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A thermodynamic evaluation on high pressure condenser of double effect absorption refrigeration system

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ABSTRACT

One of the parameters affecting the COP of the absorption system can be considered as the thermal balance between the high pressure condenser (HPC) and the low pressure generator (LPG) since heat rejected from the HPC is utilized as an energy source by the LPG. Condensation of the water vapor in the HPC depends on the heat removal via the LPG. This circumstance is significant for making an appropriate design and a controllable system with high performance in practical applications. For this reason, a thermodynamic analysis for the HPC of a double effect series flow water/lithium bromide absorption refrigeration system was emphasized in this study. A simulation was developed to investigate the energy transfer between the HPC and LPG. The results show that the proper designation of the HPC temperature improves the COP and ECOP due its significant impact, and its value necessarily has to be higher than the outlet temperature of the LPG based on the operating scheme. Furthermore, the COP and ECOP of the absorption system can be raised in the range of 9.72–35.09% in case of 2 °C-temperature increment in the HPC under the described conditions to be applied.

1. Introduction

In recent years, energy security and related issues have oriented us to heed the energy recovery and efficiency for thermal systems. Renewable source and waste heat utilization impress the science communities for the sake of insuring energy sustainability and curbing carbon emissions. Absorption refrigeration systems provide many distinctions from those points in cooling operations but have lower coefficient of performance (COP) relative to its counterparts. In order to improve the COP of these systems or adapt them to any source of energy, various modifications to the cycle configurations have been proposed [1–3]. Multi-effect cycles have higher COP values relative to the basic configurations however they require higher source temperature with increasing the effect number [4] and increased number of heat exchanger. On the other hand, raising the effect number is not energy effective alone when the system components are not operated in a suitable operational domain. It has been a primary challenge for the researchers to increase the COP of the absorption refrigeration systems to a significant degree. At this point, a theoretical analysis provides a wealth of information on the expected operational characteristic of the system and its performance. Yet, it fundamentally includes some assumptions or approximations to simplify the analysis which in turn can yield some pitfalls while not holding the physical nature of the system. Thus a realistic system analysis helps to deliver admissible outputs which serve to predict the system behavior and performance under different scenarios.

Double effect absorption system, as its name implies, utilizes double-generator; high, and low pressure which in turn provide heat recovery and improvement of the COP. In double effect series flow absorption systems, it is required the entire vapor generated at the high pressure generator (HPG) to be fully condensed via the low pressure generator (LPG). This is achieved in the practical systems by installing a throttling device which allows forming the condensate in high pressure condenser (HPC) of the absorption system, and thus the noncondensate is restricted there not to be escaped to the condenser as in the vapor form [5]. At this stage, the LPG adjusts itself somehow to come to an equilibrium temperature while furnishing the complete condensation at the HPC. The evaluation of this circumstance at the design stage of the multi-effect absorption systems is crucial to sustain maximum possible heat

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Nomenclature

f	circulation ratio
h	enthalpy, kJ/kg
$\dot{m}$	mass flow rate, kg/s
$\dot{Q}$	heat transfer rate, kW
T	temperature, °C
$\dot{W}$	power, kW
X	solution concentration, %

Greek symbol

ε	effectiveness
η	efficiency

Subscript

A	absorber
cr	crystallization
C	condenser
E	evaporator
HPC	high pressure condenser
HPG	high pressure generator
LPG	low pressure generator
P	pump; pressure
s	strong solution
w	weak solution

Abbreviation

COP	Coefficient of Performance
ECOP	Exergetic Coefficient of Performance
EV	Expansion Valve
HPC	High Pressure Condenser
HPG	High Pressure Generator
H_2O/LiBr	Water/Lithium Bromide
ITBP	Initial Thermal Balance Point
LPG	Low Pressure Generator
SHE I	Solution Heat Exchanger I
SHE II	Solution Heat Exchanger II

transfer rates at the corresponding equilibrium temperature of the HPC and other regarded system parameters. At off-design conditions, the system operates at some balanced state where optimum operating efficiency would not be obtained. Thus a realistic system analysis provides us useful knowledge to be used in the design and control of such systems during operation for attaining maximum COP at optimum condition.

