A Review on Experimental study of vortex tube

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Abstract

A vortex tube is a simple device with no moving parts which is capable of separating high pressure compressed fluid into two different low pressure streams. One of the streams is colder and another stream is hotter than inlet fluid. This phenomenon is known as temperature or energy separation. The performance of vortex tube depends on two basic types of parameter, first one is the working parameter such as inlet pressure and temperature of compressed air, and the Second one is geometric parameters such as number of nozzles, diameter of nozzle, cone valve angle, length of hot side tube, cold orifice diameter, and as well as material of vortex tube. Due to spontaneity of phenomenon vortex tube finds important applications in spot cooling, as a refrigerator in ultrasonic weld.

Keywords: *Vortex tube; temperature separation; cold mass fraction;*

I INTRODUCTION

A vortex tube separates an injected stream of compressed air gas into two streams. One of the resultant streams is at higher temperature (termed as hot flow), while second stream is at a significantly lower temperature (termed as cold flow) than the injected stream. This is a remarkable phenomenon; there are no any moving parts or work input to the RHVT. The main components of the vortex tube are inlet nozzle, diaphragm, vortex chamber, cylindrical working tube, cone valve, hot air Outlet, cold air orifice; sometimes diffuser is also installed between the cylindrical tube outlet and the hot valve. The main working principle of vortex tube depends upon the pressure difference that causes the separation of air stream. When the compressed air is injected tangentially in to the vortex chamber through the inlet nozzle, the swirls or vortex is formed due to the pressure difference that causes the separation of compressed air in to two different air streams i.e. hot air stream and cold air stream. Because of lower density of the hot air stream it gets accumulated at the peripheral of the working cylindrical inner tube, while the cold air is present in the middle of the tube. The hot air is sent back to the atmosphere from the hot air outlet present at the right hand side of the vortex tube, whereas the cold air exit reveres from the opposite side of the hot air outlet.

II LITERATURE REVIEW

K. Dincer et al. [01] performed experimental investigation of vortex tube. The internal diameter (D) of the vortex tube used in the experiments was 9 mm; the ratio of the length of the vortex tube to its diameter (L/D) was 15. Four different plug locations were studied. The maximum difference in the temperatures of hot and cold streams was obtained for the plug diameter of 5 mm, tip angles of 30^0 and 60^0, 4 nozzles and by keeping the plug location at the far extreme end.

From graph 1, it is observed that the most efficient combination of parameters is obtained for a plug diameter of 5 mm, tip angle of 30^oor 60^o, by keeping the plug at position L, and letting the air enter into the vortex tube through 4 nozzles. Increasing inlet pressure beyond 380 kPa didn't bring any appreciable improvement in the performance.

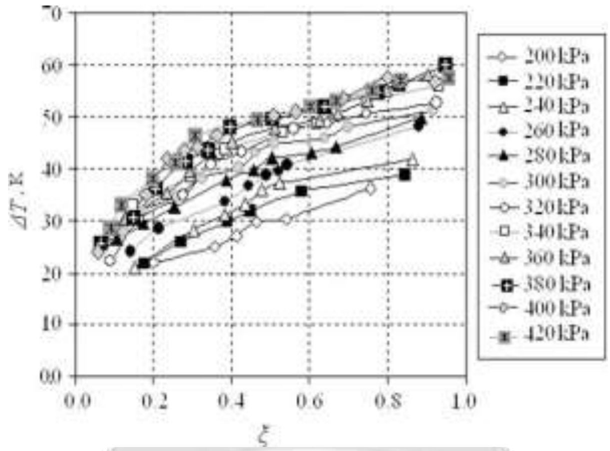

Fig. 1 The variation of ΔT with P_I [01]

According to the Prabakaran J. et al. [02] when high pressure air is injected via tangential nozzle a strong vortex flow will be created which will be split into two air streams. The main factors affecting the performance of vortex tube are inlet pressure, L/D ratio, cold mass fraction, diameter of nozzle and orifice. In this paper the performance of the vortex tube is investigated with different diameters of orifice and nozzle.

