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DEVELOPMENT AND EVALUATION OF SOLAR BASED ADSORPTION COOLING SYSTEM

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Abstract: In recent years air-conditioning systems are most widely used for human comfort. The conventionally used refrigerants in the air-conditioning systems cause ozone layer depletion and also these refrigerants have higher global warming potential. This leads to research in the area of alternative cooling methods and among the alternative cooling methods adsorption cooling systems are getting attention. The adsorption cooling system is the heat driven refrigeration system and hence solar energy can be used as the heat source in this system. In adsorption system, careful selection of the adsorbent-adsorbate pair is important. Hence, in this work water was used as refrigerant to cope with the current environmental issues. In summer the demand of the cooling system is high and hence in this work solar energy was used to drive the adsorption system. We have developed and tested an adsorption system successfully. From this work, we conclude that the development in the adsorbent technology provides solution to the shortcomings in adsorption systems and also helps to reduce global warming potential.

Keywords: Cooling, Solar, Adsorption system, development, evaluation

INTRODUCTION

The conventional air conditioning systems works on the principle of vapour compression refrigeration cycle. The conventional air conditioning consists of an evaporator, a compressor, a condenser and an expansion valve. In conventional air-conditioning system, electrical energy is supplied to run the compressor. The function of the compressor is to transfer heat from room to the surroundings. The temperature and pressure of the refrigerant is increased by the compressor due to compression of the refrigerant. The refrigerant rejects heats to the surrounding through condenser and changes its phase so that it can be used for cooling. However, the pressure of the refrigerant is high and hence the refrigerant is allowed to expand in the expansion device. The temperature of the refrigerant is reduced due to expansion and the low temperature refrigerant enters the evaporator. The refrigerant absorbs the heat from the evaporator and hence the cooling effect is produced. In recent years, air conditioners have become almost essential in homes and offices as it provides thermal comfort and indoor air quality. The

air conditioners consume significant amount of electrical energy and the production of the electrical energy from the conventional sources release greenhouse gases. The use of CFCs, HCFCs and HFCs based refrigerants in the air conditioning systems cause ozone layer depletion and contribute to global warming. Hence, researchers are carrying out studies to find suitable alternative methods of cooling. Among the different alternative cooling systems, adsorption cooling system is getting popular as it is a heat driven system and we can use waste heat or solar energy.

ADSORPTION COOLING SYSTEMS

Adsorption is the adhesion of fluid molecules on the walls of a solid material and it creates a film on the adsorbent surface. The adsorbed molecules lose energy when adsorbed by adsorption bed resulting in an exothermic reaction.

Few researchers developed a refrigeration cycle using activated carbon granules as an adsorbent and CO₂ as an adsorbate. They demonstrated that it is possible to produce a low temperature using an activated carbon bed for adsorption/desorption of carbon dioxide [1]. Few researchers recommended activated carbon /R-

134a adsorption refrigeration working pair as compared to activated carbon powder with R-507A, R-407c, R-507A, R-407c and R-134a. This is because of its higher maximum adsorption capacity than the other and also for long life performance adsorption refrigeration system [2].

Skander et al simulated the specific cooling effect and COP for the driving heat source temperatures between 30 °C to 90 °C with different cooling load temperatures. They found that the maximum COPs of ACF-CO₂ and Maxsorb-CO₂ systems are 0.083 and 0.15 respectively. Few researchers used CO₂ as the refrigerant and suggested that the two-stage adsorption refrigeration can work at lower regeneration temperatures. They reported that the COP of the two-stage cycle is higher than that of the single-stage cycle for these low regeneration temperatures [4]. Skander et al analyzed the dynamic behavior of a 4-bed adsorption chillers using R1234ze, as the refrigerant and highly porous activated carbon of type Maxsorb III as the adsorbent. Their simulated results show that the system is can produce 2 kW of cooling power with the heat source temperature of 85 °C. Few researchers suggested that the performance of CaCl₂-ammonia adsorption system can be improved by distributing activated carbon uniformly in the mass of CaCl₂. This process increases mass transfer and uplift the cooling power density [6]. Abdul Hadi et al studied the effect of the process variables on the performance of a two bed adsorption chillier with the capacity of 1.5 tons with the adsorption pair, activated carbon-methanol. They reported that the two beds adsorption system gives continue cooling effect. Also it is reported that the active carbon hollow fibers possess higher ratio of geometric area to volume as compared to classic active carbon [8]. Few researchers produced activated carbon from carbonized olive stones in the temperature range from 700 to 800 degree C and can be activated by ZnCl₂ and KOH [9]. Astina and Bun Kisa carried out experiments on activated carbon and propane adsorption refrigeration system to produce continuous cooling. From the experimental results, they reported that the adsorption refrigeration system provides cooling capacity, cycle time and COP around 50 kJ, 210 min and 0.15 respectively.

