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Experimental study on a novel microwave-assisted adsorption heat pump

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ABSTRACT

A microwave-regenerated adsorption heat pump system was manufactured and experimentally examined. The influence of the operation time of a microwave oven on the performance of the adsorption heat pump was investigated in this study. The performance criteria, i.e., coefficient of performance, specific cooling power and volumetric cooling power, were calculated for the designed and tested adsorption heat pump system. The coefficient of performance and volumetric cooling power values indicated that the microwave-regenerated adsorption heat pump system is promising for commercial applications. However, the specific cooling power value indicated that the system still needs further improvement. The coefficient of performance of the designed system was found to be 1.14 for 35 min of operation time of the microwave oven. The primary energy ratio (PER) values revealed that microwave-driven adsorption heat pumps can effectively compete with thermally driven AHPs.

Etude expérimentale sur une nouvelle pompe à chaleur à adsorption fonctionnant à l'aide de micro-ondes

Mots clés : Chauffage aux micro-ondes ; Chauffage diélectrique ; Pompe à chaleur à adsorption ; Puissance de refroidissement

1. Introduction

Adsorption heat pumps (AHPs), environmentally friendly systems that use non-hazardous refrigerants, provide heating and cooling effects by employing thermal energy sources, such as solar and geothermal energies or waste heat from industrial processes. Moreover, the primary energy efficiencies of AHPs are greater than those of mechanical heat pumps operated by electrical power. However, because of the economic benefits related to high coefficient of performance (COP) values, mechanical heat pump systems are convenient devices for heating and cooling purposes (Ulku, 1986).

To be competitive with conventional heat pumps and/or absorption systems in the market, adsorption heat pumps need to overcome several important limitations. The main drawback of AHPs is slow heat and mass transport in the adsorbent bed, which usually results in low performance indices. A survey of the literature revealed that the majority of studies focused on eliminating the aforementioned problem

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Nomenclature

COP	coefficient of performance
Cp	specific heat of adsorbent, kJ kg^{-1} K^{-1}
E	energy of electricity, kJ
f_p	primary energy factor
Q	heat, kJ
SCP	specific cooling power, W kg^{-1}
V	volume of bed, m^3
VCP	volumetric cooling power, W m^{-3}
ΔW	amount of adsorbate concentration, kg_W kg_S^{-1}
ΔH	heat of vaporization, kJ kg^{-1}
τ	cycle time, s

Subscripts

bed	adsorbent bed
cyc	cycle
des	desorption process
ev	evaporation
iso	isosteric heating process
ref	refrigeration
s	adsorbent
w	water

(Demir et al., 2008). Gui et al. (2002) designed a thin wall shell tube adsorber for improving the heat transfer rate. Activated carbon was used as the adsorbent, which was placed among the tubes that are used for heating and cooling. The rib pieces on the tubes increased the heat transfer rate from the tubes to the activated carbon by increasing the heat transfer surface (Gui et al., 2002). Restruccia et al. (2002) developed coated stainless steel tubes with adsorbent for improving heat and mass transfer rates in the bed. This method allowed for a high specific power adsorption heat pump to be obtained (Restruccia et al., 2002). Bonaccorsi et al. (2013) synthesized zeolites directly on the metal heat exchanger surfaces to increase the performance of adsorption heat pumps. Demir et al. (2010) used metal pieces as additives to enhance the thermal conductivity of adsorbent beds. In these studies, although the thermal conductivity of the adsorbent bed improved by different methods, the performance of the adsorption heat pump was not improved by using new high thermal conductivity adsorbents. Thus, there remains an obstacle in the practical application of adsorption heat pumps.

In recent years, dielectric heating systems or microwave heating systems, have been used more frequently than conventional heating systems because of their various advantages:

- high heating rate
- material-selective heating
- non-contact heating
- precise and controllable heating
- energy transfer rather than heat transfer
- compact equipment (Haque, 1999)

Microwave heating systems are mostly used for drying foods and minerals and regeneration of adsorbents in the adsorption of volatile organic compounds (VOCs). The influence of microwave heating on adsorption selectivity and desorption efficiency of volatile organic compounds (VOC) on zeolites were studied by Lopez et al. (2004) This study revealed that microwaves had a greater influence on the sorption of polar VOCs than on non-polar VOCs. Kim et al. (2007) compared to the desorption characteristics of VOCs over zeolites that were regenerated by conventional and microwave heating methods. Their conclusion was that the desorption efficiency of microwave heating was better than that of conventional heating.

Ultrasonic and microwave techniques are new methods for improving the performance of packed bed regeneration. Yao et al. (2009a and 2009b) investigated the effects of ultrasonic-assisted regeneration on dehumidification performance under different conditions. The analysis results revealed that the introduction of high-intensity ultrasonic waves to the regeneration of silica gel could help to improve its regeneration efficiency and reduce its regeneration energy (Yao et al., 2009a, 2009b; Wang et al., 2001). Kubota et al. (2011) and Kim Ick et al. (2005) used a microwave heating system to regenerate their adsorbents (zeolite and mordenite). Zhang et al. (2009) reactivated the activated carbon (AC) for vinyl acetate synthesis by using conventional and microwave heating systems. The microwave-reactivated AC showed higher adsorption capacity, BET surface area and mesoporosity than the samples reactivated by conventional heating. Similar results were also found by Ania et al. (2005), who showed that microwave heating increased the phenol adsorption capacity of the activated carbon compared to electrical furnace heating. They concluded that microwave heating improves the stability and structure of the activated carbon. Kubota et al. (2013) combined microwave heating and hot-air heating systems for the regeneration of desiccant rotors. The results showed that the combined heating system achieved higher ratios and initial regeneration rates compared to either the microwave or hot-air heating system alone.

Kumja et al. (2009) and Demir (2013a,b) simulated the microwave-regenerated adsorbent bed of the adsorption cycle. A numerical analysis of the heat and mass transfer in an adsorbent bed during an adsorption heat pump cycle was achieved with both conventional and microwave heating regeneration methods. The results showed that the coefficient of performance (COP) of the microwave-driven cycle was higher than that of the conventional one. Demir designed and built a microwave-assisted zeolite-AHP system. The maximum cooling COP of the microwave-assisted zeolite-AHP system was found to be 0.81 for 35 min of operation time (Demir (2013a,b)). The achieved COP value was substantially higher with respect to the literature (Demir et al., 2008).

First, although it is powered by electricity, the microwave-regenerated AHP is favored as an environmentally friendly system lacking any harmful refrigerants. Hence, it is worthwhile to improve the performance of AHPs to make them competitive with commercial conventional heat pumps. Second, the adsorption heat pump is capable of electro-thermal energy storage. The microwave-assisted adsorption heat pump can use electricity during the night and cool or heat its surroundings throughout the day (Alefeld et al., 1992). Moreover, the electricity required for operation of the microwave in