International Journal of Engineering Research
Volume No.3 Issue No: Special 1, pp: 6-10
ISSN:2319-6890)(online),2347-5013(print)
22nd March 2014

Effect of Inlet Nozzle and Hot end Conical Valve on the Performance of Vortex Tube

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Abstract— **Vortex tube is a simple device injected with pressurized gas through tangential nozzles, creates a strong swirl flow field. This vortex in the inlet causes the pressure distribution of the flow in radial direction. As a result a free vortex is produced as the peripheral warm stream escapes through opening of conical valve and a forced vortex as the inner cold stream escapes through orifice. The performance of vortex tube mainly depends on the flow pattern. The inlet at the nozzle and exit at the hot end are key parameters that affect the flow pattern. So the main intention of this work is to investigate the effect of inlet nozzle number and conical angle of control valve at hot end. The results revealed that temperature drop increases with increase of nozzle number whereas the same is increasing with increasing conical angle up to 45^0 and decreasing thereafter**.

Keywords— Nozzle, conical angle, control valve, temperature drop.

I. Introduction

A source of compressed gas (e.g. air) at high pressure enters the vortex tube tangentially through one or more inlet nozzles at a high velocity. The expanding air inside the tube then creates a rapidly spinning vortex. The air flows through the tube rather than pass through the cold orifice located next to the nozzles because the orifice is of a much smaller diameter than the tube. Therefore, the cone valve is applied at the hot tube end in order to control the outlet hot air flow or to let the cold air pass through the cold orifice as needed. The schematic flow diagram of flow pattern is shown in fig 1.

Fig 1: Flow pattern in Vortex tube

The vortex tube was first discovered by, Ranque [1] but it was thermodynamically highly inefficient so it was abandoned for several years. Interest in the device was revived by Hilsch [2], who reported an account of his own comprehensive experimental and theoretical studies aimed at improving the efficiency of the device. In recent years, various theoretical and analytical studies have been done on the vortex tubes.

Behera et al.[3] studied the effects of nozzle numbers on the energy separation inside the vortex tube using CFD and employing experiments. Volkan kirmaci [4] used Taguchi method to optimize the no of nozzle of vortex tube. Sachin.U et al [5] examined the role of the cold orifice to determine the conditions for maximum temperature and energy flux separation over a range of parameters. Pinar et al. [6] investigated the effects of inlet pressure, nozzle number and fluid type factors on the tube vortex performance by means of Taguchi method.

Kurosaka [7] reported the temperature separation to be a result of acoustic streaming effect that transfers energy from the cold core to the hot outer annulus. Chang et al. [8] conducted a visualization experiment using surface tracing method to investigate the internal flow phenomena and to indicate the stagnation position in a vortex tube. Bramo et al. [9-10] studied numerically the effect of length to diameter ratio (L/D) and stagnation point occurrence importance in flow patterns.

Aljuwayhel et al. [11] utilized a fluid dynamics model of the vortex tube to understand the process that drives the power separation phenomena. They reported that the energy separation exhibited by the vortex tube is due to the work transfer caused by a torque produced by viscous shear acting on a rotating control surface that separates the cold flow region and the hot flow region. Singh P.K and et al [12] states that the effect of nozzle design is more important than the cold orifice design in getting higher temperature drops. Merwin Sibulkin [13] carried out unsteady-flow analysis for the development of the flow in the vortex tube. Saidi and Valipour [14] classified the parameters that affect the performance of vortex tube as thermo physical parameters and geometry parameters. Gao [15] suggested that the entry to hot end needs more attention.

In the present work vortex tube with 10mm diameter and 170mm length is used. Different inlet nozzle numbers ranging from 1 to 3 are studied and control valve at hot exit with different conical angles of 25^0, 35^0, 45^0 and 55^0 were employed. Also tests are conducted with various input pressure and various opening at hot exit.

