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Electrospray technique to produce fine sprays of desiccant liquids. Application to moisture removal from air

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ABSTRACT

The most extended method to reduce humidity in conditioned spaces are based on cooling coils. This system reduces the amount of water in the air stream through the condensation of water on the coil surface. Desiccant materials have been assessed as an alternative to these systems aiming at improving the process efficiency. Desiccant materials efficiency is based on the contact surface between the liquid and the air stream, therefore, the higher the contact surface is, determines how much water will be removed. The combination of desiccant liquid and electrohydrodynamic techniques is considered as a challenging topic to produce a very fine spray that leads to an increase of surface contact. This paper covers the technical feasibility of electrospray technique to produce small droplets of desiccant liquids that are used to reduce the humidity content.

1. Introduction

Many of the existing buildings belonging to service sector, like hospitals, sports centres, commerce, etc show high values of latent load, there are also applications where it is required to keep very low conditions for relative humidity ratios (for example ham dryers rooms); these specific installations use to have large energy consumption profiles to support cooling demands and maintain the required conditions.

The most common thermal energy production system used for these applications are based on mechanical compression cycles (chillers or heat pumps). These systems are robust, reliable and these solutions are commercially available. However, they are not solutions that give the best energy performance.

Fig. 1 shows the typical path for the supply air in a psychrometric diagram: first, the air is cooled down to reduce the humidity to the required values to support latent load (A-C path); in this part of the process the air is blown through a cooling coil where the water is condensed and the air moisture content is reduced; after this process the air temperature is too low, so it is usually required to heat the air as to reach the set point to supply the air temperature (C-X path).

On the other hand, the maximum quantity of water that the system is able to remove is defined by the temperature of the cooling coil, if the requirements are for extremely low humidity conditions for the supply air, cooling producing units will operate in very low-temperature conditions, hence the coefficient of performance will be low; besides, it's also required to heat the supply air later to reach the needed supply conditions. As can be envisioned, the energy efficiency of this process is very low. The comparison between enthalpy jump for path A-B-C-X and path A-X show an increase of 15% for the first path.

Systems based on desiccant technology appear to give a more efficient solution to these specific applications. The most extended technology is the desiccant wheel. This technology is based on the water adsorption on the surface of hygroscopic materials (like silica gel [1], titanium oxide ([1] and [2]), activated carbon ([3]) or zeolites ([4]) that reduce the water content in the air, and increase the air temperature. Typical applications for desiccant wheels are mainly dehumification or enthalpy recovery ([5]), the performance of desiccant wheels has been deeply evaluated using mathematical models to assess heat and mass transfer and optimize running parameters ([6],[7] and [8]). Desiccant wheels are systems that typically show high energy consumption rates to blow the air through the porous material and also require a lot of space for its location. Strict maintenance operations are required to avoid dust accumulation that reduces the absorption capacity. Although the global performance of this system is low, it is interesting when com-

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Nomenclature

D_g	Desiccant drop mean diameter [μm]
D_{tg}	Theorical desiccant drop mean diameter [μm]
D_{wd}	Diffusion coefficient water in desiccant [m^2/s]
HVAC	Heating ventilatanig and air conditioning
K	Electrical conductivity [μS/cm]
LDV	Laser DopplerVelocimetry
Q	Flow rate [mL/h]
M_d	Molecular weight of desiccant [g/mol]
M_w	Molecular weight of water [g/mol]
R	Dehumidification capacity
R_g	Desiccant drop mean radius [μm]
RH	Relative humidity
t_d	Diffusion time [s]
t_V	Time of flight [s]
V(x)	Velocity at distance x [m/s]
Vol	Droplet volume [cm^3]
X_w	Molar fraction of water
ε_0	Vacuum dielectric permitivity [F/m]
ε	Desiccant liquid dielectric constant [F/m]
γ_w	Acivity factor
ρ	Desiccant liquid density [g/cm^3]

bined with the use of renewable energy sources ([9]) or heat pumps ([10], [11] and [12]) to regenerate the wheel. The use of combined solar collectors – thermal and electrical- has been evaluated by Calise ([9]) on TRNSYS simulation SW as energy and environmental impact, showing an energy coverage around 60% of thermal energy. Strong efforts and advances in the design and development of new layouts for the desiccant material are currently done to reduce air side head loss, O'Connor [13] has developed an innovative desiccant wheel where the new layout of the desiccant material on the substrate shows a very low-pressure drop (around 2 Pa).