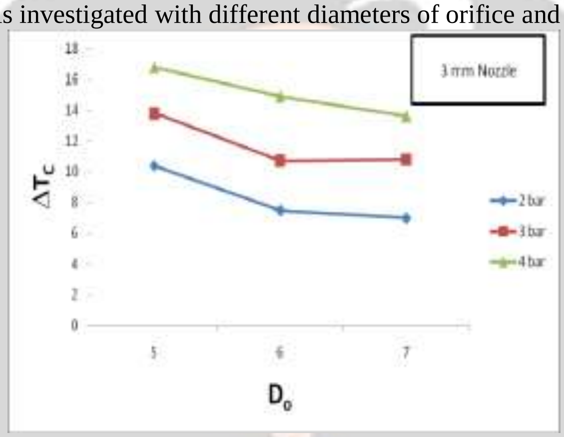

Fig.2 Variation of ΔT_c Vs diameter of orifice [02]

As shown in above graph, investigation of the effect of orifice diameter and nozzle diameter on the performance of vortex tube was done. For better cooling effect the optimum value of orifice diameter is 5 mm and nozzle diameter is 3 mm. The minimum temperature in cold end obtained was 14.50°C when atmosphere temperature was 31°C.

Hemant V. Darokar et al. [03] made experimental investigation to realize thorough behaviour of a vortex tube refrigeration system by introducing new geometry for cold end side which was having the form of convergent helical nozzles. The different parameters were calculated for the study of performance of vortex tube in atmospheric condition. It was also found that the cold end temperature difference as well as the hot end temperature difference increases with increase in inlet pressure.

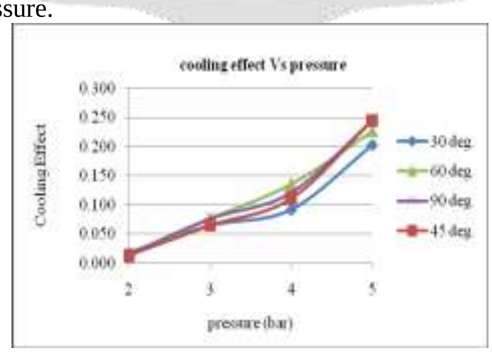

Fig.3 The effect of inlet pressure on cooling effect [03]

From the graph 3 it can be clearly seen that the cooling effect increases with corresponding increase in inlet pressure for different valve angles. The effect of inlet pressure on coefficient of performance, for different valve angles is shown in graph 4

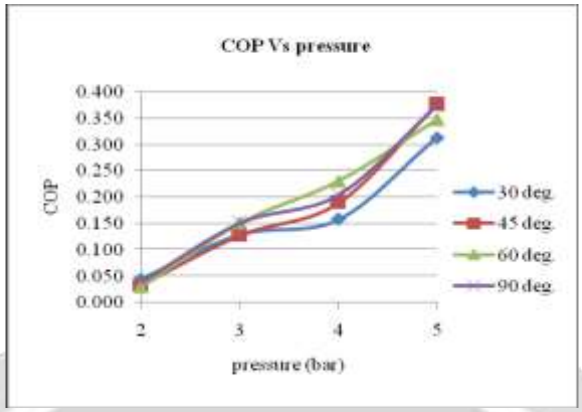

Fig. 4 the effect of inlet pressure on COP [03]

Following conclusions were drawn out of this study -

A. The maximum temperature difference of 27°C is obtained in cold end side while 18°C is obtained in hot end side.
B. With increase in inlet pressure, COP, cooling effect and isentropic efficiency of the vortex tube increases. Maximum COP and Maximum isentropic efficiency obtained is 0.376 and 23% respectively.
C. At 5 bar inlet pressure, 45° valve and 90° valve give the best result.
D. The result with helical convergent nozzle is with divergent tube is compared with literature available and it is found that results are in good agreement with previous work.

Orhan Aydın et al. [04] investigated the design parameters and performances of counter-flow vortex tubes under different inlet pressures, the length of the vortex tube, the diameter of the inlet nozzle and the angle of the control valve. Three different working gases were comparatively tested, which were air, oxygen and nitrogen. On the optimum geometry, flow visualizations are also conducted in order to have more information about the flow inside the tube. It is disclosed that the inlet pressure and the cold fraction are the important parameters influencing the performance.

