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Study of Vortex Tube Using Ansys Fluent for Variable Inlet Nozzle Lengths and Variable Blunt Type control Valve

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ABSTRACT

This paper discusses the study performed on the vortex tube based on tapered inlet nozzle diameter, cylindrical nozzle with variations in lengths and blunt shape of control valve with different minor diameters in order to improve the vortex tube's performance. By performing simulations to determine the temperatures of the cold and hot exits at a constant pressure of 5bar. This study investigates how the cold mass fraction varies with regards to variations in inlet lengths as well as varying distinct types of control valve shape. The graphs compare the variations in cold mass fraction for simulation and theoretical results.

Keywords –Inlet nozzle length, Blunt control valve, Cold mass fraction, cold exit temperature, Hot exit temperature, Inlet temperature, Inlet pressure, Length of the tube, Mass flow rate.

INTRODUCTION

Since the discovery of the vortex tube, researchers have been fascinated by the mechanism that drives the energy separation phenomenon. As a result of an incomplete understanding of vortex tube physics, these devices are extremely rare in the market and in domestic applications. As technology advances, more vortex tubes are being manufactured for a wide range of commercial applications. Vortex tubes are commonly used for the cooling purpose in operations such as welding, brazing, solidification, etc., While the vortex tubes can be useful in certain situations due to their small size, ease of manufacture and repair, where the lack of electrical or chemical power input.R. S. Maurya & Kunal Y. Bhavsaret al. [1] Numerical analysis of a vortex tube on a 3D model with 6 nozzles and an adjustable cone valve. The influence of major performance characteristics such as supply pressure, cold orifice diameter, tube diameter, and tube length suggests that the current thumb rule for better vortex tube performance could be improved at where the tube is expected to perform under constant wall temperature and constant wall heat flow conditions. It finds that the tube's cooling effectiveness is independent of the thermal state imposed on its wall.HR. Thakareet al. [2]

A review of numerous optimization studies employing approaches such as Artificial Neural Network (ANN), Taguchi method is offered, with the goal of giving intentional thought to quality results of fewer unattended vortex tube study effort. In terms of computational investigations, both 2D and 3D vortex tube models have been used to obtain insights into flow physics of temperature separation process for various turbulence models predict similar mechanism of temperature separation, but with varied magnitude. The benefit of numerical studies is their capacity to produce comprehensive profiles of various flow physics parameters inside a vortex tube.J Lagrandeuret al. [3] concentrate on optimal gas Models of counterflow vortex tubes reveal that they solve the same set of equations but lead to distinct interpretations for flow and heat transfer events. As long as kinetic energy is included in the analysis, the energy balance connects the hot and cold flow temperatures for a given cold mass fraction. Models address the radial momentum balance, which simplifies to a simple formula relating the pressure gradient and the tangential velocity. Typically, the amplitude of the radial flow influences the forced vortex or Rankine vortex shape of the velocity profile.

The major vortex tube parameters (diameter and length), the most promising route is connected to the anticipate occurrence and the good localization of the vortex breakdown inside the tube. Ch Pavan Kumar et al.[4]Energy separation will improve when the interior diameter of the hot chamber is reduced. If the length of the hot chamber can be increased, the flow of air takes longer to depart from the hot exit, allowing for more temperature exchange from the core to the tube's periphery. As a result, more energy is separated. The system's C.O.P. will be raised by increasing the number of nozzle inlets. Consistency at greater pressures increases the cooling effect. The sharpness of the tip at the end of the conical valve will affect the energy separation between the cold and hot streams inside the hot chamber.

R.Madhu Kumar et al.[5] The performance of vortex tubes with cylindrical and conical hot tubes is compared. It was discovered that the vortex tube with a conical angle of roughly 2.5 outperformed the cylinder tube in terms of COP by 25%30%. The conical vortex tube achieves the same or better performance as the standard tube while being shorter in length.Sankar Ram T et al. [6] The basic counter-flow vortex tube is a long hollow cylinder with a tangential nozzle on one end for injecting compressed air. Within the vortex tube, the flow is defined as spinning air moving on a spring-shaped vortex track.

