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Performance improvement of absorption chillers by means of additives – A numerical study

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ABSTRACT

In this work, a numerical model to quantify the enhancement of the performance of a lithium bromide absorption chiller by means of alcoholic additives is presented. The model is constituted with mass and energy balances, and is validated with experimental data of a single-stage absorption chiller with a nominal cooling capacity of 5 kW. During the simulation, inlet temperature of the hot water flowing into the generator is varied according to experimental data of a solar collector facility installed in Kassel (Germany) with an aperture area of 150 m^2. The temperature of the cooling water entering the absorber is varied as well. Results show that COP and cooling capacity of the absorption chiller are enhanced up to 83% when small quantities of surfactants are added into the aqueous lithium bromide solution.

1. Introduction

Absorption chillers represent an interesting alternative to conventional vapor compression chiller because they are able to supply a cooling demand without such a high electrical consumption. The mechanical compressor of a compression chiller is indeed substituted by a thermal compressor, where the refrigerant vapor (ammonia or water) at the outlet of the evaporator is first absorbed in an absorbent solution (water or aqueous lithium bromide), pumped to the higher pressure level and then desorbed again in the generator. To drive this process, a low-temperature heat source is needed at the generator. For this reason, these chillers are often coupled with solar thermal collectors, which are able to supply this heat flux to the generator with a zero-impact to the environment. In order to make this technology more competitive and appealing on the market, several studies on the performance of absorption chillers coupled with solar thermal collectors have been carried out in the literature.

Li and Sumathy (2001) investigate experimentally the performance of a solar powered absorption chiller with a nominal cooling capacity of 4.7 kW. The aperture area of the collectors is 38 m^2. They compare two different operation modes of the hot water storage tank (partitioned and whole mode). They measure COP up to 0.56, while the collectors supplied water at the generator with a temperature between 70 and 85 °C. They conclude that a better stability of the system is reached as the tank operates in whole mode.

Ali et al. (2008) present a performance assessment of a lithium bromide chiller with a cooling capacity of 35 kW driven by a solar collector field with an aperture area of 108 m^2. The system is used to condition a floor space of 270 m^2. The system produced 8125 kWh in a 5-year operation time, working with a COP between 0.37 and 0.81. They conclude that the specific collector area needed is 4.23 m^2/kW_{cold}.

Agyenim et al. (2010) develop and monitor a prototype of a domestic-scale solar cooling system powered by solar collectors with an aperture area of 12 m^2. The cooling capacity of the absorption chillers is 4.5 kW and it is used to supply the cooling demand of an office (82 m^3). They measure an average COP of 0.58 on a sunny day and notice that the COP decreases as the outlet temperature of the collectors increases.

Darkwa et al. (2012) investigate the performance of a solar absorption cooling system, both theoretically and experimentally. They achieve a mean COP of 0.69 and a collector efficiency η of 56% when the temperature in the hot water storage tank is stratified.

The majority of the previous work focuses on the performance of the overall system, while there is still a lack of data on the optimization of the absorption chiller. This is nevertheless a fundamental task to perform, since a higher COP of the absorption chiller leads to a lower heat power needed at the generator, and thus to a smaller area required by the solar collectors. The performance of absorption chillers can be enhanced by means of alcoholic additives. These surfactants, when added in small quantities in the aqueous lithium bromide solution, reduce its surface tension (Lonardi et al., 2016). The wetting of the horizontal tube bundle of the absorber of these chillers becomes then higher and the heat and mass transfer in the absorber are enhanced as a consequence (Glebov et al., 2002).

Beutler et al. (1996) measure the heat transfer coefficient

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Nomenclature

CCE	cooling capacity enhancement [%]
COP	coefficient of performance [–]
G	global solar radiation [W/m^2]
$\dot{m}$	mass flow rate [kg/s]
p	pressure [Pa]
$\dot{Q}$	heat flux [W]
T	temperature [°C]
$\dot{V}$	volumetric flow rate [kg/s]
x	mass concentration of water in LiBr [–]
η	solar collector efficiency [–]

Subscripts

a	aperture
Ab	absorber
Add	additive
IN	inlet
OUT	outlet
p	poor
r	rich
S	solution
Sat	saturation
V	vapor
W	water

Abbreviations

LiBr	lithium bromide
2-EH	2-ethylhexanol

enhancement in a falling film absorber with a horizontal tube bundle (copper, smooth). 2-ethylhexanol, 1-octanol and 1-decanol are added to the lithium bromide solution in six different concentrations prior to the investigations. They measure an enhancement of the heat transfer coefficient of the absorber up to 75% with a concentration of 150 ppm of 1-octanol in the aqueous lithium bromide solution. 2-ethyhexanol leads to a similar augmentation while 1-decanol slightly enhances the heat transfer coefficient.

