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Comparison of CPC driven solar absorption cooling systems with single, double and variable effect absorption chillers

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ABSTRACT

In the solar absorption cooling systems, concentrating collector can be adopted to achieve higher driven temperature and improve the system performance. The Compound Parabolic Concentrator (CPC) is a good option with both concentrating and stationary features. With higher working temperature, solar absorption cooling system with concentrating collector has more choices of absorption chillers than the system with non-concentrating collector. The aim of this paper is to find the better chiller choice for solar absorption cooling systems with CPC. The analyzed LiBr-water absorption chillers include the single effect chiller, the double effect absorption chiller and a novel variable effect chiller built by the author. Simulation is carried out in TRNSYS. Model of the variable effect absorption chiller is first derived from MATLAB artificial neural network (ANN) toolbox based on experimental data, and then built in TRNSYS. Performance of the three systems is calculated under the same condition. Performance of the three systems is compared to get the better choices. The impacts of the solar collector area, cutoff driven temperature and storage tank volume on the solar cooling fraction, auxiliary heat input, average chiller COP and average solar efficiency are analyzed. The variable effect system has high solar cooling fraction, low auxiliary heat input and high solar efficiency. The single effect system has medium solar fraction, high auxiliary heat input and medium solar efficiency. The double effect system has low solar cooling fraction, low auxiliary heat input and low solar efficiency.

1. Introduction

The solar thermal cooling systems are energy saving systems that convert thermal input directly into cooling output (Ullah et al., 2013; Wang et al., 2009). Among different solar thermal cooling systems, solar absorption cooling system is competitive due to its relatively high efficiency. The solar absorption cooling system is also environmental benign with natural refrigerants of water or ammonia. With these benefits, solar absorption cooling system has attracted the attention of researchers for decades (Eicker et al., 2015; Zhai et al., 2011). Among different solar absorption cooling systems, the systems with non-concentrating solar collectors and single effect LiBr-water absorption chiller are popular due to their simplicity and low cost. Flat plate collector (Lizarte et al., 2012; Syed et al., 2005) and evacuated tube collector (Assilzadeh et al., 2005; Darkwa et al., 2012; Yin et al., 2012) are both the common choices. However, the common operating temperature of these solar collectors are below 100 °C which is only enough to drive the single effect LiBr-water absorption chiller. Besides, these solar collectors have lower efficiency compared with the concentrating solar collectors under the same working temperature. These disadvantages all limit the performance of solar absorption cooling system with non-concentrating solar collectors.

Recently, solar absorption cooling systems with concentrating collectors have been investigated for efficiency improvement, area reduction and so on (Cabrera et al., 2013). Concentrating collectors not only allow the single effect LiBr-water absorption chiller to work longer (Mazloumi et al., 2008), but also allow the use of absorption chillers with higher efficiency due to its higher working temperature. A LFR (Linear Fresnel Reflector) driven double effect LiBr-water absorption cooling system in Spain was experimentally studied by Bermejo et al. (2010). The chiller was driven by pressurized hot water delivered from LFR with a backup natural gas burner. The average daily collector efficiency reached 0.35. The daily average COP of the chiller was 1.1–1.25. A system with 52 m^2 PTC (Parabolic Trough Collector) and 18 kW double effect LiBr-water absorption chiller was experimentally studied by Qu et al. (2010). The product of the chiller COP and the collector efficiency was about 0.33–0.44. A system with 54 m^2 external CPC (Compound Parabolic Concentrator) and 23 kW double effect LiBr-water absorption chiller was experimentally studied by Hang et al. (2014). The daily solar COP was about 0.374. Besides, the LFR direct

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Nomenclature

ANN	Artificial Neural Network
CPC	Compound Parabolic Concentrator
COP	coefficient of performance (–)
T	temperature (K)
P	pressure (kPa)
Gen	generation
Con	condensation
Abs	absorption
Eva	evaporation
Res	resorption
X	instantaneous cooling load (kW)
a,b	load coefficient (–)
t	time (h)
η	efficiency (–)
A	collector area (m^2)
G	irradiation intensity (W/m^2)
Δt	time step (h)

Subscripts and superscripts

1, 2, 3	different values
E	evaporation
G	generation
A	ambient
m	mean
a	ambient
p	peak
ave	average value
ove	overall value
S	solar collector gained

driven ammonia-water GAX (Generator Absorber heat eXchange) absorption cooling system is also a possible choice (Velázquez et al., 2010). Among the concentrating collectors, the CPC is stationary which is cost-saving. It has been shown to be able to activate the double effect absorption chiller (Hang et al., 2014). CPCs are used in this study.

