Experimental and analytical study on an air-cooled single effect LiBr-H2O absorption chiller driven by evacuated glass tube solar collector for cooling application in residential buildings

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A R T I C L E    I N F O

Article history:
Received 20 February 2017
Received in revised form 18 April 2017
Accepted 8 May 2017

Keywords:
Air-cooled absorption chiller
Steady-state test
Solar air conditioning
TRNSYS simulation

A B S T R A C T

Solar cooling turns out to be a feasible method to reduce the electricity consumption of air conditioning systems in buildings. Air-cooled single effect LiBr-H2O absorption chiller has shown advantages in residential applications. It can be driven by common evacuated tube solar collectors, and save water, maintenance expense and space, due to the absence of cooling tower. However, there is no available small capacity commercial air-cooled LiBr-H2O absorption chiller yet, because of the crystallization risk under ambient conditions. In this work, an air-cooled single effect absorption chiller for which the cooling capacity is 6 kW and a solar air conditioning system were developed. The air-cooled single effect absorption chiller was fabricated and tested under a broad range of steady-state conditions. The chiller was proved successful for real application without crystallization risk and the influence of different operating conditions was also analyzed. Moreover, the performance of a solar air conditioning system using the proposed chiller was investigated for residential cooling application. The results show that the studied absorption chiller can meet about 65% of the total cooling load of the building with an average COPth of about 0.61. Furthermore, 28% of the titled solar radiation is converted into cooling capacity by the solar air conditioning system.

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1. Introduction

Energy consumption in buildings accounts for about 40% of total energy consumption of the society and it is still increasing with the development of economy (Nejat et al., 2015). For the purpose of CO2 emission reduction and energy conservation, numerous researches have been conducted to provide heating, cooling (Zhai and Wang, 2008), hot water (Wang et al., 2015) and electricity (Tripathy et al., 2016) for buildings with solar energy.

Solar cooling has been proved to be a feasible solution to the shortage of electricity in summer, due to the compatibility of peak cooling loads with the available solar power (Zhai and Wang, 2009). By employing available solar cooling cycle can efficiently reduce the load of central electricity network. Furthermore, applications of thermally driven chillers can help solving the overheating problem of solar thermal systems which are designed for space heating in winter (Monne et al., 2011).

Absorption chillers are the most common active cooling device in solar cooling systems (Henning, 2007). Among the different absorption refrigeration techniques, LiBr-H2O absorption chiller is the most developed and commercialized product. The performance of LiBr-H2O absorption chillers has been studied both experimentally and numerically (Beausoleil-Morrison et al., 2015; Xu et al., 2016).

A single effect absorption chiller can be driven by a heat fluid with temperature over 70 °C (Asdrubali and Grignaffini, 2005). In this way, the common flat plate and evacuated tube solar collectors can serve as the heat source. Therefore, a single effect absorption chiller is a feasible choice for residential purpose. The cooling medium of condenser and absorber can be either water or air but most of the commercialized products are water-cooled. There are two main drawbacks in water-cooled systems: the risk of legionnaire’s disease and the difficulty of configuring the cooling tower in residential areas (Izquierdo et al., 2008). On the other hand, air-cooled absorption chillers can be built as a single unit, which saves both water and space in residential application.

In recent years, many studies concerning air-cooled absorption chillers have been reported based on simulation. Izquierdo et al. (2004, 2005) studied a double stage air-cooled absorption chiller to make use of low-grade heat source based on simulation. Wang et al. (2007) simulated a 16 kW gas-fired air-cooled adiabatic...
absorption chiller for residential use. Marcos et al. (2011) provided a new method to optimize the COP for air- and water-cooled absorption chillers. This method determines the effect of condensation temperatures and the solution concentration variation on COP, clearly defining the crystallization limit for different scenarios. Gonzalez-Gil et al. (2012) presented a flat-fan sheets adiabatic absorber which enables air-cooled LiBr-H2O absorption machines to work far from crystallization limits even at high ambient temperature.

Only a few experimental studies have been conducted to analyze the performance of air-cooled absorption chiller for residential use. Gonzalez-Gil et al. (2011) evaluated the performance of a direct air-cooled absorption chiller based on test results of several days. Results show that the chilled water temperatures mostly ranged between 14 °C and 16 °C with a COP around 0.6. In addition, a 4.5 kW air cooled absorption chiller driven by vacuum flat-plate collectors was studied (Lizarte et al., 2012). The lowest chilled water temperature obtained was 14.3 °C with a mean COP of 0.53. Furthermore, a comparison between direct and indirect air-cooled absorption chiller was presented (Lizarte et al., 2013). The results showed that direct air-cooled chillers had a higher COP at 0.62 and can achieve a lower chilling temperature of around 16 °C.

As only few measured data, that accurately characterize the performance of small-scale air-cooled absorption chillers, are available, there is a need for accurate test data under controlled conditions to validate the theoretical models for further research. Besides, there is not yet in-depth annual performance analysis for solar-driven air-cooled absorption cooling system. In this paper, an air-cooled single effect absorption chiller and a solar air conditioning system were developed to evaluate the feasibility and carry out the annual performance analysis of an air-cooled solar cooling system for residential buildings. Firstly, an air-cooled single effect absorption chiller was fabricated and tested under a broad range of steady-state conditions. Then, the annual performance of a solar air conditioning system with the proposed air-cooled chiller was investigated for residential cooling application.

2. Air-cooled LiBr-H2O absorption chiller

A 6 kW air-cooled LiBr-H2O single effect absorption chiller for residential use was designed and fabricated. The schematic diagram of this prototype is shown in Fig. 1 and the prototype picture is shown in Fig. 2. Its main components include a generator, a condenser, an evaporator, a solution heat exchanger, a solution pump and an absorber with a precooler.

The major distinguishing feature of this prototype is that the conventional absorber is replaced by an adiabatic one with a finned tube precooler. The absorption heat is rejected by the precooler and only mass transfer happens in the absorber. In this way, the heat transfer and mass transfer process are enhanced simultaneously. The evaporator and the absorber are assembled in the same chamber, so the vapor generated in the evaporator is directly absorbed by the subcooled solution in the absorber. For the purpose of reducing the machine size further, an air-cooled condenser is arranged in parallel with the precooler to share the same fan.

Fig. 3 compares the temperature/pressure/concentration characteristics of a typical water-cooled chiller with those for an air-cooled chiller on Dühring diagram (Zogg et al., 2005). As the heat-rejection temperature associated with air cooling is much higher, a higher driving temperature is required to achieve the same evaporation temperature level. Consequently, it will bring the cycle closer to the crystallization curve, increasing the risk of crystallization. In addition, the typical outlet temperature of the evacuated glass tube solar collectors is less than 100 °C, so the evaporation temperature of the air-cooled absorption chiller should be raised to some extent. Some studies (Gonzalez-Gil et al., 2011; Lizarte et al., 2012) have reported that chilled water temperature between 14 °C and 16 °C is still capable of residential cooling, especially for the regions with moderate or low humidity conditions. Therefore, the following design parameters have been chosen: (1) The rated hot water supply temperature of the chiller is 90 °C in order to be driven by evacuated glass tube solar
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