MATERIALS AND METHODS

The pyranometer with data logger was used in this work to measure the solar radiation flux and is shown in the Figure 1. It consists of thermopile sensor with black coating which absorbs the solar radiations and converts the thermal energy into electrical energy. It senses the solar radiations at instant and converts the heat production due to radiation into micro volts displayed in form of W/m² in data logger. A sunshine recorder was used for measuring the duration of the

sunshine. The sunshine recorder is used for measuring number of hours of sunshine in a day. It was placed from 9.00 AM to 3.30 PM in the month of April 2016, at Nagarjuna College of engineering which has latitude of 12.970 N. It doesn't record the number hours of day light but only measure the hours of radiation. It consists of three seasonal cards such as summer, equinox and winter cards and is shown in the Figure 2.



Figure 1. Pyranometer with data logger



Figure 2. Sunshine Recorder

A 10 KVA solar PV system was used in this work. A solar inverter was used to convert the variable Direct Current (DC) output from the PV panels to alternating current (AC) and then supplied to OFF-grid for the utilization and to supply power to the evaporative cooling system. Figure 3 shows the solar PV system and the solar inverter.



Figure 3. Solar PV panels with inverter

The selection of the adsorbent-adsorbate pair is essential for the successful operation of adsorption system. In adsorption system, the refrigerant is chosen based on its evaporating temperature and pressure, environmental impact, heat capacity and ability to be adsorbed on solid beds. However, the refrigerants with high heat capacity per unit volume and low environmental impact are selected. Water has higher latent heat and is non-toxic and hence it was chosen as the refrigerant. Silica gel synthetically prepared from sodium silicate contains a nano-porous silica micro-structure. It is produced from naturally occurring mineral and is purified and processed into either granular or beaded form. It adsorbs water due to its higher specific surface area. The moisture in the silica gel can be removed by adsorption rather than by absorption into the bulk of the gel. The silica gel can be regenerated at low heat source and hence it was used in this work. Hence, the adsorption pair used in this work is silica gel and water.

The adsorption system consists of desorption chamber, condenser, adsorption chamber and evaporator and is shown in the Figure 4. The adsorption system depends upon the affinity of the adsorbent bed to attract the refrigerant vapour from the evaporator and this process creates a low pressure in the evaporator. When the adsorbent bed is close to the saturation point, heat is applied to adsorbent bed. The addition of heat evaporates the refrigerant and the refrigerant vapour goes to the condenser where it is condensed in the condenser before returning to the evaporator. When this cycle is completed, the adsorbent bed is cooled by the cool water until the adsorption conditions are established. After this process, the valve between the evaporator and the adsorbed is reopened.

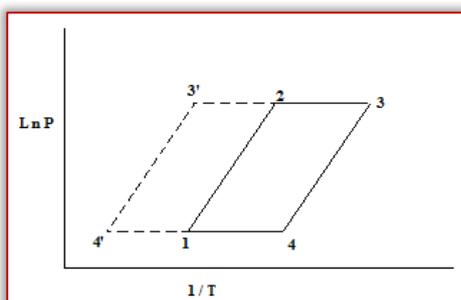
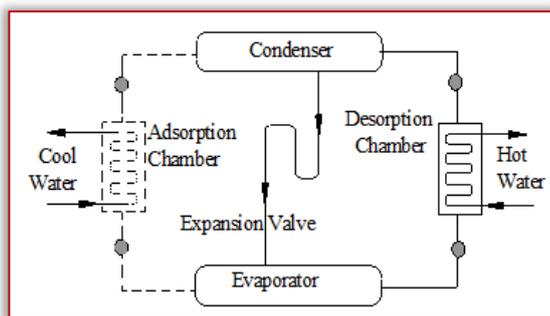


Figure 4. Adsorption Cooling System

Adsorption refrigeration system uses solid adsorbent to produce cooling effect as the bed adsorb and desorb a refrigerant to produce cooling. The adsorbent bed desorbs refrigerant when heated and adsorb refrigerant vapor when cooled. A basic adsorption cycle consists of four thermodynamic processes which is shown in the vapour pressure diagram, Figure 4.