Lin and Shigang (2011) investigate experimentally the mass transfer enhancement in an absorber of an absorption chiller with 2-ethylhexanol. The absorber consists of a single vertical copper tube. They observe that the mass transfer coefficient of the absorber is enhanced up to 100% when 2-EH is added into the aqueous lithium bromide solution with a concentration of 90 ppm. No discussion on the enhancement of the cooling capacity and the COP of the chiller is given by the authors.

Since the influence of alcoholic additives has been investigated only on the absorber in the literature, the aim of this work is to investigate numerically their influence on the performance of the whole absorption chiller. A numerical model is developed and validated with experimental data of a single-stage absorption chiller with a cooling capacity of 5 kW (Olbricht and Luke, 2015b). The inlet temperature of the hot water in the generator is varied between 65 and 95 °C according to the measured outlet temperatures of a solar collector field installed at the Hütt brewery in Kassel (Germany) with an aperture area of 150 m^2 (Fig. 1). The temperature of the cooling water is varied as well, see Table 1. The simulation is carried out for the normal operation case (without additives) and for the optimized case (assuming a quantity of 80 ppm of 2-ethylhexanol into the aqueous lithium bromide solution). In this second scenario, experimental values of the heat transfer coefficient of the absorber reported in the literature (Hoffmann et al., 1996) are used for the simulation.

2. Methodology

2.1. Numerical model

The absorption chiller is simulated with a physical model (Olbricht, 2017), which is based on energy and mass balances of each component of the cycle (Fig. 2). The thermophysical properties of the refrigerant (water) and the absorbent solution (aqueous lithium bromide) are calculated according to Haar et al. (1984) and Pátek and Klomfar (2006), respectively. The heat transfer coefficients used in the model are experimental values (Olbricht and Luke, 2015a,b, Olbricht et al., 2016 and Hoffmann et al., 1996).

The boundary conditions and assumptions of the model are the following:

- Condensation, evaporation, absorption and desorption are isobar;
- The geometric parameters of the heat exchanger (area, diameter of the tubes, etc.) are chosen according to the experimental setup used

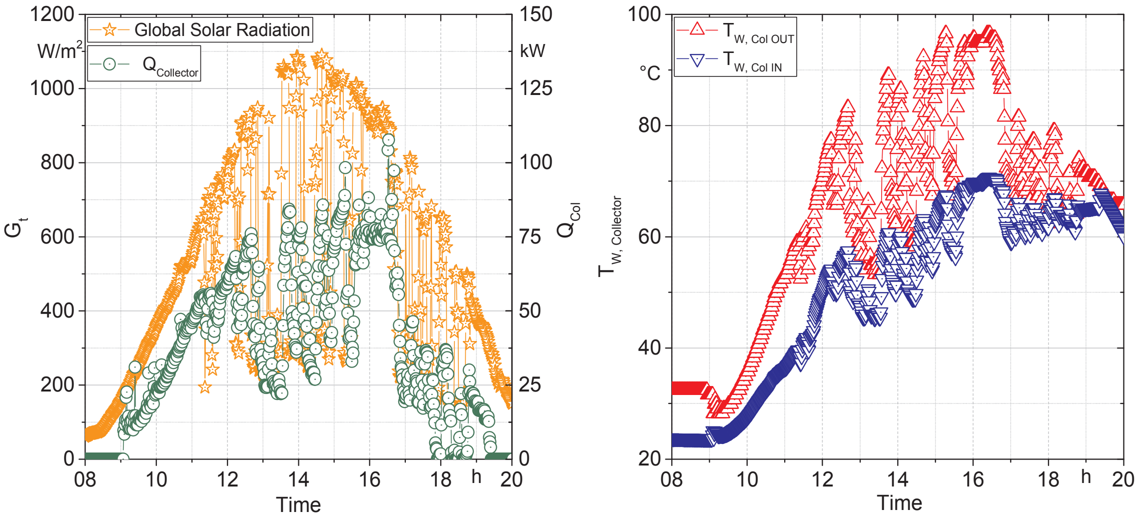

Fig. 1. Global radiation (W/m^2), output heat flux of the collectors (kW) and inlet and outlet temperatures (°C) in the collector field of the Hütt Brewery on Aug, 2nd 2011 (Lauterbach et al., 2012).