The University of Queensland - IIT Delhi Academy of Research

Title- Investigation of High-Temperature Latent Heat Storage Integrated with Supercritical CO_2 Brayton Cycle

Alok Kumar Ray

Abstract

The ever-increasing demand for energy and concern for environmental security has attracted considerable attention of researchers from fossil fuel technology towards renewable energy technology (e.g., solar energy, wind energy, etc.) and variable energy resources. Variable energy sources (e.g., Concentrating solar thermal systems, electricity spillage from PV and wind plants) can play significant roles in complete transition to renewable energy resources. However, spatial and temporal intermittency is the major hindrance to the effective deployment of renewable energy technologies. Integrating thermal energy storage (TES) systems with renewable energy technologies can reduce the discrepancy between energy supply and demand, leading to continuous energy supply.

Among the various alternatives of TES technologies, high-temperature latent heat (HT-LHS) storage has significant benefits, such as isothermal operation, high energy storage density, and high exergetic efficiency. Moreover, high-temperature latent heat storage can be integrated with advanced power generation cycles or Thermionic photovoltaic (TIPV) systems to generate cost-effective heat and power.

In this regard, a numerical investigation is conducted to study the thermo-hydraulic behavior during the melting/solidification of high-temperature metallic phase change material (silicon).

A counter-clockwise circulation pattern is observed in the molten silicon, unlike clockwise pattern in molten conventional high-temperature PCM (sodium nitrate). The energy storage density and energy storage rates of silicon-based LHS are observed to be significantly higher than sodium nitrate ($NaNO_3$) based LHS. The thermodynamic efficiency reaches 50% at 700°C, which is significantly higher than the conventional Rankine cycle. The thermal efficiency is maximized at a split ratio of 0.75 for an air temperature of 30°C. Turbine inlet pressure and air temperature are identified as the most and least sensitive parameters affecting cycle efficiency. The individual and combined effects of passive heat transfer enhancement methods on the charging and discharging performance of HT-LHS systems are numerically studied. The combined effect on thermal performance is reported to be substantially higher than the individual effect. However, the combined effect of orientation and eccentricity results in a design anomaly for HT-LHS system. Eutectic mixture (60% $NaNO_3$,40% KNO_3) is synthesized using the common solvent method, and the thermal response of the synthesized sample is studied experimentally. A lab-scale prototype and experimental test facility are designed and developed to mimic the charging and discharging process of a concentric tube HT-LHS system. To further establish the inevitability of the HT-LHS system, a techno-economic comparative study is conducted between the HT-LHS system and Li-ion battery having the same capacity. The volumetric and gravimetric energy densities are observed to be significantly higher than the Li-ion battery. The charging and discharging durations for HT-LHS system are noticed to be relatively smaller than the Li-ion battery.