Solar Energy 171 (2018) 613–620

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Energy and exergy analysis of a new direct-expansion solar assisted vapor injection heat pump cycle with subcooler for water heater

Jiaheng Chen, Jianlin Yu*

Department of Refrigeration & Cryogenic Engineering, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an 710049, PR China

ARTICLE INFO

Keywords:
Theoretical analysis
Heat pump water heater
Solar energy
Injection

ABSTRACT

A new direct-expansion solar assisted vapor injection heat pump cycle with subcooler for water heater is proposed in this paper which aims to improve the performance of traditional subcooler vapor injection heat pump cycle by utilizing the solar energy. The new cycle has two working modes (SVIC mode and DX-SVIC mode) to be switched according to the solar radiation intensity. The performance enhancement potential of the new cycle is investigated by comparing with the traditional cycle through theoretical method. Under the considered conditions, the new cycle yields an average of 14.6% and 42.9% improvement in the heating coefficient of performance and heating capacity aspects compared with the traditional cycle, respectively. Both the new cycle and the traditional cycle have optimum injection pressures to obtain the maximum heating coefficient of performance. The simulation results indicate that the DX-SVIC mode outperforms the SVIC mode on most solar radiation condition, while the latter one is suitable for the extremely low and no solar radiation condition. The energy performance and heat exergy of the new cycle are improved with enhancing the solar radiation, while the variation of exergy efficiency shows contrary tendency. As increasing the injection pressure, the exergy input decreases more rapidly than the heat exergy, and thus the exergy efficiency is improved. The increase of the solar collector area always leads to the energy performance improvement of the new cycle.

1. Introduction

With the improvement of the resident living standard, the consumption of the heating water has been continually growing in the past few decades. However, most of this demand is met by various low efficiency water heaters at present, such as natural gas water heater and electric water heater (Hepbasli and Kalinci, 2009). Hence, it's urgent task for researchers to develop more efficient water heater to reduce the energy consumption. And thus, the heat pump technology, which can obtain relatively high efficiency by extracting heat from the low grade heat source such as air or ground (Esen and Yuksel, 2013), has been attracting more and more applications in the water heater field. Researches indicated that the heat pump water heater (HPWH) can obviously reduce the power consumption compared with the traditional electric water heater (Willem et al., 2017). In the last few decades, various researches have been conducted to investigate the HPWH by experimental and theoretical method. Zhang et al. (2007) conducted an optimization for air source heat pump water heater (ASHPWH) by both the calculation and experimental methods and declared that suitable system configuration could obviously improve the system performance. Panaras et al. (2017) proposed a semi-analytical model which could evaluate the HPWH performance without using detailed geometrical and indicated that the proposed model had a satisfactory accuracy. Peng et al. (2016) developed a quasi-steady-state system model of an ASHPWH and evaluated the performance of the system with three different throttling valves. The simulation results showed that the system using electronic expansion valve achieved the best performance.

However, the heat pump system still also has an inherent drawback that the compressor compression ratios will become excessively high under the cold climate region and do harm to system reliability, heating capacity and efficiency (Cao, et al., 2009). And thus, the refrigerant vapor-injection technique, which can effectively enhance the system capacity and benefit the system efficiency at low ambient temperature condition, is widely adopted in the heat pump and heat pump water heater systems. Wang et al. (2009) investigated a two-stage heat pump system with a vapor-injected scroll compressor and declared the improvement of heating capacity by 30% and COP by 20% at the ambient temperature of −17.8 °C. Baek et al. (2014) indicated that the coefficient of performance (COP) of an injection CO_2 HPWH system was 7.6% higher than that of the non-injection system at the outdoor temperature of −15 °C. Roh and Kim (2014) applied a vapor-injection technique in a cascade HPWH system and achieved 12% improvement in the heating

---

* Corresponding author.
E-mail address: yujl@mail.xjtu.edu.cn (J. Yu).

https://doi.org/10.1016/j.solener.2018.07.019
Received 10 February 2018; Received in revised form 26 June 2018; Accepted 7 July 2018
0038-092X/ © 2018 Elsevier Ltd. All rights reserved.

Nomenclature

A	area (m^2)
COP	coefficient of performance
Ex	exergy rate of fluid (W)
F_R	heat removal factor
G	solar radiation intensity ($W\ m^{-2}$)
h	specific enthalpy ($KJ\ kg^{-1}$)
I	exergy destruction (W)
m	mass flow rate ($kg\ s^{-1}$)
n	rotate speed ($r\ min^{-1}$)
P	pressure (kPa)
Q_h	heating capacity (W)
s	specific entropy ($kJ\ kg^{-1}\ K^{-1}$)
t	Celsius temperature (°C)
T	Kelvin temperature (K)
U_L	heat loss coefficient
W	power (W)

Greeks symbol

η	efficiency
φ	percentage
α	split ratio

Subscripts

0	reference state
1 - 8	state points of refrigerant
c	condensing
com	compressor
con	condenser
dis	displacement
e	evaporating
eva	evaporator
exh	heat exergy
h	heating
is	isentropic
pl	plate
rad	radiation
soc	solar collector
sys	system
tv	throttling valve
v	volumetric

capacity. Even so, further researches also need to be carried out to design more efficient injection HPWH system.

