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The effects of nozzle aspect ratio and nozzle number on the performance of the Ranque–Hilsch vortex tube

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HIGHLIGHTS

► The temperature difference is increasing with increasing inlet pressure.
► The performance of the vortex tube decreases with increasing nozzle aspect ratio.
► The single nozzle yields to better performance than the vortex tube with 2 and 3 nozzles.
► The optimum cold mass fraction varies with the change of nozzle number.

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ABSTRACT

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 = 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.

1. Introduction

The vortex tube is a structurally simple device with no moving parts that is capable of separating a high pressure flow into two lower pressure flows with different energies, usually manifested as a difference in temperatures [1]. The typical schematic diagram of a vortex tube is shown in Fig. 1. A source of compressed gas stream enters the vortex tube tangentially through one or more inlet nozzles at a high velocity. The gas stream inside the vortex tube develops a strong swirling flow and it separates into a cold and hot gas stream [2]. Cold gas stream leaves the tube through the central of the vortex generator (cold exit), while hot gas stream at the periphery exhausts out of the other exit (hot exit).

Despite its low efficiency, the simplicity, the low cost and the feature of having no moving parts which translates into no maintenance makes the vortex tube attractive for many low temperature applications such as cooling of CNC machine equipments, plastic injection molds and electronic control cabinets, climate control process, cooling suits, testing temperature sensors, snow production and the other practical applications including amplification of DNA, liquefaction of natural gas, separation of gas mixtures, heating process, drying etc. Recently the vortex tube is also used for the cooling of microelectronic components [3].

Vortex tubes have been examined widely after Hilsch's publication [4] in 1947. Numerous experimental and numerical studies on this topic can be found in the literature, which cover the main influence factors (geometric and thermo-physical) on temperature and flow structure. Readers are referred to see the excellent reviews by Eimsa-ard and Promvonge [5], Yilmaz et al. [6] and Xue et al. [7]. Here, some of the recent experimental studies on temperature separation in the vortex tubes are described as follows:

Saidi and Valipour [8] conducted an extensive experimental study to investigate the effects of geometric and thermo–physical parameters on the cold temperature difference and efficiency of a vortex system. They concluded that the dimensionless tube length and the cold air orifice diameter should be in the range of

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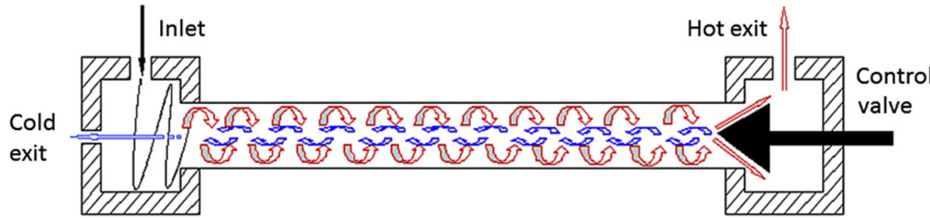

Fig. 1. The flow pattern in a counter-flow vortex tube.

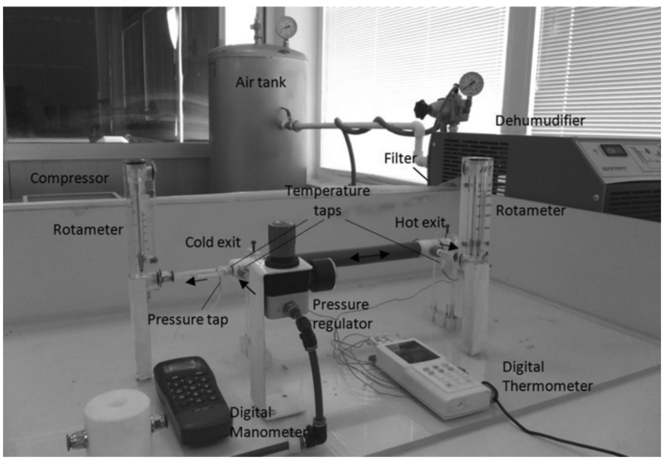

Fig. 2. Photograph of the experimental apparatus.

