Postprint: Study on the Influence of Dimensional Structure on Heat and Moisture Transfer Characteristics of Dehumidification Heat Exchangers

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Abstract

A universal test platform for dehumidification heat exchangers was established to experimentally investigate the heat and mass transfer performance of two dehumidification heat exchangers with different fin lengths (LDCHE and SDCHE) before and after desiccant coating. The results demonstrate that, compared with conventional heat exchangers, the dehumidification heat exchanger experiences a 30% reduction in heat transfer capacity and a 60% increase in pressure drop due to the desiccant coating. With other structural dimensions held constant, doubling the fin length leads to a 50% decrease in the heat transfer coefficient, a 40% improvement in dehumidification effectiveness, an 80% increase in pressure drop, and a reduction in the energy efficiency ratio for both dehumidification and regeneration processes. While increasing fin length enhances dehumidification performance, it concurrently degrades heat transfer performance and increases energy consumption.

Full Text

Experimental Study on Heat and Mass Transfer Characteristics of Desiccant Coated Heat Exchanger with Variable Structure Sizes

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Abstract

A general-purpose test platform for desiccant coated heat exchangers (DCHE) was established to investigate the heat and mass transfer performance of two heat exchangers with different fin lengths (LDCHE and SDCHE) before and after desiccant coating. Results indicate that compared with conventional heat exchangers, the heat transfer capacity of DCHE is reduced by 30% due to the thermal resistance of the desiccant coating, while pressure drop increases by approximately 60%. When fin length is doubled while other structural dimensions remain unchanged, the heat transfer coefficient decreases by 50%, dehumidification effectiveness improves by 40%, and pressure drop increases by 80%. Both dehumidification and regeneration performance coefficients decrease. Increasing fin length enhances dehumidification capacity but reduces heat transfer performance and increases energy consumption.

Key words: desiccant coated heat exchanger; fin length; heat and mass transfer; coefficient of performance; pressure drop

1. Experimental System

1.1 Test Platform Principle

[Figure 1: see original paper] and [Figure 2: see original paper] show the schematic diagram and actual view of the general-purpose DCHE test platform, respectively. The system consists of three main components: a hot water circulation unit, a cooling water circulation unit, and a test air duct. The hot water circulation unit comprises a hot water circulation pump, electric heater, and hot water storage tank, with automatic power adjustment of the electric heater to meet different temperature requirements for regeneration. The cooling water circulation unit supplies cooling water from a low-temperature thermostatic bath via a cooling water circulation pump. The air processing duct includes an air pipeline (cross-section: 500 mm × 500 mm), electric air heater, humidifier, and fan. An electric heater and humidifier at the air pipeline inlet can simulate different environmental conditions as needed, with variable air volume controlled by the fan. The DCHE under test can be modularly combined and conveniently replaced within a certain range to fulfill the platform' s design purpose.

The units are connected by solenoid valves, water pipes, and other auxiliary equipment, with thermal insulation applied to the test platform. The main equipment specifications are listed in .

The test platform can switch between dehumidification and regeneration modes for continuous operation. In dehumidification mode, cooling water flows through the DCHE. When process air passes over the heat exchanger surface, the desiccant handles the moisture load while cooling water removes adsorption heat and handles the air' s sensible heat load. After the set dehumidification time ends, solenoid valves switch the water flow path to the regeneration hot water pipeline to begin regeneration mode, where moisture in the desiccant is desorbed by heating from the hot water inside the copper tubes and discharged with the process air. The tested DCHE uses a finned tube heat exchanger as the carrier, with desiccant uniformly coated on the fin surfaces. Detailed dimensional parameters are provided in .

1.2 Data Measurement and Acquisition

The test platform measures the following variables under different operating conditions:

1. **Air side:** Inlet and outlet dry-bulb temperature (°C) and relative humidity (%RH) of the DCHE; process air velocity (m/s); inlet and outlet air pressure loss (Pa).
2. **Water side:** Circulating water flow rate (kg/s); inlet and outlet water temperature (°C).

An Agilent 34972A data acquisition system collects all data. Sensor specifications are listed in .

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2. Performance Evaluation Indicators for DCHE

Performance analysis and evaluation of DCHE are conducted from four aspects: heat transfer capacity, dehumidification capacity, dehumidification/regeneration energy efficiency ratio, and inlet/outlet air pressure loss.

