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Performance assessment of water production from solar cooling system in humid climate

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ABSTRACT

This study aims to investigate water extraction process from a solar cooling system using a vapor absorption chiller under variable fresh air ratios. The system consists of an evacuated tube solar collector, lithium bromide absorption chiller and a fan coil unit (FCU). A parametric study is carried out to investigate the effects of flow rate of the fluid in the collector, solar insolation, fresh air volume ratio, temperature and humidity on the system performance and rate of water production. The operating conditions for the best performance are identified in this work. The results showed maximum collector efficiency of 0.66 at an optimum flow rate of the collector fluid of 0.3 kg/s at $A_c = 28$ m^2, $T_f = 45$ °C, $I = 800$ W/m^2 and $R = 50\%$. For the same conditions, useful energy to the generator was found to be 14.8 kW and water production rate was 8 L/h. Using the climate data of a typical day of August for Dhahran, Saudi Arabia, the findings indicated that the chiller COP and water production rate, respectively, reached maximum (0.73 and 6.6 L/h) at noon when the incident solar flux is peak (935 W/m^2) for 45% fresh air volume ratio.

1. Introduction

Rapid increase in population and industrialization coupled with urbanization has resulted in reasonable shortage of fresh water supply alongside with high demand of air conditioning especially in the arid and semi-arid regions. An optimistic estimate of domestic water demand indicates that Saudi Arabia will be needing about 2 billion m^3/year in the next 25 years [1]. Seawater desalination plants operating on fossils-based fuel consumes reasonable amounts of energy and produces harmful carbon emissions, which contribute to environmental pollution. In this regards, new technologies and methods of obtaining fresh water at reasonable cost and clean technology are needed. It is worth mentioning that small-scale water production such as condensed water harvest from air conditioning systems will supplement the existing or conventional water desalination plants. This will go in line with the fact that the demands of both water and air conditioning is high during summer season. Condensed water from cooling systems is abandon in most cases and it wets building envelope and furnishings, contributing to the formation of potential pathogens [2,3]. Hence, managing this cooling product is highly important. Another practical way of obtaining freshwater is through cogeneration where both water and power are produce simultaneously [4,5].

Condensation of atmospheric water vapor in an air conditioning system occurs when the surface temperature of evaporator coil becomes lower than the dew point temperature of the inlet air. This condensation process produces reasonable amount of water especially for systems operating in humid environment and depending on the system cooling capacity. Loveless et al. [6] reported the regions in the world having high potential of condensate collection as water source, focusing on areas facing shortage of fresh water supply.

Many studies [7–11] have been conducted in the past on condensed water harvest from mechanical vapor compression air conditioning systems for domestic and small-scale irrigation purposes. Khalil [7] analyzed analytically the cooling and dehumidification process of a cooling system for the humid regions of United Arab Emirates (UAE). The findings revealed that the rate of fresh water production depends on the cooling coil surface area, air velocity and its properties such as humidity and temperature. Habeebullah [8] reported a theoretical study on water production from evaporator coil using climatic conditions of Jeddah, (Jeddah, Saudi Arabia, 21°23°N and 39°E). The results indicate that maximum water yield occurred during night hours due to higher humidity compared to daytime hours. Elsarrag and Al Horr [9] reported that about 7.2 L/day per kW of cooling of condensate was collected from a packaged unit air conditioner and tilted solar absorption/desorption system.

Al-Farayedhi et al. [10] carried out experimental study on water extraction from a split unit vapor compression heat pump during

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Nomenclature

a_1	first order heat loss coefficient W/m^2 K
a_2	second order heat loss coefficient $W/m^2 K^2$
A	area (m^2)
COP	coefficient of performance
Cp	specific heat capacity (J/kg K)
h	enthalpy (J/kg)
I	incident solar flux (W/m^2)
$\dot{m}$	mass flow rate (kg/s or kg/h)
P	pressure (kPa)
$\dot{Q}$	heat transfer rate (W)
R	fresh air volume ratio (%)
T	temperature (°C or K)
$\dot{W}_p$	pump work (W)
X	fraction of LiBr in solution

