Design, Fabrication and Experimentation of Vortex Tube Refrigeration System

A PROJECT REPORT
SUEMITTED IN PARTIAL FULFILMENT OF
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CERTIFICATE

This is to certify that the report entitled

DESIGN, FABRICATION AND EXPERIMENTATION OF VORTEX TUBE REFRIGERATION SYSTEM

has been submitted by

Mr. ....

in partial fulfilment of the award of

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Guide

Head of the Department

Certified that the candidate was Examined by us in the Project Work Viva Voce Examination held on .... and the University Register Number was ....

External Examiner

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CONTENTS

SYNOPSIS

Our Project deals with design, fabrication and study of the vortex tube Refrigeration system. The main advantage claimed for vortex tube is that, it is very simple in construction and the cost involved is very less. The working principle is that when compressed air is sent into the vortex tube a swirling or vortex motion is created, which produces the cold air at one end and hot air at the other end.

The main parameters affecting the working of the vortex tube are (i) Nozzle diameter, (ii) Nozzle profile. We have attempted to maximise the c.o.p of the system by conducting the experiment on a number of nozzle sizes.

NOMENCLATURE

R - Radius of the tube

D - Diameter of the tube

Dc - Diameter of the nozzle collar

d - Diameter of the nozzle

A,F - area

Do - Diameter of orifice plate

p - Pressure

t - total temperature $^{\circ}C$

T - absolute total temperature K

- Cold air fraction

- adiabatic efficiency of vortex tube

V - Velocity at any radius

C_p - specific heat at constant pressure

Pr - Prandtl Number

K - adiabatic index

- Friction factor

G - Mass flow ratio of air

Ø - Velocity coefficient

SUBSCRIPTS

i - inlet

t - total or tangential

W - wall

isn - isentropic process

c - cold side

h - hot side

CHAPTER I

INTRODUCTION TO REFRIGERATION

The American Society of Refrigerating Engineers defines refrigeration as the Science of producing and maintaining temperatures below that of surrounding atmospheric temperature. The methods of production of cold by mechanical methods are quite recent. The first development took place in 1834 when Perking proposed a hand-operated compressor machine working on ether. Then in 1856 Linde developed a machine working on ammonia.

Some of the areas where low temperatures are necessary are:

1. Food preservation
2. Chemical Industries
3. Treatment and manufacture of metals
4. Medicines and surgery

METHODS OF REFRIGERATION

1. BY USING NATURALLY OCCURING ICE

In Olden days, natural ice was used for refrigeration purposes. Ice was collected from surface of ponds and lakes and stored in insulated ice houses for use throughout the year. The object to be cooled is placed inside the insulated chamber containing ice. Heat transfer takes place from the object to ice and as a result, the object gets cooled. But this is a crude and undependable form of refrigeration.

2. BY ARTIFICIAL METHODS

i) Evaporative Refrigeration.

Heat is absorbed when a liquid evaporates. This principle is used in evaporative condenser and water evaporation refrigeration.

ii) Adiabatic Expansion of Gases:

The temperature of the gas can be reduced when it expands in a cylinder adiabatically. Assuming the temperature of the atmosphere is 27 °C and if it is compressed isentropically with pressure ratio 5 then the final temperature of compressed air T2 is given by,

$$T2 = T1 \left(\frac{P2}{P1}\right)^{0.286} = 300(5)^{0.286} = \underline{475K}$$

The high pressure, high temperature air if cooled in the heat exchanger then the final temperature will be 27 C under ideal condition and pressure will be 5 atm, considering the pressure loss in heat exchanger as zero and if this air expands isentropically untill the pressure falls to atmospheric pressure then the final temperature

$$T_f = \frac{300}{5^{0.286}} = \underline{189.5^{\circ}K}$$

which is below atmospheric temperature ($300^{o}K$)

This principle is universally used for producing low temperature in all air-refrigeration systems.

iii) Throttling of air and other gases

(Joule Thomson effect)

An adiabatic throttling process is a constant enthalpy process and enthalpy is only a function of temperature. Temperature of the perfect gas remains constant after and before throttling. However with actual gases, the temperature of the gas after throttling may either increase, decrease or remain constant. This effect is called Joule Thomson effect.

The term which indicates the magnitude and sign of the change in temperature is called Joule Thomson coefficient and it is given by

For reducing the tempeature of the gas after throttling the value of must be positive.

iv.Vapour Compression Refrigeration system:

Refrigerant liquids like Ammonia, Freon-12, Freon-13 etc at low pressure and low temperature are passed through evaporative chamber. The object to be cooled is placed inside the evaporator chamber. Heat transfer takes place from the object to the refrigerant liquid. This evaporates the refrigerant and refrigerant vapours are sucked by a compressor and compressed to a higher pressure and temperature. This is followed by heat rejection in the condensor and expansion in the throttling valve. Heat rejection in the condensor, condenses the refrigerant and expansion in the throttle valve reduces the pressure and temperature of the refrigerant. The refrigerant is again sent inside the evaporator chamber. This cycle is repeated and this forms the basic operating principle of vapour compression refrigeration system.

v. Vapour absorption refrigeration system.

The compressor of a vapour compression system is replaced by an absorber, generator and a pump. The ammonia vapours coming out of the evaporating chamber is absorbed by water, forming an aqueous solution of ammonia. This solution is pumped to the generator, where heating is effected. High pressure ammonia vapours are separated out from water and sent to the condensor and further to the throttling valve. This system is cheaper and requires less power compared to a vapour compression system.

vi. Steam Jet refrigeration system

Steam from boiler is allowed to expand in a chamber through a nozzle. The chamber is connected to a tank its pressure decreases. This pressure drop is also communicated to the water tank. Under this low pressure, top layer of water in the tank begins to evaporate. The latent heat for vapourising is taken from the remaining water, thus cooling the remaining water. By this was temperatures about 5^0C can be produced.

vii. Vortex tube refrigeration system

(Ranque effect)

When a high pressure gas or air is allowed to expand tangentially through a nozzle, there is simultaneous discharge of the cold air at the core and hot air at the periphery. This separation is facilitated due to the creation of vortex motion.

viii. Thermo electric Refrigeration system

If two dissimilar metals are joined together and direct current is passed through them, the temperature at one junction gets increased whereas at the other junction it decreases depending upon the material combinations

CHAPTER II
INTRODUCTION TO VORTEX TUBE REFRIGERATION SYSTEM

Vortex tube is a simple device for producing cold air. It was invented by G.J. Ranque in 1931. It was further developed by a German Professor Hilsch. Vortex tube is a device which provides hot and cold air simultaneously when compressed and cooled air is allowed to expand through a nozzle tangential to the pipe. To day, there are estimated 1,00,000 vortex tubes used commercially world wide. Fig.2.1 shows the schematic diagram of vortex tube.

WORKING PRINCIPLE:

Pressurised and cooled air is admitted into the supply manifold, where it enters the tube through one or more tangential nozzles. This imparts a swirling or vortex motion to the inlet air which subsequently spirals down the tube to the right of the inlet nozzle collar. A conical valve at the end of this hot tube allows the air in the periphery of the hot tube to pass through and restricts the air in the central portion of the hot tube, from making a direct exit. An orifice plate with a suitable sized hole in its centre is placed immediately to the left of the inlet nozzle collar. This allows the centrral portion of the fluid near the longitudinal axis to escape through the cold tube.

THEORY OF OPERATION:

The flow of air from the nozzle collar to the hot end valve is free vortex. The flow is restricted by the valve at the valve end, ie Kinetic energy of air is converted into pressure energy. The pressure at this stagnation point is above the pressure at the nozzle collar. So reverse axial flow starts towards the nozzle plane by forced vortex motion. The energy for the forced vortex is taken from both outer periphery air and the air in the core. So the central core temperature is reduced.

According to flow of motion there are two types of vortex tubes.

1. uniflow vortex tube
2. Counter flow vortex tube

1. UNIFLOW VORTEX TUBE

In this type both the hot and the cold air is discharged from the same end of the apparatus. In this type the separation of the two air streams is difficult.

2. COUNTER FLOW VORTEX TUBE

In this type, the two air streams flow in different ends of the apparatus.

The type chosen here is counter flow vortex tube with

a) Circular nozzle chamber

b) Four nozzles of convergent type each apart by 90°C

Advantages of vortex tube:

1) Since air is used as the working medium, the minor leakages are insignificant.

2) Its design is quite simple.

3) No moving parts are used, hence, the life of vortex tube is expected to be infinite and maintenance is almost nil.

4) It is light in weight, quite compact, easy to cool in a complicated space.

5) Cheaper in initial investment

6) Overall no expert attendant is required.

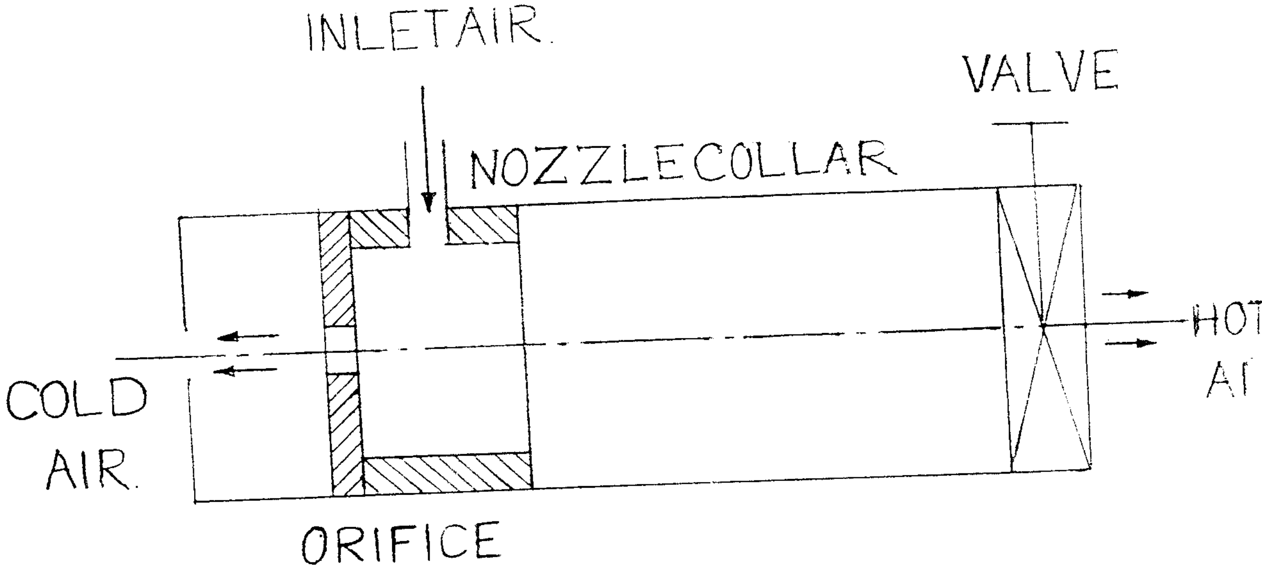


FIG.2.1. SCHEMATIC DIAGRAM OF VORTEX TUBE

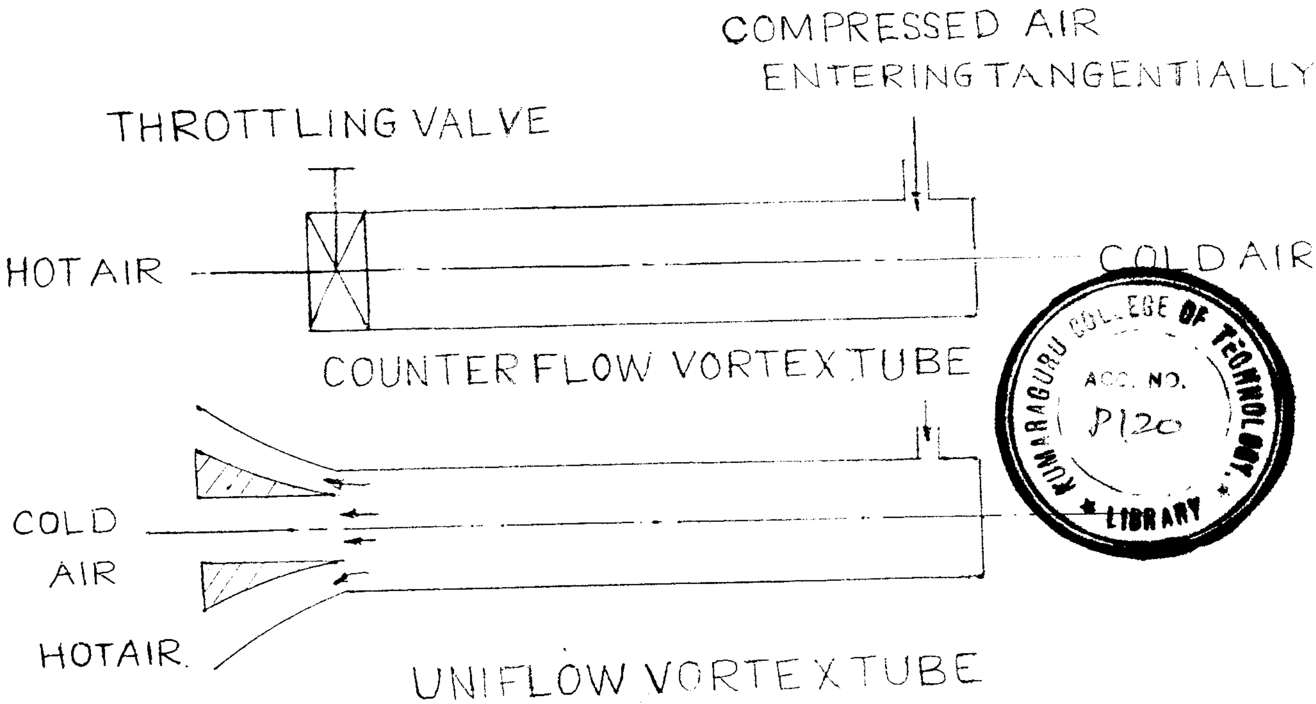
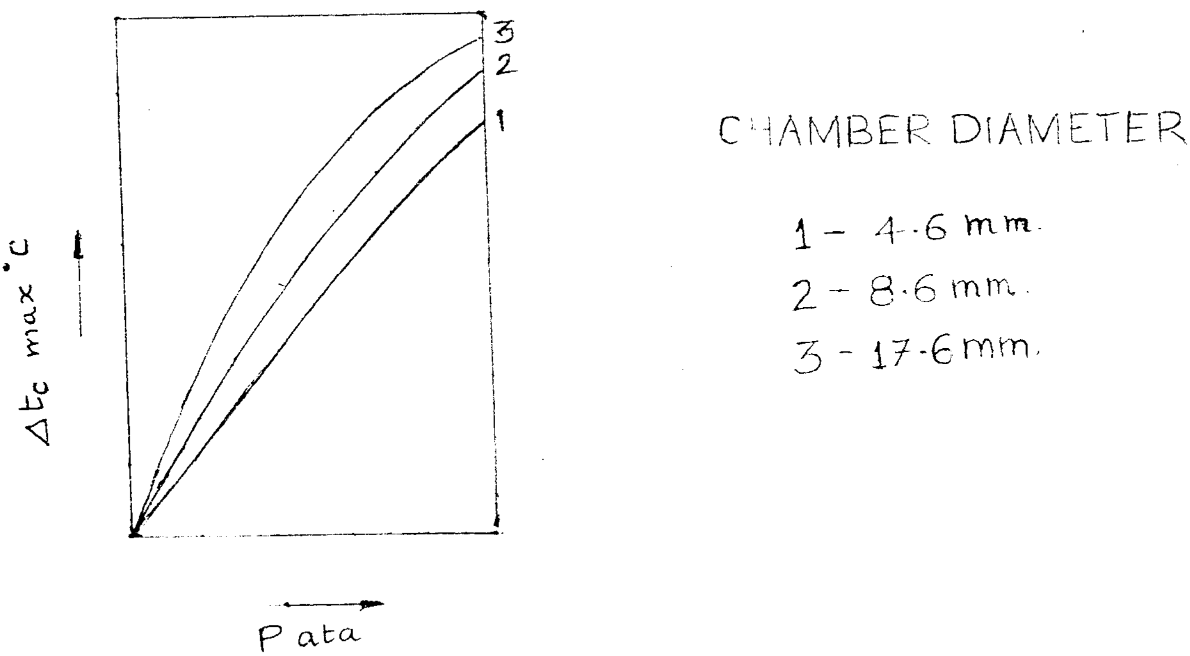


FIG.2.2. UNIFLOW AND COUNTERFLOW VORTEX TUBE



CHAPTER III

HISTORICAL BACKGROUND FOR THE DEVELOPMENTS OF VORTEX TUBE (HILSCH TUBE)

1. WORK DONE BY RANQUE.

Ranque, a French metallurgist discovered in 1931, the principle underlying the operatioon of the vortex tube, while he was working on cyclone dust separators. He observed that the central core of the stream was at a slightly lower temp.than that of the outer portion. He continued the work on the phenomenon and developed the vortex tube and decided for getting good results, the ratio of d:Do:Da=2: 3:8, where 'd' is the nozzle diameter, Do is the orifice opening diameter and Dc is the vortex collar diameter. Ranque shows two types of design, the uniflow and the counter flow type fig.2.2. He shows single and multiple entry nozzles of simple tangential as well as spiral types. The tube investigated by Ranque was 12mm diameter and gave T=32 °C for an inlet pressure of 7 kscm the corresponding being 0.46

2. WORK DONE BY HILSCH

Hilsch of Erlangen university. Germany, had done considerably work on the vortex tube. He made a systematic study of the tube. He studied 3 types of sizes. His results are shown in fig.3.1. He determined the optimum properties for the different components of the tube.

