Energy Conversion and Management 87 (2014) 29–36

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Optimization study of a single-effect water–lithium bromide absorption refrigeration system powered by flat-plate collector in hot regions

A. Saleh *, M. Mosa

Department of Mechanical Engineering, Faculty of Engineering, Al Jouf University, Sakaka, Saudi Arabia

ARTICLE INFO

Article history:
Received 3 April 2014
Accepted 30 June 2014
Available online 19 July 2014

Keywords:
Optimization
Solar absorption refrigeration
Water–lithium bromide chiller
Flat plate collector

ABSTRACT

This investigation has been carried out to present a comprehensive analysis for optimizing the operation of solar absorption system in hot regions. To optimize performance of the system, the hot source temperature should be controlled in function of incident solar radiation, chilled and cooling water temperatures. With an appropriate control, these external conditions can be monitored to detect and implement the actual optimization conditions. Adopting typical values encountered in hot regions, the overall system performance takes its optimal value at temperatures between 75 and 80 °C. It was found that in designing or selecting solar collector, selective coating type is necessary to produce hot water with potential around 80–90 °C needed to optimize operation of absorption unit. By ensuring an appropriate choice of components temperatures, *COP* of absorption unit can exceed the value 0.8. Cooling water temperature above 40 °C reduces significantly the performance of the unit which requires, under conditions of extremely high external temperatures, dimensioning and selection of condensers and absorbers that guarantee values less than this limit.

1. Introduction

In recent years, depletion of ozone layer and green house effect became serious problem. Studies have shown that the conventional working fluids of vapor compression systems are causing ozone layer depletion and green house effect [1]. Therefore many researches were devoted toward absorption refrigeration systems as they are environmentally friendly, cause no depletion of ozone layer and global warming and can be driven by low grade source of energy such as solar energy [2]. Although many absorbent-refrigerant pairs were recommended for absorption cooling cycles, two of them are used widely, namely, NH_3–H_2O and LiBr–H_2O. Despite its restriction to application in air conditioning only, LiBr–H_2O system is superior to NH_3–H_2O one in solar applications, as it can operate at a low generator temperature, has a higher *COP* and can be operated by simple flat plate collectors. Mansoori and Patel presented a comparative study for different combinations of refrigerant-absorbent and concluded that that LiBr–H_2O combination is preferred for localities with high environmental temperatures [3]. Many authors investigated LiBr–H_2O systems powered by solar energy using flat plate collectors. Fathi et al. [4] modeled and simulated a solar absorption refrigeration system by considering different temperature reservoirs and the effect of irreversibility to predict optimal operating conditions. Li and Sumathy [5] concluded that using partitioned storage tank results in a quicker cooling effect and higher *COP* compared to a normal stratified tank. Mittal et al. [6] investigated the effect of inlet generator temperature and showed that at higher reference temperature the refrigerator performance increases while decreases the surface area of system components; but lower reference temperature improves the fraction met by solar energy. Gomri [7] presented a numerical study of solar/natural gas single effect lithium bromide absorption chillers. He used natural gas burners as an auxiliary heater to heat the hot water on its way to the generator. His results showed that the maximum *COP* is 0.82 and the maximum exergetic efficiency is about 30%. Assilzadeh et al. [8] designed a solar-powered lithium-bromide absorption system using evacuated tube collectors and showed that the system performance is in phase with the diurnal variation of solar radiation. Ardehali et al. [9] studied a solar powered LiBr–H_2O cooling system and investigated the effect of clearness index on the auxiliary heating source. Lecuona et al. [10] presented a model to calculate the performance of a single-effect LiBr–H_2O absorption chiller. They determined the hot water temperature that maximizes the overall instantaneous efficiency of a solar cooling facility. Their model provided an explicit equation for the optimum temperature of vapor generation, in terms of only the external temperatures of

* Corresponding author. Mobile: +966 562345153.
E-mail addresses: asaleha@ju.edu.sa (A. Saleh), musaali10@hotmail.com (M. Mosa).

http://dx.doi.org/10.1016/j.enconman.2014.06.098
0196-8904/

Nomenclature

A, *B*, *C*	constants
A_c	collector area (m^2)
COP	coefficient of performance
COP_C	Carnot coefficient of performance
COP_{sys}	overall system performance
C_p	specific heat of water (J/kgK)
h	specific enthalpy (kJ/kg)
I	solar intensity (W/m^2)
dotm	mass flow rate (kg/s)
$\dot{Q}$	rate of heat transfer (kW)
$\dot{Q}_L$	energy extracted from the tank (kW)
$\dot{Q}_u$	useful energy (kW)
SHE	solution heat exchanger
T	temperature (°C)
T_h	hot source temperature (°C)
T_{in}	collector inlet temperature (°C)
T_o	environment temperature (°C)
T_s	storage tank temperature (°C)
U_L	over all heat transfer coefficient (W/m^2 K)
v	specific volume (m^3/kg)
x	lithium bromide mass fraction (kg LiBr/kg solution)
Δt	time period (h)

