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Heating and Cooling Performance of Adsorber Bed Powered by Solar Lamps

Ibrahim Joseph Mwasubila[1], Cuthbert Z M Kimambo[1], Joseph H Kihedu[1] , Ole J Nydal[2]

1 Department of Mechanical and Industrial Engineering, University of Dar es Salaam

2 Department of Energy and Processing Technology, Norwegian University of Science and Technology

(Corresponding Author: mwasubila.ibrahim@udsm.ac.tz)

ABSTRACT

Adsorber bed is a source of driving power in the adsorption refrigeration system. Adsorber bed affects the performance of the system due to its role of initiating the refrigeration process through desorption. This paper investigates the adsorber bed's cooling and heating performance behaviors under varying experimental conditions. Specifically, the effect of opening or closing the top and bottom part of the adsorber bed. The adsorber bed system was heated to 120 °C and then cooled to 30 °C. The average air velocity used in the experiment was 0.5 m/s to reflect the real operating environment. The short time taken to heat the system was 1362 seconds while both the top and bottom parts of the adsorber bed were closed, while 5796 seconds was the shortest time to cool the system. The average ambient temperature when experiments were carried out was 21 °C. Different temperature values were observed in the adsorber bed box during the experimental process.

Keywords: adsorption refrigeration, adsorber bed, sorption and desorption, solar lamps and solar refrigeration

NONMENCLATURE

Abbreviations	
ARS	Adsorption refrigeration system
HVAC	Heating, Ventilation, and Air Conditioning
SCP	Specific cooling power
COP	Coefficient of performance
Ta	Temperature of adsorber bed
Te	Evaporator temperature
Tc	Condenser Temperature
NTNU	Norwegian University of Science and Technology

1. INTRODUCTION

1.1 Background

The adsorber bed is the main component of the adsorption refrigeration system and its function is the same as a compressor in a vapour compression refrigeration system. The performance of the adsorption refrigeration system depends on desorption capacity, condensation capacity and evaporation capacity. Among other factors, adsorption refrigeration systems operate by using heat sources, which can be either renewable or non-renewable energy sources. The main function of the heat is to initiate the desorption of adsorbate from solid adsorbent in the adsorber bed. For the desorption and adsorption process to take place, desorption and adsorption temperatures must be attained, respectively. However, the adsorption refrigeration system (ARS) has encountered performance challenges such as low coefficient of performance and specific cooling effect. As a result, the development of adsorption refrigeration systems has been in the laboratory for decades.

1.2 Adsorber bed performance

The adsorption refrigeration system faces the challenges of low specific cooling power (SCP), low power density and high initial investment costs, limiting its commercialisation and application. Adsorber bed design and dimensioning are critical criteria during adsorption refrigeration technology implementation and performance improvement. Such criteria greatly influence the heat loss or gain through the thermal conductivity of the entire system [1,2]. Continuous cooling in adsorption refrigeration systems (ARS) has led to the development of different designs of adsorber beds. These designs can be applied in industrial chillers, vehicle air condition systems, Heating, Ventilation, and Air Conditioning (HVAC) systems and food and vaccine

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preservations [3, 4, 5, 6, 7]. Performance improvement of ARS has led to the development and investigation of single-bed, double-bed and triple-bed systems. The utilisation of multiple adsorber beds has been shown to enhance the performance of adsorption refrigeration systems by mitigating the detrimental impact of temperature fluctuations in the evaporator, a recurring issue in various AR prototypes [8, 9, 10, 11, 12, 13]. In a double-bed refrigeration system, the adsorbers alternate between desorption and adsorption. This results in wasted refrigeration capacity and increased energy consumption, leading to low performance of ARS. A continuous adsorption refrigeration system using mass recovery was experimentally studied by Yin et al. [7], and results showed a 14.02% increase in COP. The comparison between the basic cycle and the mass recovery cycle is shown in Fig.1.

