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Switching Time Effect in Solar Adsorption Air Conditioning System in Hot and Humid Climate

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Abstract

This study is presented to study the effect of switching time in solar adsorption air conditioning system designed and tested in hot and humid climate. An experimental investigation was proposed to found out the optimum switching time between the adsorption beds when the system was automatically switching between hot and cold phase in a transient time. The simulation analysis of this study was validated by the experimental work of a prototype tested and fabricated to handle the effect of all major parameters effecting the operation of the solar adsorption system to reach the optimum design. The effect of adsorption/desorption switching time for each cycle with respect to cooling capacity and the coefficient of performance values was presented. The value of the switching time was in the range of 2.5 to 10 min, where the optimum value was obtained in the experimental work. This optimum value is found to be variable with respect to cycle time and it is varied according to hot and cooling water inlet temperatures to the adsorption beds. The solar adsorption air conditioning system was operated with 10 cycles under different switching time, where the switching time starts at a value of 60 sec in the first cycle, while its value increased to 160 sec in the second cycle. After optimizing the operating parameters of the system, it was found that the optimum time for each cycle is 10 min and it consumes 10 cycles to make the outlet chilled water temperature that pass through the fan coil air conditioning system reached 16.3°C. Therefore, it is concluded that the value of switching time is not constant as the system could not reach the steady state condition in each cycle.
Keywords: Renewable energy; Solar air conditioning; Adsorption;

1. Introduction

In recent years, Solar cooling is considered as one of the most important application in solar energy due to its benign and cost reduction ability [1]. In last decades, many researches have been made to investigate the solar energy. One of these investigation processes is the solar cooling in both absorption and adsorption systems [2]. The solar adsorption cooling systems is considered as very important technology for food and vaccine preservation especially in some regions or countries were the source of electricity is almost zero [3]. Some advantages of this cooling system are the small size compared to other conventional cooling systems, no moving parts, utilizing low grade temperature as heat source, and are environmentally technology [4].

According to the simplicity of the adsorption cooling systems, this could be an advantage above the absorption systems. As in absorption systems, the utilization of some mechanical devices to make an interaction between the solution and the refrigerant [5]. While in adsorption systems, there is no mechanical parts required. For this reason and others, the consumption of mechanical energy is very low; therefore, the reduction of electricity usage can be minimized [6].

Many researches have been done in the adsorption cooling technology, M. Khan et al. [7] studied the three beds adsorption cooling cycle with the utilization of waste heat. The heat source temperature was in the range from 60 to 90ºC, with a cold water temperature of 30ºC. The study compared the three beds system with and without mass recovery. It was found that the efficiency of the system with the mass recovery was much higher than without the mass recovery. H. Luo et al. [8] built an adsorption cooling system with solar driven source of heat with low grade temperature. The system contained tow adsorption beds with two evaporators. A daily coefficient of performance of 0.096 to 0.13 was obtained in a period of three months operation.

The optimization of the adsorption refrigeration system driven by solar radiation was presented by K. Alam [9]. A thermodynamic optimization for the system was developed using an internal model, in which the COP obtained was found to be increased as the stagnation temperature of the solar collector was increased, and with the increasing of required temperature. for a large scale adsorption air conditioning systems, Antonio et al. [1] represented a 20kW central solar adsorption air conditioning system, cooling an area of 110m^2.

The COP of the system was found to be 0.6. E.E. Anyanwu and C.I. Ezekwe [4], designed a solar adsorption refrigeration system using activated carbon with methanol as the refrigeration pair. The system contains a flat plate collector, steel condenser with spiral copper tube immersed in the water. The cold water inlet temperature range was 24-28ºC with an evaporator temperature about 1-8.5ºC.

2. Problem identification and basic principle

The world is emerging from the worst economic crises in decades, and several countries have thus signed the Copenhagen Accord (UN Conference on Climate Change) to reduce greenhouse gas emissions. [International Energy Agency IEA, 2010]. Renewable energy sources are expected to play a central role in moving the world into a secure, reliable, and sustainable energy path. The potential of renewable energy is unquestionably large. However, the rate at which it contributes to the world's energy needs depends critically on government support to make renewable energy cost-competitive with other energy sources and to simulate technological advances in the field.