Many researchers have made thermodynamic analyses for improving the COP of double effect water/lithium bromide (H_2O/LiBr) absorption systems using energetic and exergetic methodologies as in the single effect [6–8]. The studies handled from the view of energetic evaluation [5,9–11] considered the effective system parameters on the COP. The analyses showed that while increasing either the HPG temperature up to a certain level or effectiveness of the solution heat exchangers (SHEs) improves the COP [5,9–11], increasing the circulation ratio [5,9,11] or solution concentration ratio [11] degrades the COP. On the other hand, many assessments have been carried out for the exergy analysis of double effect H_2O/LiBr absorption refrigeration systems [12–19] since the exergetic evaluation provides more meaningful results relative to the energetic analysis. The energetic approach has a limited use owing to the fact that it is incapable of identifying the thermodynamic inefficiencies in the system components. Combining the energetic and exergetic analyses offers a better insight to the improvement of the performance and design of such systems. The recent studies have presented that the performance variation of double effect H_2O/LiBr absorption refrigeration systems depends on various system parameters. Ravikumar et al. [12] showed that the ECOP (exergetic coefficient of performance) of the system increases with increasing the LPG temperature but decreases with increasing of the HPG temperature. Khaliq and Kumar [13] have indicated that increasing the HPG and evaporator temperatures leads to increasing in the COP and ECOP but decreasing in the absorber and condenser temperatures lowers both the COP and ECOP. Exergy destruction in each component of the system is also investigated in the study, and it is seen that the total exergy destruction in both the HPG and LPG make up between 30 and 35%, the SHEs correspond to 11–20%, the total exergy destruction in absorber is around 12–18% of the exergy change in the HPG heating water, and the expansion valves (EVs) are relatively smaller within the range of 1–5%. Gomri and Hakimi [14] drove similar inferences with [12], and further concluded that the absorber and HPG have strong effects on system performance since their contribution to the total exergy destruction is remarkable. Additionally, the effect of the LPG temperature on the COP and ECOP is examined. Increasing the LPG temperature raises the COP and ECOP sharply but higher than a certain value does not contribute substantial improvement to the performance indicators. Kaushik and Arora [15] presented that increase in the HPG temperature increases the COP and ECOP up to an optimum HPG temperature (about 150 °C). It was obtained that lowering the absorber temperature brings down the optimum HPG temperature and increases the COP and ECOP as well as their maximum values. Increasing the evaporator temperature raises the COP but reduces ECOP. Increasing the absorber temperature reduces the COP influentially as compared to increasing the condenser temperature. The absorber degrades the COP mostly in comparison to the other system components. Arora and Kaushik [16] indicated the variation of COP and ECOP with respect to the component temperatures and dead state. The results showed that the COP can be increased by employing higher HPG temperate up to a level (about 150 °C) where the COP curve levels off and even shows a marginal drop at subsequent elevating temperatures. The maximum COP is obtained at lower LPG temperatures in case either the absorber/condenser temperature is reduced or the evaporator temperature and effectiveness of SHEs are increased. The optimum HPG temperature to obtain maximum ECOP was found lower (130 °C for the series flow double effect system) as compared to the optimum HPG temperature that results the maximum COP. The ECOP reduces with an increase in the absorber, condenser and evaporator temperatures but the exergetic analysis introduced that the absorber is the worst component and requires more advancing design relative to the condenser, evaporator SHEs, respectively. Farshi et al. [17] compared three different cycle configurations (series, parallel and reverse parallel) with identical cooling capacities. The comparison study revealed that the COP and ECOP for the parallel and reverse parallel systems show similar trend but higher than those of the series flow. The study also resulted that an increase in HPG temperature to a certain value increased the COP and ECOP, and further increasing reduced the ECOP but remained the COP almost constant. It was also similarly found that the optimum HPG temperature corresponding to the maximum ECOP is lower than that of the corresponding