ICCFD10-340

ICCFD10
INTERNATIONAL CONFERENCE ON
COMPUTATIONAL FLUID DYNAMICS

Numerical Analysis of Phase Separation in Curved Ranque–Hilsch Vortex tube

Pouriya H. Niknam*, Saman Farhangdoust**, Mashallah Rezakazemi***
* Chemistry & Chemical Engineering Research Center of Iran
** Louisiana Tech University, Materials & Infrastructure Systems Engineering Department
*** Shahrood University of Technology, Faculty of Chemical and Materials Engineering

UNIVERSITÀ DEGLI STUDI FIRENZE

CCERCI

Abstract

The phase separation characteristic in a novel vortex tube using a turbulence model is discussed in the present research. The curved geometry of the introduced vortex tube contributes to an effective phase separation by liquid removal enhancement. The hydrodynamic behavior of the proposed vortex tube is investigated in different inlet boundary conditions by a 3D CFD model. The BSL k-ω turbulence model is utilized which is suitable for the complex flow pattern through vortex tube. Meanwhile, the liquid phase is moved by the axial velocity and by swirling effect to the wall side. The curvature 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. The results show that the efficiency of curved vortex tube is predicted up to 60% for the extraction of the heavy fraction.

Introduction

A common vortex tube produces hot and cold streams simultaneously from a source of compressed gas entering tangentially via nozzles. The pressure of the inlet is about 5 to 7 bar and the pressure of both outlets are about the atmospheric condition. One of the streams has a higher temperature than the inlet compressed gas, while the other one has a lower temperature; this phenomenon is called the Ranque-Hilsch effect, or the thermal separation effect [1,2].

In the present study, the cooling feature of the vortex tube is utilized for phase separation of the gas stream with condensate content. A novel modification is applied to the geometry to achieve the phase separation. The application of this phase separator includes utility units and natural gas processing industries, utility plants, and other industrial plants, which includes the challenge of gas drying.

Methods and Materials

The key modifications which are applied on a common vortex tube are shown in Fig. 1 (a) & (b). The axis of the vortex tube is bent to form a curved tube. In addition, a single drain line is connected to the curvature to accomplish the liquid removal duty. A 360° ring is considered right after the drain connection position inside the main tube, which can be found in all contours of Fig 2 and Fig 3. The Flow filed are shown in Fig.1 (c) with the streamlines flowing toward outlets 1 & 2. The radius and the velocity direction of the flow fields are different which are shown in fig.1 (c) and (d). The internal flow comes out from out 1 while the outer flow exit from out 2 in opposite direction. The velocity encounters from three components of tangential velocity (V_θ), radial velocity (V_r) and axial velocity ⟦(V⟧_ax) which are illustrated in Fig 1 (d).

