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Comparative Studies on Solar Assisted Silica Gel-Water and Activated Carbon-Methanol Based Adsorption Refrigeration System

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Abstract

The ever increasing cooling demand and the environmental concern have made in search of alternative refrigeration and for the last few decades, the energy efficient cooling systems utilizing refrigerants of no negative impact on the environment are explored. In this view, heat-driven refrigeration systems like vapour adsorption refrigeration is one of the favourable alternatives. Though adsorption cooling devices are capable of producing desirable cooling effect with a relatively low heat source temperature, their coefficient of performance (COP) is low in comparison with the existing cooling technologies. Therefore, to solve the environmental, economic and technical issues, the research is still in progress in this area. It is evident from the literature that, the performance of adsorption refrigeration depends on selecting the working pair such as silica gel-water, activated carbon-ammonia, zeolite-water etc. and driving temperature. This paper presents the comparison of performances of solar assisted twin bed adsorption refrigeration which employs silica gel-water and activated carbon-methanol as working pairs. Results are found to be good with continuous cooling in the evaporator using low temperature source of heat and the lowest temperature achieved in the evaporator for silica gel-water is 11^{o}C and for activated Carbon-Methanol is 2^{o}C. The coefficient of performance obtained is higher for silica gel based system than that of Activated carbon based system.

Keywords: *Refrigeration, adsorption, Solar energy, working pair, COP*

1.0 Introduction

The increase in industrial activities and living standards of the people are demanding comfort indoor environment which has proportionately increased the use of refrigeration and air conditioning systems which mainly works on vapour compression principles utilizing high grade electrical energy to produce cooling power. This has led to the increase of price of fossil fuels and harmful impact on the environment with the use of traditional refrigerants having greater potential of global warming and depletion of ozone layer. Statistics shows that 15% of the electricity generated is utilized for refrigeration and air-conditioning processes alone across the world. Hence, it is very important to explore nature friendly cooling systems which utilize refrigerants of no negative impact and use low grade energy for their operation [1-2].

The effective utilization of thermal energy from low-temperature resources like solar energy, waste heat from biomass combustion, industry and household waste fulfils many domestic and industrial needs such as ice-making, vaccine safety, storage of milk, fruits, vegetables, food, space cooling as well as air conditioning [3-10]. Since the heavy use of air-conditioning systems in hot weather demands high amount of electricity, heat-operated cooling systems like adsorption refrigeration system (ARS) could be an effective choice to produce cooling effect using low grade thermal energy available at temperatures less than 100°C to reduce the dependency on conventional electrical power.

The adsorption system has no moving parts and hence noiseless in operation with no lubrication requirements. Since the system can be put into operation with solar energy or waste heat, it can fulfil the cooling requirements in rural and remote areas. The major obstacles in commercializing the adsorption systems are its poor performance and bulkiness. Therefore, developing compact adsorption cooling systems with ideal combination of adsorbent-adsorbate pairs having high capacity of adsorption has become an interested research topic.

In the adsorption process, a substance from one phase is separated and gets accumulated over the another surface. The substance which accumulates is termed as adsorbate and the surface on which this process happens is the adsorbent. In the ARS highly porous solid adsorbent beds are employed for refrigerant or adsorbate to adsorb or desorb depending on the variation of temperature of adsorbent material in obtaining cooling effect. The refrigerant vapours are adsorbed at low temperatures and are desorbed or released when the temperature goes up hence achieving the thermal compression

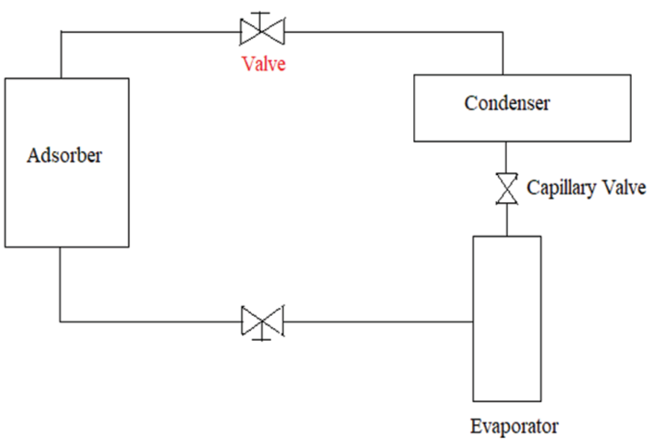

Figure 1: A typical adsorption refrigeration system

Table 1: Adsorbent-Refrigerant pairs [41]

Adsorbent	Adsorbate (Refrigerant)
Silica Gel	Water
Silica Gel	Ammonia
zeolite	Water
Activated Carbon	Methyl Alcohol.
Activated Carbon	Ethyl Alcohol
Metal Chlorides	Ammonia
Calcium Chloride	Ammonia
Metal Hydrides	Hydrogen

which drives the refrigerant. The main parts of a typical adsorption cooling device are as shown in Figure 1. The principle of adsorption cooling is the reversible adsorption between the adsorbent and the refrigerant. In ARS, normally multiple adsorber beds are employed for continuously getting cooling effect. [12–13].

