Initial Experiments of a Novel Liquid Desiccant Dehumidifier for Industrial and Comfort Air Conditioning Systems

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Abstract

A novel design of a liquid desiccant (LD) dehumidifier is presented in this paper. It shall protect against carry-over of liquid desiccant into the conditioned air stream. This dehumidifier represents a plate-type heat and mass exchanger with cross flow concerning air and desiccant flow and serpentine flow between water and desiccant cycle. It utilizes novel components and ideas in order to overcome the present obstacles, as the carryover of the LD into the air stream and the flow maldistribution of the LD over the exposed surfaces.

Two sets of experiments are shown in this paper. The first set of experiments is carried out to determine the quality of the distribution system of the desiccant fluid. The measurements represent a well estimated results and show fairly even distribution of the desiccant at a wide range of desiccant flow rates.

The second set represents initial dehumidification measurements for the supply air carried out with the desiccant $H_2O/LiCl$ for adiabatic and steady state inlet conditions for supply air and desiccant.

Some initial experimental results are reported in this paper in terms of the reduction of the relative humidity in the supply air, the temperature differences between the inlet and outlet states, and the reductions of the desiccant concentration.

1. Introduction

The main disadvantage of vapor-compression air-conditioning systems is that it is considered as an inefficient thermodynamic process. The handling of the latent load requires cooling of the air below its dew point which leads to a lower air temperature than that needed to meet the sensible load. Thus, additional energy has to be needed to reheat the air to the delivery temperature.

Liquid desiccant air-conditioning systems remove the latent load directly from the air by absorbing the moisture by a hygroscopic salt solution e.g. lithium chloride (LiCl) or calcium chloride ($CaCl_2$). The main components of an open-loop liquid desiccant air-conditioning system are the absorber (dehumidifier) and the desorber (regenerator) shown in Fig. 1.

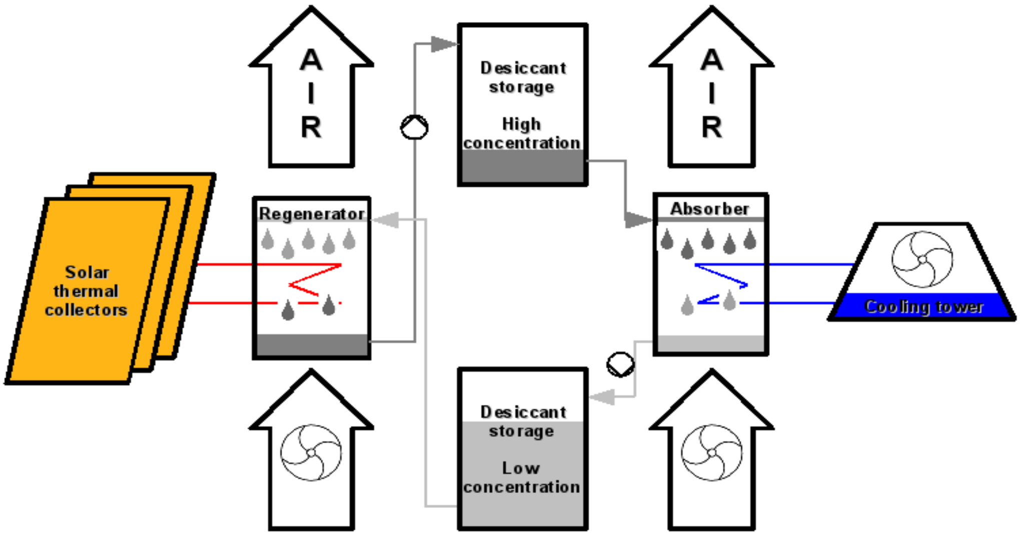

Fig. 1. Schematic diagram of a solar driven liquid desiccant air-conditioning system

In the literature about liquid desiccant systems, the most examined type of absorbers and regenerators is an adiabatic heat and mass exchanger. A typical representative is a packed bed with both, regular and random structures.

Newer studies [1-3] favored internally cooled (heated) absorbers (regenerators), designed with a parallel plate structure to obtain regular cross-sections for the air flow to be able to reduce the desiccant flow rate essentially and to prevent carry-over. For this design, the need for a sophisticated distribution system emerges as the low desiccant flow rate needs to be equally distributed over a large area.