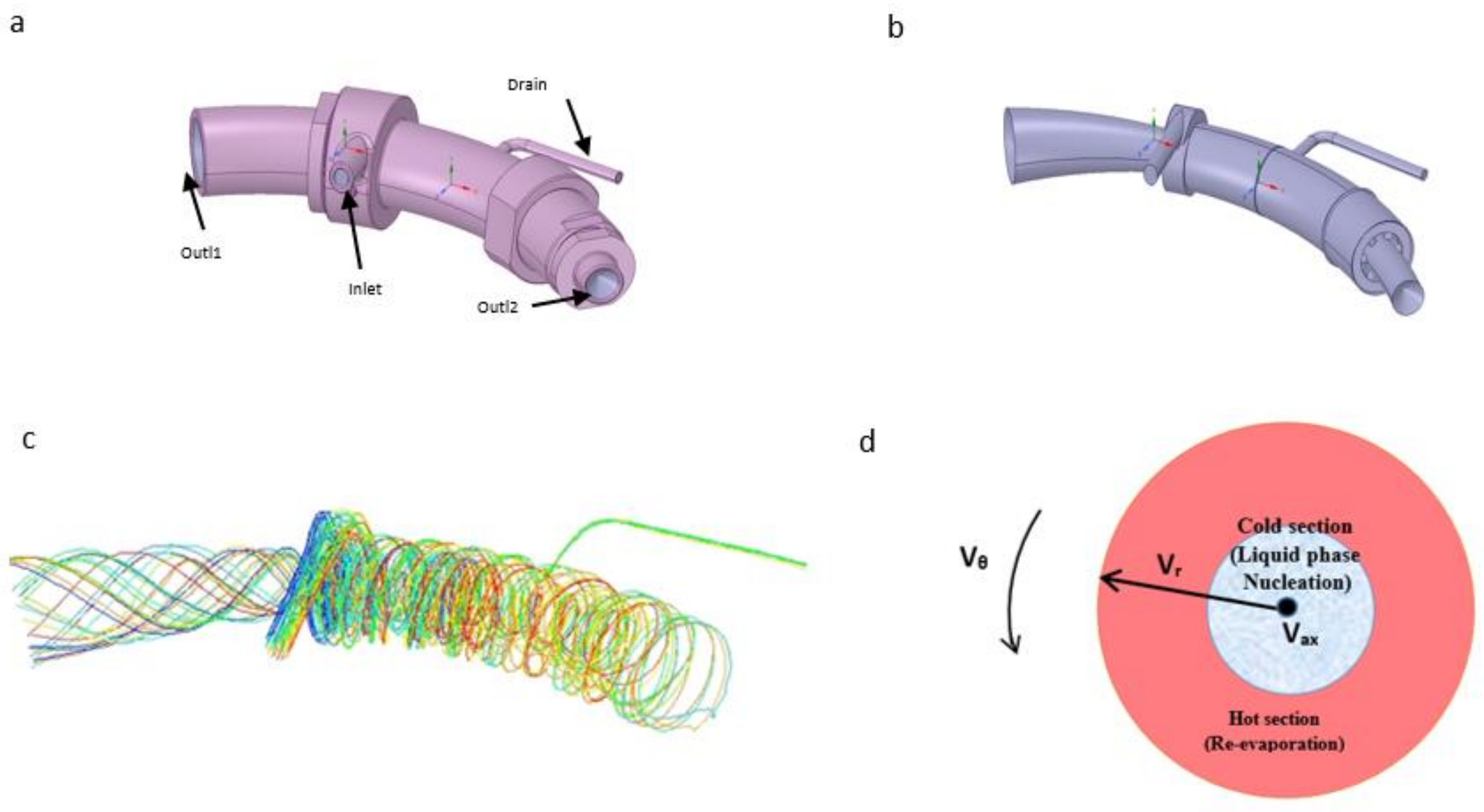

Figure 1: (a) body of curved vortex tube, (b) computational domain, (c) flow fields, (d) gas path lines