The ideal combination of adsorbent and adsorbate referred to as working pair has a significant role in achieving better performance in ARS. The affinity for each other in a pair depends on physical, chemical and thermodynamic properties. Many theoretical and experimental studies are found to know the best working pair. The most commonly adopted working pairs are presented in Table 1.

The studies of many researchers indicate the successful cold production using adsorption based refrigeration system under different operating environments.

Researchers such as Samson Paul Pinto et al [2], Dim Dim Kumar et al [14], M Gado et al [15], Saurav Mitra et al [16], Mahsa Sayfikar et al [17], Begum et al. [18], Pan et al. [19] have studied silica gel-water based adsorption chiller. There are studies on solar based adsorption by Kairul Habib et al [20], Wissam H. Khaleel [21], N. V. Ogueke et al [22], Khattab et al. [23], Hassan et al. [24], Mohammed Ali Hadj Ammar et al [25], etc. many theoretical studies were found by researchers like V Baiju et al [26], A. Asif Sha et al [27], H. T. Chua et al [28], Sakoda et al [29], Xiaolin Wang et al [30], Yongling Zhao et al [31], Marzia Khanam et al [32] etc. Research on activated Carbon with different adsorbates such as ethanol, methanol, R-134a etc. was seen by researchers like Wang et al. [33], Khattab et al. [34], Khairul Habib [35], Ramji et al [36], I. Made Astina et al [37], Ashok et al [38] Ahmed N. Shmroukh et al [39], Ahmed et al [40] and others.

From the literature it is seen that the cooling performance of adsorption system is evaluated with different combination of working pairs with different operating variables like heat source temperature, cycle time, flow rates, amount of adsorbate etc. The performance results obtained were different for different operating environments and the efforts are being made continuously by the researchers to accomplish better performance and our present purpose of study is to know the feasibility of producing cold with two types of working pairs and to get some better insights about the system's performance.

2.0 Materials and Methods

The heat source used for the desorption of adsorbent bed in this work is the hot water which is obtained from an evacuated solar collector shown in Figure 2.

Silica gel-water and granular form of activated carbon-methanol are used as working substances (Pairs) for the study. Where silica gel and activated carbon acts as adsorbents and water and methanol acts as adsorbates or refrigerants. These working pairs are chosen because of the ease of their adoptability, favourable properties and lower range of desorption temperatures. Also a 1.5 kW electric heating coil is used for achieving desirable desorption temperature since it is very difficult to obtain the required range of temperatures all the times from solar heater.

Figure 2: Solar water heating system

3.0 Experimental Details

The details of the experiment along with the operating procedures of twin bed ARS are described here under.

The Schematic diagram and photograph of the twin bed ARS is shown in Figures 3 and 4. Where CI1, CO1, CI2, CO2, HI1, HO1, HI2, HO2 are the valves supplying water to the adsorber beds. Cold and hot water valves are represented by C and H respectively. Inlet and outlet water flow is indicated with I or O and the numerical value 1 or 2 describes adsorber beds.

Adsorber bed is a finned tube heat exchanger having adsorbent packing and this bed is inserted into

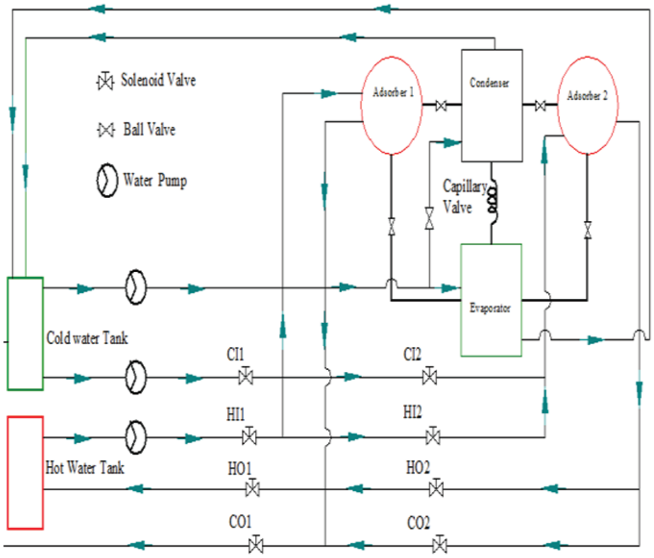

Figure 3: Schematic diagram of the experimental test setup of Double bed adsorption cooling

