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A PATH FOR HORIZING YOUR INNOVATIVE WORK

VORTEX TUBE

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Abstract: A very interesting phenomenon was observed by G.J. Ranque (1931) and R .Hilsch (1945) when a compressed gas is introduced tangentially into a tube. The tube is fitted with a central aperture orifice at one end (this end of the tube began very close to the tangential entry nozzle) and a throttle valve at the other end (this end began a little far off from the entry nozzle). The shape and size of the nozzle is such that the gas attains maximum velocity of emission as it enters into the tube. In the process of movement of the gas inside the tube towards the throttle end, there develops in the spiraling gas, a reason of high pressure in the peripheral layers and a reason of low pressure in the axis of rotation. Thus a hot stream of gas comes out through the throttle end and a cold stream through the orifice. By manipulating throttle valve, the amount of gas and also the extend of heating and cooling can be control. This is a very simple device and sometimes referred as Ranque tube, Ranque-Hilsch Vortex Tube (RHVT) or Ranque-Hilsch Energy Separator. The RHVT has been used for many decades in various engineering applications. Because of its compact design and little maintenance requirements, it is very popular in heating and cooling process. Despite its simple geometry, the mechanism that produces the temperature separation inside the tube is fairly complicated. A number of observations and theories have been explored by different investigators concerning this phenomenon. This report gives a general study about Vortex Tube. One of the earlier studies demonstrated that acoustic streaming caused by vortex whistle plays a large part in the Ranquw-Hilsch effect. Another study shows that a centrifugal field is generated in the tube. This field may be utilized in the separation of the gas mixture according to their molecular weight. As we all know that components with higher molecular weights will be concentrated at a periphery of the vortex while those with lower molecular weight at the axis. Therfore it is expected that the stream coming out of the throttle valve will be richer in higher molecular weight components and the other stream coming out through the orifice will be richer in lower molecular weight components. Thus together with energy separation, there may be separation of mass. So being a heat pump, the Vortex Tube is expected to serve as a diffused battery. There has been plenty of analysis that confirms earlier experiments. BUT there is no unifying theory that explains the temperature separation phenomena inside the Vortex Tube.

Keywords: Vortex tube, throttle valve, orifice, nozzle, uniflow, counter flow

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INTRODUCTION

George Ranque a French physics student invented the vortex tube. He was conducting experiments on a vortex tube pump that he had developed, he surprised when he observed cold air coming from one end and warm air from other end and warm air from other end. It was unpopular during its conception because of its apparent inefficiency. In 1945 a German engineer Rudolph Hilsch modified the design of tube.

The Vortex Tube is a mechanical device that separates compressed air into an outward radial high temperature region and an inner lower one. It operates as a refrigerating machine with a simplistic geometry and no moving parts. It contains the following parts: one or more inlet nozzles, a vortex chamber, a cold end orifice, a hot end control valve and a tube. When a high pressure gas (6 bars) is tangentially injected into the vortex chamber via the inlet nozzles, a swirling flow is created inside the vortex chamber, part of the gas swirls to the hot end, and

another part exit via the cold exhaust directly. Part of the gas in the vortex tube reverses for axial component of the velocity and move from the hot end to the cold end. At the hot exhaust, the gas escapes with a higher temperature, while at the cold exhaust, the gas has a lower temperature compared to the inlet temperature.