1. Heating and Pressurization (1-2)

At starting of the process, the adsorbent is cold and saturated with the refrigerant and this state is represented as point 1. When heat is applied, the adsorbent is heated which results in desorbing a certain amount of the refrigerant from the adsorbent. This process causes increase in pressure from evaporator pressure to condenser pressure, without changing the refrigerant uptake and this process continues until the minimum desorption temperature is reached. This process is called as preheating. The end of this process is represented as state point 2. This process is similar to compression in vapour compression refrigeration system.

2. Heating, Desorption and Condensation (2-3)

The adsorber continues receiving heat and the desorption process starts from the point 2 and the refrigerant is condense data constant pressure in the condenser. The desorption process continues till the adsorbent temperature reaches the maximum desorption temperature. Also the refrigerant uptake reaches the cycle minimum uptake and the point 3 shows the end of this process. This process is similar to condensation in vapour compression refrigeration system.

3. Cooling and Depressurization (3-4)

After this process, the adsorbent adsorb refrigerant vapour due to pre-cooling. This reduces the system pressure from condenser pressure to the evaporator pressure. When the system is pre-cooled further, a portion of the previously desorbed and condensed refrigerant is adsorbed. The remaining liquid refrigerant in the evaporator supplies the latent heat of vaporization required for this process. This results in decreasing the refrigerant temperature from state point 3 to state point 4. This process is similar to expansion in vapour compression refrigeration system.

4. Adsorption and Evaporation / Cooling (4-1)

The cooling effect is produced during this process and adsorber continues releasing heat when it connected to the evaporator. The adsorbent temperature decreases slowly which causes the adsorption of vapour. The heat required for the evaporation is supplied by the heat source at low temperature. The adsorption process produces the cooling effect and point 4 shows the starting of the process and the process continues due to by further cooling in the adsorber-desorber heat exchanger. This process continues until the entire

refrigerant is evaporated. This process is similar to evaporation in vapour compression refrigeration cycle. In figure 4, the line 3' to 4' represents the saturation line.

The cycle 1-2-3'-4' represents the refrigeration cycle and the cycle 1-2-3-4 represents the adsorption cycle and also represents the conditions of adsorbent. The simple adsorption system does not produce continuous cooling. In adsorption system, the adsorption bed is charged with refrigerant at low temperature and pressure. The adsorption bed is heated when adsorption slows down which causes vapour is released from the bed.

RESULTS AND DISCUSSION

Analysis of solar radiation and power production

The study of solar radiation was carried out from 9.10 AM to 3.10 PM using the sunshine recorder, pyranometer and compared with the power produced by the 8 PV panels each of 230W capacity. The card burnt length shows the hours of the sunshine at respective time on the card and solar radiation flux (W/m²) recorded with the pyranometer is plotted against time and compared with the sunshine recorded card, correspondingly the power generated from the PV Panels are noted from the solar inverter.

Figure 5 shows the results of the reading recorded by the sunshine recorder and the solar radiation flux on the Equinox card. The card is placed at 9:10 AM and the sunshine is observed from 9:15 AM to 3:10 PM. There was cloud formation during the daytime and hence there is a slight variation in the solar radiation flux. The radiation flux was high during afternoon and was appeared to be constant. The average solar radiation flux was 926.34W/m² and power generation from 9:00 to 3:30 was about 3.8 kW.

