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Exergetic and energetic comparison of LiCl-H_2O and LiBr-H_2O working pairs in a solar absorption cooling system

Evangelos Bellos *, Christos Tzivanidis, Kimon A. Antonopoulos

Department of Thermal Engineering, National Technical University of Athens, Zografou, Heroon Polytechniou 9, 15780 Athens, Greece

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ABSTRACT

The objective of this study is to investigate the use of an alternative working pair in a solar absorption cooling system. LiCl-H_2O is the new examined pair and it is compared energetically and exegetically with the conventional pair LiBr-H_2O, which is the most usual in air-conditioning applications. The simplest solar cooling system is analyzed in order to focus in the comparison between these working fluids. Specifically, flat plate collectors, coupled with a storage tank, feed the single effect absorption chiller which produces 250 kW cooling at 10 °C. The two pairs are examined parametrically for various heat source temperature levels and for three ambient temperature levels (25 °C, 30 °C and 35 °C). The minimization of the collecting area, which means maximum exergetic efficiency, is the optimization goal in every case. The final results show that LiCl-H_2O pair performs better in all cases by giving greater exergetic efficiency. More specifically, about 8% lower collecting area is required to cover the demanded cooling load with this working pair. Another interesting result is that the optimum heat source temperature for the LiCl-H_2O is roughly lower than the respective for the LiBr-H_2O. The system is analyzed in steady state with the commercial software Engineering Equator Solver (EES).

1. Introduction

The new lifestyle trends lead our society to consume larger amounts of energy in order to achieve high standards of living. The fossil fuel depletion, the high cost of electricity and the environmental threats due to CO_2 emissions are the obstacles for reaching the desired energy consumption levels. Utilization of clean and sustainable energy sources is the most promising way to produce clean energy with zero CO_2 footprints [1,2]. Solar energy is the most abundant and widespread renewable energy source and it is able to give solutions in many applications with high energy demand. Energy consumption in building sector is approximately 35% of the global energy consumption and its greatest part is responsible for covering heating and cooling loads [3]. Moreover, the new lifestyle increases the energy consumption by the progressively changing thermal comfort standards [4]. Two practices have applied in order to face this crucial situation. The first one is the optimization of the building cell [5,6] in order to reduce the energy demand on cooling and heating loads. The second way is to exploit renewable energy sources, mainly solar energy, for covering a great part of the loads.

Solar cooling is a very promising technology that is able to cover the cooling load by utilizing the solar energy. Three are the main technologies for applying solar cooling; absorption chillers, absorption chillers and desiccant systems with the first to be the most used worldwide [7]. Various collector types are able to be combined with these chillers in order to produce the demanded cooling load. Flat plate collectors (FPC), which are the cheapest and more mature technology [8], can be used for producing useful heat in temperature levels up to 100 °C. For greater temperature levels, evacuated tube collectors [9] are usually used, while concentrating collectors are also a reliable solution [10].

In the absorption chillers, two are the usual refrigerant-absorbent working pairs, with NH_3-H_2O to be used for refrigeration temperatures under 0 °C and H_2O-LiBr for higher refrigeration temperature levels. Moreover, other working pairs can be used, instead H_2O-LiBr, as lithium chloride/water (LiCl-H_2O), ammonia-sodium thiocyanate (NH_3-NaSCN) and ammonia/calcium chloride (NH_3-$CaCl_2$) [7]. According to many researches, the use of LiCl-H_2O in absorption cycle gives satisfying results compared to LiBr-H_2O pair [11,12]. Parham et al. [13] stated that the exergetic efficiency of absorption cycle with LiCl-H_2O is higher than the respective with LiBr-H_2O. She et al. [14], after a detailed analysis proved that LiCl-H_2O performs better than LiBr-H_2O in all operating conditions. Moreover, LiCl-H_2O has greater long-term stability [13] and has

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* Corresponding author.
E-mail address: bellose@central.ntua.gr (E. Bellos).

