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Exergy analysis of single effect absorption refrigeration systems: The heat exchange aspect

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ABSTRACT

The main limitation of conventional energy analysis for the thermal performance of energy systems is that this approach does not consider the quality of energy. On the other hand, exergy analysis not only provides information about the systems performance, but also it can specify the locations and magnitudes of losses. A number of studies investigated the effect of parameters such as the component temperature, and heat transfer fluid (HTF) temperature and mass flow rate on the exergetic performance of the same absorption refrigeration system; thus, reported different coefficient of performance (COP) values. However, in this study, the system COP was considered to remain constant during the investigation. This means comparing systems with different heat exchanger designs (based on HTF mass flow rate and temperature) having the same COP value. The effect of HTF mass flow rate and inlet temperature of the cooling water, chilled water and heat source on the outlet specific exergy and exergy destruction rate of each component was investigated. It was found that the lower HTF mass flow rate decreased exergy destruction of the corresponding component. Moreover, the lower temperature of heat source and chilled water inlet increased the system exergetic efficiency. That was also the case for the higher cooling water inlet temperature. Based on the analysis, since the absorber and condenser accounted for a large portion of the total exergy destruction, cooling tower modification with lower cooling water mass flow rate is recommended. Furthermore, increasing the cooling water temperature is also recommended as long as the cooling tower can meet the cooling load.

1. Introduction

A large portion of buildings energy consumption is dedicated to the commercial sector. In 2014, this sector accounted for about 19% of the total energy consumption in the United States [1]. The commercial sector covers a vast class of buildings including office, governmental, institutional, retail, utility, etc. In 2012, among about 5.6 million office buildings in the United States, about 80% were equipped with space cooling systems in order to provide the required thermal comfort during cooling season, which accounted for a huge amount of energy consumption [2]. However, the total energy consumption of this sector for space cooling is projected to decrease by about 0.2% per year reaching a total amount of 1750PJ by 2040 [3]. The projected goal is expected to be achieved despite the rapid growth in the commercial sector, which inevitably requires higher energy efficiency as well as identification and reduction of energy losses in cooling systems.

A variety of air conditioning systems are available for indoor space cooling during hot season. Among these systems, vapor compression and absorption cooling systems are the most common ones. The main difference between these two systems is that in vapor compression systems a compressor is used to increase the pressure of the refrigerant. However, in vapor absorption systems, the pressure change is carried out by means of an absorption/generation process. Nowadays, due to the advantages of absorption over vapor compression systems, absorption cooling is more favored. The advantages include low noise generation, less frequent maintenance requirements, high reliability, possibility of being driven by low-grade energy, better capacity management and control, etc. [4]. Besides, utilization of absorption cooling is in line with the current efforts to phase out environmentally unsafe refrigerants, which are normally used in vapor compression systems [5]. The generation process in absorption cooling can be carried out in several stages, which are known as "effects". The simplest configuration, single effect absorption, consists of a generator, absorber, condenser, evaporator, refrigeration expansion valve, solution pump, solution expansion valve, and solution heat exchanger. Multi effect absorption systems have more generation

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Nomenclature

COP	coefficient of performance (–)
Ex	specific exergy (kJ kg^{-1})
$\dot{Ex}$	exergy rate (kW)
h	specific enthalpy (kJ kg^{-1})
Q	refrigerant quality (kg kg^{-1})
$\dot{Q}$	heat transfer rate (kW)
RI	relative irreversibility (%)
s	specific entropy (kJ kg^{-1} K^{-1})
T	temperature (°C or K)
X	LiBr mass fraction (%)

Greek symbols

η	exergetic efficiency (%)

Subscripts

A	absorber
C	condenser
D	destruction
E	evaporator
F	fuel stream
G	generator
i	particular component
in	inlet
L	loss
out	outlet
P	product flow
T	total
0	dead state

stages with additional generators, condensers, solution expansion valves and solution heat exchangers [6]. In this study, a single effect absorption system is investigated.

