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# Experimental analysis of a Ranque–Hilsch vortex tube for optimizing nozzle numbers and diameter

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## HIGHLIGHTS

- Interchangeable parts RHVT to investigate effects of parameters on performance.
- Effect of cold end orifice–nozzle intakes distance, no of nozzles & *D* on performance.
- Cold–hot *T*out, isentropic efficiency & COP are presented.
- Best $P_{oper}$ and cold fraction, on RHVT performance are investigated.
- 2D CFD presented to extrapolate experimental data.

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## ABSTRACT

A brass vortex tube with changeable parts is used to obtain the optimum nozzle intake numbers and diameter. The effects of inlet pressure and CF (cold fraction) are also investigated. Results illustrate that increasing the number of nozzles causes a temperature drop and the optimum nozzle diameter corresponds to quarter of vortex tube diameter. The distance between cold end orifice and nozzle intakes is investigated in this work and it is found that for a better performance, this distance should be decreased. A series of experiments conducted to investigate the CF effect on VT performance and an optimum amount for this parameter is found. A two-dimensional computational fluid dynamics simulation of a VT has been carried out as well. CFD code is applied to investigate the role of nozzle diameter on the temperature separation. The highly rotating flow field structure and its characteristic are simulated and analyzed with respect to various operating inlet pressure ranges and different CFs. Finally, some results of the CFD models are validated by the available experimental data, showing reasonable agreement for future development.



## 1. Introduction

A vortex tube (VT) has one or more tangential inlet compressed gas and two outlets delivering hot and cold gas streams at the ends of the tube. Lack of moving part, makes it an ideal tools for special applications. The inlet nozzles are placed around one end of the tube. A forced field of vortex like flow is established within the central tube which causes a temperature profile along the tube. The temperature of the inner core gas is lower than the incoming feed while the temperature of the outer layer gas is higher. The process of separating the flow into regions of low and high temperature is called energy (or temperature) separation effect. There are two types of VT: the counter-flow type (sometimes called the standard type) and the parallel or uni-flow type.

VT's are selected just because of the cooling capability they have, in welding, blazing, solidifying polymers and controlling air conditioning. Although they are not economic cooling devices, VT's are getting popular applications, because they are small, easy-to-make, maintenance-free and do not need any electrical or chemical power inputs.

Despite its simple geometries, temperature separation in VT is somehow complex. Many theories have been postulated by investigators such as Hilsch [1], Deissler and Perlmutter [2], Ahlborn and Groves [3], Ahlborn and Gorden [4], Gao et al. [5], and Kurosaka [6], to analyze the flow and energy separation effects.

The computational fluid dynamics modeling (CFD) presented in recent efforts aims to explain the basis of the temperature separation effect. Frohlingsdorf and Unger [7] proposed a CFX model for the compressible flow and its turbulent effects. Aljuwayhel et al. [8]

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**Nomenclature**

| | |
|---|---|
| $T$ | gas temperature |
| $e$ | cold fraction ($m_c/m_i$) |
| $D$ | tube inside diameter |
| $L$ | main tube length |
| $m$ | mass flow rate |
| $Q_c$ | cooling power |
| $c_p$ | specific heat capacity |
| $P$ | work power |
| COP | coefficient of performance |
| $COP_{cr}$ | cooler coefficient of performance |
| $R_m$ | specific gas constant |

*Subscripts*

| | |
|---|---|
| $c$ | cold exit |
| $i$ | inlet |
| $h$ | hot exit |
| $s$ | isentropic |

suggested a CFD model to explain the basic processes running the power separation feature. In order to understand the numerical investigation of a vortex tube, Eiamsa-ard and Promvonge [9] applied the finite-volume method all together with a high turbulence flow. Skye et al. [10] made a comparison between the performance predicted by a CFD model and experimental measurements using an available commercial vortex tube.

Effect of number of nozzles, cold end orifice diameter and length to diameter ratio with CFD analysis are presented by Behera et al. [11]. They investigated the VT performance by changing geometrical parameters of a counter-flow Ranque–Hilsch vortex tube (RHVT). Dincer et al. [12] modeled VT by artificial neural networks. Their analysis was conducted in different length to diameter ratio and nozzle numbers.

