Comparison of Microwave and Conventional Driven Adsorption Heat Pump Cycle Duration

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Abstract- The present experimental study includes comparison of microwave regenerated and conventional heated adsorbent bed of adsorption heat pump. The novel adsorption heat pump driving with microwave heating system was designed and manufactured. Microwave oven was constructed for providing homogeneous temperature distribution in the adsorbent bed. Temperature and pressure variations in the adsorption heat pump for both microwave and conventional regenerated cycles were measured and investigated. Duration of isobaric desorption process with microwave heating was achieved 98.2% shorter than that of conventional heating system.

Keywords Adsorption heat pump; microwave; regeneration; dielectric heating.

1. Introduction

Adsorption heat pumps (AHP) that have advantage of being environmentally friendly, provide heating and cooling effects by employing thermal energy sources such as solar and geothermal energies or waste heat of the industrial processes [1]. Although AHPs have high primary energy efficiency, in order to be competitive with conventional heat pumps, researchers should overcome some several important limitations and improve the coefficient of performance. One of the main drawbacks of AHPs is slow heat and mass transport in the adsorbent bed that usually results in low performance criteria. A survey of the literature revealed that the majority of the studies focused on eliminating the above mentioned problem. In these studies, although the thermal conductivity of the adsorbent was able to be improved by different methods, the performance of the adsorption heat pump could not be improved by using these new high thermal conductive adsorbents.

In recent years, dielectric heating systems, or microwave heating systems, have started to be used more frequent than conventional heating systems due to their various advantages, such as: having high heating rate, providing material selective, non-contact, precise and controllable heating, transferring energy rather than heat and providing compact equipment [2]. Kumja et al. [3] and Demir [4] investigated the effect of microwave regenerated adsorbent bed on performance of the adsorption heat pump numerically. A numerical analysis of heat and mass transfer in an adsorbent bed during an adsorption heat pump cycle was performed with both conventional and microwave heating regeneration methods. The results revealed that the coefficient of performance (COP) of microwave driven cycle was higher than that of conventional one.

The main obstacle for microwave assisted AHP is philosophy of background of adsorption heat pumps in which the adsorption heat pump utilizes thermal energy sources such as solar and geothermal energies or waste heat of the industrial processes. However, it should be kept in mind that the adsorption heat pumps can be used for thermal storage [5]. The microwave assisted adsorption heat pump can use electricity during night time and cool or heat the surrounding throughout day time. Moreover, electricity required for the operation of microwave in the system can be supplied by renewable energy resources such as solar energy with photovoltaic.

The aim of present study was to investigate the effect of microwave and conventional heating systems on the performance criteria of a silica gel-water heat pump experimentally. For this purpose, temperature distributions in the bed for both microwave and conventional heating systems were investigated. Temperature and pressure variations in the intermittent AHP were monitored during the performed cycles.

2. Experimental and Method

2.1 Experimental Setup

The used adsorbent was Silica gel Rubin with moisture indicator supplied from Sigma Aldrich Chemical Ltd. The equivalent diameter of adsorbent bead varies between 1 and

3 mm. The water adsorption capacity of silica gel is given as 20%.

The designed single bed adsorption heat pump was mainly composed of an adsorbent bed, an evaporator, and a condenser. The main components of adsorption heat pump are shown in Fig.1a The level of water was viewed and measured from the sight glasses mounted in the casing of evaporator. The evaporator was heated by using water circulated in the heat exchanger inside the evaporator which has $0.23m^2$ heat transfer area. The condenser was constructed as shell and tube heat exchanger. The heat transfer area of condenser was $0.22m^2$. The vacuum tight valves were located between the evaporator, condenser and adsorber to complete intermittent cycle. The valves (V3 and V4) between evaporator and condenser can play the same role of expansion valve if it is carefully opened and closed.

The two adsorbent beds were constructed. One of them was constructed of Pyrex glass and appropriates the microwave application. The other one also was constructed of Pyrex glass and it has jacket in order to supply heat to the bed with circulating hot water inside the jacket. The heights of the two adsorbent beds were 23 cm. The radii of gap and bed were 10.2 and 2.7 cm, respectively. For microwave application, the adsorbent bed was cooled by four small fans throughout the isosteric cooling and isobaric adsorption processes. Microwave oven was specially designed to have the ability of providing homogeneous temperature distribution in the adsorbent bed. For this purpose, three magnetrons (M1, M2 and M3) were placed with 120^o angle to each other as shown in Fig.1b.

Temperature distribution in the adsorbent beds was measured by 5 thermocouples as shown in Fig.1b.

