ABSTRACT

The complex phenomenon of energy/temperature separation in vortex tube (VT) was investigated by several researchers through experimental, analytical and numerical studies. However, due to the complexity of the flow structure in the tube, the mechanism of energy separation has not been fully understood so far. In this work, extensive experimental and numerical investigations of energy and species separation in VT are carried out. Experimental results are obtained for various geometric and operating parameters to determine the optimum geometry of CFVT and operating conditions for maximum temperature separation. Cold orifice diameter, number of inlet nozzles, length to diameter ratio, hot mass fraction and the inlet pressure are found to be the parameters greatly influencing the temperature separation. Low values of isentropic efficiency, COP_R and COP_{HP}, obtained from the experimental results suggest that VT is not an efficient device for use as a refrigerator or a heat pump. An axisymmetric CFD analysis of the CFVT is carried out by using standard $\kappa - \varepsilon$, RNG $\kappa - \varepsilon$, standard $\kappa - \omega$ and SST $\kappa - \omega$ turbulence models to investigate the effectiveness of these turbulence models in predicting the energy separation. It is observed that the temperature separation mechanism remains same for all four turbulence models. Temperature separations predicted by the standard $\kappa - \varepsilon$ model are closer to the experimental data compared to those predicted by the other models. The 3D CFD analysis of the CFVT, where NIST real gas model is used for the first time to accurately compute the thermodynamic and transport properties of air inside the VT, is carried out to study the temperature separation as well as the separation of species of gas-phase air in the VT at normal atmospheric temperature and cryogenic temperature. Temperature separations predicted by the real gas model are found to be little closer to the experimental data compared to the same predicted by ideal gas law. Magnitude of temperature separation at cryogenic temperature is observed to be much lower than that at atmospheric temperature. Separation of gaseous air into its main constituents, oxygen and nitrogen, in the VT is observed at both atmospheric and cryogenic temperature with very small difference in oxygen mass fraction between the hot and the cold outlets. Soret diffusion is found to play a major role in species separation in VT, besides density difference between gaseous oxygen and nitrogen. In both axisymmetric and three dimensional CFD model the transfer of the tangential shear work from the inner to the peripheral region of the VT is found to be the major cause of energy separation. This observation is made by varying the geometrical and operating parameters as well. Comparison of the results of experimental and numerical investigation of the CFVT and UFVT clearly shows that sensible heat transfer from the peripheral to the inner fluid layers reduces the energy separation in UFVT.

Keywords: Ranque-Hilsch vortex tube; Energy separation; Experimental investigation; CFD model; Real gas model.