International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 467

THERMAL PERFORMANCE OF A SINGLE BED ACTIVATED CARBON-AMMONIA ADSORPTION REFRIGERATION SYSTEM

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ABSTRACT

This paper describes the thermal performance of an adsorption refrigerator system utilizing activated carbon-ammonia pair. The experiment was done by using thermal energy supplied by electric tape heater to the adsorber at selected temperature of 110°C with varied desorption time from 1 to 4 hours. Records of energy consumption, temperatures for adsorber, condenser, evaporator cold chamber and adsorber pressure were taken. The prototype tested attained evaporator cold chamber temperatures varying from 4.8°C to -0.6°C for desorption times of 1 to 4 hours. These temperatures are relevant to the vaccine storage requirement of 2°C to 8°C. Therefore, this adsorption refrigeration technology, which can be easily manufactured in least industrialised countries is a promising solution for off grid application.

Keywords: thermal performance, adsorption refrigeration, activated carbon-ammonia

NONMENCLATURE

Abbreviations	
AC	Activated Carbon
PV	Photovoltaic
WHO	World Health Organisation
Symbols	
hr(s)	Hour(s)

1. INTRODUCTION

Significant implications to the environment such as ozone layer depletion, global warming and huge electrical energy consumption associated with the use of conventional halogen-based refrigeration systems have made scientists search for environmental friendly refrigerating technologies [1]. Many rural areas of developing countries lack access to grid electricity; the International Energy Agency (IEA) reported that more than 20% of the world's population lacked access to electricity in the year 2010. Among them 57% lived in rural-areas of sub-Saharan Africa and had no hope of being connected to the centralised power supply in the near future [2].

Among the important application for refrigeration in the health sector is to store vaccines at the required +2°C to +8°C temperatures in intermediate vaccine stores and in health facilities [3]. Water-ammonia kerosene- and gas-driven absorption refrigerators have been used to store vaccines in un-electrified remote locations. However, they do not meet the standards established by the WHO on Performance, Quality and Safety System [4]. PV powered cooling systems preserve vaccines more efficiently and in environmentally friendly manner. However, batteries are needed [5]. Batteries live shorter than refrigerators, implying extra costs. Also, PV system have low possibility of being manufactured in most developing countries [6, 7]. Preservation of food is also important application as FAO estimated that 32% of all food produced in the world was wasted in the year 2009 [8].

Adsorption refrigeration systems can utilize low temperature waste heat or renewable energy sources like solar thermal energy to produce cooling effect [9].

Also, the use of heat generated by burning agricultural waste or biomass in general is possible, in remote parts of developing countries or islands where conventional cooling is difficult [10, 11]. Adsorption refrigerators use clean and renewable energy resource, operate with environmentally harmless refrigerants and can be manufactured with locally available resources [10, 12].

There is little information on the adsorption refrigeration products. Therefore, there is need of developing and testing the simple and robust adsorption refrigeration system by using the available environmentally friendly working pair in the least industrialised countries, with the possibility of supplying desorption heat by solar collectors and waste heat together with the capabilities to be locally manufactured. Through these criteria AC-Ammonia have been found suitable pair.

AC is the most commercialized adsorbent material, have large surface area of 800-1500 m^2/g, higher adsorption capacity, higher surface reactivity and suitable pore size for adsorption [10, 13]. Water, ammonia, methanol, and ethanol are commonly adsorbates used in adsorption refrigeration systems [14]. Ammonia has a comparatively high latent heat, about 1365 kJ $kg^{-}1$at -30 °C and density of 681 kg/m^3 [15], and is working with positive pressure which is feature of the simpler manufacturing techniques required for the system [16].

2. WORKING PRINCIPLE AND SYSTEM DESCRIPTION

2.1 The Basic Adsorption Refrigeration Cycle

The basic adsorption refrigeration cycle is shown in Fig. 1. It involves four basic steps; a, b, c and d as explain below [17].

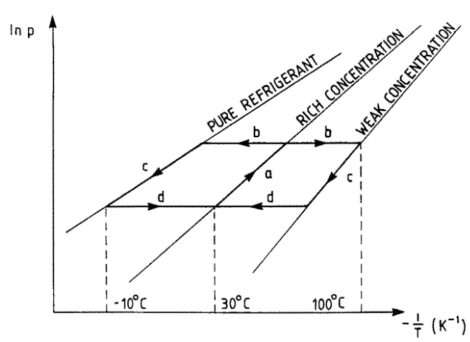

Fig. 1.: The basic adsorption refrigeration cycle [18]

(a). Heating and pressurizing: At this stage the adsorbent contains a large concentration of refrigerant. The adsorbent bed receives heat, which causes an increase of temperature and pressure as well. The mass in the generator is considered to remain constant until the condensing pressure is reached.

