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## Parametric study of an absorption refrigeration machine using advanced exergy analysis

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### ABSTRACT

An advanced exergy analysis of a water–lithium bromide absorption refrigeration machine was conducted. For each component of the machine, the proposed analysis quantified the irreversibility that can be avoided and the irreversibility that is unavoidable. It also identified the irreversibility originating from inefficiencies within the component and the irreversibility that does not originate from the operation of the considered component. It was observed that the desorber and absorber concentrated most of the exergy destruction. Furthermore, the exergy destruction at these components was found to be dominantly endogenous and unavoidable. A parametrical study has been presented discussing the sensitivity of the different performance indicators to the temperature at which the heat source is available, the temperature of the refrigerated environment, and the temperature of the cooling medium used at the condenser and absorber. It was observed that the endogenous avoidable exergy destruction at the desorber, i.e. the portion of the desorber irreversibility that could be avoided by improving the design and operation of the desorber, decreased when the heat source or the temperature at which the cooling effect was generated increased, and it decreased when the heat sink temperature increased. The endogenous avoidable exergy destruction at the absorber displayed the same variations, though it was observed to be less affected by the heat source temperature. Contrary to the aforementioned two components, the exergy destruction at the evaporator and condenser were dominantly endogenous and avoidable, with little sensitivity to the cycle operating parameters.

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### 1. Introduction

Cooling and heating machines have been crucial elements of human life for centuries. Numerous studies have thus been conducted to investigate different aspects of these machines. According to Sun et al. [1], the absorption refrigeration principle was introduced in the 1700s based on the observation that ice could be produced by evaporating pure water from a sulfuric acid solution in an evacuated vessel. In 1860, Ferdinand Carré patented a water–water absorption machine. The water–lithium bromide absorption cycle, hereafter referred to as water–LiBr cycle, was introduced in 1950. While the working principle of absorption refrigeration machines has been known for 300 years, the commercial market is still dominated by vapour compression refrigeration machines. However, the growing environmental awareness by society and fast

increasing fossil fuel costs are currently motivating a renewed interest for absorption refrigeration. In fact, one of the most important advantages of absorption refrigeration machines is that they can be powered by low grade heat sources, such as solar energy and the residual heat rejected by industrial processes, whereas conventional compression refrigeration machines are powered by high quality mechanical energy.

The development of the absorption refrigeration technology is partially governed by the search for the most efficient refrigerant–absorbent pairs, the requirements of which include chemical stability, low-toxicity, high affinity for the refrigerant at low temperature and easy separation at high temperature. Other such requirements and a review of possible working fluids, including their advantages and disadvantages, have been discussed in the literature [1,2]. Ammonia–water (ammonia being the refrigerant) and water–LiBr (water being the refrigerant) have emerged as the most efficient working fluid pairs in most applications. Kim et al. [3] used different hydrofluorocarbons (HFC) in ionic liquid solutions, and obtained a coefficient of performance (COP) of 0.57 with

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**Nomenclature**

COP	Coefficient of performance [–]
ECOP	Exergy efficiency [–]
$\dot{E}$	Exergy flow rate [kW]
$e$	Specific exergy [kJ/kg]
$f$	Circulation ratio [–]
$h$	Specific enthalpy [kJ/kg]
$\dot{m}$	Mass flow rate [kg/s]
$P$	Pressure [kPa]
$\dot{Q}$	Heat transfer rate [kW]
$s$	Specific entropy [kJ/kg/K]
$T$	Temperature [°C, K]
$\dot{W}$	Mechanical power [kW]
$X$	Mass fraction of water in working fluid [–]

**Greek letters**

$\eta$	Efficiency [–]
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**Superscripts**

AV	Avoidable
EN	Endogenous
EX	Exogenous
UN	Unavoidable

**Subscripts**

abs	Absorber
cond	Condenser
D	Destruction
des	Desorber
evap	Evaporator
in/out	Going into/leaving component
pump	Pump
Rev	Reversible
S	Isentropic
Sat	Saturation conditions
SHEx	Solution heat exchanger
0	Reference state

