Zurich, June 15-17 2016
Sustainable Built Environment (SBE) Regional Conference

Expanding Boundaries:
Systems Thinking for the Built Environment

SBE16 ZURICH

AIR DEHUMIDIFICATION WITH NOVEL LIQUID DESICCANT SYSTEM

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Abstract

Liquid desiccant systems have the potential to remove water from air efficiently. This dehumidification leverages the chemical affinity of liquid desiccants to absorb water from the air instead of classical energy and exergy intensive mechanical dehumidification. Desiccants remove water through chemical absorption, and do not require the low temperatures needed to drive condensation on cooling coils. There are both solid and liquid desiccant systems that have been implemented for buildings with the former being used in wheels to move moisture in and out of tangential air streams, and the latter being used to extract, transport and remove water in a fluid loop. Both have limitations with solids struggling with limited mobility, and liquids with corrosiveness and volatility. But the benefit of eliminating latent cooling temperatures of <8°C and focusing on sensible cooling at >14°C could cut cooling energy in half. We consider the potential of a new liquid desiccant system consisting largely of Alkoxylated Siloxane. We characterize its water absorption and desorption characteristics, and we discuss the potential suggested by these results for application in a hypothetical building system design.

Keywords:

Liquid descant, dehumidification, energy savings, building system design,

1 INTRODUCTION

Less than a century ago humans did not have access to air conditioning in buildings, and for the first few decades of its existence it was only a novelty in movie theatres. Today many people would say they cannot live without it. Tropical countries like Singapore would not be considered developed without the massive air conditioning infrastructures. Now air conditioning has provided a comfort anticipated by residents including tropical natives. Even tourists often expect to be able to “escape the heat” of the location and climate they have travelled to experience.

But in tropical environments it is not really cooling, as one would traditionally think of it, that is desired, or even that is really delivered. It is the high humidity in the tropics that drives discomfort, and the primary operation of air conditioning systems is humidity removal, defined as the latent cooling demand. In fact, the latent cooling demand for air conditioning in the tropics is more than half of the total cooling demand, which means that making the air colder is actually a less significant part of the air conditioning process than reducing humidity.

Because cooling makes up a major fraction of energy demand for buildings, it is important to critically think about how this demand is met. Traditionally, air conditioning systems use metal cooling coils that are cooled below the dew point to cause condensation of water out of incoming outdoor air streams. This requires temperatures much colder than the actual sensible air temperature one would read on a thermostat. The colder temperatures for dehumidification reduce the performance of the refrigeration

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DOI 10.3218/3774-6_51, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

machine, causing more electricity to be used per unit cooling delivered, further increasing the impact of the latent cooling on energy demand of the building systems. Therefore, addressing latent cooling at the system level provides a great opportunity to significantly reduce energy demand.

An alternative method of dehumidification is to use desiccant materials that chemically absorb water out of the air stream. These systems do not require the excessively cold temperatures, but they do require an alternative system design, and present a variety of other challenges arising from their physical nature and deployment opportunities.

We evaluate, characterize, and hypothesize the use of a novel liquid desiccant for achieving the benefits of more efficient dehumidification while overcoming some of the challenges common to desiccant systems. We consider its implementation in the context of the tropical environment, and compare its hypothetical operating characteristics to a pilot building system we recently completed in a Singapore school using solid desiccant sensible and latent energy recovery.

2 BACKGROUND

It has been shown that energy can be saved by separating the latent cooling from sensible cooling (Teitelbaum et al., 2015) [1]. The quality of the the cooling energy needed to mechanically remove moisture from the air through condensation is higher than that need to maintain the dry bulb temperature in the space. The latter space cooling can be achieved most effectively through delivery in large surface areas at temperature closer to room air. We have demonstrated the ability to provide the sensible cooling to a space using radiant cooling panels at a higher temperature, thereby separating it from latent cooling and generating it at a higher temperature (Meggers et al., 2013) [2]. This allows the chiller to run at a higher efficiency for that sensible demand, which in a humid climate ranges from 40 to 60% of the cooling demand. Low exergy system design focuses on minimizing excessive temperatures because a heat pump or chiller has a fundamental thermodynamic performance relationship that increases its efficiency as less extreme temperatures are used (Meggers et al., 2013) [2]. The integration of cooling systems into surfaces like radiant panels chilled beams to increase the heat exchange at reduced temperature differences and also facilitates architectural and spatial design opportunities that increase system efficiency, space availability and design flexibility have been demonstrated in our pilot building project in Singapore (Schlueter et al., 2016) [3].