Aydin and Baki [13] conducted a series of experiments to investigate the effect of VT length (250, 350, 550 and 750 mm), nozzle diameter (5, 6 and 7 mm) and inlet pressure (3, 4 and 5 bar). Saidi and Valipour [14] investigated the effect of nozzle intakes number (3 and 4) and inlet pressure (1, 1.5, 2, 2.5 and 3 bar) by experimental modeling of the vortex tube.

The present study reports series of experimental investigation on the effect of nozzle numbers, nozzle diameters and distance between cold end orifice and inlet intakes within a counter-flow RHVT at various inlet pressures and cold fractions (CF). The CF is the fraction of cold exit to inlet gas flow rate. The work aims to obtain the optimum parameters which are responsible for the best temperature separation in a counter-flow RHVT. In the present work a symmetric numerical investigation of flow and temperature within a counter-flow RHVT by the use of a squeezable Navier–Stokes model is presented and the temperature separation effect in a counter-flow RHVT is reported.

Despite numerous investigations reported above, the present work novelty is the effect of geometry parameters such as distance between cold end orifice and nozzle intakes, nozzle intakes number and diameter on the VT performance. It is also necessary to mention that the design of the vortex tube for this work is such that all parts of the VT are interchangeable. This unique and dominant specification of apparatus provides the ability to investigate the effects of numerous parameters on VT performance simultaneously.

## 2. Experimental set up

An experimental set up (Fig. 1) is developed to investigate the effect of tube geometry, inlet pressure and CF on VT performance. It was designed for studying the temperature difference between cold and hot exit of compressed air. Compressed air from a 0.4 $m^3$ cylindrical vessel with a maximum pressure equal to 600 kPa was supplied by a compressor. The air pressure after passing water and an oil filter was reduced by a regulator to 347.9 kPa.

A brass VT was constructed with dimensions do not changing during the whole sets of experiment as shown in Table 1. The design is in such a way that all parts of the VT are changeable. This unique and dominant specification of this apparatus provides the ability to investigate the effects of numerous parameters on above mentioned VT performance simultaneously.

Experiments were carried out at room temperature (23 °C). The compressed air enters tangentially in the VT, after passing through oil and water droplet filters. Once the VT has reached a thermal equilibrium, different changes can be made to investigate their effect on the VT performance. The inlet pressure of air is controlled by a regulator. The volumetric flow in both exits can be varied by using a conical valve which is located at the hot end of the tube (Fig. 2). When this valve is completely close, there is no hot gas stream and the entire inlet gas, exits from cold side. The temperature, pressure and flow rate at the inlet, hot and cold ends of VT are measured during the experiments.

The air flow rate is measured with a Rotameter (BESTA DK800S-6, Korea) with an uncertainty ±1%. Temperature measurement is

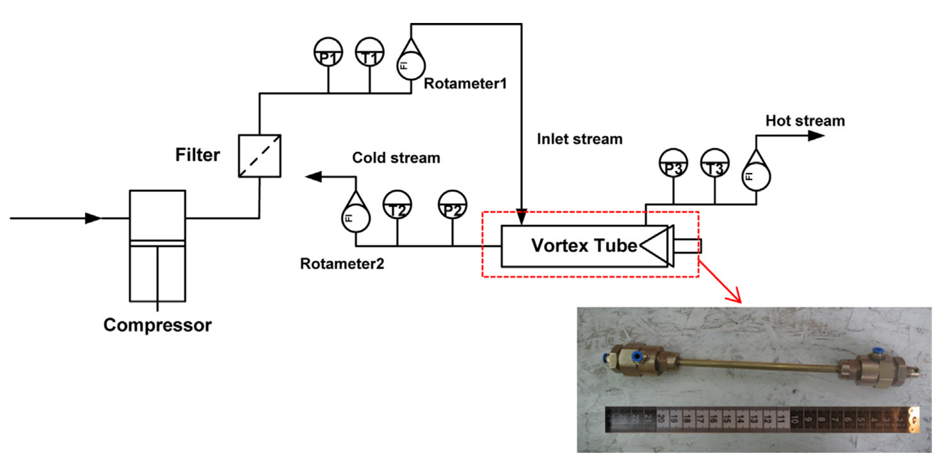


**Fig. 1.** Vortex tube and its experimental set up.