Review of Desiccant Cooling Based Hybrid Air Conditioning System

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ABSTRACT

This paper reported a review based study on the desiccant dehumidification system with multi stage evaporative cooling for hot and humid climate. Traditional vapour compression air conditioning system has caused serious pollutions due to the usage of CFCs or HCFCs. In response to these problems, solid desiccant cooling systems, which adopt water, a natural working fluid, as refrigerant and can be driven by renewable energy, have been widely recognized as a promising technology for their energy saving and CFC-free characteristics. In conventional air conditioner the dehumidification of air is achieved by bringing the temperature below the dew point in the cooling coil to condense water vapour. However, reheating is needed in most of the cases due to high latent load. Consequently a conventional air conditioner consumes large amount of electrical energy. The literature review revealed that various authors differ in their evaluation of the efficacy of these systems. This seems to be due to different methods of modeling of dehumidifier and differences in the operating conditions of the cycles employed.

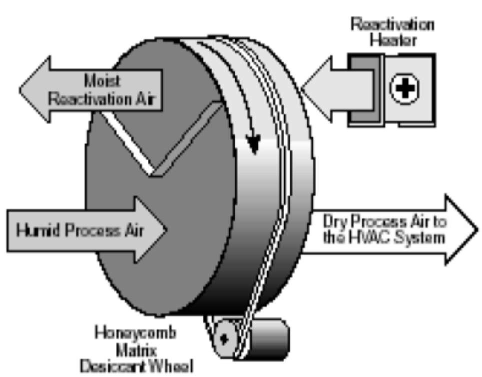
Keywords: Desiccant wheel (dehumidifier), self cooled desiccant coated system, Nocturnal and Evaporative cooling

I INTRODUCTION

The building sector is a major contributor to energy consumption worldwide and its contribution is expected to increase in the upcoming years. Further-more, the heating, ventilation and air conditioning (HVAC) system consumes the prime share of the energy consumption and can account in some cases for 70% of the total energy consumption of buildings [1]. The relatively high energy consumption of such systems is due to energy drawn by the compressor that is the heart of the vapor-compression cycle. This is a stimulating factor to find more efficient alternatives to the conventional air conditioning systems. Evaporative cooling presents itself as a potential alternative to the conventional air conditioning system in terms of lower initial cost, lower energy consumption during operation, and lower ozone depletion potential. Desiccant evaporative cooling technology combines the thermally driven sorptive air dehumidification with indirect or direct evaporative cooling to reduce the temperature of the supply air. However, the release of adsorption heat during the dehumidification process leads to a temperature increase in the sorption material. As the ability of the desiccant to adsorb moisture significantly decreases with higher desiccant temperature, cooling of the desiccant should lead to an increase in moisture adsorbed [2].

1.1 Desiccant cooling systems

Desiccant cooling consists in dehumidifying the incoming air stream by forcing it through a desiccant material and then drying the air to the desired indoor temperature. To make the system working continually, water vapour adsorbed/absorbed must be driven out of the desiccant material (regeneration) so that it can be dried enough to absorb water vapor in the next cycle. This is done by heating the material desiccant to its temperature of regeneration which is dependent upon the nature of the desiccant used. A desiccant cooling system, therefore, comprises principally three components, namely the regeneration heat source, the dehumidifier (desiccant material), and the cooling unit (Fig. 1.3) [5].



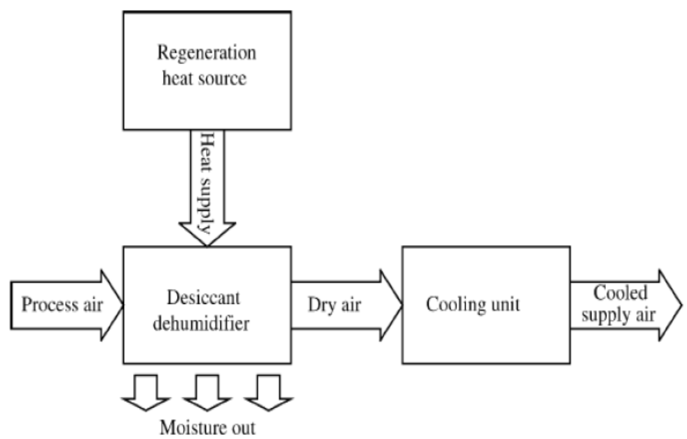


Fig.1.1 Desiccant Wheel [3] **Fig.1.2 Desiccant Cooling System [4]**

Desiccant cooling system has the unique merits that the sensible and latent heat can be processed separately and uses the various low grades thermal energy resources, such as solar energy, waste heat etc [5].