MAIN BODY: WORKING PRINCIPLE

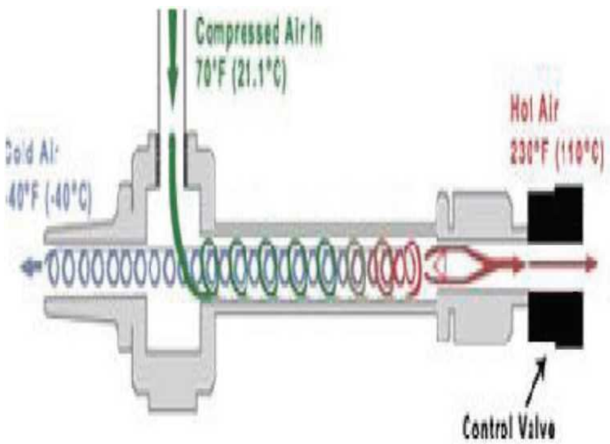

Fig: 2) WORKING IMAGE OF

A Ranque-Hilsch Vortex Tube (RHVT) has the following advantages compared to the normal commercial refrigeration device: Simple, no moving parts, no electricity, or chemicals, Small and lightweight , low cost, maintenance free, instant cold air, durable (because of the stainless steel and clean working media), adjustable temperature .But its low thermal efficiency is main limiting factor for its application. Also the noise and availability of compressed gas may limit its application. Therefore, when compactness, reliability and lower equipment cost are the main factors and the operating efficiency becomes less important, the RHVT becomes a nice device heating gas , cooling gas, drying gas, and separating gas mixture, DNA application, Liquefying natural gas and other purposes.

The physical mechanism processes that determine the cooling of gas in the device have not been resolved completely in the past. The research on vortex tube generally concerns the following aspects: the compressible fluid dynamics of the turbulent and unsteady flow; thermodynamics; and heat transfer. These aspects make the research complicated and challenging. The interest in this research dates back to the work by Westley who stated that, "Besides its possible importance as a practical device, the vortex tube presented a new and mind-blowing phenomenon in fluid dynamics".

Since the 1930's, the mechanism of energy separation inside the RHVT system has puzzled researchers. Even now, there is no clear theory that can explain the phenomena completely.

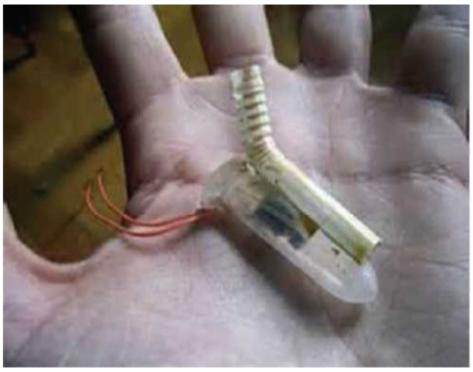

Fig: 1) MODEL OF VORTEX

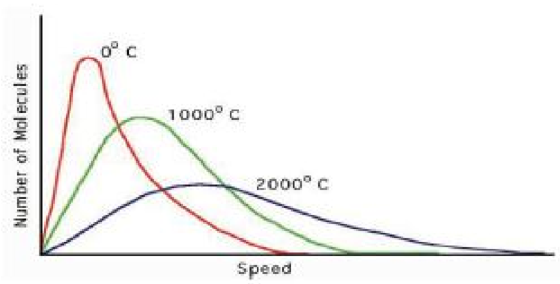

Fig: 3) GRAPH OF VELOCITIES-DISTRIBUTION

An example of such a distribution function is shown in fig:3. In this figure, we see three different graphs showing velocities distributions under three different temperature conditions. The physical mechanism inside an operating vortex tube can be observed physically, but difficult to explain. Compressed air is sent through the inlet nozzle. Swirl generators at the inlet plane create the vortex motion inside the tube. As the vortex moves along the tube, a temperature separation is formed. Hot air moves along the tube periphery, and cold air is in motion with the inner core. The hot air is then allowed to exit through the cone valve at the far end of the tube, while the cold air outlet is next to the inlet plane. This resulting radial temperature separation inside the vortex tube is also called the Ranque-Hilsch effect named after its pioneers.