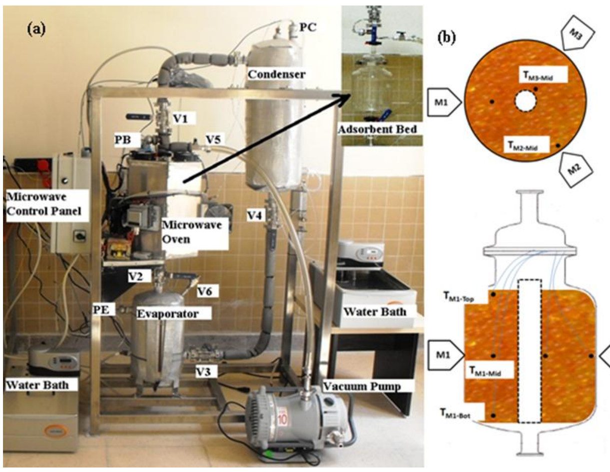


Fig.1a. Photograph of the designed intermittent adsorption heat pump, **b.** Location of thermocouples in the adsorbent bed.

Five of the thermocouples were placed across magnetrons for observation temperature distribution in the adsorbent bed. Two of the thermocouples were placed at bottom and top of the adsorbent bed. Three pressure transducers were used for measuring pressure of units. All thermocouples and data logger were calibrated by Fluke 714 temperature calibrator which has 0.8^oC measuring accuracy. The pressure transducers with ±%0.25 accuracy were located at the evaporator, condenser and adsorbent bed. The temperature and pressure were measured by sensors and acquired by using a data logger card and software. The data were transferred to a computer and automatically saved.

Figure 2 presents the microwave oven schematically. Microwave oven consists of three main parts. In the first part, microwave cavity surrounds the adsorbent bed for heating purpose. In the second part, there are three magnetrons (M1, M2 and M3) placed on the hexagonal wall to provide 120^o angle to each other as shown in Fig.1b with the aim of providing homogeneous temperature distribution in the adsorbent bed without rotating the bed itself. The power of each magnetron is 1 kW and its working efficiency is around 85%. Frequency is 2450 MHz. Third part is control panel which allows to adjust active/inactive time of magnetrons and total operation time of microwave. The magnetrons do not operate at the same time for safety precaution, hence they work sequentially. At the top of microwave cavity, four small fans are placed for supplying cooling during isobaric adsorption and isosteric cooling processes of cycle.

2.2 Experimental Procedure

The adsorbent bed was filled with 4kg of silica gel. The evaporator was filled with 10 L of distilled water. The adsorbent bed was vacuumed while being heated by microwave oven for removing the moisture of silica gel. The silica gel was dried for an hour. After the drying process, system pressure was adjusted and all valves were closed.

The isobaric adsorption process (d-a): For starting the cycle, the valve (V2 as shown in Fig.1a between evaporator and adsorbent bed was slightly opened and evaporation of water was started. The temperature of adsorbent bed increased during the adsorption process; however, the heat of adsorption was removed by four fans which were located at the top of microwave cavity. The isobaric adsorption process was continued until the saturation of silica gel. During the experiment, temperature and pressure of AHP were monitored. The end of isobaric adsorption process was decided according to bed temperature, pressure and the water level of evaporator observing from sight glass.

The isosteric heating process (a-b): After a complete adsorption process, the valve (V2) was closed and adsorbent bed was heated by microwave for 3-4 min for the isosteric heating process. For conventional heating system, hot water was circulated inside jacket of the glass adsorbent bed.

The isobaric desorption process (b-c): When the pressure of the adsorbent bed attained to the desired condenser pressure, the valve (V1) was opened for the isobaric desorption process while the heating of adsorbent bed was continued.

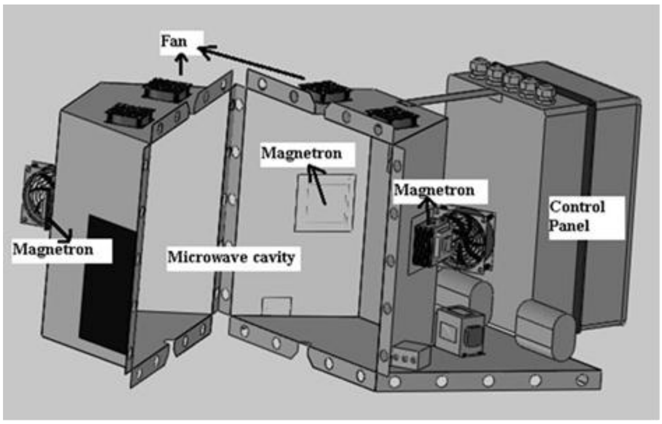


Fig. 2. Schematically illustration of microwave oven

Heating of adsorbent bed during isosteric heating and isobaric desorption processes was supplied by microwave. Each magnetron (M1, M2 and M3) operates for 30s sequentially with 15s break time. Total operation time of microwave can also be adjusted on the control panel. Four different total operation times (20, 25, 30 and 35 min) were investigated for the isobaric desorption process in this study. Electricity consumption was measured by using digital electric meters. For conventional heating system, hot water (85^{o}C) was circulated inside jacket of the glass adsorbent bed.