1.3 Self-Cooled Solid desiccant cooling based desiccant coated heat exchanger

Schematic figure of novel SCDHE system is shown in Fig. 1.3. It can be seen that cooling water within DCHE is produced by dry air produced by the system itself, no auxiliary cooling source is required, and then the system is labeled as “self-cooled”. The system consists of three main components (sensible heat exchanger, cross-flow falling film evaporative cooler, DCHE) and four groups of working fluids (process air, regeneration air, cooling water, heating water).

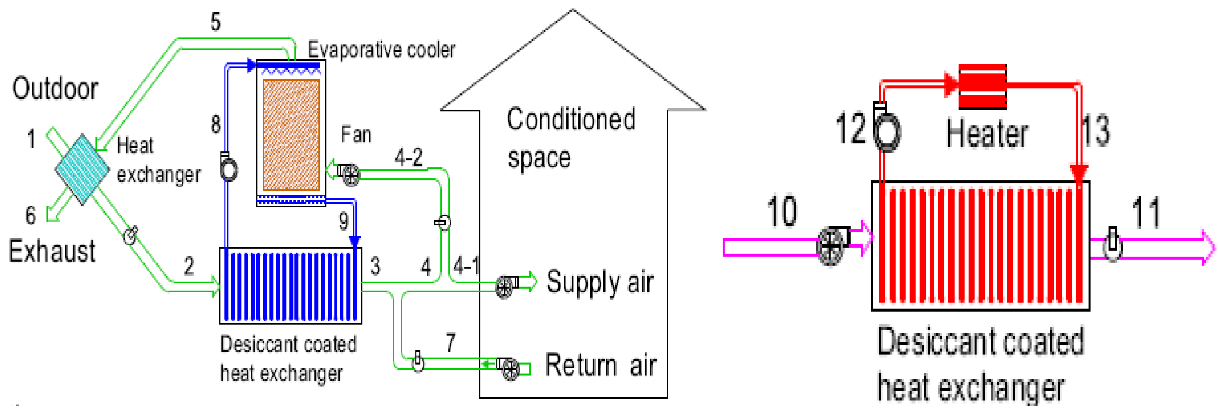
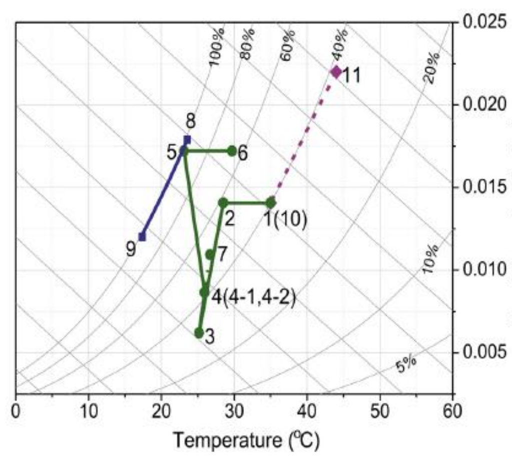


Fig. 1.3 Self-cooled desiccant coated heat exchanger cooling (SCDHE) system [5].

In dehumidification process: outdoor air (state 1) that is process air is firstly pre-cooled in a sensible heat exchanger (state 2) and then is dehumidified and further cooled in following desiccant coated heat exchanger (state 3); outlet air from desiccant coated heat exchanger (state 3) is mixed with return air from conditioned space (state 7) to constitute supply air (state 4); one group of supply air with low temperature as well as humidity ratio is directly supplied to the conditioned space and another group is pumped into evaporative cooler to complete regenerative evaporative cooling process, in which cooling water (state 8) is cooled (state 9) meanwhile supply air (state 4) is humidified and cooled (state 5); outlet air from evaporative cooler (state 5 to state 6) is adopted in sensible heat exchanger to pre-cool inlet air (state 1 to state 2).



