Advanced Materials Research Vols 374-377 (2012) pp 451-455 Online: 2011-10-24
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doi:10.4028/www.scientific.net/AMR.374-377.451

Analysis of Energy Consumption and Mode of Energy Saving of Rotary Wheel

Ming Yue[1, a], Yunfei Ding[2,b] and Huijun Wu[2,c]

[1] School of Civil Engineering, Guangzhou University, Guangzhou 510006, China

[2] Guangdong Provincial Key Laboratory of Building Energy Efficiency and Application Technologies, Guangzhou 510006, China

[a]j23-yvette@163.com, [b]dingyf@126.com, [c]wuhuijun@tsinghua.org.cn

Keywords: Rotary wheel, Heat pump, Dehumidification, Evaluation standard, Energy efficiency, SMER.

Abstract. A model of rotary wheel combined with heat pump regeneration was presented and an experimental investigation on it was also carried out. Five normal kinds of dehumidification efficiency evaluation standard were introduced in view of the existing various dehumidifying method while the current energy efficiency evaluation indices were analyzed. SMER which defines the dehumidification quantity of unit energy consumption and dehumidification system energy efficiency were introduced and used to compare energy consumption of rotary wheel with or without heat pump. The comparative analysis showed that the system of rotary wheel combined with heat pump regeneration could significantly improve SMER and dehumidification system energy efficiency of rotary wheel.

Introduction

Air conditioning system energy consumption occupies a large proportion of total energy consumption of a building. While traditional dehumidification energy consumption accounted for a large part of total air conditioning system energy consumption. With great energy saving potential, rotary wheel have been widespread used as the key unit of adsorption-typed air conditioning system in the humidity control of factory and office environments. But there was little research on the thermodynamic analysis of the rotary wheel. The dehumidification progress of rotary wheel is a dynamic process, and desorption process of rotary wheel will consume a large amount of electric energy, which is the main energy consumption of rotary wheel. Rotary wheel combined with heat pump regeneration could not only re-use heat, but also decrease the outlet air temperature of rotary wheel. It can reduce the regeneration energy consumption and save energy.

In this paper, a model of rotary wheel combined with heat pump regeneration is presented. To analyse energy consumption of the dehumidification system, five normal kinds of dehumidification efficiency evaluation standard were introduced while the current energy efficiency evaluation indices were analyzed based on the model. SMER and dehumidification system energy efficiency of the rotary wheel with or without heat pump regeneration were analyzed.

Current evaluation standard and energy consumption of rotary wheel

In view of the various existing dehumidifying method, there are multiple dehumidification efficiency evaluation standard. CEC, DCOP, exergy efficiency, SMER and dehumidification system energy efficiency are introduced here as five normal kinds of dehumidification efficiency evaluation standard. They consist of the current energy efficiency evaluation indices introduced here.

The ratio of regeneration air consumption and dehumidification gross in one cycle is defined as:

$$CEC = \frac{q_r t_z}{W_t}$$

q_r is mass flow of regeneration air required in one cycle, kg/s; t_z is regeneration time, s; W_t is water vapor adsorption quantity in one cycle, kg. It reflects the relationship between regeneration air flow and dehumidification quantity. But it can not reflect the regeneration energy consumption to get equal regeneration air flow. It has certain defects in the more accurate evaluation of the effective utilization of energy level.

Some use DCOP to evaluate the dehumidification efficiency of rotary wheel.

$$DCOP = \frac{m_p L(Y_{p1} - Y_{p2})}{m_r (h_{r1} - h_{r2})}$$

m_p, m_r is air mass flow of adsorptive and desorptive sections, respectively; L is the latent heat of vaporization for water. h_{r1}, h_{r2} is the enthalpy of desorptive air inlet and outlet, respectively. Y_{p1}, Y_{p2} is the moisture content of adsorptive air inlet and outlet, respectively. Since dehumidifying impetus is not the enthalpy difference of desorption air and when desorption air temperature is higher, humidity is lower, its regeneration effect is better, DCOP is not a very good indicator of dehumidification physical laws. On the other hand, DCOP is not easy for engineering calculation for the enthalpy of desorptive air outlet is not easy to confirm.

Exergy efficiency was also used by some for the dehumidification progress. It need to calculated exergy of wet air and the calculation is complicated. It can only be used to evaluate the dehumidifying performance after we understood the changing rules.

Based on this model of energy saving dehumidification system, SMER and dehumidification system energy efficiency were introduced and used here to analyse and compare energy consumption of rotary wheel combined with or without heat pump.

Dehumidification quantity of unit energy consumption is defined as:

$$SMER = \frac{M_d}{W_s}$$

M_d is dehumidification quantity, kg; W_s is electric energy input, kW●h.

