Experimental Analysis of a Hybrid Liquid Desiccant System with Non-Adiabatic Air-Solution Contactors at Different Working Conditions

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Abstract

The performance of a hybrid liquid desiccant prototype with non-adiabatic air-solution contactors is analyzed in this paper. In order to avoid corrosion all the components that are in direct contact with the liquid desiccant are made of plastic, especially the air-solution contactors that are made of polypropylene. The hybrid liquid desiccant system (HLDS) is an air-conditioner that separately controls the humidity and temperature of two locker rooms of a swimming-pool in Taipei (Taiwan).

The experimental prototype is firstly presented. In addition, the experimental performance of the HLDS during its operation in Taipei is shown and discussed. The thermal capacity of the system working at full load is included as well as the supplied air conditions reached by the system at different ambient air conditions.

The presented HLDS shows an adequate control of the humidity and temperature of the locker rooms at different operational conditions. At the same time, corrosion which is one of the main problems in liquid desiccant systems has been eliminated because of the use of plastic materials.

Keywords - Dehumidification, Liquid desiccant, Air-Conditioning

1. Introduction

In applications where dehumidification is important, desiccant systems are a good alternative to conventional air conditioners because they open new possibilities in different aspects such as ([1] and [2]):

- Use of low temperature heat sources such as solar or waste thermal energy.
- Operate without using greenhouse gases because conventional refrigerants are not required.
- Control of humidity of the air independently of temperature.
- Achieve very low levels of humidity.
- Can be employed in combination with vapor compression systems offering a more efficient way to control separately humidity and temperature.

In the combination of liquid desiccant systems with conventional vapor compression chillers, called hybrid liquid desiccant systems (HLDS), the liquid desiccant unit handles the latent load, and the vapor compression system the sensible one.

Despite liquid desiccant systems have many advantages compared to solid desiccant systems, such as lower regeneration temperature, chemical storage or pollutants removing [3], they are not often used because of the corrosiveness [4] and carry-over [5] of the liquid desiccant material.

Typically, dehumidifiers are made of a packed bed material. However the use of non-adiabatic dehumidifiers provide several advantages such as lower flow rates and carry-over of the liquid desiccant [6].

This paper includes the analysis of the experimental performance of a HLDS prototype that contains non-adiabatic air-solution contactors. The HLDS is working to separately control the temperature and humidity of two locker rooms of a swimming-pool in Taipei (Taiwan).

In order to avoid corrosion all the components that are in direct contact with the liquid desiccant, which is LiCl-H_2O, are made of plastic, especially the air-solution contactors that are made of polypropylene. Moreover a plasma treatment has been performed on the surface of the horizontal tubes in order to enhance its wettability when it is in contact with the liquid desiccant. A description of the system is firstly included.

2. Description of the Experimental System

A hybrid liquid desiccant system has been designed and developed within the Nancool project, a European project supported by the FP7.

A schematic of the system is shown in Fig.1. Flow rates and temperatures at design conditions are also included. Moreover specifications of the main components of the system are included in Table 1.

The system is comprised by three different subsystems:

- A liquid desiccant system whose absorber and regenerator are of the internally-cooled type and are made of polypropylene. This part is in charge of dehumidifying the air and regenerating the liquid desiccant. The liquid desiccant used is a solution LiCl-H_2O.
- An air handling unit which controls the supply air temperature and air flow rate. Return air is used to regenerate the water through the regenerator.

