162 | 5.102 | 5.054 | 4.935 | 4.810 |
| 3 | 20 | 5.124 | 5.112 | 5.062 | 5.028 | 4.890 | 4.800 |
| 4 | 30 | 5.080 | 5.030 | 4.910 | 4.925 | 4.884 | 4.788 |
| 5 | 40 | 5.022 | 4.992 | 4.946 | 4.910 | 4.832 | 4.776 |
| 6 | 50 | 4.910 | 4.900 | 4.868 | 4.821 | 4.780 | 4.720 |
| 7 | 60 | 4.800 | 4.762 | 4.722 | 4.684 | 4.620 | 4.572 |
| 8 | 70 | 4.734 | 4.700 | 4.872 | 4.622 | 4.580 | 4.514 |
| 9 | 80 | 4.625 | 4.610 | 4.575 | 4.525 | 4.510 | 4.480 |
| 10 | 90 | 4.583 | 4.552 | 4.520 | 4.476 | 4.465 | 4.410 |
| 11 | 100 | 4.564 | 4.552 | 4.520 | 4.461 | 4.442 | 4.411 |
| 12 | 110 | 4.540 | 4.520 | 4.460 | 4.418 | 4.400 | 4.392 |
| 13 | 120 | 4.500 | 4.488 | 4.432 | 4.412 | 4.374 | 4.385 |
| 14 | 130 | 4.482 | 4.456 | 4.412 | 4.375 | 4.346 | 4.376 |
| 15 | 140 | 4.440 | 4.426 | 4.400 | 4.368 | 4.329 | 4.350 |
| 16 | 150 | 4.420 | 4.405 | 4.390 | 4.362 | 4.348 | 4.332 |

## Table No. 18

Tube diameter = 5.715 cms

Tangential flow rate = 6164 LPH

Air flow rate = 1200 LPH

Correction factor for refraction = 0.85

| S. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 3000 | 400∅ | 500 |
| 1 | 0 | 5.256 | 5.218 | 5.180 | 5.122 | 4.968 | 4.880 |
| 2 | 10 | 5.210 | 5.162 | 5.110 | 5.074 | 4.922 | 4.835 |
| 3 | 20 | 5.181 | 5.125 | 5.078 | 5.018 | 4.874 | 4.820 |
| 4 | 30 | 5.126 | 5.082 | 4.962 | 4.914 | 4.823 | 4.813 |
| 5 | 40 | 5.082 | 5.024 | 4.912 | 4.875 | 4.786 | 4.762 |
| 6 | 50 | 4.924 | 4.902 | 4.854 | 4.812 | 4.740 | 4.700 |
| 7 | 60 | 4.873 | 4.832 | 4.728 | 4.683 | 4.675 | 4.590 |
| 8 | 70 | 4.812 | 4.765 | 4.714 | 4.679 | 4.612 | 4.580 |
| 9 | 80 | 4.714 | 4.682 | 4.634 | 4.592 | 4.544 | 4.500 |
| 0 | 90 | 4.610 | 4.572 | 4.600 | 4.534 | 4.510 | 4.447 |
| 1 | 100 | 4.590 | 4.529 | 4.577 | 4.521 | 4.475 | 4.424 |
| 2 | 110 | 4.582 | 4.522 | 4.519 | 4.480 | 4.424 | 4.400 |
| 3 | 120 | 4.540 | 4.490 | 4.512 | 4.460 | 4.418 | 4.391 |
| 4 | 130 | 4.525 | 4.472 | 4.436 | 4.444 | 4.400 | 4.385 |
| .5 | 140 | 4.524 | 4.469 | 4.462 | 4.432 | 4.399 | 4.381 |
| .6 | 150 | 4.492 | 4.465 | 4.440 | 4.420 | 4.398 | 4.362 |

## Table No. 19

| | |
|---|---|
| Tube diameter | = 5.715 cms |
| Tangential flow rate | = 5555 LPH |
| Air flow rate | = 320 LPH |
| Correction factor for refraction | = 0.85 |

| Sr. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 5.110 | 5.034 | 4.966 | 4.882 | 4.801 | 4.727 |
| 2 | 10 | 5.030 | 4.930 | 4.922 | 4.848 | 4.766 | 4.692 |
| 3 | 20 | 5.016 | 4.938 | 4.878 | 4.810 | 4.723 | 4.659 |
| 4 | 30 | 4.938 | 4.882 | 4.839 | 4.768 | 4.694 | 4.620 |
| 5 | 40 | 4.876 | 4.835 | 4.734 | 4.692 | 4.658 | 4.586 |
| 6 | 50 | 4.821 | 4.800 | 4.684 | 4.593 | 4.530 | 4.502 |
| 7 | 60 | 4.770 | 4.706 | 4.696 | 4.544 | 4.503 | 4.438 |
| 8 | 70 | 4.665 | 4.601 | 4.632 | 4.520 | 4.474 | 4.410 |
| 9 | 80 | 4.612 | 4.575 | 4.480 | 4.443 | 4.4.08 | 4.373 |
| 10 | 90 | 4.542 | 4.480 | 4.430 | 4.422 | 4.392 | 4.350 |
| 11 | 100 | 4.494 | 4.412 | 4.423 | 4.400 | 4.332 | 4.339 |
| 12 | 110 | 4.437 | 4.419 | 4.400 | 4.336 | 4.341 | 4.294 |
| 13 | 120 | 4.411 | 4.332 | 4.401 | 4.350 | 4.309 | 4.230 |
| 14 | 130 | 4.378 | 4.334 | 4.330 | 4.294 | 4.233 | 4.202 |
| 15 | 140 | 4.323 | 4.355 | 4.309 | 4.238 | 4.216 | 4.164 |
| 16 | 150 | 4.300 | 4.314 | 4.253 | 4.214 | 4.172 | 4.123 |

# Table NO. 20

| | |
|---|---|
| Tube diameter | 5.715 cms |
| Tangential flow rate | = 5555 LPH |
| Air flow rate | = 710 LPH |
| Correction factor for refraction | = 0.85 |

| Sr. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 5.125 | 5.062 | 5.000 | 4.926 | 4.850 | 4.749 |
| 2 | 10 | 5.080 | 4.975 | 4.924 | 4.859 | 4.800 | 4.712 |
| 3 | 20 | 4.992 | 4.926 | 4.868 | 4.817 | 4.764 | 4.678 |
| 4 | 30 | 4.885 | 4.888 | 4.810 | 4.770 | 4.723 | 4.647 |
| 5 | 40 | 4.801 | 4.839 | 4.774 | 4.726 | 4.624 | 4.605 |
| 6 | 50 | 4.780 | 4.793 | 4.720 | 4.683 | 4.645 | 4.569 |
| 7 | 60 | 4.684 | 4.748 | 4.684 | 4.638 | 4.604 | 4.533 |
| 8 | 70 | 4.654 | 4.681 | 4.642 | 4.594 | 4.564 | 4.498 |
| 9 | 80 | 4.621 | 4.601 | 4.576 | 4.509 | 4.522 | 4.460 |
| 10 | 90 | 4.574 | 4.560 | 4.524 | 4.464 | 4.468 | 4.402 |
| 11 | 100 | 4.559 | 4.5417 | 4.508 | 4.442 | 4.440 | 4.383 |
| 12 | 110 | 4.526 | 4.510 | 4.960 | 4.409 | 4.393 | 4.353 |
| 13 | 120 | 4.494 | 4.486 | 4.422 | 4.370 | 4.381 | 4.317 |
| 14 | 130 | 4.463 | 4.441 | 4.378 | 4.330 | 4.310 | 4.286 |
| 15 | 140 | 4.422 | 4.396 | 4.332 | 4.286 | 4.275 | 4.245 |
| 16 | 150 | 4.376 | 4.354 | 4.290 | 4.243 | 4.210 | 4.158 |

# Table No. 21

Tube Diameter = 5.715 cms
Tangential flow rate = 5555 LPH
Air flow rate = 1200 LPH
Correction factor for refraction = 0.85

| Sr. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axial flow in LPH | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 5.163 | 5.102 | 5.040 | 4.978 | 4.895 | 4.776 |
| 2 | 10 | 4.938 | 5.065 | 5.000 | 4.933 | 4.864 | 4.720 |
| 3 | 20 | 4.912 | 4.993 | 4.952 | 4.886 | 4.818 | 4.693 |
| 4 | 30 | 4.884 | 4.464 | 4.904 | 4.834 | 4.770 | 4.652 |
| 5 | 40 | 4.841 | 4.910 | 4.853 | 4.791 | 4.727 | 4.614 |
| 6 | 50 | 4.802 | 4.844 | 4.808 | 4.742 | 4.683 | 4.574 |
| 7 | 60 | 4.769 | 4.810 | 4.760 | 4.693 | 4.600 | 4.534 |
| 8 | 70 | 4.723 | 4.770 | 4.712 | 4.651 | 4.592 | 4.497 |
| 9 | 80 | 4.684 | 4.723 | 4.664 | 4.604 | 4.565 | 4.457 |
| 10 | 90 | 4.643 | 4.674 | 4.615 | 4.550 | 4.512 | 4.410 |
| 11 | 100 | 4.607 | 4.630 | 4.563 | 4.510 | 4.457 | 4.334 |
| 12 | 110 | 4.564 | 4.588 | 4.524 | 4.459 | 4.423 | 4.331 |
| 13 | 120 | 4.525 | 4.523 | 4.472 | 4.416 | 4.333 | 4.302 |
| 14 | 130 | 4.490 | 4.486 | 4.420 | 4.338 | 4.341 | 4.231 |
| 15 | 140 | 4.452 | 4.442 | 4.378 | 4.320 | 4.283 | 4.222 |
| 16 | 150 | 4.412 | 4.316 | 4.323 | 4.278 | 4.254 | 4.188 |

## Table No. 22

Tube Diameter = 5.715 cms

Tangential flow rate = 4945 LPH

Air flow rate = 350 LPH

Correction Factor for refraction = 0.85

| Sr. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 4.994 | 4.950 | 4.912 | 4.840 | 4.775 | 4.639 |
| 2 | 10 | 4.943 | 4.896 | 4.860 | 4.788 | 4.722 | 4.641 |
| 3 | 20 | 4.897 | 4.847 | 4.810 | 4.738 | 4.674 | 4.591 |
| 4 | 30 | 4.848 | 4.800 | 4.759 | 4.689 | 4.619 | 4.544 |
| 5 | 40 | 4.802 | 4.750 | 4.709 | 4.635 | 4.569 | 4.493 |
| 6 | 50 | 4.751 | 4.701 | 4.662 | 4.584 | 4.513 | 4.446 |
| 7 | 60 | 4.704 | 4.657 | 4.612 | 4.537 | 4.468 | 4.393 |
| 8 | 70 | 4.659 | 4.603 | 4.560 | 4.483 | 4.411 | 4.340 |
| 9 | 80 | 4.603 | 4.555 | 4.509 | 4.432 | 4.358 | 4.296 |
| 10 | 90 | 4.563 | 4.505 | 4.461 | 4.380 | 4.307 | 4.245 |
| 11 | 100 | 4.512 | 4.459 | 4.413 | 4.332 | 4.254 | 4.192 |
| 12 | 110 | 4.464 | 4.403 | 4.361 | 4.281 | 4.242 | 4.150 |
| 13 | 120 | 4.417 | 4.356 | 4.312 | 4.229 | 4.158 | 4.101 |
| 14 | 130 | 4.365 | 4.313 | 4.265 | 4.175 | 4.099 | 4.050 |
| 15 | 140 | 4.320 | 4.260 | 4.211 | 4.126 | 4.042 | 4.003 |
| 16 | 150 | 4.272 | 4.212 | 4.160 | 4.075 | 4.000 | 3.941 |

