ABSTRACT

Numerical and Experimental studies are carried out on a supercritical carbon dioxide based natural circulation loop (NCL). Constant heat flux boundary condition is considered for the heater (source side) and water-cooled or air-cooled heat exchanger is considered for the cooler (sink side). Numerical analysis is carried out considering wall axial conduction and heat loss to the ambient for high-temperature water-cooled NCL to study the effect of loop geometry (loop diameter, height, heating and cooling length), wall material, thickness, insulation and ambient temperature. Subsequently, an air-cooled CO_2 based NCL is modeled considering fin and tube type cross-flow heat exchanger. This is being reported for the first time for an air-cooled CO_2 based NCL. The extensive numerical analysis is implemented to study the effect of various controlling parameters such as heater power, air inlet temperature, and air velocity. Based on the numerical results, an experimental set-up is designed and developed for a high-pressure and high-temperature NCL based on supercritical CO_2. To minimize the required system charge, pressurizer (expansion tank) is not included in the system. Comprehensive tests have been carried out for the steady-state operation to investigate the effect of loop charge. Transient analysis is done to reveal the start-up/shut-down, step-up/step-down characteristics. Finally, accidental fan failure and complete power failure cases are investigated in detail. Based on the experimental results under steady-state conditions, a regression correlation that relates Reynolds number with modified Grashof number is obtained. Results show that at higher heat inputs, the system charge should be chosen properly to avoid problems due to over-pressure when the charge is excessive and that due to over-temperature when the charge is deficient. There exists a threshold velocity for the external coolant (air) in the heat sink, below which the system pressure rises very rapidly leading to possible catastrophic loop failure. It is expected that this study will be useful in the design and safe operation of supercritical CO_2 based natural circulation loops.

Keywords: Experimental studies; fan failure; air-cooled heat exchanger; natural circulation loops; numerical studies; supercritical carbon dioxide; steady-state operation; transient operation.