Study On Development Of Rotary Desiccant Dehumidification From Air Conditioning Point Of View

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Abstract— Rotary desiccant air conditioning system, which combines the technologies of desiccant dehumidification and evaporative cooling, is advantageous in being free from CFCs, using low grade thermal energy and controlling humidity and temperature separately. Compared with conventional vapor compression air conditioning system, it preserves the merits of environment-friendly, energy saving, healthy, comfortable, etc. Recent research suggest that new desiccant materials and hybrid system have significant potential for improving the performance and reliability and reducing the cost and size of rotary desiccant dehumidification and air conditioning system. Hence this paper explains the development of rotary desiccant dehumidification from air conditioning point of view.

Keywords— Desiccant dehumidification, Evaporative cooler, Solid desiccant, Air conditioning

I. INTRODUCTION

Desiccant materials attract moisture based on differences in vapor pressure. Due to their enormous affinity to absorb water and considerable ability to hold water, desiccants have been widely applied to marine cargo, pharmaceutical, electronics, plastics, food, storage, etc. [1]. Recently, the rapid development of desiccant air conditioning technology, which can handle sensible and latent heat loads independently without using CFCs and consuming a large amount of electric power, and thus meet the current demands of occupant comfort, energy saving and environmental protection, has expanded desiccant industry to a broader niche applications, such as hospitals, supermarkets, restaurants, theaters, schools and office buildings. The basic idea of desiccant air conditioning is to integrate the technologies of desiccant dehumidification and evaporative cooling together. While the former adopts water as refrigerant and can be driven by low grade thermal energy as solar energy, district heating, waste heat and bioenergy, the later is near-zero cost technology [2]. These indicate that desiccant air conditioning would be not only energy efficient and environment-friendly but also cost-competitive, especially for hot dry and hot humid areas. Besides, since desiccants remove moisture in the vapor phase without liquid condensate, desiccant dehumidification can continue even when the dew point of the air is below freezing; in contrast, cooling-based dehumidification is limited by freezing phenomenon occurring at 0°C. As a result desiccant air conditioning is capable of handling the dew point of the air to -40°C [3], whereas the counterpart of traditional vapor compression air conditioning (VAC) is 4°C [4].

As desiccants can be either solid or liquid, desiccant air conditioning systems can be classified into two categories, namely, solid desiccant air conditioning systems, which consist of fixed bed type and rotary wheel type, and liquid desiccant air conditioning systems. Due to being advantageous in handling latent heat load, all these technologies have been used widely. Especially, rotary desiccant air conditioning systems, which are compact and less subject to corrosion and can work continuously, attract more attention.
II. WORKING OF ROTORY DESICCANT DEHUMIDIFIER

Figure 1 illustrates the basic operating principle of rotary desiccant dehumidifier schematically. As seen, the desiccant material is impregnated into a support structure. The cross section of wheel is divided into process air side and regeneration air side by clapboard. When the wheel constantly rotates through two separate sections, the process air is dried by the desiccant due to the adsorption effects of the desiccant material and support material. At the same time, the regeneration air is humidified after being heated by a heater and desorbing the water from the wheel in tandem. It should be noted that the desiccant dehumidification process is close to an isenthalpic procedure, namely, it merely converts latent energy to sensible energy and produces no useful cooling. Therefore, in order to accommodate cooling effect, auxiliary cooler, like evaporative cooler and other air conditioning equipments, must be incorporated to remove the sensible heat; and the performance of desiccant air conditioning systems are principally determined by the system configuration when the desiccant material, wheel structure and operation condition are invariant. For this reason, extensive types of rotary desiccant air conditioning systems have been proposed and studied both analytically and experimentally [6,7–13]. To provide an overview of the recent research, the conventional rotary desiccant air conditioning cycles and the newly developed technologies are explained in the next section.

III. BASIC ROTARY DESICCANT DEHUMIDIFICATION AND AIR CONDITIONING PROCESSES

The first patent on rotary desiccant air conditioning cycle was introduced by Pennington in 1955 [8]. Figure 2 shows the Pennington cycle, also known as ventilation cycle, schematically and psychometrically. Ambient air at state point 1 is adopted as process air and passes through a desiccant wheel (DW), where its moisture is removed and temperature is increased due to the adsorption heat effect. Then this hot dry air is sensibly cooled from state point 2–3 in a heat exchanger (HE). Whereafter, the process air is evaporatively cooled to supply air state by passing through a direct evaporative cooler (DEC). On the regeneration air side, return air at state point 5 is cooled and humidified in another DEC. This air is then sensibly heat exchanged with the process air to precool the process air and pre-heat itself. The warm air stream is then further heated from state
point 7–8 by the heat source (HS). After regenerating the DW, the air is exhausted at state point 9. Since the building exhaust of room air is not centralized or is not located in a convenient location for co-processing of ambient air for some applications, a modified ventilation cycle (Figure 3), which also processes ambient air to the building, but uses ambient air for regeneration, is proposed. It is obvious that, the thermal performances including thermal coefficient of performance (COP) and specific cooling capacity would be reduced in comparison with standard ventilation cycle due to that both the humidity ratio and temperature of ambient air are usually higher than that of return air. To elevate the cooling capacity, recirculation cycle, which is a variation of Pennington cycle and reuses return air as process air, is developed.

