Study of thermal and adsorption characteristics of composite ammonia adsorber with expanded graphite and using nano fluids.

Swapnil S. Kshirsagar, Vaibhav N. Deshmukh, S. Radhakrishnan

Mechanical Engineering Department, Maharashtra Institute of Technology
Pune- 411038, INDIA

swapkshir@gmail.com
vaibhav.deshmukh@mitpune.edu.in
radhakrishnan.s@mitpune.edu.in

Abstract

The adsorption performance of composite adsorbent bed made from activated charcoal (AC) and $CaCl_2$ (50:50) with ammonia refrigerant was experimentally assessed by using nanofluid as a heat carrying agent. The amount of ammonia adsorbed at different compositions of nanofluid viz. 0.2% and 0.4% is compared with the base fluid result. Trials were conducted at different flow rates viz. 5 LPH, 10 LPH, 15 LPH, 20 LPH and 25 LPH. Results show that amount of ammonia adsorbed increases as the nanofluid concentration and flow rate of nanofluid increases. The maximum amount of ammonia adsorbed is 90.206 gm for 0.4 % nanofluid concentration and flow rate of 25 LPH. Also, new composite is prepared from expanded natural graphite (ENG) impregnated with activated charcoal and $CaCl_2$, whose thermal conductivity was calculated experimentally. Results show that thermal conductivity of activated charcoal and $CaCl_2$ (50:50) with impregnated ENG is 0.28 W/ (mK) and it is higher than the activated charcoal and $CaCl_2$ (50:50) having the thermal conductivity of 0.26 W/(mK).

Keywords: *nanofluid, expanded natural graphite, chemical adsorption, activated charcoal, refrigeration*

1. Introduction

As an environment friendly and energy saving technology, the solid-gas chemisorption is used for converting the low grade thermal energy into the high grade refrigeration power. As a thermal-driven refrigeration technology, adsorption refrigeration has advantages for the utilization of low-temperature thermal energy (i.e. waste heat and solar energy). Adsorption refrigeration has many benefits including easy control, simple structure, less noise and low maintenance [1,2] which make it very suitable for fishing boats ice making and vehicles air conditioning. Adsorption working pairs used in adsorption refrigeration includes activated carbon-ammonia, zeolite-water, activated carbon-methanol, $CaCl_2$ – NH_3, silica gel-water etc. Many researchers have worked on various working pairs and it has been observed that the chemical adsorption has larger adsorption quantity, compared to the physical adsorption [3,4]. The chemical adsorption process is one type of exothermic reaction occurred between adsorbents and adsorbate. Hence heat rejected during the adsorption process must be taken out from the system as early as possible to maintain the constant adsorption reaction rate. In this research work, nanofluid is used as a secondary fluid to carry the heat rejected during the adsorption reaction. Heat transfer coefficient of the nanofluid increases considerably compared to base fluid. Nanofluids are a new type of fluids prepared by dispersing nanometer-sized materials (fibers, tubes, rods, wires, droplets or sheet) in base fluids or in other words nanofluid consists of metallic or non-metallic nanoparticles (such as copper, silver, iron, alumina, copper oxide, Silicon carbide, carbon nanotubes, etc.) suspended in base fluid (such as water, ethylene glycol, oils, etc.). The nanotubes are expected to be very good thermal conductors along the length. The carbon nanotubes have a room-temperature thermal conductivity along its axis of about 3000 W/m.K and the copper transmits 385 W/m.K.