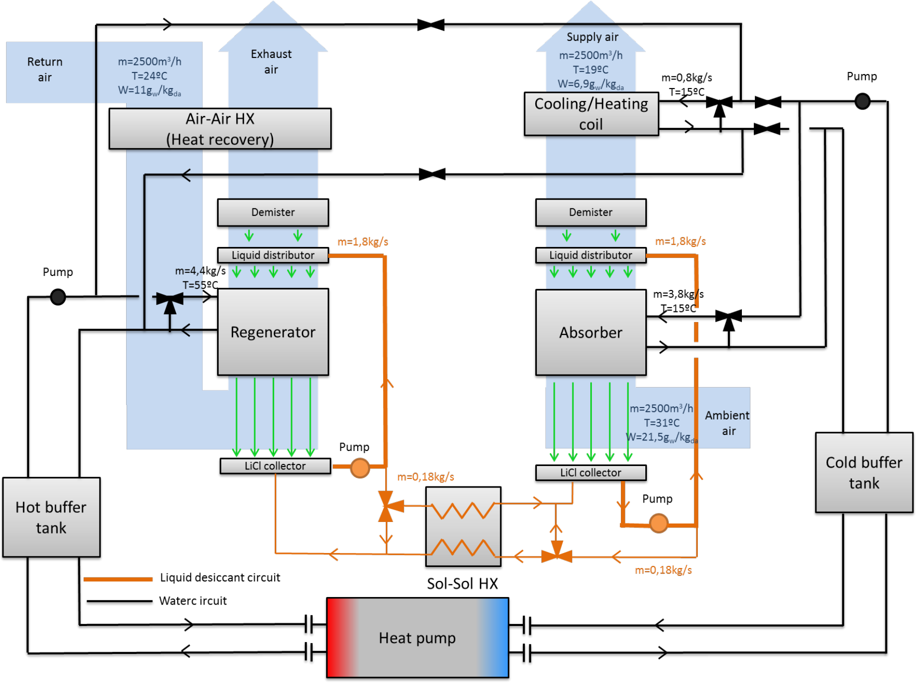

Fig. 1 Schematic figure of the proposed hybrid liquid desiccant system

- A flexible heat pump that, depending on the energy requirements, is able to condensate with water or dissipate it to the air. It supplies the chilled and hot water to the absorber and regenerator respectively. The maximum supplied water temperature from the condenser is 55ºC and the minimum supplied water temperature from the absorber is 10ºC.

Moreover the system is able to operate either at summer or at winter conditions due to the hydraulic circuit can provide chilled water from the evaporator or hot water from the condenser to the coil inside the air handling unit.

On the other hand the air-solution contactors that are of the falling film with horizontal tubes type are made of polypropylene. In order to increase its wettability with the liquid desiccant, a superficial plasma treatment has been made for the surface polymerization of acrylic acid.

All the components in the liquid desiccant subsystem including sensors, actuators and pipes are made of non-corrosive materials. Moreover, the solution-solution heat exchanger material is a compound of synthetic graphite >80% and the rest of polypropylene.

On the other hand, in order to avoid the carry-over problem, a knitted mesh droplet separator made of polypropylene is put above the absorber and regenerator.

Operational information is being collected during its operation in Taiwan. The system is installed in Taiwan since the beginning of November 2015 and it is expected to be in operation at least for two more years.

Information from all the sensors of the system can be taken remotely via internet.

Fig. 2 . The HLDS during its set-up before being transported to Taiwan

3. Experimental Results

The variation of the humidity ratios and temperatures of the air during three different days are illustrated in Fig.3, Fig. 4 and Fig.5.

Table 1. Specifications of the main components of the nanoCOOL system

Absorber cooling capacity (kW)	37.4
Regenerator heating required (kW)	39.8
Sol-Sol HX effectiveness	0.85
Air-air HX effectiveness	0.65
Cooling coil thermal capacity (kW)	8.5
Heat pump nominal capacity (kW)	58.0
Heat pump EER	2.96

