# Abstract

Carbon dioxide ($CO_2$, R-744) is a safe, environment friendly, natural refrigerant and has excellent thermo-physical properties and material compatibility. However, due to low critical temperature (31.1°C), $CO_2$ based vapour compression refrigeration and air-conditioning systems operate in transcritical cycle mode in high heat sink ambient temperature. In transcritical cycle, heat rejection takes place in supercritical zone, while heat extraction occurs in subcritical zone. But, due to diurnal and/or seasonal variation in ambient temperature, it may so happen that same $CO_2$ system may have to operate in sub- and transcritical mode around critical point. In either case, system performance must be maximized by optimizing the high-side/heat rejection pressure. Moreover, by controlling the transition (transcritical to subcritical or vice-versa) of cycle with the help of certain operating parameters (refrigerant charge, gas cooler air flow rate), both heating and cooling effect can be obtained in low ambient temperature. However, detailed literature survey shows that studies related to these topics are scarce and hence forms the basis of current research work.

In the current study, a $CO_2$ based air-conditioning unit designed and developed for 3.5 kW of cooling capacity at 35°C of ambient temperature is studied experimentally and numerically in winter season (15-21°C of ambient temperature). Experimentally, $CO_2$ unit found to operate near critical point in sub- and transcritical mode. Further, experimentally it is shown that by controlling the gas cooler/condenser air flow rate, transition of the system can be controlled to avail both cooling and heating in winter. This can be be used to develop suitable control strategies to control the transition of the cycle. Moreover, it is shown numerically that 1100 gm of charge is lower limit to run the system in transcritical mode at 17°C. Lower charge values than 1100 gm will turn the cycle in subcritical mode at 17°C. Further, a optimum high-side pressure equation is developed which is applicable for both sub- and transcritical refrigeration cycles. Moreover, performance of the system for simultaneous space heating and cooling is maximized by controlling high-side pressure with the help of developed optimum pressure equation. It is found that optimum charge and charge at optimum pressure are in agreement with some marginal error.

**Keywords:** $CO_2$, optimum discharge pressure, refrigerant charge, subcritical cycle, transcritical cycle, transition