Comparison of Different Desiccant Materials for Dehumidification Application in Comfort Cooling

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Abstract—The present article discusses the review on use of various desiccant materials used in dehumidification applications for the comfort cooling in building. The opportunities for the development in desiccant materials for wide spread use in desiccant based alternative cooling technologies in the field of space cooling. The different kinds of desiccant materials such as silica-gel, activated carbon, zeolite etc. were getting highlighted and compared in the present paper. The desiccant material which gets reactivated approximately at ambient conditions are the main aim for the researchers to save energy required for the regeneration of rotary dehumidifiers used in desiccant based hybrid cooling systems. An important aspect that leads to the further development in rotary desiccant dehumidifiers for the application of different adsorbent is also summarized in the present work.

Key words: COP, Desiccant Cooling, Regeneration, Rotary Dehumidifier

I. INTRODUCTION

Air humidity has put major attention in different traditional industries like as food conservation and processing, chemicals and petrochemicals, architectural materials, pharmaceuticals, cosmetics, paper mills, textiles, etc. [1] Dehumidified air is required for the preservation, transportation, and further processing of products. For example, the air humidity needs to be less than 12% for seed or grain storage. [2] The heightened interest in air dehumidification is due to the required low humidity in emerging industries. Furthermore, the microelectronics industry requires a very low relative humidity (RH) to avoid short circuit, corrosion, aging to lower reactivity, etc. [3] The lithium–air battery industry requires a low RH air because the batteries can be aged or deactivated under humid air due to the active Li–moisture reaction. [4] In addition, due to the environmental and health concerns regarding air humidity causing fungi activation, [5] dehumidification of air has been suggested for the amelioration in indoor air quality, specifically in humid districts. Presently, concerning the limited natural freshwater resources, an emerging trend is to integrate dehumidification technology for pure water production for a more sustainable society. Therefore, dehumidification of air has become a prime concern for the investigation worldwide.

Presently, differently technologies were used for air dehumidification. By use of Condensing dehumidification removes moisture from the air by cooling it below the dew point in the presence of refrigerants in conventional vapor compression systems, where part of the moisture is condensed and drained from the supply room air. [6] Condensing dehumidification can provide reliable dehumidification performance, and the operation is easy to dehumidify the cooling air. The main limitations of condensing dehumidification include the use of high-cost and non-environmentally friendly refrigerants, which demands an energy-intensive regeneration. Furthermore, condensing dehumidification is not suitable for deep dehumidification (<42%) due to its low energy performance at low humidity. Another traditional dehumidification technology is heating dehumidification, [7] which lowers the relative humidity by the creation of a temperature gradient through heating or circulating hot dehumidified air. Heating dehumidification includes hot air drying, heat pump drying, [8] far-infrared drying, [9] microwave drying, [10] etc. Comparatively cheaper initial investment and operating cost are the advantages of heating dehumidification. The limitation of heating dehumidification include (1) high energy requirement and (2) only the local moisture content can be lowered. Membrane dehumidification separates moisture from air by selective permeation or different permeation rates of water vapor from other components in air. With the creation of a concentration ingredient, a continuous separation process can be designed. As compared to the other dehumidification technologies, membrane dehumidification requires relatively lower energy, which is reflected in the low maintenance cost. However, the application is limited by its low penetration rate, low mechanical strength of the membrane, and high membrane fabrication cost. Liquid desiccant dehumidification selectively removes moisture from air by absorption and has been studied extensively. [11] Widely used desiccants include calcium chloride, lithium bromide, lithium chloride, Triethylene glycol, etc., which is having low surface vapor pressures at low temperature and high concentration [12] for the process of dehumidification. For liquid desiccant dehumidification, material stability, including thermal stability and mechanical stability, and the mobility of the desiccants are the major concerns to dry the air. Adsorptive dehumidification separates moisture from air that passes through it by adsorption over a solid desiccant. As compared to other dehumidification technologies, adsorption shows great promise for air dehumidification. Table 1 [13] summarizes the basic principles of different dehumidification technologies, as well as their advantages and disadvantages.