Greek

α	absorptance
τ	transmittance
ε	heat exchanger effectiveness; Emittance
η	relative performance ratio
η_c	collector efficiency

Subscripts

a	absorber
c	condenser
e	evaporator
g	generator
i	state point or index *i* = 1, 2, 3 ...
me	mechanical
r	refrigerant
ss	strong solution
ws	weak solution

the chiller. Mazloumi et al. [11] simulated a solar single effect lithium bromide–water absorption cooling system powered by a horizontal N–S parabolic trough collector. Their results showed that the collector mass flow rate has a negligible effect on the minimum required collector area, but it has a significant effect on the optimum capacity of the storage tank.

Most of Middle East countries enjoy an abundance of solar radiation. These countries are characterized by a large number of sunny days and considerable summer average of solar radiation. Because of the near coincidence of peak cooling load with availability of solar power, solar energy seems to be suitable for air-conditioning applications. Between the available options, absorption systems seem to be the most appropriate.

This investigation aims to optimize the performance of solar powered absorption system operating in hot regions. It involves the development of a computer model developed by MATLAB package, to investigate the effect of the various design parameters. The model developed resolve steady state energy and mass balances for the various components of the system. Therefore, for an energetic analysis of system performance, to achieve optimization as this study aims, steady state model meets the objective and is sufficiently accurate. The modeling and simulation included the absorption unit, the solar collector, the storage tank and the whole system.

2. Description of a single-effect absorption refrigeration cycle

Fig. 1 shows the schematic diagram of a solar single-effect absorption cooling system using LiBr–H_2O as the working fluid. Hot water from the solar collector, through the storage tank *ST*, and auxiliary heater, *AH*, is used in the generator to boil off water vapor from the weak solution. The water vapor boiled off in the generator to state 1 is cooled and condensed in the condenser to state 2 and then passed through the expansion valve to state 3 on its way to the evaporator. In the evaporator, water is again evaporated at low pressure, thereby absorbing heat from the surrounding and providing the required cooling effect to leave at state 4.

The hot strong solution leaving the generator at state 8 passes, on its way to the absorber, through the solution heat exchanger, *SHE*, and leaves at state 9 to exchange heat with the cold weak solution leaving the absorber to the generator which passes from state 6 to state 7. In the absorber, the strong solution, entering at state 10, absorbs the water vapor leaving the evaporator at state 4 and becomes a weak solution. The weak solution is pumped from state 5 to state 6 to pass through the solution heat exchanger to enter the generator at state 7. The solar energy collected by the collector is accumulated in the storage tank to be supplied to the generator.

An auxiliary energy source is provided, so that hot water is supplied to the generator when solar energy is not sufficient to heat the water to the required temperature level needed by the generator. It is located at the exit of the storage tank to boost the temperature of the hot water to the reference temperature. The reference temperature is the minimum allowable hot water temperature needed in the generator.

In this study, the behavior of low capacity chillers is examined. Low capacity chiller is intended to have typical capacity around 30–40 kW. This means a solar collector area of 200–300 m^2 is needed. Larger plants are, in fact, not common [12].

3. Mathematical modeling

Mathematical modeling of the whole solar-assisted absorption cooling system requires modeling of the absorption system and the solar system separately.

3.1. Absorption unit modeling

The simulation is based on mass and energy balances for each element of the cycle, supposed to be under steady state conditions. Referring to Fig. 1, for the generator, the mass and energy balances yield:

$$\dot{m}_{ws} = \dot{m}_r + \dot{m}_{ss} \tag{1}$$

$$\dot{m}_{ws}x_{ws} = m_{ss}x_{ss} \tag{2}$$

$$\dot{Q}_g = \dot{m}_1h_1 + \dot{m}_8h_8 - \dot{m}_7h_7 = \dot{m}_rh_1 + \dot{m}_{ss}h_8 - \dot{m}_{ws}h_7 \tag{3}$$

From Eqs. (1) and (2), the flow rates of the strong and weak solutions can be determined:

$$\dot{m}_{ws} = \frac{x_{ss}}{x_{ss} - x_{ws}}\dot{m}_r \tag{4}$$