Transcritical and Cascade Systems for Natural Refrigerants: Recent Developments

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ABSTRACT

The compulsion to attain holistic environmental safety has facilitated the recent emergence of natural refrigerants as the more benign working fluid in refrigeration and heating systems. This paper presents the new working fluids and associated technologies, with a focus on the studies conducted in the Refrigeration Laboratory of the Department of Mechanical Engineering at IIT Kharagpur.

While ammonia has been around for many years, carbon dioxide has re-emerged as a feasible green solution, although necessitating a transcritical operation characterized by extremely high pressure conditions. Being a natural substance and also inheriting excellent heat transfer properties, carbon dioxide has the potential to offer itself as a long term substitute. Detailed numerical modelling and design optimizations, including heat transfer and fluid flow effects, have led to development of a prototype system which provides simultaneous heating and cooling having either a controlled valve or a capillary tube as the expansion device. The transcritical operation leads to the existence of an optimal compressor discharge pressure which becomes a necessity unlike the conventional sub-critical systems. Pioneering analyses of adiabatic and non-adiabatic capillary tube based systems have revealed that capillary tubes can be a viable solution in smaller CO_2 based heat pump systems; this effectively addresses the existing scepticism overemphasising the need for a throttle valve to control the optimum discharge pressure. Homogeneous and separated flow models were employed to ascertain their suitability for the two-phase flow in transcritical capillary tubes. Optimization of effective distribution of total heat exchanger area ratio between gas cooler and evaporator was undertaken as well. System behaviour and performance of the system have been studied

experimentally for various operating parameters such as system pressure, water mass flow rate, water inlet temperature and expansion valve opening.

With a striking similarity in properties with CO_2, N_2O appears to be an attractive choice as well having nearly similar behaviour with respect to system temperature, pressure, compactness and properties. While CO_2 based systems have already gained large acceptance, N_2O still remains mostly unexplored. However, N_2O, due to its lower triple point temperature, can be used in the region below the application range of CO_2.

Cascade systems based on natural refrigerants have also been looked into lately. Analysis of an endoreversible system has been implemented and optimum intermediate temperature for maximum exergy and refrigeration effect have been obtained. In a novel attempt, a CO_2–propane cascade system has been numerically simulated comprehensively incorporating precision property routines for the working fluids and this numerical model subsequently has been employed for validation of the proposed analytical model. It further explores the optimum allocation of heat exchanger inventories in cascade refrigeration cycles for the maximization of performance and minimization of system cost. Re-emergence of CO_2-NH_3 cascade systems have also been observed in the industry in recent times. Novel CO_2-N_2O cascade systems have been proposed along with thermodynamic design and optimization study results.

Recent research and accompanying industrial prototypes clearly indicate that several natural refrigerants can be the green solution in the form of transcritical and cascade systems employing appropriate design optimization and related analyses. Several manufacturers have come forward lately with equipment solutions for such systems.