Development of a Composite Solid Desiccant Dehumidifier for Ventilation Air

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Abstract. The composite solid desiccant dehumidification systems have been considered as an alternative air dehumidifying system. Their inherent energy saving capability added with their ability to act as an independent dehumidification system for ventilation air make them an attractive undertaking for research. In this study, fin tube heat exchangers (FTHX) coated with composite solid desiccant have been developed to act as a dehumidifier for supplying ventilation air. Aluminum surface of FTHX was dipped with Polyurethane (PU) glue and the desiccant was attached on the FTHX surface as the PU glue acted as a binding material. The adhesion between composite desiccant and fin surface was investigated by scanning electron method (SEM) and it showed good boding between two materials. The objective of this paper is to study the performance of the dehumidifier i.e. the solid desiccant coated on fin and tube heat exchangers. An experimental setup was created in such a way that when the humid air passed through the FTHX it provided dehumidification in half cycle and after that in another half cycle desiccant coated FTHX was regenerated. In order to save energy, waste heat from the condensing unit was utilized for regeneration and the cool water from the cooling tower was used for dehumidification. The experimental results with the prevailing experimental conditions showed higher effectiveness in the regeneration process when compared to dehumidification process.

Keywords: Composite desiccant · Dehumidification · An independent dehumidification system

1 Introduction

Nowadays, there are several methods for removing moisture from the air before supplying it to the conditioned space. Researchers have considered different desiccant components and there is a lot of published works on silica gel coated on heat exchangers [1]. However, after an intensive literature review it is found that the efficiency of the systems in most of the research work is low. Because their systems require high temperature for the regeneration process and the capacity of the water content of desiccant is limited

K. Ujikawa et al. (Eds.): ACESD 2021, ESE, pp. 143–151, 2022.
https://doi.org/10.1007/978-981-19-1704-2_13

by its absorption property. So, composite desiccants were used to increase the dehumidification capacity. A lot of porous substrates such as mesoporous or microporous silica gel, alumina, porous carbon, and amorphous polymer are fabricated by impregnating into inorganic salts such as LiCl, $CaCl_2$, $MgCl_2$ or LiBr. Mesoporous silica gel – Lithium chloride composite desiccant has dehumidification rate greater than pure silica gel 20–40% [2]. The composite desiccants have higher dynamic sorption quantity and a reasonable diffusion rate constant [3]. In addition to this, several researchers developed desiccant coated on heat exchanger (DCHE) for solving humidity problems.

The desiccant coated fin-tube heat exchanger (DCFTHX) has two processes. First one is the dehumidification process, which uses cool water to increase effectiveness of desiccant. And the second one is the regeneration process, in which hot water is utilized to remove moisture from the desiccant [4].

Zheng et al. [5] studied pure silica gel and composite desiccant silica gel with LiCl, with different concentration: 10, 20, 30 and 40% by weight. Their results show that when the sorption kinetic of composite desiccant increases, the concentration of LiCl also increases. The water sorption capacity of pure silica gel smoothly grew with the increase of relative pressure. The isotherm illustrated the limiting amount adsorbed by the composite sample which is higher than pure silica gel. It is because the composite desiccant has both chemical and physical bonding with the moisture.

Ge et al. [6] studied composite desiccant by impregnating potassium formate ($CHKO_2$), with various concentrations of $CHKO_2$: 15, 45, and 75% by weight, into the pore silica gel. Their results show when adsorption performance of different coating desiccant materials under the same operating conditions are compared, both adsorption mass and initial adsorption rate increase with the increment of concentrations of $CHKO_2$ solution. They concluded that impregnating $CHKO_2$ into porous silica gel is an effective method to improve adsorption capacity. They recommended to keep saturated $CHKO_2$ solution with 75% by weight in the composite desiccant under experimental conditions.