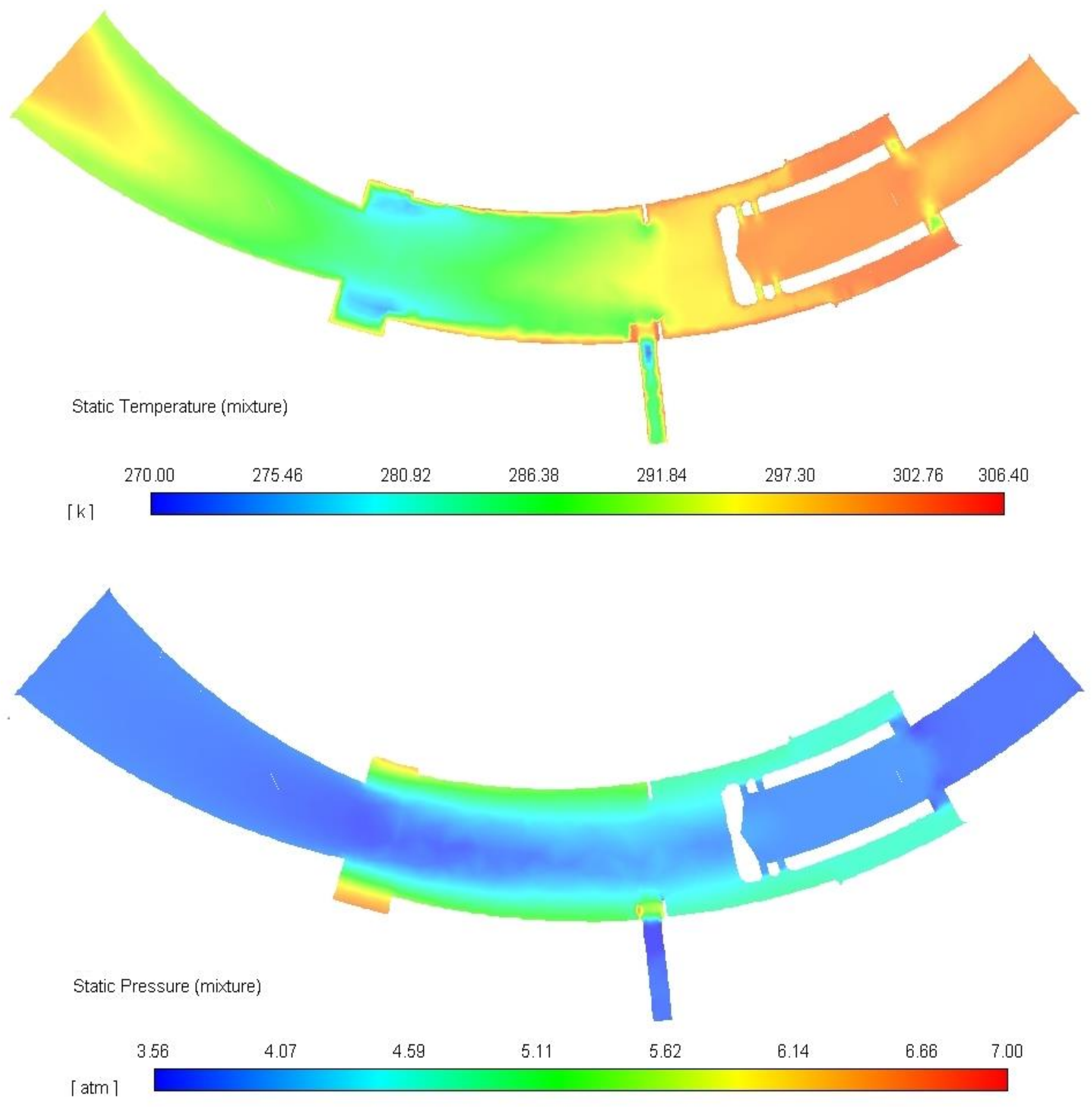

Figure 2: Static temperature (a) and Static Pressure (b) along the modified vortex tube

