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Effect of operating conditions on the performance of adsorption solar cooling run by solar collectors

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Abstract

Adsorption solar cooling appears to have prospect in the tropical countries. The present study investigates the effect of operating conditions on the performance of solar powered adsorption chiller for the climatic condition of Dhaka (Latitude $23°46'$ N, Longitude $90°23'$ E). A set of mathematical equations has been utilized to investigate the performance of the system numerically. Based on the solar radiation data, it is seen that at least 13 collectors (each of area $2.42\ m^2$) are essential to achieve the required heat source temperature in the hot and humid months. It appeared during the investigation that the unit provides the cooling capacity around 10 kW at noon with base run conditions, while the system provide the solar COP around 0.35. As the cycle time has a major effect on heat source temperature as well as on system performance, it is observed that there is an optimum cycle time for the collector size. Also, the performance of the chiller can be improved by controlling the chilled water flow rates. Therefore, it may be concluded that the collector size may be reduced by setting the optimum cycle time and the chilled water flow rate.

Keywords: Adsorption; Solar heat; Renewable energy; Air-conditioning.

Nomenclature

A	Area (m²)
c_p	specific heat (J/kgK)
I	solar radiation (W/m^2)
$\dot{m}$	mass flow rate (kg/s)
t	time (S)
T	temperature (K)
Subscripts	
chill	chilled water
f	heat transfer fluid
n	number of collector

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1. Introduction

Increasing population, global warming and power crisis are the burning issues of the developing countries of the twenty first century. Most of the space cooling or air-conditioning technologies use conventional energy sources as well as use global warming gases. It is getting essential to look for alternative energy sources and environmentally benign gases for this system. Nowadays, adsorption refrigeration and air conditioning cycles have drawn considerable attention due to its ability to be driven by low temperature heat source and for the environmental aspects as it uses environment friendly refrigerants. The advantage and development of adsorption cycle is widely studied by Meunier [1]. Extensive studies about adsorption refrigeration and air conditioning cycles have been conducted by various researchers for the development of adsorption technology. The studies mainly focused on either to enhance COP value of the system, such as, advanced cascaded cycle Meunier [2] and thermal wave cycle Shelton et al [3] or to improve system cooling capacity, such as, mass recovery cycle Wang [4] and Akahira et al. [5] and reheat two-stage cycle Alam et al. [6]. Advanced cycle could be also designed for better utilization of heat source, such as multi-bed system [7] and for utilization of low temperature heat source, such as, three-stage cycle [8] and two-stage cycle [9].

As adsorption cooling system can be driven by low heat source temperature, it could be effective to utilize solar heat. In this context, Sakuda and Suzuki [10] studied the simultaneous transport of heat and adsorbate in closed type adsorption cooling system utilizing solar heat in which authors proposed a lumped parameter model to predict the performances of the system. Solar ice making with adsorption technology has been also extensively studied by Leite and Daguenet [11] and Boubarkri [12]. Yang and Sumanthy [13] exploited lumped parameter model for two beds adsorption cycle driven by solar heat where flat plate collector is used. Clausse et al. [14], considered the models of whole units of a residential air conditioning sytem to investigate the performances of the system for the climatic condition of Orly, France. Recently, Alam et al. [15] studied the silica-gel water adsorption cooling cycle with direct coupling of solar collector under the climatic condition of Tokyo.

A tropical country like Bangladesh has prospect in utilizing solar energy as a driving source for adsorption refrigeration and air conditioning system. In preservation of medicine and food at the rural and remote places, solar heat driven adsorption refrigeration cycle could play a major roll for Bangladesh. From this point of view, Rifat et al. [16] studied adsorption cooling system for the climatic condition of Dhaka. The present study investigates the effect of some important operating system on the performances of the solar heat driven adsorption cycle.

1.1.Principal and operational process of the system

A two-bed conventional adsorption cooling cycle driven by solar heat has been considered. Silica gel-water pair as adsorbent/adsorbate and basic adsorption cooling cycle has been considered in the present study. There are four thermodynamic steps in the cycle. Two adsorption beds, an evaporator, a condenser, 13 solar collectors and a cooling tower are connected in the system. The schematic of the adsorption cooling with solar collector panel is presented in Fig 1. The adsorber (A1/A2) alternatively connected to the solar collector to heat up the bed during preheating and desorption-condensation process and to the cooling tower to cool down the bed during pre-cooling and adsorption-evaporation process. The cooling source temperature is considered to be ambient temperature. The heat transfer fluid from the solar collector goes to the desorber and returns the collector to gain heat from the collector. The valve between adsorber and evaporator and the valve between desorber and condenser are closed during pre-cooling/pre-heating period. While these are open during adsorption-evaporation and desorption-condensation process. Logical programming language FORTRAN with Compaq Visual Fortran compiler has been exploited to obtain the numerical solution of the proposed model.
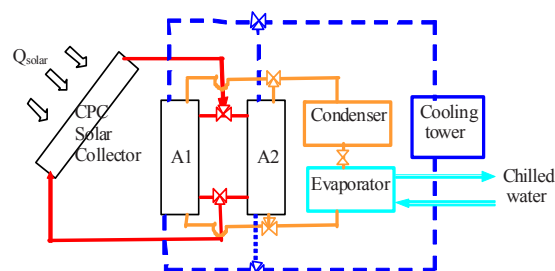

Fig. 1. Schematic of the solar driven adsorption space cooling system.

