Experimental Studies on Adsorption Refrigeration System

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Abstract— The refrigeration system is most widely used in domestic and industrial applications. The conventional vapour compression refrigeration system uses CFC or HFC based refrigerants which affects the ozone layer and also this type of systems needs conventional energy sources. Hence it is necessary to identify environmental friendly alternative cooling system which is driven by renewable energy sources. In this work, we have developed a adsorption based refrigeration system which uses solar energy and conventional electrical energy. The adsorbent and refrigerant pair used in this work is silica gel and water. The experiments were conducted at various hot water temperature and best hot water temperature was optimized. The cooling effect produced by this system was satisfactory and the energy supplied by the conventional electrical energy is reduced with the help of solar energy. From the experimental results, we conclude that the hybrid solar adsorption system can be used as a replacement for the vapour compression refrigeration system.

Keywords: Adsorption, Alternative Cooling, Solar, Hybrid, Performance

I. Introduction

The refrigeration system is becoming essential household item and this device needs higher conventional electrical energy as compared to other home appliances. The refrigeration effect is produced by the vapour compression system (VCR) which uses CFC or HFC based refrigerants. The increase in domestic refrigerators number increases the power consumption and also impact the ozone layer [1]. The use of refrigeration system in domestic and industrial application increase the peak load demand during summer [2]. The refrigerants used in the VCR system deplete the ozone layer and increases global warming [3]. It is estimated that the annual growth rate of India's energy demand from 2017 to 2026 will be about 5.2%. The increase in energy demand will increase the fossil fuel demand of India [4]. The refrigerator is the major energy consumer in the domestic application [5].

The conventional refrigeration systems are compact and gives higher system performance. However alternative cooling technologies are developed which uses renewable energy sources or waste industrial heat to reduce the operating cost [6]. The vapour adsorption refrigeration (VAR) system can be driven by low thermal energy sources such as solar energy or waste industrial heat sources [7]. The natural substances such as water can be used as refrigerant in the VAR system. This type of refrigerant is environmental friendly, non-flammable, user friendly and also cheap. However there are number of challenges in the commercial application of VAR system [8].

The performance studies were carried out on VAR system with different types of adsorption refrigeration pairs and with different operating temperature to improve the performance of the system. The most famous adsorbent and refrigerant pair are silica gel water, zeolite-water and activated carbon ammonia / methanol. The coefficient of performance (COP) of the VAR system which uses monolithic carbon and ammonia pair is 0.12 [9]. The performance of VAR system is significantly affected by the operating temperature and pressure. An air-conditioning system which uses water adsorption system was developed and tested. The desorption temperature required for this working pair is high [10]. The solar photovoltaic power system can be used to drive the cooling system. Also it is suggested that the PV cooling system is better than other cooling systems [11]. A laboratory scale an ammonia–water absorption chiller of capacity was developed and tested successfully. It is reported that the COP of this system is 0.69 at the generator temperature 114 °C [12]. The thermal conductivities of metallic nano-particles are high and hence the nano-particles like of copper, silver and iron can be used in solar absorption refrigeration system to increase heat transfer rate and also to get higher system performance [13]. A solar hybrid absorption refrigeration system which uses thermal energy storage was coupled with a thermo chemical process was developed and tested. These two systems shares same evaporator, condenser and refrigerant fluid and it is reported that thermo-chemical subsystem increases the performance of the system [14].

II. Principle of Adsorption System

The refrigeration system produces cooling effect by continuously removing heat from space to be cooled with the help of compressor in conventional VCR system. In VAR system, the refrigerant vapour is adsorbed by the adsorbent. The adsorbent has larger porous volume and the adsorbed refrigerant vapour do not undergo any chemical reaction. The refrigerant is released from the adsorbent when heat is released to it. The major components of VAR system is evaporator, condenser, expansion valve and solid absorbent bed. Figure 1 shows the components of adsorption system

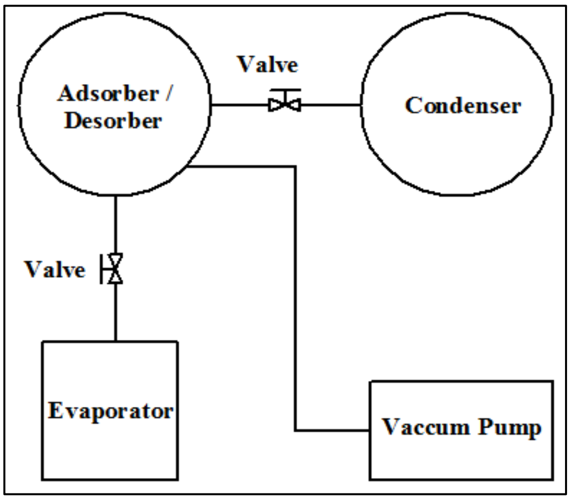

Fig. 1: Components of adsorption system

The working principle of this system is shown in the Figure 2 which consists of two cycles.