Hu et al. [7] studied performance of composite desiccant coated on heat exchanger (DCHE-C) and compared it with conventional silica gel coated on heat exchanger (DCHE-S). They reported that the dehumidification performance of DCHE-S reaches its saturation faster than DCHE-C since the moisture absorption ability of DCHE-S is limited by silica gel. However, the dehumidification capacity for DCHE-C is higher than DCHE-S.

Jiang et al. [8] reported their study on composite desiccant and conventional silica-gel coated fin-tube heat exchangers (CCHE and SGCHE). They performed an experiment to test the dynamic performance of SGCHE and CCHE. Regarding the regeneration process in their experiment, the moisture released from CCHE was much greater than SGCHE. However, the regeneration time of CCHE was longer than SGCHE. Regarding the dehumidification process, the dehumidification ability of CCHE was greater than other one although the dehumidification time was longer for CCHE.

T.S. Ge et al. [9] carried out a study on the temperature of hot water in regeneration process against COP of desiccant coated on heat exchanger (DHE). COP was calculated based on the ratio of the sensible and latent heat capacity of the system and the thermal energy consumed in the regeneration process. The COP of the system increased with increasing water temperature in the regeneration process.

2 Synthesis of Composite Desiccants and Their Properties

2.1 Method

A composite desiccant is a multiphase of solid material. In this study, mesoporous silica gels with a pore size of 10 and 15 nm were reinforced by Lithium Chloride. Details of chemical materials are shown in Table 1.

Table 1. Characteristics of materials.

Name	Type	Manufacture
Mesoporous silica gel with a pore size of 10 nm	Hight purity grade, pore size 100 A^{O}, particle size 200–400 mesh	Fluka
Mesoporous silica gel with a pore size of 15 nm	Hight purity grade (Davis Grade 643), pore size 150 A^{O}, 200–425 mesh	Sigma-Aldrich
Lithium chloride	Anhydrous 98%	Loba Chemie pvt.ltd

The details of the preparation of composite desiccant are shown in the following steps:

1) The mesoporous silica gel was weighed and then it was dried in an oven at the temperature of 373.15 K for at least 3 h until the weight was constant.
2) The ratio of mesoporous silica gel and lithium chloride aqueous solution with mass concentrations in 40 wt.% was 3:1.
3) Dry mesoporous silica gel was impregnated in a solution of Lithium Chloride at a room temperature for 24 h.
4) The composite desiccant was filtered from the solution with a vacuum filter and excess LiCl was cleaned with deionized water.
5) The composite desiccant was dried in an oven at 373.15 K for at least 24 h until the weight remained constant.
6) BET technique was used for the determination of texture properties of desiccants.

2.2 Texture Properties

Texture properties such as BET surface area, total pore volume, and average pore size of mesoporous silica gel and composite desiccant are illustrated in Table 2.

It can be seen from Table 2 that BET-specific surface area was reduced when more salt particles were immersed. The pore volume of composite desiccant decreased when impregnating mass concentration of LiCl solution.

Table 2. Texture properties of mesoporous silica gels and their composite desiccant.

Sample	Surface area (m^2/g)	Total pore volume (cm^3/g)	Mean pore diameter (nm)
Mesoporous silica gel with a pore size of 10 nm	327.16	0.889	10.865
Mesoporous silica gel with a pore size of 15 nm	292.88	1.103	15.069
Composite desiccant base on mesoporous silica gel with a pore size of 10 nm	179.82	0.5581	12.414
Composite desiccant base on mesoporous silica gel with a pore size of 15 nm	156.15	0.6168	15.801

3 The Deposition of Desiccants on Fin-Tube Heat Exchanger

During the deposition process, suitable binders are necessary to ensure continuous contact between the FTHE surface and desiccant materials. Moreover, the geometry of the FTHE is complicated, so the Aluminum sheets for the FTHE were used for the procedure of binder selection.