1.2. Mathematical model

It is assumed that the temperature, pressure and concentration throughout the adsorbent bed are uniform. The mathematical model is same as Alam et al [15].

The cyclic average cooling capacity is calculated by the equation

$$CACC = \dot{m}_{chill} C_{chill,f} \left(\int_{beginofcycletime}^{endofcycletime} \left(T_{chill,in} - T_{chill,out} \right) dt \right) \Big/ t_{cycle} \tag{1}$$

The cycle *COP* (coefficient of performance) and solar *COP* in a cycle (COP_{sc}) are calculated respectively by the equations

$$COP_{cycle} = \frac{\int_{beginofcycletime}^{endofcycletime} \dot{m}_{chill} C_{chill,f} \left(T_{chill,in} - T_{chill,out} \right) dt}{\int_{beginofcycletime}^{endofcycletime} \dot{m}_f C_f \left(T_{d,in} - T_{d,out} \right) dt} \tag{2}$$

$$COP_{sc} = \frac{\int_{beginofcycletime}^{endofcycletime} \dot{m}_{chill} C_{chill} \left(T_{chill,in} - T_{chill,out} \right) dt}{\int_{beginofcycletime}^{endofcycletime} n.A_{cr} I dt} \tag{3}$$

1.3. Simulation procedure

Measured monthly maximum radiation data for Dhaka (Latitude $23°46'$ N, Longitude $90°23'$ E) has been used. This data is supported by the Renewable Energy Research Center (RERC), University of Dhaka. Results are generated based on solar data of Dhaka in the month of April. Chiller configurations are same as Saha et al. [18] and collector data are same as Alam et al. [15]. During April in Dhaka, the sunrise time is at 5.5h and sun set at 18.5h, whereas maximum temperature is 34°C and minimum temperature is 24°C. The maximum solar radiation in this month is about 988 W/m^2 . The detail design and operating conditions input data are given in Rifat et al. [16], where the prospect of solar adsorption cooling has been studied for the climatic condition of a tropical place Dhaka.

Implicit finite difference approximation method is applied to solve the set of differential equations. The tolerance for all the convergence criteria is 10^{-4} . The program runs for consecutive several days (as it is set). After a few days the system appears to its steady state. In this paper all results are presented for the day when the system appeared at its' steady state, i.e. all output appeared to be identical for the consecutive days. The detail description of simulation is available in Alam et al. [15].

2. Result and discussion

Thirteen collectors, each of area 2.415m^2, has been taken into consideration for the present analysis. The number of collectors has been decided based on Rifat et al. [16], where a case study had been conducted to examine the performance of solar heat driven adsorption cooling unit based on the climatic condition of Dhaka. According to this study, for the month of April, 13 collectors with optimum cycle time 1000s are sufficient to run the solar cooling unit. However, later Rifat et al. [17] while investigating the prospect of the said solar unit, had concluded that the optimum cycle time and performance varies with various seasons of the year. The program is allowed to run with different cooling water inlet temperature and taking different amount of supply of chilled water to the evaporator. The rest of the operating conditions are same as Rifat et al. [16].

At first, the number of collectors and cycle time were determined for base run conditions to achieve driving source temperature level which is around 80°C for silica-gel water pair [18-19]. Then the investigation was extended to check the

performances of the system of the present study. Figure 2 presents the temperature histories of collector outlet and bed for cycle time 1000sec, the collector outlet temperature reaches 87°C while the bed temperature reaches 85°C. Rifat et al. [16] showed that when the cycle time is reduced from 1000sec the bed temperature is below 75°C. Therefore, 1000sec, the optimum cycle time is taken into consideration for running the chiller when 13 collectors are in use. The temperature of cooling source is considered as ambient temperature that is 31°C and chilled water inlet temperature is 14°C. The volumetric flow rate of chilled water to evaporator is 0.7 kg/sec.

