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Energy and exergy analysis of a double effect absorption refrigeration system based on different heat sources

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A B S T R A C T

Absorption refrigeration systems are environmental friendly since they can utilize industrial waste heat and/or solar energy. In terms of heat source of the systems, researchers prefer one type heat source usually such as hot water or steam. Some studies can be free from environment. In this study, energy and exergy analysis is performed on a double effect series flow absorption refrigeration system with water/lithium bromide as working fluid pair. The refrigeration system runs on various heat sources such as hot water, hot air and steam via High Pressure Generator (HPG) because of hot water/steam and hot air are the most common available heat source for absorption applications but the first law of thermodynamics may not be sufficient analyze the absorption refrigeration system and to show the difference of utilize for different type heat source. On the other hand operation temperatures of the overall system and its components have a major effect on their performance and functionality. In this regard, a parametric study conducted here to investigate this effect on heat capacity and exergy destruction of the HPG, coefficient of performance (COP) of the system, and mass flow rate of heat sources. Also, a comparative analysis is carried out on several heat sources (e.g. hot water, hot air and steam) in terms of exergy destruction and mass flow rate of heat source. From the analyses it is observed that exergy destruction of the HPG increases at higher temperature of the heat sources, condenser and absorber, and lower temperature of the HPG, LPG and evaporator. This destruction is maximized when hot air heat source is used and minimized with utilizing hot water heat source.

1. Introduction

Absorption refrigeration is an environmental friendly system that can utilize industrial waste heat, solar and geothermal energy sources. Therefore, there is an ongoing effort, and many research and developments (R&D) in the literature for further improvements. These R&D can be classified in various aspects such as configuration types, energy and exergy analysis, thermoeconomic analysis, effects of heat exchangers, alternative fluids [1–5]. In terms of heat source, one type heat source is preferred by researchers usually. Some researchers give properties of the heat sources of the systems. Some studies are free from environment. Kaynakli and Kilic [6] have performed a parametric study over the COP of the LiBr–water system for varying operating parameters. The results showed that solution heat exchanger increases the COP value up to 44% compared to refrigerant heat exchanger which increases the COP by only 2.8%. Aphornratana and Sriveerakul [7] have studied on a 2 kW cooling capacity system as experimental and electric heaters were used as heat source for the generator in the study. Their study described that the solution circulation ratio has a strong effect on the system performance. The measured solution ratio was 2–5 times greater than the theoretical prediction. This was due to the low performance of the absorber. The use of solution heat exchanger could increase the COP by up to 60%. Also, detailed entropy generation based thermodynamic analyses of absorption refrigeration system which had water vapor heat source were carried out by Kaynakli and Yamankaradeniz [8].

There are many types of absorption refrigeration systems such as single effect, double effects, triple effects and half effects. Double effect type is well studied in the literature. For instance, Gomri and Hakimi [9] have presented HPG and LPG temperatures effects on COP and exergy destruction of water–LiBr series flow system which was driven by pressurized hot water. They observed that COP increases with rising LPG temperature and lowering HPG temperature. Exergy analysis of a solar assisted system has been

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Nomenclature

f	circulation ratio
ED	exergy destruction (kW)
HPG	high pressure generator
LPG	low pressure generator
HPC	high pressure condenser
m	mass flow rate (kg/s)
q	heat capacity of components (kJ/kg)
P	Pressure (Pa)
Q	heat transfer rate (kW)
SHE	solution heat exchanger
T	temperature (°C)
W	mechanical power (kW)
w	work of pump (kJ/kg)
X	mass fraction of lithium bromide (%)

Greek symbols

ε	Effectiveness
η	Efficiency
ψ	Specific exergy (kJ/kg)