<table>
<thead>
<tr>
<th>Dehumidification method</th>
<th>Principle</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condensing dehumidification</td>
<td>Condensing</td>
<td>Reliable dehumidification performance; easy to manage</td>
</tr>
<tr>
<td>Heating dehumidification</td>
<td>Heating</td>
<td>Low initial investment; low operating cost</td>
</tr>
<tr>
<td>Membrane dehumidification</td>
<td>Permeation</td>
<td>Continuous water removal process; low energy consumption; low maintenance cost</td>
</tr>
<tr>
<td>Liquid desiccant dehumidification</td>
<td>Absorption</td>
<td>High efficiency; high dehumidification capacity</td>
</tr>
<tr>
<td>Adsorptive dehumidification</td>
<td>Adsorption</td>
<td>High efficiency; high dehumidification capacity</td>
</tr>
</tbody>
</table>

Table 1: Comparison of Different Dehumidification Technologies

Adsorption, on the basis of the ability of a solid adsorbent to selectively adsorb certain compounds, was widely used in the field of clean energy and the environment,
such as bio-gas cleanups, [14] greenhouse gas capture, [15] desulfurization and denitrogenation for ultraclean transportation fuels, [16] water purification, [17] etc. applications. Depending on the natural physical, biological, and or chemical properties of the targeted contaminants, namely, adsorbates, functional adsorbents can be designed for the selective removal or separation of adsorbates. One merit of adsorptive dehumidification is that it is able to selectively separate moisture from moist air over a solid regenerable adsorbent under ambient conditions. In addition, sorbent functionality can be tuned for different separation systems—that is, air with high and low moisture contents—for various applications.

II. DESCRIPTION OF THE SYSTEM

Adsorptive dehumidification can be achieved by use of solid desiccant wheel. It consists of many types such as stationery solid packed bed or rotating honey comb wheel. With the exception of rotary desiccant wheel, all of the other dehumidifiers work with two desiccant packed beds, one as a dehumidifier and the other undergoes a desorption process, [18] which are integrated into one in the case of rotary desiccant dehumidifiers. As compared with other types of dehumidifiers, rotary desiccant dehumidifiers show the following desirable characteristics: (1) high space efficiency, (2) high dehumidification efficiency, (3) continuous adsorption–desorption cycle, and (4) ability to utilize the low-grade renewable heat sources, like as solar energy, waste heat, etc., for adsorbent reactivation. Therefore, the rotary desiccant dehumidifier is considered to be a state-of-the art energy-efficient dehumidification technology. Fig. 1 [18] presents a schematic diagram of a rotary desiccant dehumidifier. It illustrates the main components of the desiccant wheel. Fig. 2 shows the supported matrix structure, used to impregnate the desiccant material [19]. The adsorbent is immobilized onto a supporting substrate by various techniques for example, in situ impregnation and paper making technique before being loaded into the dehumidification wheel.

![Fig. 1: Components of Rotary Desiccant Dehumidifier](image1)

![Fig. 2: Matrix Structure of Rotary Desiccant Dehumidifier](image2)

![Fig. 3: Working Principle of Rotary Desiccant Dehumidifier](image3)
For the rotary desiccant dehumidifier, the dehumidification performance can be determined by the desiccant or adsorbent material, system configuration, wheel structure, operating conditions, etc.

III. TYPES OF ADSORBANTS

In typical rotary desiccant dehumidifiers, the optimal operating parameters are rotation speed of 10–30 cycles per hr, wheel thickness of 10–30 cm, face velocity of 1–3 m/s, and regeneration temperature of 80–150°C. From the viewpoint of selecting the different desiccant materials, adsorbents played an important role in the rotary desiccant humidifier, and the adsorbents design has received much attention. To design efficient adsorbents, the challenges or critical issues to be overcome include (1) effective adsorbents for air dehumidification under different ambient environmental conditions, which essentially requires adsorbents with high adsorption capacity and selectivity, also at a low cost. In addition, other adsorption parameters, such as the adsorption isotherm shape, heat of adsorption, thermal capacity, moisture diffusivity, and adsorption isotherm hysteresis, [21] are of great importance for the adsorbent design. Depending on the ambient humidity, the key requirements for the adsorbents are different. (2) Second vital parameter for the selection of proper adsorbent is regenerability and lifetime, which may be affected by the material stability, such as mechanical, thermal, and hydrothermal stability. In the case of unstable adsorbents, losses of active sites occur during high regeneration temperature, which causes a decrease in the adsorption capacity after few regeneration cycles. (3) Energy consumption is a great concern for air dehumidification technology. Theoretically, evaporating 1 kg of water requires 2,100–2,800 kJ of heat at standard conditions, and the practical energy requirement for dehumidification is much greater. For example, the unit energy consumption for continuous wood drying is around 3,100–4,200 kJ/kg, sometimes requiring as high as 5,200–8,400 kJ/kg. Adsorbent regeneration is one of the main energy-intensive processes in the dehumidifier, and the regeneration temperature of the adsorbent can predominantly affect the total energy consumption of the dehumidifier for reactivation. So, the regeneration temperature was chosen as a parameter to evaluate the intensity of energy consumption. If the required regeneration temperature is comparatively low, renewable solar energy, industrial waste heat and other low-grade heat sources, such as district heat, local waste heat, etc., can be readily utilized for the regeneration process. Thus, a low regeneration temperature is demanded for an energy-efficient dehumidification process. To sum up, the adsorbent with tailored adsorption characteristics including high adsorption capacity, selectivity, regenerability, and high energy efficiency for air dehumidification are important. The adsorption capacity, regeneration temperature, textural properties etc. of the various adsorbents used as desiccant material in rotary dehumidifiers can be tabulated as follows Table 2 [21-25].