Figure 3 depicts the effect of cooling source temperature on the performances of the chiller. For the time being it appears that the cooling capacity increases when the cooling source temperature decreases. The reason of the increase in the cooling capacity is due to the increase of the adsorption capacity of silica gel bed as the temperature lift (difference between hot and cooling source temperature) increases. The same trend has been observed for cycle COP and Solar COP in a cycle. However, the coefficient of performance of the chiller increases until late afternoon and suddenly start to decline and this trend for 28°C cooling source temperature is higher than the other cases. It happens due to higher cooling capacity in late afternoon comparing the heat input at that time. The chiller is capable in producing 10 kW cooling at noon when the cooling source temperature is considered as 31°C.

The effect of chilled water flow rates on the performance of the chiller are shown in Fig 4. This figure shows that the performances (CACC, COPcyle and COPsc) of the chiller are proportional to the chilled water mass flow rates at least until 5pm. However, opposite trends are shown after 5pm. If we notice Equations (1)-(3), it is seen that the performances are directly proportional to chilled water mass flow rates as well as to the temperature difference between chilled water inlet and outlet. At the same time, chilled water outlet temperature is strongly influenced by the chilled water flow rates. This effect is visible in Fig 5.
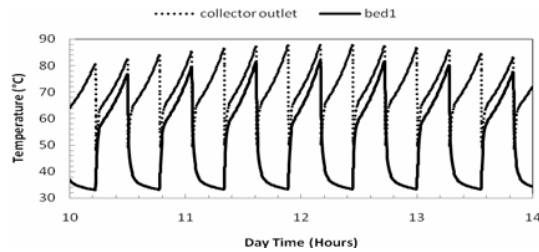

Fig. 2. Temperature histories of collector outlet and bed for 13 collector cycle time 1000s
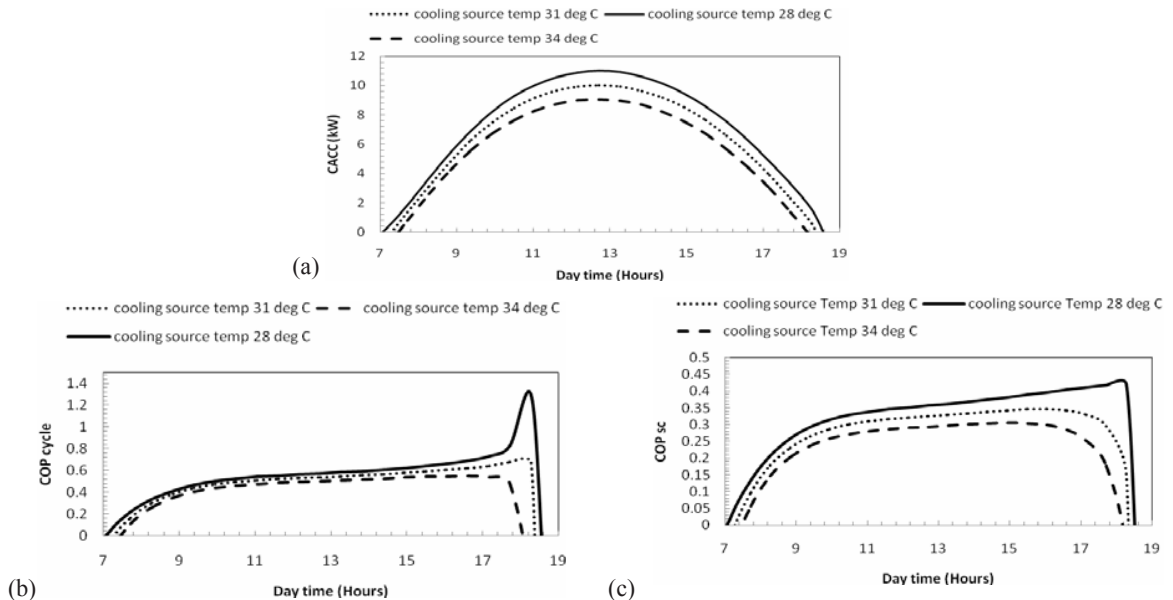

(a)

(b)

(c)

Fig . 3. Performance of the chiller for different temperature cooling water supply to the adsorber (a) cyclic average cooling capacity, (b) COP cycle and (c) COP sc

