Postprint: Study on the Effect 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 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. When other structural dimensions remain unchanged and the fin length is doubled, the heat transfer coefficient of the dehumidification heat exchanger decreases by 50%, the dehumidification effectiveness improves by 40%, and the pressure drop increases by 80%, with both dehumidification and regeneration energy efficiency ratios decreasing. While increasing fin length can enhance dehumidification effectiveness, it reduces heat transfer performance and increases energy consumption.

Full Text

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

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Abstract

This study establishes a general-purpose test platform to evaluate the heat and mass transfer performance of desiccant coated heat exchangers (DCHEs). Two heat exchangers with different fin lengths, both before and after desiccant coating (designated as LDCHE and SDCHE), were experimentally investigated. Results demonstrate that compared with conventional heat exchangers, the heat transfer capacity of DCHEs is reduced by 30% due to the thermal resistance introduced by the desiccant coating, while pressure drop increases by approximately 60%. When fin length is doubled while maintaining other structural parameters constant, the heat transfer coefficient decreases by 50%, average moisture removal increases by 40%, and pressure drop rises by 80%. Both dehumidification and regeneration performance coefficients decline with doubled fin length. Longer fins enhance dehumidification capacity but compromise heat transfer performance and increase energy consumption.

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

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Desiccant coated heat exchangers (DCHEs) utilize fin-and-tube heat exchangers as substrates, with solid desiccant uniformly coated on fin surfaces. During dehumidification, moist air flows across the fin surfaces, and water vapor is adsorbed by the coated desiccant. Simultaneously, the resulting adsorption heat is rapidly removed by circulating cooling water inside the tubes, reducing irreversible losses through internal cooling and approximating an isothermal dehumidification process. Once the desiccant becomes saturated, hot water flows through the tubes to regenerate the desiccant via thermal desorption, restoring its dehumidification capacity [1]. Since silica gel requires relatively low regeneration temperatures, low-grade heat sources such as solar energy, industrial waste heat, or condenser heat from heat pumps can be effectively utilized.

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In recent years, scholars have conducted extensive research on various aspects of DCHEs, including desiccant material optimization [2], performance testing [3-4], numerical analysis [5], mathematical modeling [6], and system applications [7]. Evidently, multiple factors influence the heat and mass transfer performance of DCHEs, encompassing coating materials, coating processes, operating conditions, and corresponding control strategies. Additionally, the structural dimensions of DCHEs themselves—including fin length, spacing, shape, and tube arrangement—represent critical parameters warranting in-depth investigation. To further explore the heat and mass transfer characteristics and their coupling effects, the authors developed a general-purpose DCHE test platform. This platform enables efficient investigation and validation of performance variations under different operating conditions without unnecessary duplication of effort. This paper presents preliminary experimental results from this platform, focusing specifically on how fin length—a key structural parameter—affects the heat and mass transfer performance of DCHEs.

1.1 Test Platform Principle

[Figure 1: see original paper] and [Figure 2: see original paper] illustrate the schematic diagram and actual view of the general-purpose DCHE test platform, respectively. The platform comprises three main components: a hot water circulation unit, a cooling water circulation unit, and an air handling duct. The hot water circulation unit consists of a circulation pump, electric heater, and storage tank, with automatic power adjustment to meet various regeneration temperature requirements. The cooling water circulation unit supplies chilled water from a low-temperature thermostat to the system. The air handling duct (cross-section: 500 mm × 500 mm) incorporates an electric air heater, humidifier, and fan, enabling simulation of diverse environmental conditions at the duct inlet with variable airflow control via frequency modulation. The tested DCHE can be modularly assembled and conveniently replaced within a certain range, fulfilling the platform’ s design objective.

Fig.1 Schematic diagram of the experimental set-up
Fig.2 Actual view of the experimental set-up

The aforementioned components are connected via solenoid valves, piping, and auxiliary equipment, with the entire platform thermally insulated. summarizes the performance parameters of the main equipment.