<table>
<thead>
<tr>
<th>Type of Desiccant material</th>
<th>Adsorption capacity (g·H₂O/g-adsorbant)</th>
<th>Textural properties</th>
<th>Regeneration temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica gel</td>
<td>0.08-0.36</td>
<td>2-10 nm</td>
<td>80-150</td>
</tr>
<tr>
<td>Zeolite</td>
<td>0.02-0.30</td>
<td>-</td>
<td>250-350</td>
</tr>
<tr>
<td>Al₂O₃-SiO₂ Composite</td>
<td>0.19</td>
<td>2 nm</td>
<td>160-280</td>
</tr>
<tr>
<td>CaCl₂-MCM-41 Composite</td>
<td>0.75</td>
<td>2-10 nm</td>
<td>70-120</td>
</tr>
<tr>
<td>Aluminium pillared clay</td>
<td>0.21</td>
<td>-</td>
<td>70-80</td>
</tr>
<tr>
<td>MOF-MIL-100 (Al)</td>
<td>0.84</td>
<td>-</td>
<td>70-100</td>
</tr>
<tr>
<td>Activated Carbon</td>
<td>0.18-0.29</td>
<td>2 nm</td>
<td>70</td>
</tr>
<tr>
<td>Silicon Aluminium Phosphate</td>
<td>0.34</td>
<td>-</td>
<td>70-120</td>
</tr>
<tr>
<td>Starch based polysaccharide adsorbent</td>
<td>0.17</td>
<td>-</td>
<td>50-80</td>
</tr>
</tbody>
</table>

Table 2: Comparison of Various Desiccant Materials

IV. RESULTS & DISCUSSION

The effects of RH on the adsorption rate constants comparing for water vapor adsorption over types of different adsorbent materials with different pore sizes and reported a greater adsorption rate on silica gel with larger pores. Diffusion resistance was suggested to affect the adsorption kinetics greatly at a lower RH, whereas the capillary condensation affects the adsorption rate constant at a higher RH. It is found that a fast kinetics of zeolite due to its high affinity to water. In comparison, the diffusion coefficients of water in pillared clays was three or four orders of magnitude lower than that in zeolite. The adsorption rate of MOF MIL-101 (Cr) at 30°C was reported to be distinctively higher than those of SAPO-34, NaX, and silica gel (Fig. 4) [26]. Therefore, sorbent parameters—that is, pore size and structure, functionality on the sorbent, and adsorption conditions—are of primary importance to the adsorption kinetics for dehumidification.

In addition to adsorption capacity, adsorptive selectivity is another important parameter for the commercialization of a successful adsorption process. However, there is rather limited information on adsorption selectivity in the literature. The presence of other impurities in air, including NOₓ, SOₓ, COₓ, etc., depending on the ambient or room air sources, might affect the adsorption of H₂O over the adsorbents due to competitive adsorption and may affect the adsorbent regenerability due to the possible formation of irreversible compounds.
In some cases, the presence of moisture may facilitate adsorption. For example, the presence of moisture helps the amine-based adsorbents in CO₂ capture from flue gas due to the formation of bicarbomates is promoted in the wet condition, rather than carbomates in the dry condition.

V. CONCLUSIONS

The recent developments of adsorbents for use in desiccant assisted cooling and dehumidification have been overviewed. Progress was made on the various factors governing air dehumidification from the technical and scientific aspects; for example, the dhimmification characteristics of individual adsorbent type. Some of the important findings can be summarized as further improvement of adsorption capacity of desiccant when regeneration temperature decreases near to ambient conditions for especially the use of renewable solar energy. It is important to predict the interaction of impurities of air with that of the sorbent when it gets dehumidified by passing through rotary dehumidifiers. The heat of adsorption lowers adsorption capacity. Finally, despite the scarcity of economic analysis, the wide spread use of low-cost desiccants are strongly recommended for the purpose of cost-effective and feasible sorption dehumidification of air for maintaining indoor thermal comfort.

VI. NOMENCLATURES

- µ: Air velocity [m/s]
- DBT: Dry Bulb Temperature [K]
- WBT: Wet Bulb Temperature [K]
- T: Temperature [K]
- R: Radius of desiccant wheel [m]
- L: Desiccant wheel thickness [m]
- Φ: Regeneration sector angle [°]
- ω: Wheel rotational speed [rph]
- Y: Relative humidity [%]

REFERENCES