## Table No. 23

Tube diameter = 5.715 cms

Tangential flow rate = 4945 LPH

Air flow rate = 720 LPH

Correction factor for refraction = 0.85

| Sr. No. | Distance along the length of tube (Cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 5.040 | 4.978 | 4.936 | 4.854 | 4.730 | 4.691 |
| 2 | 10 | 4.992 | 4.931 | 4.883 | 4.808 | 4.730 | 4.657 |
| 3 | 20 | 4.944 | 4.886 | 4.840 | 4.757 | 4.684 | 4.597 |
| 4 | 30 | 4.897 | 4.839 | 4.799 | 4.703 | 4.633 | 4.552 |
| 5 | 40 | 4.849 | 4.790 | 4.744 | 4.656 | 4.584 | 4.503 |
| 6 | 50 | 4.802 | 4.744 | 4.698 | 4.612 | 4.535 | 4.459 |
| 7 | 60 | 4.753 | 4.698 | 4.644 | 4.561 | 4.487 | 4.412 |
| 8 | 70 | 4.702 | 4.656 | 4.600 | 4.524 | 4.437 | 4.362 |
| 9 | 80 | 4.656 | 4.602 | 4.551 | 4.463 | 4.389 | 4.316 |
| 10 | 90 | 4.602 | 4.555 | 4.500 | 4.416 | 4.340 | 4.268 |
| 11 | 100 | 4.560 | 4.509 | 4.456 | 4.367 | 4.298 | 4.220 |
| 12 | 110 | 4.512 | 4.460 | 4.402 | 4.312 | 4.240 | 4.173 |
| 13 | 120 | 4.465 | 4.419 | 4.360 | 4.265 | 4.193 | 4.127 |
| 14 | 130 | 4.419 | 4.367 | 4.317 | 4.219 | 4.147 | 4.080 |
| 15 | 140 | 4.368 | 4.320 | 4.264 | 4.168 | 4.098 | 4.037 |
| 16 | 150 | 4.320 | 4.269 | 4.219 | 4.120 | 4.040 | 3.992 |

## Table No. 24

Tube diameter = 5.715 cm

Tangential flow rate = 4949 LPH

Air flow rate = 1200 LPH

Correction factor for refraction = 0.89

| Sr. No. | Distance along the length of tube (cm) | Corrected air core diameter (in cm) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 5.090 | 5.030 | 4.963 | 4.880 | 4.795 | 4.702 |
| 2 | 10 | 5.046 | 4.984 | 4.918 | 4.829 | 4.743 | 4.659 |
| 3 | 20 | 4.991 | 4.932 | 4.875 | 4.787 | 4.700 | 4.610 |
| 4 | 30 | 4.948 | 4.889 | 4.823 | 4.739 | 4.652 | 4.565 |
| 5 | 40 | 4.900 | 4.842 | 4.780 | 4.692 | 4.603 | 4.511 |
| 6 | 50 | 4.852 | 4.791 | 4.739 | 4.642 | 4.559 | 4.470 |
| 7 | 60 | 4.806 | 4.742 | 4.679 | 4.596 | 4.520 | 4.423 |
| 8 | 70 | 4.753 | 4.700 | 4.647 | 4.554 | 4.469 | 4.376 |
| 9 | 80 | 4.703 | 4.652 | 4.603 | 4.500 | 4.419 | 4.325 |
| 10 | 90 | 4.660 | 4.606 | 4.553 | 4.460 | 4.370 | 4.283 |
| 11 | 100 | 4.617 | 4.560 | 4.513 | 4.414 | 4.322 | 4.232 |
| 12 | 110 | 4.563 | 4.511 | 4.460 | 4.365 | 4.276 | 4.186 |
| 13 | 120 | 4.516 | 4.462 | 4.423 | 4.322 | 4.230 | 4.140 |
| 14 | 130 | 4.463 | 4.409 | 4.373 | 4.272 | 4.185 | 4.092 |
| 15 | 140 | 4.420 | 4.376 | 4.336 | 4.230 | 4.136 | 4.047 |
| 16 | 150 | 4.372 | 4.322 | 4.284 | 4.184 | 4.089 | 4.000 |

## Table No. 25

Tube diameter = 5.715 cms

Tangential flow rate = 4500LPH

Air flow rate = 350 LPH

Correction factor for refraction = 0.85

| Sr. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 4.950 | 4.900 | 4.851 | 4.782 | 4.703 | 4.680 |
| 2 | 10 | 4.900 | 4.851 | 4.797 | 4.729 | 4.657 | 4.624 |
| 3 | 20 | 4.843 | 4.793 | 4.741 | 4.678 | 4.590 | 4.568 |
| 4 | 30 | 4.793 | 4.742 | 4.690 | 4.622 | 4.545 | 4.510 |
| 5 | 40 | 4.742 | 4.689 | 4.633 | 4.570 | 4.493 | 4.453 |
| 6 | 50 | 4.691 | 4.634 | 4.580 | 4.519 | 4.437 | 4.343 |
| 7 | 60 | 4.642 | 4.583 | 4.527 | 4.464 | 4.383 | 4.343 |
| 8 | 70 | 4.589 | 4.523 | 4.478 | 4.411 | 4.329 | 4.289 |
| 9 | 80 | 4.533 | 4.472 | 4.420 | 4.357 | 4.273 | 4.230 |
| 10 | 90 | 4.480 | 4.417 | 4.366 | 4.308 | 4.228 | 4.169 |
| 11 | 100 | 4.431 | 4.367 | 4.310 | 4.249 | 4.165 | 4.110 |
| 12 | 110 | 4.380 | 4.310 | 4.258 | 4.195 | 4.112 | 4.056 |
| 13 | 120 | 4.323 | 4.266 | 4.204 | 4.141 | 4.059 | 4.000 |

## Table No. 26

Tube diameter = 5.715 cms

Tangential flow rate = 4500 LPH

Air flow rate = 710 LPH

Correction factor for refraction = 0.85

| Sr. No. | Distance along the length of tube(cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 4.950 | 4.900 | 4.851 | 4.782 | 4.703 | 4.680 |
| 2 | 10 | 4.900 | 4.851 | 4.797 | 4.729 | 4.657 | 4.624 |
| 3 | 20 | 4.843 | 4.793 | 4.741 | 4.678 | 4.590 | 4.568 |
| 4 | 30 | 4.786 | 4.742 | 4.690 | 4.622 | 4.545 | 4.510 |
| 5 | 40 | 4.742 | 4.689 | 4.636 | 4.570 | 4.498 | 4.456 |
| 6 | 50 | 4.691 | 4.623 | 4.580 | 4.519 | 4.437 | 4.400 |
| 7 | 60 | 4.642 | 4.583 | 4.527 | 4.464 | 4.383 | 4.343 |
| 8 | 70 | 4.589 | 4.526 | 4.478 | 4.411 | 4.329 | 4.239 |
| 9 | 80 | 4.536 | 4.472 | 4.420 | 4.357 | 4.273 | 4.230 |
| 10 | 90 | 4.480 | 4.417 | 4.366 | 4.308 | 4.226 | 4.169 |
| 11 | 100 | 4.431 | 4.367 | 4.310 | 4.249 | 4.165 | 4.110 |
| 12 | 110 | 4.380 | 4.310 | 4.258 | 4.195 | 4.112 | 4.056 |
| 13 | 120 | 4.328 | 4.256 | 4.204 | 4.141 | 4.059 | 4.000 |

## Table No. 27

| | |
|---|---|
| Tube diameter | = 6.715 cms |
| Tangential flow rate | = 4500 LPH |
| Air flow rate | = 1200 LPH |
| Correction factor for refraction | = 0.85 |

| Sr. No. | Distance along the length of tube(cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 5.032 | 4.968 | 4.900 | 4.823 | 4.711 | 4.638 |
| 2 | 10 | 4.983 | 4.919 | 4.854 | 4.775 | 4.665 | 4.592 |
| 3 | 20 | 4.935 | 4.872 | 4.810 | 4.729 | 4.621 | 4.549 |
| 4 | 30 | 4.884 | 4.821 | 4.762 | 4.679 | 4.573 | 4.500 |
| 5 | 40 | 4.832 | 4.776 | 4.716 | 4.631 | 4.527 | 4.453 |
| 6 | 50 | 4.780 | 4.723 | 4.674 | 4.585 | 4.480 | 4.412 |
| 7 | 60 | 4.733 | 4.682 | 4.28 | 4.531 | 4.435 | 4.366 |
| 8 | 70 | 4.682 | 4.620 | 4.579 | 4.482 | 4.386 | 4.312 |
| 9 | 80 | 4.623 | 4.571 | 4.532 | 4.433 | 4.348 | 4.234 |
| 10 | 90 | 4.570 | 4.524 | 4.488 | 4.387 | 4.293 | 4.217 |
| 11 | 100 | 4.522 | 4.471 | 4.435 | 4.332 | 4.233 | 4.178 |
| 12 | 110 | 4.473 | 4.421 | 4.391 | 4.289 | 4.199 | 4.123 |
| 13 | 120 | 4.425 | 4.371 | 4.345 | 4.240 | 4.152 | 4.076 |

## Table No. 28

Tube diameter = 5.715 cms

Tangential flow rate = 4500 LPH

Air flow rate = 350 LPH

Correction factor for refraction = 0.85

| Sr. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 4.926 | 4.900 | 4.782 | 4.710 | 4.652 | DISTURBANCES |
| 2 | 10 | 4.866 | 4.839 | 4.728 | 4.652 | 4.598 | |
| 3 | 20 | 4.809 | 4.775 | 4.666 | 4.590 | 4.530 | |
| 4 | 30 | 4.752 | 4.700 | 4.607 | 4.538 | 4.473 | |
| 5 | 40 | 4.688 | 4.632 | 4.549 | 4.478 | 4.412 | |
| 6 | 50 | 4.623 | 4.504 | 4.439 | 4.420 | 4.358 | |
| 7 | 60 | 4.566 | 4.512 | 4.438 | 4.368 | 4.298 | |
| 8 | 70 | 4.506 | 4.450 | 4.370 | 4.310 | 4.232 | |
| 9 | 80 | 4.442 | 4.390 | 4.312 | 4.245 | 4.180 | |
| 10 | 90 | 4.380 | 4.325 | 4.293 | 4.180 | 4.121 | |

