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Optimization of a lithium bromide–water solar absorption cooling system with evacuated tube collectors using the genetic algorithm

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ABSTRACT

Nowadays absorption chillers are of more interest due to considerable saving in energy consumption and using thermal energy sources. In this paper, a sensitivity analysis is accomplished on a double-effect absorption chiller with 100 t of cooling capacity to study the effect of different parameters on auxiliary energy. The input parameters taken into account in the sensitivity analysis are the volume of storage tank, area of evacuated tube collector, and mass flow rates of water passing through the collector and generator. It is also supposed that the evacuated tube collector is mounted at the monthly optimum angle to get as much solar radiation as possible. Two objective functions are considered for the genetic algorithm namely the auxiliary energy and the net profit obtained from the solar system. An economical analysis is required to calculate the optimum area of collector. The computer code is developed to minimize the auxiliary energy, and maximize the profit. Since the auxiliary energy costs money, it is advantageous to use the same system with minimum auxiliary energy. However, the results show that the optimum mass flow rates of hot water passing through the generator and collector have an important role on reducing the auxiliary energy.

1. Introduction

Lithium bromide–water absorption cooling systems are economical due to their excellent performance and low costs. In these systems thermal energy is used to produce cooling and hence solar energy, waste heat and other forms of low grade energy can be applied to operate the system. Since the maximum cooling load occurs when the highest solar radiation is available, absorption systems have become more interesting.

Many researchers have studied the solar cooling and air-conditioning systems so far. A theoretical microcomputer model was presented by Tsilingiris [1] to evaluate the operational behavior of a simple solar LiBr–H_2O absorption cooling system with 7 kW cooling capacity for small residential applications in Greece. The storage tank in the system was well mixed and heat losses in the interconnecting pipelines were ignored. The cooling system was simulated based on the manufacture's data of a typical LiBr absorption chiller.

A solar absorption system for a typical house in Beirut was simulated by Ghaddar et al. [2]. The absorption system was analyzed based on a thermodynamic model and the storage tank was supposed to be well mixed. The cooling capacity of the evaporator was variable. It was concluded that for each ton of refrigeration, a minimum flat plate collector of area 23.3 m^2 with an optimal water storage tank capacity ranging between 1000 and 1500 l were required for the system to operate exclusively on solar energy for about 7 h a day. The performance of a 1.5 t solar cooling unit was evaluated by Hammad and Zurigat [3]. The system consisted of a 14 m^2 flat-plate solar collector and five shell and tube heat exchangers. The unit was tested in April and May in Jordan and the maximum actual coefficient of performance obtained was 0.55. A system comprised of a solar collector, a storage tank, a boiler and a LiBr–H_2O absorption system to provide the yearly cooling load of 78,235 MJ with a maximum hourly load of 40 MJ and a yearly heating load of 12,528 MJ with a maximum hourly load of 51.6 MJ for a typical house with 196 m^2 floor area was simulated by Florides et al. [4]. The system was modeled in the TRANSYS environment and the program consists of many subroutines to model the subsystem components. The results show that it is not economical to replace any amount of load with heat collected from solar collector systems, but a dramatic increase in recent fuel price will change this result. A single-effect absorption chiller was simulated and the sensitivity analysis was conducted by Mehrabian and Shahbeik [5]. The results deduced from the computer program were used to study the effect of design parameters on cycle performance. It was

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COP coefficient of performance
$A_{collector}$ (m^2) collector area
x (wt%) concentration of solution
UA (kW/°C) conductance
F_i^L control function of load
F_i^c control function of the collector
ε effectiveness of the solution heat exchanger
$\eta_{collector}$ efficiency of the collector
Q (kW) heat transfer rate
I_T (W/m^2) hourly solar radiation intensity on a slope surface
$\dot{m}$ (kg/s) mass flow rate
$\dot{m}_c$ (kg/s) mass flow rate of water passing through the collector
$\dot{m}_L$ (kg/s) mass flow rate of water passing through the generator
m_i (kg) mass of water in each node of the storage tank
c_p (kJ/kg °C) specific heat at constant pressure
T_c(°C) temperature of ambient
$T_{s,i}$(°C) temperature of i^{th} node
$T_{c,o}$(°C) temperature of water at the exit of collector
$T_{L,r}$(°C) temperature of water at the exit of the generator
T_i(°C) temperature of water at the inlet of the collector
W (kW) power
t (h) time
N total number of nodes

