International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Experimental Investigation of Solar Adsorption Refrigeration System using Activated Charcoal-Methanol Working Pair

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Accepted 12 March 2017, Available online 16 March 2017, **Special Issue-7 (March 2017)**

Abstract

The extensive effort has made to develop the intermittent solid adsorption system that promises good alternative for solar refrigeration. Most research methods have used activated carbon–methanol for working pairs, and this has been considered as the most suitable working pair for solar solid adsorption Refrigeration. Going through the existing literature, it is revealed that there are no investigations on the simultaneous use of water cooled condenser, bypass way for adsorption process. Many researchers studied on TIM (transparent insulation material) for increasing the efficiency of solar collector. But, in this study, it is analyzed the solar powered refrigerator using polycarbonate glass, water cooled condenser with natural conduction, bypass way for adsorption to enhance the performance of solar adsorption system. Using this cyclical process it is possible to obtained cooling temperature of 11˚C. For increasing the effectiveness of solar heating, polycarbonate glass is used to achieve generator temperature up to 114˚C. In this system two valves with provision for bypass is made for easy operation and maintaining the flow of methanol during day and night. The solar powered activated charcoal-methanol paired system gives the cooling temperature up to 11˚Cfor 6kg water and achieve system COP=0.02.

Keywords: *Vapour Absorption Refrigeration, Adsorption Refrigeration, Methanol-Activated Charcoal Refrigeration*

1. Introduction

Energy supply to refrigeration and air-conditioning systems constitutes a significant role in the world. The International Institute of Refrigeration (IIR) has estimated that approximately 15% of all electricity produced worldwide is used for refrigeration and air-conditioning.

Refrigeration technology is required to evolve due to the new environmental regulation. The first regulation concerning the depletion of the ozone layer (Montreal protocol, 1988) decided to phase-out chlorofluorocarbons (CFCs) and then hydro chlorofluorocarbons (HCFCs). More recently adsorptive processes have been proposed for heat pump and refrigeration as consistent alternative to vapor compression systems. Ecological problems concerning the emission of CFCs from refrigerating unit.

Solar adsorption heat pump and refrigeration devices are of significance to meet the needs for cooling requirements such as air-conditioning and ice-making and medical or food preservation in remote areas. They are also noiseless, non-corrosive and environmentally friendly. For these reasons the research activities in this sector are still increasing to solve the crucial points that make these systems not yet ready to compete with the well-known vapor compression system. There is an increasing interest in the development and use of adsorption chillers due to their various economic and impressive environmental benefits, enabling solar energy or waste heat to be used for applications such as district networks and cogeneration plants.

1.1 Need and Objectives

The application of solar energy instead of electricity to refrigeration appears logical for countries with a good supply of solar energy. There are many remote areas where electricity is absent, but the solar irradiation is plentiful, thus the utilization of solar energy to produce cold in these areas is very important. Among the various applications of solar energy, refrigeration and air conditioning are the most interesting, because these demands are particularly strong in sunny regions. For countries with a high potential of solar energy, producing cold using solar energy is a promising way to sustainable development since the energy used is free and not harmful for the environment.

The soaring price of fossil fuel and environmental concerns has again drawn our attention to the need for reliable, pollution free and low energy cost refrigeration. Adsorption refrigeration is a thermal

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driven refrigeration system, which can be powered by solar energy as well as waste heat. The use of thermal driven systems helps to reduce the carbon dioxide emission from combustion of fossil fuels in power plants. Another advantage for adsorption systems compared with conventional vapor compression systems is the working fluid used. Adsorption systems mainly use a natural working fluid which has zero ozone depletion potential.

In the field of the sorption cooling, there are three kind of system: liquid absorption, Solid absorption (chemical reaction) and adsorption. In all these systems, the mechanical energy consumption is kept to a minimum or null. They can operate with low-grade heat from different sources such as waste heat or solar energy. The great advantage of adsorption systems over absorption ones is that they can operate without moving parts, having then lower costs of maintenance. Other advantages in comparison with the compression systems are: simple construction, environmentally benign and noiseless. Adsorption systems have less corrosion issues for the adsorbent–refrigerant working pairs when they incorporate high temperature heat sources compared to an absorption system.

1.2 Working Principle

In simple terms, adsorption is the collection of a substance into the surface of adsorbent solids. It is a heat removal process where certain particles are bound to an adsorbent particle surface by either chemical or physical attraction. Adsorption is often confused with absorption, where the substance being collected or removed actually penetrates into the other substance (Reynolds &Richards, 1996).