The peripheral flow is directed towards the hot end, where a hot end plug is installed, while the axial flow, which is driven back by the plug, is directed towards the cool end.Suraj S Rautet al.[7] The purpose of this study is to address the experimental research of the influence of the aforementioned operating parameters on the performance of the Ranque-Hilsch vortex tube. The vortex tube was created using the Chlorinated Poly Vinyl Chloride (CPVC) material, which has lower heat conductivity than metals and fewer fluid friction losses. In this experimental investigation, the performance of a vortex tube was investigated using compressed air at pressures ranging from 5 to 10 bar and fed through two tangential input nozzles. The hot side tube L/D ratio ranged from 10 to 50, and the cold mass fraction ranged from 0.20 to 0.80.Jaykumar D. Golharet al. [8]The experimental findings of energy separation in vortex tubes for various nozzle diameters while holding all other geometrical factors constant. It has been demonstrated experimentally that the nozzle diameter has a significant impact on separation performance and cooling efficiency. The most crucial factor is that the optimal nozzle diameter provides the best vortex tube performance.Xiangji Guo et al. [9]

Flow field studies, such as qualitativevisualizations and probe intrusive measurements, have a long history, but laser non-intrusive measurements and numerical simulations, particularly the former, are new methodologies. The flow structures are extremely important in understanding the energy separation process and its performance. The flow structure studies were not limited to the understanding of the flow field, and more and more researchers intend to use flow structure to explain the energy separation process or changes in energy separation performance, particularly the behavior of the reverse flow boundary and the axial stagnation point.A.V. Khaitet al. [10] Finite volume vortex gas flow is investigated as a numerical model suitable for performing optimization simulations that enable the cost of vortex tubes, i.e. the geometrical sizes of the energy separation chamber and nozzle twisting device, to be optimized. The ability of regulating vortex tube mass flow rate capacity by modifying the supersonic main nozzle inlet narrow cross section sizes was investigated. The value of the energy efficiency coefficient varies modestly throughout a wide range of main nozzle thin cross section sizes: from s = 1 mm to s = 2.25 mm (rated size is s = 1.5 mm). Lowering this size to s = 1 mm leads in a decrease in the energy efficiency coefficient value. With s = 0.5 mm, the energy efficiency coefficient reduces almost twice as much.

Working Principle

A vortex tube is a device in which air swirls around an axis inside the tube. It produces cold and hot air by forcing compressed air through a chamber, spinning the air into a vortex. The high-speed air warms up as it spins along the inner walls of the tube towards the control valve. The valve allows a portion of the heated, high-speed air to escape. The remaining air stream is forced through the center of the Vortex tube towards the cold end exit. At the other end, the interior counter flow vortex exits as extremely cold air. The temperature drop along the vortex tube was found to be precisely proportional to the input pressure.

Design of Control Valve and Inlet Nozzle

The vortex tube components were designed in solid works, and the simulation was performed in ANSYS workbench with complete geometry sketched in workbench fluent. While designing, it is considered that the shape of the control valve is not sharp conical, but rather blunt, with different major and minor diameters. The nozzle inlet is also tapered and has different lengths. Based on the design considerations, the performance of the vortex tube in various combinations is evaluated.