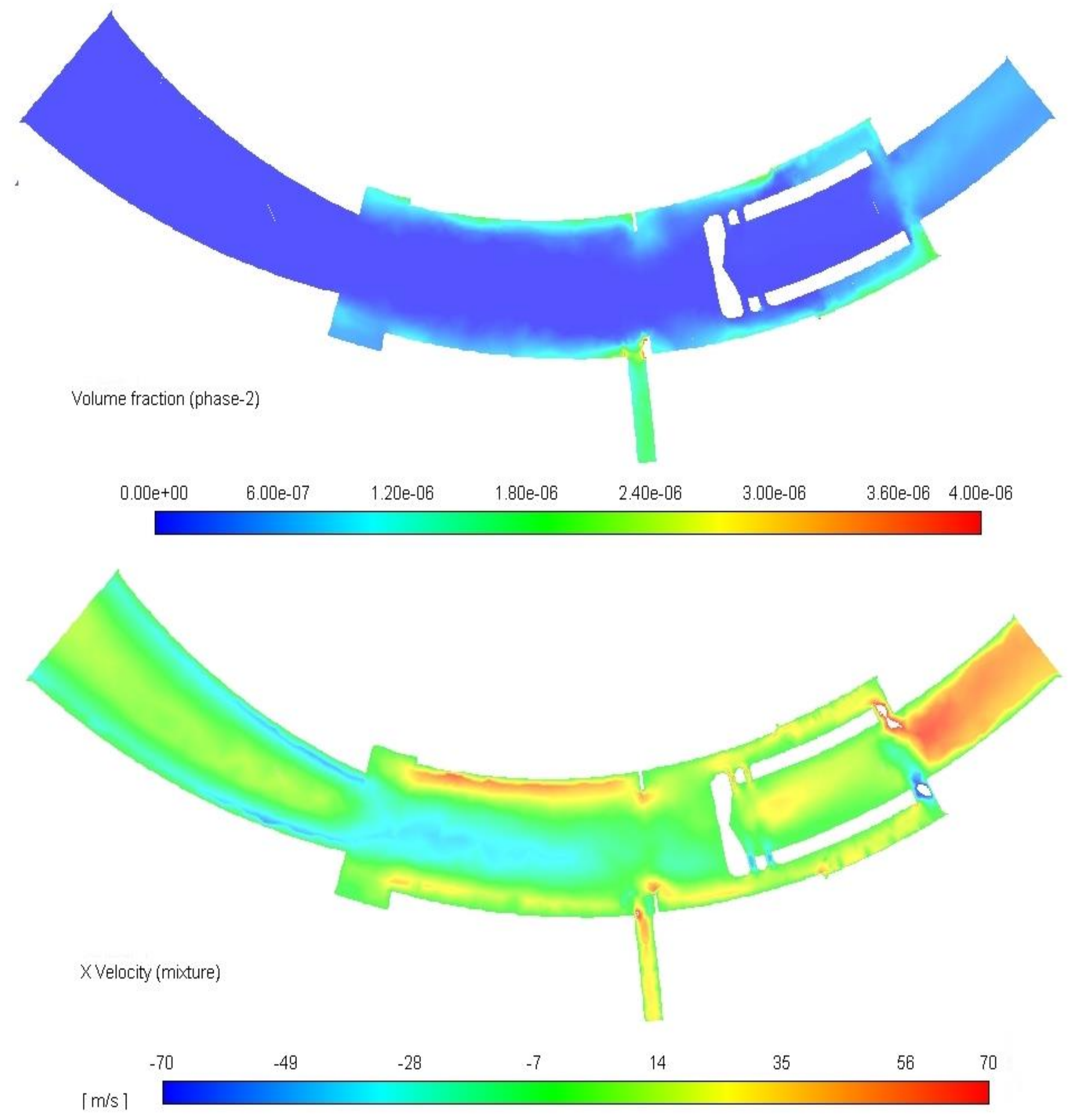

Figure 3: Liquid volume fraction (a) and axial Velocity (b) profile along the modified vortex tube

Table 1: Boundary condition of Air-H_2O feed

Case No	$\frac{P_1}{P_{in}}$	$\frac{P_2}{P_{in}}$	$\frac{P_d}{P_{in}}$	$x_{w,in}$ (%)	P_{in} (bar)	T_{in} (K)	m_{in} (kg/s)
1	0.4	0.4	0.4	0.5	10	300	0.194
2	0.5	0.4	0.4	0.5	10	300	0.194
3	0.4	0.5	0.4	0.5	10	300	0.194

Results & Discussion

The proposed geometry has a side outlet, which makes the role of the liquid trap. The highlight feature is that it removes the liquid phase with the minimum effect on the main gas stream. Moreover, the curved structure, as shown in Fig 1.a and b, of the main tube enhance the liquid removal of the whole system. Strong swirling flows with a high order of tangential velocity in countercurrent flows contribute to conduct a source-to-sink energy transport in which the primary peripheral flow is the sink and the secondary (inner) flow is the source. The condensation happens in secondary flow, which is flowing toward the cold outlet (out1) of the tube.

The cooling of internal stream contributes to the liquid phase nucleation. The nucleation is conditionally happening only if the dewpoint is within the range of the minimum acquired temperature within the vortex tube and the feed temperature. Then, the liquid droplets move toward the walls meanwhile crossing the hot section, as shown in Fig. 1 (d), in which the liquid is partly involved re-evaporation. However, the most part of the liquid reaches the wall, which is shown in fig 3 (a). The corresponding countercurrent flows is revealed in Fig. 3(b).