The heat and mass transfer performance are important parameters for adsorption refrigeration systems because it influences the adsorption and desorption rate and as well as the power density significantly [5]. The thermal conductivity of physical and chemical adsorber is very low hence heat cannot be rejected easily from the system. Heat transfer from the adsorber at the time of adsorption reaction is the key indicator of adsorption capacity. As the thermal conductivity of the composite adsorber is very low, heat cannot be rejected out from the system which affects the adsorption quantity. Expanded natural graphite can be used to enhance the thermal conductivity of the composite adsorber significantly. Many researchers have been investigated on the enhancement of thermal conductivity of the adsorber by adding expanded graphite. For example, Eun [6] and

Wang et al. [7] manufactured silica gel and AC compound blocks by mixing the adsorbents with expanded natural graphite (ENG) powders, and both achieved reasonable highly improved thermal conductivity and permeability. Tamainot-Telto and Critoph [8] made use of monolithic AC leading to the thermal conductivity up to 0.44 W/(m K). K Wang [9] et al. also developed a new type of compound adsorbent mixed by $CaCl_2$ and ENG, which improved the thermal conductivity of granular $CaCl_2$ by about 36 times.

In this work, the adsorption performance of ammonia with calcium chloride and activated carbon by using various concentrations of nanofluid was studied.

2. Materials and methods

2.1 Materials

The $CaCl_2$ were obtained from Merch Life Science Pvt. Ltd. (India). The employed $CaCl_2$ is with >98% purity. The activated charcoal was obtained from Loba Chemie Pvt. Ltd.

Fig.1 Calcium Chloride in granular form

Fig.2 Activated Charcoal in powder form

Fig. 1 shows a photo of the calcium chloride. Fig. 2 shows activated charcoal in powder form. In the present work, Carbon Nanotubes (CNT) is used as a nanoparticle which is procured from Sigma Aldrich, USA. The nanotubes have an average diameter ranging from 10-200 nm (nanometer) and a length ranging from 10-40 μm (micrometer). Fig. 3 shows the photo of CNT before dispersion into the base fluid.

Fig.3 Photo of CNT (Before dispersion into base fluid)

2.2 Preparation of Nanofluid

Generally, carbon nanotubes (CNT) are very cohesive in nature so it is difficult to disperse CNT particles into liquids such as ethanol, ethylene glycol, water etc. Ultra sonication method is used to disperse the nanoparticles into the base fluid to obtain the desired result. Ethylene glycol is used as a base fluid in the preparation of nanofluid. Two different compositions of nanofluid have been made by using 0.2% and 0.4% volume fraction of carbon nanotubes. Sodium Laurel Sulphate (SLS) is used as dispersing agent.

Initially, 200 ml nanofluid is prepared by adding CNT particle into 200 ml base fluid (Ethylene Glycol) with 0.1% SLS. This preparation is kept in an ultrasonicator for 40 min to obtain the homogeneous solution of nanofluid. Fig. 4 shows the ultrasonicator which is used for ultrasonication of nanofluid.

2.3 Preparation of Expanded Natural Graphite

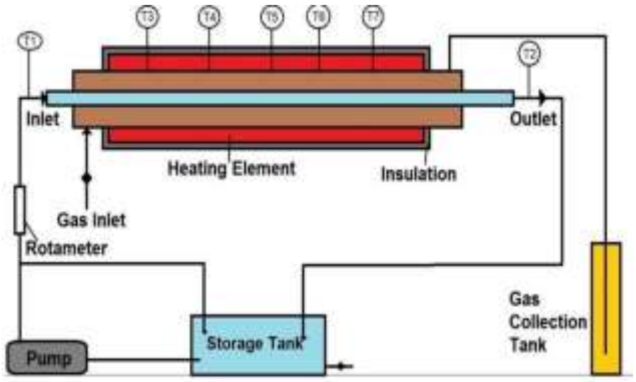
The expandable graphite is added to increase the thermal conductivity of composite adsorbent made up of $CaCl_2$ and activated charcoal. Expanded graphite of type KP80 (Mesh 80) is used in the experiment. The expanded natural graphite underwent expansion at a temperature of 400 °C for 30 min. Digital Muffle Furnace is used for heating the expanded natural graphite.

Fig.5 Digital Muffle Furnace

3. Experimental work

3.1 System design

The test system consists of the adsorption bed, heating elements, magnetic flow pump and rotameter. Fig. 6 (a) shows the process flow diagram of Adsorption refrigeration system. Adsorber bed consists of two concentric tubes made up of stainless steel. The annular gap between the inner tube and the outer tube is filled with composite adsorber material. Cooling fluid (Nanofluid) flows in inner tube and ammonia flows through the annular gap.



