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Review

General review of solar-powered closed sorption refrigeration systems

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ABSTRACT

The negative environmental impacts of burning fossil fuels have forced the energy research community seriously to consider renewable sources, such as naturally available solar energy. Thermally powered refrigeration technologies are classified into two categories: thermo-mechanical technology and sorption technology (open systems or closed systems). This paper provides a detailed review of the solar closed sorption (absorption and adsorption) refrigeration systems, which utilise working pairs (fluids). After an introduction of the basic principles of these systems, the history of development and recent advances in solar sorption refrigeration technologies are reported. The adsorption cooling typically has a lower heat source temperature requirement than the absorption cooling. Based on the coefficient of performance (COP), the absorption systems are preferred over the adsorption systems, and the higher temperature issues can be easily handled with solar adsorption systems. The thermodynamic properties of most common working fluids, as well as the use of ternary mixtures in solar-powered absorption systems, have been reviewed in this study. The paper also refers to new approaches to increase the efficiency and sustainability of the basic adsorption cycles, such as the development of hybrid or thermal energy storage adsorption systems. This research shows that solar-powered closed sorption refrigeration technologies 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 but also to meet the demands for energy conservation and environmental protection.

Contents

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Nomenclature

Abbreviations

Ab	absorber
AC	activated carbon
C	condenser
CFC	chlorofluorocarbon
COP	coefficient of performance
CPC	compound parabolic concentrator
E	evaporator
EU	European Union
EV	expansion valve
EES	engineering equation solver
G	generator
HX	heat exchanger
HFC	hydro-fluorocarbon
HCFC	hydro-chlorofluorocarbon
P	pump
PC	pre-cooler
Rb	resorber
RES	renewable energy sources
SC	solar collector
ST	storage tank
SHX	solution heat exchanger
SACE	solar air conditioning in Europe
TFE	trifluoroethanol
TEGDME	tetraethylene glycol dimethyl ether
TRNSYS	transient systems simulation
VLE	vapour–liquid equilibrium

Symbols

c_l	working mixture specific heat, J/(kg K)
c_p	specific heat at constant pressure, J/(kg K)
E_c	consumed energy, kW h
E_s	energy consumed by solar collectors, kW h
E_u	usable cooling energy, kW h
EER	energy efficiency ratio, Btu/(Wh)
p	pressure, Pa
p_c	condensation pressure, Pa
p_e	evaporation pressure, Pa
P_{el}	electrical power, kW
Q_a	sorption heat, kW
Q_c	condensation heat, kW
Q_d	regeneration/desorption heat, kW
Q_e	evaporation heat (cooling power), kW
Q_g	generator heat, kW
Q_s	solar collector's thermal power, kW
SCP	specific cooling power, W/kg
t_a	absorption/adsorption temperature, °C
t_c	condensation temperature, °C
t_d	regeneration temperature, °C
t_e	evaporation temperature, °C
t_g	generation temperature, °C
T_b	bubble point temperature, K
T_d	dew point temperature, K

1. Introduction

Energy, similar to water, food and shelter, is an essential need of all human beings in the world. The technological advancement and economic growth of every country depends on it [1], and the quantity of available energy reflects that country's quality of life. The economy, population and per capita energy consumption have caused an increase in demand for energy during the last few decades. Fossil fuels are the prominent source for generating utilisable forms of energy [2]. Therefore, fossil fuels are the major contributor to global warming and the greenhouse effect on the ozone.

Furthermore, vapour compression-based refrigeration systems are generally employed in refrigeration, air-conditioning and heat pump units operating with synthetic refrigerants, such as chlorofluorocarbons (CFCs), hydro-chlorofluorocarbons (HCFCs) and hydro-fluorocarbons (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 systems resulting from anomalies during operation accounted for 33.3% of the greenhouse effect [3]. As a result, several international protocols, such as the Montreal Protocol of 1987 [4] or the Kyoto Protocol of 1997 [5] were established to phase out, or at least to considerably reduce, the emissions of these refrigerants [6]. However, the situation continues, and there is still a need to develop alternative technologies operating with ecological substances, especially due to the increasing emissions of HFCs, although the emission of CFCs and HCFCs have been decreasing since the late 1980s [7]. Some directives have been approved to reduce the greenhouse gas emissions [8] and that another alternative can be used as natural [7] or synthetic refrigerants [9].

The ever increasing world-wide energy consumption has created an urgent need 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% from 2003 to 2030 [10,11]. In addition, 80% of the energy currently used on Earth is generated from fossil fuel resources [12]. Usual vapour compression-based cycles are electrically powered, consuming large amounts of high quality energy, which significantly increases the fossil fuel consumption. The International Institute of Refrigeration in Paris estimated that approximately 15% of all the electrical energy produced worldwide is employed for air-conditioning and refrigeration processes [13]. Moreover, electricity peak demands during summer are becoming more and more frequent due to the general increase in air-conditioning and refrigeration equipment usage.

The awareness of global warming has intensified in recent times and has reinvigorated the search for energy sources that are