Renewable and Sustainable Energy Reviews 53 (2016) 1389–1410

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Adsorption refrigeration technology – An overview of theory and its solar energy applications

Parash Goyal *, Prashant Baredar, Arvind Mittal, Ameenur. R. Siddiqui

Energy Department, Maulana Azad National Institute of Technology, Bhopal, India

ARTICLE INFO

Article history:
Received 7 April 2015
Received in revised form
25 May 2015
Accepted 17 September 2015
Available online 10 November 2015

Keywords:
Adsorption refrigerators
Working pairs
Solar thermal refrigeration
Solar collectors
Researches in India
Market trends

ABSTRACT

Adsorption refrigeration technology has established enhanced significance in last three decades, due to its noiseless, non-corrosive and environment friendly operation by the utilization of low grade heat sources, especially solar energy. A plethora of adsorption cooling systems had been developed but still these cooling systems are not ready to compete with the traditional vapor compression cooling systems. This paper aims to provide fundamental knowledge on the adsorption systems and presents a comprehensive literature review of the past efforts in the field of their solar energy utilization. This paper also presents a brief of various related researches conducted in India. A survey of developments in the market trends is also presented in this paper. It shows that a number of attempts have been made by various companies to enhance the performance of adsorption refrigeration systems and maintain their presence in market but limitations regarding their technical and economic aspects seem difficult to overcome. Nevertheless, adsorption cooling systems driven by solar energy not only lowers down the daily electricity consumption but also reduces the global warming potential due to its environment friendly nature.

Contents

* Corresponding author.
E-mail addresses: parashigoyal@gmail.com (P. Goyal), prashant.baredar@gmail.com (P. Baredar).

http://dx.doi.org/10.1016/j.rser.2015.09.027
1364-0321/

1. Introduction

Many agricultural products like meat, fish, fruits, vegetables, milk, etc., if stored at low temperatures can be maintained in fresh conditions for significantly long periods of time. Large quantities of these products are lost annually due to poor storage facilities. Because of this there exists a great discrepancy between the post-harvest and issue period food supplies. Also, several important medicines and vaccines get wasted every year due to scarcity of electricity. The International Institute of Refrigeration in Paris (IIF/ IIR) has reported that approximately 15% of all the electricity produced in the whole world is utilized for refrigeration and air-conditioning processes of various kinds, and the energy consumption for air-conditioning systems has recently been estimated to 45% of the whole households and commercial buildings [1]. Furthermore, electricity demands peaking has become a regular trend due to the improved living standards and thus increased fondness of electrical appliances mainly air conditioners and refrigerators.

Much of human's needs are fulfilled by the use of fossil fuels. However, concern grows daily over the negative impacts fossil fuels have on the environment, consistently increasing CO_2 emission and ozone depletion are serious environmental issues challenging scientific community. CO_2 (carbon dioxide) is produced when fossil fuels are burned, causing an increase to the earth's temperature and a green-house gas effect on the atmosphere's ozone layer [2]. Since the beginning of the last century, average global temperature has risen about 0.6 K according to UN Intergovernmental panel on climate change. It is also warned that the temperature may further increase by 1.4–4.5 K until 2100 [3]. The Vienna Convention for the Protection of the Ozone Layer (1985), the Montreal Protocol (1987) and the Kyoto Protocol on Global Warming (1997) are some efforts towards the reduction of CFCs (chlorofluorocarbons) to protect the ozonosphere, but decline in situation still prevails. According to the latest NASA investigation, the holes in the ozonosphere over the two poles currently occupy approximately 28,300,000 km^2, up from approximately 24,000,000 km^2 in 1994 [4]. As a consequence, the EC (European Commission) Regulation 2037/2000, implemented on 1st October,2000, works to control and schedule all the ozone depleting materials; all HCFCs (hydro chlorofluorocarbons) will be prohibited by 2015 [5,6]. The dependence on fossil fuels has to be reduced and alternative environmental friendly options must be explored. The answer to this exploration is renewable energy.

The term "renewable energy" refers to the energy produced from a natural resource (sun, water, wind etc.) having the characteristics of inexhaustibility over time and natural renewability. Renewable energy sources include hydropower, wind, biomass, geothermal, tidal, wave and solar energy sources [7]. Among all these the most promising but mystic is solar energy. Solar energy is the result of electromagnetic radiation released from the Sun by the thermonuclear reactions occurring inside its core. All of the energy resources on earth originate from the sun (directly or indirectly), except for nuclear, tidal and geothermal energy [8]. Solar energy is very large inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8×10^{11} MW which is much larger than the present consumption rate on the earth of all commercial energy sources. By utilizing this current requirements of the whole world can easily be fulfilled.

Refrigeration now a days has gained attention as solar energy application because of the near matching of peak cooling loads with the available inexhaustible solar power. The standard vapor compression refrigeration cycles are driven by electricity or heat, which strongly increases the consumption of electricity and fossil energy. Consumption of electricity is a big problem for vapor compression refrigeration system. In developing countries, an outsized proportion of population lives in rural areas where grid electricity is rarely available at present and is probably going to be the case for the next few decades. Therefore conventional, electrically powered vapor compression refrigeration systems may not be of much use for them. The conventional vapor compression system is run by commercial, non-natural working fluids, like chlorofluorocarbons (CFCs), hydro chlorofluorocarbons (HCFCs) and hydro fluorocarbons (HFCs). These are directly responsible for ozone depletion and/or global warming. Hence, the adsorption system is one of the promising solar thermal refrigeration methods, and it is environment friendly along with additional benefits of low cost and low maintenance requirements. Earlier gas separation and catalysis were the only applications of adsorptive processes but it is only recently that these have been widely studied for refrigeration and heat pumps also.

The earliest record of the adsorption refrigeration phenomenon finds its origin in the Faraday's lab in 1848 where the cooling capacity could be generated when silver chloride adsorbed ammonia. G. E. Hulse in 1920, proposed a refrigeration system in which silica gel – sulphur dioxide was used as the working pair for food storage in a train. In 1940 –1945, the adsorption refrigeration system using calcium chloride and ammonia as working pair was used for food storage in the train from London to Liverpool driven by steam at 100 °C. In 1970 s, the energy crisis occurred and it offered a great chance for the development of the adsorption refrigeration technology, mainly because of the fact that the adsorption refrigeration system is driven by a low-grade heat source such as waste heat and solar energy. Since then, researchers worldwide are working to improve the performance of adsorption cooling systems in order to overcome its current technical and economic issues. Most of the research works are related to the evaluation of adsorption and physical and chemical properties of the working pairs, development of predictive models of their behavior when working under different conditions, and the study of different cycles. This article details the various researches that had been done in adsorption refrigeration technology covering all its aspects with special reference to its solar application.

2. Working of adsorption process

Adsorption a reversible surface phenomenon, taking place due to interaction between adsorbent (solid) and a refrigerant/