Many countries are blessed with conventional energy resources, the most prominent of which are crude oil, natural gas, and coal. Some of the substitutive potentials for renewable energy-resources are hydro, solar, wind, biomass, wave or tidal and geothermal energies. Solar radiation is the most durable, and is a clean source of energy. Thus, many technologies use this source of energy compensation to address the rise in fuel prices. One such technology is solar cooling, which has become one of the most effective implementations that utilize this type of free energy source. Solar cooling systems are regarded as the most environmentally safe because of their zero rate of ozone depletion potential (ODP) and global warming potential (GWP) in comparison with other standardized models, such as vapor compression cycles. Adsorption cooling systems are also environmentally friendly systems with several advantages, including small scale, lack of moving parts, non-corrosiveness, ability to run at low source temperature, noiseless operation, and low operation and maintenance cost. Moreover, these systems entail special design requirements, large scale and volume, and generally low COP and cooling power.

The effect of switching time on solar adsorption air conditioning system had played a major role in the design and fabrication of this technology. Thus, to ensure a reasonable optimum boundary condition of the system, the switching time is evaluated by several researches. But in fact, the value of switching time has been fixed at 5 min between each cycle. This value cannot be applied on all the system as this value depends on the steady state status of the system controlled by the effective parameters.

3. Methodology

The thermodynamic analysis of the solar assisted adsorption refrigeration system using activated carbon fiber and ethanol as the refrigeration pair has been presented. The effect of the operating parameters such as input temperatures and flow rates on the cooling capacity and the coefficient of performance of the system are described also. As discussed before in chapter two, the heat source temperature is very important in the adsorption cooling systems, therefore, one of the main advantages of the system is to find the optimum values of operating temperatures and flow rates.

Figures (1) and (2) show the schematic diagrams of the two beds adsorption refrigeration cycle. The system consists of two adsorption beds, a condenser, and an evaporator. The adsorption beds, namely (*BED1* and *BED2*) with four operating phases, namely (Phase I, Phase II, Phase III, and Phase IV).

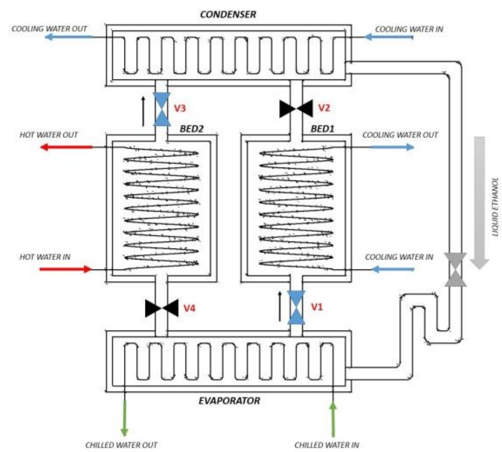

Fig. 1 Schematic diagram of two bed adsorption system (Phase I)

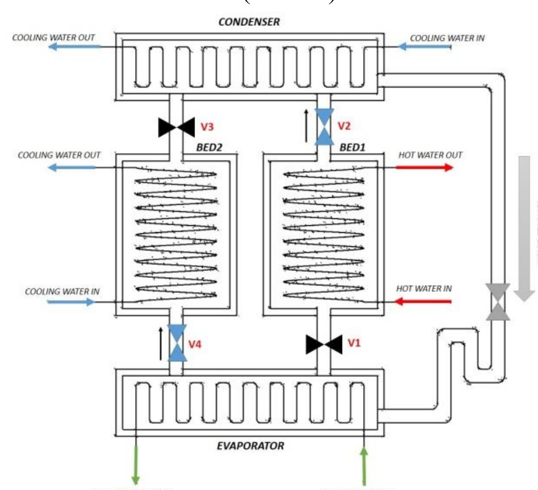

Fig. 2 Schematic diagram of adsorption system (Phase III)