## Table No. 29

| | |
|---|---|
| Tube Diameter | = 5.715 cms |
| Tangential flow rate | = 5600 LPH |
| Air flow rate | = 710 LPH |
| Correction factor for refraction | = 0.85 |

| Sr. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 4.950 | 4.934 | 4.812 | 4.747 | 4.682 | 4.630 |
| 2 | 10 | 4.899 | 4.872 | 4.755 | 4.699 | 4.625 | 4.579 |
| 3 | 20 | 4.839 | 4.812 | 4.692 | 4.637 | 4.562 | 4.517 |
| 4 | 30 | 4.775 | 4.745 | 4.640 | 4.579 | 4.513 | 4.452 |
| 5 | 40 | 4.712 | 4.680 | 4.589 | 4.512 | 4.452 | 4.393 |
| 6 | 50 | 4.651 | 4.615 | 4.522 | 4.458 | 4.397 | 4.345 |
| 7 | 60 | 4.599 | 4.556 | 4.470 | 4.400 | 4.348 | 4.283 |
| 8 | 70 | 4.532 | 4.490 | 4.411 | 4.340 | 4.280 | 4.220 |
| 9 | 80 | 4.481 | 4.432 | 4.352 | 4.284 | 4.229 | 4.166 |
| 10 | 90 | 4.422 | 4.365 | 4.293 | 4.226 | 4.163 | 4.108 |

## Table No. 30

Tube diameter = 5.715 cms

Tangential flow rate = 3600 LPH

Air flow rate = 1200 LPH

Correction factor for refraction = 0.85

| Sr. No. | Distance along the length of tube (cms) | Corrected air core diameter (in cms) for superimposed axial flow in (LPH) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 100 | 200 | 300 | 400 | 500 |
| 1 | 0 | 4.998 | 4.926 | 4.762 | 4.712 | 4.663 | 4.581 |
| 2 | 10 | 4.440 | 4.872 | 4.721 | 4.671 | 4.613 | 4.534 |
| 3 | 20 | 4.872 | 4.819 | 4.688 | 4.626 | 4.569 | 4.487 |
| 4 | 30 | 4.829 | 4.755 | 4.641 | 4.595 | 4.520 | 4.445 |
| 5 | 40 | 4.769 | 4.690 | 4.593 | 4.538 | 4.465 | 4.398 |
| 6 | 50 | 4.708 | 4.641 | 4.557 | 4.490 | 4.410 | 4.343 |
| 7 | 60 | 4.650 | 4.584 | 4.512 | 4.446 | 4.363 | 4.296 |
| 8 | 70 | 4.599 | 4.522 | 4.473 | 4.403 | 4.315 | 4.254 |
| 9 | 80 | 4.532 | 4.470 | 4.430 | 4.356 | 4.264 | 4.265 |
| 10 | 90 | 4.472 | 4.413 | 4.392 | 4.311 | 4.210 | 4.198 |

# CHAPTER IV

# DISCUSSION OF RESULTS CONCLUSIONS AND RECOMMENDATIONS

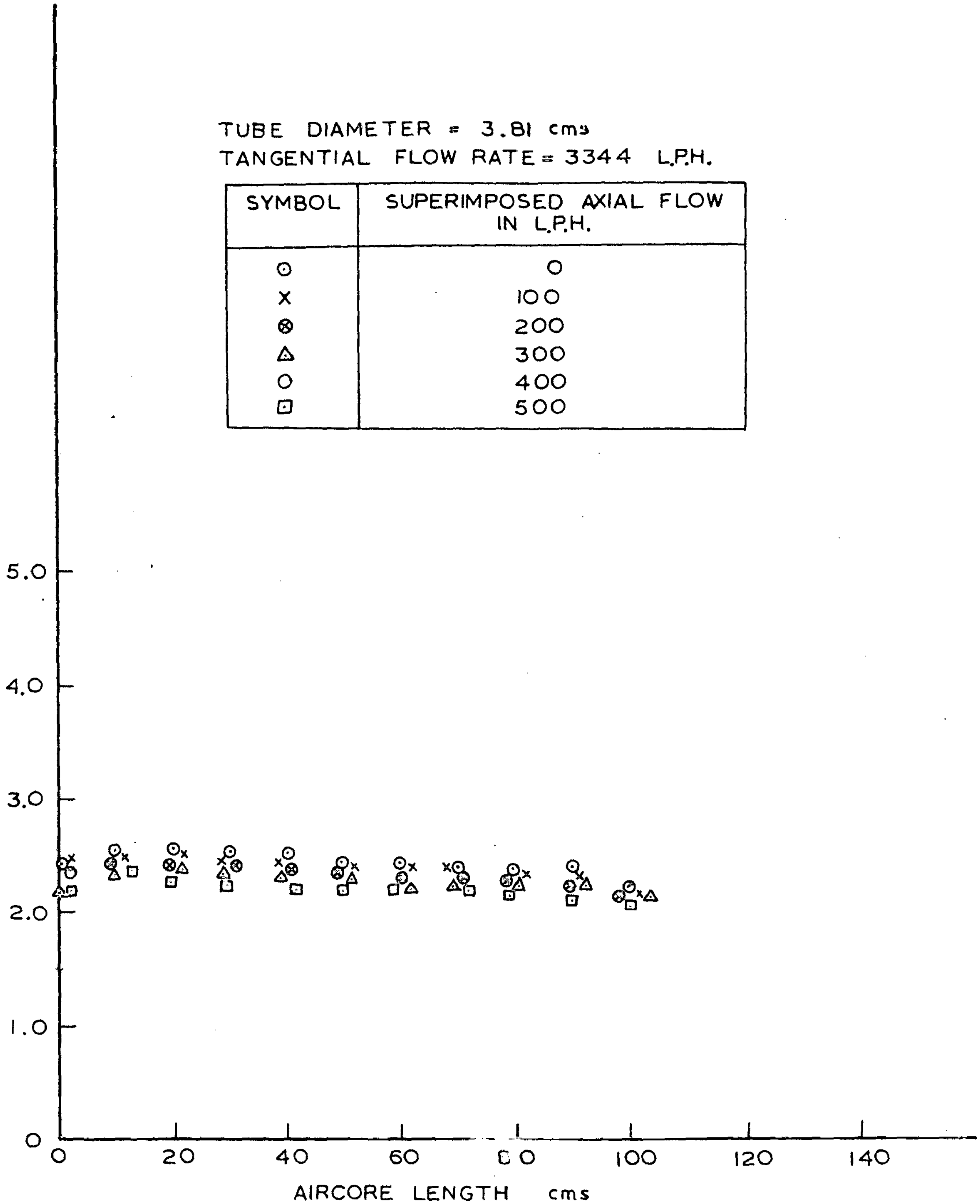
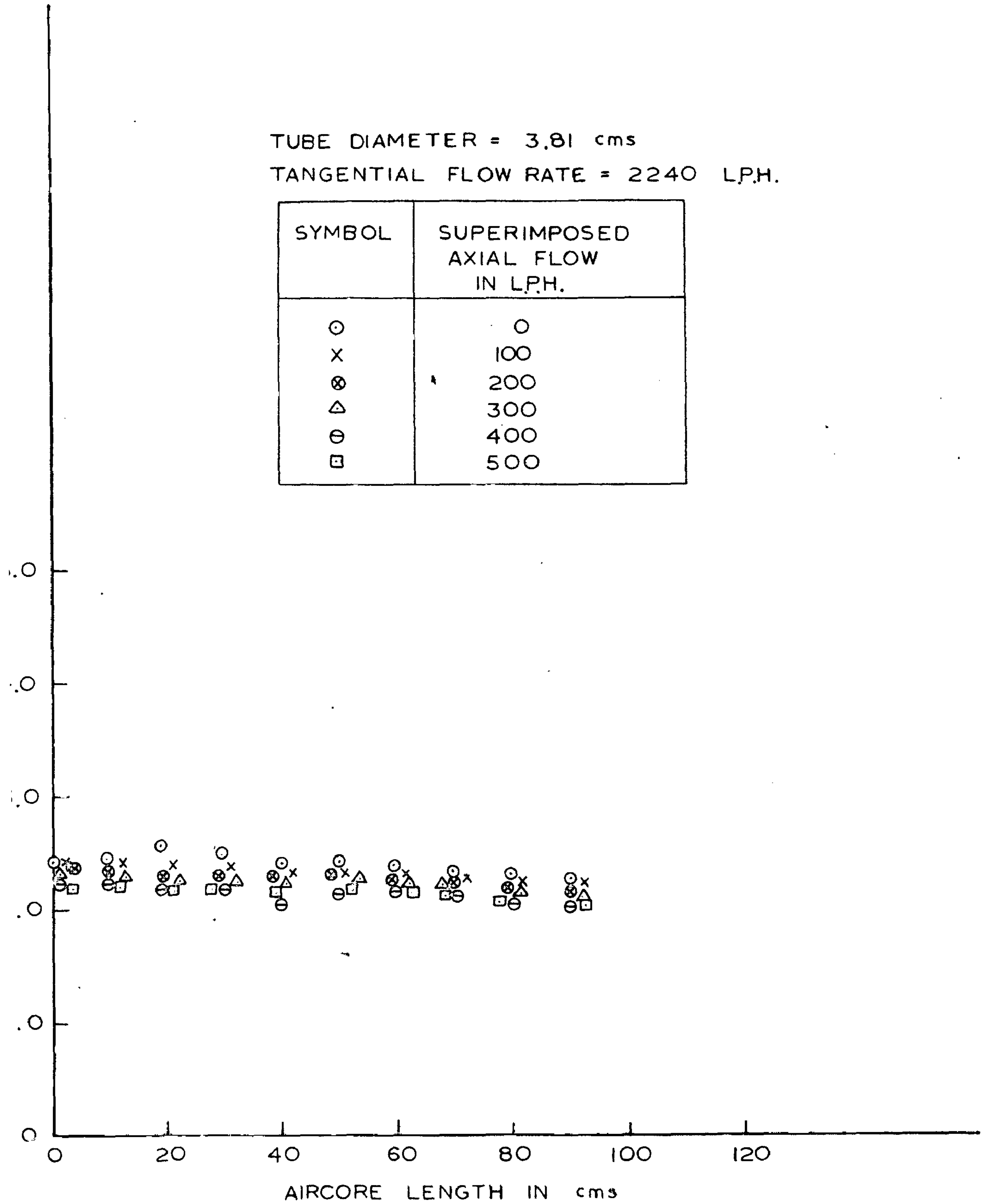
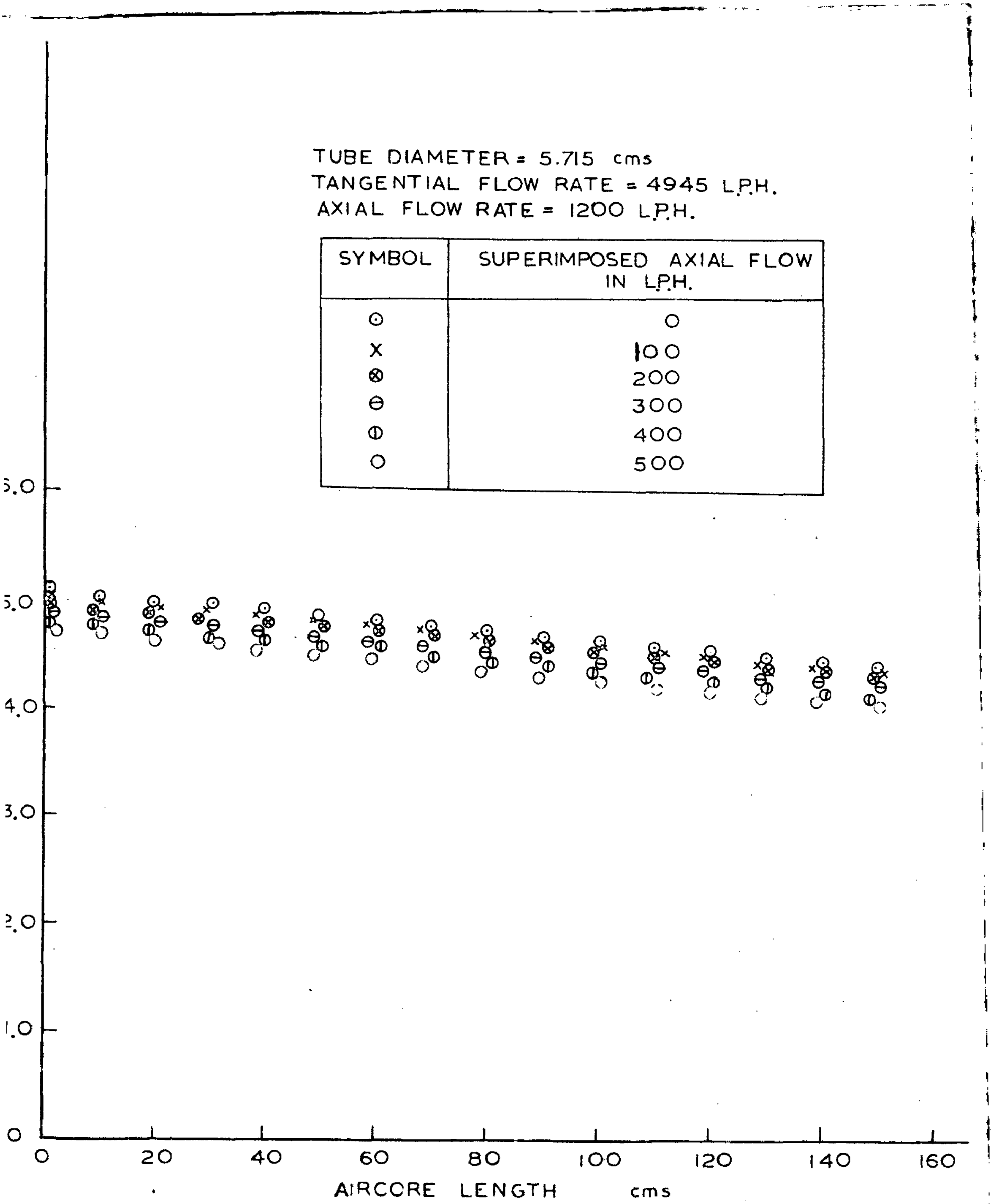



