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A review on solar-powered closed physisorption cooling systems

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A B S T R A C T

Cooling, refrigeration, and air conditioning processes are considered essential needs and major requirements for all human beings in our world today. However, the traditional vapor compression machines are dominating electricity consumers and their operation and propagation cause high electricity peak loads during the summer, especially in those countries with tropical climate. That is besides their refrigerants having high global warming as well as ozone layer depletion potentials. Providing cooling by utilizing a green energy such as solar energy is the key solution to electricity and pollution problems. Adsorption refrigeration systems that are driven by solar energy are mature technologies. They are proven to be suitable and applicable for refrigeration as well as air-conditioning applications. Solar adsorption cooling technology is divided into physisorption and chemisorption systems. The physisorption machines include open and closed cycle operation. This paper presents a review on previous researches and developments of the solar driven closed physisorption refrigeration systems. The discussion includes, experimental and numerical simulation studies as well as methods that are suggested to improve the system performance.

Contents

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1. Introduction

Energy is considered the heart and the continuous driving power for economic growth and the major requirement for technological development. The quality of life for people in a country is measured by the amount of energy they have. Increasing rate of population, economy, and the per capita energy consumption are the major forces that will be continue to cause increase in energy demand during the coming decades. We are certain that conventional energy types are neither reliable nor sustainable. Fossil fuels, such as oil, gas, and coal, are consumed at high rates and in some locations much more rapidly than they are produced. The world's reserves of oil are not large enough to be dependable in the future. Sustainable developments demand a sustainable supply of energy resources that, in the long run, are readily and sustainably available at reasonable cost and can be employed without causing adverse impacts. In addition to this, securing the supply of reliable and affordable energy and effecting a rapid transformation to a low-carbon, sustainable, efficient and environmentally benign systems of energy supply are central energy challenges facing us today. It is not an exaggeration to claim that the future of human prosperity depends on how successfully we tackle these issues. Renewable energy is that energy generated from natural resources and is renewable and naturally replenished, inexhaustible within the time horizon of humanity. Renewable types of energy are considered a perfect substitute for the traditional ones this include wind, geothermal, hydropower, biomass, wave, tidal and solar energy sources. Among these sources, solar energy comes at the top of the list due to its abundance and more equal distribution in nature than other types of renewable energy.

Solar energy is the electromagnetic radiation (including infrared, visible and ultraviolet light) released by thermonuclear reactions in the core of the sun. All the energy sources originate entirely from the sun with a few exceptions (e.g., nuclear, geothermal, and tidal energy). The surface of our planet receives a huge amount of energy flow from the sun. The solar radiation influx is expressed in terms of the solar constant S_c (i.e. the power transmitted by the sun's rays per unit cross sectional area at the mean distance of the earth). From measurements made on the earth and in spacecraft the mean value of the solar constant is considered to be equal 1368 W/m^2 [1]. Therefore, the total solar radiation transmitted to the earth's diametric plane area, which is estimated to 1.27516×10^{14} m^2 calculated at the earth mean radius which is 6371 km, is therefore approximately 1.74×10^{17} W [2].

Refrigeration and air conditioning processes mainly contribute in a considerable number of fields of human life. This includes food preservation, industrial process control, indoor air quality control, gas liquefaction, production of food and drink, and the chemical and pharmaceutical industry, and others. Along with the increasing trend in the worldwide economic growth, much more of the world's energy is being consumed to drive the conventional refrigerating and air conditioning appliances in both industry and buildings to meet the cooling demands. These traditional vapor compression machines are the dominating electricity consumers and their operation and propagation cause high electricity peak loads during the summer, especially in those countries with tropical climate. The energy consumption for air conditioning systems has recently been estimated to be 45% of the whole households and commercial buildings [3]. Furthermore, approximately 10–20% of all the electricity produced in the whole world is consumed by various kinds of the refrigeration and air-conditioning machines, as estimated by the International Institute of Refrigeration [4]. Moreover, the conventional vapor compression systems use non-natural working fluids and refrigerants like the chlorofluorocarbon (CFC), hydrochlorofluorocarbon (HCFC) or hydrofluorocarbons (HFC). These refrigerants have high global warming as well as ozone layer depletion potentials. Moreover, they contribute significantly in an opposite way to the international regulations.

Providing cooling by utilizing a clean and renewable energy such as solar energy is the key solution to decrease electricity requirements for cooling, peak electrical demand and energy costs without lowering the desired level of comfort conditions. For example, the Mediterranean countries may save 40–50% of their energy used for air conditioning by implementing solar driven air conditioning systems [5,6]. Even if 50% of present market of small AC systems can be replaced by solar powered systems, a considerable worth of electrical energy can be saved and a good amount of carbon credit can also be earned [3]. The development of solar refrigeration technologies became the worldwide focal point for concern because the peaks of requirements in cold coincide most of the time with the availability of the solar radiation. Solar refrigeration has the potential to improve the life quality for people who live in remote areas or areas with insufficient electricity. Moreover, the solar cooling technology can reduce the environmental impact raised by conventional air-conditioning systems. That is because the refrigerants used in these systems are environmentally benign, natural refrigerants and free from CFC. Therefore, these systems have zero ozone depleting as well as a zero global warming potentials.

Solar adsorption cooling technology is divided into physisorption and chemisorption systems. The physisorption machines include open and closed operating cycles. This paper presents a review on previous researches and developments of the solar driven closed physisorption refrigeration systems. We will be discussing various refrigeration technologies and advancements that were suggested to improve and enhance the performance of such technologies.

2. Principles of adsorption

Adsorption phenomenon has been known for long time and is increasingly used in many applications including separation, purification, and heat-powered green refrigeration technologies. The adsorption and absorption are mainly different processes. Adsorption is a surface phenomenon whereas absorption is a volumetric one. The heart of an adsorption process is usually a porous solid medium which provides a very large surface area and large pore volumes and therefore large adsorptive capacity [7]. The surface of the solid material is usually unsaturated and unbalanced. When surface is brought into contact with gas, there is an interaction between the unbalanced molecular forces at the surface and the gas molecular forces. That is because, solid surface tends to satisfy these residual forces by attracting and retaining on its surface the molecules, atoms, or ions of the gas. This results in a greater concentration of the gas or liquid in the near vicinity of the solid surface than in the bulk gas or vapor phase, despite the nature of the gas or vapor. The process by which this surface excess is caused is called adsorption [8]. The adsorption process may occur in two ways depending on the constraining force during the adsorption process. The first is the physical adsorption, or physisorption, and the second is the chemical adsorption, or chemisorption.

In the physisorption process, the adsorbate molecules are attracted to the adsorbent surface by the weak van der Waals force which are similar to the molecular forces of cohesion and are involved in the condensation of vapors into liquids. There are not any changes in the chemical composition of the adsorption pair. The enthalpy of adsorption is of the same order as the condensation heat of the gas. The binding molecules can be released by applying heat which usually does not exceed 80 kJ/mol. Physical adsorption is nonspecific and occurs between any adsorbate–adsorbent systems. Physical adsorbents can adsorb consecutive layers of the adsorbate gas and the thickness of the adsorbed phase is multimolecular.