A Demonstration Plant of a Liquid Desiccant Air Conditioning Unit for Drying Applications

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Abstract

A demonstration plant of a liquid desiccant system in order to dry hay bales was set up in an agricultural domain. The system consists of an absorber for the dehumidification of the supply air and a regenerator to re-concentrate the diluted desiccant solution. Laboratory experiments of a small prototype showed promising results for the temperature increase and humidity decrease of the air. Moreover, first experimental results of the demonstration plant showed a significantly reduced drying time of the hay bales, while the supply air was increased by more than 10 K and the relative humidity was reduced from more than 60% to below 30%.

1. Introduction

Drying of agricultural products is the greatest energy consuming process on the farm [1]. The target of drying is to remove moisture from the agricultural product in order to process and store it safely for increased periods of time. For hay drying the moisture of the hay needs to be reduced to about 20% to allow the storage without the risk of rot. Hot air drying increases the temperature of the air (and product) and lowers the air relative humidity and thus allows the air to carry moisture from the product.

The basic concept of liquid desiccant dehumidification system is to directly reduce the moisture and warm up the air, which is used for drying, only a few degrees above the ambient temperature. In the absorber, moisture absorbed from the process air stream dilutes the desiccant solution by loading the desiccant with water vapour (Fig. 1).

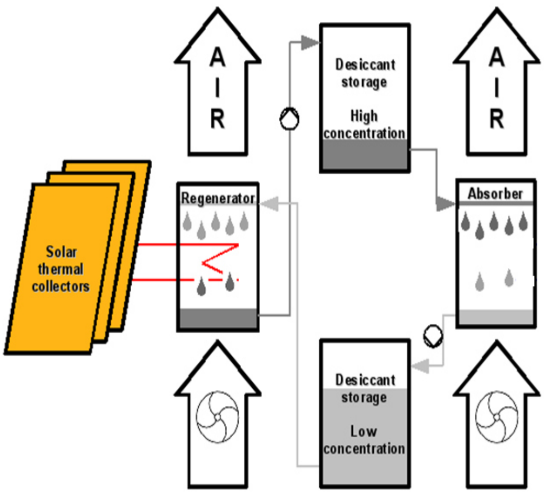


Fig. 1: Schematic of the liquid desiccant system.

The solution weakened by absorption of moisture is re-concentrated in the regenerator, where it is heated to elevate its water vapour pressure. The heat drives out the moisture from the solution and the strengthened solution is returned to the dehumidifier. A scavenging air stream contacts the heated solution in the regenerator. There, water evaporates from the desiccant solution into the air and the solution is re-concentrated.

2. Experimental Setup

Experiments were conducted to measure the moisture transfer as well as the temperature difference during the absorption and desorption processes. In all the absorber and regenerator prototypes used, the air stream and the LiCl-H_2O solution are set up in a cross flow configuration. Textile fibers are used in order to increase the exposure time of the desiccant and thereby enhance the desired mass transfer and heat exchange. The distribution system of the sorbent uses Plexiglas tubes to horizontally distribute the solution over the textile. The tubes penetrate the absorber or regenerator horizontally and spread the desiccant solution over the coated plates or tubes through a number of equally spaced holes. The size and number of the holes are selected according to distribution tests carried out in [2] to provide the desired liquid flow. The LiCl-H_2O solution flows through the distribution system, it is then throttled over the textile and trickles down along the plates or tubes by gravity. Lithium chloride is used as the liquid desiccant because of its favorable physical properties [3].

2.1. Laboratory Pilot Plant

The overall exposed surface area of a small laboratory prototype used as absorber and regenerator, is about 3.9 m^2. The heat and mass exchanger consists of a stack twin wall polycarbonate plates.