FIG. 3 VARIATION OF AIRCORE DIAMETER ALONG THE AIRCORE LENGTH FOR DIFFERENT SUPERIMPOSED AIR RATES




VARIATION OF AIRCORE DIAMETER ALONG THE AIRCORE LENGTH FOR DIFFERENT SUPERIMPOSED AIR RATES




[illegible] VARIATION OF AIRCORE DIAMETER ALONG THE AIRCORE LENGTH FOR DIFFERENT SUPERIMPOSED [illegible] RATES

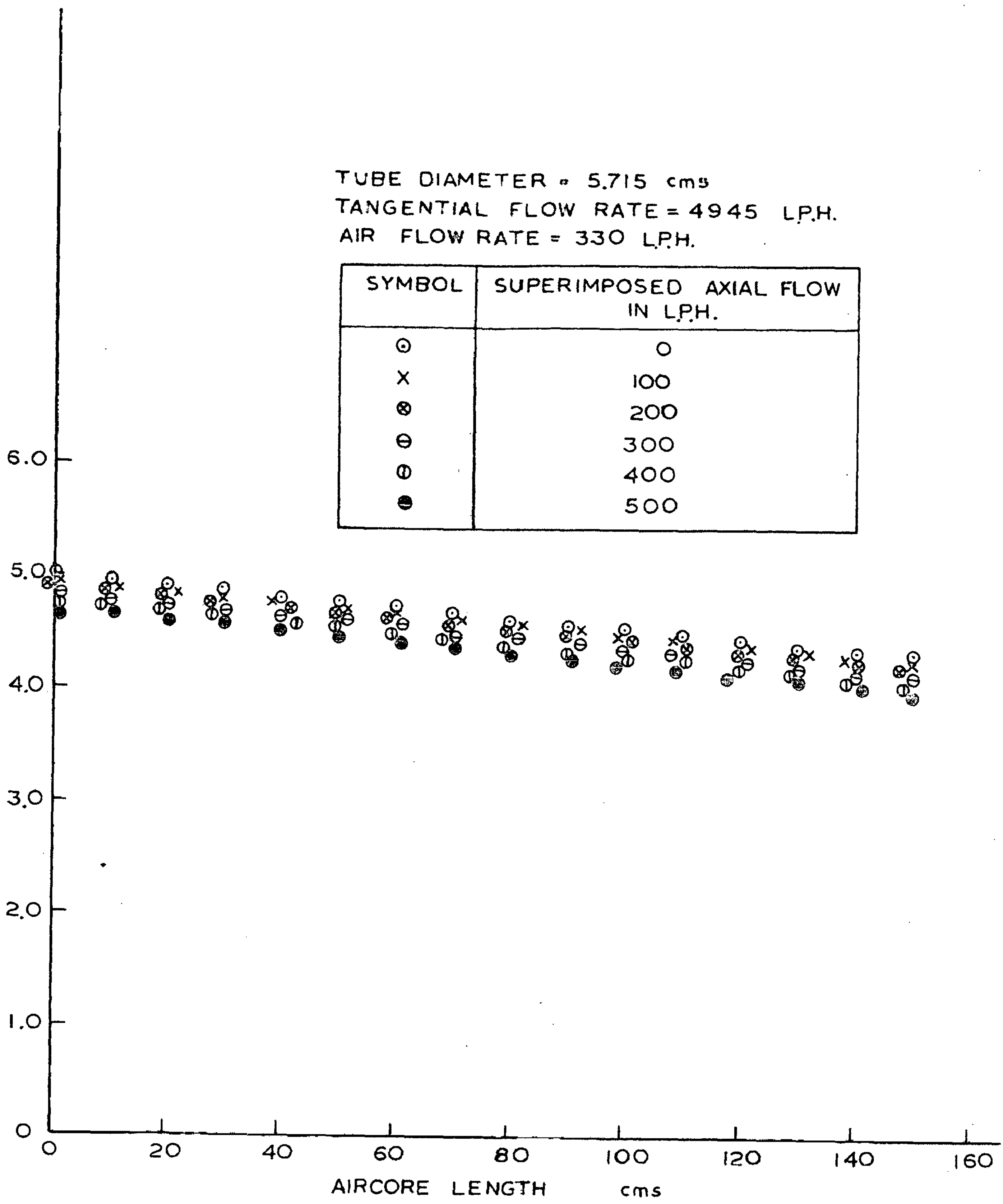



FIG. 6 VARIATION OF AIRCORE DIAMETER ALONG THE AIRCORE LENGTH FOR DIFFERENT SUPERIMPOSED AIR RATES

# CHAPTER VI

## DISCUSSION OF RESULTS AND CONCLUSIONS

The studies on the superimposition of axial flow on swirling flow have been carried out on tubes of diameter 3.81 cm and 5.715 cms. The results obtained from the data stated in chapter III are plotted. The representative plots of the same are attached.

Figure 3 and 4 shows the variation of air core diameter along the air-core length at different superimposed axial flows while keeping the tangential flow and air rate constant a value. These are the representative graphs obtained by plotting data for perspex tube of diameter 3.81 cms at higher tangential flow rates of water. Other data on this tube diameter also gave similar plots. It can be clearly seen from the graph that the air-core diameter while superimposing different axial flows does not changes appreciably from the air core diameter without any superimposition of axial flow under the experimental conditions and limits used. Similar type of representative plots obtained from the data while using the tube of 5.715 cm diameter are shown in Figure 5 and 6.

Figure 7 shows the variation of average air core diameter with different superimposed axial flow, using different air rates. From the figure it is clear that the

