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Scaling up capacity of stand-alone adsorption refrigeration tubes

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ABSTRACT

On the basis of a validated model, a parametric study is conducted to understand the effects of operating parameters on the coefficient of performance (COP) and specific cooling power (SCP) of a stand-alone adsorption refrigeration tube (ART). It is revealed that the SCP obtained based on the model with the transient pressure process (TPP) boundary condition is approximately 20% higher than that obtained without the TPP. A scaling up solution of using multiple ARTs to produce continuous cooling is also proposed and discussed.

Introduction

Whilst extensive studies have devoted into complex large-scale adsorption refrigeration systems equipped with advanced heat and mass recovery cycles [1], Zhao et al. [2,3] studied the adsorption refrigeration tube (ART) which can work independently. Multiple ARTs can therefore be integrated to scale up cooling capacities. Although each individual ART works and produces cooling intermittently, the system made from multi-ARTs would be able to produce cooling continuously as a normal cooler does. A key advantage of a prospective air-conditioner employing multiple ARTs is that any damages occurred to an individual ART would not affect the system cooling performance significantly, as they are all independent to each other. Furthermore, the capacity of a desired cooling system can be easily scaled down or up by operating less or more numbers of ARTs.The present study is a conceptual work and presents a feasibility analysis of ARTs systems from the perspectives of thermal performance optimisation and economic considerations, and it is based on the fully validated model that was detailed in Zhao et al. [2,3].

Results

The working principle of an ART was described in Zhao et al. [2,3]. Mass transfer occurs via the perforated tube which is placed in the centre of the generator. In this study, activated carbon (Calgon WS-480) and methanol were used as the working pair [4]. The adsorptive properties of the working pairs used in the modelling were given in Zhao et al. [3,4].

Operating cycle time (OCT) of four stages in a typical adsorption-desorption cycle is a crucial parameter that affects the SCP and COP of the adsorption refrigeration system in practice. Fig. 1 shows the dynamic SCP and COP based on a case study in which an outer diameter of 40 mm and evaporating temperature of 15 °C are adopted. When modelling the performance of an ART, uniform pressure inside the ART was assumed previously [1], which did not reflect what exactly occurred in the ART. In this study, the transient pressure process (TPP) characterising the non-isobaric adsorption is used, which would make the performance simulation more accurate.

It can be seen from Fig. 1 that for both the assumption, i.e. with and

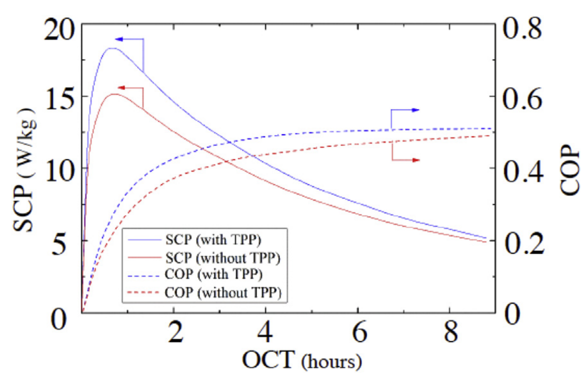

Fig. 1. Optimisation of SCP and COP of a stand-alone ART.

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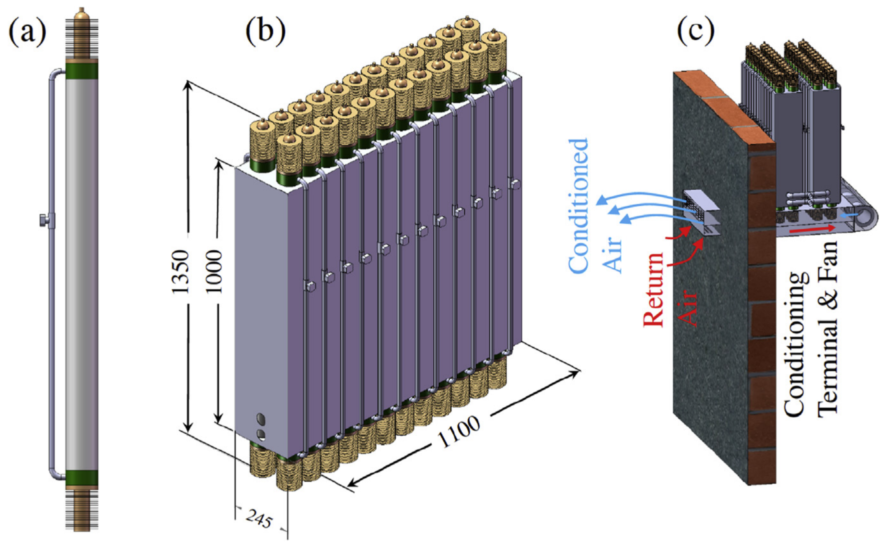