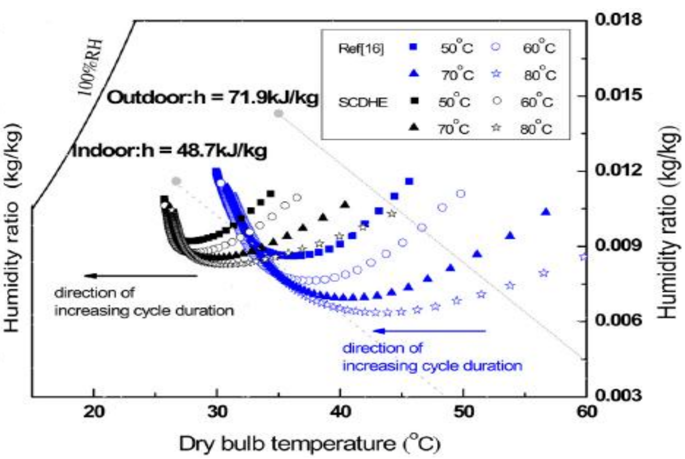


Fig. 1.4 Psychrometric chart of SCDHE [5]. **Fig. 1.5 Performance of SCDHE in ARI summer [5].**

Fig. 1.4 shows the operation of SCDHE system in psychrometric chart. It can be seen that compared with conventional solid desiccant cooling system based on desiccant wheel, solid desiccant cooling system based on desiccant coated heat exchanger can realize dehumidification process with decreasing temperature (state 2 to state 3), which can result in better moisture removal capacity as well as high overall system performance [5].

SCDHE system is feasible, it can be adopted as an independent air conditioning system or a dehumidification unit under simulated ARI summer condition and the required regeneration temperature is from 50 to 80^0 C which is lower than rotary wheel desiccant cooling system. Also, there exists an optimal switch time and suitable control mode for system to obtain enhanced performance in terms of cooling power. Performance of SCDHE system does not vary greatly with ambient temperature under simulation condition. However, both handled latent load and cooling power of the system increases under high humid condition, which demonstrates the system can operate under humid condition [5].

1.4 Evaporative cooling

When water is added to air, the temperature decreases. This is the principle used in what is called evaporative cooling. The human body works on the same principle when we perspire.

A. Direct evaporative cooling (DEC)

In DEC, the process or conditioned air comes in direct contact with the wetted surface, and gets cooled and humidified. The air gets cooled and dehumidified due to simultaneous transfer of sensible and latent heats between air and water. One can define the saturation efficiency or effectiveness of the evaporative cooling system ε as [6],

$$\varepsilon = \frac{(t_{o} - t_{s})}{(t_{o} - t_{o,WBT})} \quad \text{.................} \ (1)$$

B. Indirect evaporative cooling (IEC)

In an IEC process, the primary airstream to be cooled is separated from a wetted surface by a flat plate or a tube wall and is called cooled air. The cooled air does not directly contact the evaporating liquid. A secondary airstream flows over the wetted surface so that the liquid water will evaporate and extract heat from the primary airstream through the flat plate or tube wall. This wet secondary airstream is known as wet air [7].

1.5 Nocturnal cooling

Heat dissipation techniques are based on the transfer of excess heat to a lower temperature natural sinks. Regarding sky, heat dissipation is carried out by long-wave radiation from a building to the sky that is called radiative cooling or nocturnal cooling. The sky equivalent temperature is usually lower than the temperature of the most bodies on the earth; therefore, any ordinary surface that interacts with the sky has a net long-wave radiant loss. Radiative cooling to the night sky is based on the principle of heat loss by long-wave radiation from one surface to another body at a lower temperature. The sun radiates heat to earth in the day. At night the reverse happens when the warmer earth radiates heat to the cold night sky [8].

1.6 Evaporatively cooled sorptive-coated cross-flow heat exchanger (ECOS)

The basic approach of the sorptive coated heat exchanger is the removal of the adsorption heat directly at the location of its release in the sorptive component. In order to achieve such internal cooling of the desiccant, a different component design has to be implemented. A sorptive coated air-to-air heat exchanger is applied instead of a rotary desiccant wheel.

