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Review and future trends of solar adsorption refrigeration systems

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ABSTRACT

This paper aims to provide the current state of the art of solar adsorption refrigeration systems operating with the single-bed intermittent cycle (also known as basic cycle). A comprehensive literature review has been conducted and it was concluded that this technology, although attractive, has limitations regarding its performance that seem difficult to overcome. Therefore, new approaches were identified to increase the efficiency and sustainability of basic adsorption cycles, like the development of hybrid or thermal energy storage adsorption systems. A survey of the developments in these new research trends is also presented in this paper. It shows that there are simple adsorption cycles which can be attractive alternatives not only to serve the needs for air-conditioning, refrigeration, ice making, thermal energy storage or hybrid heating and cooling purposes, as standalone or integrated systems, but also to meet the demands for energy conservation and environmental protection.

Contents

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1. Introduction

For many years, usual vapor compression refrigeration systems typically operated with synthetic refrigerants, such as CFCs, HCFCs or HFCs. When released into the atmosphere, such refrigerants deplete the ozone layer and/or contribute to the greenhouse effect. In the late 1980s, it was estimated that the emissions of these compounds by refrigeration machines, resulting from anomalies during operation or after their useful life, accounted for 33.3% of the greenhouse effect [1]. As a result, several protocols, like the Montreal Protocol (1987) or the Kyoto Protocol (1997), were established in order to phase out, or at least to considerably reduce, the emissions of these refrigerants [2,3]. However, the situation continues claiming for the development of alternative technologies operating with environmentally friendly substances, especially due to the increasing emissions of HFCs, although the emission of CFCs and HCFCs have been decreasing since the late 1980s [4,5].

Furthermore, the ever increasing energy consumption worldwide makes it urgent to find new ways to use the energy resources in a more efficient and rational way. It is estimated that the global energy consumption will increase by 71% between 2003 and 2030 [6]. In addition, currently 80% of the energy on Earth comes from fossil fuel resources [7]. Usual vapor compression refrigeration cycles are electrically powered, consuming large amounts of high quality energy, which significantly increases the fossil energy consumption; and also largely contributing to the greenhouse effect. The International Institute of Refrigeration in Paris estimated that approximately 15% of all the electricity produced worldwide is employed for air-conditioning and refrigeration processes [8]. Moreover, electricity peak demands during summer are becoming more and more frequent due to the general increase in air-conditioning and refrigeration equipment usage.

In another perspective, a considerable percentage of the world population inhabits in remote areas where the electricity supply is scarce, deficient or even non-existent, and so it is estimated to continue over the next decades. The need for refrigeration systems in these locations is of extreme importance since, due to the electricity shortage, conventional refrigeration equipment cannot be used, for instance, in food and medicines storage, ice making or even for air-conditioning.

Therefore, the awareness on issues such as the decrease of fossil fuel resources (with the consequent increasing prices of energy), the severe environmental problems or even the location challenges (*e.g.*, remote areas) require the development of new technologies and led the humankind to look with greater interest for ecological and renewable energy sources. These include wind, solar, hydropower, biomass and geothermal energies, or even thermal waste from various processes. Solar energy is currently a subject of great interest, and refrigeration is a particularly attractive application due to the coincidence between the peak of cooling demand and the solar radiation availability. Thus, systems that have the ability to harness solar energy (or other forms of low-temperature thermal energy), as the adsorption devices, present themselves as interesting alternatives in an intelligent energy management. Recently, adsorption refrigeration processes have been investigated (theoretically and experimentally) and proposed as an alternative to vapor compression refrigeration systems, attempting to preserve the production and efficiency level of traditional systems, and becoming one of the most promising solar refrigeration methods [3].

When comparing with traditional refrigeration technologies, adsorption cooling systems are not cost-competitive, and have some technical drawbacks, such as low coefficients of performance (COP), low specific cooling powers (SCP), and poor heat and mass transfer on the adsorbent beds, which makes the systems more bulky and expensive [9,10]. Moreover, in the case of solar refrigerators, the energy source is intermittent and can also be highly irregular (*e.g.*, overcast days, seasons). However, these systems promote significant primary energy savings in comparison with common mechanical vapor compression refrigeration systems, and have simpler control, no vibration, no noise, lower operation and maintenance costs, lower environmental impact (operate with non-polluting refrigerants), and are simpler and more robust [10]. Compared with the absorption systems, adsorption systems can be powered over a large range of heat source temperatures, are more robust and less sensitive to physical impacts, do not present corrosion problems due to the working pairs normally used, and are less complex because they contain fewer moving parts [10,11]. The absorption systems, while working in a similar basis (using a heat source to drive the cooling system) and usually being more energy efficient, present the relative drawbacks stated above, mostly due to the operation with liquid sorbents, contrarily to adsorption systems (solid sorbents).

Therefore, the adsorption refrigeration systems appear as a good alternative to replace (or integrate) the traditional refrigeration systems by more environmentally friendly systems, which can be powered by renewable energy sources and contribute to a sustainable development, meeting the current international directives.

Researchers worldwide are working to improve the performance of adsorption cooling systems in order to overcome its current technical and economic issues. Most research works are related to the evaluation of adsorption and physical–chemical properties of the working pairs, development of predictive models of their behavior when working under different conditions, and the study of the different types of cycles [10]. There are several types of adsorptive refrigeration cycles: basic cycle, continuous heat recovery cycle, mass recovery cycle, thermal wave cycle, convective thermal wave cycle, cascade multi-effect cycle, among others [12]. However, the literature review and discussion about the applications and future research trends on the present paper is mainly focused on the basic adsorption cycle, since this is the simpler cycle and the basis for all the adsorption systems.

2. The process

2.1. Principles of adsorption

The adsorption phenomenon is the result from the interaction between a solid and a fluid (refrigerant) based on a physical or chemical reaction. Physical adsorption occurs when the molecules of refrigerant (adsorbate) fix themselves at the surface of a porous solid element (adsorbent) due to Van der Waals forces, thus leading to the accumulation of a substance on the surface of another. By applying heat, the adsorbate molecules can be released (desorption), whereby this is a reversible process. In turn, the