(a)

In this experiment, 9 heaters each of 3 KW are employed on the outer tube for the heating purpose. PT 100, grade A type thermometer is used for measurement of temperature having a deviation of 0.5%. T_1 and T_2 are the two thermocouples mounted at the inlet of cooling fluid and outlet of cooling fluid respectively. Remaining thermocouples T_3, T_4, T_5, T_6, and T_7 are used to measure the temperature of adsorber bed at different locations. All the temperature sensors are connected to the digital temperature indicators. The Cooling system consists of a storage tank, magnetic flow pump, and Rotameter. Rotameter is used to control the flow rate of cooling fluid which is flowing through the inner tube. Rotameter ranges from 6.6 LPH to 66 LPH with an error of 0.1%. During adsorption process, a cooling fluid is pumped from the storage tank to inner tube. Heat loss to the environment can be minimized by adding insulation to the outer tube. The flow rate of the ammonia gas can be measured by using Bypass valve. Fig. 6 (b) shows the experimental setup and components of adsorption refrigeration system.

3.2 Adsorption and Desorption cycle

In this experiment, activated charcoal and $CaCl_2$ is used as composite adsorbent which is filled in between the annular gap of the inner tube and the outer tube. Ammonia is used as an adsorbate (refrigerant) which is adsorbed on the surface of the composite adsorbent.

The heat liberated during adsorption process can be carried out by secondary cooling fluid flows through the inner tube. Nano fluid is used as a secondary cooling fluid.

Adsorption and desorption cycles are performed at various compositions of nanofluids i.e. 0% (Base fluid), 0.2%, 0.4%. The flow rate of the cooling fluid is also varied with the help of Rotameter. Adsorption and Desorption cycle is carried out at different flow rates as 5 LPH, 10LPH, 15LPH, 20 LPH and 25 LPH for each nanofluids composition.

3.3 Measurement of thermal conductivity

Activated charcoal and calcium chloride have a very low thermal conductivity which is responsible for several thermal limitations lead to low overall adsorption and desorption kinetics. Hence it is desirable to increase the thermal conductivity of the composite adsorbent. It is observed that expanded graphite (EG) increases the thermal conductivity of the composite which increases the adsorption and desorption kinetics. The thermal conductivity of composite material with and without expanded graphite is measured experimentally.

The apparatus consists of two thin-walled concentric copper spheres. The composite material is packed in between the two spheres as shown in Fig.7. The inner sphere houses the heating coil. Power supply to the heating coil is given through dimmerstat so that power supply can be varied easily. Voltmeter and ammeter are connected to measure the voltage and current at particular power supply condition. Chromel Alumel thermocouples are used to measure the temperatures. Thermocouple 1 to 3 is fixed on the inner sphere while thermocouple 4 to 6 is fixed on the outer sphere. Temperature readings are used to measure the thermal conductivity of the composite material packed between the two shells. Heat is transferred by conduction through the wall of the hollow sphere formed by the composite material packed in between two thin copper spheres.

Fig.7 Thermal conductivity measurement setup

Thermal conductivity (K) value can be determined as,

$$K = \frac{Q(r_o - r_i)}{4\pi r_i r_o (T_i - T_o)}$$

Here, r_i is the radius of inner sphere in meter, r_o is the radius of outer sphere in meter, T_i is average temperature of the inner sphere in °C and T_o is the average temperature of the outer sphere in °C. Heat input (Q) can be calculated by multiplying current and voltage value measured by ammeter and voltmeter respectively.

