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An overview of developments in adsorption refrigeration systems towards a sustainable way of cooling

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ABSTRACT

Growing energy demand and global climate change are compelling reasons to look for effective utilisation of waste thermal energy and renewable energy resources. Fifteen percent of the electricity produced in the whole world is employed for refrigeration and air-conditioning processes of various kinds. Low-temperature heat operated environment-friendly adsorption cooling systems are emerging as viable alternatives to electricity-driven vapour compression refrigeration systems. Comparatively bigger sizes of adsorption based cooling units, due to their low specific cooling power, are preventing successful commercialization of the technology. Efforts are on to enhance the performance of adsorption systems through improvements in adsorbents properties, use of advanced cycles, etc. Recent application of nano-technology in the development of adsorbent material may be a big step forward towards making this technology competitive with available technologies in the market. This paper traces the evolution of the technology and analyses the obstacles to wide spread use of adsorption chillers.

Contents

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1. Introduction

1.1. Background

Global energy demand, and as well the demand for cooling, refrigeration and comfort air-conditioning, are increasing at a fas++t rate. Cooling needs are found to be directly proportional to the standard of living of people. The International Institute of Refrigeration in Paris has estimated that approximately 15% of all the electricity produced in the whole world is employed for refrigeration and air-conditioning processes of various kinds, and the energy consumption for air-conditioning systems has been estimated to be 45% of the whole households and commercial buildings [1]. Conventional vapour compression refrigeration machines consume a lot of electrical energy, leading to depletion of precious fossil fuel resources and production of greenhouse gases. Refrigerants, used in these systems, also contribute to greenhouse gas emission. Some of the refrigerants, like CFCs (chloro-fluoro-carbon) and HCFCs (hydro-chloro-fluoro-carbon), cause depletion of stratospheric ozone layer as well.

1.2. Alternate technology

Heat driven refrigeration cycles have the potential to address these problems. Utilisation of solar energy and low grade waste heat, e.g. engine exhaust, industrial waste heat, etc. in heat driven refrigeration cycle is an attractive option in this context. Use of solar energy in cooling and refrigeration sector has an added advantage in that the availability of solar radiation is almost in phase with the requirement of cooling.

Solar-powered sorption cooling systems have zero global warming potential and zero ozone depletion potential. Among the heat driven sorption cooling processes, absorption (liquid + vapour) cooling system has established itself as a commercially available technology. However, they are found to be more suitable for larger systems [2]. More efficient double-effect and triple-effect systems require concentrated solar collectors, which make the system complex and costly.

Adsorption (solid + vapour) based cooling systems can run at a lower temperature, allowing them to run with simple flat plate or evacuated tube collectors. Balaras et al. [3] evaluated results from 54 solar cooling projects in different climatic zones of five countries under the EU project SACE (Solar Air Conditioning in Europe). Approximately 70% of the systems employed absorption chiller, while 10% of them used adsorption chillers, rest of the systems used other technologies including desiccant cooling. Fig. 1 shows that the adsorption systems, though having a lower thermal COP, operated at a driving temperature (52.5–82 °C) lower than that of absorption systems [3].

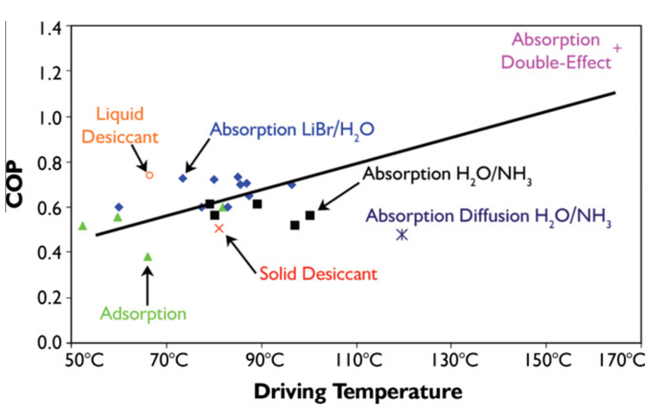

Fig. 1. COP as a function of heating medium temperature [3].

Adsorption chillers have other advantages also. Absence of moving/rotating parts makes them more reliable, maintenance free and suitable for mobile applications. They do not suffer from the problem of crystallisation and corrosion. Unlike absorption systems, the performance of an adsorption chiller is not so sensitive to the fluctuation in heat source temperature, which makes them suitable for solar application. Sumathy et al. [4] did experiments on a single stage lithium bromide absorption chiller (model WFC-600, Yazaki Co., Ltd., Japan). The data from the performance curves of the single stage chiller are presented in Table 1. It can be seen from the table that, in order to produce chilled water of 9 °C, for a given chiller nominal rating of 7 kW, the heat medium temperature and cooling water temperature should be maintained at 88 °C and 29.5 °C, respectively. With the lowering of heat medium temperature or with the rising of cooling water temperature, the performance of the chiller (both the cooling capacity and COP value) deteriorated sharply. Hence with 80 °C hot water, only 50% cooling capacity could be obtained. In the case of cooling water at 31 °C, the heat medium temperature had to be raised to 93 °C, to maintain the nominal capacity of the chiller. Authors commented that the strict demands of the chiller on its operating parameters strongly affected the performance of the system. The chiller could not always operate at its nominal rating during periods of low solar radiation and high cooling water temperature.

1.3. Research paradigm

Though the technical feasibility of adsorption based cooling systems is well established, current options to produce cold from solar energy and/or waste heat are not cost-competitive with available technologies in the market. High cost of solar collectors is a major cost component for solar heat driven adsorption chillers. Porous adsorbent materials are bad conductors of heat, and the fixed bed operation also leads to poor heat and mass transfer, making

Table 1
Performance parameters of the chiller model WFC-600 [4].

Hot water temperature (°C)	Cooling water temp. (°C)	Chilled water temp. (°C)	Cooling capacity (kW)	COP (–)
88.0	29.5	9.0	7.0	0.60
85.0	29.5	9.0	5.6	0.54
80.0	29.5	9.0	3.5	0.41
75.0	29.5	9.0	1.7	0.25
93.0	31.0	9.0	7.0	0.58
88.0	31.0	9.0	5.8	0.53
80.0	31.0	9.0	3.0	0.36
75.0	31.0	9.0	0.7	0.09