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Detached eddy simulation of Phase Separation Process in Multi-Drain Ranque–Hilsch Vortex tube

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Abstract

The Vortex-tubes are mostly used for enclosure cooling. The proposed novel idea is manipulating the same device for carrying out the separation of liquid from a gas stream. This paper represents a numerical study on a modified geometry of the common Ranque–Hilsch vortex tube which is driven in both low and high-pressure conditions. The proposed design includes a system of drainage in the middle of the tube, which is used for removing the heavy phase from the main gas stream. Detached eddy simulation (DES) is performed in a three-dimension case study of the novel design of the vortex tube, which helps to evaluate and predict the efficiency of the separation. The phase change happens by a gradual drop in temperature in the inner section of the vortex tube. The liquid layer encounters a ring-type obstacle and flows through the slit. An assessment is carried out focusing on the effect of operational conditions on the vortex tube performance. The simulation results for the case of dehydration efficiency are found to be up to 65%.

Introduction

All previous studies discussed the vortex tube performance in single phase application which is according to its main application and it seems that the usage of vortex tube in multiphase applications are missed in the literature prior to the current research.

The present investigation tried to demonstrate and evaluate the vortex tube performance in case of utilizing a two-phase flow with the potential of phase-separation. The feed includes heavy fraction with the dewpoint within the range of the minimum acquired temperature and the feed temperature. The condensation happens in secondary flow which is flowing toward the cold outlet of the tube. Meanwhile, the liquid phase is moved by the axial velocity and swirling effect to the wall side. The multi-drainage design helps the liquid layer to be removed physically by a ring and a specific drainage considered at the half of the length of the tube. It was found that energy separation and cold side temperature depend mainly on the ratio of cold and hot gas mass flow rates and the inlet conditions. The feed of humid air with 0.05% mass fraction of vapor is considered which is equal to relative humidity of 4% at 10 bar. This low humidity level is selected to show the capability of the separator which is a challenging issue and can be considered as a minimum efficiency of the device. On the other hand, using a feed with higher water content and the corresponding higher dewpoint is much easier for lying down the minimum temperature accessible in vortex tube and condense formation. The minimum temperature of a specific vortex tube is almost fixed and therefore using feed with high water content will give higher efficiency.

The application of this phase separator includes compressed-air drying units, natural gas processing industries, utility plants, and other industrial plants, which includes the challenge of gas drying.

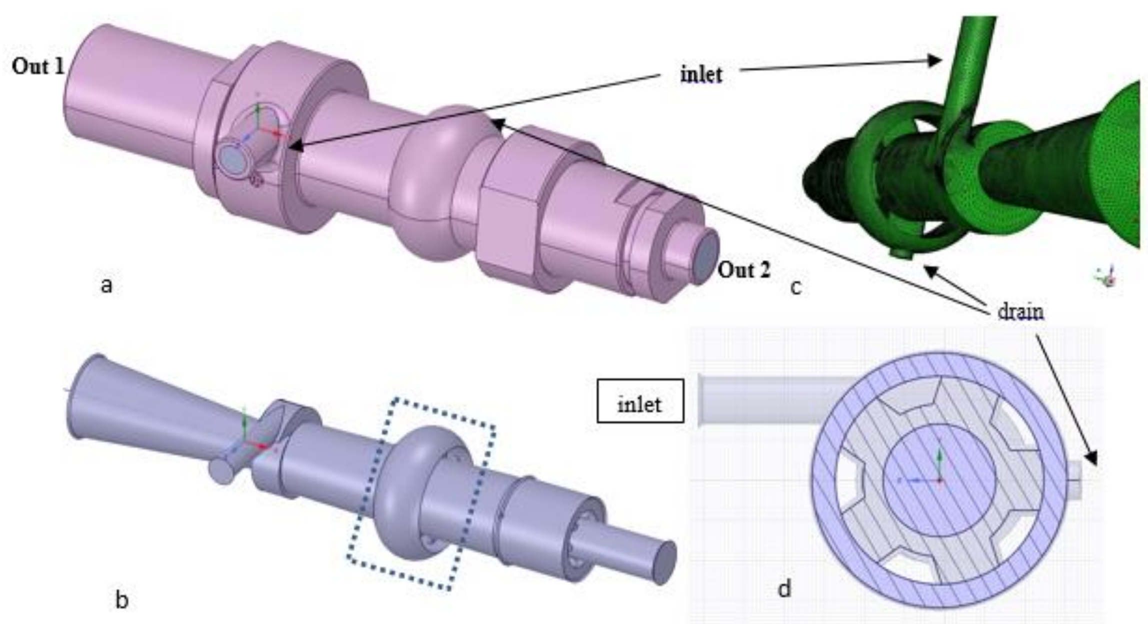

Fig 1. (a) Body of novel vortex tube, (b) computational domain (c) mesh grid sample (d) computational domain at drain section

