CHAPTER 7

Conclusions and scope of future work

7.1 Conclusions

The overall conclusions based on the experimental as well as theoretical investigations carried out on CO_2 trans-critical refrigeration system are summarized below.

- Use of IHX contributes to reduction in mass flow rate. The maximum reduction of mass flow rate in IHX recorded in our experiment is 11.2%.
- The effectiveness of IHX increase with decrease in compressor discharge pressure and evaporator pressure. The effectiveness of IHX recorded in our experiment lies within range 38% to 52%.
- Adoption of IHX leads to substantial rise in compressor discharge temperature. The maximum rise in compressor discharge temperature recorded for IHX cycle in our experiment is about 24°C for 45°C ambient temperature.
- Use of IHX contribute towards improvement of COP and exergy efficiency. The maximum improvement in COP and exergetic efficiency of IHX cycle recorded are 5.70% and 5.05% respectively.
- Approach temperature is found comparatively lower for IHX cycle, especially at extreme high ambient conditions.
- Air velocity over gas cooler, driven by fan and power consumption, thereof is found to be a significant parameter. Lower air speed near 1 $m \cdot s^{-1}$ is found to be optimum.
- Irreversibility contribution of various components of the refrigeration cycle are determined. Contribution of gas cooler followed by compressor and expansion valve are found significant at lower ambient temperature. While, at higher ambient, expansion valve

followed by compressor and gas cooler are found to contribute maximum towards system irreversibility. IHX is found to have least contribution towards exergy loss of the cycle.

- The mean relative error of prediction from the physics-based model is found to be within ±10% while the same for experimental input output data-based ANN model is found to be within ±1%.
- The trained and validated ANN model is utilized to investigate the effect of change of input parameters on COP to optimize its performance. A possibility of 5.31% improvement in COP is predicted based on the optimization of parameters, which can be established with an automated control system.

The conclusion related to investigation carried out on application of CO_2 in supermarket refrigeration are as follows:

- Work recovery expander is found to have higher share in performance improvement of booster configuration, followed by parallel compression. With regard to twin-staging booster configuration, flash gas inter-cooling configuration performs better in relatively colder climate while parallel compression followed by flash gas bypass system have better energy efficiency in warmer region.
- The lowest operating gas cooler pressure is observed for configuration with work recovery and parallel compression. The difference in COP for system with and without flooded evaporator eventually decrease with increase in ambient temperature.
- The maximum savings for booster configuration with work recovery expander and parallel compression over and above the standard booster configuration is 22.16%, 15.2%, 20.06% and 16.8% when operated in New Delhi, Seville, Phoenix and Teheran for year-round operation.
- The additional investment recovery time shows a non-linear trend with respect to local tariff for an isentropic efficiency. The slope of recovery time is steeper at lower tariff.

- Indirect/cascade configurations exhibit superior performance when operated in climate of Delhi and Phoenix. While the performance of booster configuration equipped with parallel compressor is found better when operated in cold or mild climate of Seville and Tabriz.
- The investigation on integrated refrigeration system reveals that the proposed NH_3/CO_2 cascaded booster configuration is better compared to multi-jet ejector configuration while operating in extreme warm climate.
- In extreme warm climate, the energy efficiency of the NH_3/CO_2 cascaded booster configuration exceeds that of CO_2 multi-jet ejector configuration by a maximum of about 12.23% and the total emissions are lower by up to 11.20%. CO_2 multi-jet ejector configuration performs better in cold and mild climate.
- The heating COP for the stand-alone system is found higher by a maximum of 31.1% to that of the integrated configurations, while the COP for A/C is found higher for integrated cascaded booster configuration by a maximum of 36.4%.

The work presented is expected to help adoption of natural refrigerants such as CO_2 and NH_3 for commercial application in extreme warm climate conditions prevailing in many cities of Middle East and India.

7.2 Scope of future work

- Experimental evaluation of effectiveness of various modifications for performance improvement at high ambient.
- Exploration of relevance of extrapolation using ANN model to optimise the cycle performance at operating conditions which are difficult to achieve during experimentation, such as operating the system above 11 MPa.

- Investigation of possible improvements in control strategy to enhance the heating COP and to reduce the amount of auxiliary power used in cases where heating load is greater than refrigeration load such as at low ambient temperature.
- Explore strategies to improve efficiency of CO_2 parallel compressors to achieve higher efficiency of integrated system, especially for cases where air conditioning load is higher than refrigeration loads.
- Explore adoption of ejectors while heat recovery is underway with a suitable control strategy.
- Explore adoption of ejectors in the cascade configuration where the upper and lower limit of ejector operation would be fixed, promoting better ejector efficiencies.