II. Results and Discussions

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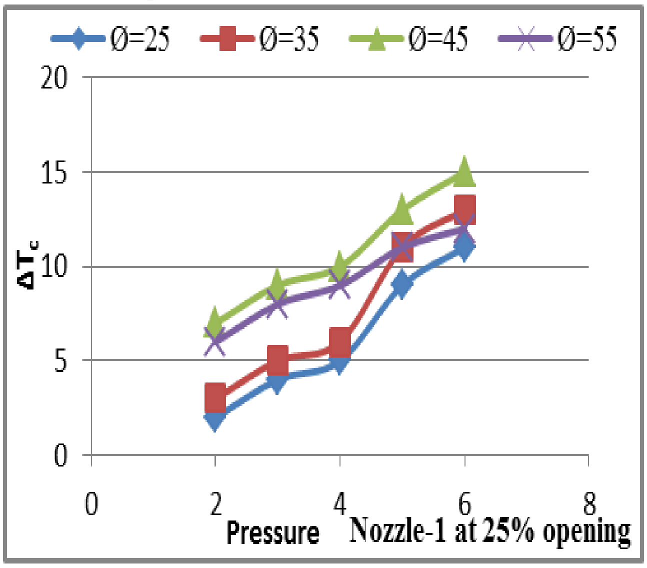
Fig 2 shows the effect of inlet pressure on temperature drop at cold end for different conical angles of control valve at hot end using different nozzle number. From the results it is observed that as pressure increases temperature drop increases irrespective of nozzle number and conical angle. It is also understood from the results that temperature drop increases with increase of conical angle up to 45^0 and decreases beyond that. Maximum drop of 15^0, 19^0 and 28^0 is attained using one, two and three inlet nozzle number. Varying the number of inlet nozzles from 1 to 2 and 4 helped to boost up the flow and to raise the mass flow rate and strong swirl flow into the vortex tube. In addition, this gave rise to higher friction dissipation between the boundary of the flows and a higher momentum transfer from the core region to the wall region. This reduces the temperature at the core while increases temperature at the wall area.



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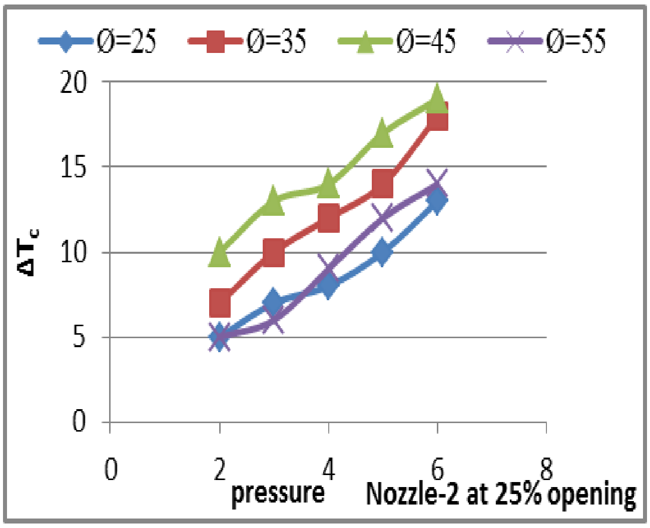

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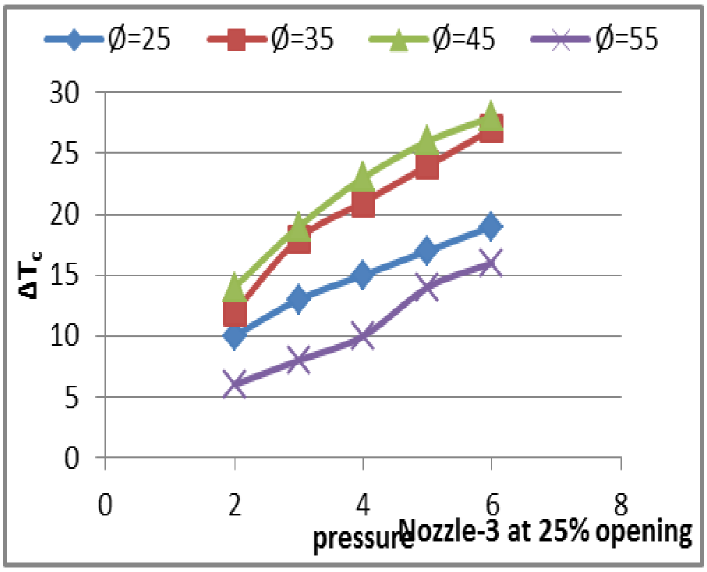
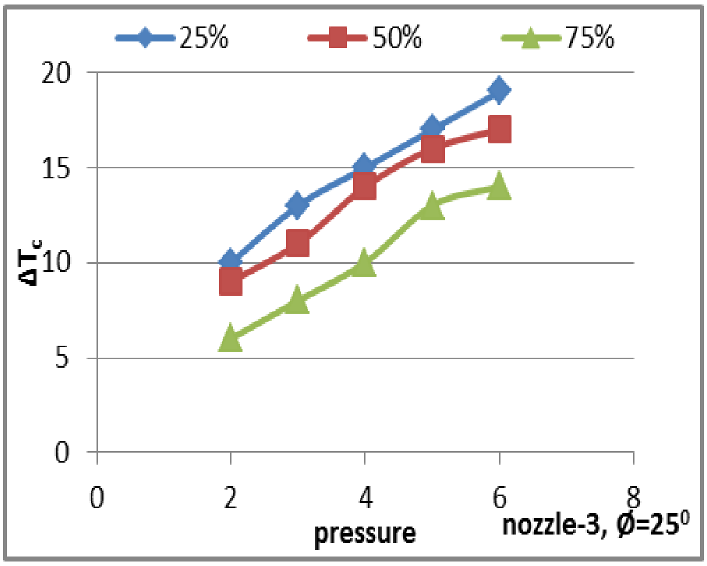


