International Journal of Scientific Research & Engineering Trends
Volume 7, Issue 5, Sept- Oct-2021, ISSN (Online): 2395-566X

Review Paper on Design of Vortex Tube Refrigeration

Prof. E. L. Manjerekar, Faizan Girkar, Prakash More, Hanish Parab, Siddharth Parab
Department of Mechanical Engineering,
S.S.P.M's College of Engineering,
Kankavli, India

Abstract- The Ranque-Hilsch vortex tube 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 processes. 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 goes over some of the major conclusions found from experimental and numerical studies since the vortex tube's invention. One of these studies showed that acoustic streaming caused by vortex whistle plays a large part in the Ranque-Hilsch effect.

Keywords- Vortex Tube, Point Spot Cooloing, Little Maintenance, Temperature Seperation.

I. INTRODUCTION

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 is used commercially in CNC machines, coolingsuits, refrigerators, airplanes, etc. Other practical applications include cooling of laboratory equipment, quick start up of steam power generators, natural gas liquefaction, and particle separation in the waste gas industry.

II. LITERATURE REVIEW

The vortex tube was invented by a French physicist named Georges J. Ranque in 1931 when he was studying processes in a dust separated cyclone. [1]

It was highly unpopular during its conception because of its apparent inefficiency. The patent and idea was abandoned for several years until 1947, when a German engineer Rudolf Hilsch modified the design of the tube. [2]

Since then, many researchers have tried to find ways to optimize its efficiency. Until today, there is no single theory that explains the radial temperature separation.

III. TEMPERATURE SEPARATION

The physical mechanism inside an operating vortex tube can be observed physically, but difficult to explain. Compressed air is sent through the inlet nozzle (Figure 1). 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. Hotair moves along the tube periphery, and cold air is in motion in 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.

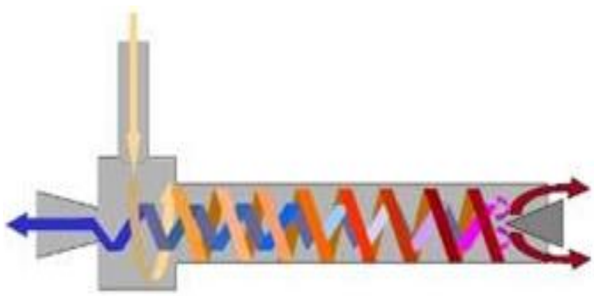

Fig 1. Vortex tube schematic.

There have been many attempted explanations for this radial temperature separation. Two early theories are acoustic streaming and the conversion of kinetic energy into heat. Among recent researchers, turbulence has become a trendy topic.

A.F. Gutsol attested that a popular, but complicated theory among specialists is that the separation is explained by turbulent pulsations in the radial direction.

In addition, Gutsol introduced the idea of turbulent element rotation. He said that the cause of energy separation is the centrifugal separation of turbulent elements in tangential velocity [3].

IV. TYPES OF VORTEX TUBES

There are two classifications of the vortex tube. Both of these are currently in use in the industry. The more popular is the counter-flow vortex tube (Figure 2). The hot air that exits from the far side of the tube iscontrolled by the cone valve. The cold air exits through an orifice next to the inlet.

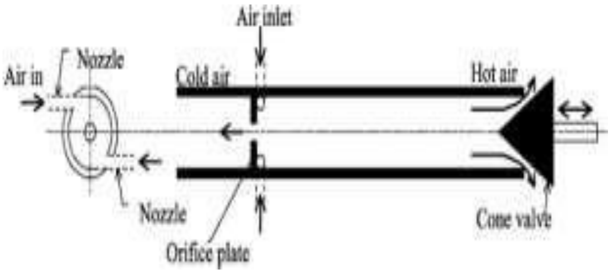

Fig 2. Counter-flow vortex tube

On the other hand, the uni-flow vortex tube does not have its cold air orifice next to the inlet (Figure 3). Instead, the cold air comes out through a concentrically located annular exit in the cold valve. This type of vortex tube is used in applications where space and equipment cost are of high importance.

The mechanism for the uni-flow tube is similar to the counter-flow tube. A radial temperature separation is still induced inside, but the efficiency of the uni-flow tube is generally less than that of the counter-flow tube.

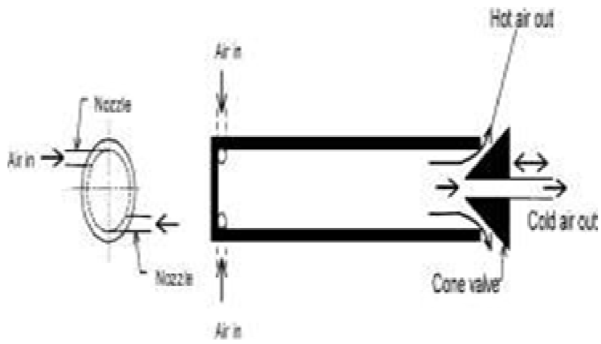

Fig 3. Uni-flow vortex tube.