Most of the present days tubes

are based on the recommendations of Hilsch and the vortex tube is often known as Hilsch tube. Hilsch found that maximum temperature drop increases with increase in pressure and for a given pressure ratio larger tubes give better results. The orifice should be as near to the nozzle as possible and the orifice diameter equal to 0.45D to 0.6D for obtaining maximum temperature drop and maximum cold respectively. The inlet diameter should be equal to 0.25Dc. The hot side should be smooth and cylindrical and the valve at a distance of 0.5Dc from the nozzle..

Hilsch gives two reasons for larger tubes giving better performance. (i) Loss due to heat transfers from the axis to the periphery becomes less important. (ii) For longer tubes the Do/Dc optimum ratio becomes smaller, so that a relatively small orifice favours the transmission of cold air which has been well expanded and is practically free from relative motion. He gives an empirical formula for the quantity of air 'G' to be supplied to the tube.

$$G = 0.8xP_i \ x \ An$$

where G is in kg/hour

G is the inlet pressure in KScm

An is the area of nozzle in mm^2

3.WORK DONE IN U.S.A

In U.S.A., Fulton, by conducting experiments on vortex and inlet pressure of 7 atm. Megee studied the flow pattern in vortex tube by using coloured liquid in a transparent vortex tube. N.Scheller and G. Brown studied the pressure velocity and temperature distribution of the vortex phenomenon.

They have stated in their article that the highest velocity static pressure, total pressure and the lowest static temperature exist just at the outlet of the nozzle, that the static temperature is higher at the axis than at the wall and lines of constant total temperature indicate that the energy is transferred from the axis towards the periphery.

4. RESEARCH WORK CARRIED OUT IN THE CONTINENT

Elser and Hoch (Germany) worked with other gases besides air, such as carbondioxide, Methane, Argon and Hydrogen. They came to the conclusion that t_c was minimum for Co2 and increased in the order given above for other gases. They have also stated that the adiabatic index has no relation to the cooling effect produced.

Hardebol (Netherlands) worked on the flow pattern in the vortex tube and published flow diagrams for a 76mm tube. The results indicate that a particle on the axis having a temperature of 90° C near the wall gets its temperature reduced to-25° C by the time it reaches the nozzle. Also at the nozzle plane the difference in total nozzle and thereafter it decreases often found that a tapering hot and gives better results than a cylinderical one and has recommended 3.6 as the optimum angle for the hot end. He also tried water jacketing the hot side of the tube and came to the conclusion that tc does not increase by water jacketing.

5.WORK CARRIED OUT IN U.S.S.R.

In U.S.S.R Alekseyeu conducted experiments with multientry nozzles and found that double entry nozzle were giving the best results. He found the optimum ratio of nozzle area to the tube cross section area as 0.125. He also found that only central circular holed orifice were giving the best results than any other form of openings. His conclusion is that for maximum temperature drop the orifice diameter should be between 0.3 Dc to 0.4 Dc, for maximum cooling effect between 0.53 Dc to 0.6 Dc. He recommends the following preparations.

Length of hot end cylindrical tube = 50 times the tube diameter

Dc: Do:d = 4:2:1

His experiments indicate that tc max increases with Dc and that of the ratio of Dc opt/Dc decreases for increasing values of Dc.

Alekseyeu found that air gives better cooling than Ammonia. He found that increasing moisture content in the air leads to decrease in the performance of the tube. This is attributes to the orifice getting partically dogged due to condensation resulting in an increase of the internal pressure which decreases expansion ratio.

Merkulev introduced the present day nozzle of the vortex tube. He suggested rectangular cross section for the nozzle which greatly simplifies the making of nozzle. He was the first to suggest that rectangular nozzles of b = 2h and nozzle area equal to 0.092 times the collar area gives the best results. He also designed a vortex refrigerator. The two principles he had made use of there in are.

(i) Straightening out the cold stream so as to raise the degree of expansion, thus increasing tc.

(ii) Pre cooling the inlet air by means of the cold air which comes out of the refrigerator chamber.

It was found by Metenior that helical tangential injection gives larger temperature drop than straight tangential injection. According to metenin the following orifice diameters are recommended.

For maximum temperature drop $D_o = 0.38\ D_c$

For maximum cold productivity Do=0.51Dc

Metenin constructed a vortex Refigerator on the lines suggested by Merkulov. But instead of straightening out the cold stream, he made use of the rotation of the cold stream for effective cooling of the cold chamber. In addition he included an ejector for drawing out the cold air from the chamber. This type of refrigerator has the best use in industry for cold treating metal parts but the main draw back is that refrigeration capacity is low.

Parulekar evolved the short type which had the overall length of the tube between 3 to 4Dc. In that the cross section of the hot side opening was gradually increasing and as the length of the hot side was considerably reduced the roughness of internal surface did not appreciably affect the results. It was shown by Parulekar that the short vortex tube is in no way inferior to the other tubes.

6. WORK CARRIED OUT IN I.I.T. BOMBAY

In I.I.T. Bombay, several development works were carried out over the vortex tube. A temperature drop of 59% of the isentropic has been obtained the previous best being only 52%. The fig.3.1, shows the temperature drops obtained by various investigators.

7. WORK DONE BY Y.SONI & W.J. THOMSON

Optimal design of the RANQUEHILSCH vortex tube was done by Y.SONI and W.J. THOMSON (Dept.of Chemical Engg.University of Idaho). They conducted the experiment on two tangential entry nozzles, i.e., each of the nozzle apart by 180.° They varied the various parameters which are affecting the performance of the vortex tube (conducted more than 300 experiments)and were able to record a cold air temperature of - 48°C.

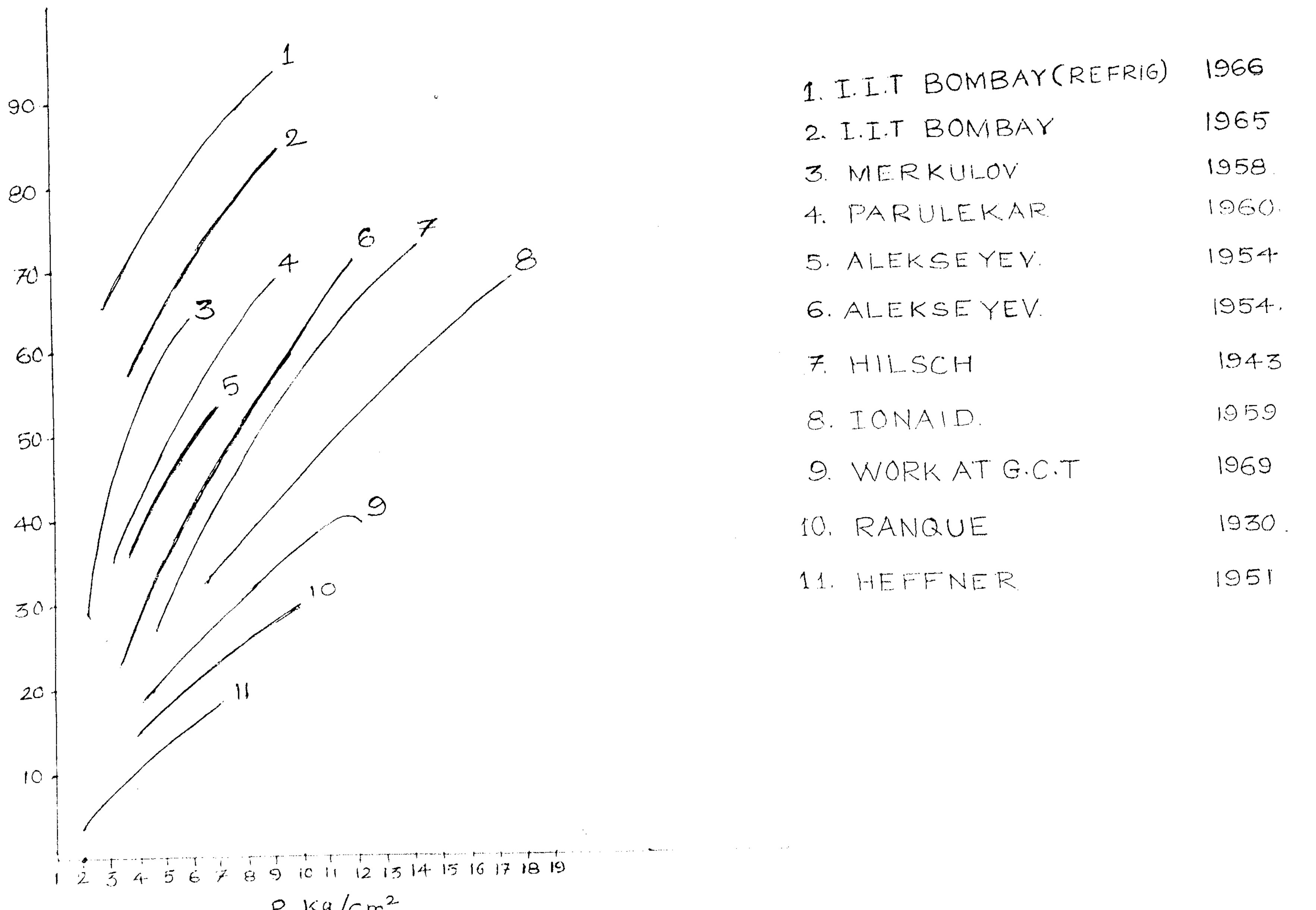


FIG.3.1. RESULTS OF VARIOUS INVESTIGATIONS ON THE VORTEX TUBE

CHAPTER IV

THEORETICAL EXPLANATION AND ANALYSIS OF THE VORTEX TUBE PHENOMENON

Several theories have been proposed so far to explain the working of the vortex tube. Some involve only the theoretical analysis, some are based on experimental investigation, while in some cases the theoretical proposals have been varied experimentally. Some present only a physical picture of the phenomenon while others try to present mathematical models. However, no theory has so far explained the phenomenon completely. Also it is not possible to determine the optimum properties of the various components of the tube on a theoretical basis nor is it possible to predict the performance of the tube for a given set of initial conditions. The following facts about the phenomenon have been established already.

(i) The cold stream starts right at the valve.

(ii) The air forms a free vortex near the wall and a forced vortex in the core.

(iii) In a given transverse section the total temperature at the wall is considerably higher than the total temperature at the axis.

(iv) The static temperature of the core is lowest at the axis and highest at the periphery of the core.

Different persons have put up different opinions regarding the mechanism of the energy transfer. Scheper and Galyaeu feel that part of the energy transfer is in the form of heat transfer from the core to the wall stream due to the existance of a higher static temperature at the core boundary. Fulton and Van Deemeter are of the opinion that there is a flow of K.E., from the core to the outer layers as the core tries to make the wall layers rotate with constant angular velocity. Kassner and Knoerschlld and Prins, Schultz-Grunov and Eckert and Hartnett believed that there is a pumping of energy from the axis to the outer periphery due to turbulance in centrifugal field and an increase in the static temperature from the axis outwards.

1. ANALYSIS GIVEN BY ECKERT AND HARTNETT

In the steady flow of the fluid without viscosity and heat conductivity there is obviously no possibility of an energy transfer from one stream tube to another, since the pressure forces can deliver no work. Consequently the total temperature remains constant. The situation is different in fluids with viscosity and conductivity.

Laminar flow in a tube POISEUILLE Flow:

The total temperature distribution for a fluid in laminar flow in a circular tube with the tube walls adiabatic may be obtained on solving the energy equation. The final result for the total temperature may be given in terms to PRANDTL number and centre line velocity Vc.

$$\frac{Tt-Tw}{V_c^2/2C_p} = (1-P_r)\,(1-r/R)^2$$

If Pr=1, the total temperature at the axis is the same as that of the wall. For the usual values of Pr the axial temperature will be greater than T_{tw}. Hence the effect of the laminar axial flow in a vortex tube will be to reduce the temperature drop obtained.

<u>Laminar Solid body Rotation</u>

The velocity distribution varies in this case linearly with the radius V=Vw (r/R), where Vw and V are respectively the tangential velocities at the wall and at any radius r. Since there are no shear stresses present, the energy equation becomes,

$$\frac{d}{dr}\left(\frac{VT}{r}\right) = 0$$

<u>Turbulant flow vortex motion</u>

It is hypothesized by Van Deemeter, Schultz-Grunov and karsner and Knoerschilld that through equilibrium temperature distribution in a highly turbulant gas flow in which pressure gradient exist normal to the flow direction should correspond to an isentropic variation with pressure. That is, if a small mass of a fluid at temperature T1 and pressure P1 moves to a new position where the pressure is P2, the temperature of the small is T2, then

$$T2 = T1\ (P2/P1)^{(K-1)/K}$$

If the temperature of the fluid already at the position is T2, no heat transfer will occur; otherwises, the resulting heat transfer will tend to establish the temperature T2. This is essentially the condition existing in the atmosphere with strong turbulant mixing. As the pressure difference between the wall and the axis is $Vw^2/2C_p$ and hence the difference in total temperature will be given by

$$T_{tw} - T_{ta} = 2V_w^2\ /2C_p$$

$$T_{tw} - T_{ta}\ \ /V_w^2\ /2C_p = 2$$

This equation indicates a greater separation effect in turbulent rotational flow than in laminar rotating flow. The experimental investigation done by Eckert and Hartnett show that the value of the dimensions parameter on the R.H.S. of the equation attains a value 1.3 to 1.8, which is a value higher than the one predicted for laminar flow; but lower than the one predicted for turbulent flow. The reasons that can perhaps be attributed to the lower value which is less than 2 is that the axial velocity tends to keep the value down as explained before.