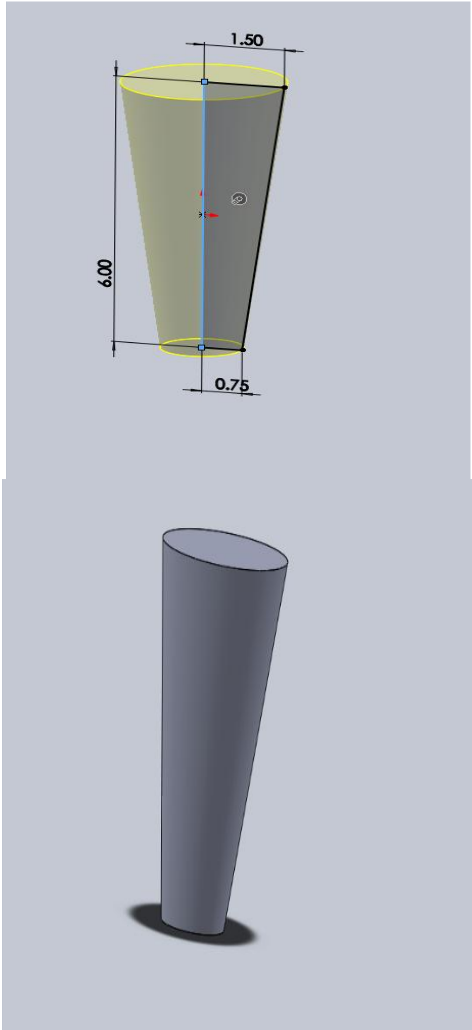


Figure 0.1 Tapered Inlet Nozzles

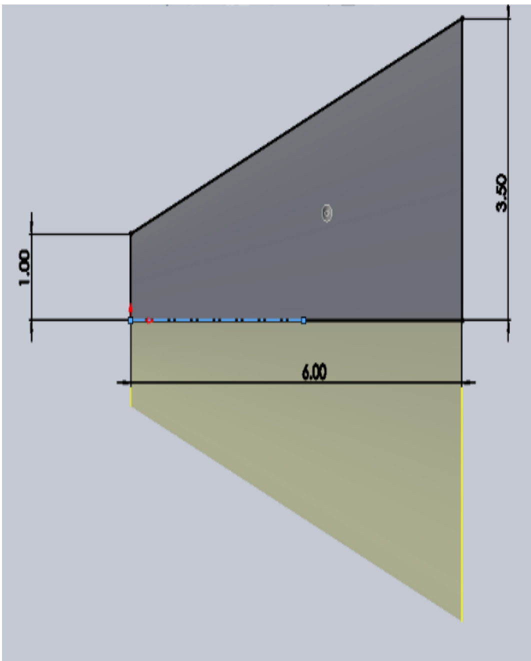


Figure 0.2 Blunt Control Valve with Minor Dia 1 Mm & Major Dia 3.5 Mm

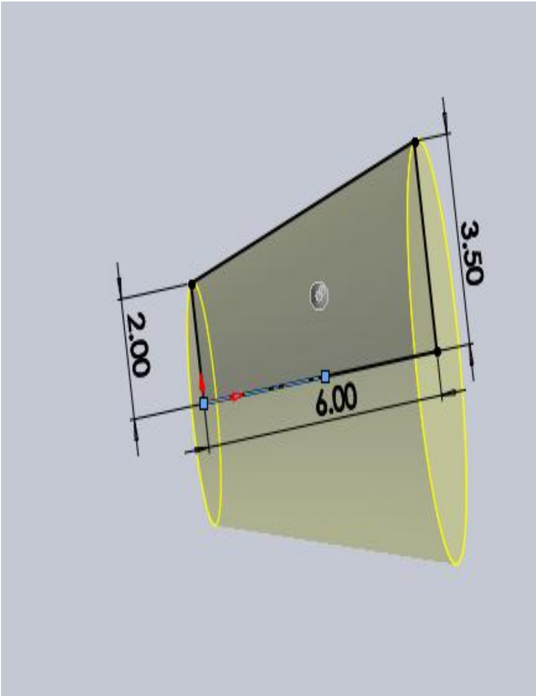


Figure 0.3 Blunt Shaped Control Valve with Minor Dia 2 Mm & Major Dia 3.5 Mm

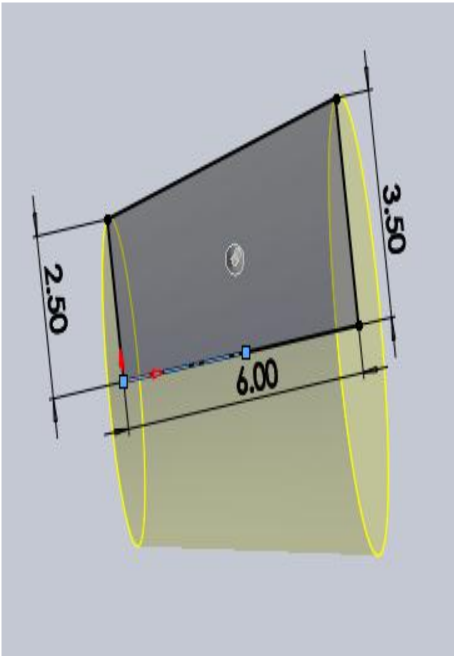


Figure 0.4 Blunt Shaped Control Valve with Minor Dia 2.5 Mm & Major Dia 3.5 Mm

Fluent Analysis of Vortex Tube

The fluid flow of the vortex tube is analyzed in the 'fluid flow FLUENT' solver with the K epsilon model as turbulence, the fluid is single phase fluid with an inlet temperature of 303K and a constant pressure of 5 bar, the average static pressure at the cold outlet is limited to 0.5bar and the average static pressure at the hot outlet is considered to be 2bar. Temperature, pressure, and velocity contours are determined for both blunt and sharp conical valves. This simulation is run for four distinct inlet nozzle lengths: 4mm, 6mm, 8mm and 10mm, and thus the results are summarized.