V. EXPERIMENTAL WORK

After Hilsch's modification of the vortex tube, many researchers have tried to explain the Ranque-Hilsch effect. Early experiments by Schepper (1951) and Scheller & Brown (1957) confirmed that there is a radialtemperature separation within the tube. They observed that the static temperature decreased radially outward, contrary to later observations.[4] Some experiments also involve the variation of tube geometry and thermo-physical parameters.

Tube length, cold end orifice diameter, inlet pressure, inlet temperature and other parameters were varied to discover their effects on temperature separation and cooling efficiency. Other experiments that were conducted to improve performance include the addition of a radial diffuserto the hot end and the use of tubes with small divergence angles.

Furthermore, some researchers carefully studied the application of gas component separation within the vortex tube. Linderstrom-Lang found that the separation effect depended mainly on the ratio of cold air to hot air mass flow rates. Presented in Appendix A is a summary of experimental data found by several investigators, including Ranque and Hilsch.

VI. KUROSAKA AND ACOUSTIC STREAMING

In 1982, Mitsuri Kurosaka attempted to explain the Ranque-Hilsch effect through acoustic streaming. He concluded that the streaming induced by periodic, orderly disturbances within the swirling flow is the main cause of the Ranque-Hilsch effect. [6] The added tangential velocity near the tube periphery converts the initial Rankine vortex near the inlet to a forced vortex along the length of the tube (Figure 4).

This metamorphosis tends to create the separation of total temperature. In order to confirm his conclusions, Kurosaka used acoustic suppressors to limit the pure tone noise in a uni-flow vortex tube. He found that there was a reduced radial temperature separation when the frequency of the vortex whistle was suppressed.

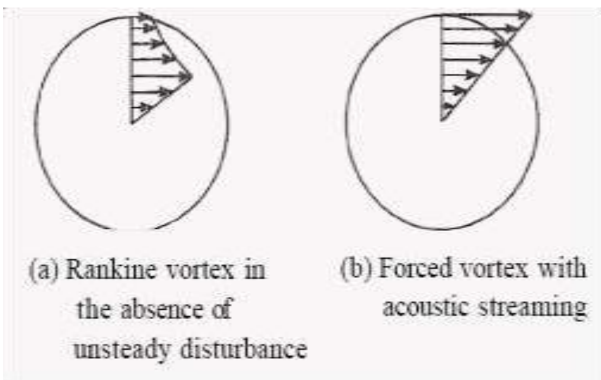

Fig 4. Vortex metamorphosis.

While Kurosaka's observations were valid, he does not take into account the conversion of energy that occurs with the temperature separation. The link between acoustic streaming and kinetic energy with respect to the vortex tube has not been explained.

VII. NUMERICAL WORK

There is an extensive amount of numerical work done recently in the hopes of explaining the radial temper- ature separation. The numerical models and analyses will not be explored in detail here. Note, however, that most of the numerical simulations in literature use various turbulence models to predict fluid flow. As aresult, conclusions that were made are highly dependent on the model used. Take, for example, the tempera- ture contour in figure 5.

International Journal of Scientific Research & Engineering Trends
Volume 7, Issue 5, Sept- Oct-2021, ISSN (Online): 2395-566X

The temperature contour on top was made with the AMS or the averaged Reynoldsstress model.

The bottomcontour is made from the k-ϵ turbulence model. While the total temperature along the length of the tube is generally similar, a big difference in temperature can be observed close to the inlet.

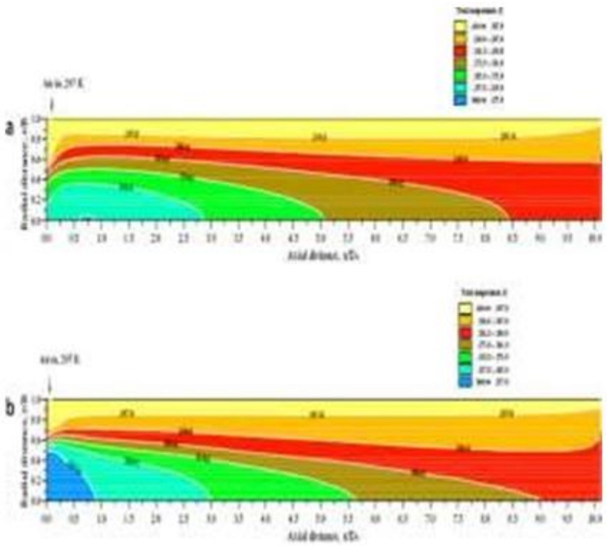

Fig 5. Temperature contour of the +vortex tube, made using (a) k-ϵ turbulence model (b) AMS model.

Nevertheless, some numerical simulations do confirm some of the earlier theories. For example, Behera etal.

Concluded that the swirl velocity profiles in the radial direction (Figure 6) show that flow in the vortex tube is largely governed by the forced vortex regime, which exists along the tube length except around the inlet zone.