The dehumidification capacity for desiccant wheels depend on several factors, but typical values for the ratio mass water/mass air is around 5–8 g_{water}/kg_{air} [14].

Systems based on liquid desiccant materials have been developed to take the best of desiccant materials and give solution to the main inconvenients of the solid desiccant approach. The physical principle is the same: water adsorption on the surface of the desiccant material, in this case, a liquid material instead of a porous solid material. As the adsorption is a surface phenomenon, th more surface is exposed to the desiccant and the air, the more water will be transferred hence the performance will be increased. The main technologies developed for liquid adsorption are listed below [15], [16] and [17]:

- Spray towers
- Packed bed towers
- Falling film towers

These technologies show relatively low values for the pressure drop on the air side, but the contact surface between the desiccant liquid and the air is not very high, this reduces the overall performance of the system and limits the quantity of water that the system is able to remove from the air stream. Therefore requiring very large units to compensate for the poor performance.

It is necessary to evaluate new technologies that process desiccant liquid that leads to a better adsorption performance system and solutions that are more compact along with maintaining the advantages previously described. The contact surface between the desiccant and air flow can be increased by reducing the droplet diameter. Standard spray towers are limited by energy consumption and noise when producing droplets, average droplet size is between 500–1000 μm.

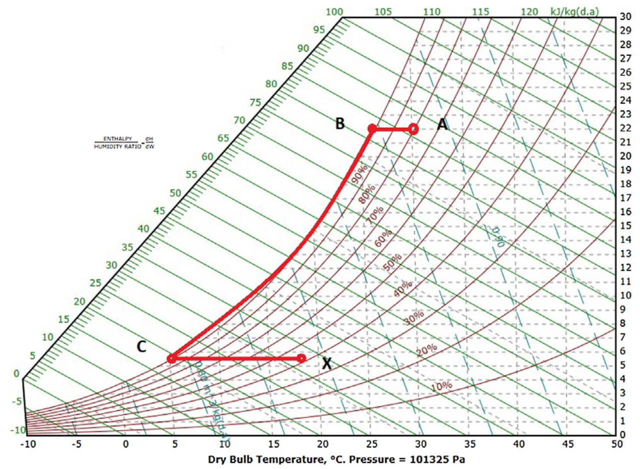

Fig. 1. Psycrometric diagram path.

This work aims at evaluating the electrospray techniques as an innovative method to produce very fine sprays of liquid into an air flow stream. This technique has been broadly used and reported by different authors: Loscertales [18] evaluated the production of the monodisperse droplets using this technique, López-Herrera [19] used this technique to produce water droplets over an air stream, R. Bocanegra [20] and, more recently, M. Parhizkar [21] has worked on the scaling up of electrospray using multinjectors. This technique shows a very low energy consumption (electrical current around nA per nozzle) and the generation of droplets with an average size between hundreds of nanometers and dozens of microns [18,19]. This reduces the size in the droplet generation significantly and thus increases drastically the contact surface per mass of liquid. As dehumidification performance depends directly on the contact surface, electrospray technique can be a suitable method to improve global performance. There is a direct contact between the air and the desiccant liquid, so it is required to consider this fact during the process definition to avoid the droplet carry over by the air stream.

This paper explains the methodology and the results of the evaluation of different atomized desiccant liquids using electrospray.

2. Methodology and experimental setup description

It is required to set an example as the base case to evaluate the technical feasibility and to assess the electrospray technique, to produce droplets of a liquid desiccant in an air stream for air-conditioning applications. In this case, an operating room has been selected as final application, a standard unit requires 2.800 m3/h of conditioned air to cover latent and sensible loads (assessed also for a specific location, in this case, Malaga-Spain), under this specific conditions supply air must be pumped at 13,7 °C and 78% RH, these values are related to a humidity content of 7,6 g water/kg air, desiccant system must reduce the humidity content from external conditions to supply air conditions, which gives as result 9,57 g water/kg air; considering the air flow rate and the conditions of the air before and after the desiccant unit, it can assess the amount of water to retain: 8,96 g/s. This will be the value considered to assess the technical and economic feasibility of the proposed solution based on electrospray technique.

The proposed methodology to assess the technical feasibility of this solution is formed by the following steps: desiccant liquids evaluation, dehumidification capacity assessment, mean time for equilibrium, liquid processability by electrospray, mean diameter