3.1 Simulation for Tapered Inlet Nozzle of Base 1.5 mm and Up With 2 mm Diameter

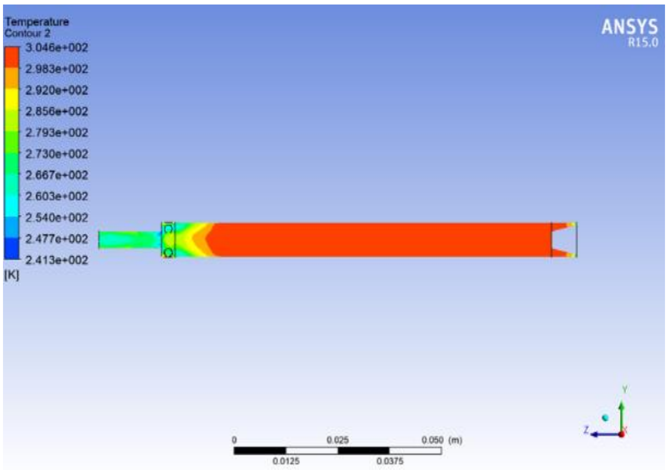


Figure 0.1 Temperature Contour- Inlet Nozzle 4 Mm Length

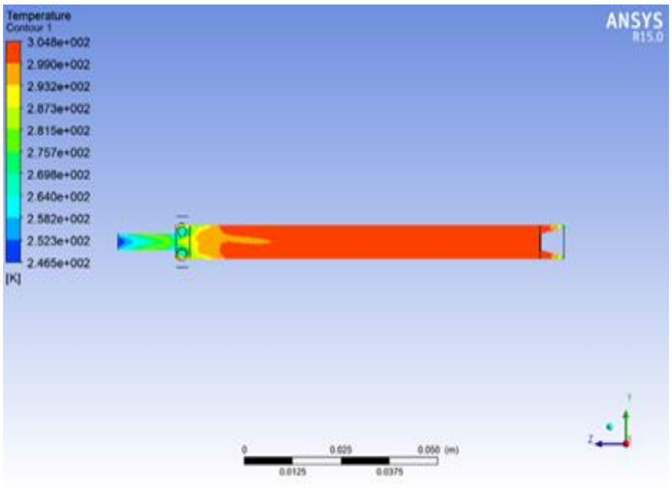


Figure 0.2 Temperature Contour - Inlet Nozzle 6 Mm Length

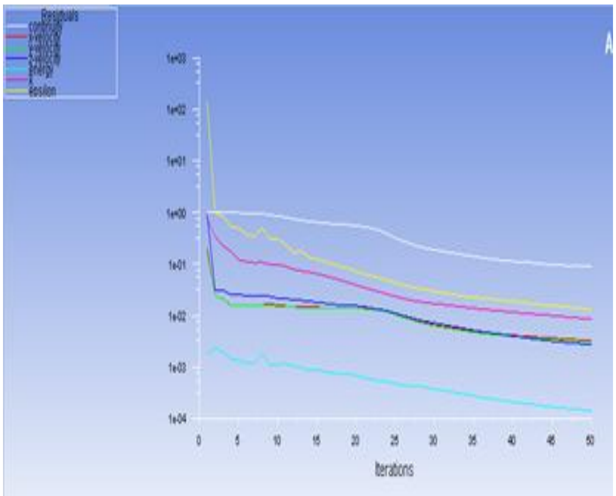


Figure 0.3 Iteration for Above Simulation

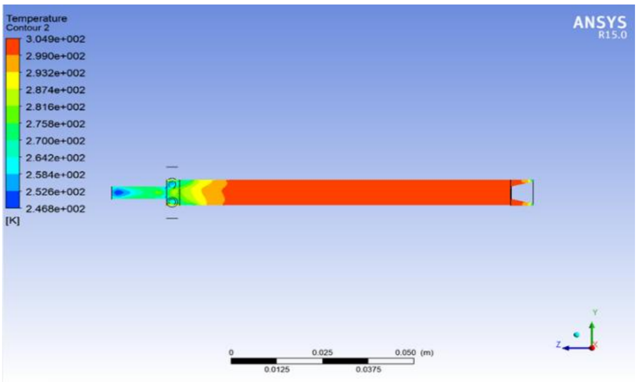


Figure 0.4Temperature Contour- Inlet Nozzle 8 Mm Length

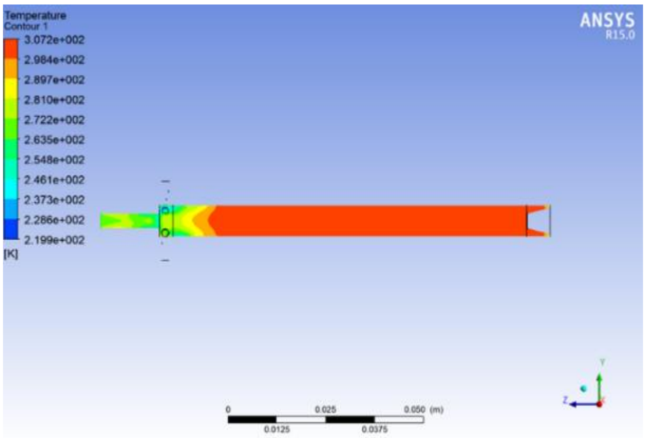


Figure 0.5 Temperature Contour- Inlet Nozzle 10 Mm Length

Indentations and Equations

M - Mass flow rate (kg/s)
P - Pressure (Kpa)
T - Temperature (K)
μc - Cold mass fraction
Coefficient of performance (COP)

CoP = $\eta_{ab} * \eta_{ac} *(\frac{p_a}{p_i})^{\frac{\gamma-1}{\gamma}}$

Cold mass fraction (M_c) = $\mu_c – M_h$
Hot mass fraction =M_i-M_c

RESULTS

Table 0-1 Tapered Inlet Nozzle – COP Data Based On Nozzle Length Variations

S No	Inlet minor diameter	Inlet Major diameter	Length of Nozzle	Hot Outlet Temperature (T_h)	Cold Outlet Temperature (T_c)	Cold Mass Fraction (μ_c)	Coefficient Of Performance (COP)
1	1.5	2	4	304	261	0.0232	0.0043
2	1.5	2	6	307	250	0.070	0.0166
3	1.5	2	8	304	260	0.022	0.0042
4	1.5	2	10	305	254	0.039	0.008

The table 5-1 table shows for tapered inlet nozzle which results in better coefficient of performance and cold mass fraction for inlet nozzle length of 6 mm when compared to 4,8,10 lengths

Table 0-2 Cylindrical Nozzle Inlet- COP Data Based on Nozzle Length Variations

S No	Inlet minor diameter	Inlet Major diameter	Length of Nozzle	Hot Outlet Temperature (T_h)	Cold Outlet Temperature (T_c)	Cold Mass Fraction (μ_c)	Coefficient Of Performance (COP)
1	1.5	1.5	4	307	280	0.148	0.015
2	1.5	1.5	6	312	263	0.183	0.033
3	1.5	1.5	8	308	272	0.138	0.019
4	1.5	1.5	10	313	260	0.188	0.036