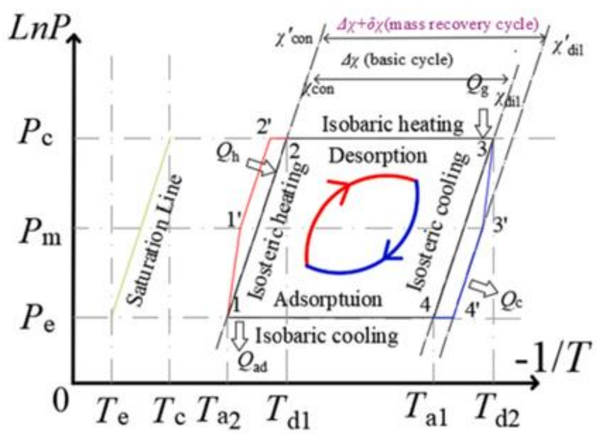

Fig.1. Comparison between basic cycle and mass recovery cycle

2. MATERIAL AND METHODS

2.1 Manufacturing of adsorber bed system

The adsorber bed system was designed, manufactured and tested in the laboratory. The sides of the adsorber bed box were insulated to prevent heat loss to the surroundings. A top part was made from a transparent material, allowing the simulated solar radiation to penetrate and cause heating of the adsorber bed plates. The bottom part/lid was insulated to prevent or allow heat loss during different experiments. Testing the system was conducted to ensure that the system operates as intended.

2.2 Experimental setup

The adsorber bed cooling and heating were carried out in different conditions of the bed frame, such as heating when either the top part of the bed was open or when the bottom part was open or closed. The source of heat in this experiment is a 2 kW solar lamp available in the laboratory. The ambient air velocity was measured and simulated in the laboratory to reflect the actual operating environment. The type K thermocouples and data logger were used to record the temperature at an interval of one second.

3. RESULTS AND DISCUSSION

Results from various experiments are presented through figures and discussed in this chapter. It can be noted that plates 1 and plate 2 refer to the temperature readings of two fixed plates in the absorber bed box. On the other hand, the inner temperature represents the air temperature measured within the adsorber bed box. Experimental results are presented in Fig. 2 to Fig. 6.

Temperature behaviors in the adsorber bed during heating and cooling while the top and bottom lid are open with air velocity of 0.5 m/s are shown in Fig. 2. The results show that the system took 1560 seconds to be heated up to 120 °C. The cooling process took 5796 seconds to cool from 120 °C to 30 °C, while the maximum air temperature in the adsorber bed box was 53.86 °C. The average ambient temperature was 21 °C. Due to heat loss, heating the adsorber bed when the bottom and top lids open takes longer than when the top and bottom lids open.

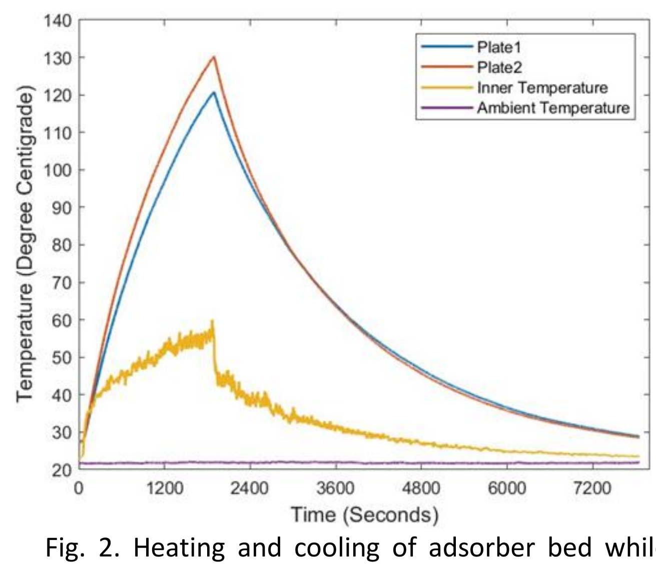

Fig. 2. Heating and cooling of adsorber bed while both top and bottom lids are open.

The results of the performance investigation of the adsorber bed when the top and bottom parts of the bed are closed with an average air velocity of 0.5 m/s are shown in Fig. 3. The results show that the system was heated to 120 °C for 1364 seconds. The average ambient temperature in the laboratory was 21 °C. The adsorber bed took 13842 seconds to cool to 30 °C. During heating, the system achieved the desorption temperature (120 °C) faster than the open top and bottom system. Despite the positive results during heating, the adsorber bed took longer to cool down due to inadequate heat transfer to the surroundings.

