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A Review on Experimental and CFD Analysis of Ranque Hilsch Vortex tube

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Abstract
The vortex tube or Ranque–Hilsch vortex tube is a simple device used in industry for generation of cold and hot air streams from a single compressed air supply. It consists of nozzle, vortex chamber, separating cold plate, hot valve, hot and cold end tube without any moving parts. As the temperature difference decreases as the nozzle aspect ratio increases some research used the dry air as working fluid. Compare the CFD model with the experimental measurement uses different diameter D, 2D, 0.5D, 0.25D, 0.125D from that they conclude that for small diameter has worst performance.

Introduction

The vortex tube, also known as the Ranque-Hilsch vortex tube, is a mechanical device that separates a gas into hot and cold streams. Vortex tube is a simple device, which can cause energy separation. It consists of nozzle, vortex chamber, separating cold plate, hot valve, hot and cold end tube without any moving parts. In the vortex tube, when works, the compressed gaseous fluid expands in the nozzle, then enters vortex tube tangentially with high speed, by means of whirl, the inlet gas splits in low pressure hot and cold temperature streams, one of which, the peripheral gas, has a higher temperature than the initial gas, while the other, the central flow, has a lower temperature. Vortex tube has the following advantages compared to the other commercial refrigeration devices: simple, no moving parts, no electricity or chemicals, small and light weight, low cost, maintenance free, instant cold air, durable, temperature adjustable. Therefore, the vortex tube has application in heating gas, cooling gas, cleaning gas, drying gas, and separating gas mixtures, liquefying natural gas, when compactness, reliability and lower equipment cost are the main factors and the operating efficiency becomes less important The vortex tube can be classified into two types: 1) the counter-flow and 2) the uni-flow as shown in figure 1. In a counter-flow vortex tube the two exits are placed at opposite ends of the tube, and in a uni-flow vortex tube the two exits are placed at the same end. In general, the counter-flow vortex tube is recommended over the uni-flow vortex tube for its efficient energy separation.

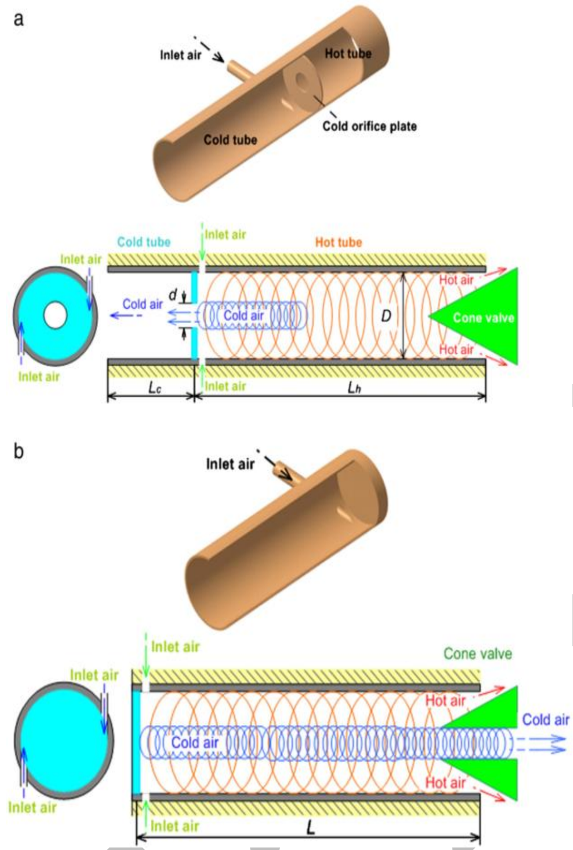

Fig.1. (a) Counter-flow type and (b) uni-flow type.