4. Results and discussion

In this experiment, adsorption performance of composite adsorber AC-$CaCl_2$ (50:50 compositions) with NH_3 is investigated. The adsorption performance of the system is investigated at different compositions of nanofluid. Adsorption performance of the system is also investigated at different flow rates of cooling fluid. Fig.8 shows the amount of ammonia adsorbed for various flow rates of nanofluid. In adsorption cycle, for 0% nanofluid amount of ammonia adsorbed is 69.147 gm, 69.933 gm, 75.140 gm, 76.521 gm and 79.411 gm for 5LPH, 10LPH, 15 LPH, 20LPH and 25LPH respectively. In adsorption cycle, for 0.2% nanofluid, an amount of ammonia adsorbed is 75.671 gm, 75.905 gm, 80.303 gm, 82.428 gm and 84.1 gm for 5LPH, 10LPH, 15 LPH, 20LPH and 25LPH respectively. In adsorption cycle, for 0.4% nanofluid, an amount of ammonia adsorbed is 75.0125 gm, 76.011 gm, 78.71 gm, 83.703 gm and 90.206 gm for 5LPH, 10LPH, 15 LPH, 20LPH and 25LPH respectively.

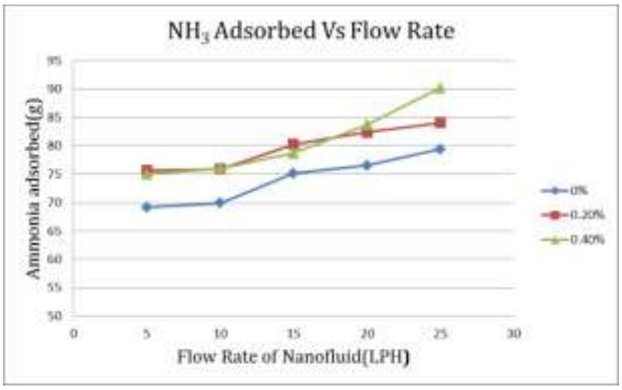


Fig.8 NH_3 Adsorbed Vs. Flow Rate of Nanofluid

Fig.9, Fig.10 and Fig.11 shows the heat transfer coefficient values versus Reynolds Number for base fluid, 0.2% nanofluid and 0.4% nanofluid. From Fig.9, it is observed that HTC values for base fluid approximately lies in between 75 W/(m^2K) and 200 W/(m^2K). However, from Fig. 10, it is observed that HTC values for 0.2 % nanofluid approximately lies in between 100 W/(m^2K) to 225 W/(m^2K). From Fig.11, it is observed that HTC values for 0.4% nanofluid approximately lies in between 150 W/(m^2K) to 360 W/(m^2K). It is observed from the Fig.9, Fig.10 and Fig.11 that Reynolds Number is varying from 50 to 500.

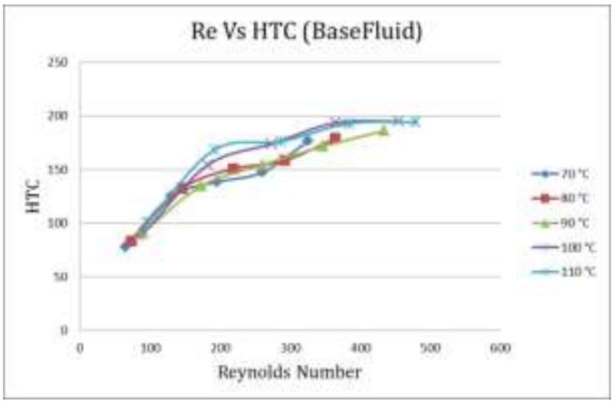


Fig.9 Re vs. HTC of Base Fluid

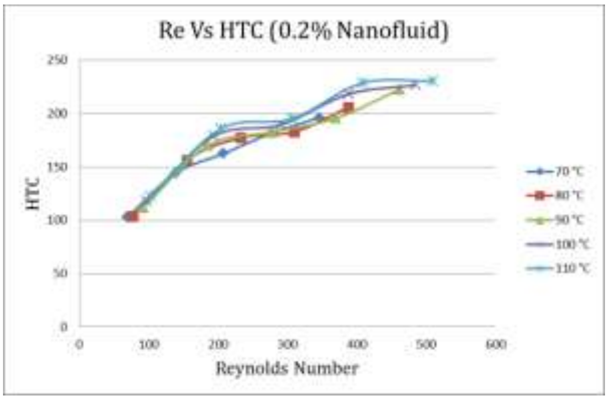


Fig.10 Re vs. HTC of 0.2% Nanofluid.