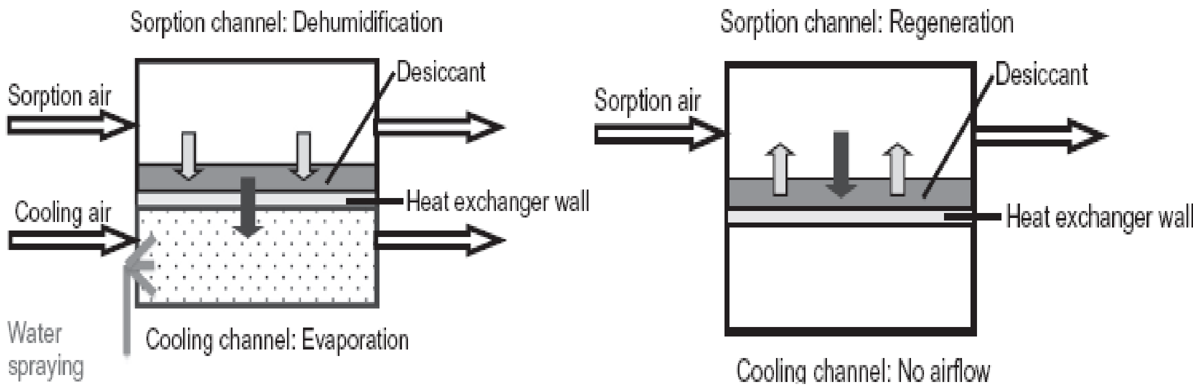


Fig. **1.6 Evaporatively cooled sorptive heat exchanger operation [9]**

In the air-to-air plate heat exchanger the sorption side is coated with a desiccant. During the adsorption stage the sorption air is dehumidified by adsorption of water vapour onto this desiccant. The heat exchanger walls of the sorption channels are in thermal contact with the cooling channels which are passed by cooling air (e.g. building return air). As liquid water is sprayed into the cooling channels, the heat exchanger walls are covered by a thin water film. This enables the efficient evaporation of water into the cooling air. The energy needed for water evaporation in the cooling channels is supplied by the heat released during adsorption on the sorption side. Therefore, the adsorption heat is transferred from the desiccant to the cooling side, leading to a temperature reduction of the desiccant [9].

1.7 Dehumidification system with two-stage evaporative cooling

The hot and humid outdoor air is drawn using the fresh air fanFAF-1 where it enters the adsorption compartment of the desiccant wheel. The air loses moisture to the desiccant material and exits the desiccant wheel at higher temperature and lower humidity ratio. Next to the fresh air enters a sensible wheel where it exchanges heat with the air exhausted from the room by means of the exhaust air fan

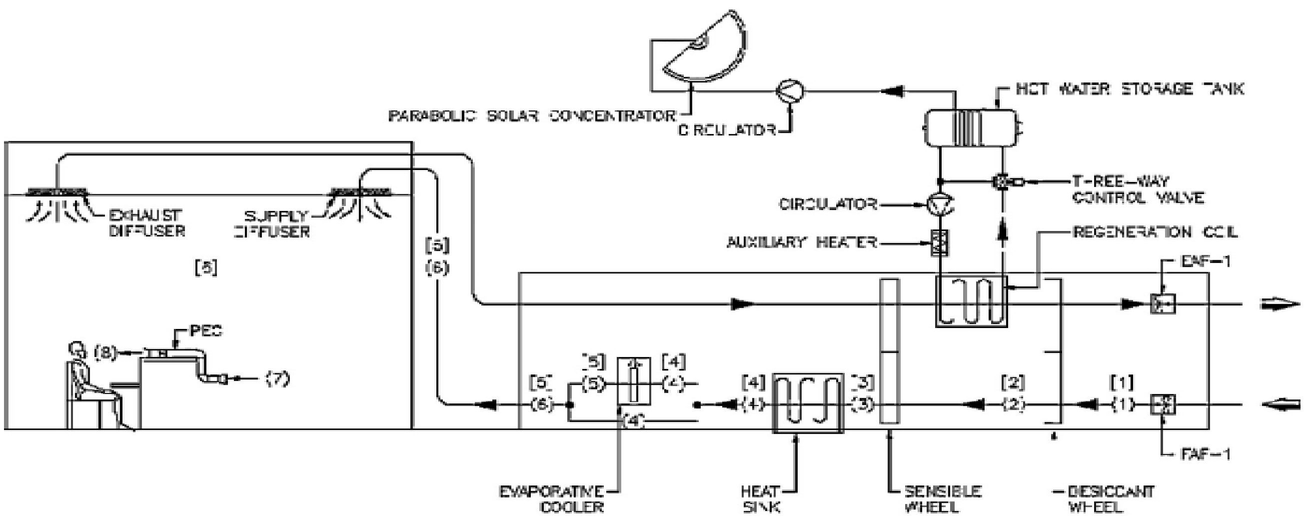


Fig.1.7 Schematic two-stage system layout. The state points in brackets correspond to the single-stage system; those in parenthesis correspond to the two-stage system [10].