2.1 Heat Transfer Capacity Evaluation

In conventional finned tube heat exchangers, the heat transfer coefficient is a key performance indicator. Similarly, for DCHE research, the heat transfer coefficient $K, \mathrm{W}/(\mathrm{m}^2 \cdot \mathrm{K})$ evaluates heat transfer performance and investigates the coating’ s thermal effects:

$$K = \frac{Q}{A(t_{a,in} - t_{a,out})}$$

where A is the total heat transfer area (m^2); $t_{a,in}$ and $t_{a,out}$ are the inlet and outlet air temperatures (K); and Q is the total heat transfer rate (kW).

$$Q = \dot{m}_{a,in} h_{a,in} - \dot{m}_{a,out} h_{a,out}$$

where $\dot{m}_{a,in}$ and $\dot{m}_{a,out}$ are the inlet and outlet air mass flow rates (kg/s); $h_{a,in}$ and $h_{a,out}$ are the inlet and outlet air enthalpy values (J/kg).

2.2 Dehumidification Capacity Evaluation

DCHE dehumidification capacity is evaluated using three indicators: instantaneous dehumidification amount Δd_{DE} (kg/kg(DA)), average dehumidification amount $\Delta d_{DE,avg}$ (kg/kg(DA)), and dehumidification rate $\Delta M_{v,DE}$ (kg/h):

$$\Delta d_{DE} = d_{a,in} - d_{a,out}$$

$$\Delta d_{DE,avg} = \frac{\int \Delta d_{DE} d\tau}{\tau}$$

$$\Delta M_{v,DE} = \dot{m}_{a,out} \Delta d_{DE,avg}$$

where $d_{a,in}$ and $d_{a,out}$ are the inlet and outlet air humidity ratios (kg/kg(DA)); τ is the dehumidification cycle period (h).

2.3 Dehumidification and Regeneration Energy Efficiency Ratio

The evaluation indicators for latent heat processing capacity during dehumidification/regeneration are the dehumidification energy efficiency ratio ξ_{DE} and regeneration energy efficiency ratio ξ_{RE}:

$$\xi_{DE} = \frac{\gamma \Delta M_{v,DE}}{\dot{m}_{w,DE} c_{pw} (T_{w,out} - T_{w,in})}$$

$$\xi_{RE} = \frac{\gamma \Delta M_{v,RE}}{\dot{m}_{w,RE} c_{pw} (T_{w,out} - T_{w,in})}$$

where γ is the adsorption heat (kJ/kg); $\dot{m}_{w,DE}$ and $\dot{m}_{w,RE}$ are the cooling water and regeneration hot water mass flow rates (kg/s); c_{pw} is the specific heat capacity of water (kJ/(kg · K)); $T_{w,in}$ and $T_{w,out}$ are the inlet and outlet water temperatures (K).

2.4 Inlet/Outlet Air Pressure Loss

$$\Delta P = P_{a,in} - P_{a,out}$$

where $P_{a,in}$ is the inlet air pressure (Pa) and $P_{a,out}$ is the outlet air pressure (Pa).

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3. Experimental Results and Analysis

The cooling water and regeneration hot water supplied by the heat sources were maintained at 20°C and 50°C, respectively, with flow rates of 0.098 kg/s and 0.100 kg/s. Environmental conditions were 26.3°C and 73.4%RH humid air, with a cycle period of 12 min. Based on these conditions, experiments were conducted at different air velocities to study the performance of DCHEs with different fin lengths before and after desiccant coating. The DCHE with 88 mm fin length is designated as LDCHE, and the DCHE with 44 mm fin length as SDCHE.

3.1 Heat Transfer Capacity Analysis of DCHE

[Figure 3: see original paper] and [Figure 4: see original paper] compare the heat transfer coefficients of heat exchangers with different fin lengths before and after coating under various air velocities when cooling water (20°C) and hot water (50°C) are supplied, respectively. Results are compared from three aspects: water temperature effect, desiccant coating effect, and fin length effect.

Water temperature effect: For any heat exchanger configuration, the heat transfer coefficient with cooling water is approximately 1.7-2.5 times that with hot water, with the ratio gradually decreasing as air velocity increases. The superior heat transfer with 20°C cooling water enables more adsorption heat to be removed during dehumidification, thereby improving dehumidification effectiveness.

Desiccant coating effect: At 20°C water temperature, the heat transfer coefficient of SDCHE before coating is 1.3-1.9 times that after coating, while for LDCHE the ratio is 1.4-1.7. At higher air velocities, the heat transfer coefficients converge and the ratio decreases. At 50°C water temperature, the precoating heat transfer coefficient of SDCHE is 1.05-1.1 times the post-coating value, while for LDCHE the ratio is 1.1-1.3, showing minimal influence from air velocity. Coating reduces heat transfer capacity, with a greater reduction observed when cooling water is used compared to hot water.