The isosteric cooling process (c-d): Once isobaric desorption was completed, the isosteric cooling process was started with closing valve (V1) and adsorbent bed was cooled by four small fans. After reducing adsorbent bed pressure to the evaporator pressure, the isobaric adsorption process was performed by opening the valve (V2). The condensed water inside the condenser was transferred to evaporator with opening valves V3 and V4 slightly without change in pressures of units. Hence, the cycle of intermittent adsorption heat pump was completed. The same procedure was repeated for conventionally regenerated cycles and next cycles.

3. Results and Discussions

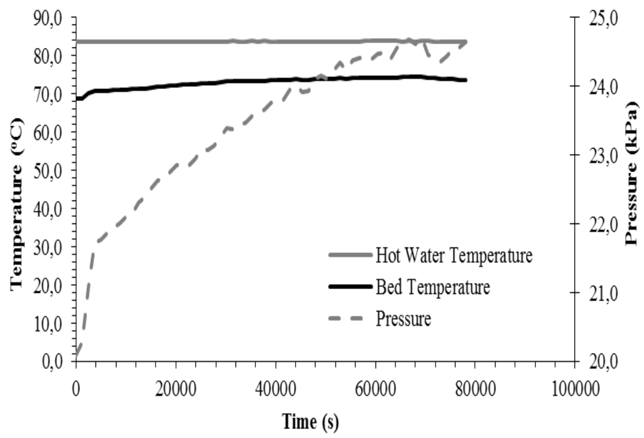
Figure 3 represents the pressure and average temperature of adsorbent bed during desorption processes for conventional and microwave heating systems. In conventional heating system, hot water (85^{o}C) was circulated inside the jacket of adsorbent bed. In Figure 3a, temperature difference between hot water and adsorbent was easily observed. The pressure of adsorbent bed gradually increased and reached 25 kPa at the end of desorption period. Duration of desorption process for conventional heating system was 22.2 h. Poor thermal conductivity of adsorbent bed affected on duration of desorption process. Figure 3b illustrates the adsorbent bed pressure and temperature in the front of magnetrons during desorption process. The adsorbent bed pressure for the case of microwave heating increased gradually and reached 25 kPa as in the case of conventional heating. Three temperature profiles across the magnetrons were very close to each other. This reveals that the magnetrons operate with the similar performances by providing homogenous temperature on adsorbent bed. The zigzag behavior of temperatures indicates active periods of magnetrons. The each magnetron operates for 30 s and break for 15s sequentially. The duration of desorption process for microwave heating was 0.4 h (26.7 min).

Comparison of desorption periods of conventional and microwave heating systems reveal that desorption of water molecules from adsorbents with microwave heating were faster and easier. The poor thermal conductivity of the adsorbent bed affected on the periods of the desorption process through slow heat and mass transfer. The reason of fast desorption process with microwave is that microwave transferred only energy but not heat. Microwave creates heat in the adsorbent bed by vibrating the water molecules. Thus, this fact clears the questions on that matter and it can be concluded that poor thermal conductivity of adsorbent bed did not influence the periods of desorption process. The long periods of cooling and adsorption processes influenced the performance of AHP which will be discussed in detail below. The bed pressures for both cases reached 25kPa. Insufficient condenser capacity caused to increase the desorption pressure of bed even in conventional heating case which was observed slow heat and mass transfer in the bed.

In Figure 4 the variation of adsorbent bed temperature was illustrated along the bed across the first magnetron. Figure reveals that there is no significant temperature fluctuation through the longitudinal of bed.

The variations of bed pressure and average temperature during the whole cycles for conventionally regenerated bed and microwave regenerated bed were presented in Fig.5. Long desorption period (b-c) for conventionally regenerated adsorption heat pump was easily observed in Fig.5. In microwave heating case, the isosteric heating period (a-b) cannot be observed in Fig.5b because of being too short. The limitation of adsorbent bed was overcome with microwave technique in isosteric heating (a-b) and isobaric desorption processes (b-c). However, effect of the poor thermal conductivity of adsorbent was observed in isosteric cooling (c-d) and isobaric adsorption (d-a) processes for both cases. The microwave technique only reduced the periods of heating processes. The total duration of cycle with microwave heating still needs further improvements.