A series of experiments were conducted to investigate some design features of the counter-flow vortex tubes. For different inlet pressures at which the working fluid is supplied into the vortex tube, the following three factors influencing the performance were: the length of the pipe, the diameter of the inlet nozzle, the mass flow rate of the inlet flow and the angle of the control valve

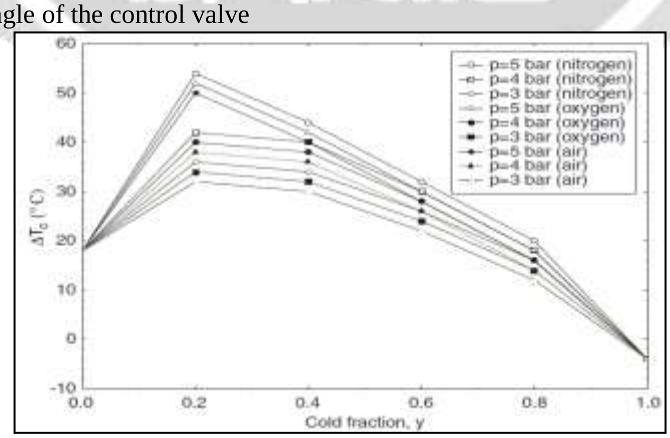

Fig.5 Comparison of the thermal performance of different gases [04]

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It is clear that the inlet pressure is the necessary driving force for the energy separation. Experiments show that the higher the inlet pressure, the greater the temperature difference of the outlet streams. It is also shown that the cold fraction is an important parameter influencing the performance of the energy separation in the vortex tube. Optimum values for the angle of the control valve, the length of the pipe, and the diameter of the inlet nozzle are obtained to occur approximately in the ranges $\phi \approx 50$, $L/D \approx 20$ and $d/D \approx 1/3$, respectively, which are expected to useful for vortex tube practitioners.

K. Dincer et al. [05] investigated the performance of counter flow type Ranque-Hilsch vortex tubes (RHVT). The measure of performance was chosen as the difference between the temperatures of hot outlet stream and cold outlet stream. Refer to the following graph.

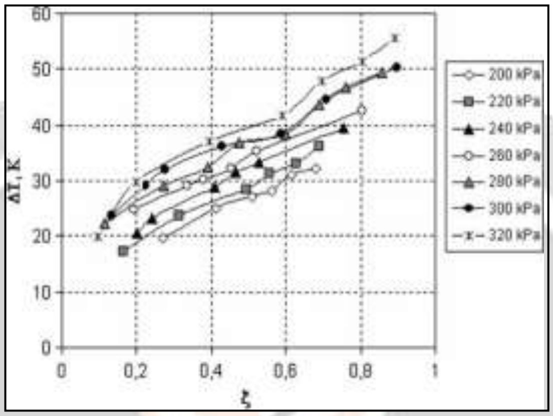

Fig.6 Variation of ΔT with P_i for different values of n at L/D =15 and N= 4 [05]

The performances of RHVTs were experimentally tested and it was concluded that the best performance was obtained when the ratio of vortex tube's length to the diameter was 15 and the nozzle number was at least 4, and higher inlet pressure.

The results of the experiments show that it is possible to get a temperature difference between hot and cold streams as high as 56 K, as shown in graph 6. A vortex tube with L/D of 15 and with at least 4 nozzles seems to be giving the best performance. Employing pressures as high as possible at the inlet is also recommended. It is understood that the desired temperatures may be obtained by controlling the rate of the hot output stream.

R. Manimaran et al. [06] performed the experimental studies to investigate the effect of geometrical parameters on temperature separation and flow field in the vortex tube. Inlet dimensions, cold orifice diameter, length and diameter of vortex tube are the main geometrical parameters that were taken into account. Experiments show that most of the temperature separation happens near inlet for the length considered. Inlet nozzle with lower aspect ratio gives better temperature separation.

- From the experimental studies, it is found that most of the temperature separation happens near inlet. This is evident from the studies on different lengths of vortex tube.
- Higher temperature separation is obtained with lower inlet aspect ratio as dividing stream surface area is increased. Studies on different cold stream exit orifice diameter show that higher temperature separation is obtained at orifice diameter of 9 mm.
- From the geometrical studies on length, inlet and cold stream exit orifice diameter, the flow visualization experiments show that number of helical turns, closeness of helical turns and residence time are important for temperature separation. Number of helical turns and residence time increase with the temperature separation.
- Studies on scale effect between smaller and bigger vortex tubes performed here indicate that mass flow-rate in vortex tube of D = 53 mm has to be increased nearly seven times as compared to the vortex tube of D=19 mm to obtain higher temperature separation. The decrease in the inlet aspect ratio in bigger vortex tube enhances the temperature separation.