In phase I, both valves V1 and V3 are opened, with V2 and V4 are closed. The adsorption bed *BED 1* in a process called adsorption, as well as the evaporator, while *BED 2* and condenser are in desorption process. The adsorption process in *BED 1* and evaporator takes place when the pressure is equal to the evaporating pressure P_{evap}, thus the adsorbent (ethanol) is evaporated at the evaporator to reach the evaporation temperature T_{evap} and gained heat from the chilled water comes in. After that, the evaporated ethanol is adsorbed by the adsorbate (activated carbon fiber ACF) where the heat is removed by the cooling water. At a pressure equal to condensation pressure P_{cond}, desorption – condensation process occurs. The hot water comes in and entering the second adsorption bed *BED 2* and heated it. The ethanol vapor cooled down to the condensation temperature T_{cond} inside the condenser by passing the cooling water in which it will remove the heat of condensation. On the other hand, when the concentration of ethanol in the adsorption and desorption process is near the equilibrium level, therefore, the cycle is continued while all the ethanol valves are closed (Phase II).

Phase II starts when the hot and cooling water flows are changing their directions in order to get the isosteric heating and isosteric cooling processes at *BED 1* and *BED 2*, respectively. The valves between *BED 1* and condenser as well as between *BED 2* and evaporator are opened when the pressure of adsorption and desorption process are both equal to the condensation and evaporation pressure P_{cond} and P_{evap}, respectively.

In phase III, valves 2 and 4 are opened (Figure 2), while valves 1 and 3 are closed. The condenser and *BED 1* are in desorption process, while the evaporator and *BED 2* are in adsorption process. In this phase, all the ethanol valves are opposite in operation to phase I.

Phase IV takes the action in which the isosteric heating process in *BED 2* or the isosteric cooling process in *BED 1* starts, which is opposite in operation to phase II.

The adsorption rate is estimated using equation (1). Glueckauf [10] found a relation between $k_s a_v$, and the constant of time diffusion D_s/R^2_p this is given in equation (2). El-Sharkawy et al. [11] studied the kinetics of the activated carbon fiber/ethanol pair using the Thermo-Gravimetric Analyzer (TGA). It was found that the numerical value of F_o was 11. The surface diffusion D_s can be found using equation (3). The values of E_a and D_{so} were found to be 306.7×10^3 and 1.8×10^{-12} respectively.

$$\frac{\partial w}{\partial t} = k_s\, a_v\, (W - w) \tag{1}$$

$$k_s\, a_v = F_o \frac{D_s}{R_p^2} \tag{2}$$

$$D_s = D_{so} \exp\left(-\frac{E_a}{RT}\right) \tag{3}$$

El-Sharkawy [12] calculated the isosteric heat of adsorption for the activated carbon fiber/ethanol pair, as it can be described in the following equation:

$$\frac{(\Delta H_{st} - h_{fg})}{E} = [\ln(W_o/W)]^{1/n} + a\,(T/T_c)^b \tag{4}$$

Where, a= 6.717, b= 9.75.

For the analysis of the solar adsorption system, a simple lumped model proposed by Li Yong [12] was used:

$$\left(MC_p\right)_{eff}^{bed} \frac{dT_i^{bed}}{dr} + \left[mC_p\right]_{i-phase} \frac{dT_i^{bed}}{dt} = \emptyset M_{acf} \left(\frac{dw_i^{bed}}{dt}\right) (\Delta H_{st}) - \left(\dot{m}\, C_p\right)_j \left(T_{j,o} - T_{j,in}\right) \tag{5}$$

In the above equation, $\emptyset = 0$ for isosteric cooling and heating, and $\emptyset = 1$ for adsorption/desorption, i indicates adsorption/desorption bed and j the cooling/heating source. The left hand side of equation (6) represents the rate of change of internal energy, where this rate occurs due to the thermal mass of activated carbon fiber, ethanol, as well as the heat exchanger during the adsorption/desorption process. The first term in the right hand side of the above equation represents the release of adsorption heat during desorption process, while the second term represents the total heat released to the cooling water during adsorption. The first term represents the heat input during desorption process, and the second term may represent the heat released by the hot water during desorption process. Therefore, for the small difference in temperature that occur during cooling/heating fluid such as water, the outlet temperature of the heat source is good enough to be modeled by the Logarithmic Mean Temperature Difference (LMTD) method, this is given by the following equation:

$$T_{j,o} = T_i^{bed} + \left(T_{j,in} - T_i^{bed}\right) exp\left[\frac{-(UA)_i^{bed}}{\left(\dot{m}\, C_p\right)_j}\right] \tag{6}$$

In the above equation, A^{bed}, and U^{bed} represent the heat transfer area and the overall heat transfer coefficient respectively.