2. Description of the dehumidifier design

In this heat and mass transfer prototype, the desiccant solution and the air stream are brought into contact in a cross flow configuration. The dehumidifier consists of a stack plates, made of standard twin wall polycarbonate (PC). Each plate has a surface area of 600 x 600 mm^2 and a thickness of 6 mm. The inner chambers of the twin wall plates are used for internal water driven cooling circuit. The plates are covered with a promising textile in order to increase the exposure time of the desiccant on the plates and thereby enhance the desired mass transfer and heat exchange. Also better wetting of the surface will be achieved. The overall exposed surface area of the investigated absorber is about 3.9 m^2. Figure 2 shows the dehumidifier, connected to the air and hydraulic circuit.

Fig. 2. Liquid desiccant absorber, connected to the air and hydraulic test rigs in the pilot plant stage in the laboratories of Kassel University (August 2009).

In this design, the LD distributor uses a plurality of parallel plexiglass tubes to horizontally distribute the LD over the wick. The tubes penetrate the dehumidifier stack of plates horizontally and spread the desiccant solution over the coated plates through a number of equally spaced holes.

The size and number of the holes are selected according to distribution tests carried out [4] to provide the desired liquid flow.

3. Test procedure and instrumentation

Before testing the whole absorber prototype, preliminary tests were conducted with the liquid desiccant distribution in order to determine the optimal size and number of holes distributed along the plexiglass tube.

In the second stage an initial set of experiments has been conducted with the absorber unit with desiccant and air flow, while the cooling water circuit was inactivated. The experiments were aimed to investigate the air temperature rise due to condensation and the reduction of the relative humidity in the air.

120 l of lithium chloride with a 43% concentration by weight has been used within the absorber.

The flow rate of the strong LiCl solution is continually monitored by using a magneto-inductive flow meter (Endress, Hauser FlowTec Picomag). The solution passes through a filter with a pore size of 300 µm in order to remove any contaminants that might affect the discharge bores along the plexiglass pipes. The weak LiCl solution concentration is continuously monitored by a density transmitter (Anton Paar, L-Dens 313) with an accuracy of 1×10^{-3} g/cm^3.

The inlet and outlet of the dehumidifier are connected to a 250 mm-diameter flexible duct. The inlet and outlet temperatures and relative humidities of the air are measured with a combined capacitive humidity sensor and a PT100 sensor for temperature (rotronic, Hygroclip). The sensors accuracies are 0.8% points for the relative humidity and 0.1 K for the temperatures. The air volume flow rate through the air duct system could be varied from 400-1800 m^3/h. The air duct system is equipped with a steam generator in order to set the relative humidity of the supply air according to desired conditions.

4. Test results

Figure 3 shows experimental results of tests with different bore diameters and desiccant flow rates.

