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New method for COP optimization in water- and air-cooled single and double effect LiBr–water absorption machines

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ABSTRACT

In this work a new method to optimize the COP in water- and air-cooled single and double effect LiBr/H_2O absorption chillers is proposed. This method determines the effect of condensation temperatures and the solution concentration variation on COP, clearly defining the crystallization limit for different scenarios. This limit is especially important in the design of air-cooled chillers. Taking this into account a simulation program has been developed to calculate the optimum COP. In the case of parallel flow double effect chillers this program estimates not only the optimum COP but also the percentage of refrigerant vapour generated in the high and low temperature desorbers in terms of the condensation temperature. Additionally it provides the mass flow of the solution that should be distributed to each desorber to attain the desired variation in solution concentration.

Nouvelle méthode pour l’optimisation du COP dans les machines à absorption au LiBr / eau à effet simple ou à double effet refroidies à l’eau et à l’air

Mots clés : Condenseur ; Refroidi à l’eau ; Refroidi à l’air ; Système à absorption ; Bromure de lithium ; COP ; Simulation

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Nomenclature

ABS	absorber
COND	condenser
COP	coefficient of performance
c_p	specific heat at constant pressure (kJ kg^{-1})
D	desorber or generator
EVAP	evaporator
HTD	high temperature desorber
LTD	low temperature desorber
h	specific enthalpy (kJ kg^{-1})
HR	high temperature regenerator
LR	low temperature regenerator
$\dot{m}$	mass flow (kg s^{-1})
p	pressure (kPa)
$\dot{Q}$	heat transfer rate (W)
R	regenerator
SUB	sub-cooler
T, t	temperature (°C)
v	specific volume (m^3 kg^{-1})
w	specific work (kJ kg^{-1})
$\dot{W}$	power (W)
X	mass fraction of LiBr (%)

Greek letters

ξ	effectiveness
η	efficiency

Subscripts

aux	auxiliary equipment
C	sum of condensation plus sub-cooling heat
cw	cooling water
dsol	diluted solution
el	electrical
i	inlet
r	refrigerant
o	outlet
odb	outdoor dry bulb
p	pump
th	thermal

1. Introduction

Lithium bromide–water is the working pair of choice in many water- and air-cooled single and double effect absorption chillers. At this writing, no air-cooled double effect chillers are available on the market. Where heat exchangers are large, such as in double effect chillers, designing an absorber that can operate efficiently at absorption temperatures of over 45 °C (such as in air-cooled chillers) is a complex undertaking.

The Eduardo Torroja Institute for Construction Science's Heat Pump Laboratory, which forms part of the Institute's Experimental Solar Energy Plant at La Poveda, Madrid, has been developing a new generation of LiBr/water absorption chillers since 2003. These chillers are designed to work in extremely warm weather at condensation temperatures higher than found in commercial chillers. Air-cooled single and double effect prototypes have been built. A new adiabatic absorber that can operate highly efficiently at outdoor temperatures of 42 °C has also been developed (Palacios et al., 2009). Descriptions of these units have been published by Marcos (2008) and an international patent has been awarded (Izquierdo et al., 2009). The external fluids (water or air) used to cool the absorbers and condensers in these chillers flow in a series configuration.

Water-cooled single effect chillers are the most common type on the market. Analytical models have been developed over the years to evaluate their yield depending on the working pair (Alefeld, 1987; Tufano, 1998); to identify the ideal cycle (Felli, 1983; Tozer and James, 1997); or to predict their performance based on simulation (Hellmann and Ziegler, 1999; Kaynakli and Kilic, 2007). Recently, Kim and Infante Ferreira (2008) published a paper describing single effect chiller performance for different working pairs.

Double effect absorption chillers, in turn, were designed and developed to increase the efficiency of single effect machines. The main structural difference is that they are fitted with two desorbers, also called generators, rather than one. This arrangement delivers more refrigerant, thereby raising chiller efficiency. To this end, the temperature reached in the cycle must be higher than in single effect cycles so the refrigerant vapour generated in the high temperature desorber (HTD) can provide the energy needed to boil the solution flowing through the low temperature desorber (LTD). Single effect chillers operate with a heat source from 70 to 105 °C, whereas double effect machines require a heat source upward of 150 °C (Henning, 2007).

Double effect chillers can be classified by the way the solution (internal fluid) flows through the regenerators and desorbers. In "series flow" double effect chillers, the solution flows successively through the low temperature regenerator (LR), high temperature regenerator (HR), HTD and LTD. In "parallel flow" machines, by contrast, part of the solution flows to the HR/HTD and part to the LR/LTD.

Single effect and double effect series flow cycles have been studied by a number of authors (Anand and Kumar, 1987; Gommed and Grossman, 1990; Arun et al., 2000). More recently, Gomri (2009) and Kaushik and Arora (2009) analyzed these cycles both energetically and exergetically. The condensation temperatures used in their simulations are characteristic of water-cooled chillers, while air-cooled machines are especially useful in dry climates where water is scarce and condensation temperatures may reach values of up to 55 °C (Izquierdo et al., 2004). Since under these conditions the chiller may have to operate in areas of the Dühring diagram close to the crystallization line, the LiBr concentration in the solution must be controlled very strictly. All these researchers calculated the maximum COP in terms of the temperature of the HTD.

The present study aimed to develop a new method for calculating the working conditions that maximize COP in water- and air-cooled single and double effect LiBr/water