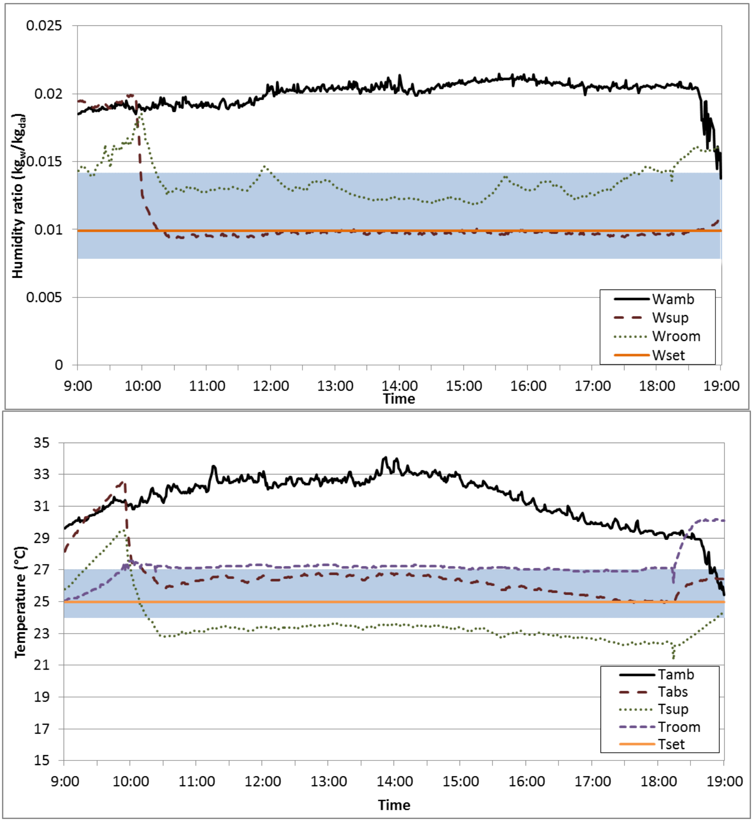

Fig. 3 Temperatures and humidity ratios in the HLDS during a warm and humid day

Fig. 3 contains the experimental results obtained for a day with high ambient temperatures and humidity ratios. On the other hand Fig. 4 shows them for a day with medium ambient temperatures and humidity ratios and Fig. 5 for a cool and dry day.

Every Figure also contain a blue band that represens the range between the maximum and the minimum values at which room humidity ratio and room temperature were set in the control parameters.

Finally, Fig. 6 illustrates the variation of the heat transfer rates of the main components of the HLDS as well as the ventilation and internal loads during the warmest and most humid day that corresponds with the same day than Fig. 3.

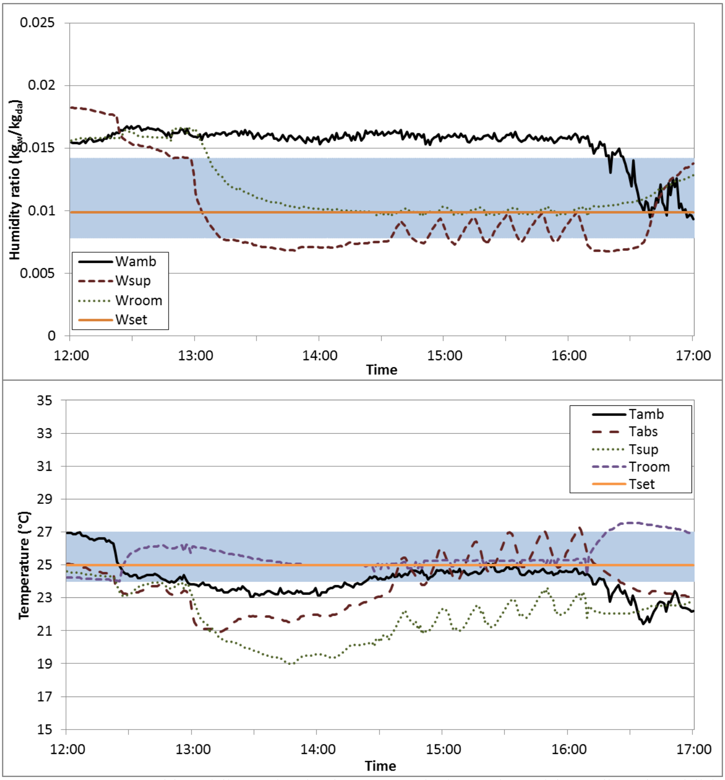

Fig. 4 Temperatures and humidity ratios in the HLDS during a day with medium humidities and temperatures