(c)

Fig 2: Effect of pressure on temperature drop for various conical angle of control valve using (a) one nozzle (b) two nozzles (c) three nozzles

Fig 3 shows the effect of pressure eon temperature drop for various opening towards hot exit using different conical angle. It is observed from the results that performance of the tube at cold end declines with increase of opening towards hot end. It is observed that a maximum temperature drop of 19^0, 27^0,28^0 and 16^0 is obtained using conical angle of 25^0, 35^0, 45^0 and 55^0. Irrespective of the opening towards the hot end temperature drop increasing with increasing of pressure at all conical angles. Also it is observed that at lower and higher conical angle the effect of opening is not dominating whereas at moderate conical angle performance of the tube is sensitive to the opening towards hot exit.



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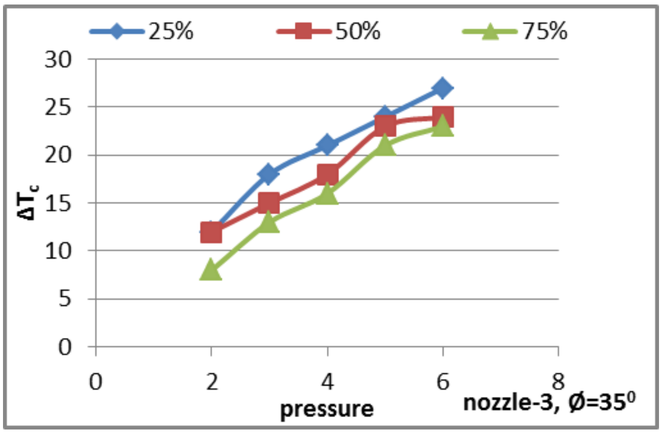

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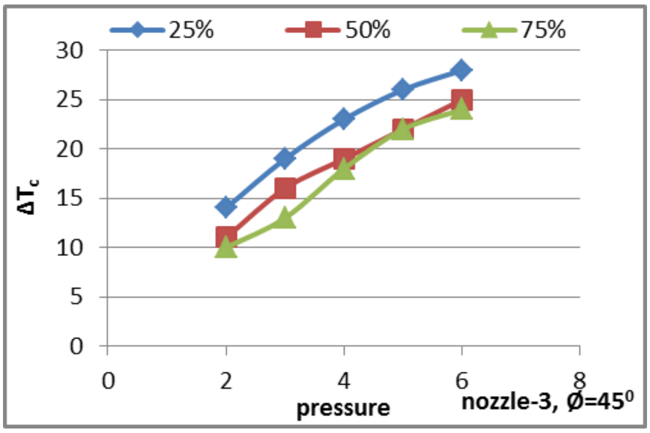