As the CPC is used, single effect and double effect LiBr-water absorption chiller can be adopted. These traditional absorption chillers have stable COP under a small range of driven temperature (Gebreslassie et al., 2010). However, the working temperature of solar collector is not stable which doesn't correspond well with the absorption chiller. When the solar heat source temperature is low, the absorption chiller can only work in low efficiency or can't be activated. When the solar heat source temperature is high, there will be a waste of energy grade. In order to achieve better match between solar collector and absorption chiller, various absorption cycles have been developed (Hong et al., 2011; Wang and Zheng, 2009; Xu and Wang, 2016; Ying et al., 2002) including the variable effect absorption refrigeration cycle proposed by the author (Xu et al., 2013). The variable effect absorption cycle is proposed for high efficient utilization of heat source with variable temperature. It needs driven temperature between 95 °C and 135 °C which is suitable for the CPC. The variable effect LiBr-water absorption chiller, along with the single effect and double effect LiBr-water absorption chiller are selected as the options for the chillers.

In order to compare the solar absorption cooling systems based on the different absorption chillers and find the better choices, the system performance is studied through simulation. A commercial CPC (Lu et al., 2013) is selected as the heat source for these solar absorption cooling systems. The models of the commercial solar collector and the variable effect absorption chiller are built from tested data. The solar absorption cooling systems are built in TRNSYS which has been widely used for solar cooling system simulation (Al-Alili et al., 2012; Cabrera et al., 2013; Fong et al., 2010; Qu et al., 2010). Both short-term and long-term operations of the three solar driven absorption cooling systems are calculated and analyzed.

2. The LiBr-water absorption chillers

2.1. Choices of absorption chillers

The single effect, double effect and the variable effect LiBr-water absorption chillers are the analyzed options in this paper. Fig. 1 shows their corresponding P-T-x diagrams. The single effect chiller has driven temperature around 90 °C and achieves COP around 0.7. The double effect chiller has driven temperature above 150 °C and achieves COP around 1.2.

The variable effect absorption cycle has an extra resorption-generation heat exchange comparing with the double effect cycle. The

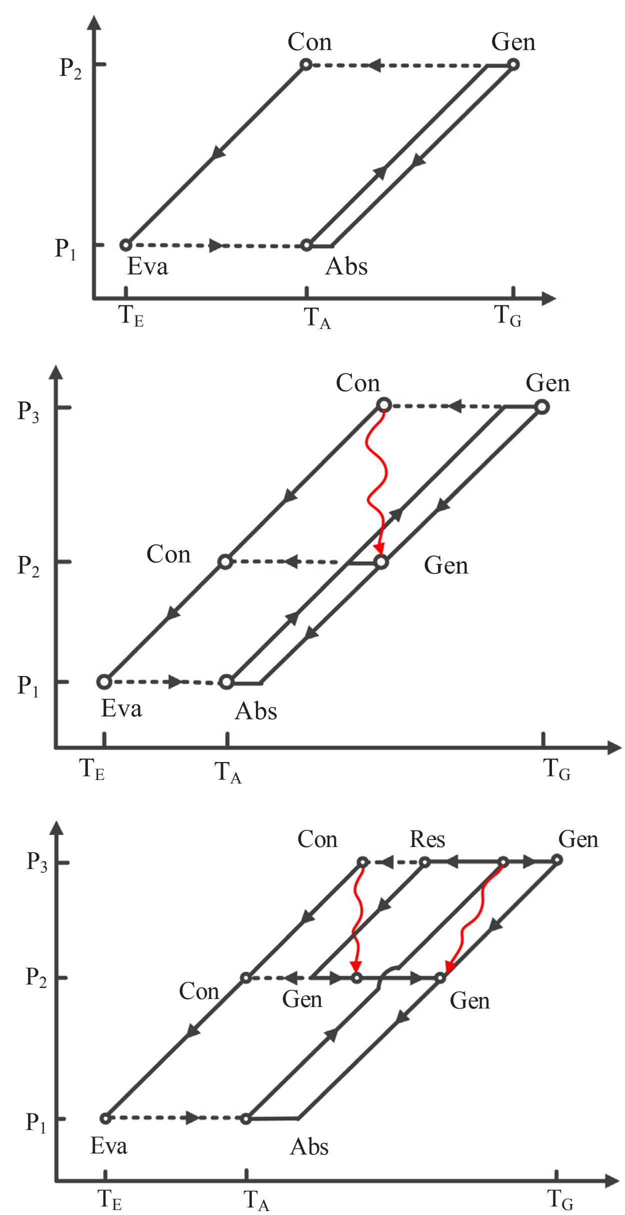

Fig. 1. P-T-x diagrams of the single effect (a), double effect (b) and variable effect absorption refrigeration cycles (c).