Volkan Kırmacı et al. [07] experimentally verified the vortex tube performance against cold mass fraction, inlet pressure, and nozzle number.

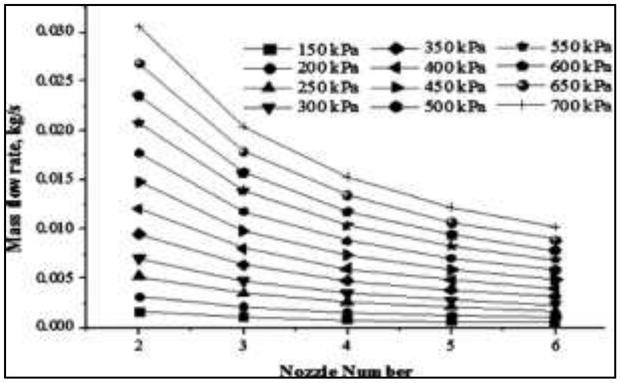

Fig.7 Mass flow rate variation according to the nozzle number [07]

These experimental data for a counter flow type vortex tube with L/D=15 have been tested by using the compressed air and five different orifices with different nozzle numbers N=2,3,4,5,6 under the processing conditions of 150–700 kPa with 50 kPa increments and cold mass fractions of 0.5–0.70 with 0.02 increments to obtain the vortex tube performance. To do so, the difference between the heating effect and the cooling effect is used as the performance metric. According to the experimental results, the temperature gradient between the cold and hot outlets is decreased when we take into account the effects of the nozzle numbers. But, if we consider each nozzle separately the increase in the pressure increases the temperature gradient. Furthermore, it appears that as the nozzle number increases, the temperature gradient becomes less sensitive to the inlet pressure. The maximum temperature gradient between the cold and hot outlets is obtained when the orifice number is 2. This can be explained by the flow rate variations. For a fixed mass flow rate, when the nozzle number is increased it means that the total flow area increases and the orifice exit velocity decreases, as shown in 7

Jaykumar D. et al.[08] presented experimental results of the energy separation in vortex tubes for different nozzle diameters keeping all other geometrical parameters constant. It is experimentally evidenced that the nozzle diameter greatly influences the separation performance and cooling efficiency. The most important point revealed is that there is an optimum nozzle diameter that gives the best performance of vortex tube.

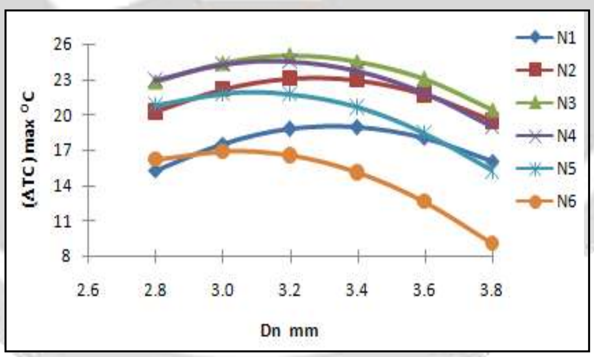

Fig.8 The variation of ΔT_c with Dn [08]

After the experimentation on the vortex tube with different nozzle diameters, it is concluded that, nozzle diameter have great influence on the performance of vortex tubes. Cold temperature drop (ΔT_c) max varies with the variation of nozzle diameter. But there is a unique nozzle diameter that gives the optimum performance for various geometrical parameters like nozzle angle (ϕ), orifice diameter (Do), nozzle number (N), tube length (L) and physical parameter like pressure (P). The optimum value of nozzle diameter (D_n) for maximum cold temperature drop (ΔT_c) max is 3.2 mm, as shown in graph 8

Mohanty et al. [09] presented an Experimental modeling and investigation of change in cold mass fraction and nozzle numbers on Performance of counter Flow vortex tube.