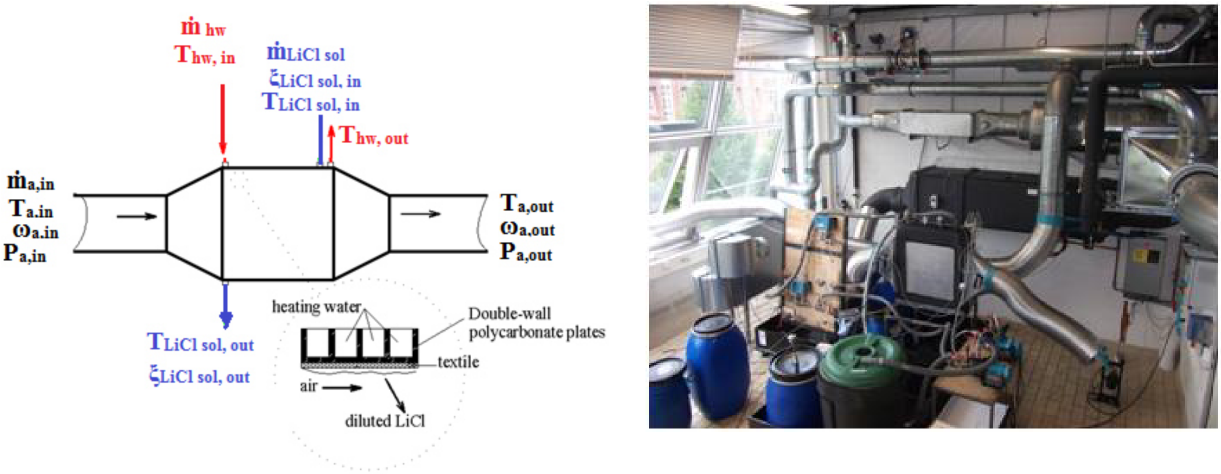
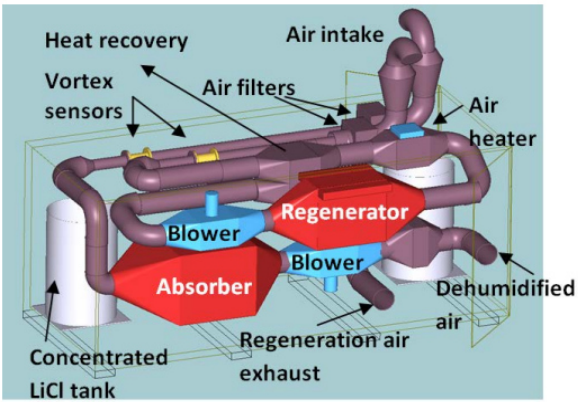


Fig. 2 Schematic diagram of the experimental setup, pilot plant stage

The air is conditioned according to the required set-value with a series of instruments (electric air heater, air cooler/dehumidifier, steam generator). For monitoring of the air, a vortex flow meter, and HygroFlex humidity and temperature transmitters are used at the inlet and outlet of the component. The density and the temperature of the LiCl-H_2O solution are monitored before and after the heat and mass exchanger, the flow rate is measured with a magneto-inductive flow meter. All values were continually monitored during the experiments.

2.2. Demonstration Plant for Drying Hay Bales

The desiccant absorber in the demonstration plant consists of a plate type heat and mass exchanger with a total exposed surface of about 75 m^2. The dried and heated air is blown through a hose to a wide air channel with a circular opening for one hay bale. The desiccant regeneration system consists of a heat and mass exchanger made of copper pipes, protected from corrosion with a thin powder coating layer. Textile sleeves are applied over the copper tubes. The total exposed surface area of the regenerator is about 9 m^2. Hot water supplied by solar collectors flows through the copper tubes to heat the desiccant solution in order to concentrate it again.



Schematic diagram of the exp. setup

Demonstration plant during installations

Construction of the solar collector field (155m^2), April 2012

The drying-sorption plant connected to the hay bale, July 2013

Fig. 3: Demonstration plant in Frankenhausen (near Kassel)

3. Inlet Values for Laboratory Experiments

The prototype was tested in an adiabatic dehumidifier mode. 12 experimental runs were conducted in three experimental sequences.