Figure 4: Photograph of the test setup

the cylindrical metallic vessel which forms the part of ARS. The adsorber bed can be heated or cooled by circulating hot or cold water. Condenser is similar to the adsorbent bed with no adsorbent filling. Evaporator is a vessel to which known volume of refrigerant can be filled which is subjected to cooling effect during the operation of the system. This cooling effect can be taken by circulating the water via a heat exchanger coil immersed in the refrigerant having its ends outside.

3.1. Experimental Procedure

Evaporator is filled with a refrigerant of definite quantity and the system is evacuated. Bed 1 and bed 2 are alternately subjected to adsorption and desorption by circulating hot water and cold water respectively for the desirable time. The cold water circulation through the condenser is continuous. After the particular span of time, bed 1 is put through desorption and bed 2 is put through adsorption. The same procedure is repeated.

In ARS the evaporator reaches lowest value of temperature if the cold produced is not used for cooling an external heat load, it is referred to as the condition of no-load where no refrigeration power is produced. Refrigeration effect is produced when the system is subjected to an external heat load by circulating the water. Where the circulated water experiences heat loss by giving its heat to the evaporator and decreases in its temperature and this is called load condition. At different flow rates of water through the evaporator coil, refrigeration effect is evaluated. Pumps are used to circulate the hot and cold fluids to the different components of the system. The system is evacuated at regular intervals using vacuum pump.

4.0 Results and Discussion

The variation in temperature at different components of ARS with respect to time under different conditions for silica gel-water and activated carbon-methanol are discussed as follows.

The temperature variation for different components using silica gel-water and AC-Methanol is shown in Figure 5 and 6 respectively. Under no load condition the minimum temperature observed in the evaporator are 11°C and 2°C respectively for silica gel and activated carbon based system respectively.

Under load condition the effect of operating parameters on COP for both silica gel-water and AC-Methanol working pairs are discussed in the following lines. Cooling capacity and COP are obtained with following equations. Cooling Capacity = m× Cp × (Ti – To) Where m, Cp, Ti and To represents mass flow rate, Specific heat, inlet and exit temperatures of flowing water through the evaporator coil.

COP = Cooling capacity/Heat input

The effect of temperature of hot water supplied to the adsorber on performance of the system is indicated in Figure 7. It is observed that, the COP increases with increase in temperature of hot water for both working pairs. This is due to the fact that the water vapour is desorbed at faster rate at the higher desorption

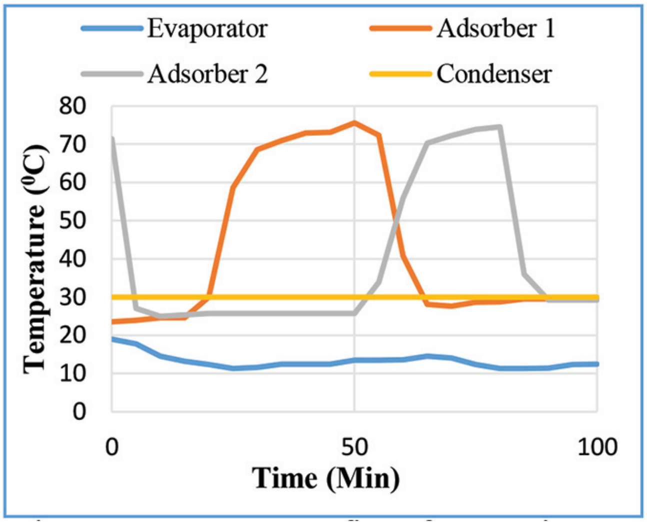

Figure 5: Temperature profiles of adsorption and desorption under no load for Silica gel-water

