Investigations of a Tube-Bundle, Liquid-Desiccant Dehumidifier for Summer Air Conditioning

Summary

An internally cooled tube-bundle dehumidifier for a liquid desiccant air conditioning system was designed, built, and experimentally examined using an aqueous solution of lithium chloride (LiCl-H_2O) with a mass fraction of about 0.4 kg/kg. A parametric analysis was carried out to evaluate the influence of desiccant solution flow rate on the supply air conditions.

Keywords: Liquid desiccant, tube-bundle, Dehumidifier, Air conditioning

1. Introduction

In liquid desiccant air conditioning systems, ambient air streams along a concentrated desiccant solution. Due to lower water vapor pressure of the desiccant solution compared to the air, water vapor of the air is absorbed by the desiccant solution. Heat of sorption (condensation of water vapor and heat of dilution) released during the process is transferred to a cooling-water loop inside the dehumidifier (absorber). The desiccant solution is diluted in the absorber. To re-concentrate the desiccant solution, low temperature heat is used in the regenerator. Fig. 1 shows a general set-up of a liquid air conditioning system.

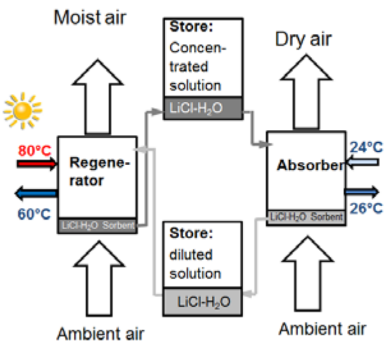

Fig. 1: Liquid desiccant air conditioning system.

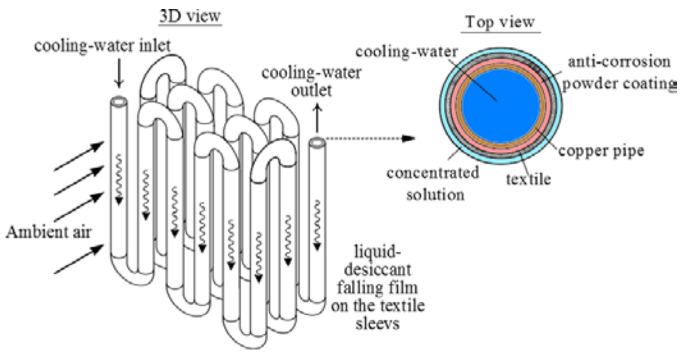

Fig. 2: Tube-bundle dehumidifier (left), cross section of the tubes (right).

In order to reduce energy consumption, the latent load of air is removed by a liquid desiccant rather than by cooling the air below the dew point of its water vapor. In an internally cooled liquid desiccant dehumidifier, the supply air is dehumidified and cooled simultaneously directly from the initial to the final states.

In the presented study, an internally cooled, desiccant based tube-bundle dehumidifier with a surface area of 4.2 m^2 is experimentally examined for air conditioning applications. The dehumidifier consists of 22 tube-bundles made of copper. The tubes are 5 m long, have an outer diameter of 12 mm and a wall thickness of 1 mm. The copper tubes are coated with a thin powder layer with a thickness of 0.24 mm to protect them from the corrosive LiCl solution. The coated tubes are covered with 0.4 mm thick sleeves made of cellulose fibers. Fig.2. shows a scheme of the tube-bundle dehumidifier as well as a cross section of one of the tubes.

2. Experimental Investigations

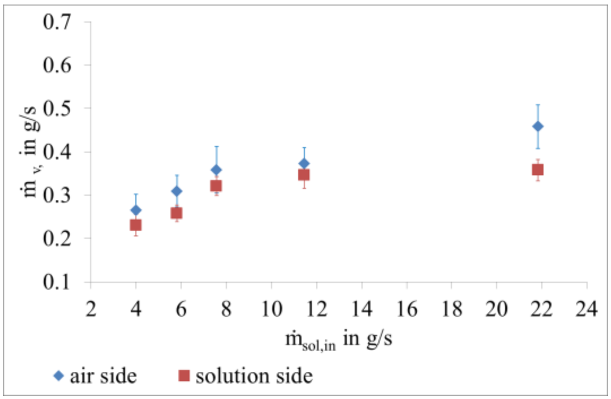

Fig. 3: Experimental results. Water vapor mass flow rate calculated from measured temperatures and humidity at the air side (diamonds) and from measured temperatures and density at the solution side (squares) over the solution mass flow rate.