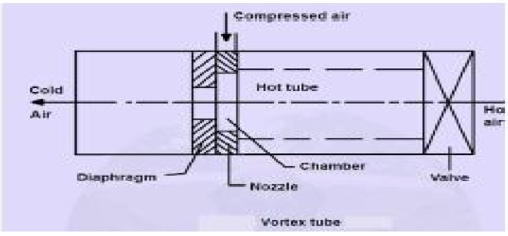

Fig: 4) SECTIONAL VIEW OF VORTEX TUBE

WORKING CYCLE

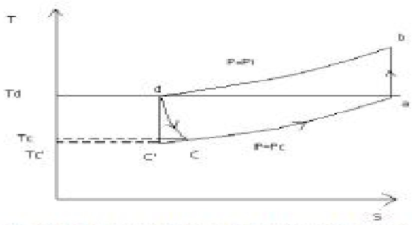

Fig: 5) T-S DIAGRAM OF VORTEX TUBE CYCLE

COUNTERFLOW RHVT TUBE

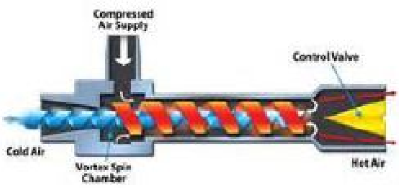

Fig: 6) COUNTERFLOW RHVT SYSTEM

From the above fig. it is observed that air is admitted to the compressor at atmospheric temperature Ta and pressure Pa (point a).This air is compressed adiabatically to pressure Pi. These air is then cooled at constant pressure Pi to the atmospheric temperature by water cooling .It then enters the vortex tube where it is separated into two streams (hot and cold streams).The principle of separation is very well understood by now, however a convincing theory of its performance has not been available .It uses compressed air and it does not have any moving part. It is available in two designs (1) COUNTERFLOW AND (2) UNIFLOW. When the cold exhaust is placed at the same side of the hot exhaust it is named UNIFLOW. When the cold exhaust is placed on the other side from the hot exhaust is called COUNTERFLOW.

TYPES OF VORTEX TUBES

There are two classifications of vortex tube. Both of these are currently used in industries. They are:

- COUNTERFLOW RHVT TUBE
- UNIFLOW RHVT TUBE

The most popular is the COUNTERFLOW RHVT TUBE.

Their detailed explanation is given below.

Compressed air is passed through the nozzle; the air enters tangentially at the inlet and rotates as a forced vortex with high velocity at the periphery and low velocity in its core. The cold air comes out of the orifice .The air travels towards the throttle valve and the valve creates some back are produced. If the valve is open partially, warm air flows through valve and cold air through the orifice and if the valve is further opened the flow rate of cold air through the orifice and its temperature both decreases. The minimum temperature is gain when the flow rate is between 1/3 to % of total flow rate .Further decrease in flow rate increases the temperature .When the air flows through the nozzle its kinetic energy increases along with decrease in static temperature. Considering the flow to be adiabatic stagnation temperature will be same as nozzle inlet temperature. It rotates like a tom ado moves towards the valve and warm air escaped through valve. The air which does not escape turns back towards nozzle .Now the back pressure becomes stagnation pressure at the valve and the valve pressure in the plane of nozzle is static pressure which is lower than back pressure. Hence the flow in the core of the tube reverses and moves backward towards the nozzle in axial velocity. The pressure of axial stream is above the atmospheric pressure ,hence it expansion to atmospheric pressure gives lower temperature air near the periphery is retarded by tube valve friction ,as a result some kinetic energy is dissipated by viscous dissipation and it becomes a warm stream.

UNIFLOW RHVT TUBE

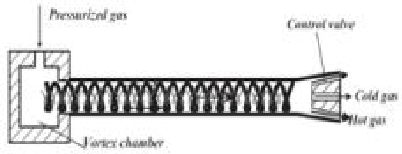

Fig: 7) UNIFLOW RHVT TUBE

The major drawback of vortex tube is that it has low Coefficient of Performance (COP), limited capacity .In Uniflow RHVT Tube the flow reverse does not occur since there is no opening at the nozzle end. The flow in this case is divided into inner core which losses momentum to outer vortex. The outer vortex becomes warm because of this and also due to viscous dissipation at the tube valve as well as due to the compression arising out of centrifugal force. Both the vortices (vortex flow) moves in the same direction and rotates in the same sense .The inner core comes out at the lower temperature and the outer core is at higher temperature. A Vortex tube divides the flows in two streams low temperature and low kinetic energy stream and a higher kinetic energy warm stream.