4. Results and discussions

The switching time has always been an important parameter in the adsorption cooling systems. The definition of the switching time could be obtained when the BED reaches the saturated temperature whether it is in hot or cold position.

The experimental results of the solar assisted adsorption air conditioning system have been presented with the most important operating parameter, which is the switching time. Many researchers in the field of adsorption system refrigeration and air conditioning systems were given an opportunity to the switching time and its influence on the performance of the cooling system. In this study, different experimental procedures according to the switching time were obtained. Then, the results were compared with each other to conduct the effect of varying the switching time in the adsorption/desorption process. The first procedure was set to fix the switching time between each cycle to 10min, where the (transient time) between the cycles is 10min to let the temperature profiles return to the optimum values.

The second experimental procedure was to decrease the switching time between the cycles to 7min. It is found that when decreasing the switching time from its maximum value (10min), then the adsorption/desorption process could not be completed. Therefore, it is very difficult to get an optimum switching time due to the actual experimental work, while in the simulation always the switching time is fixed at a certain value.

The variation of the switching time between the cycles actually depends on the time that the BED consumed to reach the optimum value of hot or cold temperature in order to switch and pass the Ethanol to them. In Figure 3, the cycles show the temperature profile of BED1 and BED2 for a 10 cycles experiment, where the switching time was set to be 13min to obtain a fixed value of hot and cooling temperature to each BED.

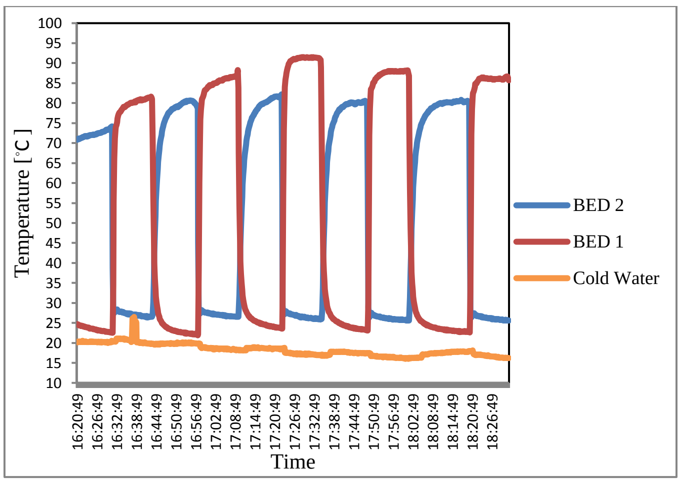

Fig. 3 Temperature profile for 10 cycles with 13min switching time

From the figure above, it can be noticed that the hot and cooling water for each cycle in each BED is almost has the same profile. After each cycle the temperature profile for BED1 or BED2 has the same input and output values of temperature. It has been conducted that BED2 has a lower temperature than BED1; this is due to the losses in heat as BED2 is located far from the heat source. While in BED1, the temperature is slightly higher as BED1 is very close in position to the hot water source.

In order to get more detailed information about the effect of switching time on the adsorption system, the cycles of each run of the system were described separately. Figure 4 represents the first two cycles of the system (out of 10 cycles), where the switching time between cycle 1 and cycle 2 is represented by the hash line area. The first cycle starts by entering hot water at about 70˚C to BED2, while BED1 with cooling water inlet at 25˚C. It is noticeable that both inlet temperatures remain almost constant with only slight increase in hot water inlet temperature as the evacuated tube solar collector heat up the water. After 10min of first cycle, the switching time is considered about 1 min where BED1 inlet temperature is increased from 25˚C to 70˚C, while BED2 inlet temperature was decreased to be more than 27˚C. This difference in cooling water temperature between cycle 1 and cycle 2 is due to the heat generated by the previous hot water passing through BED2 in the first cycle. Figure 5 shows the second two cycles, where the figure represents both cycle 2 and 3 with switching time. The switching time in the second two cycles is longer than in the first two cycles (about 3 min), this is due to the fact that BED 1 was already in cold phase while BED2 was in hot phase. Therefore, BED1 is positioned close to the heat source (hot water inlet). For the next two cycles of the system (cycles 2 and 3), the switching time was decreased to 2 min (compared to the first and second two cycles). Figure 6 represents the switching time between each cycle in an adsorption system running for 10 cycles with 10 min period of each cycle.