Fin length effect: At 20°C water temperature, the heat transfer coefficient of LDCHE before coating is 0.46-0.58 times that of SDCHE, and 0.45-0.54 times after coating. At 50°C water temperature, LDCHE' s coefficient is 0.40-0.53 times that of SDCHE before coating and 0.35-0.39 times after coating, with the ratio gradually increasing at higher air velocities.

Therefore, the thermal resistance from the desiccant coating reduces DCHE heat transfer capacity by 30%. During dehumidification, increasing air velocity, reducing coating thickness, and shortening fin length benefit heat transfer capacity.

3.2 Dehumidification Capacity Analysis of DCHE

Average dehumidification amount evaluates the DCHE' s capacity to process air humidity content per unit volume; higher values indicate better dehumidification effectiveness per unit volume. As shown in [Figure 5: see original paper], average dehumidification amount decreases with increasing air velocity. When face velocity is below 0.6 m/s, fin length has minimal impact on dehumidification capacity due to sufficient air-heat exchanger contact at low velocities. At velocities above 0.6 m/s, LDCHE' s average dehumidification amount is approximately 1.4 times that of SDCHE under the same velocity.

Dehumidification rate evaluates the DCHE' s capacity to process air humidity content per unit time; higher values indicate better dehumidification effectiveness per unit time. As shown in [Figure 6: see original paper], dehumidification rate increases with air velocity. When face velocity is below 0.6 m/s (airflow 210 m^3/h), fin length has minimal impact at low flow rates. At velocities above 0.6 m/s, LDCHE' s average dehumidification amount is about 1.4 times that of SDCHE at the same velocity.

As process air flows across the fins, relative humidity gradually decreases, reducing the relative humidity difference with the desiccant and diminishing the driving force, which weakens desiccant effectiveness. Consequently, the desiccant' s dehumidification capacity gradually decreases from the inlet to the outlet of the same fin. With other structural parameters unchanged, doubling fin length only increases dehumidification effectiveness by 35-40%.

3.3 Dehumidification and Regeneration Energy Efficiency Analysis of DCHE

Dehumidification and regeneration energy efficiency ratios evaluate the DCHE' s latent heat processing capacity during these processes. As air velocity increases, the dehumidification energy efficiency ratio of both heat exchangers gradually increases, while the regeneration energy efficiency ratio first increases then decreases. Under the same velocity, SDCHE' s dehumidification energy efficiency ratio is about 1.1-2.1 times its regeneration ratio, with the ratio increasing at higher velocities. For LDCHE, the dehumidification ratio is about 1.1-1.9 times the regeneration ratio, also increasing with velocity. Since the heat transfer coefficient at 20°C is much greater than at 50°C, the dehumidification energy efficiency ratio is significantly higher than the regeneration ratio. SDCHE' s dehumidification energy efficiency ratio is about 1.28 times that of LDCHE, and its regeneration energy efficiency ratio is about 1.25 times that of LDCHE, confirming SDCHE' s superior heat transfer capacity.

3.4 Inlet/Outlet Air Pressure Loss Analysis

As shown in [Figure 9: see original paper], pressure loss increases with air velocity for any heat exchanger configuration. Under the same velocity, the inlet/outlet air pressure loss of DCHE after coating is about 1.6 times that before coating. Before coating, LDCHE’ s pressure loss is about 1.9 times that of SDCHE; after coating, LDCHE’ s loss is about 1.7 times that of SDCHE. Due to resistance from the duct structure itself and measurement errors, the pressure loss ratio between LDCHE and SDCHE is less than 2.

Conclusions

Using the general-purpose DCHE test platform, DCHEs with different fin lengths were tested and compared. The experimental results demonstrate significant differences in heat transfer capacity, dehumidification capacity, and dehumidification/regeneration energy efficiency ratios:

1. Increasing fin length reduces the heat transfer coefficient; doubling fin length decreases the coefficient by 50%.
2. Increasing fin length increases dehumidification amount; doubling fin length improves dehumidification effectiveness by 40%.
3. Increasing fin length reduces both dehumidification and regeneration energy efficiency ratios, though the dehumidification ratio remains higher than the regeneration ratio due to stronger heat transfer during dehumidification.
4. The desiccant coating increases pressure drop by 60% compared to conventional heat exchangers under the same conditions; doubling fin length increases pressure loss by approximately 80%.

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