The feed of humid air with 0.5% fraction of vapour is considered in the simulation for determining the flow, pressure, temperature and liquid phase profile inside the proposed vortex tube computational domain. The final result of phase separation is summarized in Table 2 which includes the mass balance of the outlets and the relative water content of the outlet No. 1 which the main dry product of the device. It is revealed that the case 2 has the highest drying efficiency while the flow of the dry gas is minimized. Therefore, the overall efficiency depends on the application and a balance between the dry gas quality and dry gas flow should be maintained by changing pressure conditions

Table 2: Mass balance and water removal results

Case No	$\frac{m_{w,1}}{m_{w,in}}$	$\frac{m_{w,2}}{m_{w,in}}$	$\frac{m_{w,d}}{m_{w,in}}$	$\eta\ (\frac{x_{w,1}}{x_{w,in}})$
1	0.353	0.514	0.133	0.50
2	0.156	0.710	0.134	0.40
3	0.360	0.470	0.130	0.64

Conclusions

This study highlighted the potential and the challenges of using vortex tube to be used as a phase separator. To improve separation and liquid phase collection performance, a novel curved geometry has been employed for the vortex tube. In the future study, a three-dimensional CFD approach is utilized to investigate the energy and phase separation of the apparatus. The results show that the curved vortex tube has a remarkable capability for the extraction of the heavy fraction and the condensate content of the output can be decreased up to 40% of the feed condensate content.

Contact

Pouriya H Niknam, PhD of Chemical engineering
Email: pouriya.niknam@unifi.it, pniknam@ccerci.ac.ir

References

[1] Rattanongphisat, W., & Thungthong, K. Improvement vortex cooling capacity by reducing hot tube surface temperature: Experiment. Energy Procedia, 52, 1-9, 2014.
[1] Abulencia, J. P. and Theodore, L. Flow Mechanisms. Fluid Flow for the Practicing Chemical Engineer, John Wiley & Sons, Inc., Hoboken, NJ, USA, 2010.
[2] Aljuwayhel, N.F., Nellis G.F. Parametric and internal study of the vortex tube using a CFD model. Int. J. of Refrigeration 28(3), 442–450, 2005.
[3] Behera, U., Paul, P.J., Kasthurirengan, S., Karunanithi, R., Ram, S.N., Dinesh, K., Jacob, S. Star CD CFD analysis and experimental investigations towards optimizing the parameters of Ranque-Hilsch vortex tube. Int. J. of Heat and Mass Transfe 48(10), 1961–1973, 2005.
[4] Baghdad, M., Ouadha, A., Imine, O., Addad, Y. Numerical study of energy separation in a vortex tube with different RANS models. Int. J. of Thermal Sciences 50, 2377–2385, 2011.
[5] Bovand, M., Valipour,M.S., Eiamsa-ard, S., Tamayol, A. Numerical analysis for curved vortex tube optimization. Int. Communications in Heat and Mass Transfer 50, 98 –107, 2014.
[6] Niknam, P. H., Mortaheb, H. R., & Mokhtarani, B. Numerical Investigation of a Ranque–Hilsch Vortex Tube using a Three-Equation Turbulence Model. Chemical Engineering Communications, 204(3), 327-336, 2017
[7] Farhangdoust, S., Mehrabi, A.B., Mowsavi, S.F.A., NDT Methods Applicable to Health Monitoring of ABC Closure Joints, 27th Research Symposium - The American Society for Non-destructive Testing (ASNT), Orlando, Fl, 26-29 March 2018.
[8] Menter, F. R. Two-equation eddy-viscosity turbulence models for engineering applications. AIAA journal, 32(8), 1598-1605, 1994.
[9] Niknam, P. H., Mortaheb, H. R., Mokhtarani, B. Dehydration of low-pressure gas using supersonic separation: Experimental investigation and CFD analysis. Journal of Natural Gas Science and Engineering 52, 202-214, 2018.