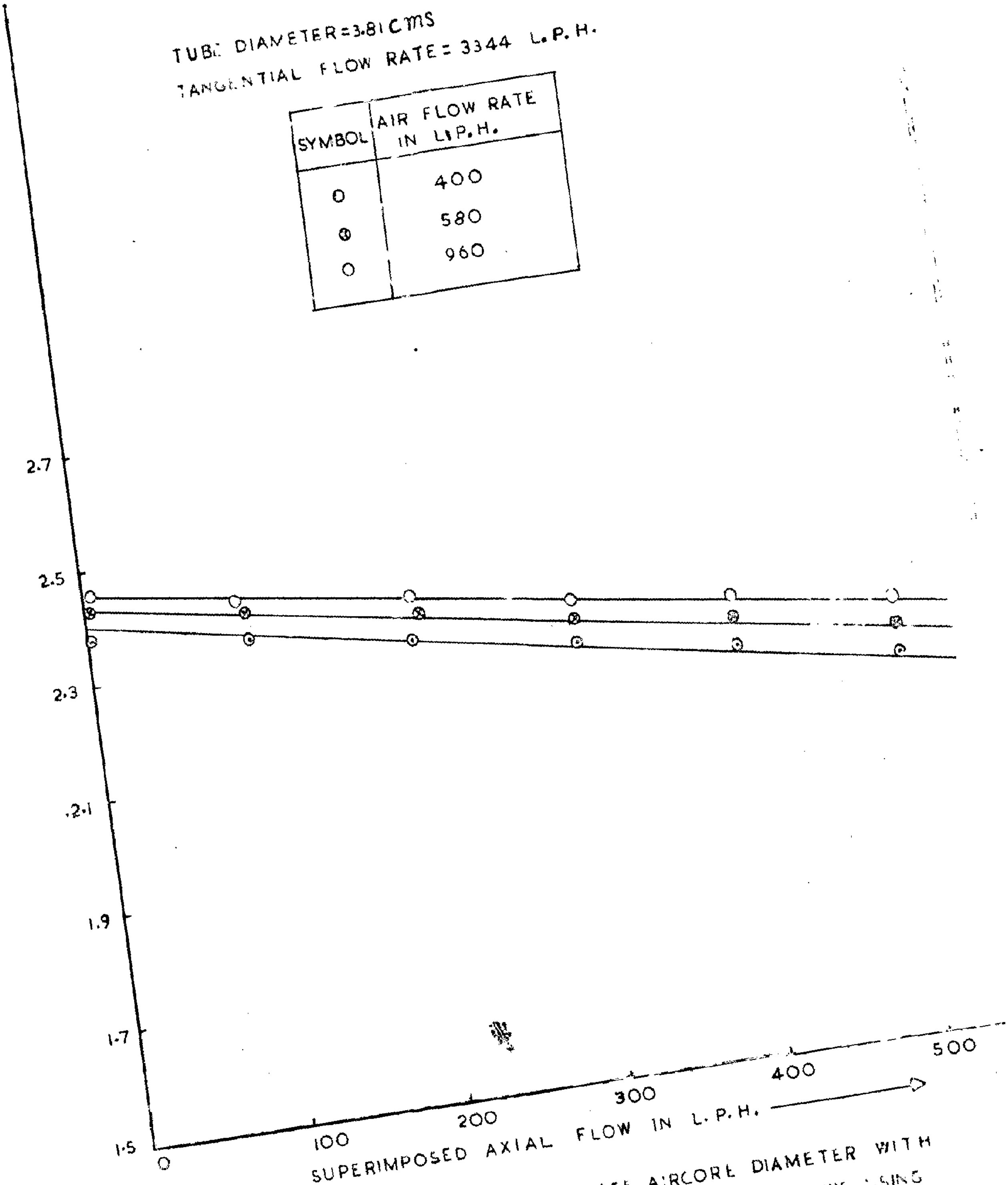



FIG. 7 VARIATION OF AVERAGE AIRCORE DIAMETER WITH DIFFERENT SUPERIMPOSED AXIAL FLOWS USING DIFFERENT AIR RATES

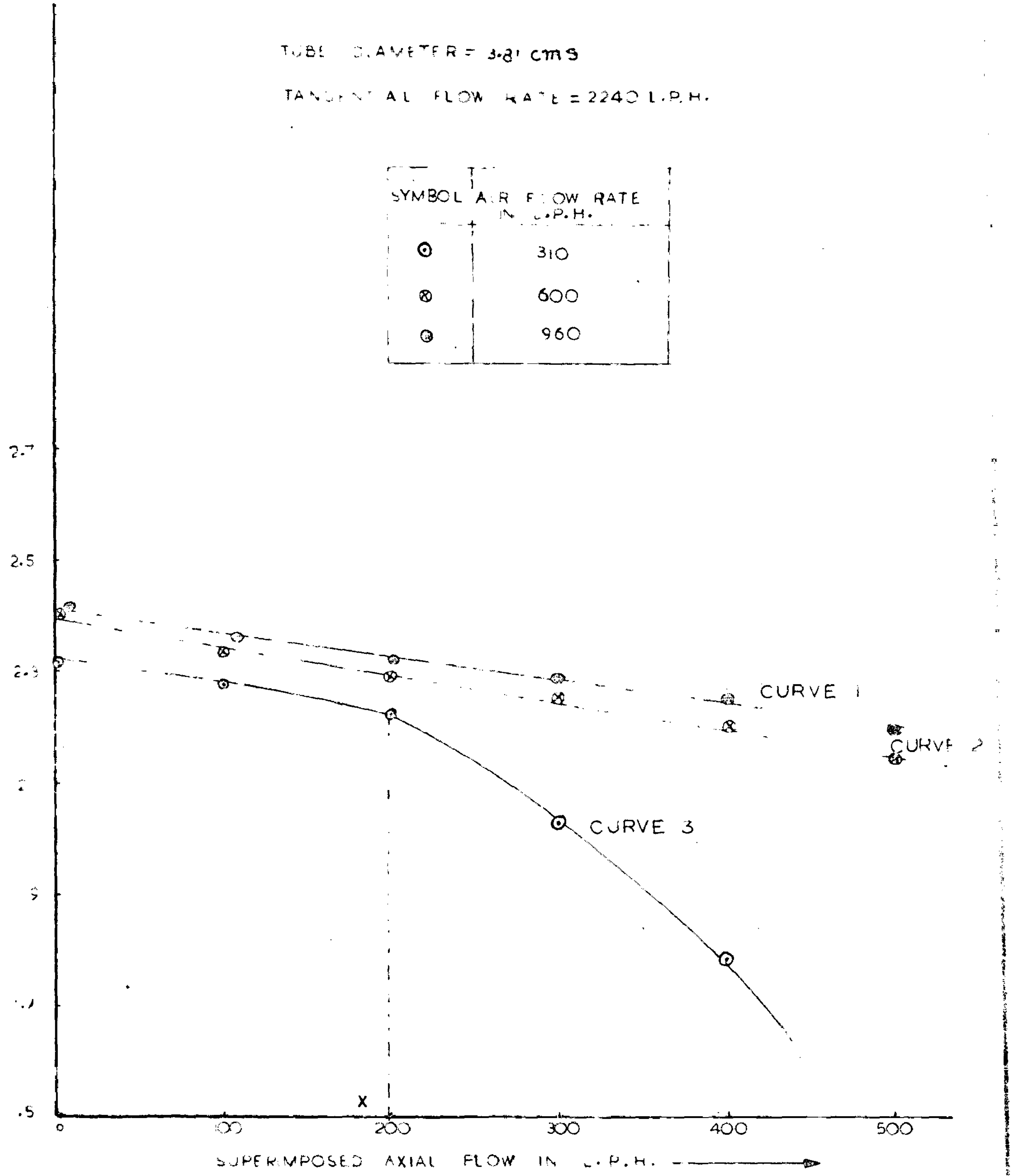



**FIG.8** VARIATION OF AVERAGE AIRCORE DIAMETER WITH DIFFERENT SUPERIMPOSED AXIAL FLOWS USING DIFFERENT AIR RATES

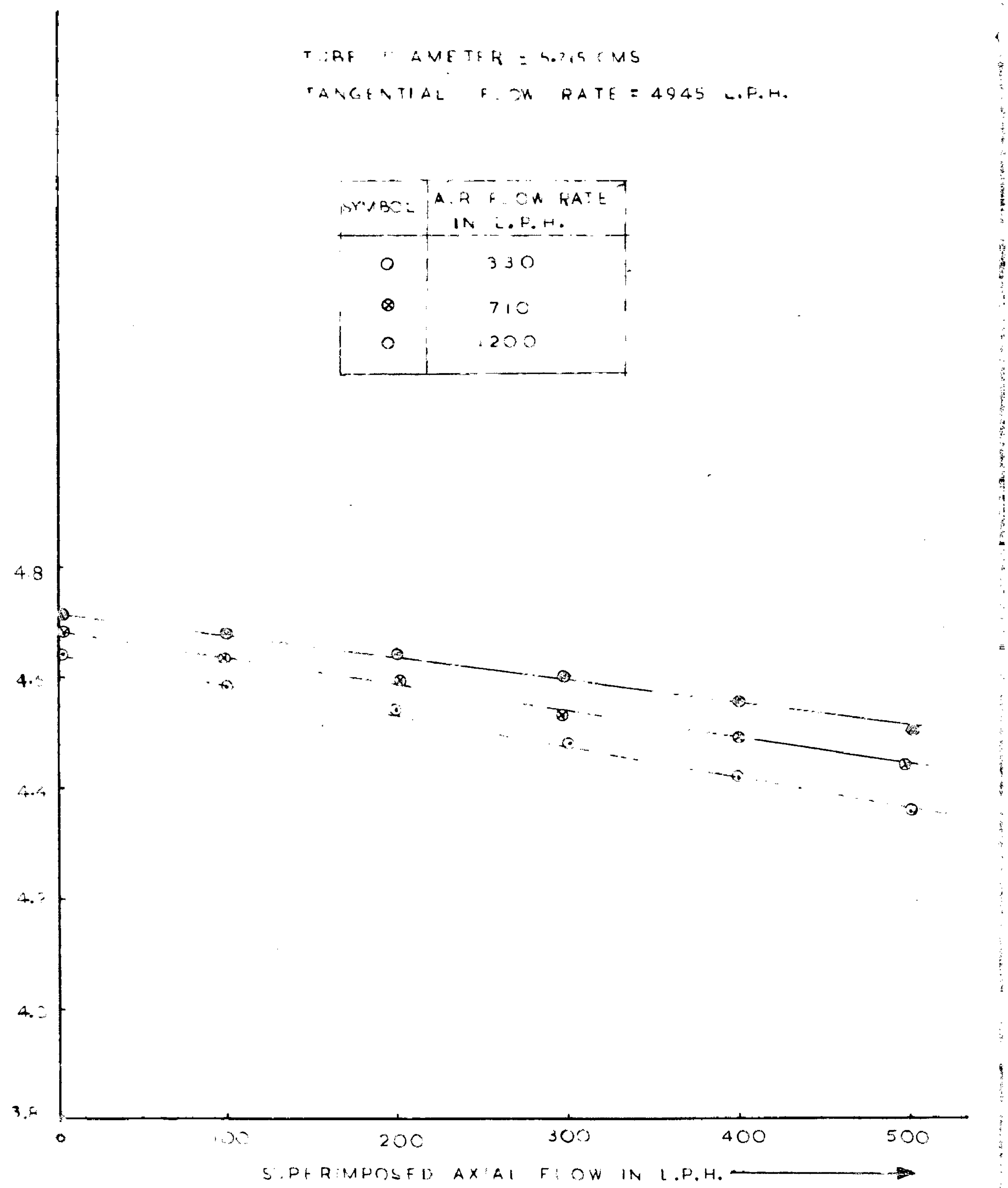



FIG. 9 VARIATION OF AVERAGE AIRCORE DIAMETER WITH DIFFERENT SUPERIMPOSED AXIAL FLOWS USING DIFFERENT AIR RATES

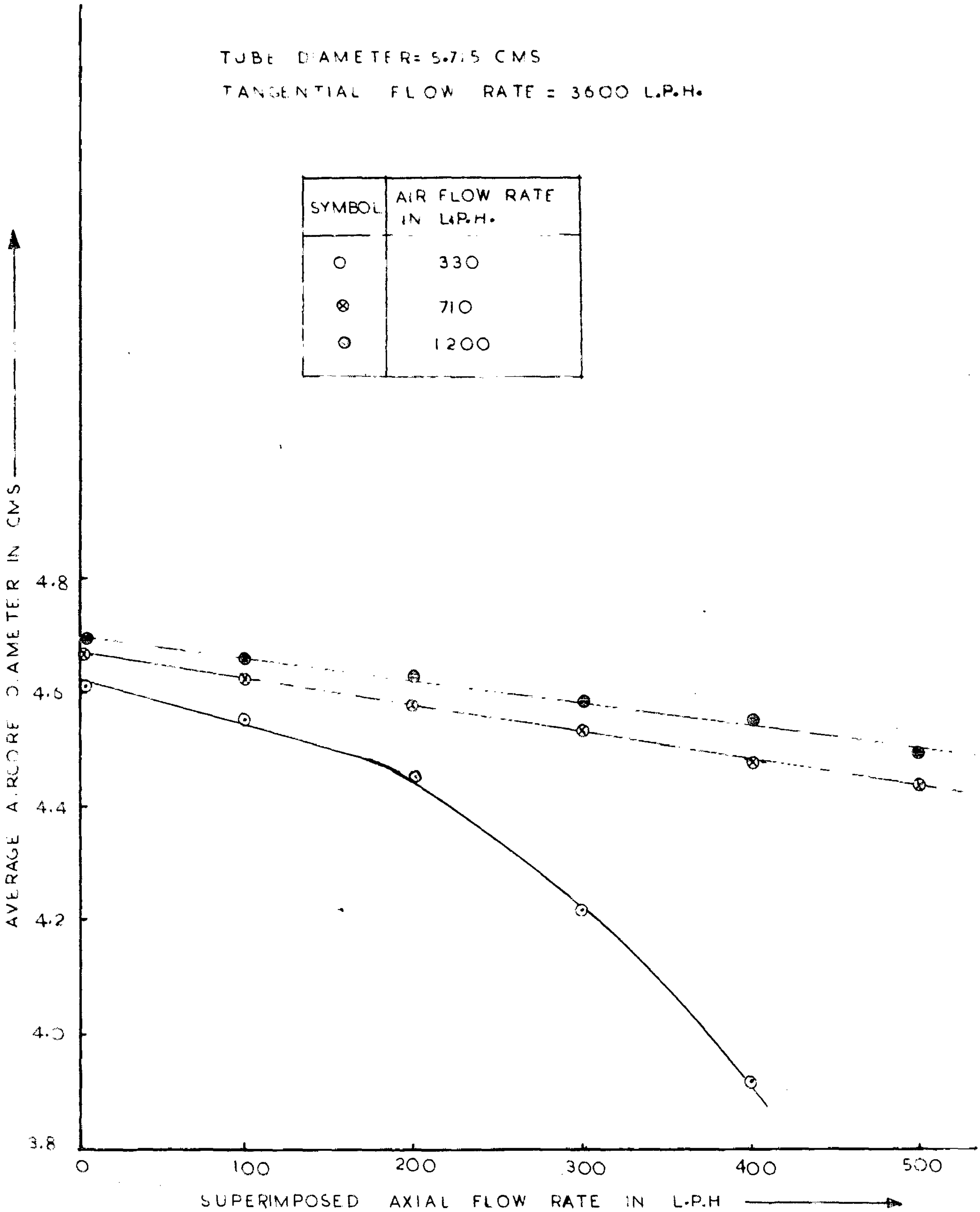



FIG.10 VARIATION OF AVERAGE AIRCORE DIAMETER WITH DIFFERENT SUPERIMPOSED AXIAL FLOWS USING DIFFERENT AIR RATES

average air-core diameter decreases as the superimposed axial flow increases. It can also be seen from the Figure that the slope of curves keeps on increasing with decreasing air rates, which reveals that the rate of decrease in average air-core diameter with superimposed axial flow rates is more at low air rates. Figure 8 also shows the variation of average air core diameter for superimposed axial flow rates using different air