Table 1: Inlet conditions for the laboratory tests in dehumidification mode (absorption)

	$\bar{m}_{des.}$ kg/h	$\bar{T}_{air,in}$ ºC	$\bar{\omega}_{air,in}$ g/kg
Test seq.1	var:14.1-56.3	24.6 ± 0.1	14.36 ± 0.27
Test seq.2	14.2 ± 0.63	var:24.5-30.1	14.69 ± 0.21
Test seq.3	44 ±0.54	25.3 ± 0.2	var:13.64-20.20

The air mass flow rate was kept constant of 375 kg/h ± 4 kg/h, desiccant inlet temperature of 27 ºC ± 1.1 ºC and desiccant mass fraction (ξ) of 0.43 kg/kg.

Moreover, the prototype was tested in a non-adiabatic regenerator mode by using hot air and water streams. Six experimental runs were conducted in two experimental sequences. The air mass flow rate was kept constant of 302 kg/h ± 4 kg/h, desiccant inlet temperature of 27 ºC ± 1.1 ºC, inlet heating-water temperature of 50.3 °C and desiccant mass fraction of 0.36 kg/kg, while varying the air humidity ratio and the desiccant mass flow rate.

4. Results and Discussion

4.1. Laboratory Experiments of a Small Heat and Mass Exchanger

The results of the supply air adiabatic dehumidification show a consistent reduction in the relative humidity, a consistent reduction in the humidity ratio, and an increase in the air temperature. Figure 4 shows an example of one of the experiments; the change in the relative humidity reaches about 42 percent-points and an increase in the air temperature of about 5.2 K.

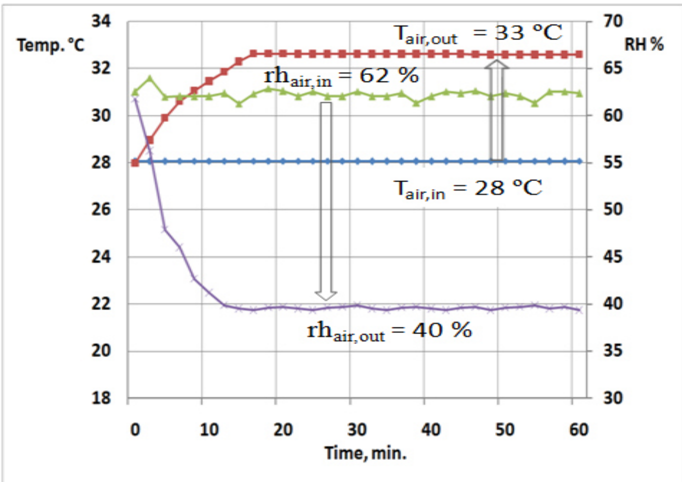


Fig. 4: Example measurement: Dehumidification in a small laboratory prototype.

The mass transfer performance of the dehumidifier was evaluated in terms of the moisture removal rate. The moisture removal rate, $\dot{m}_v$, is calculated by Eq. 1 [4].

$$\dot{m}_v = \dot{m}_a \cdot (\omega_{a,in} - \omega_{a,out}) \qquad \text{Eq.1}$$