$20 \leq L/D \leq 55.5$ and equal to 0.5, respectively, for achieving the best thermal performance. They also observed that increasing air moisture content decreases the cold temperature difference and, in turn, the efficiency. Xue and Arjomandi [9] examined the effect of vortex angle on the performance of vortex tube. They observed that the vortex angle played an important role in both the separation of cold and hot streams and the vortex tube performance. Depending on their experimental results, a smaller vortex angle demonstrated a larger temperature difference and better performance for the heating efficiency of the vortex tube, while resulting in better cooling efficiency only at lower values of input pressure. Hamoudi et al. [10] investigated the thermal characteristics of a micro-scale vortex tube at low pressure ranging from 2.5 to 75 kPa. They observed that the optimum cold air mass fraction is not constant and can be higher than the conventional vortex tube while the effects of L/D and dc/D ratios are similar to those in the conventional devices. Dincer et al. [11] investigated the effects of control valve geometry, control valve location and nozzle number on performance of vortex tube under different inlet pressures. Nimbalkar and Muller [12] conducted a series of experiments focusing on various geometries of cold end exit for different inlet pressures and cold fractions. They observed that the cold end exit diameter and the cold fraction significantly influence both the cooling and heating efficiency of the vortex tube. They pointed out that the effect of cold end orifice diameter is negligible for cold fraction $\leq$60% while it becomes prominent above 60%. Kırmacı [13] examined the influence of orifice nozzle number and inlet pressure on heating and cooling performance of vortex tube using air and oxygen as test fluids. His results indicated that the temperature difference between the hot and cold fluid decreases with increasing nozzle number. Eiamsa-ard [14] experimentally studied the energy separation phenomenon effect and cooling

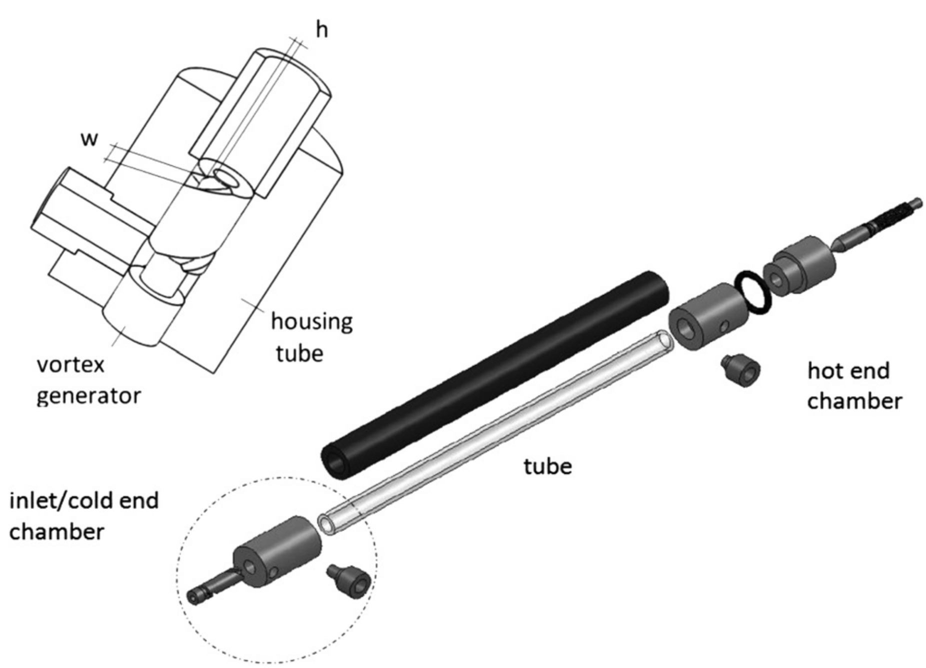

Fig. 3. Schematic view of the vortex tube and vortex chamber.