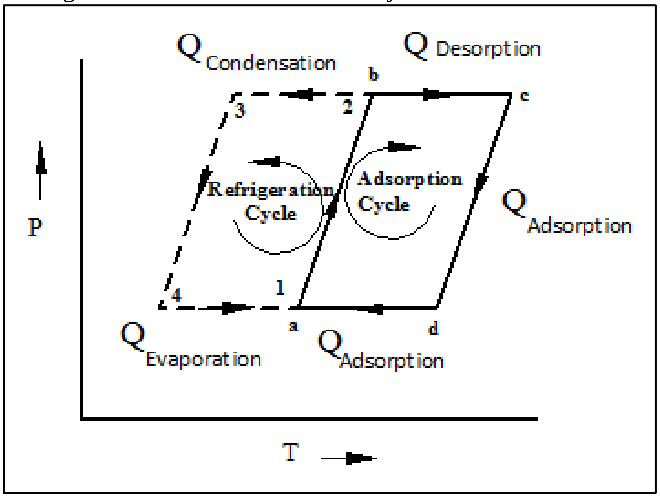

Fig. 2: Clapeyron diagram

In this refrigeration system, cooling effect is produced due to combined adsorption and refrigeration cycles. The working principle is based on clapeyron cycle. The cycle a-b-c-d-a is called as adsorption cycle which shows the state of the adsorbent during the cycle. The cycle 1-2-3-4-1 represents refrigeration cycle which produces the cooling effect. The process, a – b, is called as pre heating process which increases the pressure of the system. The initial state of the adsorbent is represented as 'a' in the clapeyron cycle. When the hot water is supplied to the system, the adsorbent is heated and its temperature gradually increases. The heating of the adsorbent causes desorption of water from the silica gel adsorbent. The increase in temperature increases the pressure of the system from lower pressure to higher pressure. This process ends at state 'b' and this process is called as preheating process. This process a-b is almost similar to compressor work in VCR system.

The process, b-c, is called as heating and desorption which takes place at constant pressure. The continuous supply of heat at constant pressure to the system causes desorption and this process will continue until the adsorbent temperature reaches its peak value. The process, c-d, is called as depressurization as pressure of the system is reduced. The process, d-a, is called as cooling and adsorption process. The cooling effect is obtained during the adsorption process and this process ends at the state 'a'. The cycle 1-2-3-4 represents the refrigeration cycle which produces cooling effect during the adsorption cycle. The water vapour separated from the adsorbent is cooled by the condenser which reduces the temperature. Then the pressure of the system is reduced from higher pressure to lower pressure and the end of this process is represented by state '4'. Process 4-1 is the refrigeration or cooling effect which produces the cooling effect. This is the simplest refrigeration cycle and do not produce continuous refrigeration effect.

III. Materials and Methodology

The water was used as refrigerant in this work as it is environmental friendly and is easily available. This system can be operated at lower thermal energy source and hence reduces the operating cost and positive impact on the climate as compared to other refrigerants. The silica gel was chosen as the adsorbent due to its better adsorption properties. The silica gel is an amorphous and porous form of SiO_2 with nano-scale pores. The silica gel is chemically unreactive, nonflammable and nontoxic. The specific surface area of silica gel is high and adsorbs water. Hence it can be used as adsorbent as it absorbs moisture on its porous space. The saturated silica gel can be regenerated by heating. Figure 3 shows the silica gel beads used in this work.

Fig. 3: Silica gel

The major components of this refrigeration system are condenser unit, evaporator, absorber cum desorber and vaccum pump. The condenser unit is used to condenser the water vapour produced during the cooling cycle. It contains compact heat exchanger which is made of aluminum. Two compact heat exchangers are connected in series and water passes through the tubes and cools the water vapour. The fins are provided on the tubes increases the heat transfer.

The evaporator produces required cooling effect and the water kept in the evaporator is cooled during the adsorption cooling cycle. The adsorption unit is similar to condenser unit and hot water and normal/ cooling water are circulated as per the adsorption cooling cycle using pumps.

The VAR system is hot water driven and hence conventional solar water heating system was used to absorb the solar energy. The hot water generated by this system was supplied to the hot water storage system. The additional heat was provided by the electrical heater so that the hot water temperature increases to required value. The working principle of this system is based on clapeyron cycle. A series of processes were performed as per clapeyron cycle to produce the cooling effect. The refrigeration effect is produced in the alternative cooling cycle and hence this system do not produce cooling continuously. The refrigeration effect is produced during adsorption process and this process happens alternatively in a single bed adsorption system. The continuous cooling effect can be produced by using two absorbers. In this work, the hot water temperature were varied and the temperatures considered were 80, 85 and 90° C.