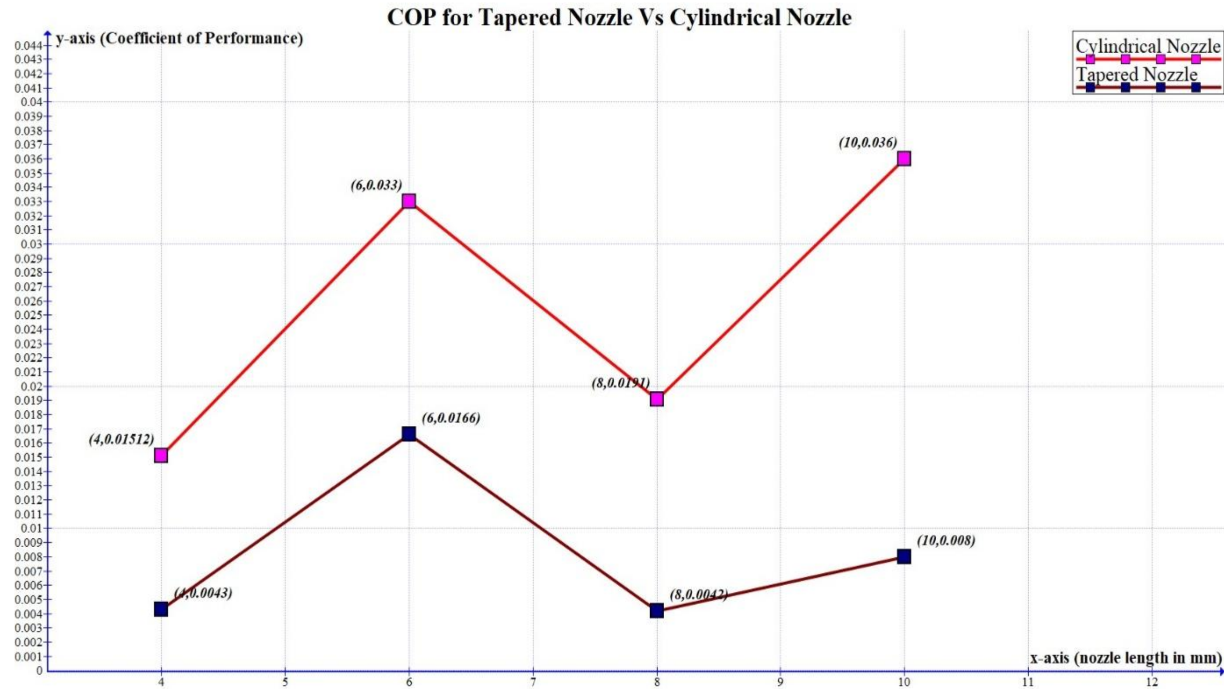
The table 5-2 table shows for cylindrical inlet nozzle which results in better coefficient of performance and cold mass fraction for inlet nozzle length of 10 mm when compared to 4,6,8 lengths

Table 0-3Variations for Blunt Control Vale Vs COP for 6 Mm Length Tapered Nozzle

S No	Blunt Shape Minor Diameter	Blunt Shape Major Diameter	Hot Outlet Temperature (T_h)	Cold Outlet Temperature (T_c)	Cold Mass Fraction (μ_c)	Coefficient Of Performance (COP)
1	2	7	309	270	0.153	0.022
2	4	7	312	260	0.173	0.033
3	5	7	310	273	0.175	0.025

The table 5-3 table shows for blunt control valve which results in better cold mass fraction and coefficient of performance for minor diameter of 4 mm when compared to 2,5 mm diameters.