The graph between cold outlet temperatures of the air at 5 bar inlet pressure verses cold mass fractions. For each one of the nozzles used, when the lc was adjusted to 0.578 with N = 3, 4, 5, 6 the cold outlet temperatures were measured as follows: 263.4 K, 267.9 K, 274.1 K, 275.2 K respectively. The minimum cold outlet temperature is obtained for N = 3. In this study, the experimental data for a counter flow type vortex tube with L/D = 16 has been obtained by using the compressed air and with different nozzle numbers N = 3, 4, 5, 6 under the pressure of 5 bar and cold mass fractions of 0.5–0.72. According to the experimental results, the minimum cold outlet temperature of 263.4 K and maximum hot outlet temperature of 326.6 K is obtained for N = 3. The temperature gradient between the cold and hot outlets is decreased when we take into account the effects of the nozzle numbers. But the maximum temperature gradient is obtained for N = 3. It is also seen from the result that the minimum cold outlet temperature (i.e. 263.4 K) has been obtained at decreased cold mass fraction (i.e. 0.578) and maximum hot outlet temperature (i.e. 326.6 K) is obtained at increased cold mass fraction (i.e. 0.711). From the results it is concluded that, the cold outlet temperature (i.e 263.4 K) which is the minimum temperature obtained in N = 3 for a fixed mass flow rate can be used for application in spot cooling of electronic equipments, cooling of cutting tools in manufacturing processes. Similarly the hot outlet temperature (i.e 326.6 K) which has been obtained in N = 3 for fixed mass flow rate when the cold mass is increased can be used for heating applications such as melting the glues, softening the plastics ,humidifying the ambient air etc.

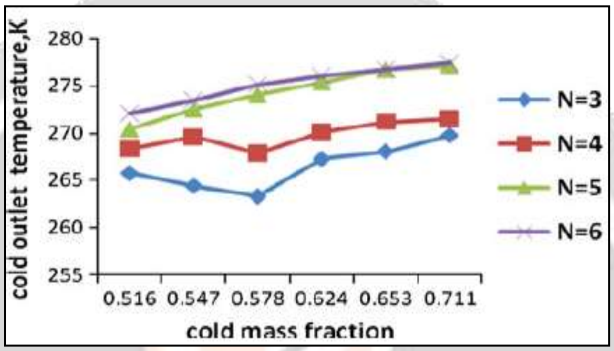

Fig. 09 Cold outlet temperature verses cold mass fraction at Pi = 5 bar [09]

Dorkar et al. [10] studied the effect of cold orifice diameter and geometry of hot end valves on performance of converging type Ranque Hilsch vortex tube.

Figure 10 shows the effect of conical valve angles and orifice diameter on cold end temperature. For 5, 6 and 7 mm orifice diameters and valves of 300, 450, 600, 900 angles. The figures are plotted for 5 mm 6mm and 7mm orifice diameters individually. The results depict that the performance of 450 conical valve angles is best for highest supply pressure of 5 bars and with orifice diameter as 7mm; the temperature observed is 50C on cold end side. Performance of 900 valves is also comparable to that of 450 conical valves it also produces the low temperature on cold end. The 30 and 60 degrees conical valve performance is not much promising. The result show that with increase in valve angles the temperature drops at all supply pressures, With change in valve angles the flow is guided and when valve angle is 45 degrees the reversal of flow is smooth and as the orifice diameter increases chances of secondary circulation are minimized hence there is no mixing of the hot stream and cold stream. At highest input pressure and adiabatic expansion at the entry the temperature drop increases. The expanding flow as reaches the hot end because of the converging section of the tube attains high velocity. The velocity along the axis increases because of convergent section and provides potential for the heat transfer among the hot stream and cold stream. The results also reveal that the mass of air escaping out from the hot end is less. If the pressure is held constant, changes in valve angles shows change in temperature in the descending sequence of 60, 30, 90 and 45 degrees. Thus valve angle has effect on the energy separation. Almost 15 to 25% changes are observed with increasing valve angle from 30 to 45 degrees.