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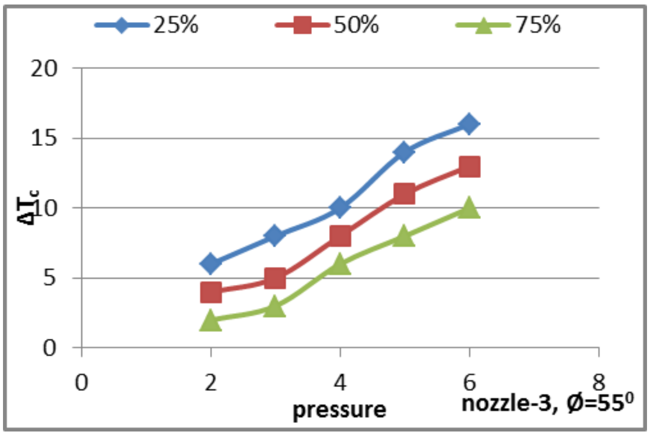
The centrifugal characteristics of the forced vortex flow, the tangential velocity of the air near the tube wall would be larger than that in the central region. This would naturally leads to increase of temperature near the tube wall than that in the central core. Also, the higher frictional force among fluid particles as well as among the fluid particles and the tube wall near the wall region is accountable for part of this trend. The higher the inlet pressure, the greater the centrifugal force. Then the difference between the tangential velocity in the near-wall region and that in the central region would be larger, and hence the difference between the temperatures of the two regions.



(d)

Fig 3: Effect of pressure on temperature drop for various opening at hot end using control valve with conical angle of (a) 25^0 (b) 35^0 (c) 45^0 (d) 55^0

Fig 4 shows the effect of pressure on cooling efficiency for different conical angles. It is observed that not much variation of efficiency with increase of pressure. Using three nozzles maximum efficiency of 15.65%, 22.24%, 23.3% and 13.18% is attained for conical angles of 25^0, 35^0 ,45^0 and 55^0. It shows that even though temperature drop is increasing with increase of pressure, it is not sufficient as input is increasing too much. It means that increase of temperature drop is not rapid at higher pressure.

Also it is seen from the results that efficiency is slightly decreasing with increase of pressure for conical angle up to 45^0 but whereas the same is slightly increasing with increase of pressure. At low pressure the desired flow pattern can be maintained where as at higher pressure too much abundant air particles disturbs the flow and results in low performance of the tube.

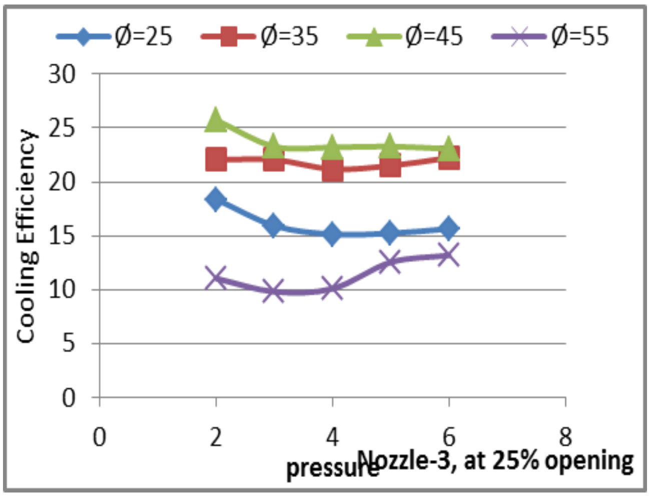


Fig 4: Effect of pressure on cooling efficiency for various conical angles of control valve.

Fig5 shows the effect of pressure on temperature rise for different conical angles. Here also temperature rise increases with increase of conical angle up to 45^0 and decreases thereafter. The reason is that at lower conical angle much air get escapes through hot end and only the remaining small amount of air gets converged and forms reversed forced vortex flow results in low performance. At the same time too high conical angle provides complete obstacle to the forward vortex flow and majority air gets converged and the flow pattern disturbs. Therefore moderate conical angle gives better temperature separation. Using three nozzle number at 25% opening a maximum temperature rise of 16^0,18^0,19^0, and 18^0 is obtained at conical angle of 25^0, 35^0 ,45^0 and 55^0 for 6 bar inlet pressure.