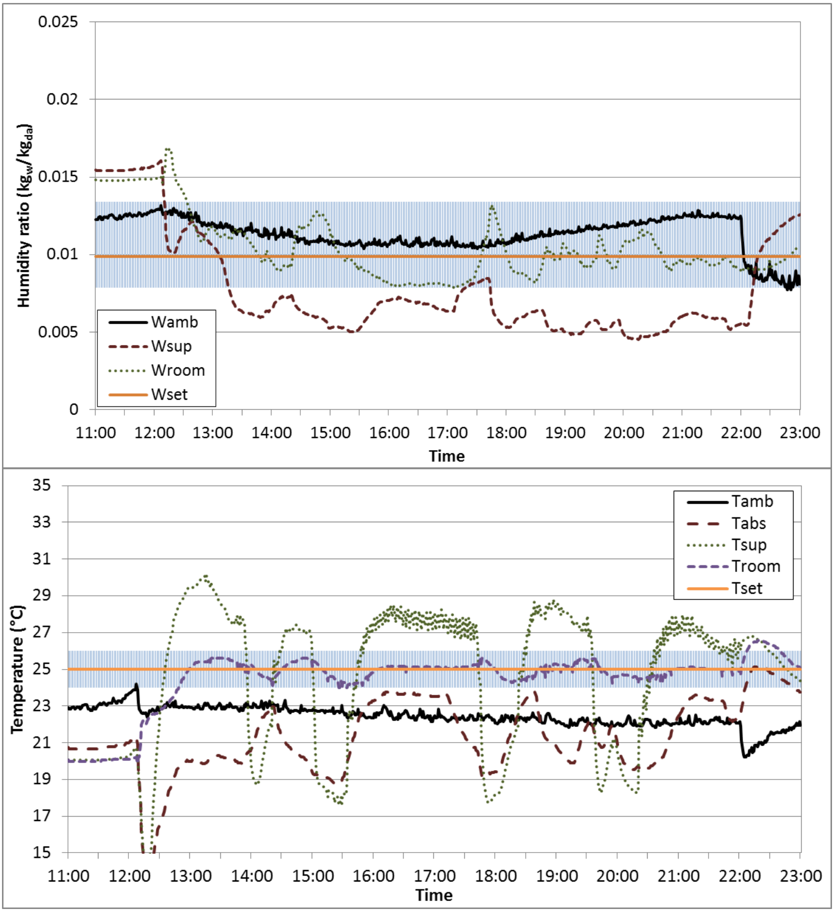

Fig. 5 Temperatures and humidity ratios in the HLDS during a cool and dry day

4. Discussion

Results illustrated from Figures 3 to 5 show how the HLDS has worked to achieve the set point conditions at three very different working conditions. During the day represented in Fig. 3, when ambient conditions were warmer (up to 34ºC) and more humid (up to 0.021 kg_w/kg_{da}), the HLDS had to operate at full load during the whole day. In these conditions neither the room temperature nor the room humidity ratio achieved the set point conditions along the day. However they were kept below the maximum values assigned in most of the time (27ºC for the temperature and 0.014 kg_w/kg_{da} for the humidity ratio). Absorber was able to dehumidify the air below 0.010 kg_w/kg_{da} and cool it down up to 26ºC.

