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An illustrated review on solar absorption cooling experimental studies

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ABSTRACT

This paper constitutes a first part of a literature review on solar absorption cooling studies. It is dedicated to experimental studies. Based on several experimental studies intentionally selected, this review aims to highlight the operational aspects inherent to drive an absorption chiller by solar heat. Such an installation is the product of the interconnection of several components. The separate operation of each component under defined environmental conditions differs from its operation as a part of the overall system because of the varying temperature levels and heat transfer rates because of the inherently variable and unpredictable nature of the intensity of the solar energy on the one hand and the encountered heat losses within the installation itself on the other hand. Also, this review aims to provide to the reader a summary of results and conclusions from different case studies and identify the shortcomings of these systems through a comparative study. It was felt that illustrating the review with selected results would be very beneficial and more informative to the reader. The operating principles of a variety of solar absorption cooling options are presented. Each system description is supported by a related literature review concerning a short historical development, reported demonstration projects and performance data. It begins with the early studies motivated by the energy crisis where no economic consideration was observed in the conception of the experimental facilities to the most recent investigations that take into account the economic aspect by modifying the experimental setup configuration or combining solar cooling with other cooling modes or even implementing innovative heat storage and rejection systems.

Contents

1. Introduction

Estimates of global energy consumption from 2003 to 2030 indicate an increase of about 71% [1]. Increasing rates of population growth, economic development and per capita energy consumption constitute the major force causing increase in energy demand, which could reach 35% from 2010 to 2035 according to the International Energy Agency [2]. More than ever, there is a general consensus among the scientific community that if human activities continue with the same cadence, the globally averaged surface temperature is projected to increase by 1.4–5.8 °C over the

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period 1990–2100 [3]. This phenomenon will worse environmental problems that are already responsible for planetary scale disasters despite the measures taken by the international community to stop the process.

Among these measures, the Kyoto Protocol is an international agreement under which industrialised countries must reduce their collective emissions of greenhouse gases by 5.2% compared to the year 1990. Especially regarding the reduction of carbon dioxide, being an inevitable by-product of industrial activities [4].

Along with the global warming impacts and climate changes, the demands for air-conditioning and refrigeration continue to grow due to increasing thermal loads, increasing living standards and occupant comfort demands, building architectural characteristics and trends, like an increasing ratio of transparent to opaque surfaces in the building envelope [5]. The energy consumption for air conditioning systems has been estimated to be 45% of the whole households and commercial buildings [6]. Almost of these demands is always satisfied by conventional vapour compression machines that are dominating electricity consumers and lead to frequent high electricity peak loads during summer, particularly in regions with warm and arid climate [1]. Although there are numerous attempts to improve efficiencies of conventional machines to reduce their energy consumption, these machines contribute significantly in an opposite way to the international regulations to global warming and depleting the ozone layer through using harmful refrigerants [7].

To meet the energy demands and mitigate the problems associated with climate change, there is a worldwide consensus among scientists and politicians that using renewable and clean energies is a key solution. Among the main issues, solar cooling is considered as an intuitive and attractive solution since the cooling demand coincides mostly with the intensity of solar radiation. Many demonstration and development projects of solar cooling technologies were initiated since the eighties [8] and various solar cooling technologies are available in the market [9].

However, a large market penetration of solar cooling technology has a lot of barriers. The high costs of absorption chillers, as well as lack of standardisation, market familiarity and compatibility with building design. The need of a cooling tower is also a barrier for absorption chillers commercialization [10]. To better address these issues and reconcile these conditions that many projects continue to be initiated such as those initiated in the frame of the Solar Heating & Cooling Programme (SHC) of the International Energy Agency and those funded by the European Commission like SACE (Solar Air Conditioning in Europe), CLIMASOL CESAR (Cost-Effective Solar AiR conditioning), (SOLAIR), etc. The purpose of these projects is to develop a small scale, cost-efficient absorption cooling unit, with efficient ambient air heat dissipation and which can use renewable heat sources and therefore have a minimum electricity consumption [11].