Subscripts
abs absorber
aux auxiliary
con condenser
db dry bulb
e exit
eva evaporator
i input
V expansion valve
gen generator
p pump
shx solution heat exchanger
wb wet bulb

concluded that increasing the evaporator and generator temperatures or decreasing the condenser and desorber temperatures can improve the second-law efficiency of the cycle. A solar LiBr–H_2O absorption cooling system with an evacuated tube collector was simulated and optimized in TRANSYS environment for Malaysia's climate by Assilzadeh et al. [6]. It was proposed that a 0.8 m^3 hot water storage tank and a collector of area 35 m^2 at 20° slope angle for a 3.5 kW cooling load was required to achieve continuous operation and increase the reliability of the system. A solar single-effect lithium bromide–water absorption cooling system was modeled in Ahvaz by Mazloumi et al. [7]. The solar energy was absorbed by a horizontal N–S parabolic trough collector and stored in an insulated thermal storage tank. The results show that the collector mass flow rate had a negligible effect on the minimum required collector area, but it had a significant effect on the optimum capacity of the storage tank.

A full simulation model for absorption cooling systems, combined with a stratified storage tank, steady-state or dynamic collector model, and hourly building loads was achieved by Eicker and Pietruschka [8]. In order to validate the above-mentioned model, they used experimental data from various solar cooling plants. Since the absorption chillers could be run at reduced generator temperatures under partial load conditions, the control strategy had an important effect on the solar thermal performance and design. To study the influence of the special load time series for a given cooling power, various cooling load files with a dominance on either external or internal loads for different building locations and orientations were created. It was concluded that largely different collector areas and storage volumes, depending on the characteristics of the building load file and the chosen system technology and control strategy were needed to achieve a given solar fraction of the total heat demand. The results also showed that doubling the collector mass flow decreased the collector area resulting in reducing solar thermal system costs by 30%. Tsoutsos et al. [9] studied the performance and economic evaluation of a solar heating and cooling system of a hospital in Crete using the transient simulation program (TRNSYS). Simulating a complete system consisted of a solar collector, a storage tank, a backup heat source, a water cooling tower, and a LiBr–H_2O absorption chiller were the main objective of this research. A fraction of the total cooling and heating energy demands of a hospital in Crete throughout the year was provided by this system. Some parameters namely Collector area, collector slope angle, volume of hot water storage tank, nominal power of absorption chiller, cooling tower and backup heat source were considered as the optimization parameters. It was deduced that the investment cost was quite high but the highest environmental benefits, the lower payback time, and the highest total annual savings compensated this. Lizarte et al. [10] investigated an innovative solar-driven, directly air-cooled, single-effect, 4.5 kW LiBr–H_2O absorption chiller prototype. Air-conditioning a 40-m^2 room located in Madrid was the goal of this project. Its solar facilities were a vacuum flat-plate collector field, with a total aperture area of 42.2 m^2, a 25-kW external plate heat exchanger and a 1.5-m^3 storage tank. The results comprised of the information including solar cooling facility temperatures and thermal power, solar fraction, COP and SCOP (solar coefficient of performance) values on a day when the outdoor dry bulb temperature ranged from 30 to 37.7 °C. It was observed that despite the high temperatures (109 °C) of the fluid fed by the solar facility into the prototype generator, no LiBr–H_2O crystallization was observed. Congradac and Kulic [11] accomplished the optimization of chillers operating using artificial neural networks and genetic algorithms. The process of making specific chiller models used for testing the results of application of the genetic algorithm in usage optimization was shown as well as the basic characteristics of artificial neural networks. The paper also provided the optimal criteria used to obtain optimization results. The results of the artificial intelligence methods in the chiller optimization were validated in addition to the simulation tools Simulink and EnergyPlus and through a series of experiments on a real office building. The experimental tests were achieved between March and September 2008. It was observed that the artificial intelligence methods could be implemented on all subsystems of a modern integrated BMS, such as the lighting subsystem, the subsystem for protection from solar radiation, the subsystem for error prediction, etc. Thermodynamic modeling of a double-effect LiBr–H_2O absorption refrigeration cycle was simulated by Iranmanesh and Mehrabian [12]. Conductance of all components was evaluated based on the approach temperatures assumed as input parameters. The effect of input data on the cycle performance and the exergetic efficiency were also investigated. A dynamic analysis of a single-effect absorption chiller regarding the effects of all thermal masses on the key parameters of an absorption chiller namely heat duty of all main components, coefficient of performance, and the exergetic efficiency was conducted by Iranmanesh and Mehrabian [13]. To validate the dynamic model, the results predicted from the dynamic simulation were compared with the steady-state results and relative errors for all cases were calculated. The results showed that thermal masses of main components have a minor effect on the heat transfer rate to/from low-pressure