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Experimental analysis on performance of high temperature heat pump and desiccant wheel system

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ABSTRACT

In order to solve the problem of high energy consumption for regeneration of desiccant wheel in the rotary desiccant system, high temperature heat pump and desiccant wheel (HTHP&DW) system and corresponding air conditioning unit is built and tested in the extensive thermal hygrometric environment. When the mixture refrigerant BY-3 is involved in the air source heat pump, the supply air temperatures are in the range as expected except that when in the extreme hot environment (above 36 °C), dehumidification capability are satisfied and the regeneration temperatures can satisfy the regeneration requirement of desiccant without additional heat. It is also found that outdoor air temperature, humidity ratio and regeneration air flow rate have great impact on the performance of heat pump based on the coefficient of performance (COP) evaluated. COP is not quite high, as the maximum value is 2.26 for heat pump and 2.08 for whole system respectively. Hence several suggestions are made for optimizing the system which is also helpful for facilitating the development of mature product. As a conclusion, HTHP&DW system could be a potential alternative with effective operation which can be promoted in most areas of China based on the result of our experiment.

1. Introduction

Sensible load arising from heat transfer into the conditioned space and latent load arising from moisture generated within the space are two main types of the loads that have to be handled in the air conditioning system. In a conventional vapor compression cooling system, air is usually cooled below its dew point and subsequently heated up to the desired supply temperature, which often costs a large amount of energy for overcooling and reheating [1,2].

The desiccant cooling systems are being developed as an alternative to overcome the flaws of vapor compression system [3]. Especially, rotary desiccant air conditioning systems, which are compact and less subject to corrosion and can work continuously, attract more attention [4]. Many configurations of rotary desiccant system are designed and studied and the encouraging results are obtained [5–7]. It is also found that efficient energy saving and low environment impact are achieved when the desiccant wheel is regenerated by means of low temperature thermal energy such as solar heat [8–10], energy from co-generators [11,12], and waste heat [13]. Although the costs of these technologies are near-zero [14], the applications of them are limited due to the climate or regional factors. One type of rotary desiccant system is a combination of the rotating desiccant wheel and of the vapor compression system, which can be widely and efficiently used without limitations. The shortcoming is that the thermal heat recovered from the condenser is not sufficient for the desiccant regeneration and a supplementary heater is needed [4], which will increase the energy input and equipment investment. The proposed method in this paper will solve this problem by utilizing the characteristics of high temperature heat pump.

Heat pump has a heating capacity at the condenser and a cooling capacity at the evaporator, which is an approach to satisfy simultaneous energy demands for heating and cooling. Many researchers have worked on such systems for simultaneous production in various applications [15–17]. Take advantage of simultaneous production of heating and cooling, heat pump desiccant system as a novel topic has been studied. Lazzarin [18] has investigated a new equipment of self-regenerating liquid desiccant cooling system for supermarket application. Enteria [19] has performed an experimental evaluation of a new solid desiccant heat pump system, the main feature of which is direct impregnation of the desiccant material in the evaporator and condenser of the heat pump system. In Ref. [20], the variable refrigerant volume (VRV) system has been operated in conjunction with a self-regenerating heat pump desiccant unit. And its energy consumption has been analyzed as opposed to the VRV system coupling with heat recovery ventilation

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Nomenclature

c_p	specific heat of the air (kJ/kg K)
COP	coefficient of performance
HTHP	high temperature heat pump
DW	desiccant wheel
V	air volumetric flow rate (m^3/h)
m	air quality flow rate (kg/h)
t	air temperature (°C)
h	enthalpy of the air (kJ/kg)
Q	heat energy (kW)
E	electrical input power (kW)
DBT	dry bulb temperature (°C)
WBT	wet bulb temperature (°C)
TR	temperature of refrigerant (°C)
PR	pressure of refrigerant (MPa)
BY-3	refrigerant of No.3 of BeiYang
FAR	fresh air ratio (%)
AFR	air velocity (m/s)

Greek symbols

ω	air humidity ratio (g/kg)
ρ	air density (kg/m^3)