Table 1 Parameters of the devices in the experimental set-up

The platform can switch between dehumidification and regeneration modes for continuous operation. In dehumidification mode, cooling water circulates through the DCHE. As process air flows across the heat exchanger surface, the desiccant handles the moisture load while cooling water removes adsorption heat and manages sensible heat load. After the preset dehumidification duration, solenoid valves switch the water flow path to the hot water pipeline, initiating regeneration mode. Desiccant moisture is thermally desorbed by the hot water inside the copper tubes and expelled with the process air. The tested DCHEs are fin-and-tube heat exchangers with desiccant uniformly coated on fin surfaces; detailed dimensions are provided in **Table 2**.

Table 2 Structural parameters of two DCHEs

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); pressure drop across the inlet and outlet (Pa)
2. **Water side:** Circulating water flow rate (kg/s); inlet and outlet water temperature (°C)

An Agilent 34972A data acquisition system collects all measurements. **Table 3** lists the specifications of the sensors employed.

Table 3 Specification of the different test instrumentation

2 Performance Evaluation Indicators

DCHE performance is analyzed and evaluated across four aspects: heat transfer capacity, dehumidification capacity, dehumidification/regeneration energy efficiency ratios, and air-side pressure drop.

2.1 Heat Transfer Capacity Evaluation

In conventional fin-and-tube heat exchangers, the heat transfer coefficient serves as a critical performance metric. Similarly, DCHE research employs a heat transfer coefficient K, expressed in W/(m²•K), to evaluate thermal performance and investigate desiccant coating effects on heat transfer:

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

where A is the total heat transfer area (m²), $t_{a,in}$ and $t_{a,out}$ are the inlet and outlet air temperatures (K), and Q is the total heat transfer rate (kW):

$$Q = m_{a,in} \cdot h_{a,in} - m_{a,out} \cdot h_{a,out}$$

where $m_{a,in}$ and $m_{a,out}$ are the inlet and outlet air mass flow rates (kg/s), and $h_{a,in}$ and $h_{a,out}$ are the inlet and outlet air enthalpies (J/kg).

2.2 Dehumidification Capacity Evaluation

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

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

$$\Delta d_{DE,avg} = \frac{\int_0^{\tau} \Delta d_{DE} \, d\tau}{\tau}$$

$$\Delta M_{v,DE} = m_{a,out} \cdot d_{a,out} - m_{a,in} \cdot d_{a,in}$$

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

2.3 Dehumidification and Regeneration Energy Efficiency Ratios

The energy efficiency of latent heat processing during dehumidification and regeneration is evaluated using the dehumidification coefficient of performance ξ_{DE} and regeneration coefficient of performance ξ_{RE}:

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

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

where γ is the heat of adsorption (kJ/kg), $m_{w,DE}$ and $m_{w,RE}$ 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)), and $T_{w,in}$ and $T_{w,out}$ are the inlet and outlet water temperatures (K).

2.4 Inlet/Outlet Air Pressure Drop

Pressure drop is calculated as:

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

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

3 Experimental Results and Analysis

Experiments were conducted under the following baseline conditions: cooling water at 20°C and 0.098 kg/s, regeneration hot water at 50°C and 0.100 kg/s, ambient air at 26.3°C and 73.4%RH, and a cycle period of 12 minutes. Performance was evaluated at various air velocities for both coated and uncoated conditions. The DCHE with 88 mm fin length is designated LDCHE, while the 44 mm version is SDCHE.

3.1 Heat Transfer Capacity Analysis

[Figure 3: see original paper] and [Figure 4: see original paper] compare the heat transfer coefficients of both fin lengths before and after desiccant coating under cooling and heating water conditions, respectively. The analysis considers three aspects: water temperature effects, desiccant coating effects, and fin length effects.

Water temperature effects: For any heat exchanger configuration, the heat transfer coefficient with 20°C cooling water is approximately 1.7-2.5 times that with 50°C hot water, with the ratio gradually decreasing as air velocity increases. The superior heat transfer with 20°C cooling water enables more effective removal of adsorption heat, thereby enhancing dehumidification performance.