R152a and a 100 °C heat source temperature. Meng et al. [4] used an R134a–dimethylformamide working fluid pair in their study of a hybrid absorption–compression refrigeration machine, concluding that the proposed machine allowed for 53% energy saving compared to a conventional mechanical compression machine. Pilatowsky et al. [5] investigated an absorption refrigeration cycle with a monomethylamine–water mixture working fluid, with condenser and absorber temperatures ranging between 25 °C and 35 °C, and evaporator temperatures ranging from –10 °C to 10 °C. The cycle was operated at moderate pressures, which was presented as an important advantage over the ammonia–water absorption cycle. Chekir and Bellagi [6] used a butane–octane mixture working fluid in their study of a single-effect absorption cooling machine, obtaining a COP of 0.36 when the desorber temperature was 150 °C. The authors then proposed a modification of the machine design, with the rectifier being cooled by the weak solution before it enters the desorber. This rather trivial modification resulted in a significant reduction of the heat demand for the separation process, and the COP soared to 0.59. The benefits of inserting recovery heat exchangers between the desorber and the absorber, between the condenser and the evaporator, or a combination of the foregoing have been examined by Sozen [7]. The author concluded that having both heat exchangers or only having the heat exchanger between the desorber and absorber resulted in comparable performances, while only having a heat exchanger between the condenser and evaporator did not have a noticeable effect on the performance of the machine. Numerous other studies discussed absorption refrigeration technologies, including half, single and multiple effect cycles, combined compression–absorption cycles, combined ejector–absorption cycles, etc. [2]. For example, Xie et al. [8] studied a water–LiBr absorption machine and showed that raising the refrigerant pressure before it enters the absorber was a means of increasing the cycle efficiency. Xu et al. [9] noted that the 110–140 °C heat source temperature interval is too high for the operation of a single-effect water–LiBr absorption machine and too low for the operation of the double effect machine. They thus proposed a variable effect cycle comprised of a series of three generators and a high pressure absorber which was operated with heat source temperatures ranging from 85 °C to 150 °C, resulting in COP values between 0.75 and 1.25. In another study, Sirwan et al. [10] showed that adding a flash–tank between the condenser and the evaporator of an ejector–absorption cooling machine could

contribute to augmenting the generated cooling effect. Sozen et al. [11] investigated the possibility of using solar driven ejector–absorption systems and concluded that this technology could be effectively used for cooling applications over 8–9 months per year in Turkey. Besides solar energy, Kalinowski et al. [12] showed that 5.2 MW waste heat can be recovered from a 9 MW gas turbine to generate cooling using an ammonia–water absorption cycle, with a COP varying between 0.41 and 0.47, depending on the cycle design and refrigerated environment temperature. Other combined absorption cooling and power generation applications are available in the literature [13], while Margalef and Samuelsen [14] for example reported the successful use of a commercial 300 kW molten carbonate fuel cell and a 40 ton absorption chiller for an overall thermal efficiency of 72%.

Most published studies on absorption refrigeration machines assessed the performance based on the COP which compares the cooling effect generated by the machine and the energy input required to drive the machine [3,4,8–10,12,14]. Kaushik and Arora [15] analysed a water–LiBr absorption cooling machine and observed that the COP increased with the desorber temperature and decreased when the absorber temperature increased. Bulgan [16] observed that the COP of an ammonia–water refrigeration machine increased when the evaporator temperature increased. These observations are consistent with those of Le Lostec et al. [17] who reported a 4% increase of the COP when the heat source temperature increased by 10 °C and a 25% decrease of the COP when the temperature of the refrigerated environment decreased by 10 °C.

Second law approaches and exergy analysis are currently gaining increased attention because of the additional information they provide on the quality of the energy conversion processes and the actual improvement potential of proposed designs. For this purpose, several studies directly compared the actual cycle COP to the COP that would be achieved by a reversible refrigeration machine operated under the same conditions [5,11,18,19]. Palacios-Bereche et al. [20] presented a methodology for the calculation of the exergy of water–LiBr solutions, identifying both a physical component and a chemical component to the exergy, and insisting on the importance of accounting for the activity of both constituents in the calculation of the chemical exergy. A detailed numerical example of the calculation of the dissolution exergy was provided in the textbook by Szargut et al. [21]. Sencan et al. [22] conducted an exergy analysis of a water–LiBr absorption

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