The most commonly used measure to evaluate the efficiency of a refrigeration system is the energy efficiency in terms of coefficient of performance (COP) [7]. The first law of thermodynamics (energy analysis) is related to energy conservation, while the second law of thermodynamics (exergy analysis) takes entropy into account via irreversibilities and deals with the quality of energy [8]. Exergy is based on a combination of the first as well as the second law of thermodynamics; thus, it is a measure of the quantity and quality of energy. In systems without flow, exergy is defined as the maximum amount of work obtained from a process, which brings the system into equilibrium with its environment [9]. Consequently, unlike energy, exergy is dependent upon the properties of the system and its surrounding environment [4]. Exergy analysis is useful for improving the efficiency of energy-resource use, since it quantifies the locations, types and magnitudes of losses [10]. Therefore, minimizing exergy destruction of energy systems results in sustainable development [11].

Many studies analyzed the energetic and exergetic performance of different types of absorption systems. Table 1 presents a summary of investigated single effect LiBr/H_2O absorption systems based on exergy analysis. The components are sorted from the highest exergy destruction to the lowest one. It shows that, generally, the absorber and generator had the highest exergy destruction, which was due to the heat of mixing [12]. Furthermore, Table 2 shows a list of investigated parameters with exergetic analysis of single effect LiBr/H_2O absorption systems. It shows that the system components temperature (the first four rows) and HTF temperatures (the last three rows) were investigated in many studies. Earlier studies indicated that the higher heat source temperature resulted in higher COP, while the system exergetic efficiency decreased [12]. This was attributed to the higher exergy loss in the generator as a result of higher temperature difference with the ambient. Moreover, higher chilled water outlet temperature resulted in higher COP and lower exergetic efficiency [12,13]. The reason for the deteriorated exergetic performance is the higher capacity of cooling for colder chilled water temperature. The effect of HTF temperatures on the first law and second law efficiencies are depicted in Figs. 1 and 2, respectively. They show that there is a conflict between the first and second law efficiencies for the suitable HTF temperature. This type of difference is further explained in this study.

In heat exchangers, HTF mass flow rate is an important design parameter. Advantages of higher HTF mass flow rate include higher convective heat transfer coefficient, which in turn brings better overall heat transfer. On the other hand, lower heat exchange rate, higher pressure drop and requirement of a bigger pump are the drawbacks. Therefore, the suitable HTF mass flow rate is the one that satisfies all the mentioned parameters. However, the effect of HTF mass flow rate variation on the exergetic performance of the system is also significant.

Different systems have been exergetically analyzed investigating the effect of mass flow rate; e.g. combined heat and power [14], solar PVT [15] and Rankine cycle [16]. For the absorption cooling, to the best of the authors' knowledge, few studies focused on HTF mass flow rate using exergy analysis. Morosuk and Tsatsaronis carried out a qualitative investigation under constant HTF temperatures [17]. It was concluded that, generally, increasing the heat source and absorber cooling water mass flow rate increases the exergy destruction. Kaynakli et al. only focused on the heat source and considered different temperature and mass flow rates [18]. It was reported that higher heat source HTF mass flow rate resulted in higher exergy destruction of the generators in a double effect absorption system. Recently, the effect of the refrigerant, solution

Table 1
Summary of studies with exergy analysis of single effect LiBr/H_2O absorption systems.

[12]	[20]	[21]	[22]	[23]	[24]	[25]	[26]	[27]	[28]	[29]	[30]	[31]	[32]	[33]	[34]
A	A	G	G	A	G	G	G	A	A	G	G	G	A	G	G
G	C	A	A	G	A	E	A	G	G	A	A	A	SHX	A	A
SHX	E	E	E	E	E	A	C	E	SHX	E	E	E	C	E	C
C	G	SHX	SHX	SHX	C	C	E	C	C	C	C	C	G	C	E
E	SHX	C	C	C	SHX	SHX	SHX	SHX	E	SHX	SHX		E		SHX
REV		REV	RHX	REV		REV					REV				REV
		RHX	P	SEV		SEV					P				P
		P		P											

A: Absorber; E: Evaporator; RHX: Refrigeration heat exchanger; SHX: Solution heat exchanger; P: Pump; C: Condenser; G: Generator; REV: Refrigeration expansion valve; SEV: Solution expansion valve.