Subscripts

com	compressor
sys	system
proc	process air
reg	regeneration air
f	fan
c, *h*	cooling and heating, respectively
W, *N*	states of outdoor air and indoor air, respectively
C, *E*	inlet and outlet state of the process air, respectively
O	state of supply air
A, *B*	inlet and outlet state of the regeneration air, respectively

unit. By utilizing the characteristics of high temperature, Hao and Zhang [21] have explored the potential of integrating the moderate or high temperature heat pump subsystem to the desiccant wheel. However the performance of this kind of system is less complex investigated over a wide range of operating conditions. Therefore, a detailed experiment is carried out in this paper with the objectives as follows:

- A new high temperature heat pump coupling with solid desiccant wheel (HTHP&DW) system is designed, and the corresponding air conditioning unit is built.
- The mixture refrigerant of "BY-3" is involved and tested in order to ascertain that BY-3 can be a candidate for this system.
- An experiment is conducted to study the applicability for extensive thermal hygrometric conditions representing most climate zones in China, and the performance of HTHP&DW system.

2. HTHP&DW air conditioning unit design

2.1. HTHP&DW system

Fig. 1 shows the schematic diagram of HTHP&DW system. The ventilation system supplies minimum levels of outdoor airflow and re-circulates a large amount of indoor air on the process side. The return air (state N) and outdoor fresh air (state W), with specific ratio of FAR = 20%, are mixed to become the process air (state C) which flows through the desiccant wheel where a large amount of moisture is removed by the desiccant (state E). The process air is then cooled by the evaporator of HTHP that is controlled for conditioning the room air temperature to a comfortable level (state O). The outdoor fresh air (state W) is used for regenerating the rotating desiccant wheel. The regeneration air is heated up by the condenser of the heat pump (state A) and is expelled after regenerating the desiccant wheel (state B).

2.2. Air conditioning unit design and manufacture

The high temperature heat pump, desiccant wheel and fans are the main components of the air conditioning unit. The main specifications of the machines are listed as follows:

Desiccant wheel: the desiccant material is silica-gel and the configuration is honeycomb. The wheel is characterized by the following layout: process air passes 75% of the flow area and regeneration air the remaining 25%. The other characteristics of the wheel are: diameter and thickness equal to 450 mm and 200 mm respectively, the nominal rotational speed is 15 r/h.

HTHP: The invariable frequency closed piston compressor branded with Copeland made in America is used with the nominal input power of 2 kW. The type of heat exchanger is air source chip tubular. The manual expansion valve with brand of Swagelok is used to adjust the flow rate of the refrigerant. The volume flow rate is in the range of 0–0.084 m^3/h.

Fan: the frequency conversion fans are chosen in order to obtain the desired speed. The nominal power of both process and regeneration fans are 0.3 kW and the frequency is 0–50 Hz.

Mature commercial products were adopted for assembling this air-conditioning unit. Fig. 2 shows the layout of air conditioning unit and the experiment is carried out on this facility. The following contents should be noted with attention during design and commissioning:

(a) Insulation is necessary due to the temperature difference between different air flows.
(b) In order to prevent exchange between the process air and regeneration air, elastic material with high temperature resistance should be well sealed on the surface edge of desiccant wheel. Simultaneously harmful gas should not be produced from the elastic material during the operation of unit.
(c) The wind resistances of main machines should be taken into consideration during the selection of fans that can ensure the external residual pressure. Besides noise, size and performance of fans should also be considered.
(d) The main machines are fixed on a steel frame with scroll wheels on the bottom to meet the requirement of mobile operation.

It is expected that our experience with the above unit can facilitate development of commercial product.

Compared to the conventional cooling-based dehumidification air conditioning system, this air conditioning unit has the following advantages:

- The sensible and latent heat load are handled independently.
- This method is used for connecting the desiccant wheel and HTHP to make full use of both heating and cooling from the condenser and evaporator of the heat pump that can provide the thermal energy for desiccant regeneration without additional heat.
- The desiccant wheel can be driven only by the heat pump without any heating machine, which will save the cost of equipment investment.
- The structure of this air conditioning unit is compact, with the feature of less occupied area.