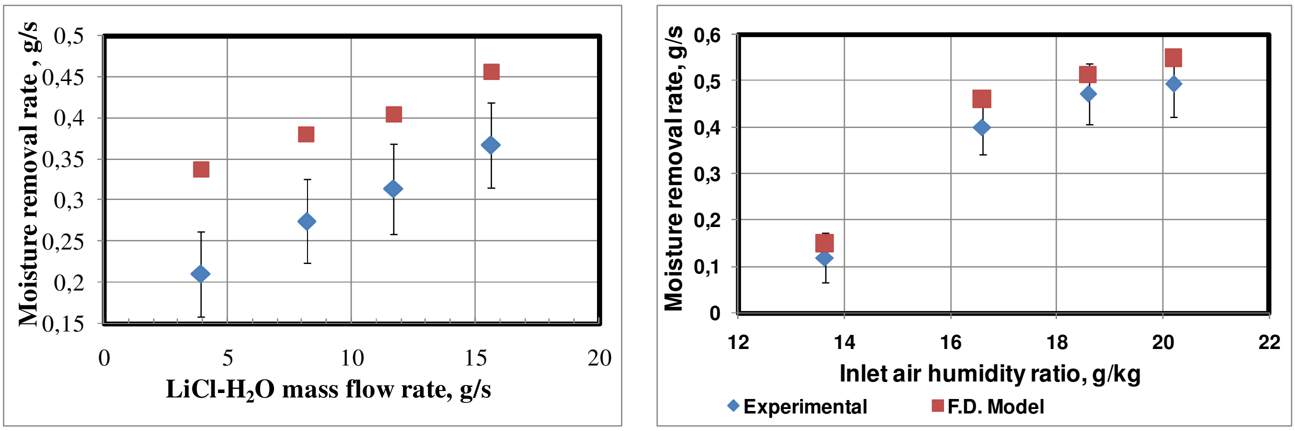


Fig. 5: the moisture removal rate as a function of desiccant flow rate and air inlet humidity ratio for the dehumidification experiments.

As shown in Figure 5, the moisture removal rate in both directions increased remarkably with increasing desiccant flow rate for both of absorption and regeneration systems. The moisture removal rate increases with increasing the air inlet humidity ratio in the absorber and vice versa for regeneration.

The effect on the moisture removal rate was caused by the increased average water vapor pressure difference between the air and the desiccant with increasing air inlet humidity ratio.

The experimental results were compared with an ideal numerical finite difference model. In Figure 5, the blue points represent the experimental results and the red points represent the finite difference results. The comparison between the experimental and numerical results shows divergences, both, due to uncertainties of experimental data and due to idealized assumptions of the numerical model. A more detailed analysis of the deviations will be carried out in future investigations.

4.2. First Experimental Results of the Demonstration Plant

Table 2: Initial measurements from the demonstration plant for a drying experiment of a hay bale.

	Inlet	Outlet
Bale humidity, %	about 30	about 9.2
Air temperature, °C	19.2	29.6
Air relative humidity, %	62	29
Air humidity ratio, g/kg	8.59	7.47

Air mass flow rate, kg/h	1360
Moisture removal rate, kg/h	1.52
Drying time hour	about 4 hours
Liquid desiccant mass flow rate. kg/h	46

5. Conclusions

Plate and tube bundles type heat and mass exchangers were built and tested in a pilot plant stage and in a demonstration plant as an air dehumidifier and desiccant regenerator.

Parameter variations were carried out in the laboratory. The experimental results of a small laboratory prototype show a reduction in the supply air humidity ratio in the absorption process of about 4.8 g/kg for typical reference conditions. The results show a consistent reduction in the relative humidity and an increase in the air temperature, which are the main factors that affect how readily moisture moves from the drying product. The parametric analysis results in reduction of the air relative humidity in the range of 18-46% points and an increase in the air temperature in the range of 3.7-8.0 K are observed, depending on the inlet parameters. The mass fraction of the diluted desiccant solution (from 0.38 to 0.43 kg/kg) was possible by using hot water of 55-60ºC.

The results were analyzed and compared with results from a finite difference model.

In a demonstration plant, first measurements showed promising results of the dehumidification of hay bales. The drying time for a hay bale could be reduced significantly. The air stream temperature was increased by more than 10 K while relative humidity was reduced by more than 40%-points during the tests.

Acknowledgements

This research project is supported by the German Federal Ministry for Education and Research in the framework of the research program “KLIMZUG Nordhessen – Climate Change in Regions”.

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