The salient features of this theory is that the temperature difference predicted across a cross section is very much closer to the experimental values. This theory does not explain how the free vortex near the nozzle is transfered into a forced vortex nor is the nature of the energy exchange explained adequately.

2. ANALYSIS BY VAN DEEMETER

Van Deemeter presents his analysis of the vortex phenomenon with only circumferential flow by using complete energy equation. He has calculated the temperature distributions corresponding to several assumed velocity distributions. Like Eckert and Hartnett, he assumes a transformation from a free vortex to a forced vortex and hence there exist a flow of K.E., from the wall to the axis due to static temperature difference and flow of heat from the axis to the wall due to the turbulance mixing in which there is a tendency towards adiabatic distribution of the static temperature.

Van Deemeter has obtained performance curves whgich agrees with Hilsch's measurements. But the knowledge of velocity profile is necessary to use his formula.

3. ANALYSIS BY TAKAHAMA

H. Takahama has done investigation regarding the relationship between velocity and temperature profiles and a dimension of the main tube, nozzle, orifice etc. He has obtained equations for the velocity and the temperature profiles and he has found that if An/Ac is less than 0.08, the experimental results do not coincide with the data obtained from his equations. The reason according to Takahama is that An/Ac is less than 0.08, the jet flow from the nozzle is too weak to form perfect forced vortex flow in the central region. Thus for maximum efficiency of energy separation, he recommends a nozzle area of 8% of the tube area.

4. ANALYSIS BY SIBLKIN

He predicts that the temperature of the gas in the centre of the tube is the lowest when u=0. The geometric parameters which directly affects the vortex tube performance, according to his findings is the highest of the inlet nozzle. But Takahama has shown that the tangential velocity profile obtained by Siblkin's formula does not coincide. So well with the experimental results, as the results of Takahama's own theory do.

5. ANALYSIS PROPOSED BY PARULEKAR

Parulekar and his research assistants in their paper a new synthesis to explain the vortex separation phenomenon postulate the following theory. They have conducted a few simple experiments to give a sound understanding of the phenomenon of energy separation.

VORTEX TRANSFORMATION

The air enters the tube tangentially and forms a free vortex which travels along the wall. As a result of the obstruction of the valve on the hot side,,the air ceases to rotate at the valve region and a reverse stream starts. Due to the contact of this reversed stream with the internal surface of the vortex, it (the reversed stream) is made to rotate. Thus the axial stream forms a forced vortex. The external energy regained by the forced vortex is supplied by the free vortex is supplied by the free vortex and thus there is flow of energy in the radially inward direction. However the flow of energy in the opposite direction, to be explained presently much exceed this inward flow.

MECHANISM OF ENERGY TRANSFER

Turbulent mixing in the centrifugal field results in the pumping of energy from low pressure to the high pressure regain at the periphery. Also the air in the transverse plane through the nozzle collar has the highest rotation speed, which decreases gradually from the nozzle collar towards the valve where it is almost nil. There is thus a relative sliding between the various transverse planes by which there is a continuous flow from the plane of the nozzle collar to the valve. By this momentum transfer and also by the mass of the air shifting towards the valve. Fig.4.1 shows the mode and direction of energy transfer. But this theory does not give any idea of the rotative magnitudes of the energies transfered.

Vortex tube performance characteristics

The author of the paper named above have analysed the performance of the various components of the vortex tube and have given optimum proportions for the nozzle and orifiice.

They start their analysis with the equation for the total temperature just before the orifice as

$$T_{dt} = T_d + V_{dt}^2 /2C_p + V_d^2 /2C_p$$

where Td is the static temperature in the orifice for cold air fraction ( )and Vdt and Vd are the tangential and axial components respectively of the velocity of flow through the orifice. If the pressure just outside the orifice is less than that before the orifice (ie) if Pc Pd, T_{ct} T_{dt}, due to Joule Thomson effect, Fig.4.2 shows a typical performance curve for a vortex tube. The above mentioned equation is studied with reference for a vortex tube where the various points of importance mentioned below. Nozzle inlet-1, Nozzle throat-2, Tube periphery and Nozzle outlet-3, valve inlet-4, Diaphram inlet-5, orifice inlet-6, cold side-7 & valve outlet-8.

Each term that contribute to the total temperature on the cold side can be expressed in terms of the air and the tube parameters.

a) T_6 : $T_6 = T_t - \quad T_1 - T_{is}$ where gives the effect of friction. The actual value depends upon the shape, size and finish of various components will be considerably less than 1. $T_t - T_{is}$ is the isentropic drop in temperature between the points 1 and 6.

b) $V_{6t}^2 / 2C_p$; If we assume solid rotation, we get an expression for mean tangential velocity in terms of the peripheral velocity V_{3t}.

$$V_{6t}^2 / 2C_p = 4/9x \; (D_6/D_3)^2 \; x \; V_{3t}^2 / 2C_p$$

$$= 4/9 \; x \; f_6 / f_3 \; x \quad T_i - {}^3{}_{is}$$

where f_6 and f_3 are the orifice and the tube cross section areas. According to Eckert and Hartnet hypothesis, $P_3 = (P_1 P_6)^{\frac{1}{2}}$ and this enables us to fi

$T_i - {}^5{}_{is}$

c) $V_{6t}^{2} / 2C_p$; To find V_6 use is made of rotation

$$G_6 = G_2$$

ie., $V_6 f_6 \times P_6 / RT_6 = V^2 \times f^2 p^2 / RT_2$

$$V_6 = (f_2 / f_6)\ (P_2 / P_6)\ V_2\ (T_6 / T_2)$$

$$V_{6t}^{2} / 2C_p = (F_2 / F_6)(P_2 / P_6)\ (T_6 / T_2)^2 \quad T_1^{-2} \text{ is } ^2$$

Adding a, b and c, T_{6t} vs curve can be plotted is the flow conditions are specified.

In their calculations the authors assume critical flow at nozzle throat and discuss the flow through the orifice for two different conditions there, critical and sub critical. When the flow through the orifice changes from sub critical to critical becomes $_{cr}$. Then they get the equation.

$$f_2 / f_6 = (1.732/P_1)\ (T_1/T_6)^{\frac{1}{2}}$$

where T_6 is the static temperature at the orifice exit for =1. They have also concluded that for optimum performance $_{cr}$ =1 and have developed final expression for the ratio of nozzle area to diaphragm area as f_2 / f_6 =1.9/ P_1. Fig.4.3 shows the influence of f_2 / f_6 for a given pressure. The f_2/f_6 areas plotted against inlet pressure show that optimum ratio f_2 / f_3 varies from 13% to 4% as the pressure varies from 3.57 atm. to 12 atm.

6. VORTEX TUBE CHARACTERISTICS BY SOKOLON

The seperation effect is explained by sokolov with the help of the following simplified process. In the tube, the rotating streams of gas with different thermodynamic temperature and different distribution of velocities flow in opposite directions. The peripheral stream moves from the nozzle collar to the hot end, central stream moves in the opposite direction from the hot end to the nozzle. Due to the turbulance of the peripheral stream on the way from the nozzle to the exit section, the thermodynamic temperature of the stream increases continuously and its tangential velocity gets reduced. The central stream which moves in a direction opposite to the peripheral one is formed of gas particles which are carried away from the peripheral stream.

Thermodynamic temperature and angular velocity of central stream have the lowest values of the orifice. In the process of direction, interaction of the two streams, smoothening out of their temperature and angular velocity takes place. During this process heat and K.E., are transfered from the central stream to the peripheral stream. As a result, the total temperature of the peripheral stream increases and that of the central stream drops.

The working of the vortex tube is a complicated dynamic process. At present sufficient accurate methods of analysis and calculations for the process do not exist.