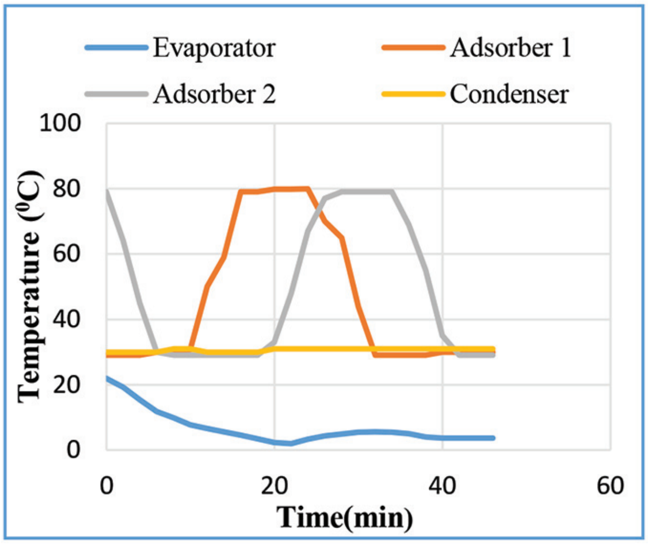

Figure 6: Temperature profiles of adsorption and desorption under no load for AC-Methanol

