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Comparison of absorption refrigeration cycles for efficient air-cooled solar cooling

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ABSTRACT

Absorption chiller is a widely used technology owing to its capability to utilize low grade thermal energy including solar thermal energy and waste heat. Yet, most solar absorption cooling systems need cooling tower to dissipate heat rejection into ambient. The use of cooling tower increases both the initial investment and water consumption, which can be improved by air-cooled solar absorption cooling system. In this paper, to give the best absorption cycle options under different conditions, five absorption refrigeration cycles suitable for air-cooled solar cooling including three double lift absorption cycles and two semi-GAX (Generator-Absorber heat eXchange) absorption cycles were compared. Steady-state simulation is carried out. Efficiencies of these cycles were calculated with LiBr-water and water-ammonia working pairs in the scenario of air-cooled solar cooling. Heat source temperatures of 75–100 °C from non-concentrating solar collector and air temperatures of 20–40 °C were considered. Both air-conditioning condition with evaporation temperature of 5 °C and sub-zero condition with −10 °C were discussed. It is found that mass-coupled semi-GAX absorption cycle with ammonia-water is suitable for air-conditioning with higher heat source temperatures, mass-coupled double lift absorption cycle with water-LiBr is suitable for air-conditioning with lower heat source temperature and mass-coupled double lift absorption cycle with ammonia-water is suitable for sub-zero conditions.

1. Introduction

Utilization of low grade thermal energy including solar thermal power and waste heat is both environment benign and energy saving. The thermally driven absorption cycle is among the most popular choices for low grade thermal energy utilization. It can be applied to solar cooling (Kim and Ferreira, 2008; Wang et al., 2009), waste heat recovery (Ma et al., 2003; Popli et al., 2013; Sun et al., 2012) and CCHP (Li and Hu, 2016; Zhao et al., 2015) for either refrigeration or heat pumping. In typical solar absorption cooling systems, cooling towers are used to dissipate heat rejection to the ambient. The use of cooling tower will increase the initial investment and maintenance cost of solar absorption cooling system (Al-Alili et al., 2012), especially for the small scale applications. In order to reduce the initial cost and avoid the water consumption, air-cooled solar absorption cooling system could be used. However, the use of air-cooled system rises two issues.

The first issue is about the absorption cycle. In typical solar absorption cooling, non-concentrating solar collectors and single effect water-LiBr absorption chillers are popular choices for the low initial investment and easy operation (Assilzadeh et al., 2005; Lizarte et al., 2012; Syed et al., 2005). In the case of air-cooled solar absorption cooling system, non-concentrating solar collectors are not always enough to drive the single effect absorption cycle considering the high cooling temperature, which causes performance degradation or even shutdown of the absorption cooling system. Absorption refrigeration cycles with lower driving temperature should be considered. In the last two decades, various absorption cycles were developed for different driving temperatures, output temperatures, working pairs and efficiencies (Xu and Wang, 2016). In general, there are two pursuits for the cycle improvement, i.e. larger temperature lift or higher efficiency (Kang et al., 2000), and absorption cycles with larger temperature lift are proper for the air-cooled solar absorption cooling. Ziegler and Alefeld (1987) presented three configurations of double-lift cycles including mass-coupled cycle, heat-coupled cycle and resorption cycle. Superposition method was used for COP estimation. The heat pump efficiencies of 1.28, 1.20 and 1.23 were obtained with water-ammonia solution for the three configurations respectively. Kim and Ferreira (Kim and Ferreira, 2009) studied the air-cooled heat-coupled double lift absorption cycle with LiBr-water solution. COP of 0.37 was obtained with 90 °C hot water and 35 °C ambient condition. Lin et al. (2011) and Du et al. (2012) studied the air-cooled mass-coupled double lift absorption chiller with water-ammonia both theoretically and

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Nomenclature

GAX	generator absorber heat exchange
DL	double lift absorption cycle
SGAX	semi-GAX absorption cycle
A	absorption
G	generation
C	condensation
E	evaporation
R	resorption
RE	rectification
T	temperature (°C)
P	pressure (kPa)
X	concentration (g/g)
h	enthalpy (kJ/kg)
m	mass flow rate (kg/s)
Q	heat exchange amount (kW)
COP	coefficient of performance (–)
α	workable range ratio (–)