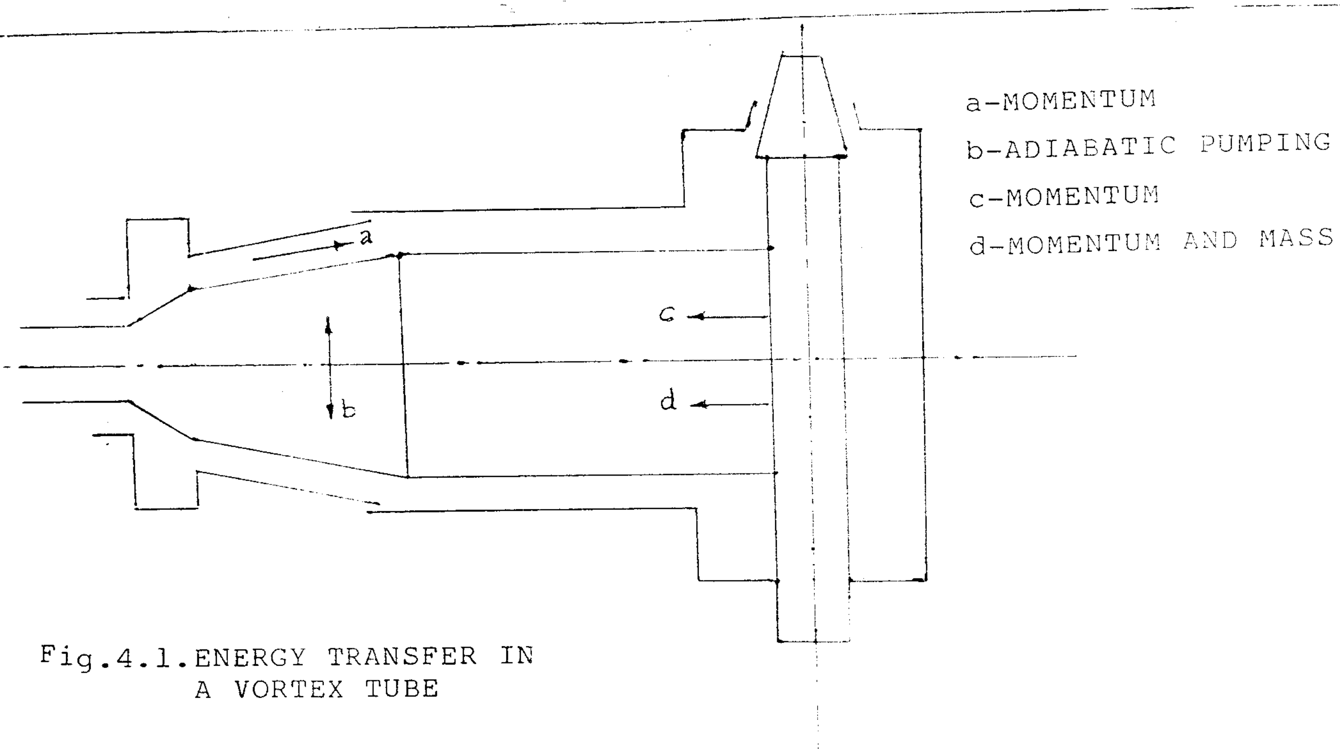


Fig.4.1.ENERGY TRANSFER IN A VORTEX TUBE

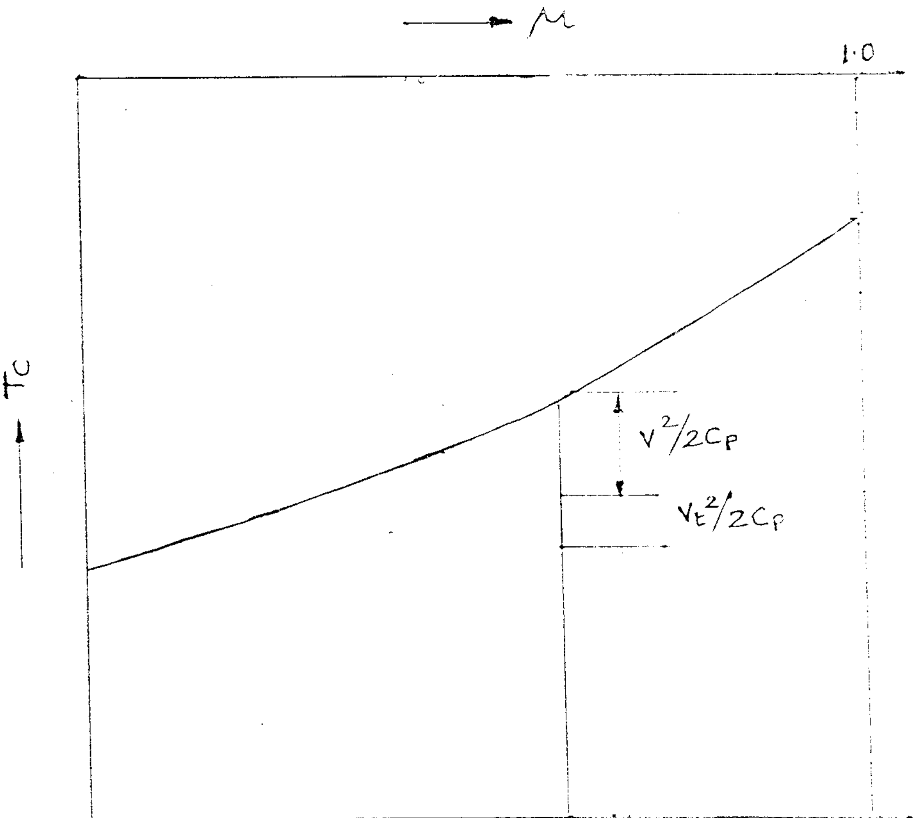


FIG.4.2. PERFORMANCE CURVE OF A VORTEX TUBE

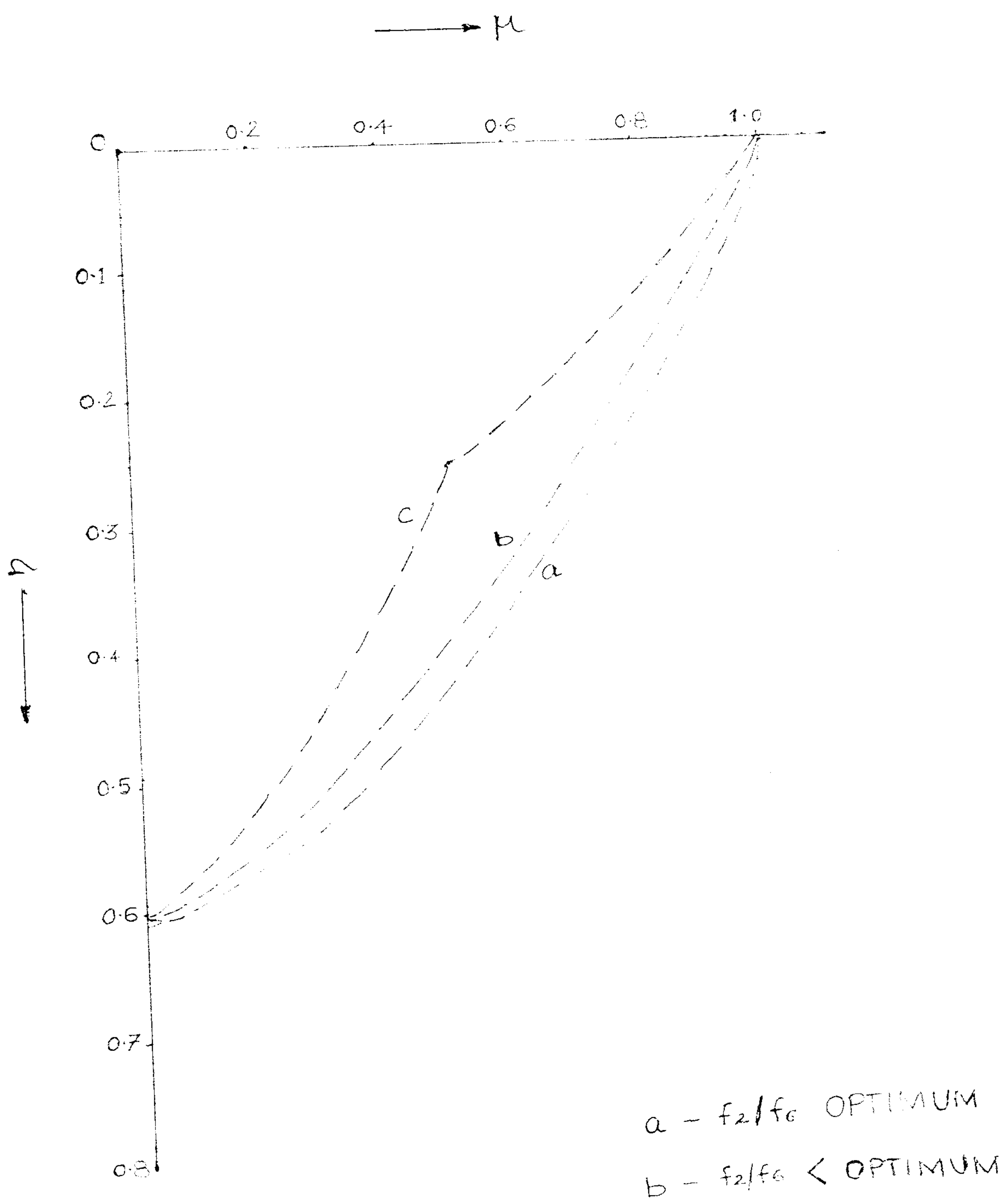


FIG.4.3.TYPICAL PERFORMANCE CURVES AND FOR A GIVEN PRESSURE

CHAPTER V

DESCRIPTION OF THE APPARATUS

The various parts of the vortex tube are given in the fig.1. It is essentially consists of a nozzle collar,orifice plate, two coaxial tubes which are connected by means of flanges. The fastening arrangements is made such that the nozzle collar can be changed and assembled easily.

The nozzle collar of the vortex tube is the heart of the tube and it provides the vortex action for the air. it is a gunmetal collar with two and four convergent circular cross section passages which passes radially, and is tangential to the inner periphery of the collar. The various shapes of the nozzle collar are shown in the fig.9 to 16.

The orifice plate is a M.S. ring with the hole having the diameter smaller than the inner diameter of the nozzle collar. This is placed by the side of the nozzle and allows the cold air to pass through. Adjacent to the orifice plate is placed the cold side tube. On the otherside of the nozzle hot air tube is fitted which serves as passage for the hot air. At the end of the hot tube a full way valve is fitted, which controls the flow rate of the hot air (ie, indirectly controls the cold air fraction).

The compressed air is passed inside the annular ring by a flexible hose. A nipple threaded to the annular ring ... hose to the vortex tube .

Provisions are made in the annular ring, the cold and hot tube, for measuring the corresponding temperatures. To present air leakage Rubber gasket is used in between annular ring and the two flanges.

DESIGN OF THE VORTEX TUBE

Our design is based on the experimental results of W.J. THOMSON AND Y.SONI (U.S.S.R). They conducted more than 300 experiments by varying the various parameters listed below., In their design two nozzles were provided in the nozzle plate. To improve the operating characteristics of the system we have used four nozzle entries. Also we have used 2 nozzle entries for the sake of comparison.

The factors which affect the performance of the vortex tube are:

1. Diameter of the collar (D_c)
2. Length of the hot tube (L)
3. Cross sectional area of the nozzle (A_n)
4. Cross sectional area of orifice (A_o)
5. Inlet pressure(P_i)
6. Fraction of inlet air exiting at the cold air end( )

The performance of the vortex tube refrigeration system can be studied by finding out T_c and dependant variablies.

1. T_c - Maximum difference in temperature between the inlet air and the cold air coming out of the cold tube.

2. Maximum Thermodynamic efficiency.

$$= (T_c) /(T_{cisn}) \times C.F$$

where,

T_{cisn} isentropic temperature drop at the nozzle

C.F Cold air fraction

$$= T_h - T_i/T_h - T_c$$

The optimum values of the dependent variables were arrived by changing the design parameters occuring to the Evop (Evaluational operation) procedures at fixed values of inlet pressure (is not included in EVop but adjusted to the optimum).

The results indicated following optimum design parameters for maximum T_c and maximum .

AN (Nozzle area/tube area) = 0.11± 0.01(0.084±0.001)

AQ (orifice area/tube area) = 0.08±0.01(0.145±0.035)

L/D 45 (48), D = 26mm (18mm)

DESIGN

From the experimental results of HILSCH it is found that maximum temperature drop is found to occur for a collar diameter of 17.6mm. The collar diameter is selected as 19mm. From the collar diameter (D_c), the orifice diameter (D_o) nozzle diameter (d) and tube length (L) where to be designed using the optimum performance results of Hilsch.

1. Orifice area/tube area = 0.14

   Orifice diameter = $(0.14 \times (\text{tube diameter})^2)^{\frac{1}{2}}$

   $= (0.14 \times 19^2)^{\frac{1}{2}}$

   = 7mm

2. Hot tube length/dia of the chamber 45

   L/D = 50

   LH = 50x19

   Hot tube length (LH) = 950mm

   Cold tube length (l)/hot tube length = ½

   add tube length L_c $= \frac{950}{2} = 475$

3. The dimensions of the various components listed below are

   (i) Nozzle collar

   Length = 18mm

   Outer diameter = 35mm

   Inner diameter = 19mm

   Nozzle diameter = 4mm, 6mm

   (ii) orifice plate

   Thickness = 6mm

   Outer diameter= 35mm

inner diameter = 7mm

iii) Flange

Outer diameter = 85mm

inner diameter = 23mm (M25 thread)

Pitch circle diameter = 57mm

Hub diameter = 35mm

Total thickness = Hub thickness+Flange thickness
= 20+10 = 30mm

(iv) Tube

Outer diameter = 25mm

Inner diameter = 19mm

Thickness = 3mm

(v)Annular ring

Outer diameter = 92mm

Inner diameter = 63mm

thickness = 20mm

DESIGN CHECK:

The maximum pressure with which the vortex tube i
designed 10 Ksc. The check for the thickness at variou
sections of components is done as follows.

Thickness of the plate of pressure vessel f
longitudinal joint is given by

$t = P_f \; D_i/2 \quad S_t \quad x \; F.S$

where, Di = internal diameter of the vessel

St = hoop stress

... pressure = 10Kscm

= assumed 100%

Fs = Factor of safety =5

CHECK FOR THICKNESS OF ANNULAR RING

$t = P_f D_i / 2 \; S_t x \; F.S$

$= \frac{10x6.3}{2 x1x1700} x5$ (S_t of C.I.= 1700 kgf/cm^2)

= 0.09cm = 0.9mm

The thickness of the annular ring is taken as 14.5 mm which is conservative value

2. CHECK FOR THICKNESS OF THE NOZZLE COLLAR

$t = P_f \; D_i \; /2 \; S_t \; x \; F.S$

S_t of Gunmetal = 40x1000 Psi (Conversion Psi = 0.07 Ksc)

= 2800 Ksc.

ie. $t = \frac{10 \; x \; 1.9}{2x1x2800} x5 = 0.019$ cm

We have taken t=18mm, so the design is safe.

3. CHECK FOR THICKNESS OF THE PIPE

$t = P_f D_i / \; 2 \; S_t \; X \; F.S$

S_t of pipe material (PVC) = 350 kgf/cm^2

ie, $t = \frac{10 \; x \; 1.9}{2x1x350} x5 = 0.13$ cm = 1.3mm

We have taken t = 3mm, so the design is safe.

FABRICATION AND MANUFACTURE OF VORTEX TUBE

1) NOZZLE COLLAR:

This is the heart of this system. To prevent corrosion, the nozzle material is chosen as Gunmetal. Also Gunmetal can withstand a high amount of pressure. The nozzle collar of Outer Diameter 35mm and 19mm Inner Diameter, with different nozzle profiles, where cast in Gun metal. The offset used for the profiles are 11mm, 16mm, 21mm, 26mm.

2. ORIFICE PLATE:

The material choosen for orifice plate is mild steel. The required inner diameter 7mm, outer diameter 35mm and thickness 6mm was machined in lathe.

3. GASKET

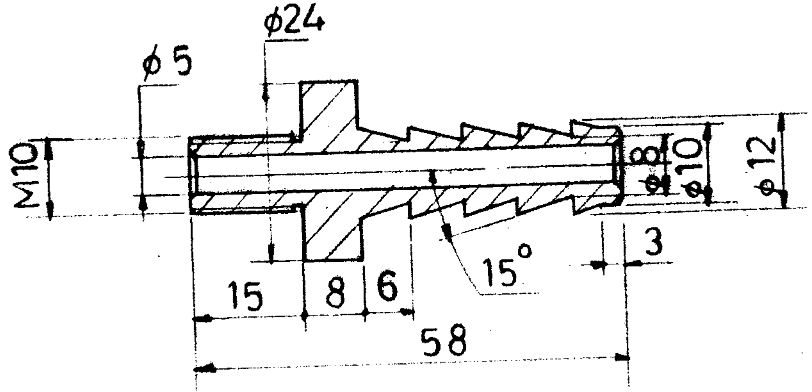
The material of the gasket is Rubber. This supports the nozzle collar and orifice plate and for that a groove of thickness 2mm and diameter 35mm was taken. Outer diameter 85mm, inner diameter 19mm and thickness 4mm was cut. Then 6mm diameter 4 holes were drilled for alligning purposes on a pitch circle Diameter of 57mm .

4. FLANGE

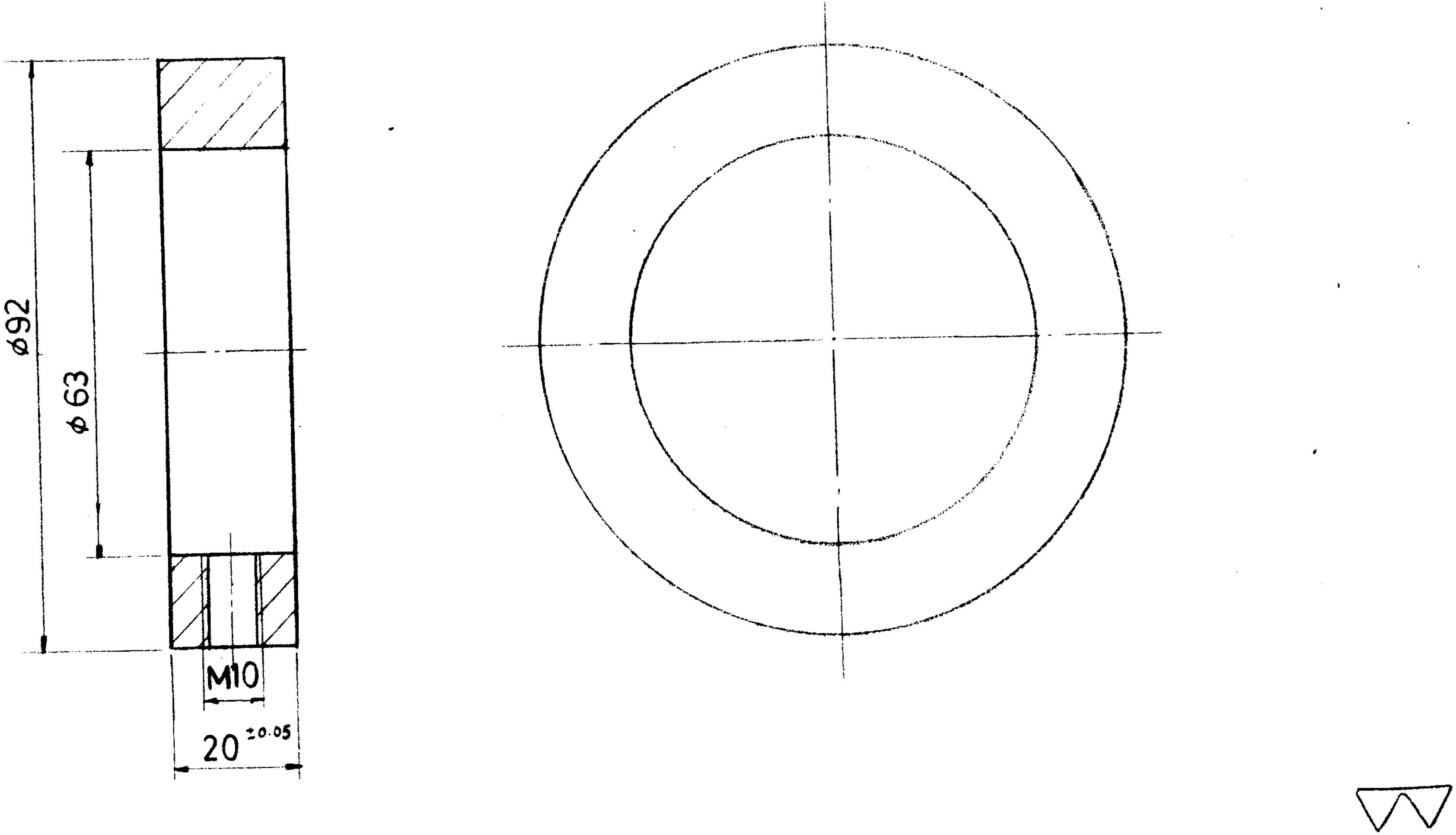
The material of the flange is C45 (EN8), inner diameter 23mm and M25 thread was machined to screw the hot and cold tube. Hub diameter 35mm and flange diameter 85mm was machined in lathe. Thickness of the hub 20mm, flange 10mm was machined. Then 6mm diameter, four holes were drilled for alligning purposes on a pitch circle diameter of 57mm.

5. HOT AND COLD TUBE

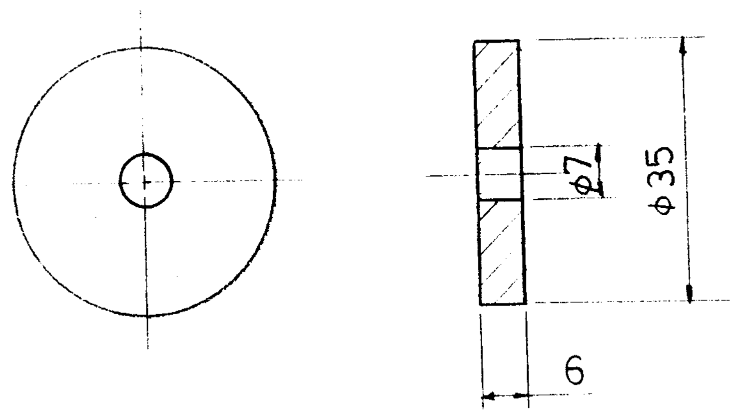
The PVC tube with outer diameter 25mm and inner diameter 19mm was selected. The PVC tube with these dimensions is available in standard. Length of the hot and cold tube were cut with 950mm and 475mm respectively. Also thread of M23 size was machined hot and cold tubes.