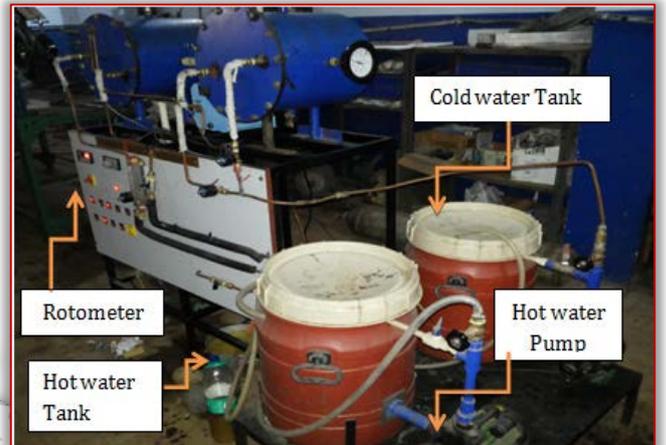
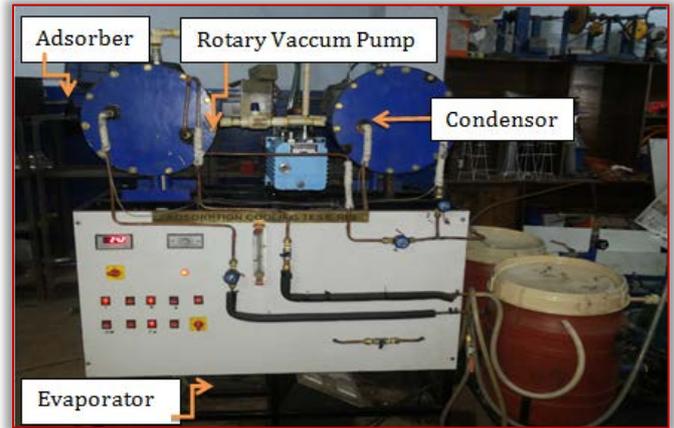


Figure 6. Adsorption Refrigeration System

The adsorption operating condition is as follows. The evaporator and adsorber pressures were maintained at 655 and 650 mm of Hg respectively. The temperature of the hot fluid supplied to the system is 75°C. The reduction in temperature due to adsorption process with the time is shown in the Figure 7. Adsorber cooling water inlet temperature of about 34 degree C, was evaporating temperature of 14 degree C and adsorption/desorption phase time was 15 minutes. Effect of cooling load on evaporator pressure

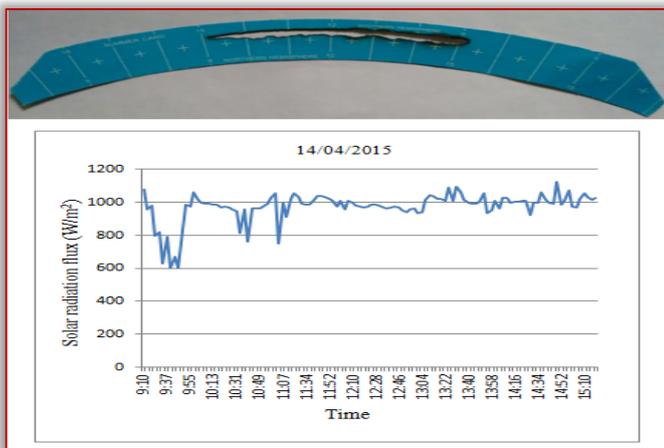


Figure 5. Sun shine hours and solar radiation of Equinox card

A silica gel and water based adsorption system was developed and tested successfully. Figure 6 shows the adsorption refrigeration system which was powered by solar PV panel.

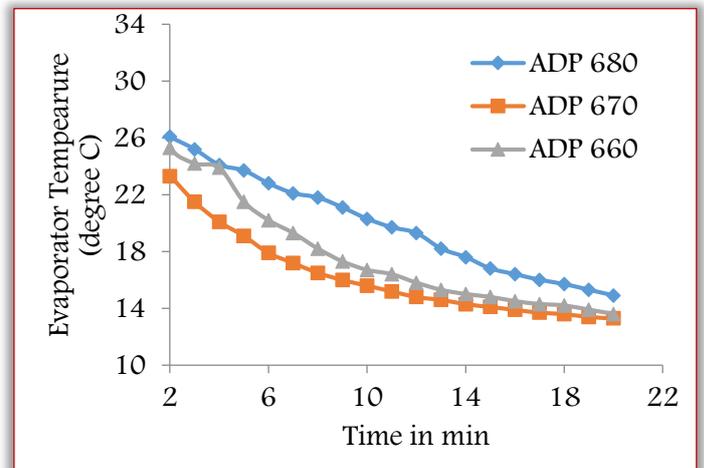


Figure 7. Variation in Evaporator Temperature with respect to time with 500 ml water

The effect of adsorption pressure on the evaporator temperature with respect to time and at cooling load of 500 ml is shown in the Figure 7. From the figure, it is observed that the adsorption pressure significantly affects the evaporator temperature. The adsorption pressure of 670 mm of Hg gives lowest evaporator temperature as compared to other pressures. The adsorption pressure of 680 mm of Hg gives higher evaporator temperature. Hence, the optimized adsorption pressure required for this adsorption system is 670 mm of Hg.