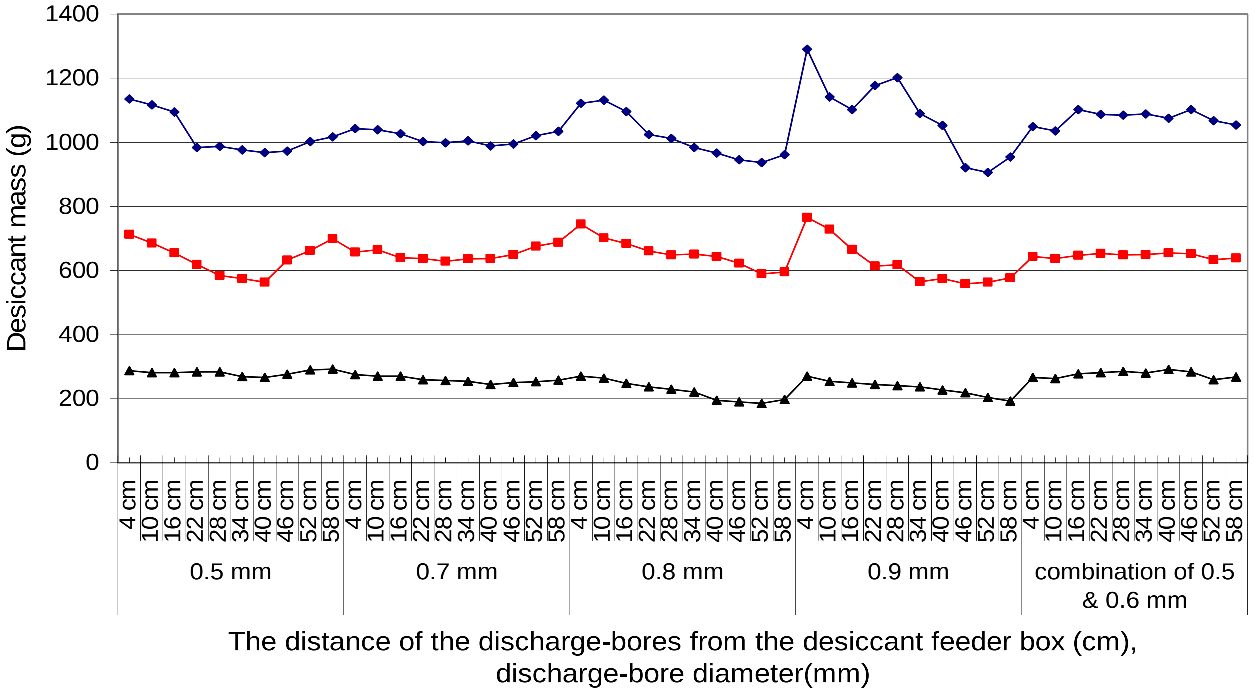

Fig. 3. Experimental investigations of LiCl distribution through the perforated pipe distributor

It can be seen that a combination of bore diameters of 0.5 and 0.6 mm along the LD distributor pipes deliver fairly even distribution for a wide range of LD flow rates. So, a fairly even distribution of the LD over the wick can be ensured.

Table 1 represents a summary of the initially monitored data. Here, the prototype was tested only with desiccant while the cooling water circuit has been inactivated. The experiments were aimed to investigate the air temperature rise due to condensation and the reduction in the relative humidity of the air.

The dehumidification efficiency of the absorber as defined in equation 1 has been calculated for the given operating conditions; a value of about 26 % was achieved for a desiccant flow rate of 1.5 l/min.

$$\eta_{dehumidification} = \frac{\omega_{a,in} - \omega_{a,o}}{\omega_{a,in} - \omega_{es,air/LD}} \qquad (1)$$

The observed significant reduction in the relative humidity of about 30% points can make this absorber sufficient to be used for the handling of the latent air conditioning load.

Table 1: Summary of the inlet and outlet monitored measured data

Supply air dry-bulb temperature difference, ΔT_{air}	7.8 K
Supply air relative humidity difference, ΔRH_{air}	33 %
Desiccant weight-concentration difference, ΔX_{LiCl}	3 points
Supply air humidity ratio difference, $\Delta\omega_{air}$	3.25 g/kg
Saturation humidity ratio of air at equilibrium with desiccant, $\omega_{e,air/LiCl}$	4.7 g/kg
Supply air volume flow rate, Q_{air}	600 m^3/h
Desiccant volume flow rate, Q_{LiCl}	1.5 l/min
Air/desiccant mass flow ratio, $\dot{m}_{air} / \dot{m}_{LiCl}$	7
Dehumidification efficiency, $\eta_{dehumid.}$	25.9 %

5. Conclusion and Outlook

A LD distribution system has been constructed, that delivers a fairly even LD-distribution for a wide range of desiccant flow rates. This makes the desiccant distributor flexible to serve the required LD flow rates for varying air conditioning cooling load.

The initial results of the dehumidification of the supply air show a consistent reduction of about 30% points in the relative humidity.

Further experiments shall be carried out in order to detect the interaction between the different parameters and boundary conditions:

- Supply air inlet conditions; temperature, flow rate and humidity
- Desiccant inlet conditions; desiccant type, flow rate, temperature and concentration.

Those interactions shall be studied in an adiabatic and non-adiabatic process; with and without operation of the cooling water circuit. In the case of non-adiabatic process the influence of the inlet water operating conditions (volume flow rate and temperature) shall be investigated as well.

Furthermore, measurements are in progress to detect possible salt solution particles in the dehumidified air stream which can be observed as long term corrosion in the supply ductwork.

References

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