INTERNATIONAL JOURNAL OF REFRIGERATION 45 (2014) 128–135

Available online at www.sciencedirect.com

ScienceDirect

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Optimum generator temperature to couple different diffusion absorption solar cooling systems

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ARTICLE INFO

Article history:
Received 28 February 2014
Received in revised form
16 May 2014
Accepted 23 May 2014
Available online 6 June 2014

Keywords:
Solar cooling system
Diffusion absorption
Solar collector
NH_3–NaSCN
NH_3–$LiNO_3$

ABSTRACT

This paper presents the generator temperatures to achieve the highest efficiency in different solar diffusion absorption cooling systems. Ammonia-lithium nitrate (NH_3–$LiNO_3$) and sodium ammonia-thiocyanate (NH_3–NaSCN) were examined as the working mixtures, and the flat-plate collector (FPC), the flat-plate collector improved (FPCI), the evacuated-tube collector (ETC) and the compound parabolic concentrator (CPC) were the thermal energy sources. The study was conducted with a simulation in steady-state conditions. The effects of the generator temperature on the global efficiency of each solar cooling system were studied. The results show that the FPC and the FPCI cannot activate the cooling system at evaporator temperatures below 0 °C and the ambient temperature is at 40 °C. At evaporator temperatures above 5 °C with an ambient temperature of 30 °C, all solar collector technologies activated different working mixtures. The optimum coupling temperatures were between 70 and 150 °C. The ETC/NH_3–$LiNO_3$ was between 5 and 54% relatively better than other technologies.

Température optimale du générateur pour couplage de divers systémes de refroidissement solaire á absorption

Mots clés : Système de froid solaire ; Absorption á diffusion ; Capteur solaire ; NH_3–NaSCN ; NH_3–$LiNO_3$

1. Introduction

A solar cooling system is a technology that results from coupling a cooling system with a solar collector, which provides heat to activate the cooling unit. Hwang et al. (2008) reported the current solar cooling technologies and mentioned that it is necessary to develop solar collectors with high efficiency and high temperatures and cooling technologies with high efficiency that can be activated at low temperatures and low construction cost. This subject also concerned the solar diffusion absorption cooling systems, which required no electrical power because the mechanical part is not necessary and the required heat energy can be supplied by several resources. This technology, which was first introduced by Swedish engineers Von Platen and Munters

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http://dx.doi.org/10.1016/j.ijrefrig.2014.05.016

Nomenclature

T	temperature (°C)
P	pressure (bar)
m	flow mass (kg s^{-1})
M	molar mass (g mol^{-1})
N	mole number (mol)
Q	heat transfer (kW)
h	enthalpy (kJ kg^{-1})
x	ammonia mass fraction in the solution
y	ammonia mass fraction in the gas mixture
Fr	heat removal factor
Ul	heat transfer loss coefficient (W $m^{-2\circ}$ C^{-1})
Gb	beam radiation (W m^{-2})
Gt	global radiation (W m^{-2})
C	collector concentration
Subscripts	
1,2,3…	system's point designation (Fig. 1)
a	absorber
c	condenser
e	evaporator
g	generator
h	inert gas
r	rectifier
Greek letters	
η	solar collector efficiency
α	absorber absorbance
ρ	mirror reflectance
τ	cover transmittance

(1928), used direct fire to operate. Since its development, much effort has been made to make this technology sustainable by incorporating solar energy.

A few studies on diffusion absorption solar cooling systems highlighted the work of Jakob et al. (2007), which designed and experimentally studied a diffusion absorption cooling system that functioned as an air conditioner. The used mixture was NH_3–H_2O, with a cooling capacity of 2.5 kW. The achieved experimental COP was 0.38. The solar collector was a flat-plate collector; however, there is no evidence of the efficiency and the area of the solar collector.

In an investigation by Kim and Infante (2008) on the absorption cooling system with NH_3–H_2O as the working mixture, the diffusion absorption solar cooling system assisted by flat-plate collectors does not exceed a global efficiency of 0.25 and a maximum cooling capacity of 2.5 kW in the evaporator (Gutiérrez 1998, Kunze, 2000).

The achieved temperature and efficiency of a solar collector are mainly associated with the geometrical design, the materials, the weather conditions and the ambient temperatures. However, the maximum temperatures and the efficiency curves of different solar collector systems have been established in a review by Kalogirou (2004), which mentioned that flat-plate collectors theoretically do not reach temperature above 80 °C.

Some researchers have incorporated different working mixtures instead of the conventional mixture to decrease the required heat energy of the cooling system, which permitted the use of solar systems as the energy source (Bourseau and Bugarel (1986), Wang (2012), Zohar et al. (2009)). According to Acuña et al. (2013), NH_3–$LiNO_3$ and NH_3–NaSCN working pairs demand less energy in the generator than the NH_3–H_2O working mixture, which makes these mixtures notably attractive for use in solar diffusion absorption cooling systems.

It is important to determine the activation temperature of the solar cooling system because it allows one to establish the design parameters. Pfaff et al. (1998) proposed a diffusion absorption cooling system that could be activated with solar energy because the required activation temperature in the generator was between 66 and 78 °C when the LiBr–H_2O working mixture is used.

Ben Ezzine et al. (2010) demonstrated that a diffusion absorption system could be activated by solar energy because the required generator temperature was between 80 and 180 °C using the R124/DMAC working pair.

The latest review of diffusion cooling systems by Rodríguez-Muñoz and Belman-Flores (2014) mentioned that the investigation trend is to develop alternate systems that can be activated with residual or solar energy. By employing different working mixtures with low activation temperatures, the number of possible solar technology systems to be used as heat sources is increased in this type of technologies.

Thus, to research new configurations of solar cooling systems and how the generator temperature affects their performance, this study presents different parametric studies to establish the optimal generator temperature to couple a diffusion absorption cooling system that uses NH_3–$LiNO_3$ and NH_3–NaSCN as the working mixtures with different solar collector technologies: flat-plate collector (FPC), flat-plate collector improved (FPCI), evacuated-tube collector (ETC) and compound parabolic concentrator (CPC). Moreover, it studies the global efficiencies of the solar cooling system, which is the product of the COP of the diffusion absorption cooling system and the solar collector efficiency at different ambient temperatures. Subsequently, the generator temperature was defined where the highest global efficiency is obtained. Solar collection systems were selected because they do not require any tracking system.

1.1. System description

The solar cooling system under study is a diffusion absorption cooling system that uses an array of solar collectors, which are indirectly coupled as the heating source. The working mixture consists of a refrigerant (NH_3), an absorbent substance (NaSCN or $LiNO_3$) and an inert gas (He).

Fig. 1 illustrates a schema of the system under study. The generator is loaded with a mixture with high concentration of refrigerant. The solar collector converts the solar radiation in heat energy, which is transferred to the generator. The mixture increases its temperature until it reaches the saturation temperature, where it begins to boil, and bubbles will rise up in the tube of the bubble pump. Vapor is released and