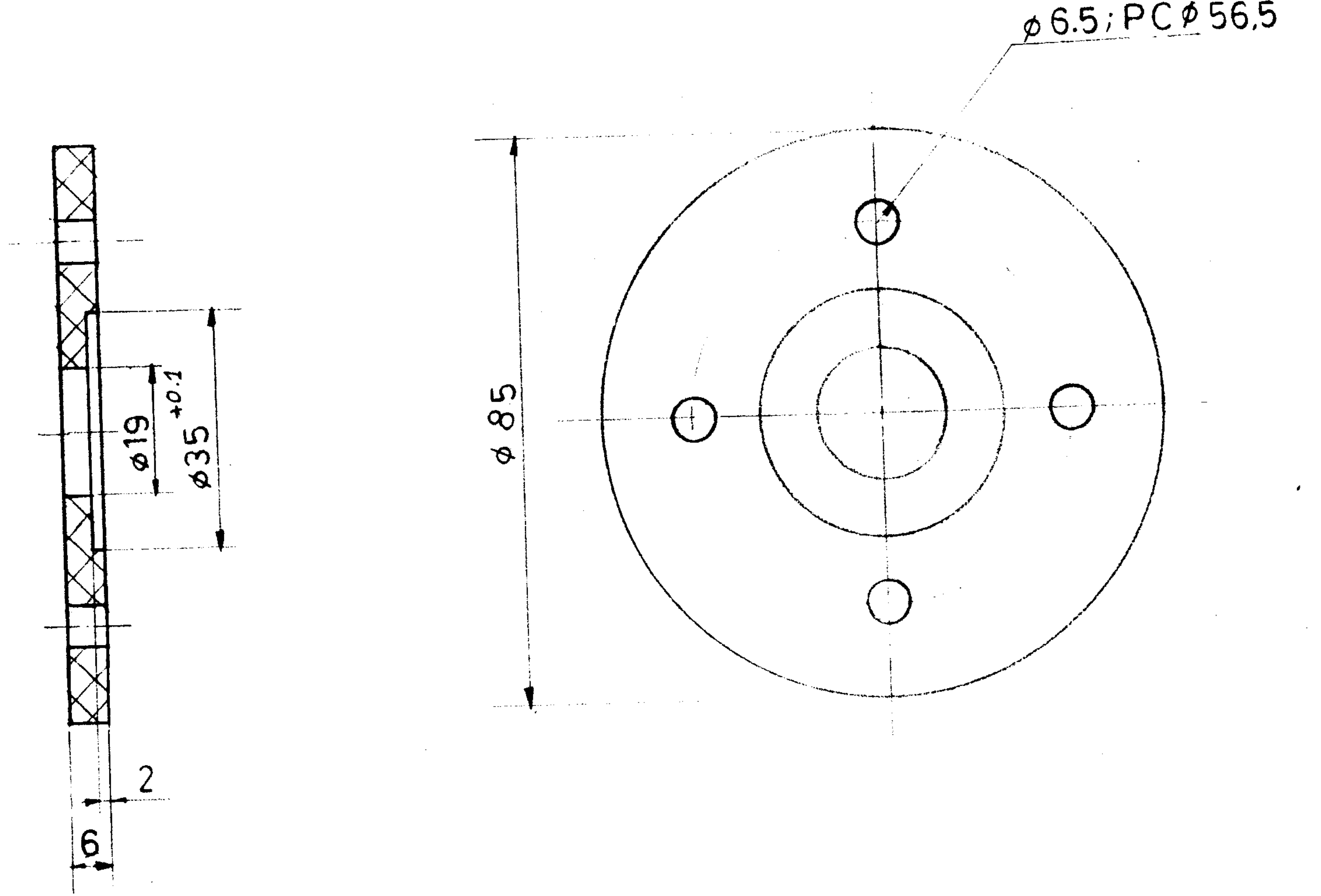
		Matl	No off	Toler	KUMARA GURU COLLEGE OF TECHNOLOGY coimbatore
		EN 8	1	IS2102 med	
		P. no	S. no		
Revision	date				
Scale 1:1	Design	V.R			



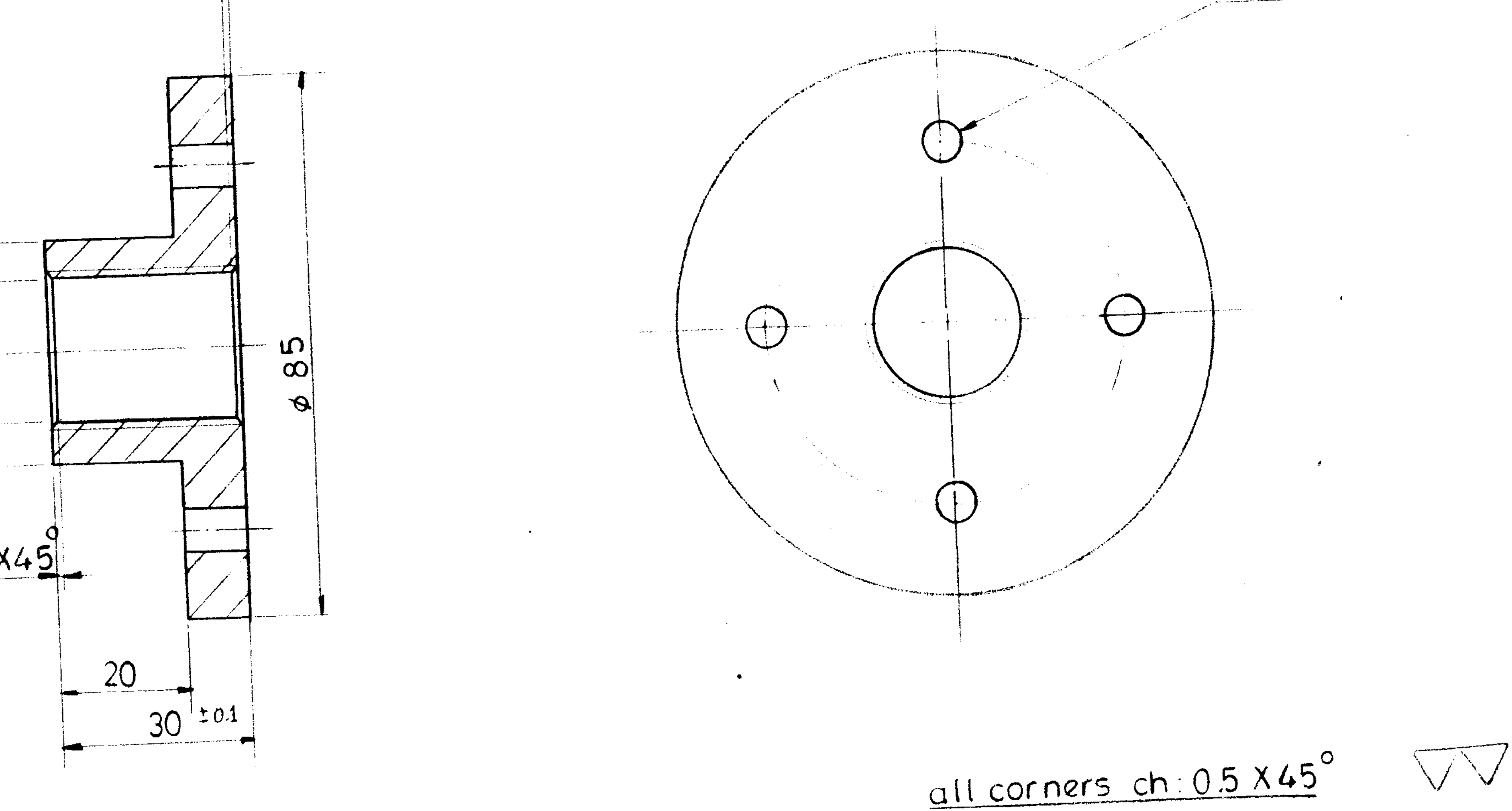
		Matl	No oft	Toler	KUMARA GURU COLLEGE OF TECHNOLOGY coimbatore	
		C I	1	IS2102 med		
Revision	date	P no	S no			
Scale 1:1	Design	V·R	2	3		Annular ring
	Drawn	K·M				



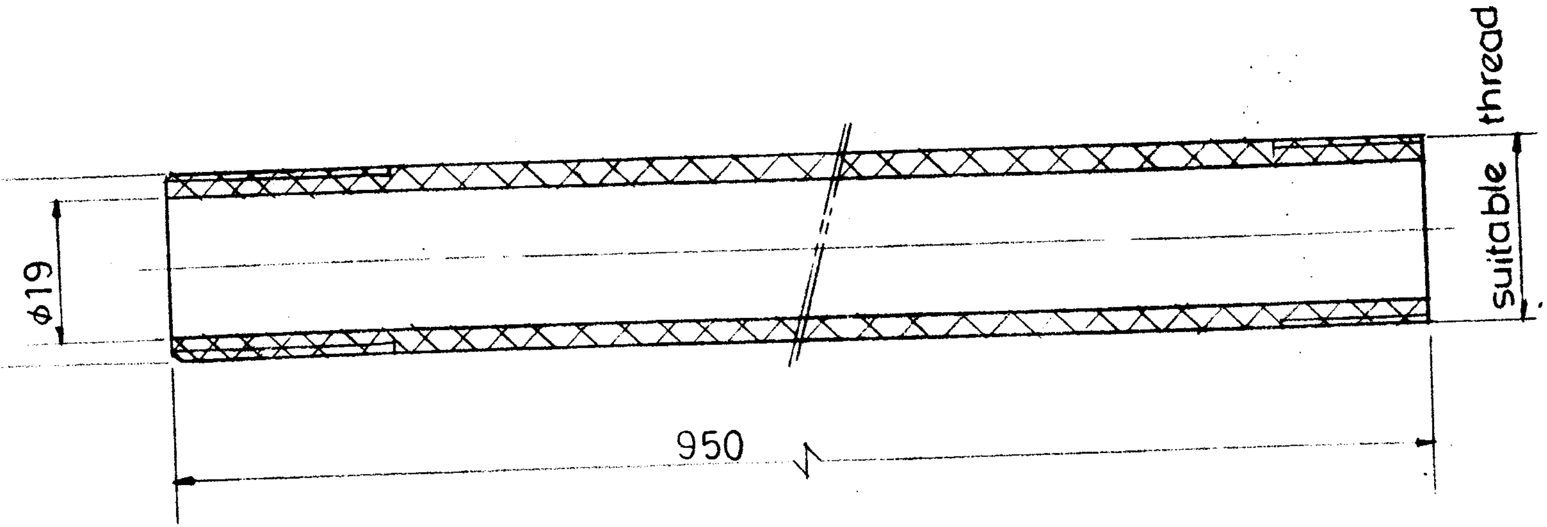
		Matl	No off	Toler	
		EN-8	1	IS2102 med	KUMARA GURU COLLEGE OF TECHNOLOGY coimbatore
		P no	S no		
Revision	date				
Scale 1:1 Design	V.R	5	4		Orifice plate
Drawn	K.M				



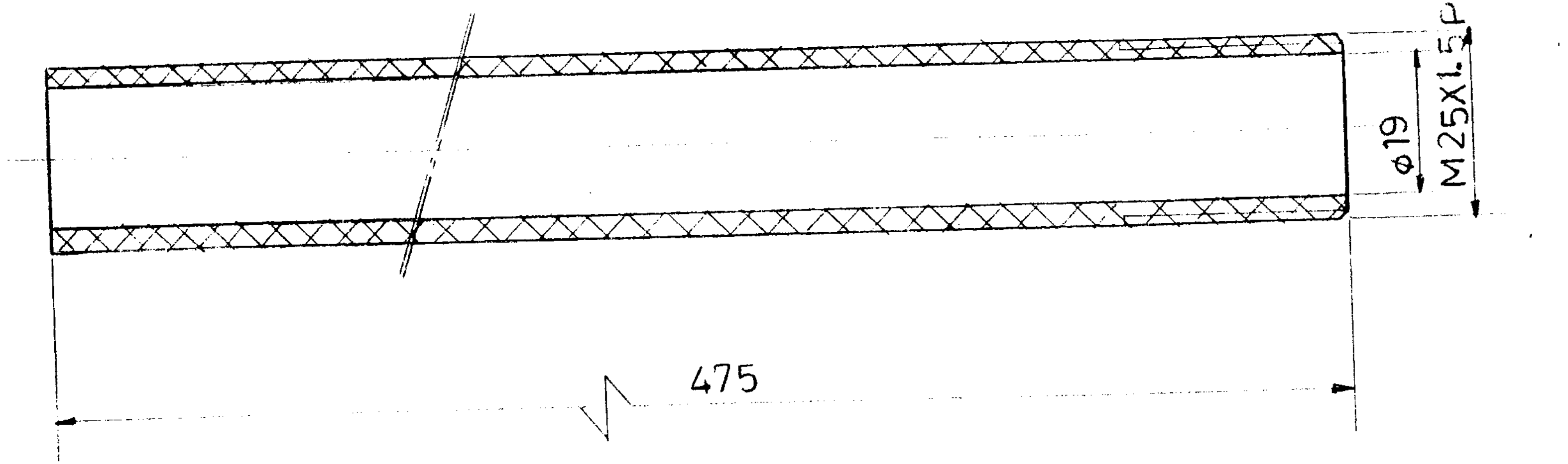
		Matl	No off	Toler	KUMARA GURU COLLEGE OF TECHNOLOGY coimbatore
		Rubber	2	IS2102 med	
		P. no		S.no	
Revision		date			
Scale 1:1	Design	N.R	3	5	Gasket
	Drawn	K.Mg			



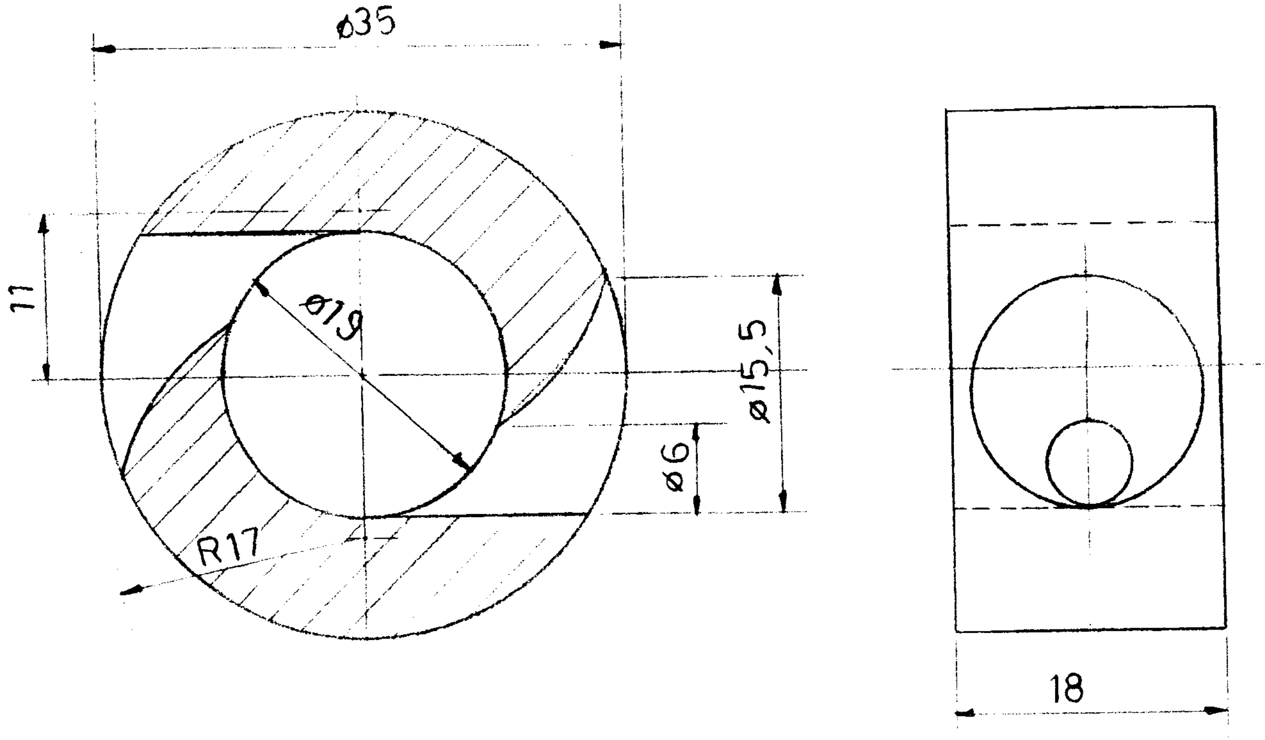
		Matl	No off	Toler	KUMARA GURU COLLEGE OF TECHNOLOGY - coimbatore
		EN · 8	2	IS2102 med	
		P. no	S. no		
Revision	date				
Scale 1:1 Design	V.R	6	6		Flange
Drawn	K.K				