EAF-1. The fresh air exits the sensible wheel at lower temperature and at the same humidity ratio, while the exhausted air leaves the sensible wheel at higher temperature. After that, the fresh air will be brought into a heat sink where it will be subjected to further cooling. The final step of fresh air treatment consists of taking a fraction of the air exiting the heat sink and cooling it using a direct evaporative cooler to further decrease its temperature below the sink temperature. The remaining air is bypassed across the evaporative cooling pad before being mixed again with the cooled fraction and supplied to the room. Once the treated fresh air comes inside the room, it picks up the load of the room and its temperature increases. The PEC handles the room air and supplies it to the individual’s breathing zone at lower temperature.

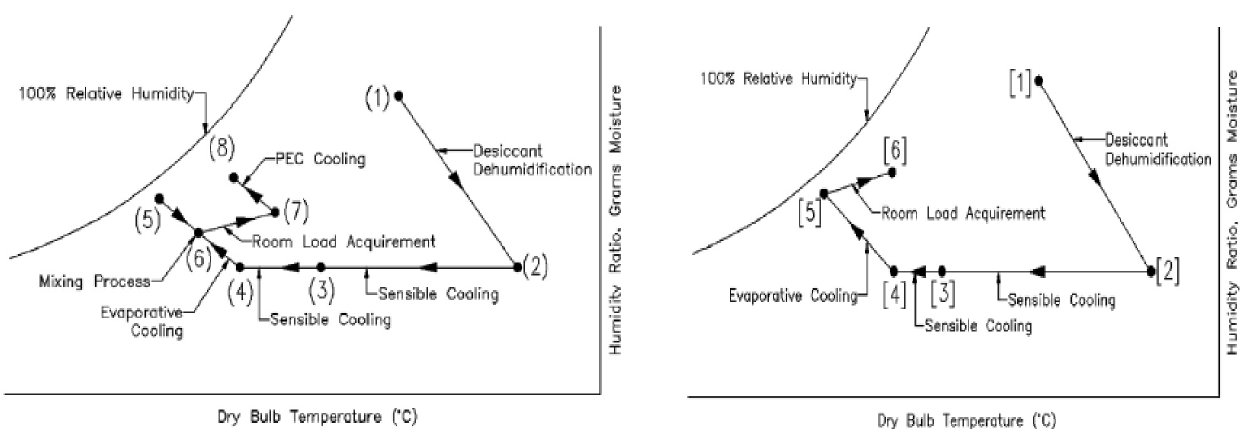


Fig.18. Psychrometric process; (a) two stage system and (b) single stage system [10].

Fig. 1.8(a) and (b) summarizes the psychrometric process of the single-stage and two-stage evaporative cooling systems respectively. The corresponding state points are shown in Fig. 1.8 where the state points in brackets correspond to the single-stage system while those in parentheses correspond to the two-stage system. For the case of the two-stage system, the room conditions at state (7) correspond to higher temperature and lower relative humidity compared to the room conditions at state (6) for the single-stage system [10].

The two-stage evaporative cooling system is a feasible system to be implemented in hot and humid condition since it achieves the same level of thermal comfort as a traditional single-stage evaporative cooling system but at lower running cost due to personalized cooling. The reduction in energy consumption during the summer season was 16.15% while the reduction in water consumption was 26.93%.

II CONCLUSION

A brief review has done on desiccant cooling and self cooled desiccant coated system. Review shows that lots of work has done to study desiccant cooling. Some researchers have done theoretical analysis. Some have developed mathematical model and some found empirical correlation for the moisture conservation in desiccant layer. There is lots of work done in field of desiccant wheel based hybrid air conditioning also by developing prototype models for experimentation with different designs and concepts. The review shows that majority of work has carried out where desiccant cooling system is used in hot and humid climate. Taking advantage of sky as a renewable source of the passive cooling, the desiccant wheel based hybrid air conditioning system can be considered as an environmentally clean and energy efficient system. Thus, this system can be used as a replacement for mechanical vapor compression systems, leading to decrease electrical energy consumption.

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