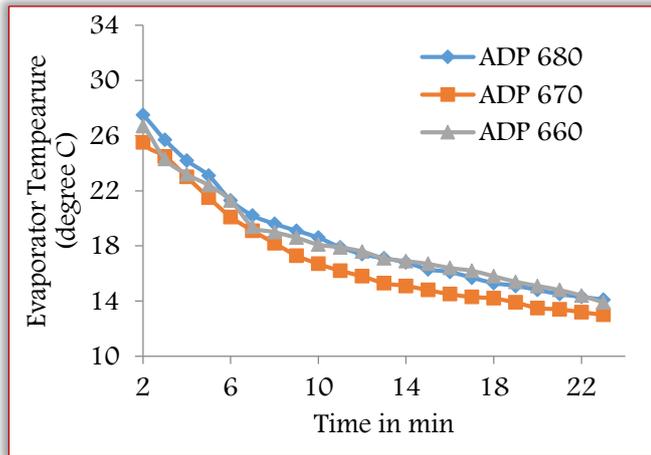


Figure 8. Variation in Evaporator Temperature with respect to time with 750 ml water

Figure 8 shows the effect of adsorption pressure on the evaporator temperature with respect to time and at cooling load of 750 ml. From the figure, it is observed that the adsorption pressure of 670 mm of Hg gives lowest evaporator pressure. However, the variation in evaporator pressure is minimum for the adsorption pressure of 660 and 680 mm of Hg. Also, this pressure gives higher evaporator pressure as compared to the adsorption pressure of 670 mm of Hg.

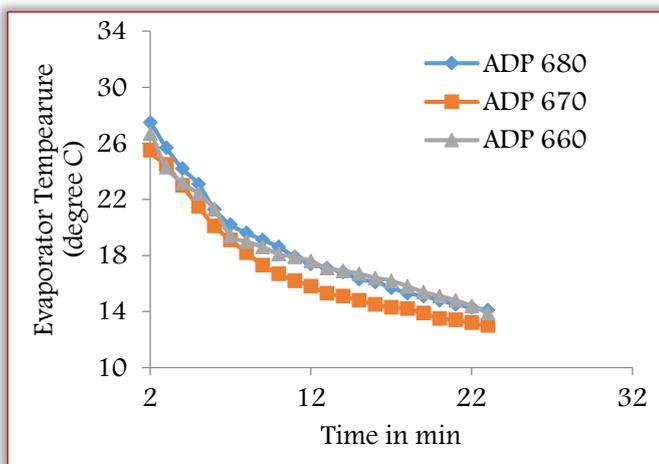


Figure 9. Variation in Evaporator Temperature with respect to time 1000 ml of water

Figure 9 shows the effect of adsorption pressure on the evaporator temperature with respect to time and at

cooling load of 1000 ml. From the figure, it is observed that the adsorption pressure of 670 mm of Hg gives lowest evaporator pressure as compared to other pressure values such as 660 and 680 mm of Hg. Initially the variation in evaporator pressure is significant, however this difference is small after a particular time interval. From the above discussion we observe that the adsorption pressure of 670 mm of Hg is better for the designed solar powered adsorption system.

CONCLUSION

A solar based adsorption system was developed and tested successfully. The system was able to produce a cooling effect and the lowest temperature obtained was 13.5 degree C. Since the demand of the cooling system is high during summer, the solar based adsorption system will provide an alternative to the conventional energy sources. The adsorption pressure of 670 mm of Hg gives the lowest evaporator temperature as compared to other pressure values such as 660 and 680 mm of Hg.

Acknowledgment

Author thanks the financial support provided by VGST, Government of Karnataka and Mr.Prabhu for his help during the experimental work.

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ISSN:2067-3809

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