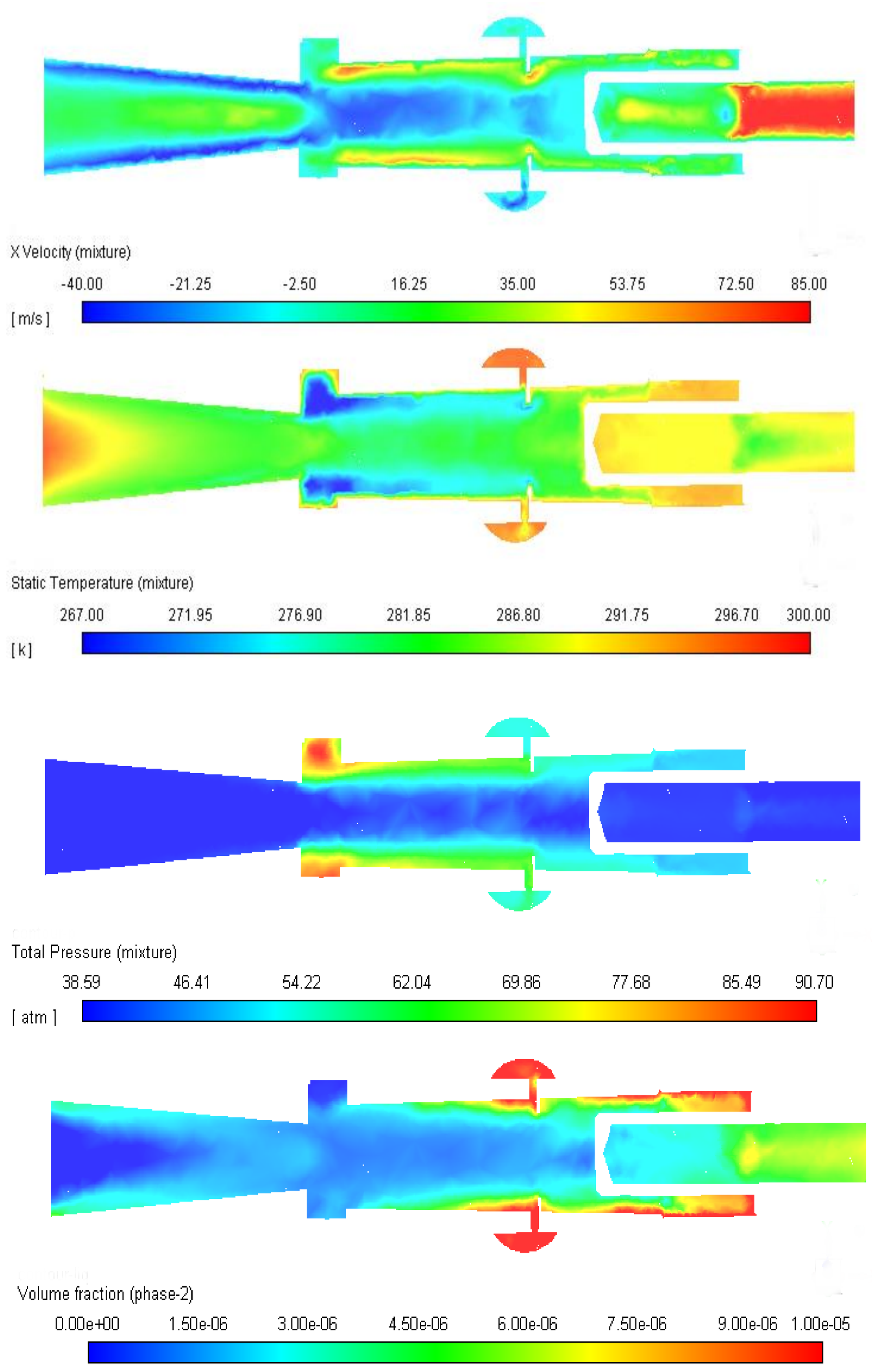

Figure 2: Static temperature (a) and Static Pressure (b) along the modified vortex tube