Subscripts

A	Absorber
C	Condenser
E	Evaporator
EV	Expansion Valve
w	Weak Solution
S	System
s	Strong Solution
P	Pump

carried out by Ravikumar et al. [10]. Kaushik and Arora [11] have performed the first and second law thermodynamic analysis of single effect and double effect water–LiBr system that is connected in series. Their first law analysis results indicate that the COP of double effect system is about 60% greater than the single effect system. Also, the optimum COP is reached at 91 °C for single effect and 150 °C for double effect system. Similarly their second law analysis results indicate that the optimum exergetic efficiency is reached at 80 °C for single effect and 130 °C for double effect system. They mentioned about only temperature of heat source. Equilibrium of low pressure generator temperature has been studied by Arun et al. [12]. Farshi et al. [13] have compared the effects of operating parameters on crystallization phenomena in series, parallel and reverse parallel configuration of double effect lithium bromide water absorption refrigeration systems which have hot water heat source with a computational model. Their study showed that the range of operating conditions without crystallization risks in the parallel and the reverse parallel configurations is wider than those of the series flow system. Farshi et al. [14] have studied on the first and second law analysis for ammonia salt systems. The heat storage process by absorption has been investigated by N'Tsoukpoe et al. [15] and an absorption refrigeration system operated at industrial manufacturing of detergent has been carried out by Lamine and Said [16].

The objectives of this study are to perform energy and exergy analysis on a double effect series flow absorption refrigeration system with water/lithium bromide as working fluid pair. To conduct a parametric study for investigating the effect of operation temperatures of the overall system and its components on heat capacity and exergy destruction of the HPG, coefficient of performance (COP) of the system, and mass flow rate of heat sources. Also, to carry out a comparative analysis on several heat sources (e.g. hot water, hot air and steam) in terms of exergy destruction and mass flow rate of heat source.

2. Double effect absorption refrigeration system

The double effect series flow absorption refrigeration system is represented in Fig. 1. The system consists of a condenser, an evaporator, an absorber, a solution pump, a high pressure generator, a high pressure condenser (HPC), a low pressure generator, two heat exchangers, two solution expansion valves and two refrigerant expansion valves. There are three pressure levels, which are low condensing, high condensing and evaporating pressures. The absorber pressure is equal to the evaporator pressure and the condenser has the same pressure level of the LPG. Also, the HPC pressure is the same as the HPG pressure.

Water–LiBr solution concentration has three concentrations levels, which are strong, stronger and weak solutions. The concentration is weak, strong and stronger at absorber outlet, HPG outlet and LPG outlet, respectively. The LPG receives heat only from HPC. The HPG gets heat from an energy source either hot water/steam or air. The absorber and condenser are cooled with water at 25 °C. Chilled water is produced by the evaporator. Heat exchangers are for heat recovery. They reduce the external heat requirement and thus, enhance the overall performance.

2.1. Importance of energy source

Absorption refrigeration systems allow use of variable heat sources such as industrial waste heat, solar energy and geothermal energy. Also, thermal energy obtained from these sources can be transferred with hot water/steam, hot air and the other exhaust gases after thermal processes. Selection of a suitable heat source depends on many parameters such as temperature, mass flow rate and the other thermodynamic properties. Contrary to its COP value, the exergy destruction of the absorption refrigeration systems does change based on the type of heat sources. Thus exergy equations should include the above mentioned heat source parameters. Hot water/steam and hot air are the most common available heat source for absorption applications. Table 1 shows an array of applications of absorption refrigeration systems [17,18].

2.2. Assumptions

In order to simplify the analysis following assumptions [19] are made;

- The system runs under steady-state conditions.
- The water at the outlet of condenser is saturated liquid.
- The water at the outlet of evaporator is saturated vapor.
- Pressure losses in the two heat exchangers and in the all pipelines are negligible.
- The reference environmental state for the system is water at an environment temperature of 25 °C and 1 atmospheric pressure.
- The moisture of hot air is fixed.
- The evaporator capacity is fixed.
- The HPG is driven by saturated hot water, hot air and steam separately.
- There is no heat transfer from the system to surroundings excluding HPG, evaporator, condenser, and absorber.