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Solar driven double-effect absorption cycles for sub-zero temperatures

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ABSTRACT

This paper presents a theoretical study of a solar driven double-effect absorption system with ammonia–lithium nitrate for sub-zero evaporation temperatures. The performance of a double-effect parallel flow ammonia based absorption system with lithium nitrate as absorbent is investigated. This includes the determination of the effect of the strong solution distribution on performance. A ratio of 0.65 appears to be the most advantageous. The paper also presents the dynamic performance of a double-effect ammonia–lithium nitrate absorption system driven by solar energy under Mediterranean summer conditions. The solar energy is obtained by horizontal N–S parabolic trough solar collectors because they can deliver high temperatures that are required to drive the double-effect absorption system. Simulations of the solar absorption systems with a hot storage are performed in order to supply the cooling load of a pork slaughterhouse with maximum cooling load of 600 kW.

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Cycles d'absorption à double effet fonctionnant grâce à l'énergie solaire pour des températures inférieures à zéro

Mots clés : Absorption à l'énergie solaire ; Cycle à absorption à double effet ; Ecoulement parallèle ; Ammoniac-nitrate de lithium ; Simulation

1. Introduction

At the moment, most cold energy is produced by means of vapour compression systems which are electrically driven. These systems have a lot of success due to the development of suitable refrigerants and equipment. More research is necessary for the development of absorption systems which become more advantageous when they are driven by renewable energy sources such as solar energy.

Alternative systems which apply sorption systems for cooling purposes have been discussed by Wang et al. (2009). These authors distinguish between adsorption and absorption systems. Wang and Oliveira (2006) give a list with the best performances obtained by different adsorption refrigeration prototypes. From experimental data, Infante Ferreira (2011) has concluded that the second law efficiency of single stage adsorption cycles is around 0.25 while absorption cycles show second law efficiency values in the range 0.46–0.50. The

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Nomenclature

A	solar collector area, m^2
COP	coefficient of performance
D	distribution ratio
I	radiation on the collector surface, $W\ m^{-2}$
$\dot{m}$	mass flow, $kg\ s^{-1}$
p	pressure, Pa
$\dot{Q}$	heat flow, W
t	temperature, K
$\dot{W}$	electrical power, W
x	ammonia concentration, $kg\ kg^{-1}$

Greek symbols

δ	declination angle
η	solar collector efficiency
ϕ	latitude angle
ω	hour angle
θ	incident angle
θ_z	zenith angle

Subscripts

A	absorber
af	application fluid
C	condenser
cw	cooling water
E	evaporator
G	generator
HC	high pressure condenser
HG	high pressure generator
hm	heating medium
LG	low pressure generator
P	pump
s	strong solution

intermittent operation of the reactors as adsorber and as desorber makes adsorption systems less reversible. For this reason this study focuses on absorption systems.

The performance of refrigeration cycles is dependent on the properties of the working fluid used. Absorption systems use a binary solution as working fluid which consists of a refrigerant and an absorbent. Presently, the most widely used refrigerant–absorbent combinations are ammonia–water (NH_3–H_2O) and water-lithium bromide (H_2O–LiBr). The absorption refrigeration cycles with H_2O–LiBr allow very reasonable COPs for applications with evaporating temperatures above 0 °C, generally air-conditioning applications. However, for sub-zero applications of cooling and freezing this mixture cannot be applied due to the required evaporation temperatures. In this case, ammonia-based absorption systems are required. The main disadvantage of ammonia–water mixture is that the absorbent has a high volatility, so after boiling the vapour is not pure refrigerant. For this reason, a rectification is needed after the generator and this makes the system more complicated. Alternative refrigerant–absorption pairs have been proposed. Several publications suggested that ammonia with sodium thiocyanate (NaSCN) salt or ammonia with lithium nitrate ($LiNO_3$) salt can improve the absorption system performance (Antonopoulos and Rogdakis, 1996; Best et al., 1991; Infante Ferreira, 1984; Jeday and Le Goff, 1988; Ruiter, 1990; Sun, 1998; Thioye, 1997).

One advantage of ammonia-salt absorption systems is that they allow evaporation temperatures below 0 °C due to the use of ammonia. In addition, the desorption temperature is lower. As compared to single-effect H_2O–LiBr cycles which require generation temperatures in the range from 90 to 110 °C, the generation temperatures for single-effect NH_3–$LiNO_3$ cycles are decreased to the range 60–90 °C allowing to use a low temperature heat source such as solar energy that can be absorbed easily by flat plate solar collectors.

Another main advantage is that the ammonia-salt absorption systems do not require additional components like NH_3–H_2O systems. The distillation column and the rectifier are not necessary because the salt is a non-volatile absorbent. Thus, the configuration of the ammonia-salt absorption systems is simpler and it has a lower investment cost than that of ammonia–water absorption systems. Previous studies have shown that the coefficients of performance for the systems operating with these solutions are about 10% higher than the ones for NH_3–H_2O system working at the same conditions (Infante Ferreira, 1984).

A solar intermittent absorption refrigeration system with ammonia–lithium nitrate mixture has been studied by Rivera and Rivera (2003). The theoretical performance of this system has been presented for the purpose of ice production in Mexico climate conditions. The same type of system has been studied experimentally by Rivera et al. (2011).

Double-effect H_2O–LiBr systems have been studied by several authors (Liu and Wang, 2004; Xu and Dai, 1997). The COPs of these systems are 1.1–1.2 which is significantly higher than for single effect systems. Three different configurations of the double-effect absorption systems are available depending on the solution flow: series flow, parallel flow and reverse parallel flow (ASHRAE, 2010). The advantage of the parallel flow configuration is that the operating conditions are far away from the crystallization line. This configuration has been shown to lead to higher COPs than the series flow arrangement (Arun et al., 2001).

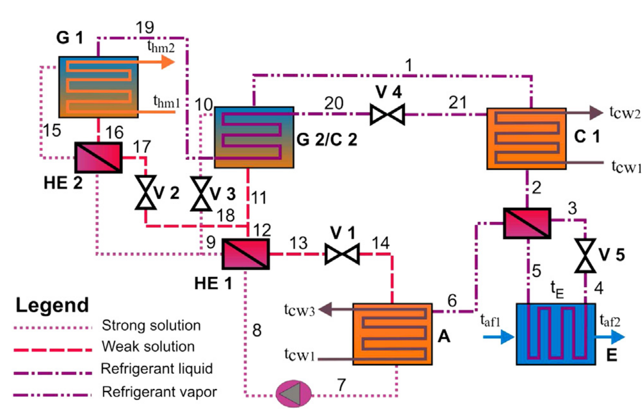

Fig. 1 – Ammonia-salt absorption refrigeration system.

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