Feasible study on desiccant wheel with CO₂ heat pump

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Abstract. A kind of desiccant wheel with CO₂ heat pump is proposed. The main features of this proposed system include: (1) there are two optional ways of desiccant dehumidification and cooling dehumidification; (2) for the subsystem of desiccant dehumidification process, the air regeneration process occurs inside a closed loop, and a CO₂ heat pump is utilized inside this loop for air regeneration, which has the potential to significantly reduce energy consumption compared to a traditional regeneration process. The operating performance of the system is simulated and analysed. Compared to the traditional vapor compression air conditioning system, the hybrid system can save approximately 50% to 90% of energy.

1. Introduction
With the requirements of energy saving and emission reduction in the world, desiccant wheels have been expanded greatly from special areas such as electronics, food, storage and pharmaceutical industries, to supermarkets, restaurants, schools, hospitals, and office buildings[1]. Most research works focus on the performance analysis of desiccant systems. Many works analyze the performance of hybrid vapor compression-desiccant wheel systems and show that this technology can save significant energy compared to the traditional systems where the vapor compression system is used for dehumidification [2-10]. The biggest advantage of hybrid vapor compression-desiccant wheels system lies in the elimination of overcooling and reheating.

In the above mentioned research studies, it is reported that the regeneration process of the desiccant wheel has the following features: (1) the air regeneration process occurs inside an open cycle; (2) regeneration heating sources are electricity, fossil fuels, or rejected heat from a condenser.

In this paper, a new desiccant wheel system with closed-loop air regeneration is introduced and analyzed. In a transcritical CO₂ cycle heat pump, the cooling process in the supercritical region is a gas cooling process, which is particularly suitable to heat regeneration air to high temperature. The regeneration air can be heated to the desired temperatures, and no auxiliary heater is needed. Therefore, a CO₂ transcritical cycle heat pump is utilized in the closed-loop for air regeneration.

2. Methology
Figure 1 illustrates the schematic of a traditional desiccant wheel system. The desiccant wheel is divided into two sections for the process air and the regeneration air. Significant heat energy is required for the regeneration process. The hot and humid regeneration air leaving the desiccant wheel is then discharged to the ambient. Process and regeneration airflows can be either in counter-flow or parallel-flow arrangements.
Figure 1. Schematic of traditional desiccant wheel system
A schematic of the new desiccant wheel system with closed loop air regeneration is illustrated in Figure 2 (a). The process air side is the same as the traditional system. However, the regeneration air side is different. The air regeneration process occurs inside a closed loop. A transcritical CO\(_2\) heat pump is utilized for the recycled air regeneration including dehumidification, cooling and heating process. One subcooler is utilized to keep the CO\(_2\) temperature at the inlet of the expansion valve at a low value to improve COP. An air heat exchanger is utilized to pre-cool the recycled regeneration air, which can decrease the cooling load of the evaporator. An external gas cooler is utilized to adjust regeneration heating capacity inside the closed regeneration air loop. The pressure-enthalpy diagram and temperature-entropy diagram of the CO\(_2\) heat pump cycle are shown in Figure 2 (b) and (c). The operating parameters of the two systems are different only on the regeneration air side when the conditions of the fresh air and supply air are the same.

The coefficient of performance of CO\(_2\) heat pump is described by the following equation,

\[
COP = \frac{h_7-h_6}{h_2-h_1}
\]  

In addition, for a desiccant wheel system, its goal is dehumidification. In order to evaluate its coefficient of dehumidification performance, COP\(_{\text{latent}}\) is defined as the following in this paper,

\[
COP_{\text{latent}} = \Delta \omega \times \rho \times V \times L / W
\]  

Where,
- \(\Delta \omega\) — humidity ratio difference of air between inlet and outlet of a desiccant wheel, (kg.kg\(^{-1}\))
- \(\rho\) — density of air-water vapor mixture (kg.m\(^{-3}\))
- \(V\) — volume flow rate of air-water vapor mixture (m\(^3\).s\(^{-1}\))
- \(L\) — specific latent heat of vaporization of water (kJ.kg\(^{-1}\))
- \(W\) — power of compressor (kW).

### 3. Simulation results

Figure 3 shows the coefficient of performance of the proposed desiccant wheel system. Figure 3 (a) presents the variation of COP as a function of the fresh air temperature, \(T_{in}\), using an evaporation temperature, \(T_e\), of 10 °C and a discharge pressure, \(P\), of 8 MPa. It can be seen that the COP increases from 5.7 to 6.5 when the fresh air temperature \(T_{in}\) decreases from 38 °C to 2 °C. Thus, the COP remains at high values over an entire year and the ambient temperature has little impact on it. The CO\(_2\)
temperature, T5, at the inlet of expansion valve has a significant influence on the COP of a transcritical CO2 cycle. T5 is only affected by the evaporating temperature, Te. Since Te and the heat transfer temperature difference remain constant at 10 °C and 5 K, respectively, T5 remains constant at 15 °C. When the fresh air temperature, Tin, is lower than Te, the system operating parameters remain the same. Therefore, the COP remains constant when Tin is lower than 10 °C, as shown in Figure 3 (a). Figure 3 (b) presents the variation of COP as a function of humidity ratio difference, Δω, when the inlet air temperature is 20 °C, and relative humidity is 90%. It can be found that the COP(latent) increases with Δω.

![Graph](image1.png)

(a)

![Graph](image2.png)

(b)

**Figure 3.** Performance of proposed desiccant wheel system when evaporating temperature Te is 10°C and P is 8 MPa: (a) variation of COP with fresh air temperature T_fresh-air; (b) variation of COP(latent) with humidity ratio difference when Tin is 20°C, 90%.
4. Summary
A kind of desiccant wheel is proposed, where air regeneration process of the desiccant wheel occurs inside a closed loop using a CO₂ heat pump for dehumidification, cooling and heating. The operating performance of the proposed desiccant wheel system is simulated. The COP of the CO₂ heat pump varies from 5.7 to 6.5 as the ambient air temperature varies from 38 ℃ to 2 ℃. Its coefficient of dehumidification performance is also simulated. The results show that the proposed system is feasible and potential to save energy.

The future work is to analyze and compare the energy consumption of proposed system with traditional desiccant wheel system.

Acknowledgement
This work is sponsored by Shanghai Pujiang Program (Project NO. 17PJ1407200).

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