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Abstract

Doctor of Philosophy

Analysis of Ejector Expansion Transcritical R-744 Refrigeration Cycles Using Thermodynamics and CFD Based Investigations

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In this thesis, we use the techniques of thermodynamic modeling, namely, the energy analysis and the exergy analysis, to analyze the performance of various R-744 transcritical refrigeration cycles. We first analyze the performance of the basic ejector expansion transcritical cycle. Afterwards, we analyze the various modifications of the basic cycle like inclusion of internal heat exchangers, multiple compressors, multiple intercoolers, multiple ejectors etc. We analyze the impact of these modifications on the coefficient of performance (COP) and the second law efficiency of the cycle, on the pressure recovery, entrainment ratio and the vapor quality etc. inside the ejector. The performance of the multi compressor ejector expansion R-744 transcritical refrigeration cycle (MCEETRC) is found better compared to other cycles for all evaporator temperatures. Pressure recovery is observed to be higher in cycles without internal heat exchangers (IHX) compared to those with IHX. MCEETRC+IHX shows the highest COP among all the cycles for operation up to 40°C while the relative advantage of MCEETRC+IHX is somewhat lost to the multi compressor multi-intercooler ejector expansion R-744 transcritical refrigeration cycle (MCMIEETRC) for operation at temperature greater than 40°C.

Since an ejector is the most important component of any such cycle operating in high ambient temperature conditions, the phase change process occurring inside it affects the overall cycle efficiency. Therefore, we investigate the phase change process of R-744 inside an ejector geometry using the homogeneous equilibrium model and the non-equilibrium condensation model based on the classical nucleation theory. We observe better results with the Span-Wagner equation of state for R-744 from NIST Refprop compared to those obtained with the Redlich-Kwong equation of state in Ansys CFX. For the phase change process inside the ejector, we observe very high droplet nucleation rate ($\sim 10^{33}$ nucleation per m^3 per second) around the throat of the motive nozzle. Condensation of R-744 starts from this region and then the liquid droplets are advected downstream in the diverging portion of the motive nozzle and ejector mixing section. Droplets of size $\sim 10^{-8}$ m and number densities of $\sim 10^{23}$ per m^3 prevail in most of the motive, mixing and diffuser sections under steady state condition. A maximum supercooling level of 1.1 K is observed inside the ejector. The work performed in this thesis will be useful to the engineering community involved in the design and fabrication of CO_2 based refrigeration systems.