The role of orifice or diaphragm is to block the kinetic energy air from moving out of the orifice and thus moves the air towards the valve.

1)Temperatures from -40^0 C to -127^0 C

2)Flow rates from 1 to 150 SFCM

3)Refrigeration up to 2571 kcal/hr.

Ranque himself explained the effect in the following manner. According to him the rotating stream (in a screw like motion) produces a region of increased pressure near the wall inside the cylinder by adiabatic compression and region of decreased pressure near the pressure near the axis. Hence the temperature is increased near the wall and decreased near the axis. Therefore, according to Ranque the diaphragm end which permit the escape of air only from the central region and thereby emits the old stream, the throttle valves however emit the hot stream.

The experimental Fact of such separation is also known for fluid in nominal Ranque tubes. Flow heat separation was numerically simulated and the example of Laminar self-laminar whirled flows in expanding cone-like channels, channels had an injection vector oriented along the porous wall. The mechanism of the process, which has kinematic basics, is brought to light. The kinematics factor that is exhibited by the intense flow swirl conditions stipulates higher inner supply of viscous dissipation heat of fluid kinetic energy compared to its absence(by means of an increased radial speed gradient near the wall in its essence). The implemented mathematically model allowed reconstructing qualitatively the non-monotonic character of excess temperature (t-tw) alternation in the cross section of the channel with cooled walls and heat outflow of the channel, and also its negative values near the real Ranque tube axis. The realized (t-tw) are conditioned by the recurrent character of transition lines (via convection and thermal conductivity) of heat in the meridional section of the cone channel, those lines coincide at a specific point r=0 from where they start. The results of the self-similar heat task solution also prove the non-monotonic profile of excess temperature and recurrence of transition lines in the case of flat cone-type fluids flow (Hamel flow in flat extending channel). The specific case of stagnation temperature stratification along the channel section in a cone-like whirled flow of viscous gas is discussed

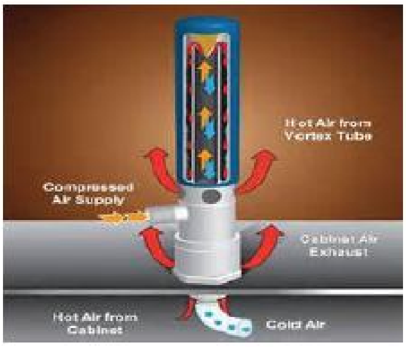

Fig: 8) MECHANISM OF RANQUE EFFECT

APPPLICATIONS

The importance of Vortex Tube can be realized from the applications of it

(1) Dave Williams has proposed using Vortex tubes to make ice in third-world countries. Although the technique is inefficient, Williams expressed hope that vortex tubes could yield helpful results in areas where using electricity to create ice is not an option.

2) There are industries applications that result in unused pressurized gases. Using vortex tube energy separation may be a method to recover was pressure energy from high and low pressure sources. Helicon vortex separation process: It is an aerodynamic uranium enrichment

process designed around a device called a vortex tube. This method was designed and used in South Africa for producing reactor fuel with uranium-235 content of around 3-5%, and 80-93% enriched uranium for use in nuclear weapons. The Uranium Enrichment Corporation of South Africa. Ltd., (UCOR), developed the process, operating a facility of Pelindaba (known as the 'Y' plant) to produce hundreds of kilograms of HEU. Aerodynamics enrichment processes require large amount of electricity and are not generally considered economically competitive because of high energy consumption and and substantial requirements for removal of waste heat. The South African enrichment plant has apparently been closed.