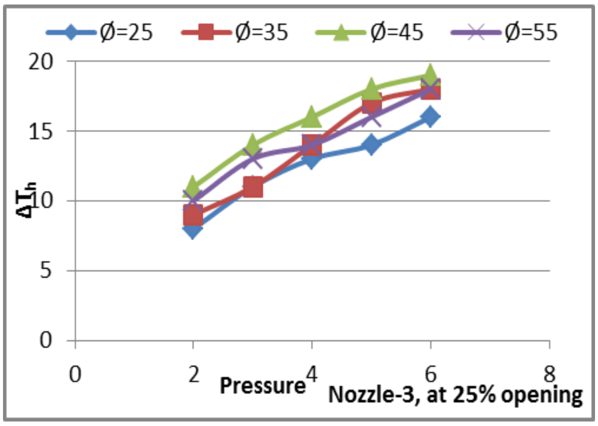
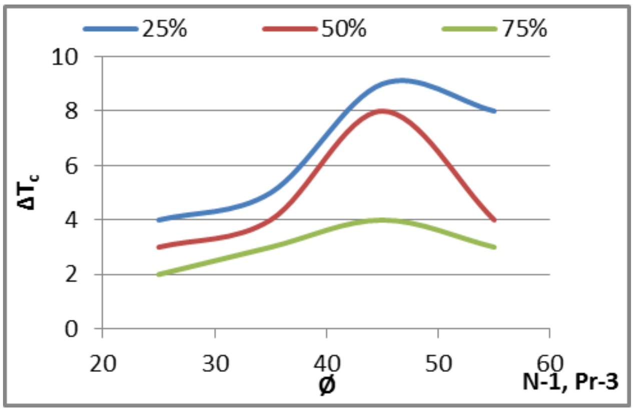


Fig 5: Effect of pressure on temperature rise for various conical angles of control valve

Fig 6 shows the effect of conical angle on the temperature drop for different opening towards hot exit. It is observed that temperature drop increases with increase of conical angle at first up to 45^0 and decreases there onwards for all the nozzle numbers. A maximum temperature drop is attained at 45^0 and at 25% opening. At small opening towards hot exit , majority air is available to flow towards cold end and better temperature separation takes place. Also it is observed that as nozzle number increases performance of tube increases because as nozzle number increases higher quantity of air gets into the tube and more particles of air takes role in temperature separation results in better performance.



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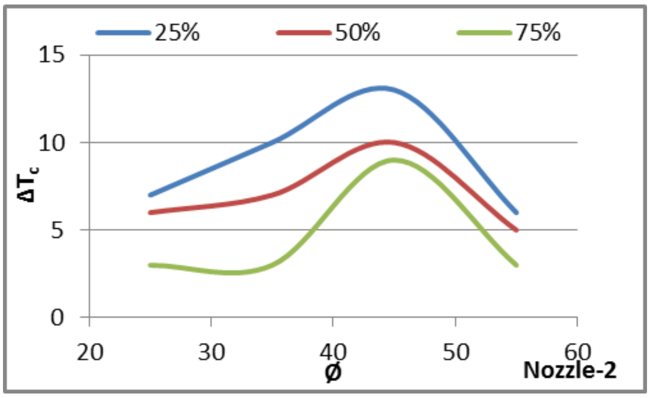

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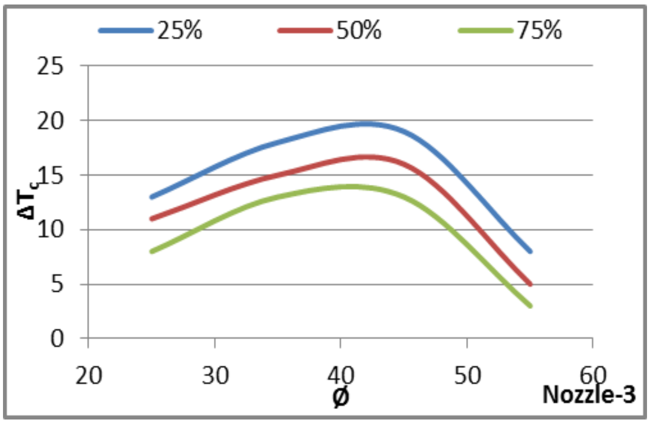

(c)

Fig 6: Effect conical angle on temperature drop for various opening towards hot exit using (a) one nozzle (b) two nozzles (c) three nozzles.

III. Conclusions

From the obtained results following conclusions are summarized:

- Temperature drop increases with increase of input pressure. Therefore pressure is the key parameter that affects the performance of the vortex tube.
- Temperature drop decreases with increase of opening towards hot end. 25% opening is the optimum opening towards hot end.
- Temperature drop at cold end increases with increase of conical of control valve up to 45^0 and decreases thereafter.
- Performance of vortex tube increases with increase of nozzle number and three is the optimum number of nozzles.
- A maximum temperature drop of 28^0c and temperature drop of $19^0$is obtained with three nozzle number at 25% opening and 45^0 conical angle.

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