Exergetic analysis of LiBr-Water absorption system for Airconditioning applications

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Abstract- Absorption systems have the potential of employing thermal energy such as waste heat to produce chilled water and for producing refrigeration effect. In the present study, a lithium bromide/water (LiBr/H2O) absorption system for airconditioning applications was analysed on the basis of the first and second laws of thermodynamics. Calculations were employed to determine the coefficient of performance (COP) and the exergetic efficiency of the absorption.

Keywords: Absorption airconditioning, LiBr- water systems, thermodynamics, second law analysis

I. INTRODUCTION

Heat-driven absorption systems have been less popular than their electricity-powered vapour-compression counterparts because of higher costs and lower efficiency. However, absorption systems can become more attractive when some factors such as total energy utilization and electricity demand side management are considered. Absorption systems have the potential of employing waste heat from thermal processes as driving energy to produce chilled water and/or hot water for building cooling and heating applications, thus improving the total energy utilization. The demand for electricity in industrial facilities as well as in residential and commercial buildings has grown dramatically in the last two decades. The demand for building cooling is a major contributor to creating the electricity demand peaks during summer. Demand side management to lessen the demand for cooling is a more economical way than constructing new power plants. Application of heat-driven absorption systems is one elective way to reduce peak demand for air-conditioning usage. Therefore, many power companies are currently offering rebates to their customers to encourage installation of absorption systems for building cooling. In addition, the CFC and HCFC refrigerants used in vapour-compression systems are the main factor for the depletion of the ozone layer. The bans on certain CFCs and HCFCs have encouraged engineers and researchers to give more consideration to absorption systems.

In recent years, there has been a growing interest in the use of the principles of the second law of thermodynamics for analysing and evaluating the thermodynamic performance of thermal systems as well as their technologies (Alefeld, 1989; Moran, 1989). Adopting this approach, the present study simulates a lithium bromide/water (LiBr/H O) absorption system for cooling and analyses its coefficient of performance (COP) and exergetic efficiency under different operating conditions.

II. OPERATION OF ABSORPTION CYCLE

A basic LiBr/H O absorption system consists of an evaporator, a condenser, a generator, an absorber, a solution heat exchanger, a throttling valve, and a solution pump. The system schematic is shown in Figure 1. As is shown, a strong solution (State 11, high concentration of lithium bromide in the solution) leaving the generator (G) through the solution heat exchanger (HX) enters the absorber (A) to absorb the water vapor (State 3, refrigerant) from the evaporator (E) and becomes a weak solution (State 6). External cooling water (State 4) is introduced into the absorber to extract heat and keep the temperature from rising since the absorption process is exothermic. Then, the weak solution is delivered to the generator by the solution pump through the solution heat exchanger where this solution recovers some heat transferred from the strong solution. An external heat source at a high temperature (State 8) supplies heat into the generator to generate water vapour from the weak solution. The vaporized water (State 10) goes into the condenser (C) where it is condensed by means of an external cooling water loop (State 13). After this, the condensed water (State 15) passes through

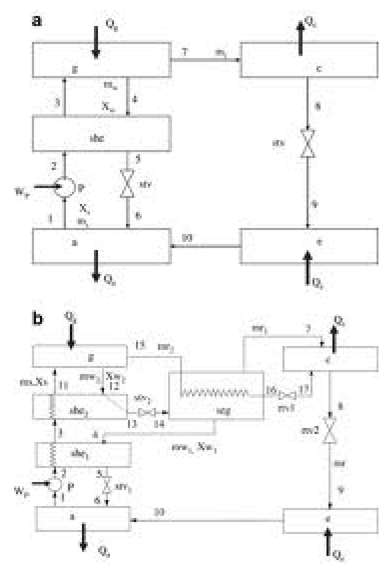

Figure 1: Schematic of the Single-effect absorption system

a throttling valve (V) and goes back to the evaporator where the water is evaporated at a low temperature by extracting heat from the chilled water (State 1) to create a cooling effect. Finally, this water vapour leaves the evaporator to the absorber and is absorbed by the strong solution, thus completing the cycle. Instead of providing chilled water, the absorption system in Figure 1 can also supply hot water for heating applications at the same circulation of the working fluids as for cooling applications. The deference of operation between the two applications is the useful output energy and the operating temperature and pressure levels in the system. The useful output energy of the system for heating is the heating capacity obtained from the absorber and condenser, while the input energy is supplied to the generator

III. THERMODYNAMIC ANALYSIS

In performing a thermodynamic analysis for an absorption system, the principle of mass Conservation and the first along with the second laws of thermodynamics are applied to Individual components of the system. Each component can be treated as a control volume with inlet and outlet streams, heat transfer, and /or work. In the system, mass conservation includes the mass balance of total mass and each material species (such as refrigerant and absorbent). The governing equations of mass and species conservation for a steady-state and steady-flow system are, respectively,

$$\Sigma(m)in - \Sigma(m)out = 0 \quad (1)$$

$$\Sigma(mc)in - \Sigma(mc)out = 0 \quad (2)$$

Where m is the mass flow rate and c is the mass concentration of LiBr in the solution. The first law of thermodynamics readily yields the energy balance of each component of the absorption system.

