Abstract

The refrigeration and air-conditioning industry is in an unprecedented transition phase, caused by environmental concerns with the impacts of refrigerant emission. To combat the twin menace of ozone layer depletion and global warming caused by synthetic refrigerants, there is increasing interest in technology, based on the environmentally safe refrigerants. Instead of looking for new chemicals, use of natural refrigerants is ecologically safe. CO_2 is one of the natural refrigerants which was used earlier and has witnessed a recent revival as a strong contender. Being a low critical temperature refrigerant, CO_2 cycle systems operate in transcritical mode where condenser gets replaced by a gas cooler. Availability of large temperature glide in gas cooler makes the CO_2 system effective and efficient for simultaneous cooling and heating application where high-side pressure is controlled by the throttle valve. However, capillary tube can be an option to control the high side pressure. In a transcritical CO_2 cycle, employing a capillary tube is quite a different proposition than in subcritical cycles due to the unique thermodynamic properties of CO_2.

The main objective of this research work was to carry out theoretical and experimental study on capillary tube flow including flow characteristics and performance evaluation of adiabatic and non-adiabatic capillary tubes in a transcritical CO_2 heat pump system for simultaneous heating and cooling applications. First, optimization of two-stage transcritical CO_2 heat pump employing several options has been presented. Staging not only brings down the optimum gas cooler pressure but there exists an optimum intermediate pressure as well yielding a maximum system COP which is not quite the value predicted by the classical estimate of the geometric mean between gas cooler and evaporator pressure. Among the several options analysed, the flash gas bypass system appears to yield the best performance. However, the flash intercooling system does not show any performance improvement.

Detailed analysis and evaluation of the capillary tube as an expansion device option for the transcritical CO_2 system was carried out next. Analysis of adiabatic capillary tube flow indicates that flow characteristics and friction factor are unaffected by the choice of viscosity model unlike that in case of conventional refrigerants such as R22 and R134a. For a given capillary tube, there is an optimum evaporator temperature that yields maximum cooling capacity. Capillary tube length rapidly decreases, almost exponentially, with increase in refrigerant mass flow rate. The non-adiabatic model explored a capillary tube-suction line

heat exchanger (CL-SLHX) option for the heat pump system where frictional pressure drop dominates the heat transfer which result minor possibility of re-condensation. Relatively it is more beneficial to form the CL-SLHX in the supercritical region. The transcritical nature of CO_2 where pressure and temperature are independent, makes heat transfer rate profile with respect to gas cooler temperature dissimilar to that for traditional refrigerants and is influenced by initial quality, refrigerant mass flow rate and the temperature difference at the gas cooler.

The simulation of a CO_2 heat pump system for simultaneous heating and cooling applications employing capillary tube as an expansion device reveals that there is an optimal length of capillary tube for a given diameter at which the heat pump runs optimally and the system is evidently quite flexible regarding changes in ambient temperature. Employing a capillary tube improves the exergetic efficiency by about 23% over that of a controllable expansion valve based heat pump for similar operating and design conditions. An exergy flow diagram is presented which shows that the compressor contributes the maximum share while the evaporator contributes the minimum to system irreversibility. A novel nomogram has been developed which is expected to help design the system with ease.

Finally a test rig was developed to evaluate the prototype experimentally. Experimental studies reveal that with a fixed charge condition and a chosen capillary tube, gas cooler pressure increases rapidly with water inlet temperature and mass flow rate in the gas cooler and strive for optimum condition. Effect of water flow rate on system performance is modest. There is an optimum refrigerant charge at which the system yields the maximum COP. Performance deterioration is more severe at under charged state than at over charged condition. Fairly good agreement was observed between predicted and measured values of capillary tube parameters. In conclusion, it is clear that the capillary tube still can be a good option for small capacity transcritical CO_2 systems with optimal operation.