rates. The tangential flow rate in case of Fig. 7 is more than that of in case of Fig. 0. From Figure 8 we find that at low tangential flow rates the rate of decrease of air core diameter is much more rapid as compared to those at higher tangential flow rates in case of low air rates. This implies that as the tangential flow rates increases the rate of decrease of average air core diameter for different superimposed axial flows decreases.

From Fig. 8 curve 3 we observe that point x such that the slope of the curve corresponding to axial flows more than x is greater than the slope corresponding to axial flows less than x. The value of axial flow rate at x for this particular tangential flow rate, tube diameter and air rate can be called as critical axial flow., which is the maximum axial flow which can be superimposed at this value of tangential flow without disturbing the air core. If we take average air core diameter corresponding to 300 [illegible] of axial flow

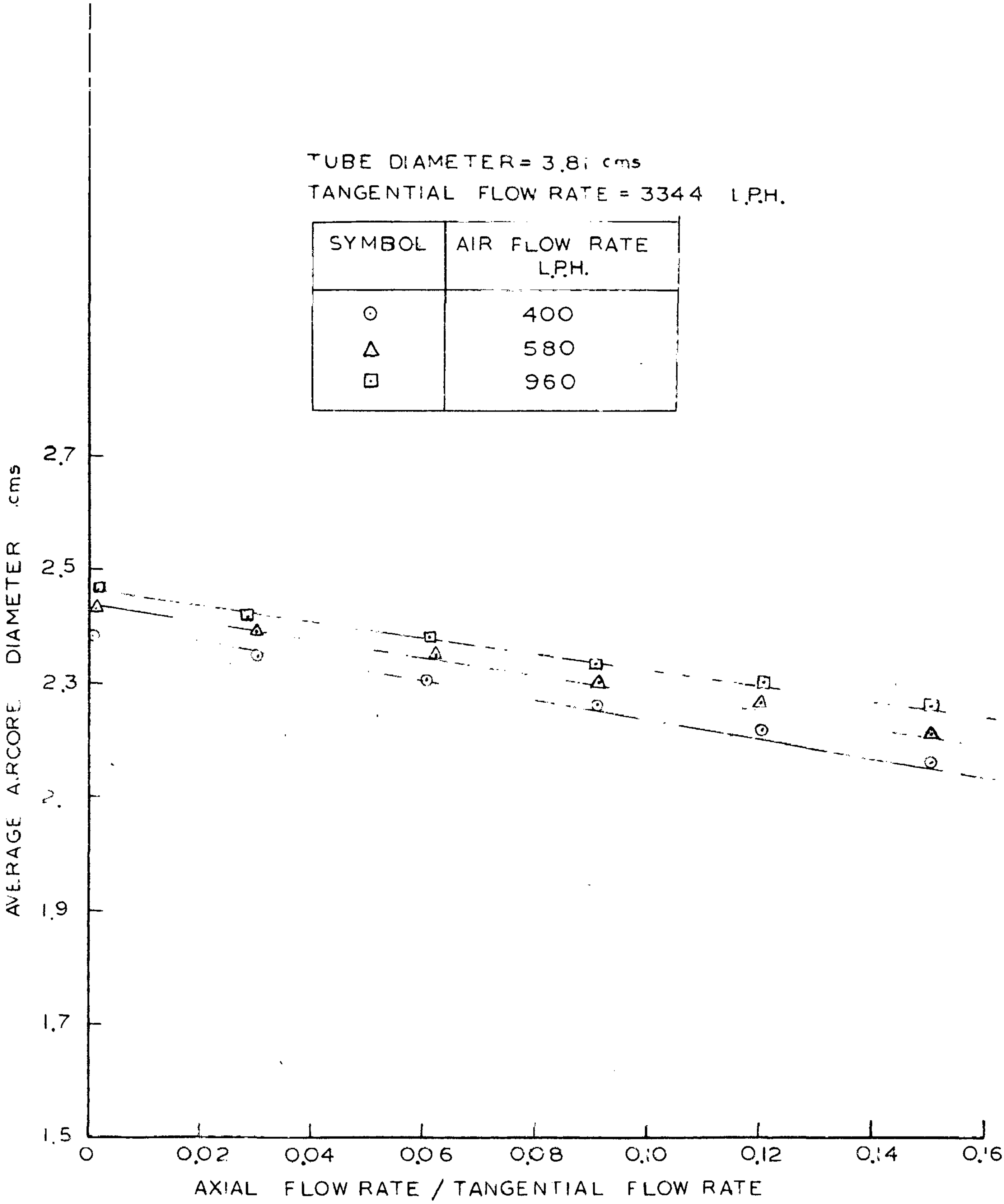
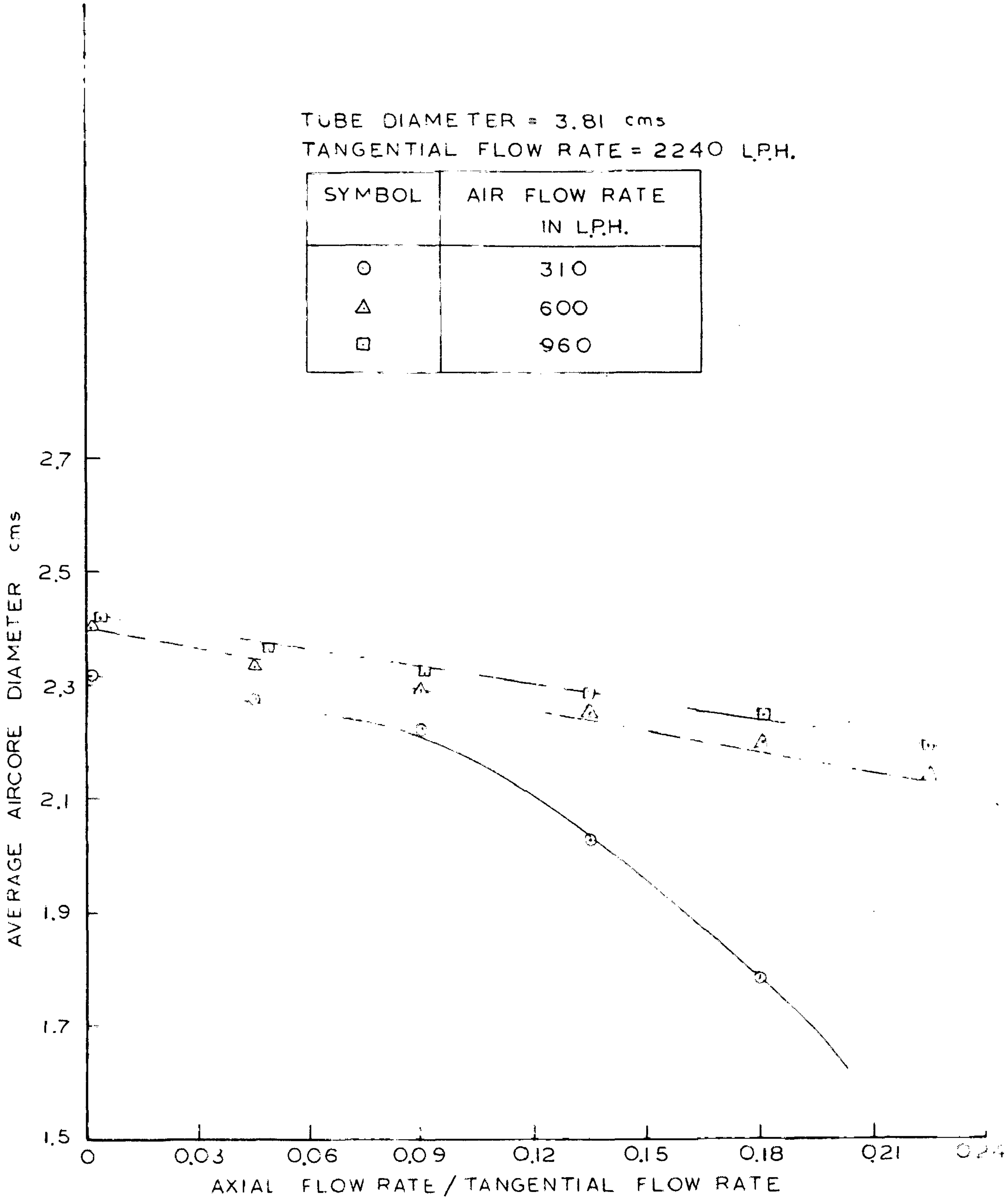