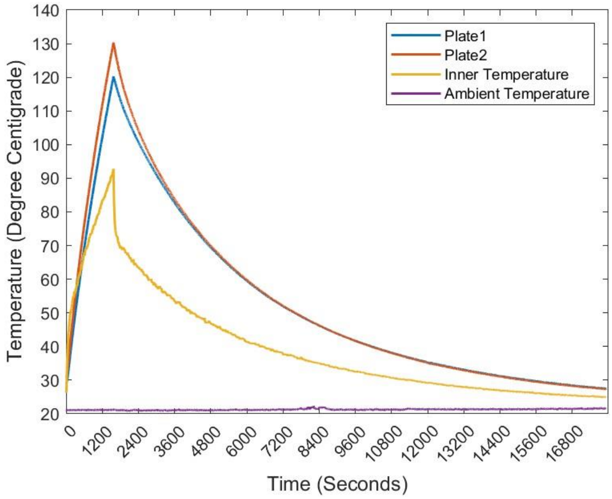

Fig. 3. Temperature profile in adsorber bed when both top and bottom lids are closed.

Temperature behaviour in the adsorber bed when top is open while heating and cooling but closed bottom during heating and cooling is shown in Fig. 4. The results show that the system took 3648 seconds to attain 120 °C when heating. It took 7275 seconds for the system to cool up to 30 °C while the average ambient temperature was at 21 °C. Closing the bottom part of the adsorber bed when heating reduces the heat loss but takes longer compared to the closed top lid due to heat loss at the top part of abdsober bed.

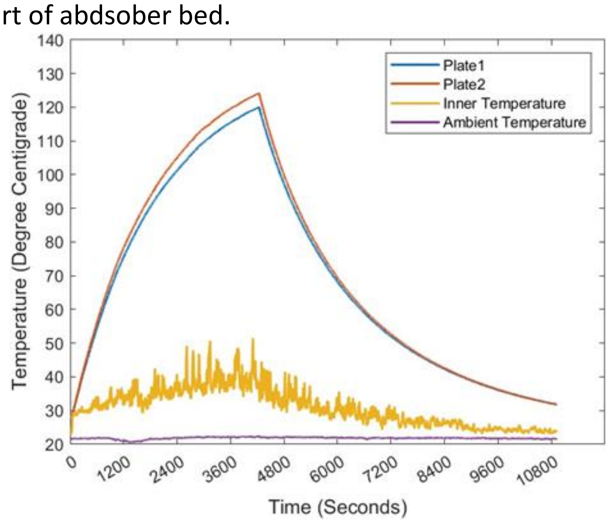

Fig. 4. Heating of an adsorber bed when the top lid is open but closed the bottom lid and cooling when the top lid is open and bottom lid is closed.

The temperature behavior of the adsorber bed during heating and cooling when both top and bottom are open are shown in Fig. 5. The data obtained from the experiment shows that it took 3929 seconds to heat up the adsorber bed to 120°C, while the average ambient temperature during heating and cooling was 21°C. On the other hand, the cooling process took 9000 seconds to bring the temperature back down from 120 °C to 30 °C. The system performs poorly compared to a closed top and bottom system due to heat loss to the surroundings during the heating process.

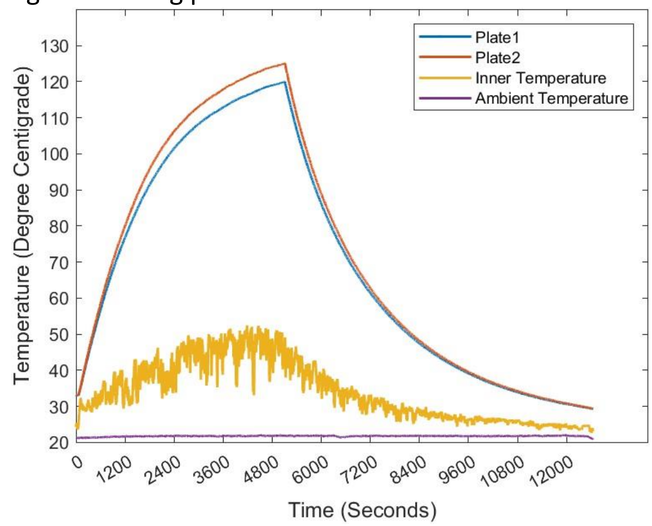

Fig. 5. Heating and cooling of adsorber bed while both top and bottom lids are open.