**Figure 2. Pennington cycle.**

**Figure 3. Modified ventilation cycle.**

**Figure 4. Recirculation cycle.**

**Figure 5. Dunkle cycle.**

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As depicted in Figure. 4, ambient air is used for regeneration in this cycle. Due to the humidity ratio and temperature are relatively low, the thermal COP of this cycle is commonly not more than 0.8 [6]. The main disadvantage of recirculation cycle is lacking in fresh air. Dunkle cycle [9] combines the merits of ventilation cycle, which can provide cold air with relative low-temperature for the HE, and recirculation cycle, which can provide the conditioned space with relative large amount of cooling capacity. As seen in Figure. 5, an extra heat exchanger is incorporated. Like recirculation cycle, Dunkle cycle is also limited by the lack of fresh air. It is obvious that fresh air not only means comfort and health but also represents an additional load. Furthermore, many cooling loads do not require that outdoor air be the source of system. Hence, fresh air should be maintained at the required level to ensure both favorable system performance and good indoor air quality. In view of this, Maclaine-cross [10] proposed a simplified advanced solid desiccant cycle, namely, SENS cycle. Figure. 6(a) illustrates the schematic of the SENS cycle. As seen, ambient air is first dehumidified in a DW. Then the air is sensibly cooled in two HEs in tandem. Afterwards, it is mixed with certain amount of return air and cooled further in a cooling coil (CC) by exchanging heat with cold water from a cooling tower (CT). Then the air stream is divided into two parts. While one part is redirected to the CT and exhausted after exchanging heat with the process air in a HE, the other part is supplied to the conditioned space. On the regeneration side, ambient air is pre-heated in a HE. It is then heated by HS, drawn through the DW and exhausted back to the outdoors. Mathematical modeling predicted that the SENS cycle can achieve a thermal COP above 2.0. Moreover, testing at the Solar Energy Applications Laboratory at Colorado State University [6] demonstrated that the thermal COP of this cycle was about 2.45 under ambient conditions of 26 °C and 26% RH. However, this cycle is blocked by its complexity. REVERS cycle [11] is a simplified version of SENS cycle with the only change of removing a HE, as shown in Figure. 6(b). Figure. 7 depicts the direct-indirect evaporative cooling (DINC) cycle proposed by researchers in Texas A&M University [12].
Differently from REVERS cycle, the CC and CT are replaced by an indirect evaporative cooler (IEC) and a DEC. This change simplifies the system configuration further. In addition, only an IEC is added in comparison with modified ventilation cycle. As Waugaman [12] predicted, the thermal COP of DINC cycle could be over 1.6 under ARI conditions.

IV. RECENT APPLICATION

The industry market of rotary desiccant dehumidification has been well-developed since the 1980s [1]. Corresponding rotary desiccant air conditioning system has also been experiencing an aggressive commercial application increase for several decades. With the more than half a century R&D in rotary desiccant dehumidification for comfort control as well as the increase of occupant comfort demands and deterioration of global energy and environment crisis, more and more commercial and building owners have been willing to invest in dehumidification equipment [15,16]. Hence, favorable market prospect can be expected. Due to the largest energy expenditure in a desiccant system is the heat used to reactive the desiccant, according to the heat source coupled with, rotary desiccant air conditioning systems can be generally classified into two categories in practical application, namely, solar-powered rotary desiccant air conditioning system and rotary desiccant air conditioning system powered by other low grade heat sources, such as district heating, heat supplied from a combined heat and power (CHP) plant, waste heat and bioenergy.

CONCLUSIONS

Rotary desiccant air conditioning is a typical thermally activated technology, which mainly consumes low grade heat sources as solar energy, district heating, waste heat, etc., thereby decreasing the peak electric demand caused by traditional air conditioning systems. Nowadays due to development in desiccant material and hybrid system their practical applications have been implemented around the world. This is a significant achievement compared with the earlier research works, which were primarily performed on computer analysis [6]. While the most widely used desiccant materials in market, namely silica gel and lithium chloride, are either limited by dehumidification capacity or problematic for crystallization and corrosion, composite desiccants combine the merits of existing desiccants and overcome these problems by confining salt to porous host adsorbent, and have been recognized as a better choice. Additionally, the reduction in regeneration temperature and the increment in dehumidification capacity over a wide range will be of great benefit to utilize low-temperature heat and expanding the application of desiccant air conditioning.

The majority of existing rotary desiccant air conditioning systems originates from the typical basic configurations, such as ventilation cycle, recirculation cycle and Dunkle cycle. These cycles are appropriate for different applications, for example, ventilation cycle is recommended for conditioned-space with high outside air requirement, whereas recirculation cycle is suitable to space requiring much less fresh air. Hybrid desiccant air conditioning is most researched as it combines the merits of desiccant dehumidification system and other air conditioning systems, desiccant air conditioning producing both dry air and chilled water is a newly proposed technology using desiccant dehumidification with regenerative evaporative cooling and is worthwhile for future research for its outstanding property of realizing independent temperature and humidity control without any assistance from VAC unit.
REFERENCES