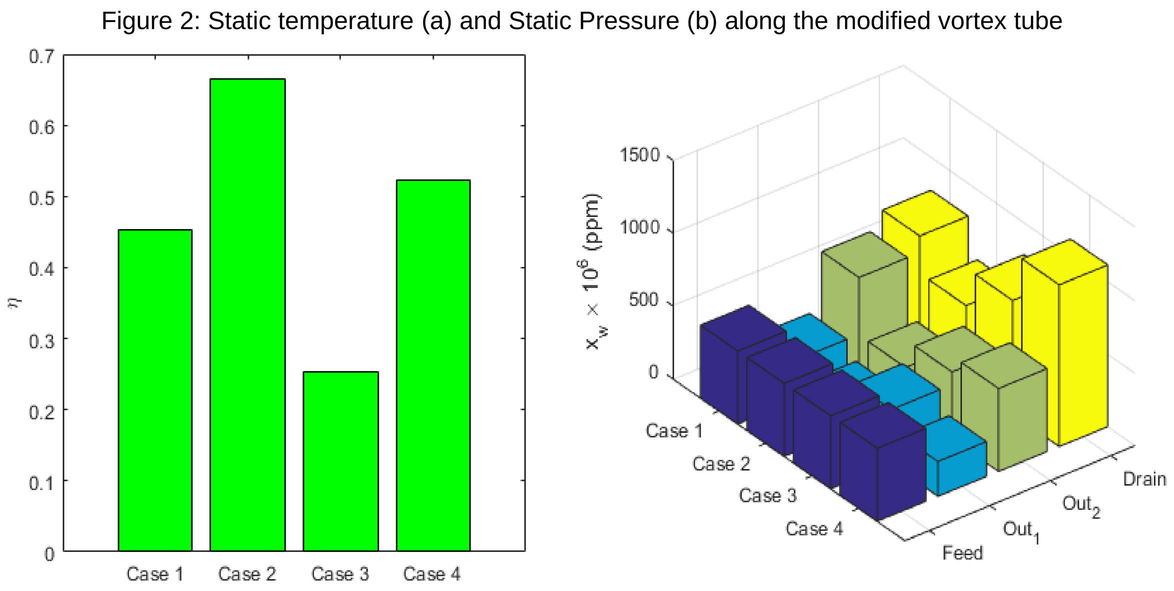

Fig 3. Separation efficiency (a) Water content at inlet & outlets (b).

Table 2. Operation conditions of the vortex tube case studies

Case No	Fluid mixture	P_{in} - $P_{out,1}$ - $P_{out,2}$ – P_{drain} (bar)	T_{in} (K)
1	Air-H_2O (0.05%)	100-60-60-40	300
2	CH_4-H_2O (0.05%)	100-60-60-40	300
3	Air-H_2O (0.05%)	10-6-6-4	300
4	CH_4-H_2O (0.05%)	10-6-6-4	300

Results & Discussion

A DES 3D approach was carried out through ANSYS Fluent to simulate the phenomena of energy separation, temperature, and velocity gradients, and to evaluate the applied turbulence models. Temperature, pressure, velocity, and volume fraction profiles were extracted through hybrid LES-RANS simulation. Fig 2. (d) Shows the key achievement of the simulation, as represents the volume fraction distribution along the tube. The delicate liquid layer lies upon the inner surface of the tube, which is the same as the expectations, according to the vortex tube working principle. The liquid formation happens in internal cold flow and then it moves towards the walls due to the swirling flows and the subsequent axial velocity. The liquid fraction contour revealed the performance of the novel design to physically removing the liquid and let the liquid to be gathered through the multi drainage system.

The water content of the inlet and outlets of the vortex tube and the consequently achieved efficiency are shown in Fig 3 (a) & (b) respectively. The main goal of the device is phase separation and the consequent separation efficiency (η) can be estimated by comparing the water content of inlet and outlet streams.

$$m_0 x_{w0} = m_1 x_{w1} + m_2 x_{w2} + m_d x_{wd}$$

$$\eta = (m_d x_{wd})/(m_0 x_{w0})$$

It was found that the water content and the pressure are the prime parameters affecting the efficiency. Higher feed pressure and more water content both contribute to a higher partial pressure of the water vapor and higher dew point temperature, which makes the condensation more likely to happen. On the other hand, the effect of the gas type is significant as well in the present study, where the separation efficiency for C_1-H_2O is 20~30% higher than for Air-H_2O mixture. It is due to the difference of specific heat and thermal conductivity [7] of the fluid and the related effect on the dew point temperature.

Conclusions

Multi-Drain design for phase separation was evaluated in this study, which highlighted the potential and the challenges of using vortex tube as a phase separator or as a dehydration unit. The application of the vortex tube for phase separation is a new research area and the dehydration potential was estimated up to 65%, which is comparable to other common approaches. Moreover, using the vortex tube in industries can contribute to save cost and space occupancy, while not requiring any additional electric power. The feed pressure and the fluid type are key parameters affecting the separation performance. Higher efficiency was found in high-pressure operations. Humid Methane and humid air mixtures were compared and a better efficiency was found for the humid methane feed. The calculations showed that the high-pressure methane feed has the highest efficiency.

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