Temperature behaviour in an adsorber bed during heating using a single lamp when both top and bottom are closed and open during the cooling process is shown in Fig. 6. The result indicates that the heating process attained 120 °C in 3000 seconds and cooled to 30 °C in 5820 seconds. The system depicts lower heat loss during heating process. Also takes short time during the cooling process due to open top and bottom which increases the cooling rate.

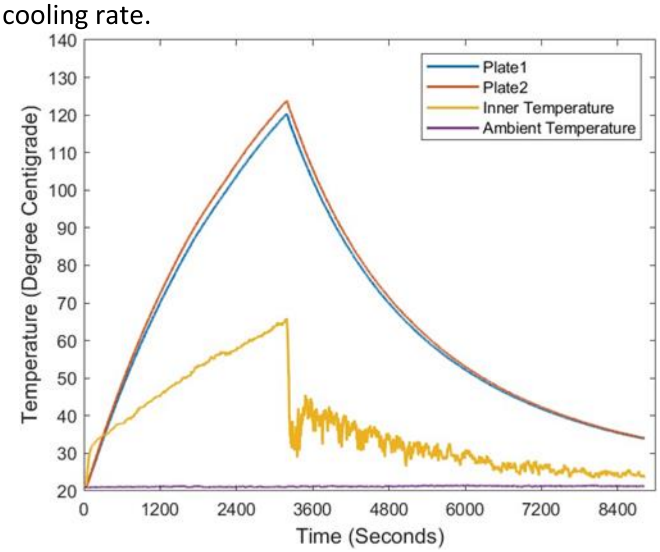

Fig. 6. Heating of adsorber bed while top and bottom lids are closed and cooling while bottom and top lids are open

Temperature distribution in the adsorber bed during heating while the top and bottom are closed and open top when cooling are shown in Fig. 7. The results indicate that it took 2940 seconds for the temperature to reach 120 °C during heating and 8004 seconds to cool down to 30 °C. Closing the bottom part of the adsorber bed reduces the heat loss during heating while opening the top part and bottom increases the heat loss to the surroundings.

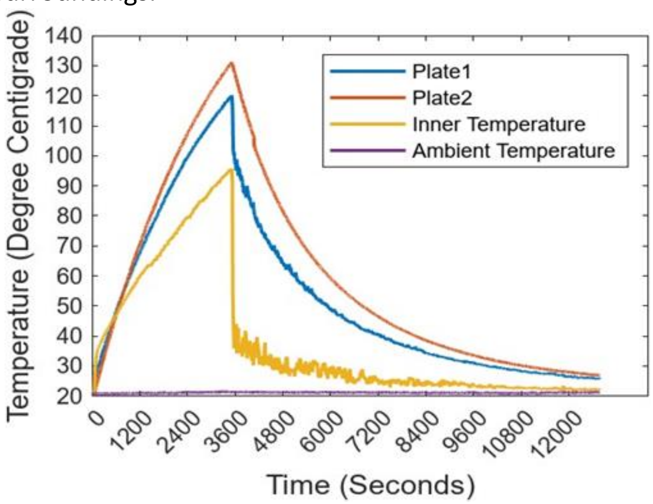

Fig. 7. Heating when the top and bottom lids are closed and cooling when the top lid is open.

4. CONCLUSIONS

From the findings of this study, it can be concluded that using a system closed on both sides during the heating of the adsorber bed helped reduce the heat loss to the surroundings and took a short time to attain the desorption temperature. Also, during the cooling stage, an open system on both sides helps cool the system for a shorter time than other systems. Future work will research on optimisation of adsorber beds for domestic adsorption refrigerators.

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DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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