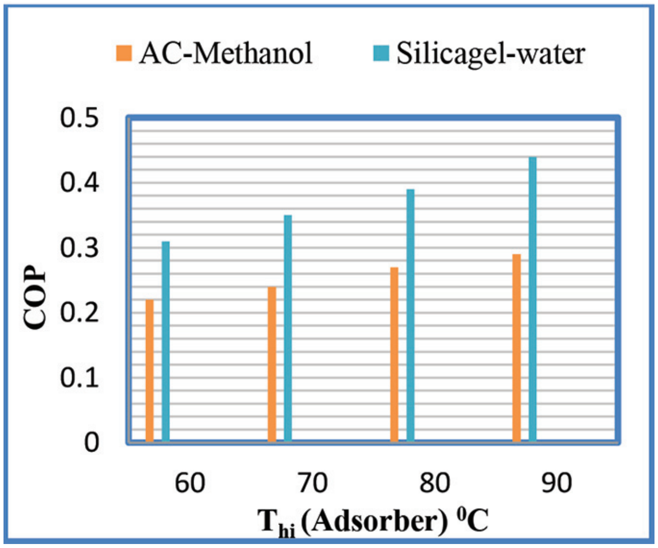

Figure 7: Effect of inlet temperature of hot water to adsorber

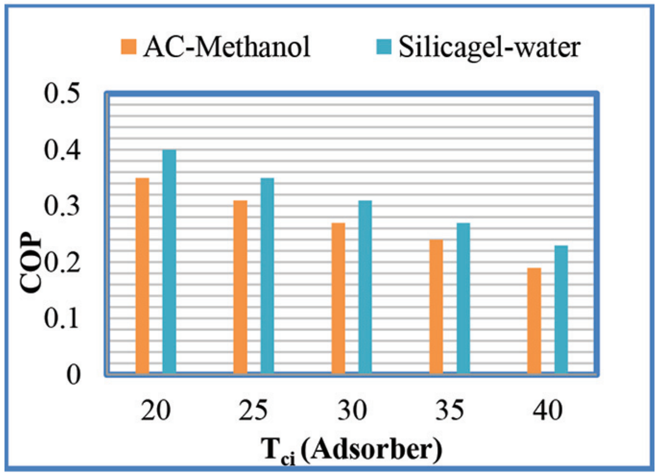

Figure 9: Effect of cold water inlet temperature

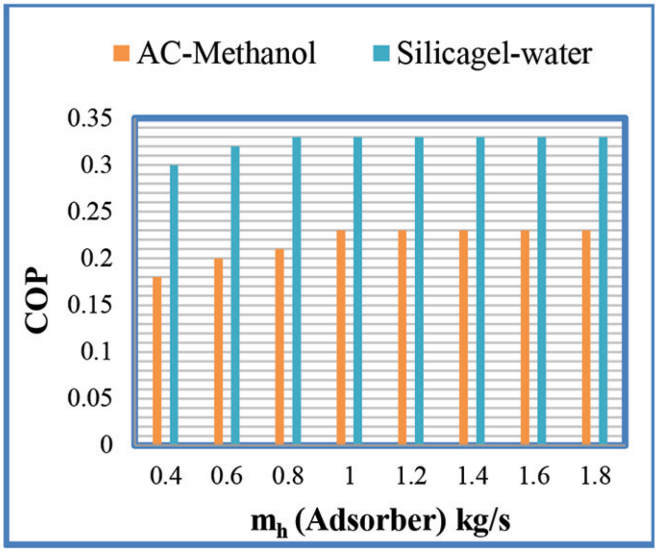

Figure 8: Effect of hot water flow rate to adsorber

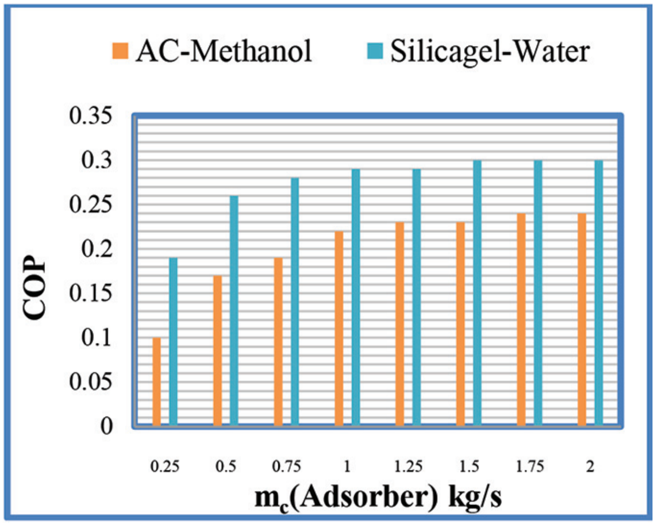

Figure 10: Effect of mass flow rate of cold water to adsorber

temperature thereby making more water vapour to be adsorbed during the next cycle of adsorption process.

Figure 8. reveals the influence of flow rate of hot water to the adsorber on COP. Increase in flow rate of hot water increases the value of COP because increase in hot water flow will enhance the heat transfer in desorber bed which makes more vapours to be desorbed and also increases the accumulation of more vapours during the next adsorption process. The increase of COP is marginal above some optimum value of flow rate.

Figure 9 indicates the effect of temperature of cooling water supplied to the adsorber on COP. As observed from the graph, lower temperatures of cooling water at inlet achieves higher values of COP because of the adsorption of more quantity of water vapour on the adsorbent bed since the low temperature promotes adsorption.

The influence of mass flow rate of cold water on COP is shown in Figure 10. As the cooling water flow rate increases, the COP shows increasing tendency because it cools down the adsorber bed very quickly which allows more vapours to get adsorbed. This trend is followed up to some optimum flow rate and afterwards the performance gets saturated.

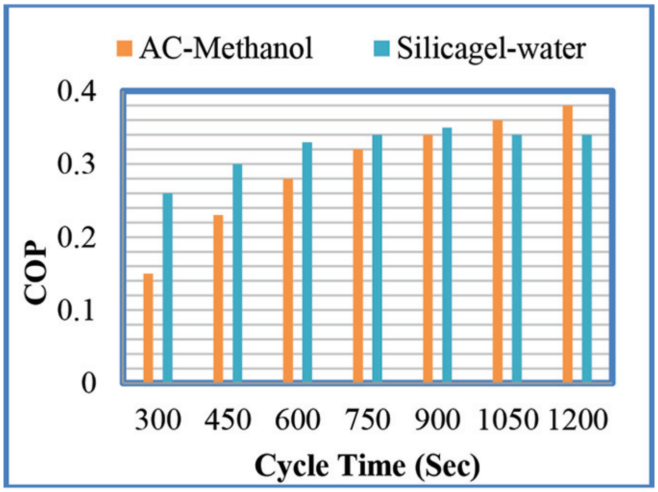

Figure 11: Effect of Cycle Time

As shown in Figure 11, the COP for both the working pairs shows the increasing trend with increase in cycle time because of the increase of adsorption and desorption time. COP gets saturated beyond some cycle time and starts decreasing due to the reduction in cycle average cooling capacity for the same heat input.

5.0 Conclusions

The experiments are conducted on solar assisted two bed adsorption refrigeration system using silica gel-water and activated carbon-methanol as working pairs and the cooling effect is produced by varying the operating conditions. For no load condition, the minimum temperature obtained is 11^{o}C and 2^{o}C in the evaporator respectively for silica gel and activated carbon based system for the executed cycle time. The obtained COP for both the working pairs was in the range of 0.1–0.4 under various operating variables considered. The COP of silica gel water pair is higher than the Activated Carbon-Methanol pair because the latent heat of vaporization for silica gel-water pair is higher than that of Activated Carbon-Methanol. It is very much required to maintain the system under low vacuum pressure without any leak and the same is very difficult to maintain for long duration of time since the system is bulky. In the present work, heat input required to operate the system is in the form of hot water and the same is obtained partially from solar water heater thereby minimizing the usage of electricity. Many HVAC industries are taking part in reducing carbon emission and solar assisted adsorption systems will have good market potential in future. From the present studies, it is suggested that the solar assisted adsorption refrigeration is feasible to produce cold and can be used as an alternative to conventional cooling in order to reduce its negative environmental impact. There is still a lot of scope for the study of adsorption cooling for enhancing the performance of the system and Experimental and Simulation studies can be carried out to achieve the same with optimum process variables.

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