1.1. A brief literature survey on solar cooling reviews

Solar absorption cooling has been actively investigated for nearly fifty years and the development of solar cooling techniques was always supported by a prolific literature that attempts to understand and master their different aspects.

Tabor [12] presented the general technical and theoretical aspects of solar cooling devices in both domains of refrigeration and air-conditioning. Their economic aspects were also discussed. He concluded that among the heat-operated cooling devices, the most promising in a solar use are the closed-cycle absorption machines.

Grossman and Johannsen [13] described the various approaches of solar cooling and presented their thermodynamic principles. The different methods and cycles were compared. In a more recent paper [14], Grossman described the up-to-date trends in solar-powered air-conditioning which has been influenced by the growing awareness of global warming and other environmental problems. It was mentioned that closed-cycle heat-powered cooling technology is mainly dominated by LiBr–H_2O absorption chillers. The principles of multi-staging absorption systems were described. These systems which make it possible to reduce the amount of heat required per kW of cooling but require high-temperature solar collectors.

Being based on papers and discussions of the workshops held in 1994 in Dresden and 1995 in Freiburg, Germany, Lamp and Ziegler [8] reported the new trends leading to an innovative design of both solar collectors and chillers over the European research experiences up to 1996. It was stated that cheaper collectors providing higher temperatures and specially designed chillers for use with low-grade heat as input were being investigated.

In their handbook, Henning et al. [15] discussed practical design aspects of thermally driven cooling systems and solar collectors. The systems under consideration are generally divided into two main categories: closed and open cycles. The handbook also puts a major focus on the entire systems including all auxiliary components and experiences derived from real life installations.

Kim and Infante Ferreira [4] presented a state-of-the-art review of solar refrigeration technologies. Besides solar thermal and solar electric technologies, some new emerging technologies were presented. An economic and efficiency comparison between the different solutions was performed. The electric and thermo-mechanical systems were judged more expensive than thermal sorption systems. Although the absorption and adsorption systems are comparable in terms of performance, the adsorption ones are more expensive and bulkier than the absorption chillers. The single-effect LiBr–H_2O was estimated to be the lowest cost alternative. In another most recent paper, the same authors [9] investigated the most promising alternatives among the solar methods used to supply the cooling needs in residential and utility buildings in northern and southern Europe. Vapour compression systems combined to PV collectors seems to be the most attractive solution followed by vapour compression systems driven by electricity provided by parabolic dish collectors and Stirling engines. The best thermal alternative is the double-effect absorption machine driven by a concentrating trough collector followed by desiccant systems equipped with flat-plate collectors while the adsorption systems option remains more expensive.

Chidambaram et al. [16] reviewed research articles in the field of solar cooling techniques, solar collectors and storage methods using thermal stratification and cascaded thermal storage systems. It was outlined from the review that thermal storage is essential in the solar circuit, in order to take maximum advantage of the solar resource and control differences between the cooling/heating demand and solar radiation availability. Although solar cooling is an emerging market with a promising potential, the success of its technologies depend on the promotional schemes offered by the policymakers.

Hassan et al. [7] presented a comprehensive literature review on absorption based solar-powered refrigeration and air-conditioning systems. Beside the presentation of thermodynamic operating principles of these systems, a discussion of the previous experimental and numerical studies was given.

Aiming to draw a picture about the solar cooling concept based on the use of concentrating solar collectors, Ayadi et al. [17] exposed the reasons behind the selection of these solar collection technologies for solar cooling applications. It has been claimed that starting from 2004, the number of installations was growing and that commercially available single axis parabolic trough collectors and Fresnel solar collectors were combined with double-effect LiBr–H_2O and single-effect H_2O–NH3 absorption chillers. Also, it has been stated that best performances are achieved with