(b). Heating and desorption: The adsorbent bed continues receiving heat while it is connected to the condenser, thus the condenser pressure prevails within the system. Further increase in the adsorbent temperature induces desorption of the refrigerant vapour and the vapour condenses in a condenser. The concentration of refrigerant decrease as the temperature increases from the lower to the upper generating temperatures.

(c). Cooling and depressurisation: The adsorbent bed is cooled, which induces a change in pressure from condensing to evaporation pressure. The mass in the generator is considered to remain constant until the evaporating pressure is reached.

(d). Cooling and adsorption: The adsorption bed is cooled while connected to the evaporator, thus the evaporator pressure prevails within the system. The adsorbent temperature continues decreasing, which induces adsorption of the refrigerant vapour that is adsorbed in the adsorption bed. This adsorbed vapour is vaporised in the evaporator with the evaporator heat being supplied by the heat source at lower temperature. The concentration increases as the temperature decreases from initial adsorption to final adsorption temperature.

The adsorption refrigeration cycle can also be explained by two processes, adsorption process and heating desorption process [19]. At low temperatures, adsorbent adsorbs refrigerant that evaporates in the evaporator. Liquid refrigerant evaporates by adsorbing heat from the refrigeration cold box. Thus, the refrigeration occurs until the adsorbent is saturated. The adsorber, which is rich in adsorbed refrigerant is heated; temperature and pressure increase. When the system pressure increases to condensation pressure the desorbed refrigerant gas condenses in the condenser. The adsorbent will cool down by natural convection, which will also decrease the pressure. Then, the next adsorption refrigeration cycle begins when the pressure is reduced to evaporation pressure.

2.2 The System Description

The adsorption refrigerator laboratory prototype (Fig. 2.) consists of the adsorber, which contains the adsorbent-adsorbate pair of activated carbon-ammonia; the water-cooled condenser; refrigerant storage tank; the evaporator, which is contained in the cold chamber; an electric tape heater and controller; connecting pipeline; and affiliated parts. The adsorbent bed is heated by temperature controlled electric tape heater thermocoax isopad IT-20

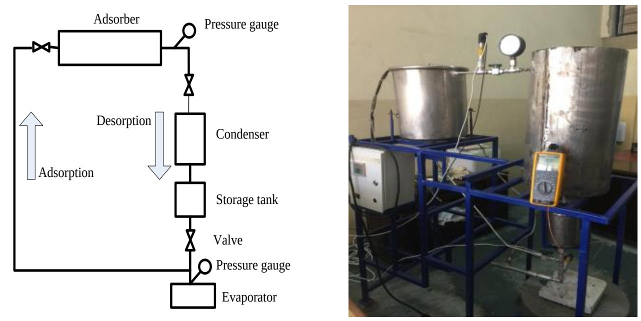

Fig. 2.: Adsorption refrigeration prototype, schematic and photograph

3. PREPARATION AND EXPERIMENTS

3.1 Material and Methods

Activated carbon used in this experiment was supplied by Palvi Power Tech Sales PVT. Ltd of India as a mining chemical. The particle size of the AC was reduced to 0.8-1.6mm by using Retsch Hammer Mill, Sieves and Sieve Shaker. The ammonia used is an industrial standard refrigerant supplied by BOC Tanzania. The prototype was manufactured at the Department of Mechanical and Industrial Engineering of the University of Dar es Salaam in Tanzania. The evaporator cold chamber was filled with 0.5 litre of water.

The adsorption refrigeration rate was measured by supplying a constant desorption temperature and varying desorption time from 1 hour to 4 hours for the fixed desorption temperature of 110°C. Adsorber temperature, condenser water temperature, cold chamber water temperature and ambient temperature were recorded using Pico TC-08 USB Thermocouple Data Logger with Pico Log Data Logging Software. Heat energy supplied by the electric tape heater was measured by using Energy meter PM498 with accuracy of +/- 3% of the measured values. The programmable timer switch AX300 was used to switch the electric heater. Pressure was recorded by Aplisens pressure transmitter PCE-28.

4. RESULTS AND DISCUSSIONS

4.1 Adsorption Temperature Profile and Adsorption Rate

Fig. 3 show the adsorption refrigeration temperature profile for adsorber, condenser, evaporator cold chamber and the adsorber pressure. In the heating desorption zone, the adsorber temperature increased from the ambient temperature to desorption temperature of around 120°C and pressure of 10bar. At this constant pressure the condenser temperature increased as it condensed the desorbed ammonia vapours. This temperature was maintained for 3 hours before the heater was switched off to allow the cooling of the adsorber.