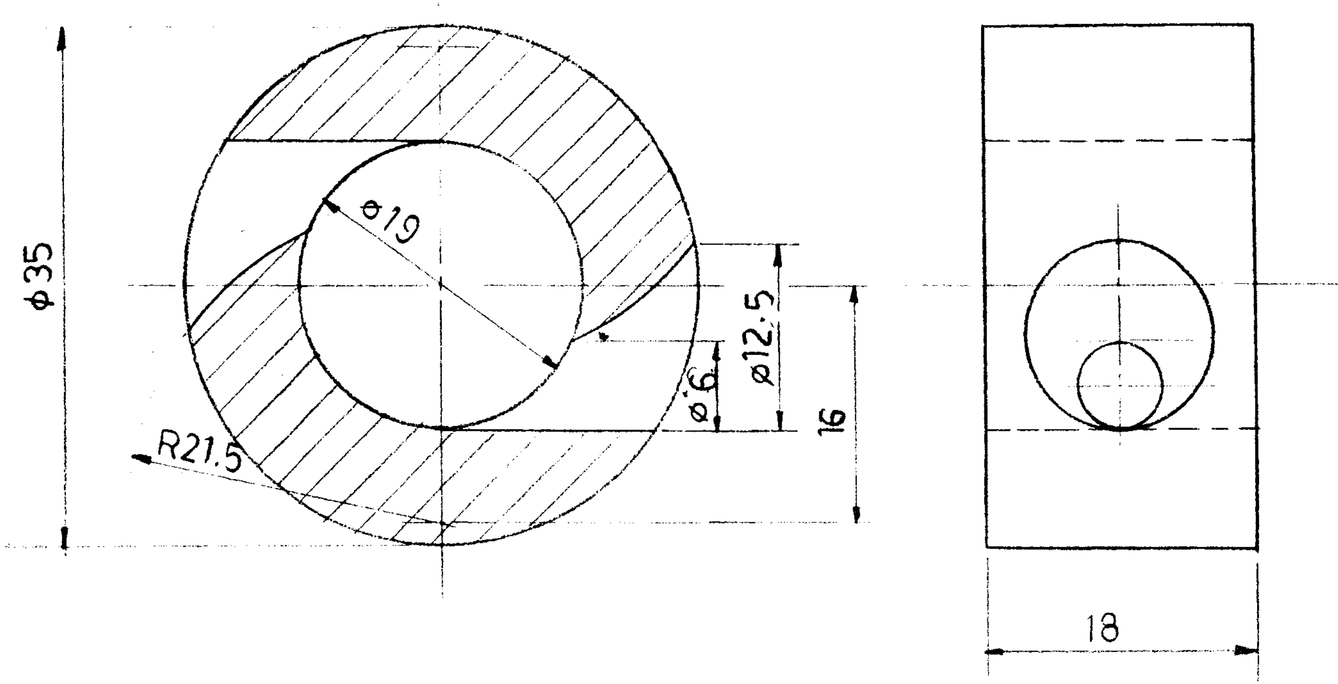
		Matl	No off	Toler	KUMARA GURU COLLEGE OF TECHNOLOGY coimbatore
		PVC	1	IS 2102 med	
		P. no	S. no		
Revision	date				
Scale 1:1 Design	v.R	7	7		Hot tube
Drawn	k. Me				



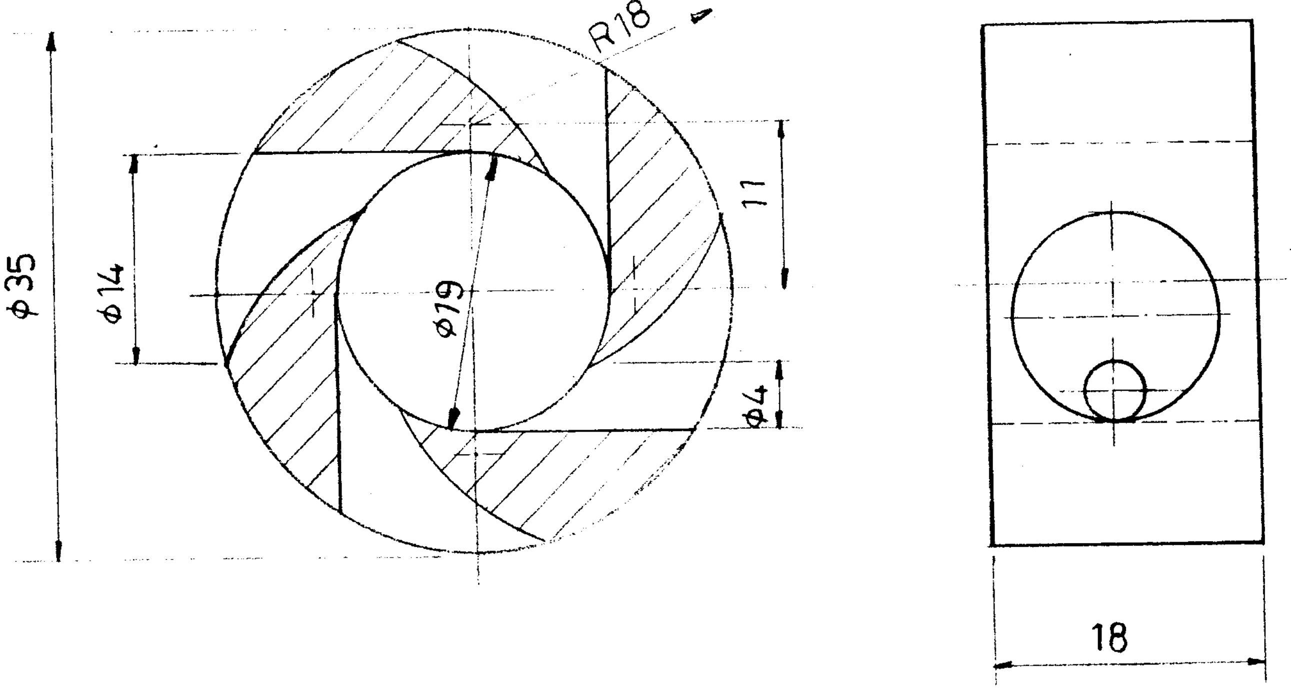
		Matl	No off	Toler	KUMARA GURU COLLEGE OF TECHNOLOGY coimbatore
		PVC	1	IS2102 med	
Revision	date	P.no	S. no		
Scale 1:1 Design	V.R	8	8		Cold tube
Drawn	K.M.G				



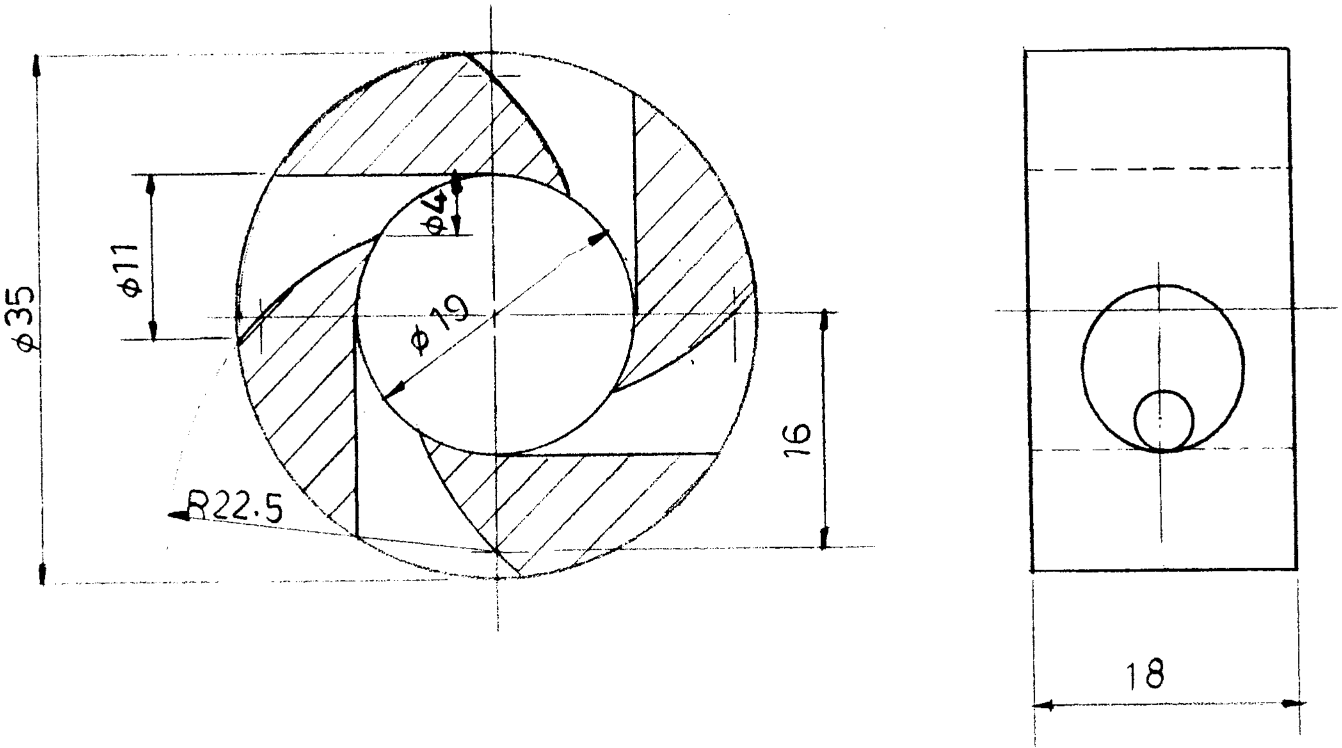
	Matl	No off	Toler	KUMRA GURU COLLEGE OF TECHNOLO[illegible] coimbatore
	G.Metal		IS 2102 med	
Revision / date	P no	S no		
Scale 2,1 / Design V.R / Drawn K.M[illegible]	4	9		Nozzle collar



	Matl	No off	Toler
	G·Metal		IS2102 med
Revision / date	P.no	S.no	KUMARA GURU COLLEGE OF TECHNOLOGY coimbatore
Scale 2:1 / Design: V.R / Drawn: K.V	4	10	Nozzle collar



		Matl	No off	Toler	KUMARA GURU COLLEGE OF TECHNOLOGY coimbatore
		G·Metal	1.	IS2102 med	
Revision	date	P. no	S.no		
Scale 2:1 Design	VR	4	13		Nozzle collar
Drawn	K 42				



		Matl	No off	Toler	KUMARA GURU COLLEGE OF TECHNOLOGY coimbatore
		G.Metal		IS2102 med	
Revision	date	P no	S no		
Scale 2:1 Design	V.K	4	14		Nozzle collar
Drawn	K.M				

CHAPTER VI

USES AND APPLICATION OF THE VORTEX TUBE

The Coefficient of the performance of the vortex tub is very low. The actual valve ranging from 0.15 to 0.20 but the vortex tube is very compact, simple in constructio and there is no moving parts. It is quick in action and use air as a working substance. No specially trained attendan is required and the control is simple and effective.

The tube can very conveniently be used in shops havir their pneumatic system for cooling or air-conditioning, the requirements are intermittant nature. Shell laboratori are using the tube in process work. They have also used to study the combusion performance of compression igniti engines under cold running conditions. It is also used f cooling the instrument panel of supersonic planes, whe the cooling load per unit are quite high.

It can be used in the lower cascade with F-12 in t higher one of coscade refrigeration system to produce tem of the order of $-80^{\circ}C$ to $-100^{\circ}C$. Markulv and Metenin ha developed refrigerators which are being used in a f industries for cold treatment of small machine parts. T principle of vortex tube has been used by U.S. Navy temperature measurements in high speed plane (upto 500mph Hooper and Juhosz have developed an electric dew point met which is cooled by vortex tube.

Because air leaves the tube at sonic speed its operates with a characteristic air hiss. To reduce the noise such arrangements like baffle muffler or stuffed muffler can be used at both hot and cold tube ends.

The various uses of the vortex tube listed below.

1. INDUSTRIAL

Cooling of bearings, tools, gas turbine blades, air powered equipments, cooling of drinking water and beverages, personal cooling, environmental chambers, portable refrigerators, automobile cooling and heating, shrink, air suits, etc.

2. MINE

In mines, temperature will be high valve. It is not desirable for the workers. So to provide cooling effect or cold air, the vortex is used. This system is only possible for use in mine.

3. AVIATION

Air conditioning, cooling of electronic equipments, skin cooling etc. The use of vortex tube in military air craft may have a marked advantage overall other systems as small cockpit is cooled.

3. CHEMICAL PROCESSING

Self cooling of natural gases, heating and cooling processes.

4. BIOLOGY AND MEDICINE

Controlled freezing, skin treatment, surgery, etc.

5.EDUCATIONAL

Student demonstration, instruction and research.

6. EXPERIMENTAL

Material testing, thermo couple cold junctions, testing and calibrating thermo meters, spectroscopy, reaction rates,freezing point determination, soluability tests, viscosity determination, heating and cooling of Plastics etc.

CHAPTER VII

EXPERIMENTS ON THE VORTEX TUBE

1. EXPERIMENTAL SET UP

The experiment was conducted on the 19mm vortex tube. Since only a low capacity compressor of 24cF per minute was available in the laboratory, it was decided to conduct all the experiments on the 19mm tube which according to calculations is capable of maintaining a maximum inlet pressure of about 9 Kscm. The tube was fitted with various nozzles and the experiments were conducted.

The vortex tube was connected to the receiver outlet. The pressure gauge in the receiver and a thermometer in the inlet pipe were used to measure the pressure and temperature of inlet air. A thermometer which ranges from +50°C to - 50°C was used to measure the temperature of the cold air. Another thermometer having the range -10° C to +50 °C was used to measure the hot air temperature. The fittings were checked to avoid leakage of air. Care was also taken to see that the nozzle opening was just below in the correct position. So that perfect tangential entry of air into the nozzle was possible. Fig.6.1 shows the schematic arrangement of the experimental set up.