Fig. 2. Scaling up of cooling capacity. (a) a stand-alone ART, (b) an ART unit and (c) and an ART module.

without the TPP, the SCP peaks within a very short time (approximately 30 minutes), and then decreases with prolonged OCT. It is also worth noting that the peak performance in terms of the peak SCP simulated would be underestimated with the uniform pressure assumption (i.e. without the TPP model) by approximately 20%. This is because the TPP boundary condition could simulate the pressure difference cross the adsorbent bed, which is closer to what actually occurs inside the ART. The performance of an ART, in terms of COP depends on the operating cycle time (OCT). Although the SCP and COP have different and somewhat contrary development trends, it is evidenced that about 1.5 ~ 2.5 hours is the OCT for the ART studied.

Since each individual ART works independently, a scaling up of capacity can be easily achieved. Fig. 2 illustrates a schematic for an individual ART, an ART unit (composed of stand-alone ARTs) and an ART module (composed of two or more ART units). The generator of the individual ART is one meter long and the diameter is 0.0762 m (containing 2 kg of adsorbent). The ART unit shown in Fig. 2(b) is comprised of 24 single ART and a joint water jacket, which is able to produce a cooling power of about 0.75 kW, which is calculated based on the total cooling capacity of a refrigeration cycle and the OCT. In order to achieve continuous cooling, at least two units are needed. Fig. 2(c) illustrates the schematic of an ART module that is made from with two ART units. Each unit produces cooling alternatively thus the module is able to produce continuous cooling at 1.5 kW, which is able to provide a cooling capacity for a room of approximately 15 m^2 according to a usual HVAC standard.

The economics of the ART module/cooler is also assessed in this study. The initial capital investment of an ARTs module providing a 1.5 kW cooling capacity is approximately estimated to cost USD 1250, including fans, ducts and necessary fittings. Compared to conventional air-conditioners in the market, the price of a 3.0 kW air-conditioner is currently about USD 1000. Clearly, if two ARTs modules were employed to build a 3.0 kW modular system, the initial capital investment is about 2.5 times of a traditional air-conditioner. It is worth clarifying that the estimation of the initial capital investment is not rigorous, which is only used to demonstrate the potential of commercialising such ART-based systems.

In order to compare the total cost versus time to understand the economy of the ART modular system, a typical usage is assumed to be 8 hours per day and 120 days per year and electricity rate for residential usage is assumed to be 0.25 USD/kWh. For the modular ART system, two extreme scenarios utilizing completely free energy (solar or waste heat) and paid electricity are assumed. Fig. 3 shows that for the two scenarios, the critical payback times are 6 and 10 years, respectively (indicated by the circles). Hence, for mid-to long-term usage, the modular ART system could bring obvious commercial advantages.

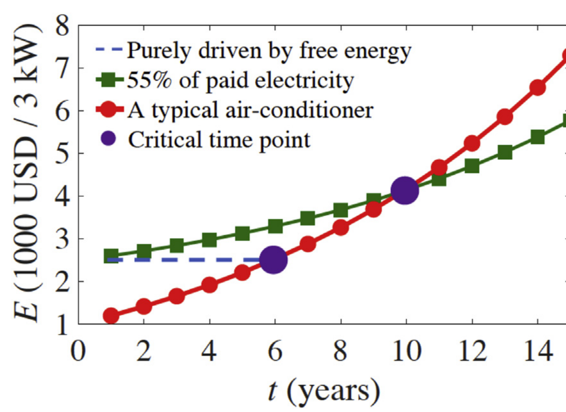

Fig. 3. Total cost versus usage time employing the ARTs system and traditional vapor mechanical compression system, respectively.

Conclusion

This study reveals the previous models which did not use TPP assumptions would underestimate the performance by about 20%. The individual intermittent ART could be easily scaled up to form a continuously working large cooler that is powered by low grade heat. Depending on the electricity price and annual usage hours of the ART cooler, the payback time of it can be as short as 6 years for domestic usage. The savings can be even more dramatic for applications where cooling requirement is more intense, such as 7/24 data centres. Therefore, it can be concluded that the ART cooler proposed has great potential for commercialisation.

Conflict of interest

There is no conflict of interest.

Acknowledgments

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