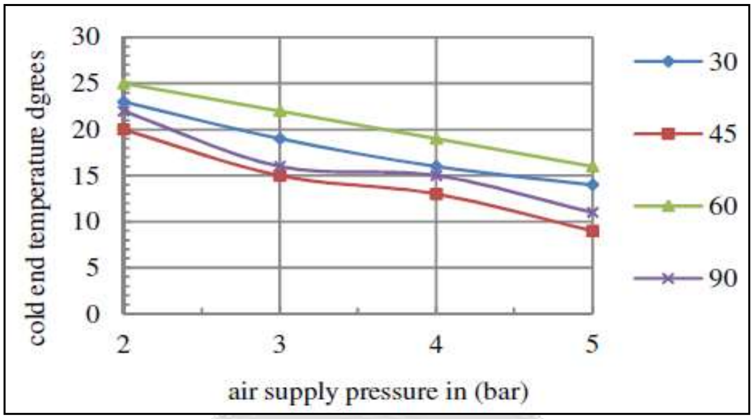

Fig. 10 Effect on cold end temperature orifice [10]

Agarwal et al. [11] presented experimental investigation of vortex tube using natural substances.

Performance evaluation of the Ranque – Hilsch vortex tube has been carried out experimentally. Figure 11 shows there is a value of cold mass fraction at which vortex tube performs optimally at the given pressure and L/D ratio. The maximum cold temperature drop is also obtained at cold mass fraction/ratio of 60%. Further, it is found that the vortex tube of L/D ratio 17.5 performs optimally. For a given L/D ratio, as the gas pressure increases, cold end temperature difference increases but the optimum value of cold mass fraction remains same. In the tested range, COP and cooling capacity both shows increasing trend with cold mass fraction up to cold mass fraction of 60%. It is also observed that the cooling effect produced by the vortex tube depends on properties of the gas, molecular weight and specific heat ratio.

The vortex tubes perform better with carbon dioxide compared to air and nitrogen owing to its high molecular weight and low specific heat ratio. Three different single nozzle vortex tubes of the length 125 mm, 175 mm and 225 mm of L/D = 12.5, 17.5 and 22.5 are tested with the tube diameter as 10 mm and inlet nozzle diameter as 2 mm. Cold end diameter and cone angle of hot valve was taken as 3 mm, 4 mm & 5 mm and 45°, respectively.

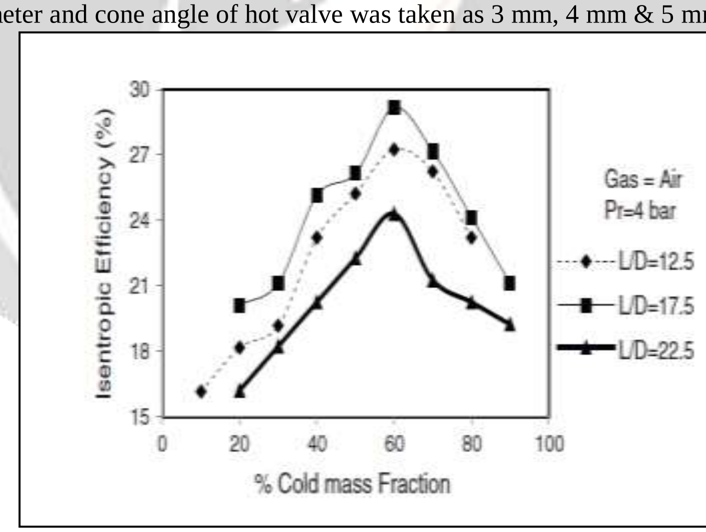

Fig. 11 Variation of cold end temperature drop with cold mass fraction at various L/D ratios [11]

III CONCLUSION

Inlet pressure is the necessary driving force for energy separation in a vortex tube the Higher the inlet pressure greater is the temperature separation of the outlet air streams. The performance of the vortex tube is also depends on the cold fraction. As the length of the vortex tube increases the magnitude of temperature separation increases only up to the certain length, however a further increase in the length does not improve the temperature separation. In case of diameter, as the diameter of the vortex tube increases the magnitude of angular velocities decreases and therefore the magnitude of temperature separation decreases. Performance reduction occurs due to secondary circulation of flow which also appears to be characteristics of the cold end orifice diameter. The maximum temperature separation can be achieved by an optimum diameter of cold-end orifice. The optimum performance factor of vortex tube is attainable at 60% of the cold fraction irrespective of the inlet pressure and orifice diameter. Number of nozzles is also play an important role in the performance as the number of nozzles increases the power of cooling increases while the temperature at cold end decreases moderately. the variation of the temperature along the surface of the vortex tube helps locating the stagnation point along the axis of the vortex tube along the flow field.

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