IV. EXPERIMENTAL SETUP

Figure 4 depicts the experimental setup and figure 5 represents the schematic of the solar hybrid ARS. The temperature of the hot water storage system was increased to 90°C. The vacuum pump was switched on and the adsorbent bed reactor is fully vacuumed. The evaporator unit was closed during this process. Then the hot water pump is turn-on and hot water is circulated to start adsorbent bed regeneration. The adsorbent bed pressure increases after that the hot water pump is switched off. Then the cold water pump is switched on and required flow rate was maintained by using the control valve. The water vapour generated during desorption is cooled using condenser water. The adsorbent bed is allowed cool for 10 min. The vacuum pump was turned-on to create required vacuum. Once the required vacuum pressure is reached, the vacuum pump was turn-off and the valve between evaporator and absorber was open. The evaporator is exposed to the lower pressure and the water in the evaporator evaporates and cools the space. This process continues till the adsorbent is saturated with the water vapour. During this cyclic process, cooling effect is produced. This cycle is repeated to get intermittent cooling.

Fig. 4: Experimental Setup

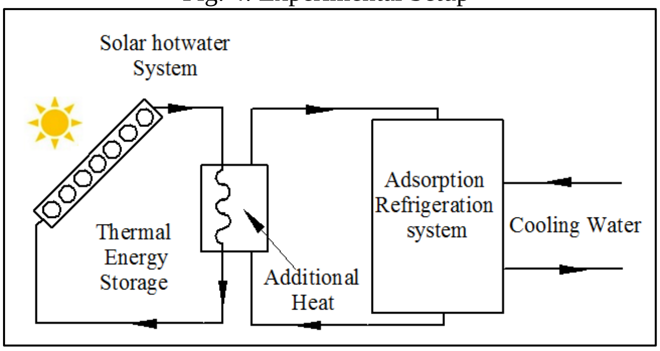

Fig. 5: Schematic of Experimental Setup

V. RESULTS AND DISCUSSION

The experiment setup was developed and integrated with the solar water heating system. An electrical heater was provided in the storage tank to increase the temperature of the water to 90°C. The experiments were conducted after the temperature of the hot water reaches the required value. The experiments were conducted at the evaporator pressure of 640 mm of Hg, absorber pressure of 630 mm of Hg and condenser pressure of 680 mm of Hg. The experiments were conducted with various hot water temperatures such as 80, 85 and 90 ^{0}C.

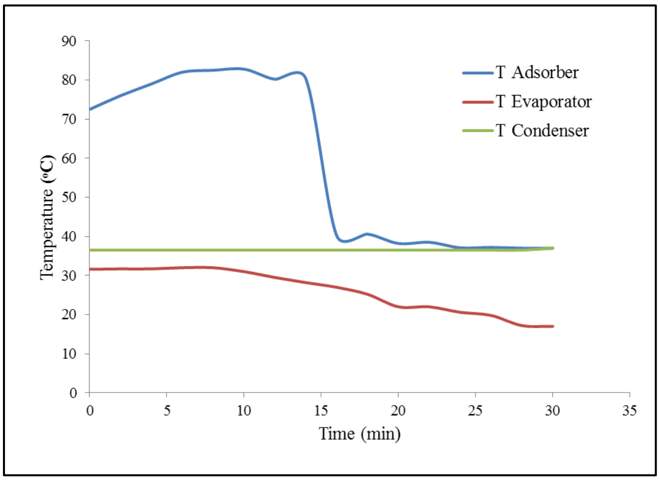

Fig. 6: Variation in process temperatures v/s Time at 90 ^{0}C

Figure 6 depicts the variation of evaporator, condenser and adsorbent temperatures with respect to time in a cyclic process at the hot water temperature of 90 ^{0}C. The hot water temperature was initially constant and reduces gradually and reaches lower value. The temperature of the condenser is almost constant during this experiment. Initially the temperature in the evaporator is constant and after some time it starts to decrease and the value reduces significantly. The lowest temperature of 8.9° C was obtained in a cyclic process. However the evaporator temperature can be lowered by reducing the pressure in the absorber.