3.1 Binder Options

Experiments were conducted on four types of binder, namely: Cyanoacrylate, Hydroxyethyl cellulose (HEC), Polyurethane glue (Polyurethane in solvent from Bond-Tech company) and spray glue for metal surfaces combined with Polyurethane glue. Results of adhesion of the glue and Aluminum surface are shown in Table 3.

Table 3. Binders selection and their adhesion.

Binder selection	Results
Cyanoacrylate glue	This binder had poor adhesion between desiccant and Aluminum surfaces
HEC starch glue	The HEC glue had poor adhesion on the Aluminum surface
Polyurethane glue, (Polyurethane dissolved into its solvent from Bond-Tech company)	It had good adhesion with desiccant, but the glue layer peeled off from the substrate surface
Spray glue for metal surface amalgamates with polyurethane glue	It had good adhesion with desiccant and an Aluminum surface

3.2 The Detail of Capability of Spray Glue for Metal Surface Amalgamates with Polyurethane Glue

The Spray glue for the metal surface was sprayed on the Aluminum surface as primer. Then, the Aluminum was dipped into the Polyurethane glue. After that the desiccant was deposited on the top of the glue with a shaker machine. A scanning electron microscope was used to produces an image of the composite desiccant particle and Aluminum which showed the topography and composition of these two materials. This image is used to investigate the adhesion between composite desiccant and fin surface.

An image from the scanning electron microscopic of deposition of desiccant over the metal surface is shown in the Fig. 1.

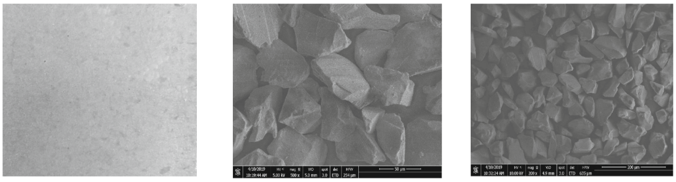

(a) desiccant on Al sheet (b) 500x (c) 200x

Fig. 1. Photo and SEM image of deposition of desiccant on an Aluminum surface.

The aim was to have a thin layer of Polyurethane glue over the fin surface, with desiccant over this PU layer for proper moisture absorption. But instead, when the binder adhered between desiccant and the sample of a fin-tube heat exchanger, which is cut for 2.54 cm^3 as shown in Fig. 2 (a), PU glue not only bonded desiccant and fin-tube surface but also covered the surface of desiccant. The PU glue for the flow through the gap of a fin during the dipping process covered the surface of the desiccant due to its high viscosity as shown as in Fig. 2 (b). The polyurethane glue couldn't be diluted with a solvent as it has a long chain with engagement.