As a renewable and clean energy resource, the solar energy has been widely utilized in various heat pump systems (Esen, 2000; Esen et al., 2017; Omojaro and Breitkopf, 2013), of course including the HPWH systems. At present, the solar assisted HPWHs mainly consist of two types: the indirect expansion solar assisted HPWH (IDX-SHPWH) and the direct expansion solar assisted HPWH (DX-SHPWH). The IDX-SHPWH attracts more and more attention in recent years because of fewer system components and lower initial investment (Facão and Carvalho, 2014). However, the IDX-SHPWH is essentially a traditional single-stage HPWH with an integrated solar collector-evaporator, and thus the heating capacity and efficiency will seriously weaken under the cold climate or low/zero solar radiation condition (Sun, et al., 2015). In fact, the above drawback of the IDX-SHPWH can be overcome by applying the vapor injection technology. In summary, the vapor-injection technology and the solar energy utilizing technology can improve the HPWH performance in different ways, and are complementary to each other.

To authors' knowledge, there is no such an HPWH system that adopts both the vapor-injection technology and the solar energy utilizing technology at present. Therefore, a new direct-expansion solar assisted vapor injection heat pump cycle with subcooler (DX-SVIC) for water heater is proposed in this study, which combines the vapor-injection technology and the solar energy utilizing technology together to achieve more significant performance improvement. The DX-SVIC system has two working modes: SVIC mode and DX-SVIC mode. Under the low/zero solar radiation condition, the system works in the SVIC mode and operates just like the traditional vapor subcooler injection heat pump cycle (SVIC). Under the relatively high solar radiation condition, the system chooses the DX-SVIC mode and uses the solar energy to improve the system performance. And thus, the DX-SVIC system can obtain relatively high performance even on the extremely cold or no solar radiation conditions, because it combines the virtues of the vapor-injection technology and the solar energy utilizing technology. The energetic and exergetic characteristics of the DX-SVIC system will be investigated by the theoretical method, and its potential performance enhancement will be also evaluated by comparing to the traditional SVIC system. The purpose of the present study is to explore the possibility of adopting the DX-SVIC to improve the efficiency of the water heater and save the electricity consumption.

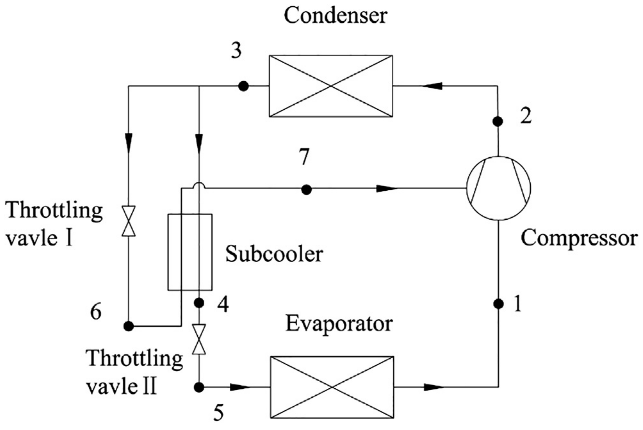

Fig. 1. Schematic diagram of the SVIC system.

2. Cycle description

Fig. 1 illustrates the structure of a traditional subcooler vapor injection heat pump cycle, which mainly includes six components, i.e. a vapor injection compressor, a condenser, a subcooler, an evaporator and two throttling valves. To improve the cycle performance, a new direct-expansion solar assisted vapor injection heat pump cycle with subcooler is proposed. As shown in Fig. 2a, the DX-SVIC system has two operation modes to be switched by controlling the on-off of the solenoid valves A and B: SVIC mode for the extremely low and no solar radiation condition; DX-SVIC mode for relatively high solar radiation condition. Due to the fact that the SVIC mode is actually same as the traditional SVIC system, the SVIC mode will not be detailed in this study and the abbreviation DX-SVIC is only refers to the DX-SVIC mode of the DX-SVIC system in the following content.

As shown in the Fig. 2b, the DX-SVIC mode of the DX-SVIC system operates in the following manner: the high pressure refrigerant vapor (state 2) discharged from the compressor enters the condenser and condenses to the saturated or subcooled liquid (state 3). After that, the refrigerant flow splits into two flows: one part of flow expands to the

Download English Version:

https://daneshyari.com/en/article/7935043

Download Persian Version:

https://daneshyari.com/article/7935043

Daneshyari.com