$$\Sigma(mh)in - \Sigma(mh)out + [\Sigma Qin - \Sigma Qout] + W = 0 \quad (3)$$

Where the Q's are the heat transfer rates between the control volume and its environment, and W is positive if work is performed on the system. Second law calculates system performance based on exergy. Exergy is defined as the maximum useful work attainable from an energy carrier at a given state in any process that brings the energy carrier into equilibrium with its environment (Moran, 1989). If a large reference environment is at a temperature To, then the exergy of a material stream can defined as

$\varepsilon = (h-h0) - To\ (s-s0)$ (4)

where ε is the exergy of the fluid at temperature T; and h and s are the enthalpy and entropy of the fluid; the subscript 0 refers to the reference state.
Exergy balance for the steady-state process of a control volume (each component) can be
Expressed as

$\Delta E = \Sigma(m\varepsilon)in - \Sigma(m\varepsilon)out + [\Sigma(Q\ (1- To/T\ )\ )\ in\ \ - \Sigma Q\ (1- To/T\ )\ )\ out\ ] + \Sigma w$ (5)

ΔE is the lost exergy or the irreversibility that occurred in the process. The first two terms of the right-hand side are the exergy of the inlet and outlet streams of the control volume. The third and fourth terms are the exergy associated with heat transferred from the source maintained at a temperature T, and sometimes are called 'equivalent' work. The last term is the exergy of mechanicals work added to the control volume, and is negligible for absorption systems unless solution and refrigerant pumps are considered. First law analysis of the absorption system leads to computing a coefficient of performance (COP), which is defined as the ratio of the useful energy obtained from the system by the external water loop at the evaporator to the primary energy input via other external water loops at the generator.

COP cycle = useful energy output / (6)
primary energy input

For an absorption cooling system the numerator of Equation (6) is the cooling capacity obtained from the evaporator, and the denominator is the heat added to the generator. Therefore the cooling COP of the absorption system in Figure I can be expressed as

$$COP= \frac{Qe\ \ M1(h1-h2)}{Qg\ \ \ m8(h8-h9)} \qquad (7)$$

Where m is the mass flow rate and h is the enthalpy of the working fluid at each corresponding state point.
The second –law efficiency of the absorption system is measured by the exergetic efficiency, Eex, which is defined as the ratio of the useful exergy (or available energy) gained from a system to that supplied to the system. Therefore, the exergetic efficiency of the absorption
System is the ratio of the chilled water exergy at the evaporator to the heat source exergy at the generator
(9)
Eex, cooling
= ΔE chilled water/ΔE heat source (8)

For cooling, or the ratio of the combine supply hot water exergy at the absorber and condenser to the heat source exergy at the generator for heating

(10)
Eex, heating (9)
= ΔE supply hot water/ΔE heat source

IV. RESULT AND DISCUSSION

The variation of the coefficient of performance (COP) and exergetic efficiency (Eex) of the absorption system for airconditioning with two different cooling water temperatures (29.4 and 35.00C) entering the absorber and the condenser versus the heat source temperature supplied to the generator. It can be seen that the cooling COP of the system is higher for the lower cooling water temperature as expected, and increasing the heat source temperature contributes to more improvement in the COP for the system with a higher cooling water temperature. It should be noted that, although the COP of the system increases with increasing the heat source temperature, the rate of increase of the COP become smaller as the former is temperature. This behavior may be explained by the fact that although the high heat source condenser and absorber which results in a decrease in the COP. This negative temperature in the beneficial effect of the high temperature of the heat source on the COP.

In the second–law analysis of the cycle, a lower cooling water temperature gives the absorption system a higher exergetic efficiency as expected. The effect of the heat source temperature. on the exergetic efficiency does not produce the same behaviour as that for the COP for the absorption chiller within the operating range of the heat source temperature. The exergetic efficiency of the with the lower cooling water temperature decreases monotonically when increasing the heat source temperature. But for the case with the high cooling water temperature, the exergetic efficiency increases first, levels off, and then decreases with a further increase in the heat source temperature. This decrease of the exergetic efficiency can be explained by the fact that even though a high-temperature heat source increases the output cooling exergy, it also means that more input exergy is added to the system, and the net results leads to a smaller exergetic efficiency from second law standpoint.

V. CONCLUSIONS

Performance simulations have been carried out for a LiBr/H2O absorption system for Cooling applications. Both the first and second law efficiencies have been investigated and compared over a host of operating conditions. In the parametric analysis of the absorption system for cooling with varying operating conditions, it was clear that a low cooling water temperature yields both a higher cooling COP and higher exergetic efficiency as expected. Result also showed that, although the absorption system operating with the higher chilled water temperature has a better cooling COP, this system has a smaller exergetic efficiency than those having a low chilled water temperature. Increasing the heat source temperature can improve the cooling COP of the absorption system, but as the heat source temperature increases beyond a certain threshold, the COP of the system level off and even decreases. This negative effect of increasing the heat source temperature is more noticeable for the exergetic efficiency values shown in the previous section. In the parametric analysis of the absorption system for heating, it is evident that increasing the heat source temperature will increase both the heating COP and the exergetic efficiency. However, increasing the heat source temperature could result in a high risk of crystallization for the LiBr/H2O absorption system does not have good thermodynamic performance for heating, and may not even be able to operate normally because of the freezing problem of refrigerant (water). When such a situation arises, the heat source stream should probably be supplied to the heating spaces directly without operating the absorption system.

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