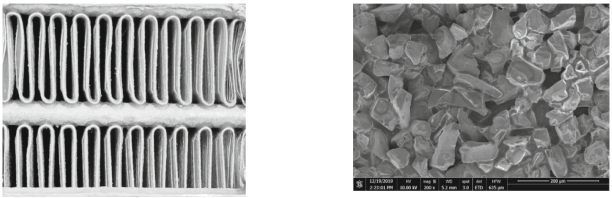
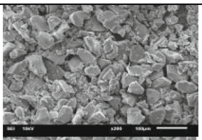
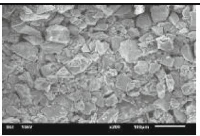
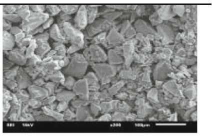
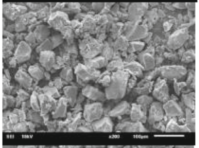
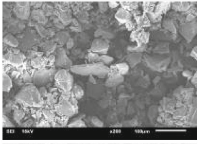
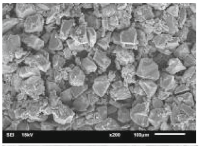
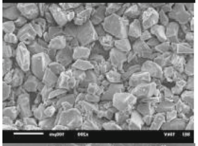
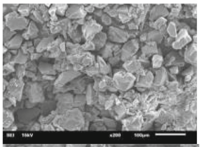
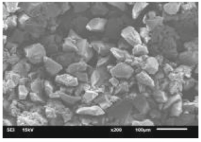
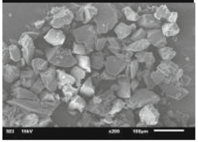
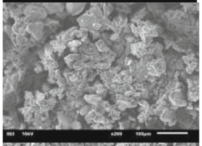
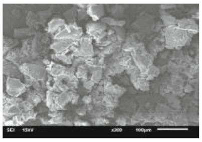
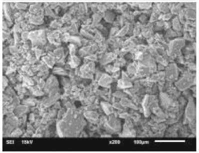
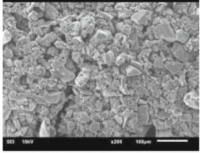
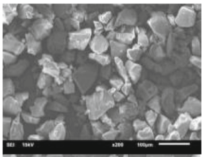
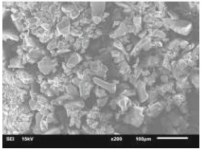
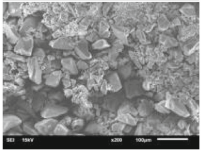
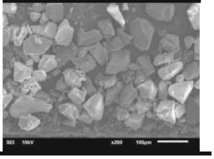

(a) A sample of fin-tube heat exchanger (b) 200x

Fig. 2. Photo of a fin-tube sample (a) and SEM image of desiccant was deposited on the surface of the fin-tube sample (b).

Due to this prevailing problem, a new polyurethane glue with short chain was used which is polymerized urethane monomer and oligomer. The new binder was used for the deposition of desiccant on the surface of fin- tube samples. The adhesion of synthesized polyurethane glue was tested 2 times; 3 samples were used each time. The sample was cut at 3 positions of the fin to investigate the adhesion and arrangement of desiccant on the fin surface by SEM technique. Some position on the fin had a single layer of desiccant while some other position had two-layer of desiccant as illustrated in SEM images as shown in Table 4. Overall, the new PU glue had a pretty good arrangement and adhesion of particles of desiccant over the Al surface as shown in Table 4.

Table 4. SEM images of desiccant deposited on the fin surface of fin-tube samples at 200x zoom.

Sample / Positions of fin	1st position	2nd position	3rd position
No.1			
No.2			
No.3			
No.4			
No.5			
No.6			

4 Desiccant Dehumidification

Dehumidification performance of composite desiccant, which is based on mesoporous silica gel with pore size of 15 nm, was tested by depositing the desiccant on the fin-tube heat exchanger. The fin tube heat exchanger after deposition and drying was set up as dehumidifier unit. The temperature of cooling water for the dehumidification process and hot water for the regeneration process were set as 303.15 ± 3 K and 323.15 ± 3 K, respectively. The temperature of cold water is close to ambient temperature and the temperature of hot water is low. This implies that, hot water can be used from low-grade energy sources like the water from the condensing unit and the cold water can be used from the cooling tower. The inlet absolute humidity and air velocity of the process air are 24 kg_{wv}/kg_{da} and 0.4 m/s, respectively. The time of both the dehumidification and regeneration process is 20 min.

The dehumidification system comprises of two dehumidifier units. One of the dehumidifier units work on the dehumidification process so it was supplied with cool water to adsorb moisture in ambient air, while the other dehumidifier units work on the regeneration process, was supplied with hot water to remove water from the saturated desiccant. Two of these dehumidifiers work simultaneously; while one dehumidifies the working air, the other gets regenerated. The two switch their operations periodically to achieve dehumidification of the work in process.

The outlet absolute humidity of process air and temperature of the water from the measurements are illustrated in Fig. 3. The outlet absolute humidity of process air in the absorption process decreased slightly. However, the outlet absolute humidity of process air in desorption process increased gradually.