Subscripts and superscripts

G	generation
A	ambient
E	evaporation
i	different streams
p	solution pump

experimentally. Theoretical COP of 0.34 and experimental COP of 0.21 were obtained with 85 °C hot water for air-conditioning. Through heat-coupled configuration, Aprile et al. (2015) improved the experimental COP of double lift absorption chiller with water-ammonia up to ~0.3 for air-conditioning. They later extended the heat-coupled double lift absorption cycle with water-ammonia for sub-zero condition, and obtained experimental COP about 0.25 under brine outlet temperature of −5 °C (Toppi et al., 2017). Except for the conventional configurations, advanced configurations for double lift absorption cycle were studied for performance improvement. For instance, the combined single effect and double lift absorption cycles were (Yan et al., 2013; Yattara et al., 2003) proposed to achieve both higher COP than double lift absorption cycle and more cooling output than single effect absorption cycle. The semi-GAX absorption cycles were studied to achieve higher COP than double lift cycle (Erickson and Tang, 1996; Toppi et al., 2016). Other options include the 2/3 effect cycles and triple lift cycles (Inoue, 2003). Among these absorption cycles, cycles like the double lift absorption cycles have lower driving temperatures but lower efficiencies, while cycles like semi-GAX absorption cycles have higher efficiencies but higher driving temperature. The tradeoff between working range and efficiency should be decided by the performance comparison.

The second issue is about the working fluid. Water-LiBr and ammonia-water are the most popular choices in commercial absorption chiller for air-conditioning and sub-zero conditions. In the air-cooled condition, the crystallization risk of water-LiBr solution is high which makes the water-ammonia working pair favorable. However, the ammonia-water system usually has lower efficiency than the water-LiBr system under the same condition. Besides, the crystallization risk of water-LiBr solution also varies with the absorption cycles even when the working conditions are the same. Detail analysis is needed to give the better option.

In order to find the better options for air-cooled solar absorption cooling, five absorption cycles suitable for air-cooled solar cooling system, i.e., three double lift absorption cycles and two semi-GAX absorption cycles with water-LiBr and ammonia-water working pairs, were studied and compared in this paper. Typical heat source temperatures and air temperatures for air-cooled solar cooling system were considered with evaporation temperatures of 5 °C for air-conditioning (with both water-LiBr and ammonia-water) and evaporation temperature of −10 °C for sub-zero condition (with only ammonia-water). Efficiency maps of these absorption cycles were calculated, and better options were given.

2. Absorption refrigeration cycles for air-cooled solar absorption cooling

A typical solar absorption cooling system includes the solar collector, storage tank, absorption chiller, cooling tower, cooling load and the pumps. For air-conditioning purpose, single effect LiBr-water absorption chiller with driving temperature about 80–100 °C can be used with non-concentrating solar collector (Assilzadeh et al., 2005; Lizarte et al., 2012; Syed et al., 2005). However, if air-cooled system is used instead of cooling tower for heat dissipation as shown in Fig. 1, the condensation temperature and absorption temperature will be increased, which requires higher temperature of heat source. Either solar collector with higher working temperature or absorption chiller with larger temperature lift at parity of evaporation and driving temperatures could be the solution. Since the cost of solar collector significantly

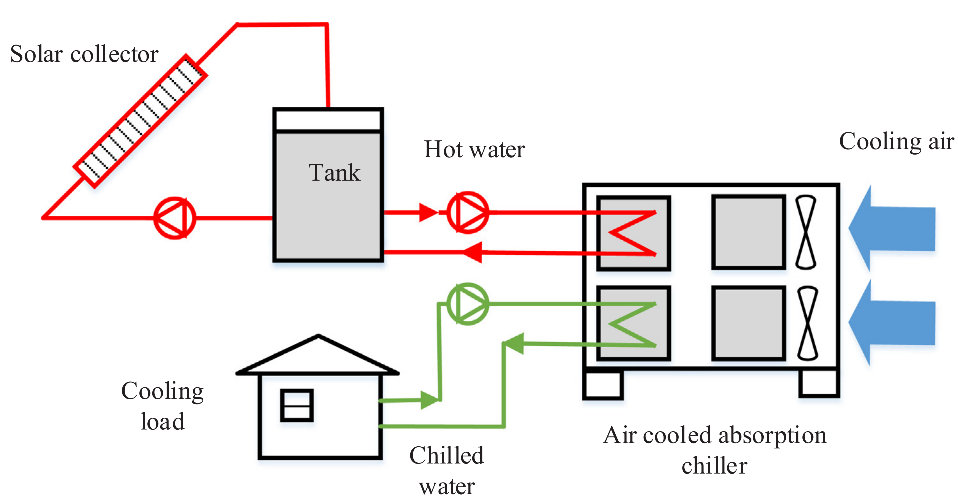

Fig. 1. Schematic of an air-cooled solar absorption cooling system.

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