Graphs



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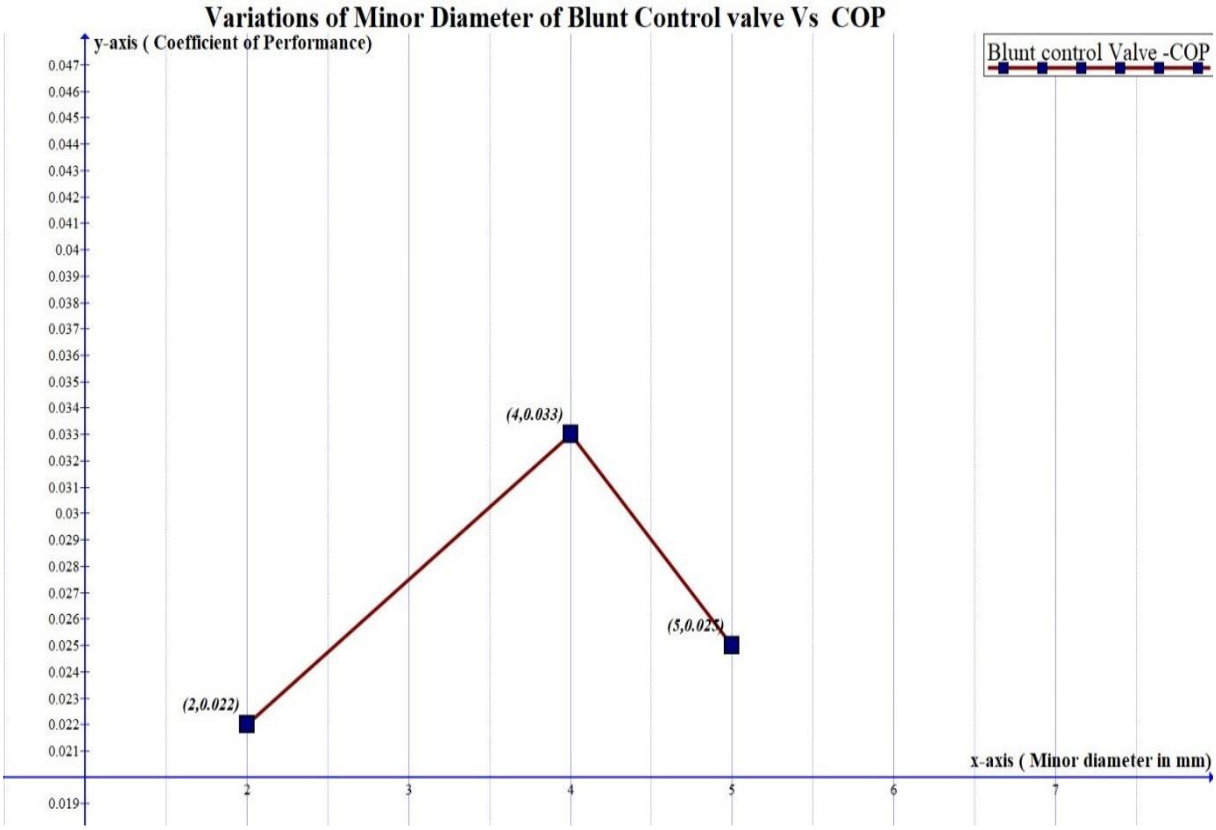
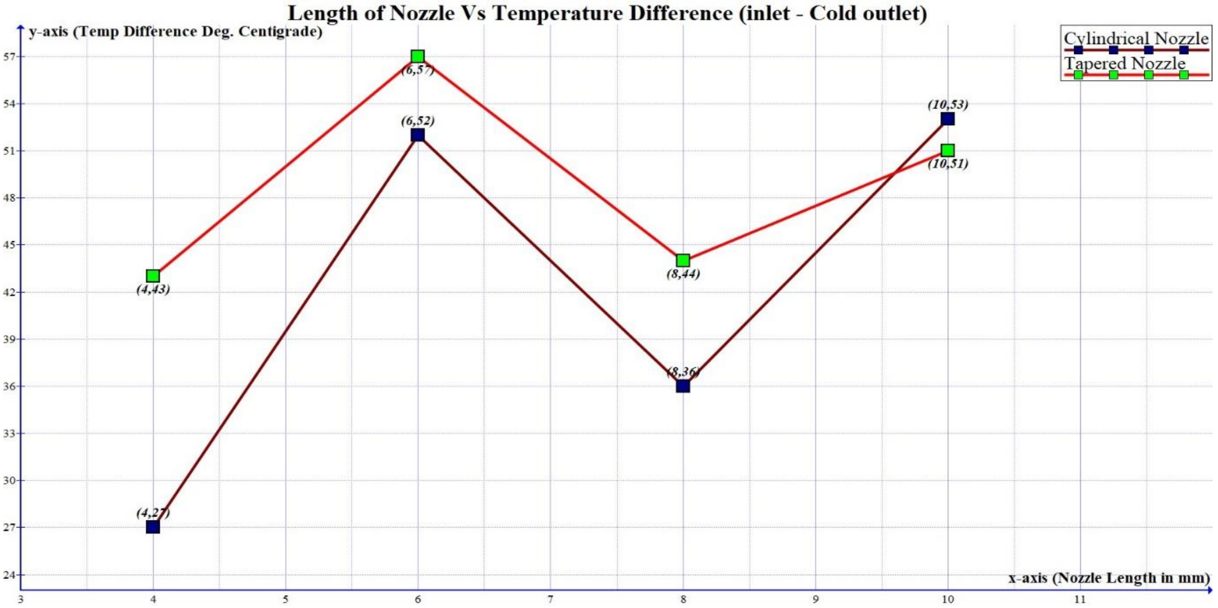
Graph6-1 shows the results for coefficient of performance which results in better coefficient of performance and cold mass fraction for inlet nozzle length of 10 mm for taper nozzle and 6 mm length for cylindrical nozzle.