The operation principle of the solid adsorption refrigeration system utilizing solar heat is shown in figure 1. The system is composed of a container of adsorbents, which serves as a solar collector, a condenser and an evaporator which acts as a refrigerator and Refrigerator Cabinet. A combination of adsorbent and adsorbate is confined in a closed system where no carrier gas exists. The collector is supplied with adsorbent which is adsorbed with adsorbate.

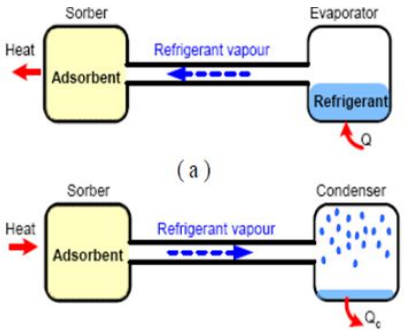


Figure 1 (a) Adsorption (refrigeration) process
(b) Desorption (regeneration) process

During the day-time the adsorbent along with the refrigerant is heated in the collector. As the temperature in collector increases, refrigerant evaporates from the adsorbent bed and then is cooled by the condenser and stored in the evaporator. During the night-time, the collector is cooled by ambient air and the temperature of the bed reaches a minimum. In this period, refrigerant begins to evaporate by absorbing heat from the water to be frozen and is adsorbed by the adsorbent. As the evaporation of the refrigerant continues, the water temperature decreases until it reaches required temperature as per the application.

2. Experimental Set Up of System

Adsorption refrigeration system uses solid adsorbent beds to adsorb and desorbs a refrigerant to obtain cooling effect. These solid adsorbent beds adsorb and desorb a refrigerant vapor in response to changes in the temperature of the adsorbent. Here adsorbent is an Activated carbon and the refrigerant used is methanol. The basic adsorption refrigeration system, commonly referred to as the adsorption heat pump loop, or a adsorption refrigeration circuit, it consists of four main components: a solid adsorbent bed, a condenser, and an Refrigerator Cabinet. The solid adsorbent bed desorbs refrigerant when heated and adsorb refrigerant vapor when cooled. In this manner, the bed can be used as a thermal compressor to drive the refrigerant around the system to heat or cool a heat transfer fluid or to provide space heating or cooling. Thus in this system bed(of activated carbon) acts as compressor so as to drive refrigerant(methanol) similar to compressor in basic refrigerator as explained in Figure 2.The refrigerant is desorbed from the bed as it is heated to drive the refrigerant out of the bed and the refrigerant vapor is conveyed to a condenser. In the condenser, the refrigerant vapor is cooled and condensed to liquid. The low pressure condensate passes to an evaporator where the low pressure condensate is heat exchanged with the process stream or space to be conditioned to vaporize the condensate. When further heating no longer produces desorbed refrigerant from the adsorbent bed, the bed is isolated and allowed to return to the adsorption conditions. When the adsorption conditions are established in the bed, the refrigerant vapor from the evaporator is reintroduced to the bed to complete the cycle .For the circulation of methanol in the system the whole system should be vaccumised.

2.1 Components of Solar Adsorption Refrigeration system

The schematic layout of a no valve solar flat plate Refrigerator is shown in figure…. The solar Refrigerator consists of adsorbent bed (2), a condenser (5), an evaporator (7), water tank (8), insulation box (9) as well as connecting pipes. For this system, there are no any reservoirs, connecting valves and throttling valve, the structure of the system is very simple. The

working principle of this no valve solar Refrigerator is described as follows.

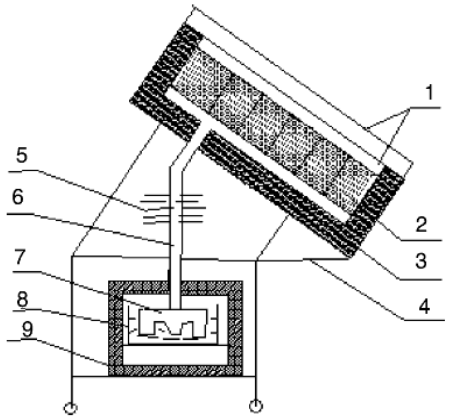


Figure 2 The sketch structure of the no valve solar Refrigerator: (1) cover plate, (2) adsorbent bed, (3) insulation materials, (4) frame, (5) condenser, (6) connecting pipe, (7) evaporator, (8) water tank, (9) Insulation box