Literature review

Following are some research work carried out on the experimental and CFD analysis of vortex tube. Mete Avc (2013) An experimental study is carried out to investigate the effects of nozzle aspect ratio and nozzle number on the performance of a vortex tube. Two sets of vortex generator (a single nozzle set with aspect ratio of AR ¼ 0.25, 0.44 and 0.69 and a multiple nozzle set with 2 and 3 nozzle number having the same total flow area) are tested under different inlet pressures. Dry air is used as the working fluid. The experimental results reveal that the nozzle aspect ratio has a great effect on the energy/temperature separation mechanism. The increase in the nozzle aspect ratio leads to the larger mixing zones, which, in turn, decreases the temperature difference between the cold and hot stream, the heating and the cooling performance. The results also showed that the vortex tube with a single nozzle yields better performance than the vortex tube with 2 and 3 nozzles. The author concluded some remarks are the nozzle geometry (aspect ratio) has a considerable effect on the energy/temperature separation mechanism. The temperature difference decreases with increasing nozzle aspect ratio due to the back flow mechanism occurred near the cold exit of the vortex tube The vortex tube with a single nozzle leads to better performance than the vortex tubes with 2 and 3 nozzles. This enhancement can be attributed to the flow structure and resistance at the entrance of the vortex chamber. The temperature difference between the cold and hot stream is increasing with increasing inlet pressure [7]

H.M. Skye, G.F. Nellis, S.A. Klein (2006), the author presents a comparison between the performance predicted by a computational fluid dynamic (CFD) model and experimental measurements taken using a commercially available vortex tube. Specifically, the measured exit temperatures into and out of the vortex tube are compared with the CFD model. The data and the model are both verified using global mass and energy balances. The CFD model is a two-dimensional (2D) steady axisymmetric model (with swirl) that utilizes both the standard and renormalization group (RNG) k-epsilon turbulence models. While CFD has been used previously to understand the fluid behavior internal to the vortex tube, it has not been applied as a predictive model of the vortex tube in order to develop a design tool that can be used with confidence over a range of operating conditions and geometries.[6]

H. Khazaeia, A.R. Teymourtash, M. Malek-Jafarians(2012)They are uses the different diameters, respectively, D, 2D, 0.5D, 0.25D, 0.125D, have been studied in which ‘‘D’’ is the original diameter in Hartnett and Eckert’s work. In the CFD analysis, all dimensions (except diameter), Tin, and velocity components for all case are the same. Total temperature differences (Ttotal− Tin) and tangential velocity (w) profiles were provided at 3 axiallocations, namely, x = 0.0254, 0.1524 and 0.4572 m (or x/D =0.333, 2 and 6, respectively), from the nozzle, It can be seen that the total temperature difference is nearly proportional to the tangential velocity magnitude, and very small diameters have the worst performance, which can be attributed to low tangential velocity in the tube. At very small tube diameters of tube, the rotating flow would decrease too quickly, on account of the small rate of flow, and the more important contribution of friction between the gas and walls.

Upendra Beheraet al. has conducted Computational fluid dynamics (CFD) and experimental studies towards the optimization of the Ranque–Hilsch vortex tubes. Different types of nozzle profiles and number of nozzles are evaluated by CFD analysis. The optimum cold end diameter (dc) and the length to diameter (L/D) ratios and optimum parameters for obtaining the maximum hot gas temperature and minimum cold gas temperature are obtained through CFD analysis and validated through experiments. The coefficient of performance (COP) of the vortex tube as a heat engine and as a refrigerator has been calculated. The swirl velocity, axial velocity and radial velocity components of the flow and the flow pattern have been obtained through CFD. The analysis shows that the flow has forced and free vortex components up to stagnation point and temperature difference between hot and cold gas flow can be maximized by increasing the length to diameter ratio of vortex tube such that stagnation point is farthest from the nozzle inlet and within the tube. Many investigators have so far determined the optimum nozzle profile and number of nozzles of vortex tube by experimental investigations. The work reported here shows that CFD analysis provides an elegant and more accurate way to arrive at these critical parameters. For a 12 mm diameter vortex tube this study has shown that swirl generator with six numbers of convergent nozzles gives the best performance. The critical design parameters of the vortex tubes, namely the cold end diameter (dc) and the length to diameter ratio (L/D) also could be most effectively decided by CFD techniques rather than depending on experimental correlations, which are conventionally used by vortex tube designers. The accuracy of these simulated results for 12 mm diameter tube has been validated by experimental investigations. The CFD and experimental studies have shown that for 12 mm diameter vortex tube, the cold end diameter of 7 mm is ideal for producing maximum hot gas temperature, while cold end diameter of 6 mm is optimum for reaching the minimum cold gas temperature. The investigations have shown that L/D ratio in the range of 25–35 is optimum for achieving best thermal performance for 12 mm vortex tube. These optimized vortex tube could produce maximum hot gas temperature of 391 K at 12–15% hot gas fraction and a minimum cold gas temperature of 267 K at about 60% cold gas fraction. The studies conducted have confirmed the presence of secondary flow for vortex tubes with low dc/D values. However CFD analysis and experimental results indicate that secondary circulation flow could be a performance degrading mechanism in vortex tubes. An optimally designed vortex tube has only two regimes of forced and free vortex flows and with optimal dc/D value, the secondary flow is eliminated which results in its higher temperature separation between cold end and hot end. For the 12 mm vortex tube the optimum dc value is 7 mm corresponding to dc/D = 0.58. The maximum COP of the vortex tube is found to be 0.59 as a heat engine and 0.83 as a refrigerator.[8]