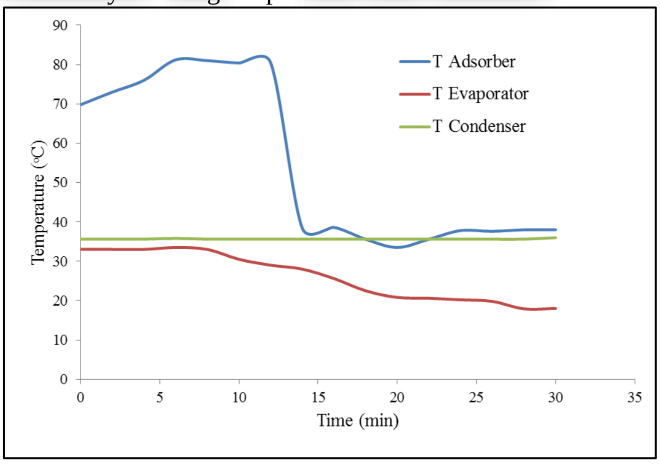

Fig. 7: Variation in process temperatures v/s Time at 85 ^{0}C

The variation of evaporator, condenser and adsorbent temperatures with respect to time in a cyclic processes at the hot water temperature of 85 ^{0}C is shown in the Figure 7. The characteristics of this figure are similar to figure 6. However the temperature of the hot water is lower and evaporator temperature is higher than the figure 6. This is due to reduction in adsorption performance which reduces the cooling effect.

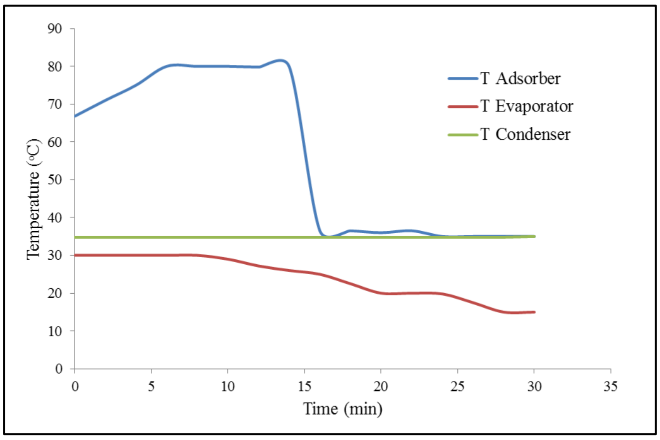

Fig. 8: Variation in process temperatures v/s Time at 80 ^{0}C

Figure 8 depicts the variation of evaporator, condenser and adsorbent temperatures with respect to time in a cyclic processes at the hot water temperature of 80 ^{0}C. The hot water temperature was reduces drastically initially and then reduces gradually and reaches lowest value. The temperature of the condenser water is slightly higher due to recirculation of this water. The reduction in evaporator temperature is initially low and ten decreases significantly. However the lowest evaporator temperature obtained by this hot water temperature is higher than other hot water temperature.

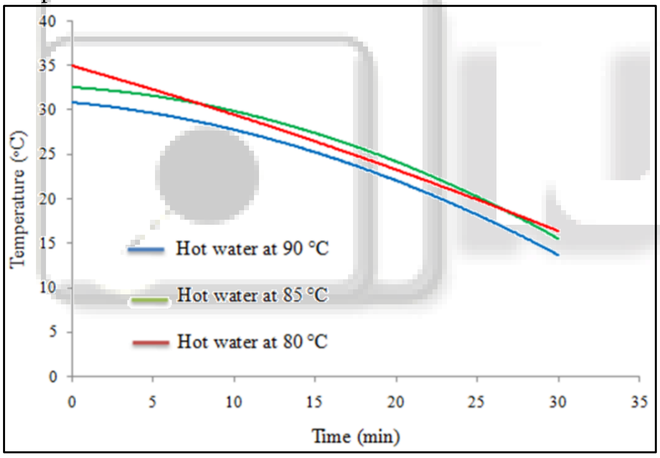

Fig. 9: Comparison of evaporator temperatures v/s Time at various hot water temperature

The variation in evaporator temperature with reference to time, at different hot water temperatures such as 80, 85 and 90 ° C is shown in the Figure 9. The hot water temperature of 90 ° C results in lowest evaporator temperature as compared to other hot water temperature. The highest evaporator temperature was obtained with hot water temperature of 80 ° C. However the variation in evaporator temperature of 80 and 85 ° C is small.

VI. CONCLUSION

The adsorption refrigeration system is one of the alternative cooling systems to the conventional VCR system. The ARS uses natural refrigerant such as water and the use of this type of refrigerant will reduce global warming and ozone layer depletion. A hybrid solar water ARS was developed and tested successfully in this work with silica gel and water as adsorbent and refrigerant pair. The use of solar energy reduces the conventional energy requirement. The hybrid solar ARS system produces a lowest temperature of 8.9 °C and further work is being carried-out to reduce the evaporator temperature. This study shows that the ARS can be used as an alternative cooling system to the VCR and can be integrated with solar or other industrial hot water systems to reduce the operating cost.

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