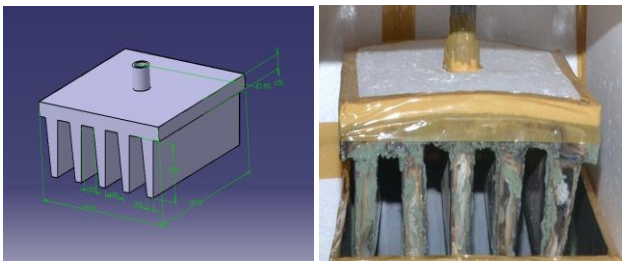
On a sunny day, the adsorbent bed absorbs solar radiation energy, which raises the temperature of adsorbent bed as well as the pressure of methanol in adsorbent bed. When the temperature of adsorbent reaches the desorption temperature, the refrigerant begins to evaporate and desorb from the bed. The desorbed refrigerant vapor will be condensed into liquid via the condenser and flows into the evaporator directly; this desorption process lasts until the temperature of adsorbent reaches the maximum desorption temperature. During night, when the temperature of the adsorbent bed reduces, the refrigerant vapor from the evaporator gets adsorbent back in the bed. During this adsorption process, the cooling effect is released from refrigerant evaporation, and the ice is formed in the water tank placed inside thermal insulated water box. In this system the compressor is replaced by a charcoal bed which is operated by heat instead of a mechanical energy. The vaporized refrigerant is adsorbed in the pores of the adsorbent in the reaction chamber i.e. adsorbent bed. Thus the operation of the adsorption cooling system depends on adsorption/desorption characteristics of the particular adsorbent/refrigerant pair. Due to the loading of the adsorbent, the thermal compressor is operated intermittently.

3. Design of Solar Powered Refrigerator

The system for solar powered adsorption refrigerator is composed of bed which acts as thermal collector, a condenser, evaporator and Refrigerator Cabinet. Design of each parameter is explained in detail below:

3.1 Evaporator

The evaporator must have sufficient volume to collect all condensed methanol. In order to enhance the heat transfer effect, the heat exchange surface is designed as a series of four trapezoidal cells shown in Fig., the dimension of the evaporator is 300mm *300mm* 100mm. evaporator is made up of stainless steel The evaporator is partly immersed in a water tank, which is made of stainless steel, and both the evaporator and water tank are placed in box covered with insulation.
The lower portion of evaporator is made up of trapezoidal shape and dimensions are 30mm*45mm. This increases surface area and ensures better heat transfer.

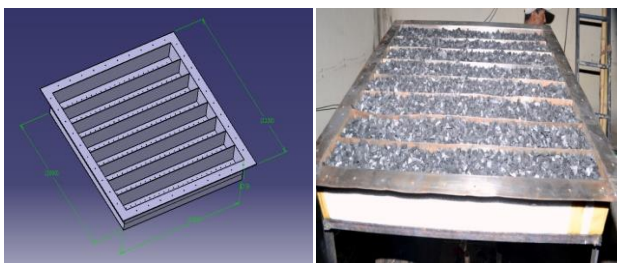


a) Evaporator model b) Actual evaporator

Figure 3 Design of Evaporator

3.2 Adsorbent Bed

Adsorbent bed is the most important part of the Solar Powered Refrigerator and hence the performance of the solar Refrigerator depends highly on the characteristics of the adsorbent bed. Generally speaking, a good adsorbent bed must have good heat and mass transfer. The adsorbent bed is made of flat plate Galvanized iron(GI) box, having surface area 1 m^2, also 20 kg adsorbent (activated carbon produced from coconut shell) is charged and sealed inside the GI box, then selective coating is covered on top surface of the GI box. The permeability of the fibre plastic plate for solar radiation is about 0.92, which is higher than that of glass. In order to guarantee better heat transfer between the front side and the adsorbent, many fins are placed inside the adsorbent bed box in contact with the front side and the activated carbon.



a) Adsorbent Bed model b) Actual Adsorbent Bed

Figure 4 Design of Adsorbent Bed

3.3 Condenser

Specifications of water cooled condenser are as below:

- Tube material : copper material
- Tube diameter(inner) : 12.7 mm
- Coil diameter(condenser) : 225 mm
- Total length of one tube : 10000 mm
- Number of tubes used : 1
- Tube thickness : 1mm

During the process of desorption of methanol, a well designed condenser is needed to reject the desorption heat. This condenser is water cooled type of condenser Role of condenser in the system is as follows: when vaporized methanol flows from bed to condenser through pipes it gets cooled because of water applied in condenser, thus vaporized methanol is converted into liquid methanol. This liquefied methanol now goes to evaporator.

a) Condenser model b) Actual Condenser

Figure 5 Design of Condenser

The integration of components for solar powered adsoption system is as shown in figure 6.