Dehumidification system energy efficiency is introduced here which maybe defined as:

$$\eta = \frac{Q_h}{W}$$

Q_h is evaporation heat needed of adsorptive moisture unit time, kW; W is energy consumption of the dehumidification system unit time, kW. SMER and dehumidification system energy efficiency can analyse energy consumption and reflect dehumidification performance and energy utilization ratio of the dehumidification system. Since the rotary wheel combined with heat pump regeneration could not only re-use heat, but also decrease the outlet air temperature of rotary wheel, it can increase SMER and dehumidification system energy efficiency, improve energy utilization ratio and save energy of rotary wheel.

The principle of rotary wheel combined with heat pump

As shown in Fig.1, the rotary wheel is divided into two sections: adsorption section and regeneration section. As shown in Fig.2, the moist air was passed over adsorption section where water vapor should be adsorbed, then dry and hot air returned to room. In the regeneration section, the water vapor of adsorbent was released to atmospheric air when heated. The main problem is high energy consumption of rotary wheel regeneration, and this leads to energy efficiency lower of rotary wheel.

A novel system combining the rotary wheel with the heat pump was proposed as shown in Fig.3. It consists of a rotary wheel, a auxiliary regeneration heater and a set of heat pump. The heat pump evaporator can not only recycle heat from outlet air of rotary wheel, but also decrease outlet air temperature of rotary wheel. Meanwhile, the heat pump condenser heat regeneration air from environment could keep at a constant temperature in the range of 90～95℃.

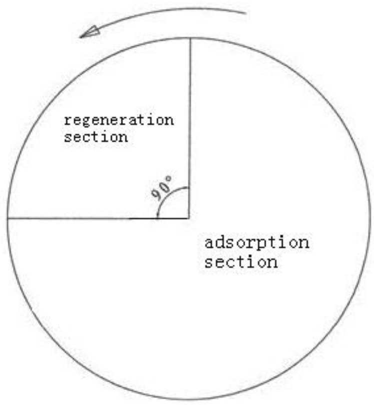


Fig. 1 Diagram of adsorption and regeneration

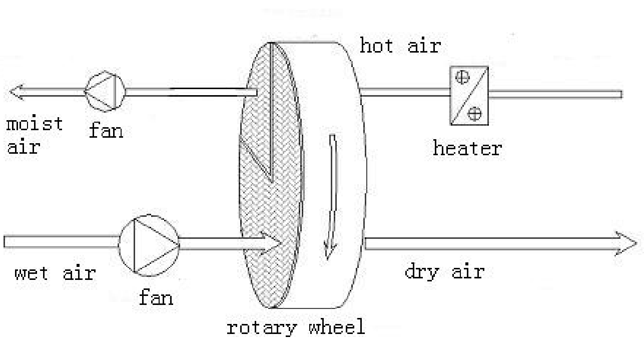


Fig. 2 Schematic diagram of rotary wheel

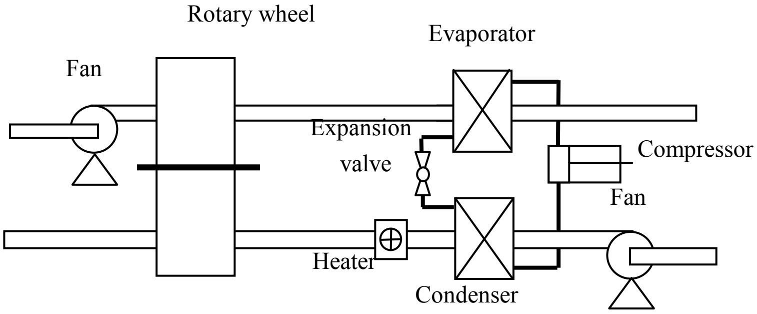
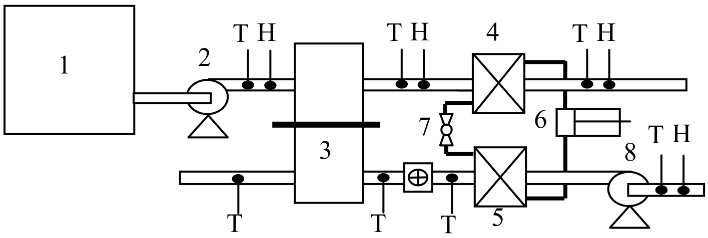


Fig. 3 Schematic diagram of rotary wheel combined with heat pump Regeneration

Analysis of energy efficiency of rotary wheel combined with heat pump regeneration

Experimental Setup. Fig.4 shows the experimental setup of measuring the temperature and humidity of the rotary wheel combined with heat pump regeneration. It consists of a chamber of constant temperature and humidity, a rotary wheel, adsorptive and regenerative fans, a regenerative heater, a set of heat pump, and temperature and humidity transmitters. The diameter and length of rotary wheel coated Al^{3+} -doped silica gel adsorptive materials were 30cm and 20cm, respectively. The rotary wheel was divided into two sections: adsorption section and regeneration section. The area ratio of the adsorption to desorption section was 3:1. The rotational speed of wheel is 8r/h. The temperature transmitter was copper-constantan thermocouples, and its accuracy was ±0.5℃. The humidity transmitter was made by Honeywell (model 3601) with the accuracy of ±2%RH.