Chilled water outlet temperature histories of 13 collectors with different volumetric flow rate have been depicted in Fig 5. It is seen that the lower the flow rates of chilled water the lower temperature of chilled water outlet. Chilled water outlet is importmant for the end user as outlet chilled water is utilized for space cooling. It is seen that Cooling capacity and COP are increasing with the increase of chilled water mass flow rate. But at the same time, increase in chilled water mass flow rate causes increase in chilled water outlet tempertaure which may cause uncomfort to enduser. Therefore, it is important to select appropriate chilled water flow rate so that the system can provide better performance and appropriate chilled water outlet temperature.
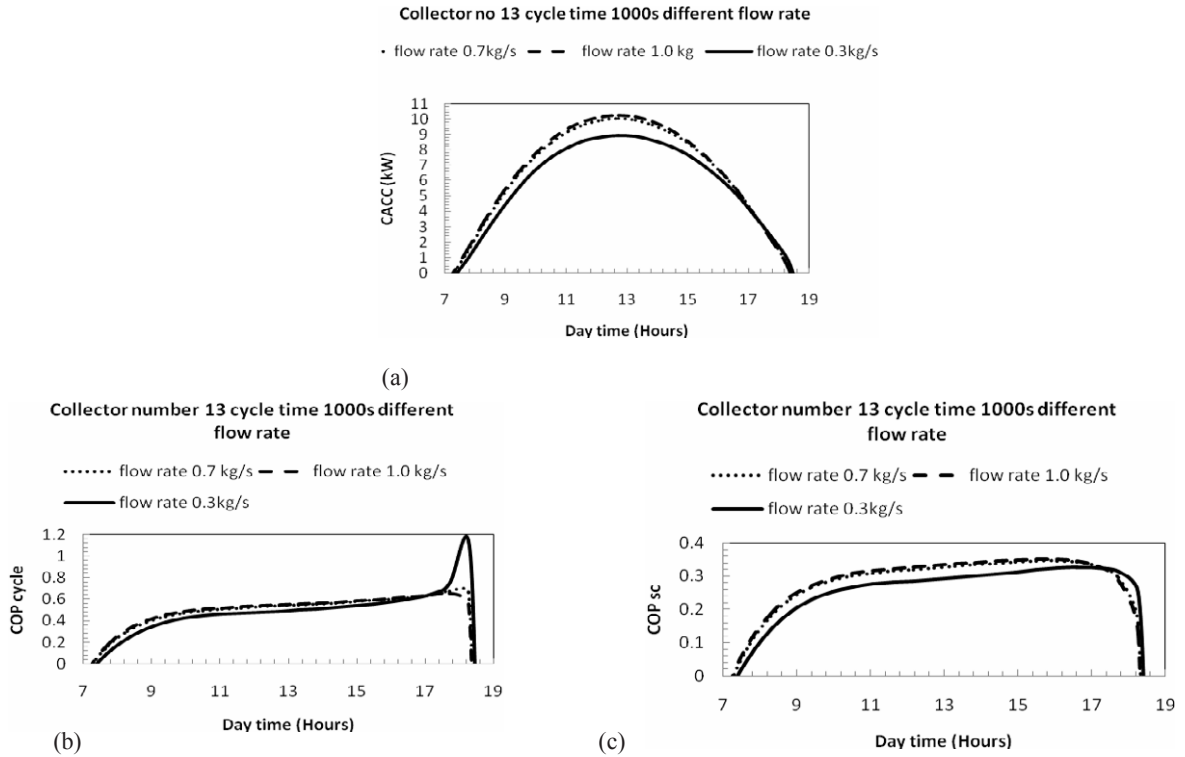

(a)

(b)

(c)

Fig. 4. Performance of the chiller with 13 collectors cycle time 1000s with different chilled water flow rate (a) CACC, (b) COP cycle and (c) COP sc
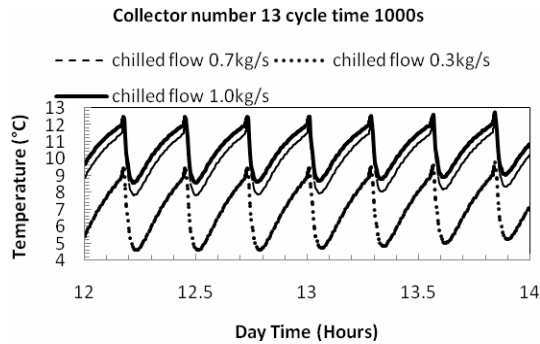

Fig. 5. Chilled water outlet temperature for 13 collectors different chilled water flow rates

3. Conclusion

An analytical investigation has been conducted to examine the effect of operating condition on solar driven adsorption air-conditioning system for the climatic condition of Dhaka. 13 collectors each of area 2.415 m^2 with optimum cycle time 1000sec has been studied with different temperature of cooling source and chilled water flow rates for base run conditions.

Based on the investigation the following conclusions can be drawn.

- Cooling capacity and COP increases with the decrease of cooling source temperature.
- COP of the chiller can be improved by increasing the flow of the chilled water to the evaporator, at the same time it causes increase in the temperature of chilled water outlet.
- Chilled water outlet temperature could be controlled by controlling the flow rates of chilled water.
- At least 31°C cooling water and 14°C chilled water flow of 1 kg/sec is needed to ensure 10kW cooling capacity, 0.6 cycle COP and 0.35 solar COP for 13 collectors with optimum cycle time 1000sec in base run condition at noon.

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