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Nomenclature

A	area (m^2)
D	diameter (m)
E	exergy flow (kW)
G_T	solar radiation (W/m^2)
h	enthalpy (kJ/kg)
L	height (m)
m	mass flow rate (kg/s)
M	the storage water mass (kg)
P	pressure (kPa)
Q	heat rate (W)
SCOP	solar coefficient of performance
t	time (s)
T	temperature (K)
U_L	tank heat loss coefficient (W/m^2)
V_T	tank volume (m^3)
X	LiBr mass concentration in mixture

Greek symbols

η	efficiency
ρ_f	water density (kg/m^3)

Subscripts and superscripts

A	absorber
am	ambient
C	condenser
chill	chiller
col	collector
E	evaporator
ex	exergy
HEX	heat exchanger
in	inlet
G	generator
loss	heat losses
out	outlet
r	refrigerant
S	heat source
sol	solar energy
st1	1st zone of the storage tank
st2	2nd zone of the storage tank
st3	3rd zone of the storage tank
Str	strong solution
sun	sun
T	titled
th	thermal
U	useful
w	weak solution

Abbreviations

COP	coefficient of performance
EES	Engineer Equator Solver
FPC	flat plate collector
LiBr	lithium bromide
LiCl	lithium chloride
SCOP	solar coefficient of performance

great internal energy storage capacity [11], two important reasons for selecting this working pair in an absorption refrigeration chiller. Sahem et al. [15] investigated parametrically the performance of LiCl-H_2O in various operating conditions and proved that the maximum COP is close to 0.8. Furthermore, they stated that the maximum accepted temperature of the cooling medium has not to exceed 40 °C. Beausoleil-Morrison et al. [16] studied a Small-scale solar air conditioning system operating with LiCl-H_2O and proved that when the generator temperature is ranged from 71 °C to 93 °C, the COP varies from 0.53 to 0.83.

This study aims to compare the working couple LiCl-H_2O with the usual couple LiBr-H_2O in solar cooling applications, something that is not well-established up today. This study is innovative because the comparison is parametrically for various values of ambient temperature and heat source temperature, something that is missing from the literature. In every case, the optimized system is determined in order to minimize the demanded collecting area for producing the desired cooling load. The systems are examined energetically and exegetically in order to present a more detailed analysis. The optimization parameter is the heat source temperature, the temperature of hot water in the generator inlet, a methodology that has been also followed in many studies [15,17,18]. The suitable selection of heat source temperature maximizes the exergetic efficiency of the system and minimizes the demanded solar field area. The simulation is made for steady state conditions with commercial software EES (Engineer Solver Equator), in order to focus on the comparison between the two working pairs. The properties of each working fluid are taken from EES database. More specifically, for LiCl-H_2O the properties are taken from Patek and Klomfar study [19] which is on accordance with a newer study of Li et al. [20].

2. Study case

2.1. System description and assumptions

A solar cooling system is analyzed in steady state conditions in order to focus in the comparison between the examined working pairs. Simultaneously, the system operation is optimized in order to evaluate every working pair in the suitable operating conditions. The main parts of the examined system are the solar collector field, the storage tank and the absorption chiller. These parts are coupled to each other according to Fig. 1. More specifically, solar energy is captured by flat plate collectors and the working fluid is getting warmer. The working fluid is pressurized water in order to remain in liquid phase during the process. The hot water from the collector field outlet is stored in a storage tank. This storage tank is modelled with mixing zones and loss heat into the environment (Q_{loss}). This tank has two inlets and two outlets, according to Fig. 1. The hot water from the collectors has temperature $T_{c,out}$ and enters in the upper part of tank. From the lower part of the tank, water with temperature $T_{c,in}$ leaves it and enters to the collector field. On the other side of the tank, hot water from its upper part with temperature $T_{s,in}$ goes to the generator of the absorption chiller. This temperature level is characteristic for this study and will be referred as heat source temperature. The return stream from the chiller has temperature $T_{s,out}$ and enters in the lower part of the tank.

The absorption chiller is a single effect chiller with heat exchanger and operates with LiBr-H_2O or LiCl-H_2O. Solar energy is the input energy into generator and the energy input in the evaporator is the cooling load of this system. Heat rejection to the environment takes place in the condenser and in the absorber. In order to simulate this system, some assumptions have been made. These