Building and Environment 46 (2011) 2052–2059

Contents lists available at ScienceDirect

Building and Environment

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

Analysis on performance of a novel frost-free air-source heat pump system

Li Yongcun, Chen Guangming*, Tang Liming, Liu Lihua

Institute of Refrigeration and Cryogenics, State Key Laboratory of Clean Energy Utilization, Zhejiang University, 38 Zheda Road, Hangzhou 310027, PR China

ARTICLE INFO

Article history:
Received 20 January 2011
Received in revised form
10 April 2011
Accepted 11 April 2011

Keywords:
Air-source heat pump
Frost-free
Solution
Performance

ABSTRACT

Heating capacity of an air-source heat pump (ASHP) system often decreases due to frost on the air-side heat exchanger (evaporator) when the air temperature drops in winter. If the amount of frost accumulates to a certain value, performance of the system will degrade. Therefore, defrosting mode needs to be operated periodically. In order to solve the above problems, heat transfer enhancement or advanced defrosting methods should be adopted, but all these methods cannot solve the problems mentioned in essence. A novel frost-free air-source heat pump system is proposed, the new system can realize heating which does not need defrost in winter. In this new system, extracting heat process from environment includes two steps: the first one is extracting heat from the environment and then to the solution, the second one is releasing heat to the evaporator from the solution, avoiding frosting on the evaporator surface. A theoretical model is established to analyze the performance of the system. Results indicate that the novel system can operate more efficiently than the conventional air-source heat pump in winter. In addition, the new system does not need to run in defrosting mode periodically.

1. Introduction

Air-source heat pump (ASHP) system as cooling and heating source for building heating, ventilating and air conditioning (HVAC) systems becomes increasingly popular in central and south China [1]. In these regions, heating requirements will represent a challenge for air-source heat pumps, since the ambient air temperatures in this region will be subzero in winter. During the heating season, ASHP systems extract heat from the outside cold air and release the heat inside the living space. Under certain weather conditions, frost will form on the outdoor heat exchanger surface that is one of the main problems for ASHP systems. Frost depositing and accumulating on the outdoor heat exchanger surface will act as thermal insulator between the surface and the humid ambient air, and the growth of the frost layer will degrade the ASHP's performance. Therefore, the frost needs to be removed periodically to improve the efficiency of operation.

Many studies on the performance of the ASHP system under frosting conditions were reported. Ma Guoyuan et al. [2] developed an improved ASHP system for cold regions, in which a subcooling system employing scroll compressor with supplementary inlet was used. Yi-guang Chen et al. [3] experimentally investigated on the reverse-cycle defrosting characteristics of a split-type ASHP system, and effects of the outdoor air parameters on defrosting cycle performance and dynamic defrosting characteristics of the ASHP unit are discussed. S.M. Sami and P.J. Tulej [4] presented a combined cycle fully integrated air/air heat pump, which is a fully integrated unit and the evaporator and condenser are placed indoors. Laboratory tests and field testing showed that this heat pump out performs existing air/air heat pumps under similar conditions for heating modes. Yang Yao et al. [5] investigated on the characteristic of the air-side heat exchanger in an ASHP system under frosting in order to optimize its structural layout, which can increase its energy efficiency and operational reliability. Wang Zhiyi et al. [6] developed a new heat pump defrost system with a refrigerant charge compensator, which is a key component for the frosting cycle performance, and test data on several engineering units showed that the compensator worked as expected. Zhiqiang Liu et al. [7] simulated the dynamic performance of air-source heat pump during hot-gas defrost. Yanjun Ding et al. [8] proposed using a bypass solenoid valve in the ASHP system which can bypass the thermal expansion valve when it is used in the reverse-cycle defrosting mode. Yanjun Ding et al. [9] also proposed a new subcooling system employing a scroll compressor with supplementary injections in ASHP system and the relevant dynamic performance was tested. Di Liu et al. [10] used heat recovery facility in ASHP system to prolong the heat pump frost time and reduce its growth, which mixed the exhausted indoor and outdoor air before entering

* Corresponding author. Tel./fax: +86 571 87951680.
E-mail address: gmchen@zju.edu.cn (C. Guangming).