S. Eiamsa-ard et al. [2010] studied the effect of cooling of hot tube on the energy/temperature separation and cooling efficiency of the vortex tube. The experimental set up is as shown in Fig.2.In this system a cooling water jacket is assembled around the hot tube wall of the counter-flow vortex tube to function as a heat receiver of the hot gas in the peripheral region of the vortex tube. It is expected that cooling effect will promote heat transfer from inner region to outer region of the vortex tube and offer higher cooling efficiency of the vortex tube. The study focuses on the influence of the cooling system on the temperature separation (the temperature reduction of cold air) and cooling Efficiency characteristics. The inner tube or hot tube of counter flow vortex tube is covered with cooling. [2]

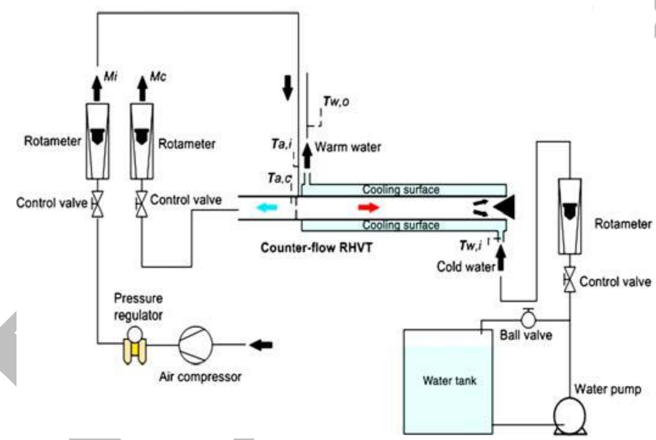

Fig.2 Schematic of the experimental Apparatus.

YunpengXueet al (2008) investiguâtes the effect of the valve angle on the performance of the vortex tube. Four different values for the valve angle have been used: 30^{o} 45^{o} 60^{o}and 75^{o} The effect of the valve angle is tested for various values of the inlet pressure (3, 4 and 5 bar (absolute)), L/D (10, 20, 30 and 40) and the length of the helical swirl flow generators, h (10 mm, 15 mm, 20 mm, 25 mm and 30 mm), In addition, helical swirl flow generators is explained whose function is to prevent the sudden change of flow direction with a perspective of minimizing energy loss. A series of experiments are conducted to determine the optimum values for vortex tube dimensions corresponding to the highest efficiency for varying values of the inlet pressure, the cold mass fraction and L/D. Mainly the effect of the valve angle for a counter-flow vortex tube is studied for varying design and operating parameters. It is disclosed that this effect is generally negligible. However, for small values of L/D, this effect becomes considerable. It is disclosed that it’s better to use the conical valves with a smaller angle in order to improve the performance of the vortex tubes with smaller L/D.[1]

Dr.Y.B.Yarasu,B.D.Wankhede(2012) explained three method in order to improve performance of vortex tube. In the first method modifications are done in internal parts of vortex tube such as in nozzle intake, nozzle and added new part called a diffuser. Vortex tube developed with these modifications gives higher performance compared to conventional vortex tube. In second method new part called vortex generator which placed near the inlet of vortex tube and allows compressed gas to enter at different angles in vortex tube. Then performance parameters are evaluated. In third method hot tube of vortex tube is directly cooled by cooling jacket. Then performance is evaluated and compared to vortex tube without having cooling jacket. Out of three methods the vortex tube with modification in nozzle intake, nozzle and with added diffuser proves to be more efficient than other two methods explained here.[3]

Conclusion

In this paper the some experimental and CFD analysis work explained which is done by some researcher. They used the different nozzle diameter. Compare the CFD model with the experimental measurement uses different diameter D,2D,0.5D,0.25D,0.125D from that they conclude that for small diameter have worst performance.

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