CONCLUSION

After performing extensive Literature Survey, which has revealed the huge amount of work done in field of Ranque-Hilsch Vortex effect, it shows that this is quite important for academic and industrial purpose. Finally we know that compressed air can be used as a refrigerant up to -400 C .The vortex tube gives two types of temperature output at the same

instant. We see the two types of vortex tube system and compared them. So, we conclude that counter flow RHVT system is better than uniflow RHVT SYSTEM. We studied the mechanism behind generation of cold air even though still exact reason behind them is

not yet cleared. Even after so many works done in this field, there still remain some questions about these topics unanswered. Moreover the fair number of applications of this vortex tube like mass separation of gases, measurement of velocities of airplanes etc, shows huge scope of this subject.

By studying the cost survey for various instruments, literature survey, collection of information for proceeding on this project and defining or objectives has helped us start on a right note on this project.

SUGGESTIONS FOR FUTURE WORK

The simplicity of this apparatus has been alluring to many research workers. The mechanism of this experiment is still obscured. Vortex tube has the potential to be utilized in a compact and separation system that can extract and liquefies oxygen for many purposes including onboard propellant generation for rocket vehicles.

Many analysts identify carbon-dioxide capture and separation as a major road block in efforts to cost efficiency mitigates green house gas emissions via sequestration.

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REFERENCE

1. Merculov, A.P. Vortex Effect and Engineering applications. Moscow, Mashinostroenie, 1969.(In Russian).

2. Finko, V.E. Peculiarity cooling and liquation of gas into vortex stream. Journal Technical Physics 53, vol.15(22), 1989.(In Russian)

3. Ranque, G.J.J. Pkys. Radium, 45, 112,(112).

4. Kotousov, L.S. By Liquation of gas into vortex stream. Physics, vol. 61, iss.2,1991.(In Russian)

5. Saburov, E.N., Karpov, S.V., Ostashev, S.I. Heat exchange and air dynamic of Vortex flow in cyclone units. Leningrad, Leningrad University Pub.,1989.(In Russian)

6. Koltelnikov, V.I. High-Efficiency Vortex Pipes. TIEES-96, Trabzon, Turkey, ISBN 975-95505-8-X.

7. Ahlborn, B.K., Keller, J.U., Rebhan, E. The Heat tube. J. Non-Equilib. Thermodynamic. 1998, vol.23, nO.2.

8. Zasalavski, B.I., Yuriev. B.V. Study of structure flow in the flat vortex camera. J. Applied mechanic and theoretical physics Science Progress, Volume 167,, No.6.(In Russian)

9. Kotelnikov, V.I. The Vortex Effect in Transfer of Energy. Sustainable Energy and Environment Technology. World Scientific Publishing Co. Pte. Ltd., ISBN 981-02-2829-5, Singapoor, 1996.

10. Gustsol, A.F. The Ranque effect. J.Physics Science Progress, Volume 167,No.6(In Russian)

11. Stiffler A.K., Bakhsh H, A gas jet impacting a cavity. J. Fluid Mech. 1986, vol. 172, pp 127-141.

12. Kurosaka M., Acoustic streaming in swirling flow and Rannque-Hilsch (Vortex-tube) effect. J. Fluid Mech., 1982, vol 124, pp 1339-172.

13. Lavan Z., Fejer A.A., Luminescence in supersonic flow, J. Fluid Mech, 1965, vol. 23, part, 1,, pp. 173-183.

14. Deissler R.G., Perlmutter M, 1960, Int. J. Heat Mass Transfer 1, pp.173-191.

15. Linderstrom-Lang C.U., 1971, J.Fluid Mech, Vol 45, pp161-187.

16. Sprenger M., Ueber Thermische Effect in Resonanzrohren. Mitt. Inst. Aero.