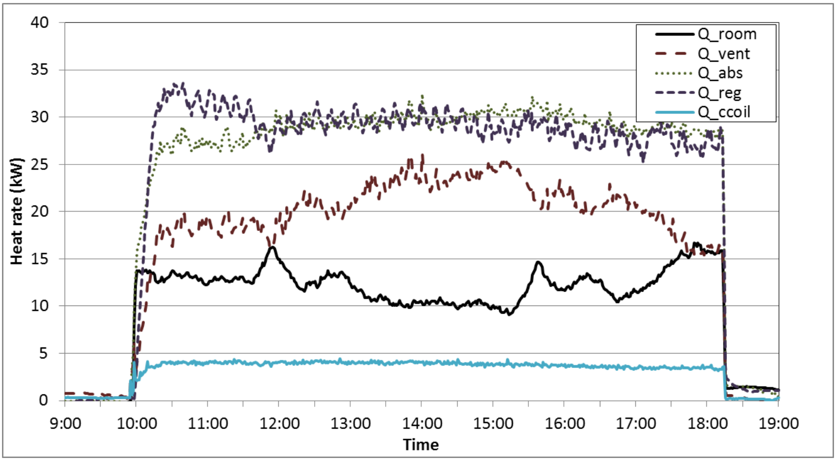

Fig. 6 Heat transfer rates of the main components of the HLDS and ventilation and internal loads for the warmest and most humid day

Moreover Fig. 6 contains the main heat rates in the air during that day. As it can be observed from this Figure, ventilation loads were bigger (from 20 to 25 kW) than internal loads (from 10 to 15 kW) under those conditions. On the other hand, cooling provided by the absorber was in the range of 30 kW (not only latent cooling but also sensible cooling) and the provided by the cooling coil was in the range of 4 kW.

Fig. 4 illustrates a day when ambient temperature was about 24ºC and ambient humidity ratio was 0.016 kg_w/kgda. During this day the system was able to achieve the set point conditions in the locker room after 40 minutes of operation. After 14:30 h it can be observed from supply air conditions that the system started to work at partial load trying to control and achieving the room temperature and humidity ratio (25ºC and 0.010 kg_w/kg_{da} respectively). At the beginning of the day, under full load conditions, the absorber was able to dehumidify the air down to 0.007kg_w/kg_{da}.

Finally, Fig. 3 shows a day when ambient temperature was always below 23ºC and ambient humidity ratio was between 0.011 and 0.013 kg_w/kg_{da}. In this Figure it can be clearly observed that the HLDS controls separately the room humidity and temperature.

Under these dry ambient conditions the system tried to control the set point humidity ratio. However, once the minimum assigned value for the humidity (0.008 kg_w/kg_{da}) was reached after 17:00h the dehumidification of the system was stopped. After that moment room humidity increased very fast and reached the maximum humidity in less than 15 minutes when the dehumidification system started to operate again being able to reach the set humidity ratio. Supply humidity ratio achieved by the absorber was sometimes below $0.005 kg_w/kg_{da}$ for some moments of the day.

On the other hand, in order to control the room temperature during this day, the coil in charge of controlling the temperature was operating in both, heating and cooling mode. Whenever the minimum set temperature inside the room (24ºC) was achieved, the coil changed from cooling to heating mode (this happened at 14:30h, at 15:30h, at 18:30h and at 20:30h). The opposite thing happened when the maximum set temperature inside the room (26ºC) was gotten (this happened at 14:00h, at 15:00h, at 18:00h and at 19:30h).

5. Conclusions

The presented HLDS shows an adequate independent control of the humidity and temperature of the locker rooms at different operational conditions.

On the other hand the maximum cooling provided by the system was about 34kW in which the dehumidifier cooling was about 30kW and the cooling coil 4kW. This happened when ambient conditions were about $0.021 kg_w/kg_{da}$ and 34°C. The supply air humidity ratio and temperature in this case were $0.010\ kg_w/kg_{da}$ and 23°C respectively.

Finally corrosion, which is one of the main problems in liquid desiccant systems, has been eliminated because of the use of plastic materials.

Nomenclature

HLDS	Hybrid liquid desiccant system	*Q*	Heat rate (kW)
T	Temperature (ºC)	*W*	Humidity ratio of air (kg_w/kg_{da})
Subscripts			
abs	Absorber	*room*	Locker Rooms
amb	Ambient	*set*	Set Point
ccoil	Cooling Coil	*sup*	Supply
da	Dry air	*w*	Water
reg	Regenerator		

Acknowledgment

This work has been supported by the European Nanocool project (ref n. 314701) co-founded by the EC under FP7-2012-NMP-ENV-ENERGY-ICT-EeB.

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