Desiccant coating effects: At 20°C water temperature, the uncoated SDCHE exhibits heat transfer coefficients 1.3-1.9 times higher than when coated; for LDCHE, this ratio is 1.4-1.7. Higher air velocities yield smaller differences between coated and uncoated performance. At 50°C water temperature, the ratios reduce to 1.05-1.1 for SDCHE and 1.1-1.3 for LDCHE, with minimal velocity dependence. Desiccant coating reduces heat transfer capacity, with more pronounced degradation during cooling water operation than during hot water regeneration.

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

Consequently, the thermal resistance from desiccant coating reduces DCHE heat transfer capacity by 30%. During dehumidification, increasing air velocity, reducing coating thickness, and shortening fins all benefit heat transfer performance.

3.2 Dehumidification Capacity Analysis

Average moisture removal rate evaluates the DCHE' s ability to reduce humidity per unit air volume—higher values indicate better dehumidification effectiveness. As shown in [Figure 5: see original paper], average moisture removal decreases with increasing air velocity. When face velocity falls below 0.6 m/s, the lower airspeed allows more complete contact with the heat exchanger, making fin length effects negligible. At velocities above 0.6 m/s, LDCHE's average moisture removal is approximately 1.4 times that of SDCHE under identical conditions. With all other structural parameters constant, doubling fin length only yields a 35-40% improvement in dehumidification effectiveness.

Dehumidification rate, which measures moisture removal per unit time, increases with air velocity ([Figure 6: see original paper]). Below 0.6 m/s (approximately 210 m^3/h airflow), fin length has minimal impact on dehumidification capacity. At higher velocities, LDCHE' s dehumidification rate is about 1.4 times that of SDCHE. As process air flows across the fins, its relative humidity gradually decreases, reducing the driving force for moisture transfer and diminishing desiccant effectiveness along the flow path.

3.3 Dehumidification and Regeneration Energy Efficiency Analysis

Energy efficiency ratios assess the latent heat processing capability during dehumidification and regeneration. As air velocity increases, both heat exchangers exhibit increasing dehumidification COP, while regeneration COP first increases then decreases. Under identical velocities, SDCHE' s dehumidification COP is 1.1–2.1 times its regeneration COP, with the ratio increasing at higher velocities; for LDCHE, this ratio is 1.1–1.9. The substantially higher heat transfer coefficient at 20°C compared to 50°C results in dehumidification COP significantly exceeding regeneration COP. SDCHE' s dehumidification COP is approximately 1.28 times that of LDCHE, and its regeneration COP is about 1.25 times higher, confirming SDCHE' s superior heat transfer performance.

3.4 Inlet/Outlet Air Pressure Drop Analysis

[Figure 9: see original paper] reveals that pressure drop increases with air velocity for all configurations. At any given velocity, pressure drop across coated DCHEs is approximately 1.6 times that of uncoated heat exchangers. The pressure drop across uncoated LDCHE is about 1.9 times that of SDCHE, reducing to 1.7 times after coating. Due to duct structural resistance and measurement errors, the LDCHE-to-SDCHE pressure drop ratio is less than the theoretical value of 2.

Conclusions

This study utilized a general-purpose DCHE test platform to evaluate heat exchangers with different fin lengths. Comparative experimental results reveal significant differences in heat transfer capacity, dehumidification capability, and energy efficiency ratios:

1. Increasing fin length reduces heat transfer coefficient; doubling fin length decreases the coefficient by 50%.
2. Increasing fin length enhances dehumidification capacity; doubling fin length improves dehumidification effectiveness by 40%.
3. Increasing fin length reduces both dehumidification and regeneration COPs, though dehumidification COP remains higher due to superior heat transfer during the cooling phase.
4. Desiccant coating increases pressure drop by 60% compared to conventional heat exchangers under identical conditions; doubling fin length increases pressure drop by approximately 80%.

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