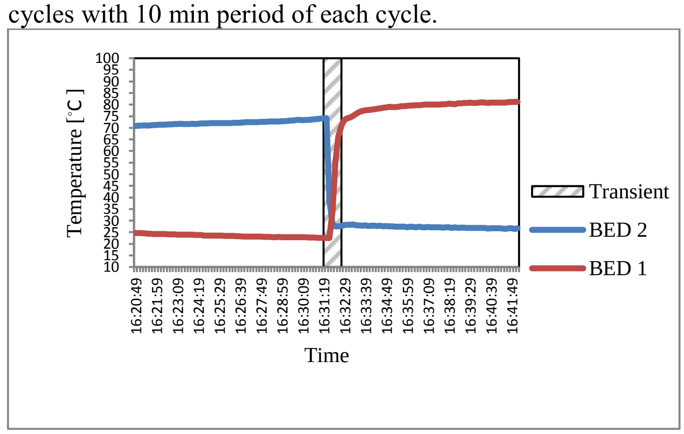

Fig. 4 Temperature profile of cycles 1 and 2 with switching time

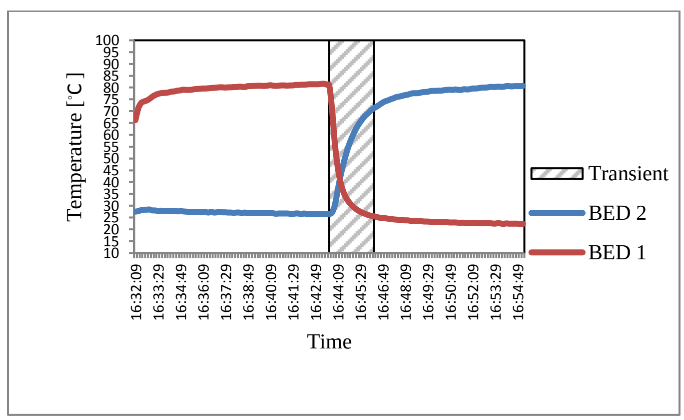

Fig. 5 Temperature profile of cycles 2 and 3 with switching time

The switching time between BED1 and BED2 is about 1 min in the case when BED1 is switched from hot phase to cold phase, while BED2 is switched from cold to hot phase. This is due to the fact that BED2 needs longer time to gain the heat as it is positioned slightly far from the main hot water inlet source. While in BED1, it has been noticed that when switching BED1 from cold phase to hot phase, the ability to gain heat is higher than in BED2, or on another word, the ability of releasing heat in BED2 is less than in BED1, (Figure 6).

