Abstract

In recent years, growing energy needs, cooling load demand, scarcity of fossil fuels and ecological threat due to CFC and CO_2 emissions have necessitated greater use of ecologically sustainable energy options. In this context, sorption technology offers an environmentally benign alternative for refrigeration as systems employing this technology use low grade renewable energy sources and natural refrigerants. Among the sorption systems, ammonia (NH_3) based solid sorption refrigeration systems offer advantages due to compactness, high heats of reaction, fast reaction kinetics and higher operating temperature range. Considering the long-term benefits of sorption systems, in order to improve performance and to overcome practical design and operational problems, theoretical and experimental studies are being carried out throughout the world on various aspects of this technology.

In the present study, efforts have been made experimentally in determining the hitherto unreported thermodynamic, thermo-chemical and thermo-physical properties of pure and mixed sorbents with expanded natural graphite (ENG) as additive. A test facility was fabricated to carry out thermodynamic and reaction kinetic studies on the sorbents namely, $BaCl_2$, $SrCl_2$, $BaCl_2$−ENG, $SrCl_2$−ENG, and mixture of $BaCl_2$−$SrCl_2$ that are employed in this study. Material characterization was carried out using an array of precision advanced techniques such as X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM) analysis and Energy Dispersive X-ray Spectroscopy (EDS) analysis. Heat of reaction (ΔH) and reaction entropy (ΔS) of sorbent−NH_3 pair were determined using the custom designed test facility. A constant volume, variable pressure method is used to estimate the absorption and desorption reaction rates. From analysis of data, reaction behaviour is studied during absorption and desorption and reaction constants are suggested by fitting the data through non-linear regression. Reaction advancement, pressure drop and temperature profiles during absorption and desorption are determined. The relevant thermo-physical properties of the materials are measured using a variety of techniques/apparatus. Laser Flash Apparatus (LFA-427) is employed to measure the thermal diffusivity of green compact sorbents. Coefficient of thermal expansion (CTE) is obtained using Thermo Mechanical Analysis (TMA) and specific heat of sorbents is estimated through Differential Scanning Calorimetry (DSC). Thermal conductivity is determined from the measured values of thermal diffusivity, specific heat and thermal coefficient of expansion.

$SrCl_2$ and NH_3 working pair is analyzed based on the heat and mass transfer aspects of the solid sorbent reactors (absorber/generator) to obtain the performance of a solid sorption refrigeration system. The transient heat and mass transfer model duly considers the effects of reactor wall mass and contact conductance between the reactor wall and the bed. A reasonably good match is obtained between the theoretical results and published experimental results on a reactor. The complete system, consisting of two absorber/generators, condenser, expansion valve and evaporator, is then analyzed using the heat and mass transfer model of the reactors. Results are obtained in terms of the COP and specific cooling power which indicate the possibility of optimizing the bed and operating parameters leading to high COP and/or SCP. The bed thickness, sink temperature and the global reaction advancement are found to affect the performance of the system significantly. Experimentally obtained thermodynamic and kinetic data of the sorbents, namely $BaCl_2-NH_3$, $SrCl_2-NH_3$, $BaCl_2-ENG-NH_3$, $SrCl_2-ENG-NH_3$, mixture of $BaCl_2-SrCl_2$ were used in modelling a quasi−continuous system with optimum parameters obtained from simulation model of $SrCl_2-NH_3$ system and compared in terms of COP and SCP.

A novel method, as suggested in the literature, is applied to the solid sorption systems with and without internal heat recovery (IHR) to carryout thermodynamic analyses. Three basic systems working with $BaCl_2$, $CaCl_2$ and $SrCl_2$ and four combinations of salts, namely, $MgCl_2/SrCl_2$, $MgCl_2/CaCl_2$, $CaCl_2/SrCl_2$ and $CaCl_2/CaCl_2$ are studied for systems with internal recovery. Results are obtained for a system that can produce ice at -10^oC using a waste heat source, available at 613 K. Energy and entropy balance equations are applied to analyse each of the processes to estimate the individual heat transfer and entropy generation rates for all the systems. Effects of sorbent and reactor mass are duly considered. Results obtained from the analysis show that Cooling/heating of generator/absorber results in significant entropy generation in all the systems and internal heat recovery improves the performance significantly. Finally, based on the experimental and theoretical studies conclusions are drawn and recommendations are made for future studies.