FIG. 11

VARIATION OF AVERAGE AIRCORE DIAMETER WITH DIFFERENT AXIAL TO TANGENTIAL FLOW RATE RATIOS USING DIFFERENT AIR RATES




# FIG.12

VARIATION OF AVERAGE AIRCORE DIAMETER WITH DIFFERENT AXIAL TO TANGENTIAL FLOW RATE RATIOS USING DIFFERENT AIR RATES

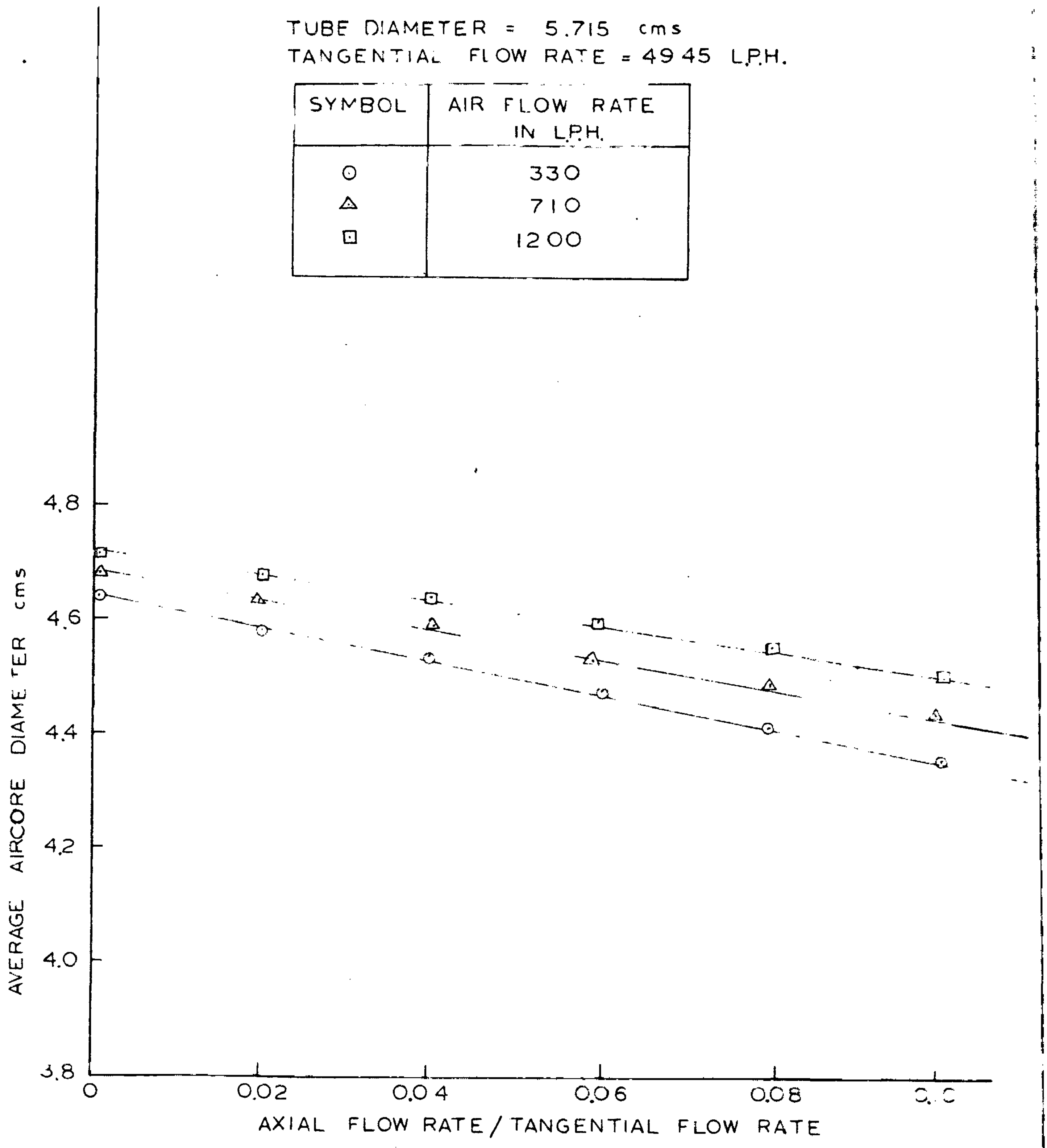



FIG.13 VARIATION OF AVERAGE AIRCORE DIAMETER WITH DIFFERENT AXIAL TO TANGENTIAL FLOW RATE RATIOS USING DIFFERENT AIR RATES

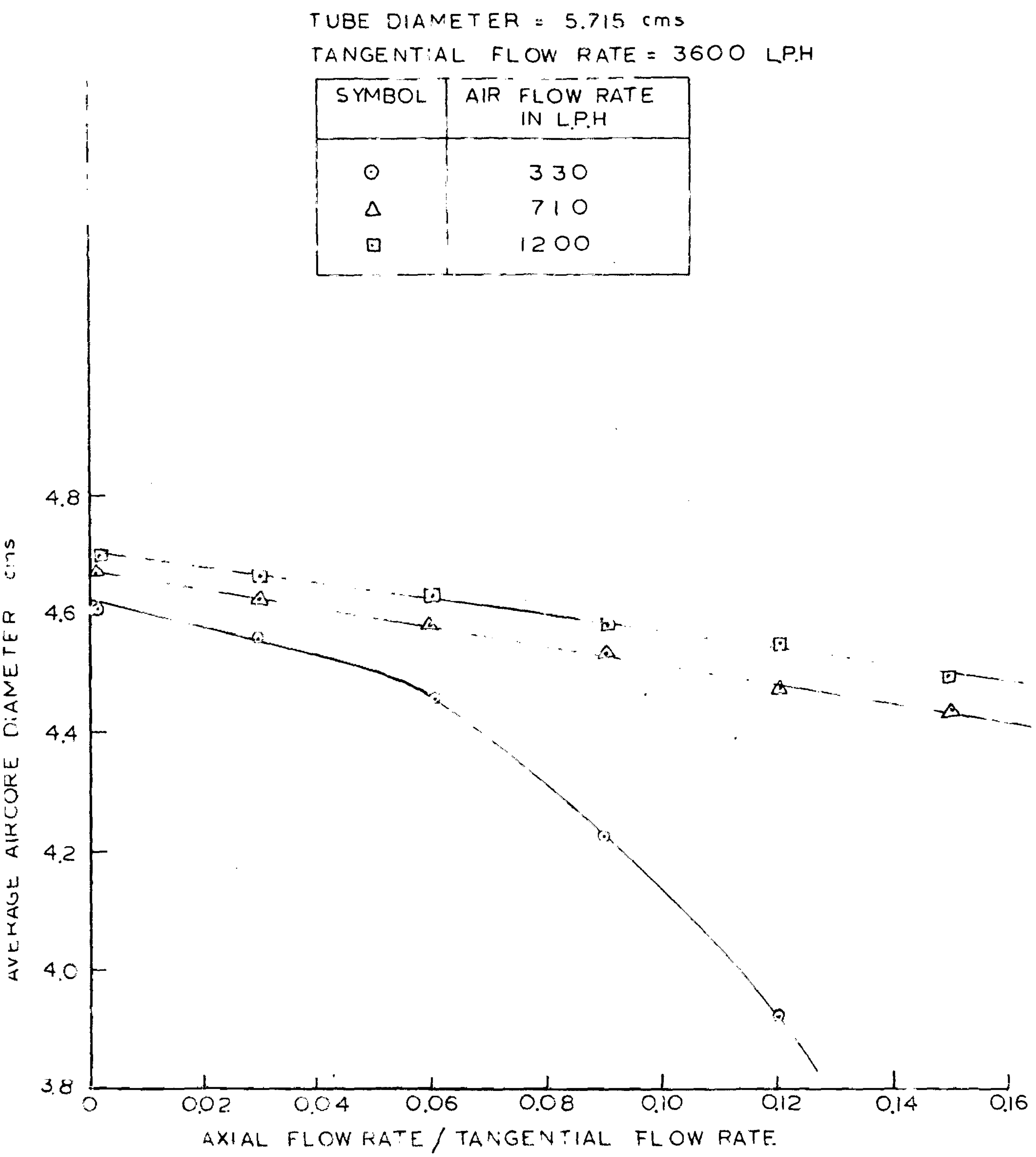



FIG.14 VARIATION OF AVERAGE AIRCORE DIAMETER WITH DIFFERENT AXIAL TO TANGENTIAL FLOW RATES RATIOS USING DIFFERENT AIR RATES