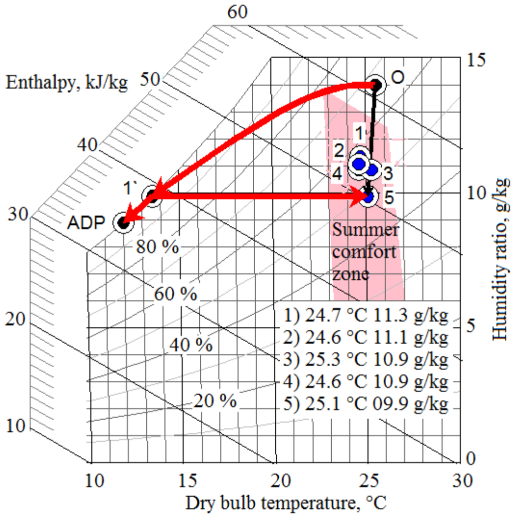

Fig. 4. Experimental results of supply air conditions (dehumidified air) and schematic dehumidification cycle in the psychrometric chart for an internally cooled and a conventional vapor compression processes.

A parametric analysis was carried out to evaluate the influence of the desiccant solution flow rate on the supply air conditions. Fig. 3 shows the moisture removal mass flow rate from the supply air stream to the concentrated LiCl-H_2O solution in the absorption process, $\dot{m}_v$, of five dehumidification experiments over the desiccant mass flow rate with an average air inlet temperature of 24.8 °C and an average humidity ratio of 14.0 g/kg (outdoor conditions). A cooling cycle removes the heat of sorption to reach nearly isothermal conditions. The moisture removal rate is calculated from the air side (AS) and from the solution side (SS).
On the air side, it is a function of the air humidity ratio spread, Δω, eq. 1

$$\dot{m}_{v,AS} = \dot{m}_{da}(\omega_i - \omega_o) \qquad \text{(eq. 1)}$$

On the solution side, it is a function of the water content spread of the desiccant solution ΔX, eq. 2

$$\dot{m}_{v,SS} = \dot{m}_{LiCl}(X_o - X_i) \qquad \text{(eq. 2)}$$

Where, $\dot{m}_{da}$ and $\dot{m}_{LiCl}$ represent the dry air and LiCl-salt mass flow rates, respectively.

The results show a consistent reduction of the air humidity ratio. In the experimental runs the humidity ratio is reduced between 2.4 and 4.1 g/kg, corresponding to a reduction of the relative humidity of 12 to 18 %-points.

The moisture removal rate increases considerably by increasing the desiccant flow rate. This trend is expected, because by increasing the solution flow rate, both of the solution concentration and temperature rise are reduced and thus keeping the desiccant solution at low vapor pressure. Furthermore, the wetting of the textile is improved by increasing the solution flow rate.

Fig. 4 shows the corresponding supply air conditions in the psychrometric chart. The supply air conditions for all experiments lie within the thermal comfort zone, specified by ANSI/ASHRAE Standard 55-1992, [1]. The points 1 to 5 represent the performed experiments in the order of increased solution flow rate. Furthermore, Fig. 4 shows the internally cooled dehumidification process (O→5) of the 5^{th} experiment compared to a conventional vapor compression process with an apparatus dew point temperature (ADP) of 12 °C (O→1´→5). For the considered outlet air conditions, a cooling coil surface temperature of 12 °C, a bypass factor (BPF) of 0.2, and without recirculation air, the total required load obtained is 3.6 kW. Applying the internally-cooled liquid desiccant absorber the required cooling load obtained is about 1.3 kW.

References

[1] ASHRAE, 1997. Handbook of Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.