1-Manual air resource; 2,8-Fan;3-Rotary wheel;4-Evaporator;
5-Condenser;6-Compressor;7-Expansion valve;
8-Electric heater; T-Thermocouples; H-Humidity sensor

Fig. 4 Schematic of experimental setup of rotary wheel combined with heat pump

Testing Results. In the experimental test, the air flow rate of adsorptive and desorptive sections were 300 m^3/h and 100 m^3/h, respectively. The air temperature and the humidity ratio of adsorptive section from manual air resource were 26℃ and $15g_{vap}/k_{gda}$, respectively, and are 45℃ and $6g_{vap}/k_{gda}$, respectively in outlet of adsorptive section. As the rotary wheel independently worked without the heat pump, the desorptive air was heated from 35℃ to 120℃ driven by an electric heater. When the novel system of rotary wheel combined with heat pump regeneration works, the air temperature of adsorptive section outlet was decreased to 35℃ owing to the evaporator of heat pump. The desorptive air temperature was heated from 35℃ to 92℃ owing to the condenser of heat pump, and further heated up to 120℃ by the electric heater. The COP of heat pump was 2.2.

Energy Efficiency Analysis of Rotary Wheel. For the rotary wheel without heat pump regeneration, in order to analyse and compare energy consumption of the system, the energy input considered here were energy consumption of the electric heater and an extra chiller to cool outlet air of rotary wheel. Q_h was 2.04 kW while W was 3.058kW which equals 2.856kW of the electric heater plus 0.202kW of the extra chiller to cool outlet air of rotary wheel. In this case, SMER was 1.06 kg/(kW●h) while dehumidification system energy efficiency η was 0.67. Since adsorptive process of rotary wheel was an isenthalpic process, the outlet air temperature would increase, and had to be cooled by an extra chiller. The rotary wheel combined with heat pump regeneration could not only recycle heat, but also cool outlet air of rotary wheel. It can not only replace the extra chiller to cool outlet air but also save electric energy of the heater.

Energy Analysis of Rotary Wheel Combined with Heat Pump Regeneration. For the rotary wheel with heat pump regeneration, in order to analyse and compare energy consumption of the system, the energy input considered here were energy consumption of the electric heater and the heat pump. Q_h was 2.0397 kW while W was 1.813kW which equals 0.941kW of the electric heater plus 0.872kW of the heat pump. In this case, SMER was 1.79 kg/(kW●h) while dehumidification system energy efficiency η was 1.126. Table 1 shows the improvement of rotary wheel clearly. Rotary wheel combined with heat pump can save a large amount of electric energy in regeneration and increase SMER and dehumidification system energy efficiency obviously. Therefore, the dehumidification system that rotary wheel combined with heat pump could significantly improve energy efficiency of rotary wheel.

Table 1 Comparison of energy consumption and efficiency

	electric heater	all energy input	SMER	energy efficiency
without heat pump	2.856 [kW]	3.058 [kW]	1.06 [kg/(kW•h)]	0.67
with heat pump	0.941 [kW]	1.813 [kW]	1.79 [kg/(kW•h)]	1.126

Conclusions

A model of rotary wheel combined with heat pump regeneration was presented and an experimental investigation on it was also carried out. Five normal kinds of dehumidification efficiency evaluation standard were introduced in view of the existing various dehumidifying method while the current energy efficiency evaluation indices were analyzed. According to the model of rotary wheel combined with heat pump regeneration, SMER and dehumidification system energy efficiency of rotary wheel were introduced and calculated. The results showed that SMER and dehumidification system energy efficiency of rotary wheel without the heat pump regeneration was 1.06 kg/(kW●h) and 0.67, respectively. Since the adsorptive process of rotary wheel was isenthalpic, the outlet air temperature increased and had to be cooled by an extra chiller. The rotary wheel combined with heat pump regeneration could not only recycle heat, but also cool the outlet air of rotary wheel. SMER and dehumidification system energy efficiency of rotary wheel could be risen up to 1.79 kg/(kW●h) and 1.126 respectively after the heat pump regeneration was combined. Therefore, the heat pump could significantly increase SMER and dehumidification system energy efficiency, improve energy utilization ratio and save energy of rotary wheel.

Acknowledgements

This project (Contract No. 08C052) was supported by the research plan of the Education Bureau of Guangzhou city. Corresponding author: DING Yunfei; Tel: 02039366651; E-mail:dingyf@126.com

References

[1] Shanshan Hu and Wei Li: submitted to Building Science (2011), in Chinese.

[2] Xukun Zhang, Huadong Li, Gang Xu, Kangming Xiong and Zhen Gu: submitted to Transactions of the CSAE (2006), in Chinese.

[3] Xiaoqiang Jiang, Zhiqiang Guan, Jing Xie and Zhongzhou Huang: submitted to Transactions of the CSAE (2011), in Chinese.

[4] Yutang Fang, Jing Ding, Juan Fan, etal: submitted to Journal of South China University of Technology (2004), in Chinese.

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10.4028/www.scientific.net/AMR.374-377

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