Figure6 Integrated system for solar powered refrigerator

4. Results and Discussion

As the system is a pilot project, experiments are carried out so as to check the exact working of the system. Following are some of the analysis made on the system.

4.1 Variation of Temperature of Adsorbent Bed with Time

The graph shown below is expected behavior of adsorbent bed. It is variation of temperature in the adsorbent bed because of incident solar radiations.

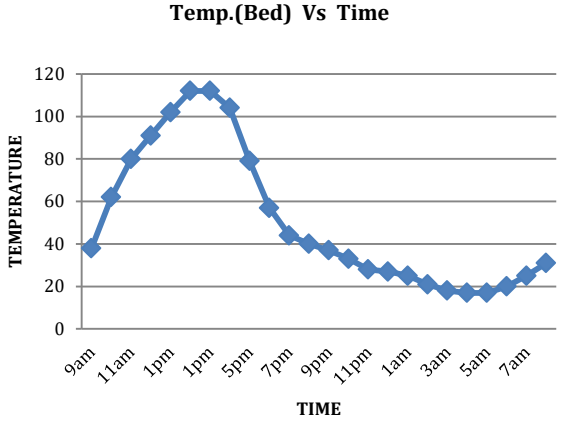


Figure7 Variation of temperature of adsorbent bed with time

Temperature in bed is directly proportional to the incident solar radiation. Effective solar radiations are available during period of 10 a.m. to 3 p.m. thus the temperature in bed during this period reaches to 100 to 114 ºC after 3 pm the temperature in the bed gets lower and lower till at 5:30 pm the temperature lowers to 18 degree c and adsorption continues till that time. After this temperature remains almost constant till 10 pm now the adsorption of methanol starts. As adsorbent bed adsorbs vapors of methanol thus the temperature of adsorbent bed increases upto 60 ºC, approximately at midnight temperature is about 60-70 ºC, after this the temperature again starts decreasing and exothermic reaction carry on. The bed will attain temperature of surrounding i.e. 26 ºC.

4.2 Variation of Temperature of Water in Refrigerator Cabinet With Respect to Time

The graph shown below is the expected graph of variation of temperature of water in Refrigerator Cabinet with respect to time.

The graph shows that during desorption process the temperature of water is 30 ºC, it remains constant till desorption process ends. Desorption process has duration of about 7-8 hours. It ends approximately at 7 p.m.

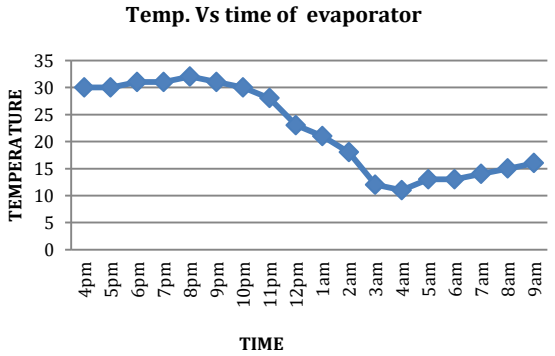


Figure 8 Variation of temperature of water in water box with time

As the desorption ceases the adsorption process will start. After a particular timing the temperature of water decreases rapidly, that timing is critical timing of approximately about 11.30 p.m. During this process methanol absorbs heat of water and thus methanol will evaporate and evaporated methanol will be adsorbed by Activated carbon, thus water temperature get reduced and temperature of the water in the refrigerator cabinet will be 11 ºC at about 4am. After 4 am. Temperature of water increases slightly to 13 ºC. It remains constant till approximately 6 a.m.

Conclusion

Fabrication and analysis of Activated charcoal-Methanol paired solar adsorption system was performed. From this study, one can conclude that the possibility of using nonpolluting materials and to save the energy involved in this sector are obviously the most important characteristics but simplicity, low maintenance, and the absence of noisy components are also very important features that make this type of system suitable for numerous other applications i.e. future scope of the project is such as air-conditioning in cars or food transportations or solar cooling with the use of: multi-bed systems.

The adsorption bed (generator) is the heart of the system and it has the greatest effect on the performance of the system. A good design of the generator leads to smooth operation and better results, so more attention must be go to the design influence on the performance of the system.

The adsorption /desorption tests for activated carbon/methanol pair showed that there must be sufficient time to get the highest desorption of methanol, and the optimum time for that was found to be 5-10 hours.

The generation temperature must be over 114°C in order to generate higher volume of methanol from activated carbon.

The COP of the system achieved is 0.12, which is comparatively low but as the system works on solar energy it is eco-friendly system.

It is understood from the experimentation that new configurations of the solar regenerator are highly welcome to maximize its benefits.

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