0360-1323/$ – see front matter
doi:10.1016/j.buildenv.2011.04.018

Nomenclature

C	specific heat, [kJ/kg K]
COP	coefficient of performance
D	humidity ratio, [kg/(kg d a)]
h	specific enthalpy, [kJ/kg]
m	mass flow rate [kg/s]
m_a	dry air mass flow rate, [kg/s]
q	heat transfer rate, [kW]
w	Power, [kW]
T	temperature, [K]
P	pressure, [kPa]

Greek letters

η	efficiency of regenerator
Φ	air relative humidity
ε	isentropic efficiency of compressor

Subscripts

a	air
com	compressor
con	condenser
e	equilibrium condition
eva	evaporator
h	heat
in	inlet
o	outlet
phe	pre-heat exchanger
r	refrigerant
re	regenerating
s	solution
she	solution heat exchanger
sr	subcooling-regenerating

the evaporator. Stefan S. et al. [11] studied an air-source two-stage heat pump using R-410A as refrigerant, which could run under ambient temperature as low as −30 °C, but the cost of the two-stage system is considerably higher than the current single-stage air-source heat pump.

Although there are so many studies on solving the problem of ASHP system frosting, some problems still exist. In order to solve the above problems in essence, a novel frost-free air-source heat pump (FFASHP) system is proposed, this system can realize heating which needs not defrost in winter.

2. The novel frost-free air-source heat pump system

The schematic diagram of the novel FFASHP system is shown in Fig. 1. The system is composed of three subsystems: a compression refrigeration subsystem, a solution endothermic subsystem and a solution regeneration subsystem. The compression refrigeration subsystem is composed of a compressor, a condenser, a subcooling-regenerating heat exchanger, an expansion valve and an evaporator. The working fluid is refrigerant. The solution endothermic subsystem is composed of a solution tower, a solution pump (solution pump A), an adjusting valve (adjusting valve 1) and which couples with the compression refrigeration subsystem by the evaporator. The working fluid is solution. The solution regeneration subsystem is composed of an adjusting valve (adjusting valve 2), a solution heat exchanger, a pre-heat exchanger, a first regenerator, a second regenerator, two solution pumps (solution pump B and C) and which couples with the compression refrigeration subsystem by subcooling-regenerating heat exchanger. The working fluid is solution.

In the compression refrigeration subsystem, the superheated refrigerant is discharged by the compressor as high pressure vapor (state 17) flows through the condenser, in which heat transfers from the refrigerant to the water and the refrigerant becomes saturated liquid (state 18). Then refrigerant passes through subcooling-regenerating heat exchanger, in which heat transfers from the refrigerant to the solution and becomes subcooled liquid (state 19), and then refrigerant flows through expansion valve which causes the pressure to drop, leading the refrigerant to expand and partly vaporize (state 20). Refrigerant flows into evaporator, in which heat transfers from the solution to the refrigerant, reducing the temperature of the solution. At the same time, refrigerant becomes low temperature and low pressure vapor (state 21). At last, refrigerant flows into the compressor.

In the solution endothermic subsystem, the pressure of the solution is raised by solution pump A and becomes high pressure solution (state 3). Then solution flows through adjusting valve 1, by which the flow rate is adjusted to a needed value (state 14) and then mixed with another stream of solution (state 13) from the solution regeneration subsystem. The mixed solution (state 15) then flows through the evaporator, in which heat transfers from the solution to the refrigerant (state 16). Then solution flows into solution tower, in which heat and mass transfers from the ambient air to the solution and the solution becomes weak solution (state 2).

To improve the energy utilization ratio, a multi-stage regeneration process is designed. Though this process is complicated than conventional regeneration, this mode of regeneration can raise the driving force for heat and mass transfer between solution and air, so the regeneration effectiveness is higher than conventional regeneration. In solution regeneration subsystem, one part of the solution (state 3) flows through adjusting valve 2 which makes this part of solution at a certain flowrate (state 4) and flows into solution heat exchanger, in which heat transfers between two streams of solution and makes the temperature of the solution higher (state 5). Then solution flows into pre-heat exchanger, which makes the temperature of the solution further increased (state 6). And then solution passes through the first regenerator, in which heat and mass transfer from the solution to the ambient air, which makes the concentration of the solution increase (state 7). The solution pump B raises the pressure of the solution (state 8), then flows through subcooling-regenerating heat exchanger to improve the temperature of the solution markedly. The heated solution (state 9) flows into the second regenerator in which heat and mass transfers from the solution to the ambient air and the solution becomes strong solution (state 10). The ambient air is driven and flows through the first regenerator (state 22), the second regenerator (state 23), and the pre-heat exchanger (state 24), respectively. Solution pump C raises the pressure of the solution (state 11), and it passes through the solution heat exchanger (state 12). Finally, adjusting valve 3 adjusts the flow rate of the solution (state 13) to mix with another stream of solution (state 14).

3. Analysis of the frost-free air-source heat pump system

To simplify the analysis of the FFASHP system, several assumptions are adopted as followings:

a) Compression process of the compressor is adiabatic with a constant isentropic efficiency of 0.8.