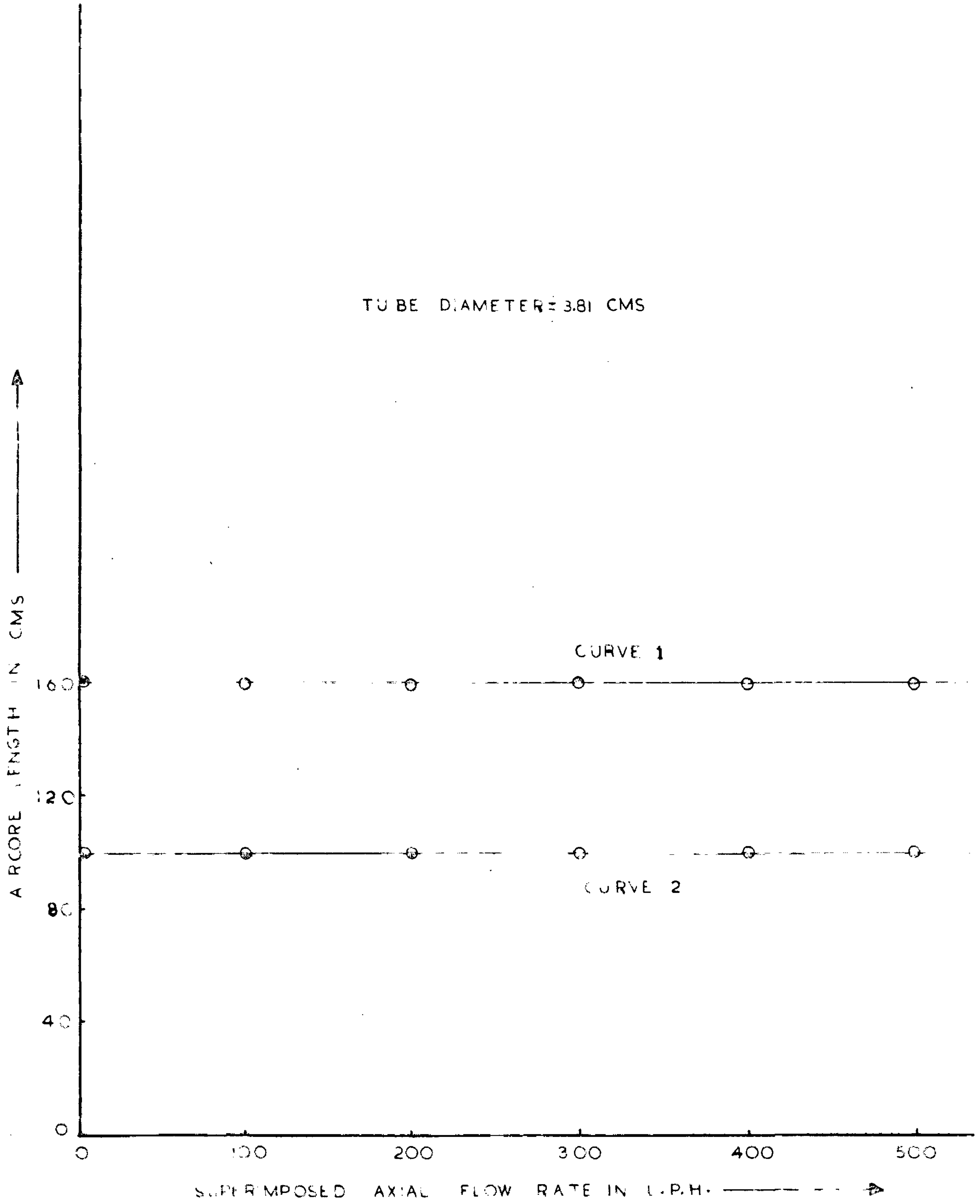



FIG.15 VARIATION OF AIRCORE LENGTH WITH DIFFERENT SUPERIMPOSED AXIAL FLOW RATES

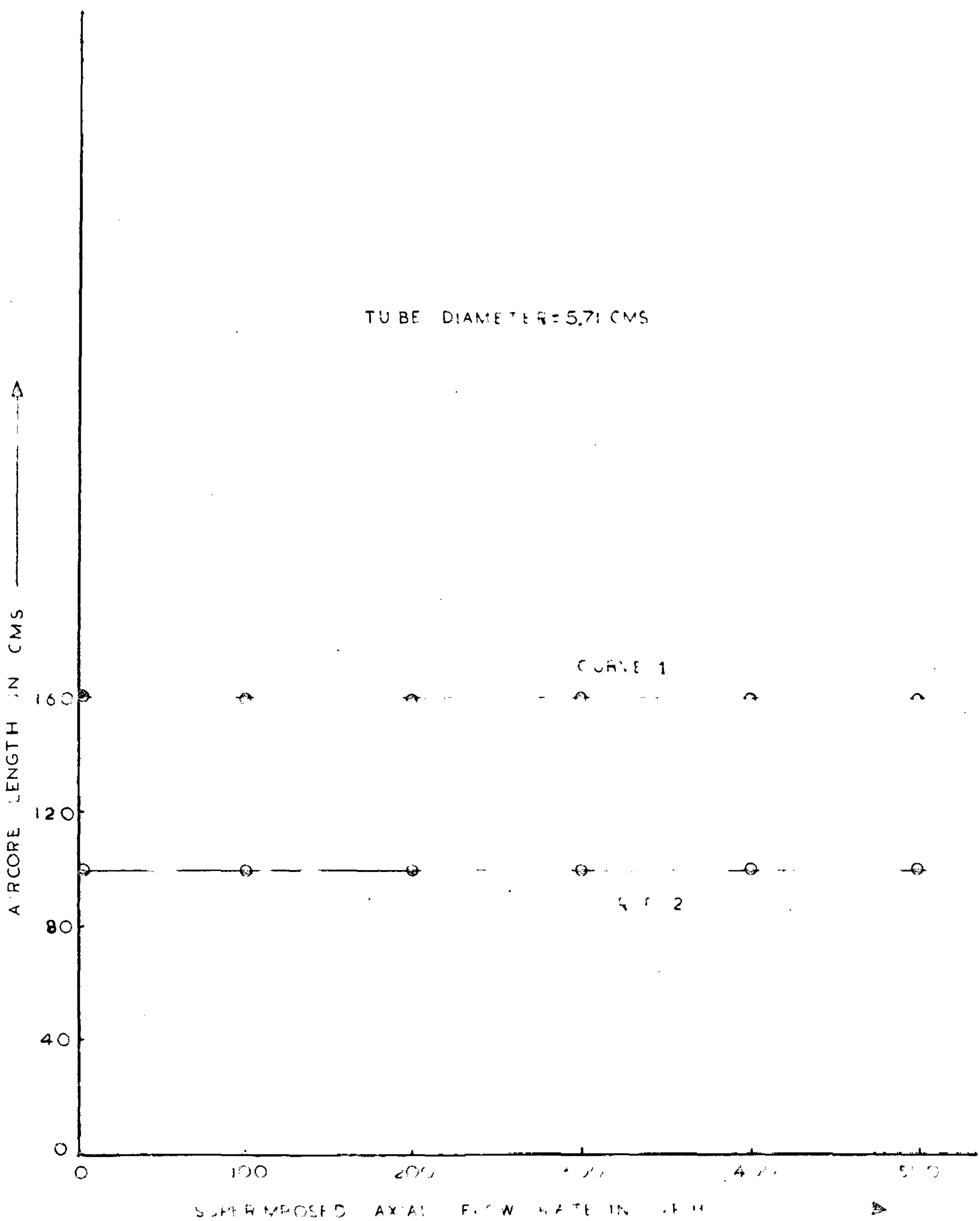



FIG.16 VARIATION OF AIRCORE LENGTH WITH DIFFERENT SUPERIMPOSED AXIAL FLOW RATES

we find that average air core diameter lies in disturbed zone for curve 3 and in stable zone for curve 1 and 2. So we can conclude that, with higher air rates more axial flow can be superimposed without disturbing the air core.

Fig. 9 and 10 represent the similar results for the tube of diameter 5.715 cms.

Fig. 11 and 12 for tube diameter of 3.81 cm and 13 & 14 for for tube diameter of 5.715 cms. give an idea of the axial to tangential ratios which can be used without disturbing the air core for the given experimental conditions. These figures also reveals that at low tangential flow rates more axial to tangential ratio can be used without disturbing the air-core by increasing air input rates.

The effect of superimposition of axial flows on the length of the air core is shown in Fig. 15 and 16 for tubes of diameter 3.81 cm and 5.715 cms respectively. It can be seen that the length of the air core is nearly unaffected by the superimposition of axial flows under the experimental conditions of investigation. However, it may be added that some times it was difficult to exactly pin point the length of the air core.

RECOMMENDATIONS

From the experimental work carried out it has been found that it is possible to superimpose axial flows on tangential flows without disturbing the air core provided higher values of air rates are used. By such superimposition of axial flows there shall be less pressure drop for the total flow rate of water in such systems and this will help in reducing the power consumption while using tangential flow systems.

We could not superimpose axial flows more than 500 LPH because of the non availability of rotameter in the flow range of 500 to 1500 LPH. This is why we could not get the critical axial flow rates (i.e. the maximum allowable axial flow which can be superimposed without disturbing the aircore) for higher tangential flow rates and air rates.

Further work should be carried out using a flow o meter covering the flow range of 500 to 1500 LPH, to measure a axial flows. It is also desirable that some device may be used to measure more accurately the axial and tangential flow rates, with such an arrangement, critical axial flows can be obtained for different air rates and tangential flow rates. A separate graph can be plotted between critical axial flow rate and tangential flow rate for different air rates to obtain optimum values of air rate and tangential flow rate for a particular tube.

# CHAPTER V

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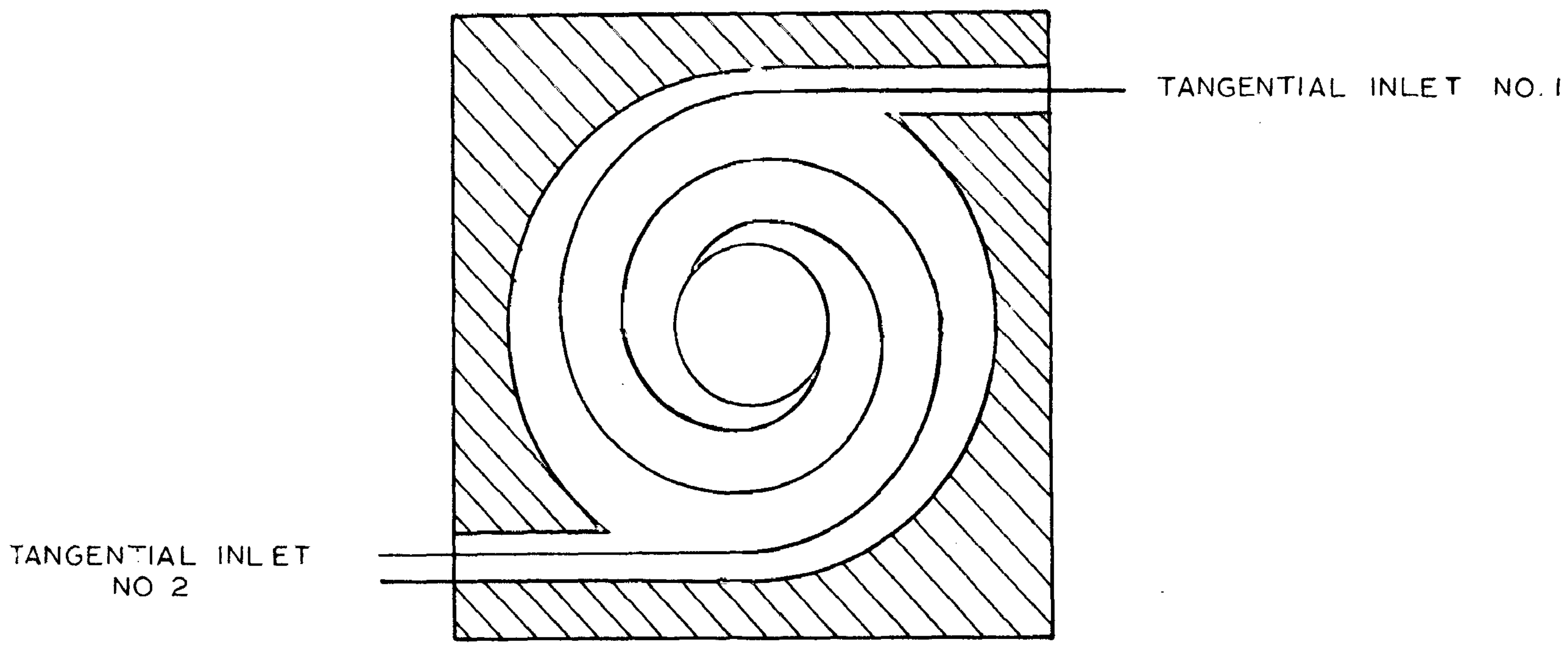


FIG. 1

PRODUCTION OF SWIRLING FLOW BY TANGENTIAL INJECTION OF LIQUID