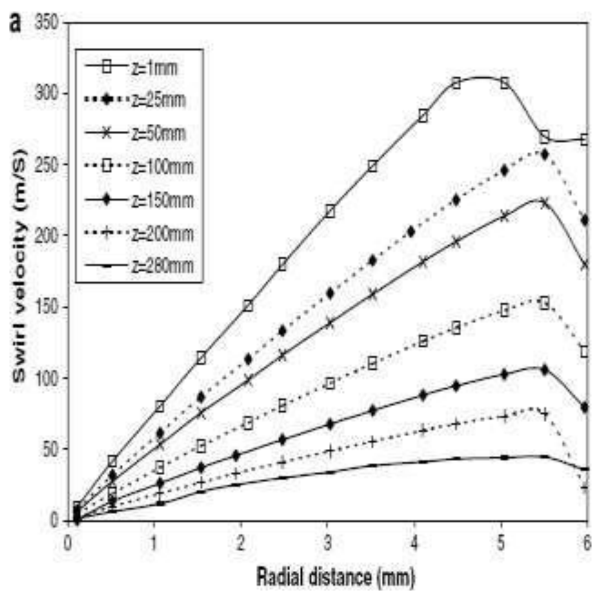

Fig 6. Radial profile of the swirl velocity component inside the vortex tube.

Presented in Appendix B is a summary of numerical studies on vortex tubes, including the model each investigator used and comparisons with actual measurements.

VIII. OBJECTIVE

While making the project following points should be covered as much as possible:

- It should have no moving parts, maintenance free, high reliability
- Its output should beeasily controllable
- It should give constant temperature
- It should not consume any electricity or RF interference
- It should be intrinsically safe
- It should not use any refrigerant or chemicals
- It should be effective at spot cooling
- It should be made at possible low cost
- It should be compact and lightweight
- Vortex tube should be simple in design and it should avoid control systems.
- It should not have any moving parts in vortex tube.
- It should be light in weight and requires less space.
- It cost should be initially low and its working expenses are also less, where compressed air is readily available in factories.
- Its maintenance should be simple and no skilled labours should require.

IX. CONCLUSION

It is nearly impossible to explain and predict the phenomenon inside the vortex tube. Kurosaka believed that acoustic streaming produces the total temperature separation within the vortex tube. However, he does not mention any energy conversion effects. Ahlborn, et al. concluded that the conversion of kinetic energy into heat explains the Ranque-Hilsch effect, but no explanation of vortex whistle or turbulence effects was made.

Furthermore, numerical analyses are highly dependent on the turbulence model used to create simulations.Studies confirmed some of the earlier observations, but the numerical data still do not completely explain the temperature separation.

This author believes that a combination of the many observations may be able to explain why the vortex tube induces a radial temperature separation. It may be concluded that acoustic streaming, energetics, turbulence effects, etc. are somehow connected with each other, but the missing links are yet to be found. The conclusions presented here have not been entirely refuted, but the single unifying theory that accounts for the Ranque-Hilsch effect is still a hot topic of research.

REFERENCES

[1] RANqUE, G.J. Experiments on expansion in a vortex with simultaneous exhaust of hot air and coldair. Le Journal de Physique et Le Radium, 4(7):112–115, 1933.

[2] HILSCH, R. The use of expansion of gases in a centrifugal field as cooling process. The Review of Scientific Instruments, 18(2):108–113, 1947.

[3] GUTSOL, A.F. The Ranque effect. Physics - Uspekhi, 40(6):639–658, 1997.

[4] EIAMSA-ARD, S. & PROMVONGE, P. Review of Ranque-Hilsch effects on vortex tubes. Renewable and Sustainable Energy Reviews, 12:1822–1842, 2008.

[5] LIGHTHILL, J. Acoustic streaming. Journal of Sound and Vibration, 61(3):391–418, 1978.

[6] KUROSAKA, M. Acoustic streaming in a swirling flow and the Ranque-Hilsch (vortex tube) effect. Journal of Fluid Mechanics, 124:139–172, 1982.

[7] KUROSAKA, M., CHU, J.Q. & GOODMANN, J.R. Ranque- Hilsch effect revisited: Temperature separa- tion effect traced to orderly spinning waves or vortex whistle. AIAA (82- 0952) AIAA/ASME 3rd Joint Thermo-Physics of Fluids, Plasma and Heat Transfer Conference, 1982.

[8] AHLBORN, B., KELLER, J.U., STAUDT, R., TREITZ, G., REBHAN, E. Limits of temperature separa- tion in a vortex tube. J. Phys. D.: Appl. Phys., 27:480–488, 1994.

[9] EIAMSA-ARD, S. & PROMVONGE, P. Numerical investigation of the thermal separation in a Ranque-Hilsch vortex tube. International Journal of Heat and Mass Transfer, 50(5).

[10] BEHERA, U., PAUL, P.J., DINESH K., & JACOB, S. Numerical investigations on flow behaviour and energy separation in Ranque-Hilsch vortex tube. International Journal of Heat and Mass Transfer, 51:6077–6089, 2008.