(a)



(b)

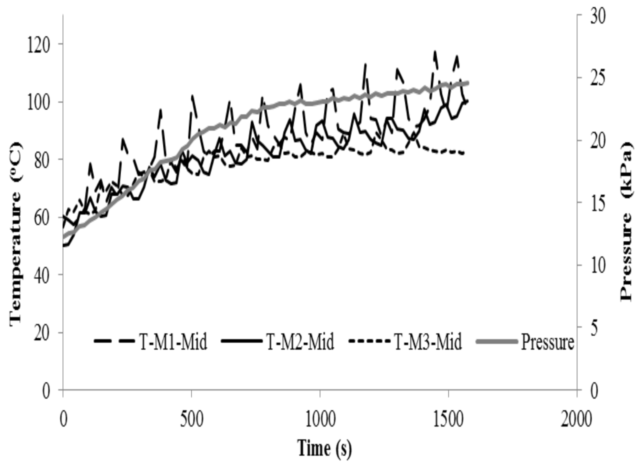


Fig. 3. Adsorbent bed temperature and pressure during isobaric desorption process for a) Conventional heating system b) Microwave heating system

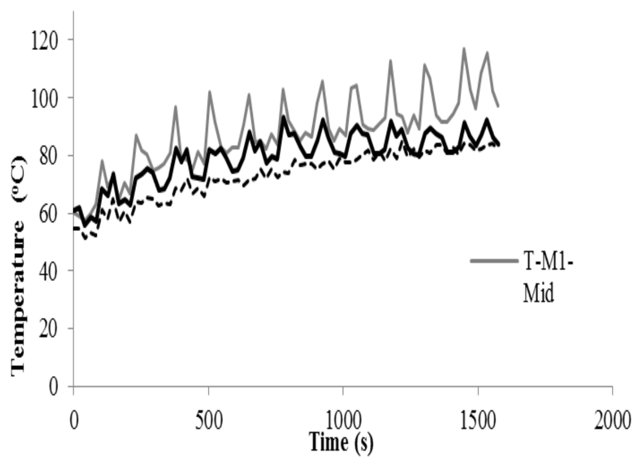
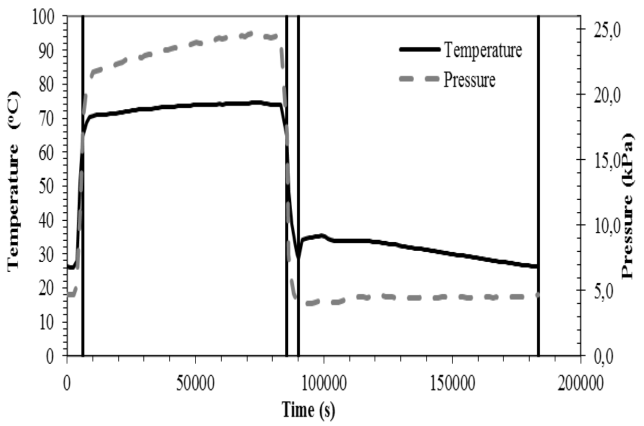


Fig.4. Variation of temperature along the adsorbent bed across the magnetron 1.

(a)



(b)

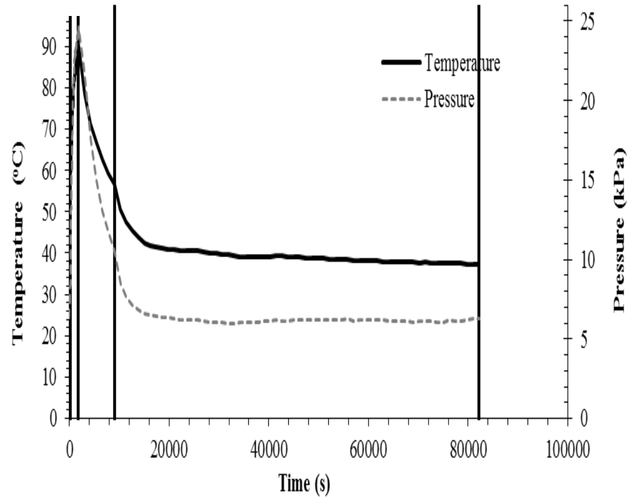


Fig.5. Variations of bed temperature and pressure during all cycle process for a) Conventional heating b) Microwave heating

4. Conclusions

The microwave regenerated and conventionally regenerated adsorption heat pumps successfully manufactured and operated to have complete cycles. Following conclusions can be made:

- The cycles were obtained experimentally with microwave regeneration without any problem such as electrical arc, overheating of adsorbent, vacuum leakage etc.
- The designed microwave provided homogenous temperature distribution in the adsorbent bed.
- Heat transfer resistance in adsorbent bed was overcome by microwave heating during heating processes.
- Microwave technique is powerful over conventional heating system since the duration of desorption process with microwave system was 98.2% faster than that of conventional heating system.
- The duration of adsorption processes should be improved in order to reduce the total cycle time.

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