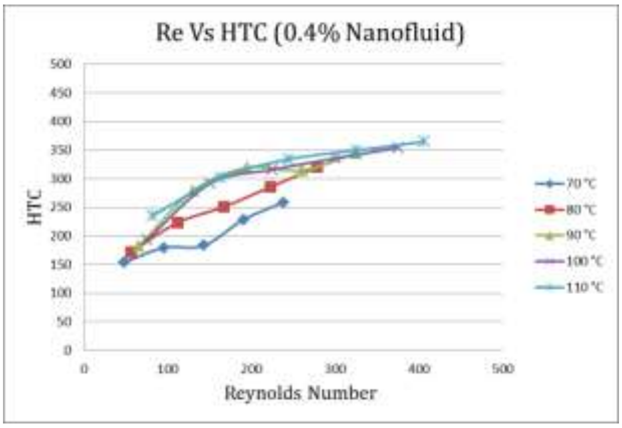


Fig.11 Re vs. HTC of 0.4% Nanofluid

The thermal conductivity of composite made up of activated charcoal and $CaCl_2$ is low. Hence expanded natural graphite is added into the composite to increase the thermal conductivity of the composite. Thermal conductivity is measured by adding 1% ENG and 2% ENG in activated charcoal and $CaCl_2$ (50:50 compositions). Fig.12 shows the variation of thermal conductivity with heat input. From Fig.12, it is observed that thermal conductivity increases with increase in ENG percentage. Maximum thermal conductivity observed is 0.28 W/(m^2K) for 2% ENG impregnated in a composite of activated charcoal and $CaCl_2$.

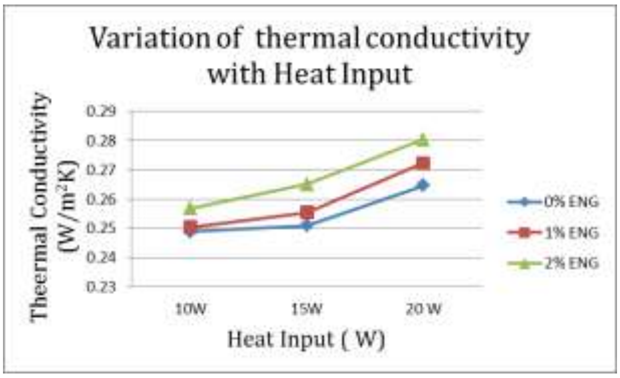


Fig.12 Variation of thermal conductivity with heat input

5. Conclusions

Nanofluid is used as heat carrying agent during adsorption process, as adsorption process is an exothermic process. The amount of ammonia adsorbed was measured for different nanofluid composition with different flow rates. In order to improve the thermal conductivity of activated charcoal and $CaCl_2$ (50:50 composition), expanded natural graphite is added into the composite. Conclusions were yielded as follows:

1) The amount of ammonia adsorbed increases with increasing nanofluid concentration and increasing flow rate of nanofluid.
2) Results of the base fluid trial show that amount of ammonia adsorbed is 69.147 gm for flow rate 5 LPH while the amount of ammonia adsorbed increases to 79.411 gm for flow rate 25 LPH.
3) For 25 LPH Nanofluid flow rate, the amount of ammonia adsorbed is 79.411 gm, 84.1 gm and 90.206 gm for 0% nanofluid, 0.2% nanofluid and 0.4% nanofluid respectively.
4) It is observed from the graph that the HTC value increases with increase in nanofluid concentration.
5) The thermal conductivity of the composite increase with increasing percentage of expanded natural graphite (ENG).

6. References

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