Greek symbols

ε	effectiveness
η	efficiency
Φ	relative humidity
ω	specific humidity

Subscripts

ab	absorber
c	collector
con	condenser
ev	evaporator
f	fresh or ambient air
gen	generator
m	mean, mixed air
p	pump
r	room
u	useful
w	water

hot and humid season in Dhahran, Saudi Arabia. The results indicate that both ambient humidity ratio and temperature affected the rate of water extraction from the system but that of the humidity ratio was more significant. Khan and Al-Zubaidy [11] collected more than 2600 L of condensed water from air handling units for the climatic conditions of Dubai, UAE. Nada et al. [12–14] studied similar systems with several configurations and identified the one that gave the highest fresh water production rate, better cost and power savings.

It is a well-known fact that mechanical vapor compression cooling systems consume higher energy compared to vapor absorption type. In addition, vapor compression systems uses refrigerants based on chlorinated fluorocarbon compounds (CFCs) that contribute to the ozone layer depletion. This situation has prompted the use of absorption chillers for cooling purposes as they consume less energy compared to the compression chillers. Because of rising cost of electricity and global warming, alternative and renewable energy sources such as solar, wind and biomass are receiving much attention [15]. Mazharul et al. [16] studied the prospects of using solar thermal energy for space cooling in Saudi Arabia, covering about 21 locations of different regions. They noted that in summer (between April and September), most of the selected locations have solar insolation greater than 6 kW h/m^2/day which is quite attractive for solar absorption cooling applications. Hence, the use of renewable energy sources such as solar for space cooling and water production is a viable option for minimizing the energy consumption and protecting the environment. Absorption chillers are mostly installed in large capacity buildings such as shopping malls, hospitals and institutional buildings that require high volume of outdoor or fresh air. This high volume of fresh air will subsequently increase the chances of producing more water from the cooling process, depending on the system cooling capacity and weather conditions. Based on the above literature survey, it is evident that the previous studies focused on investigating the water vapor condensation process and the quantitative measures of water extraction from vapor compression air conditioning systems. To the best of the authors' knowledge, no work had been conducted to study the water vapor condensation process and rate of water production using solar absorption cooling system. Therefore, the objective of this study is to investigate the water extraction process from a solar cooling system operating using a vapor absorption chiller under variable fresh air ratios. Energy analysis of the cooling system has been carried out as well.

2. System description

The complete system consists of evacuated tubes solar collector array, a single–effect lithium bromide (LiBr) absorption chiller and other auxiliary components such as pumps and control valves as shown in Fig. 1. The absorption chiller consists of four main components: evaporator, absorber, generator and condenser. Single-effect LiBr absorption chiller generally operates at generator temperature of 75–95 °C acquired from a heat source [17]. In this study, the chiller receive input energy (hot water) from the solar collector to the generator and convert it to cooling energy (chilled water) in the evaporator. Fig. 2 shows the psychrometric representation of the cooling/dehumidification process. Referring to the figure, different ratios of fresh air stream from state *f* is mixed adiabatically with the return or room air at point *m* as normally encountered in air conditioning systems. The resulting mixed air stream then enters into the coil unit (FCU) where it is further cooled and dehumidified. The air then leaves the FCU at state, *s* to the room and this the room supply air while the condensed water produced as a result of the cooling/dehumidification process drips down the coil unit via gravity and collected in a container. Point *d* of Fig. 2 represents the apparatus dew point of the coil of FCU and T_d is the apparatus dew point temperature. The apparatus dew point temperature is the minimum possible or the ideal exit air temperature the coil can achieved.

3. System modeling

A model for the absorption chiller is developed based on energy and mass conservation applied to every component considering the following assumptions:

- Steady state operation.
- Refrigerant exiting the condenser is saturated at the condenser pressure.
- Refrigerant leaving the evaporator is saturated at the evaporator pressure.
- Pressure drop due to friction in heat exchangers and the piping system is neglected.
- Heat losses from the components of the system to the ambient is neglected.
- Pumping and fan powers are negligible compared to thermal energy input [18].