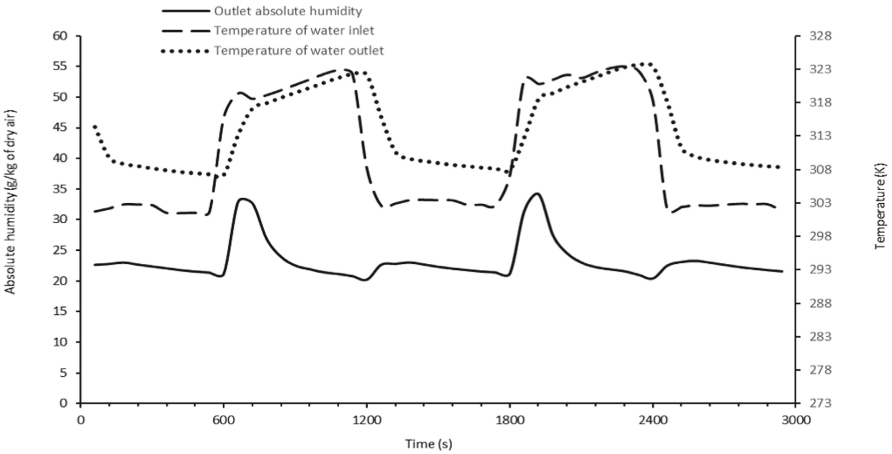


Fig. 3. The dehumidification and regeneration process utilizing the composite desiccant coated FTHX.

4.1 Performance Parameters

4.1.1 Moisture Removal Capacity in the Process (MRC)

This term represents the amount of moisture that is removed after the process air passes through the desiccant in the dehumidification process.

$$MRC = \dot{m}_{a,deh} \times (w_{inlet} - w_{outlet}) \tag{1}$$

where, $\dot{m}_{a,deh}$ is the mass flow rate of dehumidification process air (kg/s) and $\mathrm{W_{inlet}}$ and $\mathrm{W_{outlet}}$ are the absolute humidity of inlet and outlet air of the process air ($\mathrm{kg_{wv}/kg_{da}}$), respectively.

4.1.2 Moisture Removal Regeneration (MRR)

It is the amount of moisture that is removed from the desiccant after the desiccant adsorbs moisture and reaches equilibrium.

$$MRR = \dot{m}_{a,reg} \times (w_{inlet} - w_{outlet}) \tag{2}$$

where $\dot{m}_{a,reg}$ is mass flow rate of regeneration process air (kg/s).

4.1.3 Dehumidification Effectiveness ($\mathbf{E_{deh}}$)

It represents the ratio of the amount of humidity reduction to inlet humidity in the adsorption process.

$$E_{deh} = \frac{W_{in} - W_{out}}{W_{in}} \tag{3}$$

4.1.4 Regeration Effectiveness ($\mathbf{E_{reg}}$)

It is the ratio of the amount of humidity removal to the inlet humidity in desorption process.

$$E_{reg} = \frac{W_{in} - W_{out}}{W_{in}} \tag{4}$$

The maximum amount of moisture removal value in dehumidification and regeneration process in this experiment are 0.22 kg/s and 0.63 kg/s, respectively. In addition to this, dehumidification and regeneration effectiveness are 0.15 and 0.42 respectively.

5 Conclusion

The composite desiccant was deposited on the fin-tube heat exchanger surface and the experiment was conducted with the conditions to imitate the real-world application. The effectiveness of regeneration process is higher than the dehumidification process which means the studied dehumidifier i.e. the FTHE coated with composite desiccant can handle the moisture in the air-conditioned room. This experiment shows the potential of a composite solid desiccant dehumidifier system in hot and humid climate of Thailand. Field experiments of the desiccant dehumidifier are necessary future work to access the potential application of this system in the hot and humid climate of Thailand.

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