2. EXPERIMENTAL PROCEDURE

The receiver outlet valve was kept closed and the compressor was run. When the pressure inside the receiver was about 9 Kscm the compressor was stopped. To start with the side gate valve was closed completely. Now the air was admitted into the vortex tube by fully opening the outlet of the receiver, as quick as possible in order to avoid the throttling effect. Now the gate valve in the hot side was gradually opened and the flow through the hot side adjusted to obtain a maximum temperature drop in the cold side. This position was left without any disturbance. This way only a trial run and now the tube was ready for experiment. Now the receiver outlet valve was closed and again the compressor was run to build up the required pressue in the receiver after which the compressor was stopped.

The outlet of the receiver was fully opened and as the pressure fell down slowly, for various inlet pressures, the inlet temperature, the cold air temperature and the hot air temperature were noted. This experiment was conducted with nozzles of various shapes and various diameter. The experimental results are tabulated at the end.

3. TEMPERATURE DROP

The temperature difference between the inlet and the cold side was found out. This is the measure of the coldness produced due to the vortex motion of the air in the nozzle.

4. COLD FRACTION

This can most conveniently be calculated by stiking on enthalpy balance for the air entering the vortex tube. Consider 1 kg of air entering the tube

$$1 \times T_i \times C_p = \mu T_c C_p + (1-\mu) T_h C_p$$

$$T_h - T_i = \mu(\Delta T_h - \Delta T_c)$$

where $\Delta T_h = T_h - T_i$

$$\Delta T_c = T_i - T_c$$

$$\Delta T_h = \mu(\Delta T_h + \Delta T_c)$$

therefore $$\mu = \frac{\Delta T_h}{\Delta T_c + \Delta T_h}$$

The cold air fraction can also be determined by the use of orifice meters.

5. RELATIVE TEMPERATURE DROP OF THE VORTEX TUBE (ΔTrel)

In the air cycle refrigeration system the ideal cycle consists of an isothermal compression followed by an isentropic expansion.

The vortex tube is always compared with the air cycle systems, considering the amount of cold produced and the temperature drop obtained for the purpose of comparison.

Relative temperature drop (ΔT_{rel}) of the vortex tube is the ratio of difference in temperature obtained actually to the fall in temperature if the air is expanded isentropically, i.e.,

$$\Delta T_{rel} = \frac{\Delta T_c}{\Delta T_{cisn}}$$

6. ADIABATIC EFFICIENCY OF THE VORTEX TUBE. η_{av}

Adiabatic efficiency of the vortex tube is defined as the ratio of actual cooling gained in vortex tube to cooling possible with adiabatic expansion i.e. $\eta = \mu \times \Delta T_{rel}$

7. MODEL CALCULATIONS

The fourth reading of the experiment Number 1. is taken for model calculations

Diameter of the nozzle = 6mm

offset = 11mm

$$\Delta T_c = T_i - T_c = 36-9 = 27^{\circ}C$$

$$\Delta T_h = T_h - T_i = 40-36 = 4^{\circ}C$$

$$\mu = \frac{\Delta T_h}{\Delta T_c + \Delta T_h} = \frac{4}{27 + 4} = 0.129$$

$$T_{isn} = \frac{T_i}{(P_i / P_c)^{\frac{K-1}{K}}} = \frac{36 + 273}{(4.8)^{0.285}}$$

$$= 199.61^{\circ}K$$

$$\doteq - 73.39^{\circ}C$$

$$\Delta T_{isn} = T_i - T_{isn}$$

$$= 36 - (-73.39)$$

$$= 111.39^{\circ}K$$

$$\Delta T_{rel} = \Delta T_c / \Delta T_{isn} = \frac{27}{111.39}$$

$$= 0.242$$

Adiabatic efficiency of the vortex tube

$$\% \eta_{av} = \mu \times \Delta T_{rel} \times 100$$

$$= 0.129 \times 0.242 \times 100$$

$$= 3.12\%$$

8. TABULATION

1.NOZZLEDIAMETER= 6mm, OFFSET 11mm (2 NOZZLES)

Sl No	P_i KSCM	T_i °C	T_c °C	T_h °C	ΔT_h °C	ΔT_c °C	μ	T_{isn} °C	ΔT_{rel}	ΔT_{isn} °C	η_{av}%
1	8	38	10.6	39	1	27.4	0.035	-101.05	0.197	139.05	0.689
2	7	38	11.6	41	3	26.4	0.102	- 94.38	0.199	132.38	2.02
3	6	37	17.0	38	1	20.0	0.047	- 86.97	0.169	123.97	0.757
4	5.6	36.5	14.0	40	3.5	22.5	0.135	- 83.58	0.187	120.08	2.52
5	4.8	36	9.0	40	4	27.0	0.129	- 73.39	0.242	111.39	3.12
6	3.8	35.5	18.2	42	6.5	17.3	0.273	- 62.13	0.177	97.63	4.83
7	2.6	35	22.2	39	4	12.8	0.238	- 38.42	0.174	73.42	4.14

2. NOZZLE DIAMETER = 6mm, OFFSET 16mm (2 NOZZLES)

Sl. No	P_i KSCM (abs)	T_i °C	T_c °C	T_h °C	ΔT_h °C	ΔT_c °C	μ	T_{isn} °C	ΔT_{isn} °C	ΔT_{rel}	η_{av} %
1	8.0	38.0	15.2	41.0	3.0	22.8	0.116	-101.1	139.1	0.163	1.9
2	7.0	37.5	14.8	38.5	1.0	22.7	0.042	- 94.7	132.2	0.171	0.72
3	6.0	37.0	17.4	39.0	2.0	19.6	0.093	- 94.96	131.96	0.148	1.381
4	5.6	37.0	15.2	39.0	2.0	21.8	0.084	- 86.97	123.97	0.175	1.476
5	4.8	36.0	13.0	39.5	2.5	23.0	0.098	- 74.75	110.75	0.207	2.034
6	3.8	36.0	16.8	39.0	3.0	19.2	0.135	- 61.79	97.79	0.196	2.646
7	2.6	36.0	18.4	38.0	3.0	17.6	0.146	- 37.66	73.66	0.239	3.48

3. NOZZLE DIAMETER = 4mm, OFFSET = 11mm (4 NOZZLES)

Sl. No	P_i KSCM (abs)	T_i °C	T_c °C	T_h °C	ΔT_h °C	ΔT_c °C	μ	T_{isn} °C	ΔT_{isn} °C	ΔT_{rel}	η_{av} %
1	8.0	37.0	10.0	39.0	2.0	27.0	0.068	-101.61	138.69	0.195	1.33
2	7.0	37.0	11.2	39.5	2.5	25.8	0.088	- 94.96	131.96	0.196	1.70
3	6.0	36.5	15.0	40.0	3.5	21.5	0.140	- 87.27	123.77	0.173	2.42
4	5.6	36.0	13.0	40.0	4.0	23.0	0.148	- 83.88	119.88	0.192	2.84
5	4.8	35.0	8.0	37.0	2.0	27.0	0.068	- 73.03	111.03	0.243	1.65
6	3.8	34.0	17.2	38.5	4.5	16.8	0.211	- 63.13	97.15	0.173	3.65
7	2.6	32.0	20.2	37.0	5.0	11.8	0.298	- 40.71	70.71	0.167	4.97

Sl. No	P_i KSCM (abs)	$T_1\,^oC$	$T_c\,^oC$	$T_h\,^oC$	$\Delta T_h\,^oC$	$\Delta T_c\,^oC$	μ	$T_{isn}\,^oC$	$\Delta T_{isn}\,^oC$	ΔT_{rel}	η_{av} %
1	8.0	38.0	13.2	39.0	1.0	24.8	0.038	-101.05	139.05	0.178	0.676
2	7.0	37.5	14.0	39.0	1.5	23.5	0.06	- 94.67	132.17	0.178	1.06
3	6.0	37.0	15.2	38.5	1.5	21.8	0.064	- 86.96	123.96	0.176	1.13
4	5.6	36.0	12.0	40.0	4.0	24.0	0.143	- 83.88	119.88	0.20	2.86
5	4.8	36.0	10.0	41.0	5.0	26.0	0.161	- 75.39	111.39	0.233	3.75
6	3.8	35.0	11.0	39.5	4.5	24.0	0.158	- 62.47	97.47	0.246	3.88
7	2.6	33.0	13.8	39.0	6.0	19.2	0.238	- 39.95	72.95	0.263	6.25

9. GRAPHS:

The performance of the vortex tube can be studying the following characteristics.

a) Effect of inlet pressure on T_c

b) The relation between inlet pressure and adiabatic efficiency of the vortex tube.

10. RESOURCES AND INFERENCES

It was found from graphs & experiments done on the vortex tube that the 2 nozzles of 6mm diameter with 11mm profile, gave a maximum temperature drop of 27.4 $^{\circ}$C with an adiabatic efficiency of 0.689%. Also, the 4 nozzles of 4mm diameter with 11mm profile gave a maximum temperature drop of 27 $^{\circ}$C, with an adiabatic efficiency of 1.33%.

The cold air fraction ( ) was found to increase with increase in T_c.

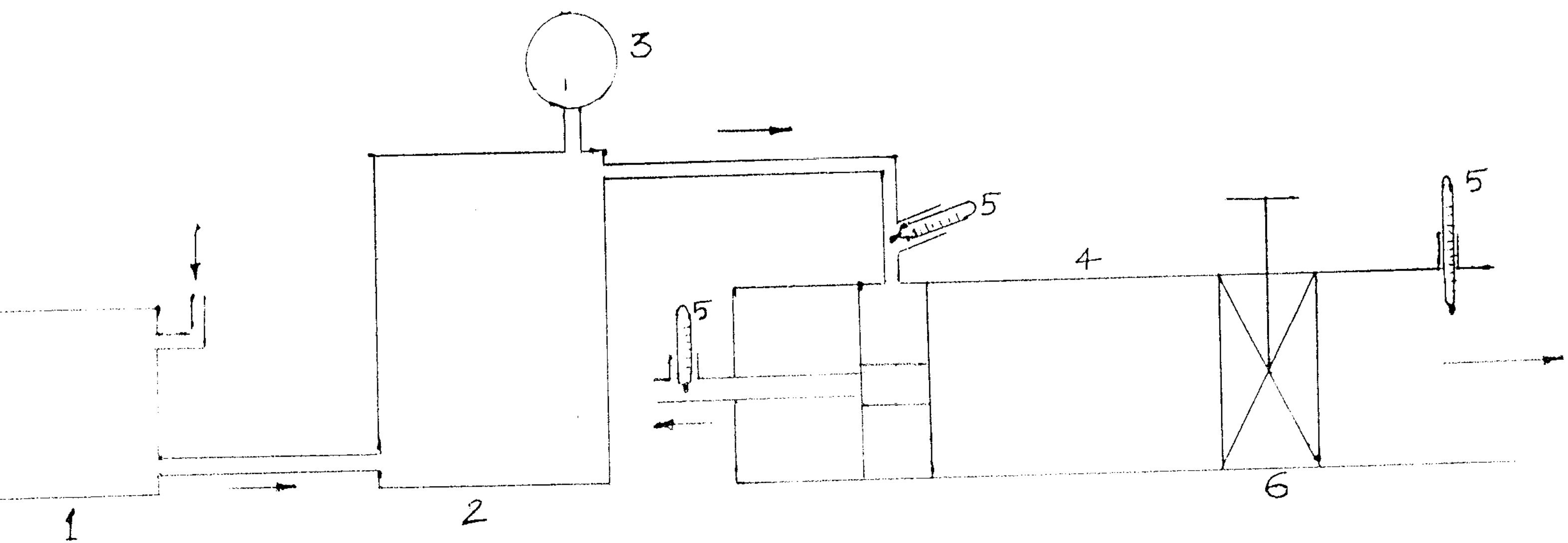
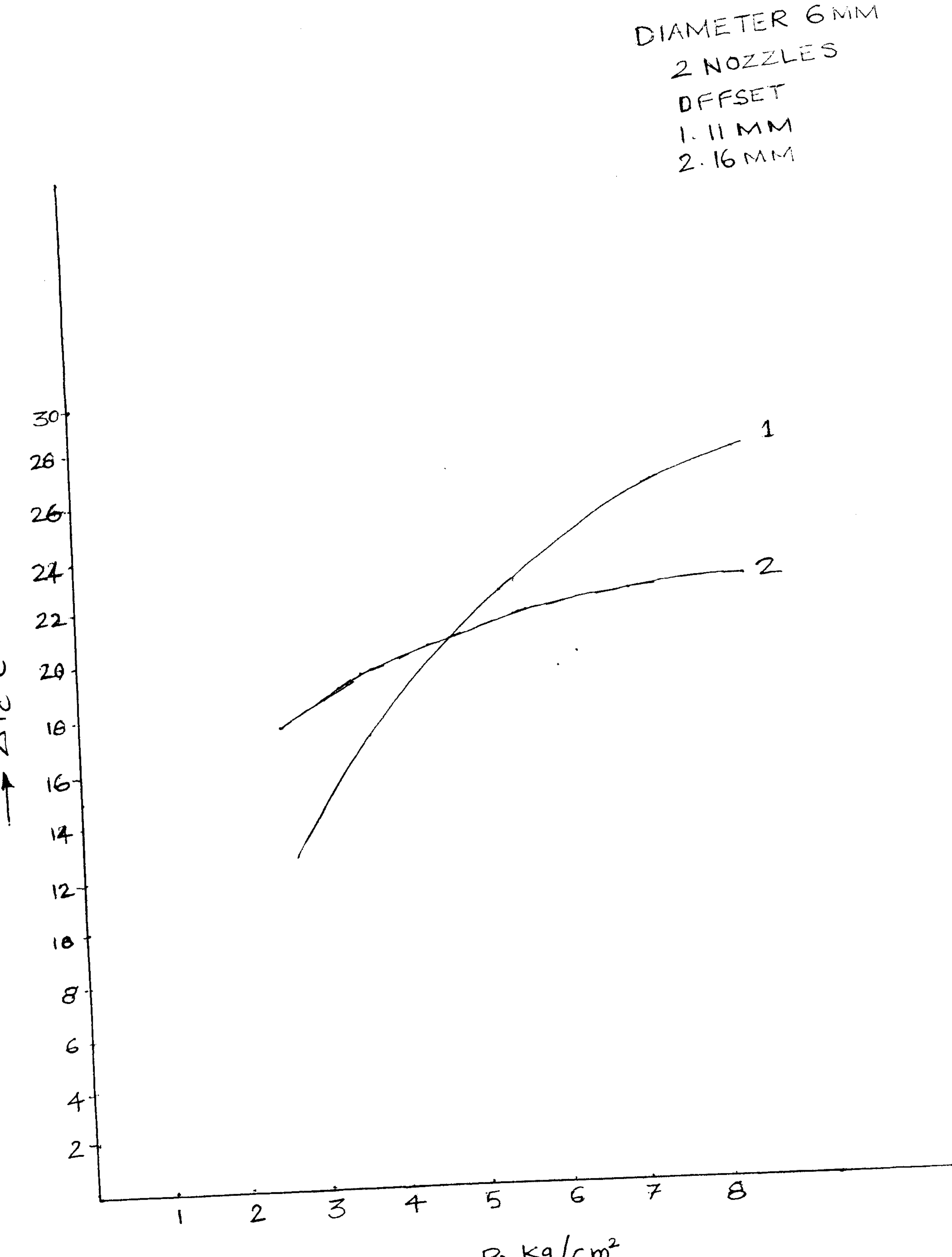
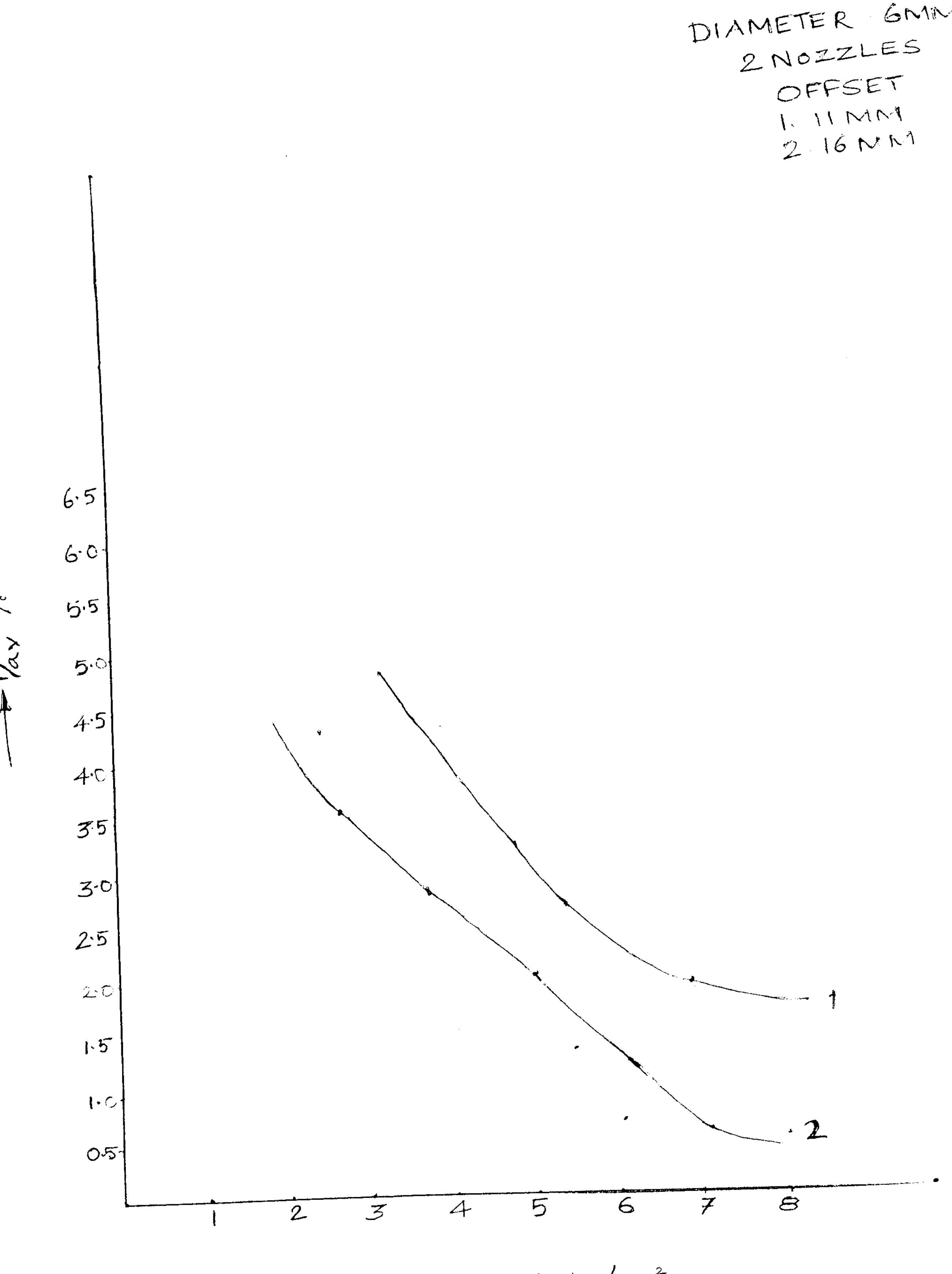