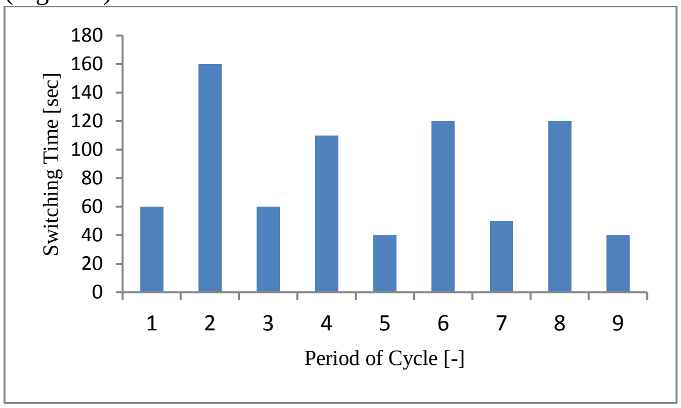

Fig. 6 Switching time values for each cycle period

6. Conclusions

The investigation and calculation of switching time effect on the performance of the system to get the optimum synchronization in time between switching, cycle, and transient times was presented in this paper. Different procedures was conducted in the experimental analysis with variable and fixed cycle time for the system in terms of 10 cycles per test. It was found that the optimum cycle time is 10 min for each cycle with switching time of 5 min; while it was found that varying the switching time until get the steady state conditions of temperatures in each adsorption bed could lead to increase the performance of the system. Whereas the temperature of the adsorption bed reaches its steady state position (saturation condition) as the temperature of the activated carbon fiber inside reaches 80°C and above. This leads to balancing the heat transfer rate between the adsorbent and adsorbate inside the bed. In this paper, it was concluded that the switching time between the cycles in the air conditioning adsorption systems cannot be constant at a value of 5 min or 10 min, but this value could be varied during all the cycles of the system.

Abbreviations

A	Area (m^2)
acf	Activated carbon fiber
ads	Adsorption
C_p	Specific heat capacity (J/kg K)
D_{so}	Pre-exponential constant (m^2/s)
E_a	Activation energy (J/kg)
F	Characteristic coefficient of solar radiation
i	Indoor
j	Index number of data
$k_s a_v$	Mass transfer coefficient (1/s)
$\dot{m}$	Mass flow rate (kg/s)
R	Ideal gas constant (J/kg K)
R_p	Fiber radius (m)
t	Time (s)
T	Temperature (K)
U	Overall heat transfer coefficient (W m^2/K)
w	Instantaneous uptake (kg/kg)
W	Equilibrium uptake (kg/kg)
W_o	Maximum uptake (kg/kg)
ΔH_{st}	Isosteric heat of adsorption (J/kg)

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Commonwealth Energy and Sustainable Development Network (CESD-Net)

CESD-Net is a major global initiative in energy and sustainable development. The objective of network is to promote energy and sustainable development in commonwealth countries.
Focussing on Multidisciplinary Research, Promoting Future Low Carbon Innovations, Transferring Knowledge and Stimulating Networking among Stakeholders to Ensure the UK Achieves World Leading Status in Energy and Sustainable Development. https://www.weentech.co.uk/cesd-net/

The 1st International Conference on Energy, Environment and Economics (ICEEE 2016) was held at Heriot-Watt University, Edinburgh, EH14 4AS, UK, 16-18 August 2016. ICEEE2016 focused on energy, environment and economics of energy systems and their applications. More than fifty eight delegates from 31 countries with diverse expertise ranging from energy economics, solar thermal, water engineering, automotive, energy, economics and policy, sustainable development, bio fuels, Nano technologies, climate change, life cycle analysis etc. made conference true to its name and completely international. During conference total 51 oral presentations and six posters were shared between delegates. The presentations showed the depth and breadth of research across different research areas ranging from diverse background. ICEEE2016 aimed:

- To identify and share experiences, challenges and technical expertise on how to tackle growing energy use and greenhouse gas emissions and how to promote sustainability and economical, cost effective energy efficiency measures.

In total 11 technical sessions and two invited talks both from academia and industry provided insight into the recent development on the proposed theme of the conference. Preparation, organisation and delivery of the conference started from July 2015 and further co-ordinated by vibrant team of Conference Centre, Heriot Watt University. Conference organisers would like to acknowledge support from the sponsors particularly World Scientific Publication ltd and its team members for the delivery of the conference. Organisers are also thankful to all reviewers who contributed during peer review process and their contributions are well appreciated. At the end and during vote of thanks following awards have been announced and we would like to congratulate all well deserving delegates.

- Best Paper –Academia: Amela Ajanovic, EEG, TU Vienna, Austria
- Best Paper – Student : Christian Jenne,University of Duisburg-Essen, Germany
- Best Poster – Student: Yoann Guinard, University of New South Wales, Sydney, Australia
- Best Poster – Academia: E. Salleh, Universiti Kebangsaan Malaysia, Malaysia
- Active Participation Award - Yoann Guinard, University of New South Wales, Sydney, Australia

At the end we would like to extend our gratitude to all of you for your participation and hopefully welcome you again during ICEEE2017.

Editors:
Dr. Singh is Senior Scientist at Indian Agricultural Research Institute, New Delhi, India. Her area of expertise are bio energy and bio fuels, environmental engineering, carbon accounting and renewable energy integration for rural development.
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