Graph 0-1 Graphical Representation of COP Variations



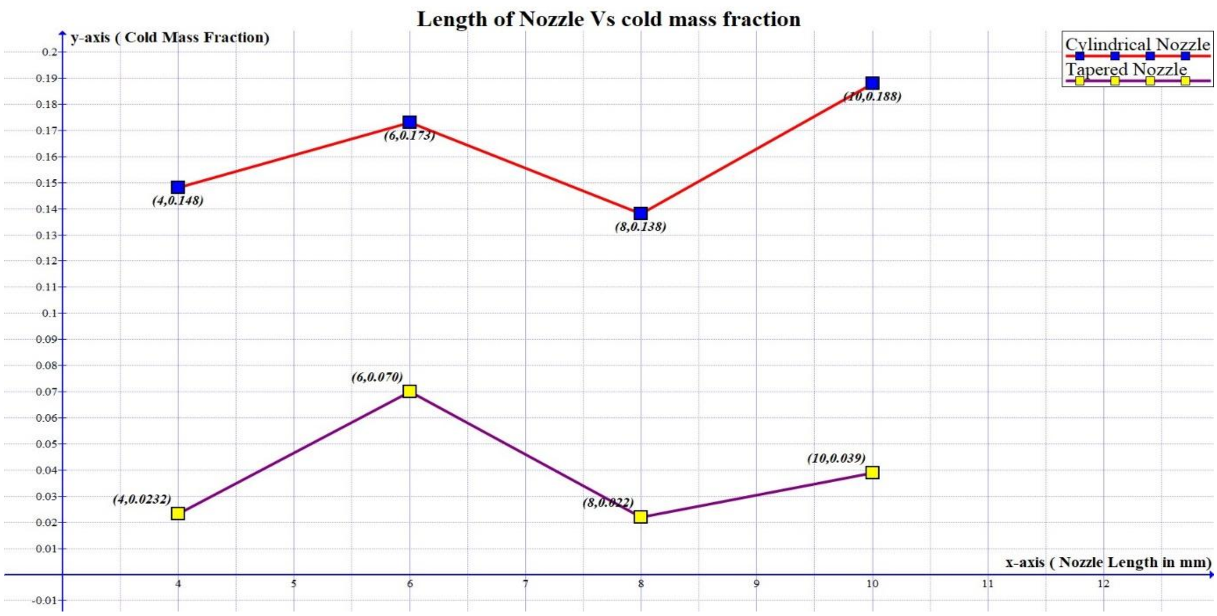
The graph 6-2 shows the results for coefficient of performance which results in better coefficient of performance and cold mass fraction for blunt control valve of 6 mm.

Graph 0-2 Variations of Minor Diameter of Blunt Control Valve Vs COP



The graph 6-3 shows the results for temperature difference which results in better temperature drop and for inlet nozzle length of 6 mm for taper nozzle and 10 mm length for cylindrical nozzle.

Graph 0-3 Length of Nozzle Vs Temperature Difference



The graph 6-4 shows the results for cold mass fraction which results in better cold mass fraction and for inlet nozzle length of 10 mm for cylindrical nozzle and 6 mm length for cylindrical nozzle.

Graph 0-4 Length of Nozzle Vs Cold mass fraction

CONCLUSIONS

1. The graphs show that the COP of the vortex tube is greater in the cylindrical nozzle when the nozzle length is 10 mm, while in the case of the tapered nozzle; the performance is greatest at 6 mm nozzle length for the same L/D ratio or length of hot chamber of the vortex tube.
2. Because the maximum COP developed at 6 mm nozzle length, the COP is maximum when the minor diameter of the Blunt conical valve is 4 mm and the major diameter is 7 mm.
3. The temperature difference is maximum at 10 mm nozzle length for cylindrical nozzles and 6 mm nozzle length for tapered nozzles.
4. The greatest cold mass fraction happened at 10 mm nozzle length for cylindrical type while it maxed at 6 mm nozzle length for tapered, when observed the graph**6-4**cold mass fraction at 6 mm nozzle length in both cylindrical and tapered, the cylindrical exhibits greater.
5. When the findings are discussed, it is evident that a tapered inlet nozzle with a short length provides the best performance, whereas a cylindrical inlet nozzle with a long length provides the best performance.

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