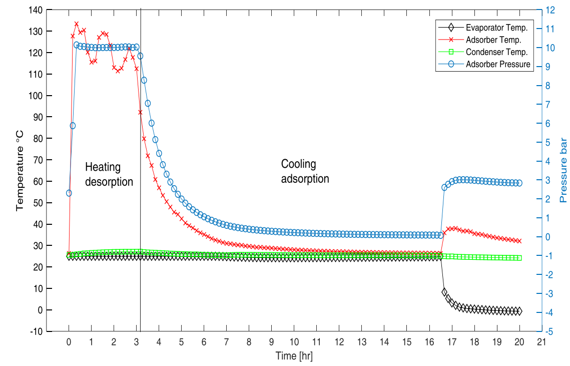

Fig. 3.: Temperature and pressure profile of the adsorption refrigeration prototype

In the cooling adsorption zone, the adsorber cooled by natural convection and the temperature and pressure dropped. When adsorber temperature cooled to ambient temperature of around 28°C the adsorption was initiated by opening the valve between evaporator and adsorber and adsorber pressure increased to evaporator pressure. The liquid ammonia evaporated in the evaporator, which cause the temperature drop in the cold chamber while increasing temperature in adsorbent bed. The process continued until the adsorbent was saturated with ammonia or all the liquid ammonia evaporated.

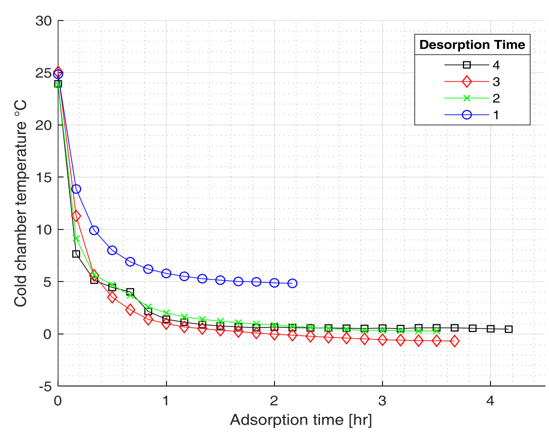

Fig. 4.: Adsorption rate for heating desorption temperature of 110°C

Fig. 4 shows the trends of adsorption rate of AC for ammonia at desorption temperature of 110°C at heating/desorption periods of 1 to 4 hours. The evaporation temperature decreased rapidly at the beginning period of the adsorption refrigeration process then the rate decreases. Low temperatures at the cold chamber were attained with longer desorption times. For 1-hour desorption period the energy supplied by the electric heater was enough to generate ammonia to cool the cold chamber to 5°C. There was no significant difference for heating/desorption periods ranging from 2 to 4 hours; both resulted in cold chamber temperatures ranging between 0 and 1°C.

4.2 *Thermal Performance of the Adsorption System*

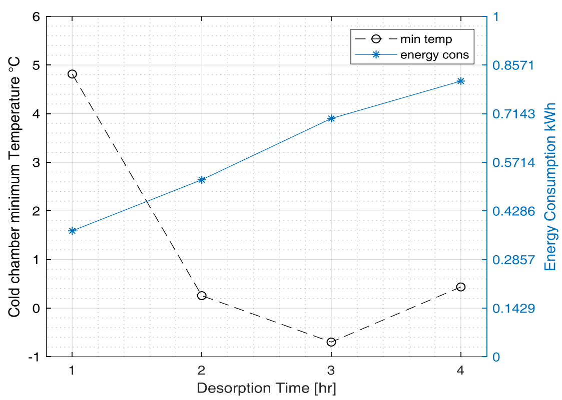

Fig. 5.: Energy consumption and minimum attained cold chamber temperature

Fig. 5 shows the heat energy supplied during heating/desorption process and the minimum temperature attained by the cold chamber of the evaporator for the same heating/desorption temperature. The energy supplied increased from 1 hour to 3 hours; then the rate of increase decreased as the amount of the ammonia in the adsorbent decreased.

The maximum cooling was obtained at the heating/desorption time of 3 hours. For the tested heating/desorption temperature of 110°C and heating/desorption times of 1 to 4 hours the cold chamber of the prototype attained temperatures between -0.6 to 4.8°C, which are within the range of vaccine storage requirement of 2 to 8°C [3].

5. CONCLUSION

Adsorption refrigeration systems have shown great potential to meet cooling demands in off grid areas. The tested laboratory adsorption prototype attained temperatures that are sufficient for storage of vaccines by using low temperature heat source of 110°C. The tested temperature can be supplied by low temperature waste heat and solar thermal collectors. Also, the use of heat generated by burning biomass materials such as agricultural waste is possible, in the remote parts of developing countries or islands where conventional cooling is difficult.

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