FIG.7.1. EXPERIMENTAL SETUP USED

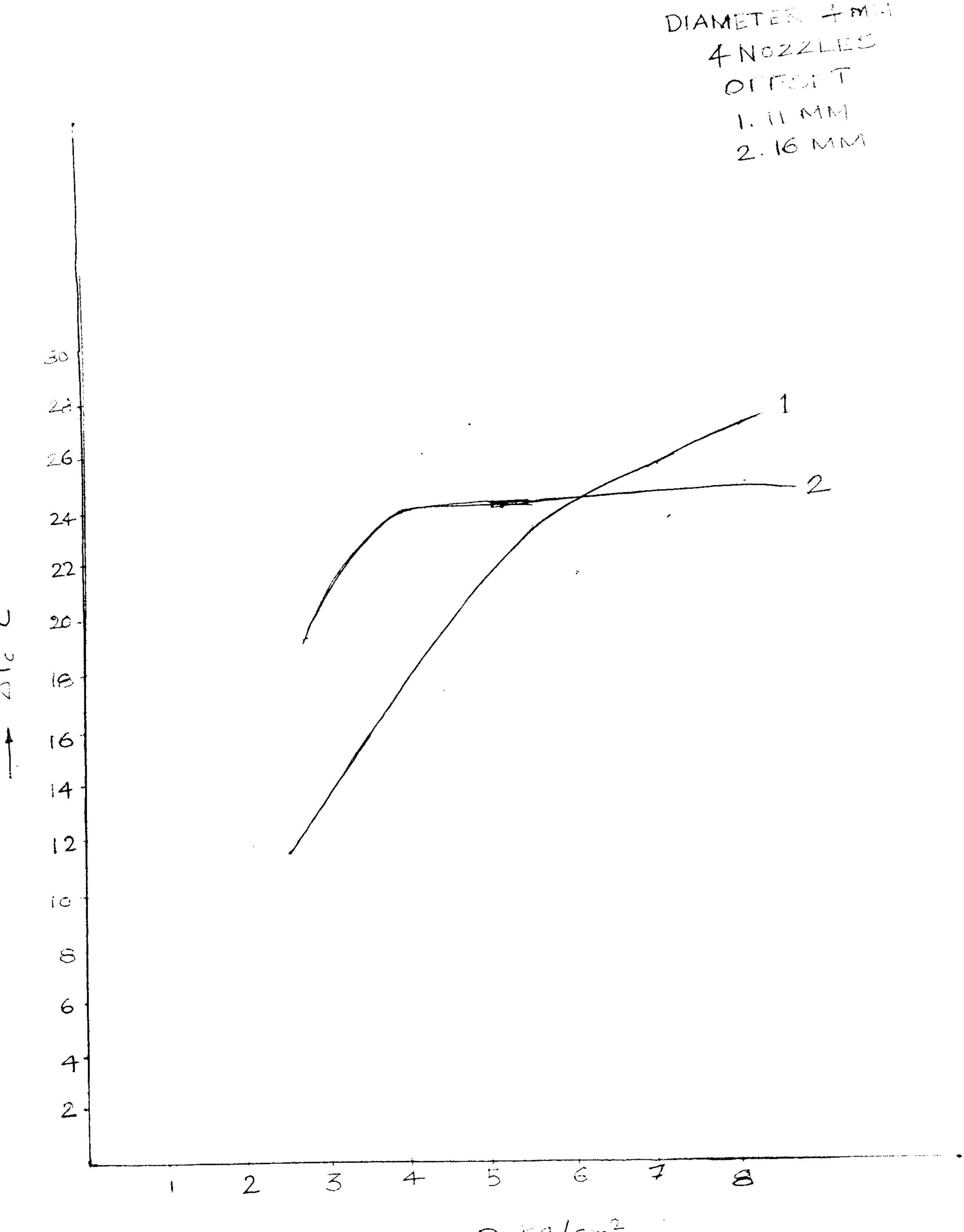
1. COMPRESSOR
2. RECEIVER
3. PR.GAUGE
4. VORTEX TUBE
5. THERMOMETER
6. FULL WAY VALVE

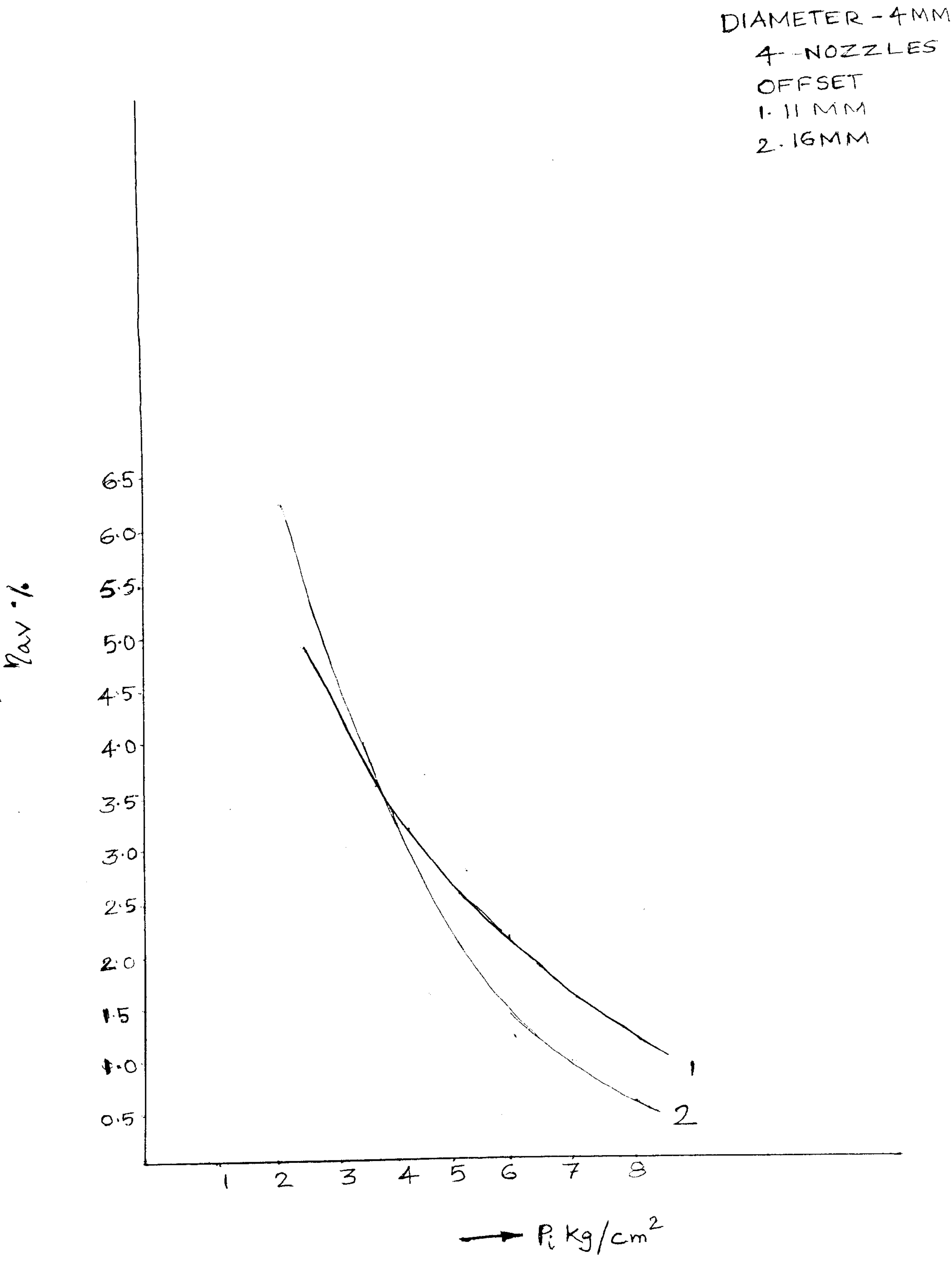


DIAMETER 6 MM
2 NOZZLES
OFFSET
1. 11 MM
2. 16 MM
30
28
26
24
22
20
18
16
14
12
8
6
4
2
1
2
3
4
5
6
7
8
1
2



DIAMETER 6MM
2 NOZZLES
OFFSET
1. 11MM
2 16MM
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
1
2
3
4
5
6
7
8
1
2


DIAMETER 4 MM
4 NOZZLES
OFFSET
1. 11 MM
2. 16 MM
1
2
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
1
2
3
4
5
6
7
8


DIAMETER - 4MM
4 - NOZZLES
OFFSET
1. 11 MM
2. 16MM
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
η_{av} %
1
2
1 2 3 4 5 6 7 8
→ P_i kg/cm^2

CHAPTER VIII

FABRICATION COST

1) Nozzle collar cost

Core boxes and pattern making charges	= Rs.1400.00
Gunmetal casting cost	= Rs. 200.00
Machining cost	= Rs. 30.00
Total cost	Rs.1630.00

2) Raw material cost

Material	Required Dimensions in mm		Quantity	Total cost in Rs.
	Diameter	Length		
EN - 8 Rod	95	100	1	50.00
Cast iron	100	30	1	25.00
Rubber sheet	90	2	6	5.00
EN-8 plate	38	20	1	5.00
		Total cost		Rs.85.00

3) Machining cost

Machine hour rate

Lathe = Rs. 15/hour

Drilling=Rs. 15/hour

Handwork= Rs. 15/hour

CHAPTER IX

CONCLUSION AND SUGGESTIONS

CONCLUSION

The vortex tube is a simple and fascinating device for producing cold air. It finds place in every field by being investigated and improved. The tube that was fabricated in our college was a simpler and smaller one (19mm) and with that a maximum temperature drop 27.4°C and maximum adiabatic efficiency of the vortex tube of 6.25% were obtained. There are many parameters which can be varied and their effects can be studied.

In this project, the diameter of the nozzle, no.of nozzles and the shape of nozzle were varied. The temperature can further be lowered by the use of an air compressor of higher capacity and an effective after-cooler with the compressor unit. Also, the cold air can be used to lower the temperature at the inlet. The following experiments can be done in this vortex tube.

1. Influence of smoothness of nozzle and chamber surfaces.
2. Effect of nozzle material.
3. Performance of supersonic nozzles at high pressure.

As a further improvement of this project, study of vortex refirgeration can also be made.

Suggestions

The main drawback of the vortex tube is low coefficient of performance. The coefficient of performence can be further improved by the experiments listed above. The second drawback is noise due to supersonic speed of air. The vortex tube hot air outlet which is usually vented without being used can carry a baffle type muffler with loss (or) no loss in operation efficiency. The hot end also can be muffled with a stuffed muffler. The cold air outlet cannot directly muffled without some loss in cooling efficiency. Often the air is ductedto some enclosure (or) hood where sound is not a problem. For those applications where the cold air goes directly to atmosphere, some means of sound reduction must be used which does not interfere with air flow. The cold end cannot tolerate stuffer mufflers for two reasons, clogging with ice particles and sensitivity to back pressures, Mufflers must be of the straight through (or) baffle type with the large opening. They may be used in conjuctions with chamber designed for reflection and cancellation or ease with sound deadening walls. To prevent ice formation, the desicant material can be used at the compressor outlet to absorb the water vapour which is present in atmospheric air.

In commercial point of view, the vortex tube can be used in automobiles. The cold air fraction can be increased by keeping the outlet temperature of the cold air end above subzero temperature at around 15 $^{\circ}C$, so that this can be used for airconditioning purposes. The ramming air can be used to cool the compressed air which enters the vortex tube. The hot air also can be used for the engine to increase the thermal efficiency of the system.

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