Traditionally latent cooling requires temperatures below the dew point to cause condensation to remove the water. These temperatures are typically around 6 to 8 °C. At this temperature saturated air at 10 to 12 °C can easily be produced. When this air is distributed to the building it heats up resulting in air at roughly 20 to 25 °C with humidity 40 to 50%, achieving standard comfort criteria. In older systems or very inefficient contemporary ones, additional heat is used to reheat the subcooled air. In places like Singapore this is not allowed, which is good for efficiency, but it leads to challenges in correctly predicting the ability of air to heat back up in ducts and mix into rooms. Many people have experienced the excessively cold temperatures from mechanically dehumidified cooling air when they unfortunately sit under an air diffuser to which air is being supplied without being adequately reheated (Lstiburek and Harriman, 2009) [4].

We argue that a system that avoids excessive cold temperatures and focuses on delivering cooling at temperatures closer to room air will be both more efficient and more comfortable. Still, just splitting the latent cooling from the sensible does not eliminate these temperatures, as dehumidification is required. Desiccant provides a solution to replace the condensing latent cooling with chemical absorption. The main benefit is the desiccant can be regenerated using excess heat rather than cold, and heat is more readily available in cooling environments. The main challenge is moving these chemical desiccants effectively in and out of air streams. Solid desiccants have provided solutions for recovery of latent energy across supply and exhaust streams as is being done in our pilot implementation in Singapore (Schlueter et al., 2016) [3]. Solid desiccants can be regenerated, but generally need higher temperatures and are spatially constrained by the need to physically move the solid material (usually by rotating it on a wheel between air stream). We are therefore interested to explore new opportunities for utilization of novel liquid desiccants.

Glycols and halide salts are currently used as liquid desiccants. Glycols are highly volatile and require constant systems refilling which significantly increases system operation cost. On the other hand, halide salts are not volatile, but they are corrosive, hence require parts of the system to be made out of titanium or some other materials that do not corrode. For halide salts the carry over from the liquid into the air stream represents a significant problem. Once desiccant droplets enter airstream supplied to the indoor environment they can cause health problems for building occupants and degradation of materials.

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3 METHODS

The liquid desiccant is a 70-90 wt% alkoxylated siloxane mixture, with the remaining 10-30 wt% consisting of polyol. We performed two types of experiments to test properties of novel liquid desiccant.

When absorption of liquid desiccant was measured, liquid desiccant was placed in a beaker and exposed to the air at 25 °C and relative humidity (RH) of 80 %. This air condition corresponds to the humidity ratio of 15.9 g/kg and partial water vapour pressure of 2535.4 Pa. A mixing magnet was placed into the beaker to ensure that whole volume of desiccant is mixed and absorb water vapour from air. Change in weight of the desiccant system was recorded every 60 s using scale with ±0.001 g accuracy. Change of weight was recorded until 5 consecutive measurements could not be distinguished within the scale accuracy. Air in contact with desiccant surface was quiescent, with restricted movement above contact surface and fully mixed with the fan in the conditioning chamber.

In order to measure desorption of liquid desiccant 3 % wt of deionized water was added to the liquid desiccant and mixed with the mixing magnet. Water was desorbed at the air - liquid interface surface. Air used in desorption process had temperature of 23C and RH 27.4 % relative humidity. This air condition corresponds to humidity ratio of 5 g/kg and water vapour partial pressure of 813 Pa. Change of weight was measured every 60 s using a scale with ±0.001 g accuracy. Similar to the previous experiment air in contact with the liquid desiccant surface had 3 flow regimes.

3.1 Concept development

We intend to develop air conditioning system that can be integrated with facade and floor and provide sufficient dehumidification for the building in the tropics. This type of integrated system will provide dehumidification of air immediately at the indoor - outdoor interface. This allows ventilation to be introduced into the building immediately at the facade and reduces necessity for application of large centralized air handling unit. Air used for ventilation in the tropics has very high latent load, hence goal of our concept is to totally decouple dehumidification and sensible cooling. This paper will address part of the concept that focuses on the air dehumidification.

4 RESULTS

4.1 Absorption rates

X - axis on Figure 1 represents time and y - axis on represents increase in weight of liquid desiccant - water solution due to the absorption of water vapour from the air. Results on Figure 1 show that air movement above the contact surface significantly influences absorption. For the quiescent air case, water vapour moved through boundary layer due to diffusion and partly natural convection. When air in the contact with liquid desiccant surface was mixed with the fan, boundary layer absorption was higher. Absorption difference between quiescent and mixed air increased through time.

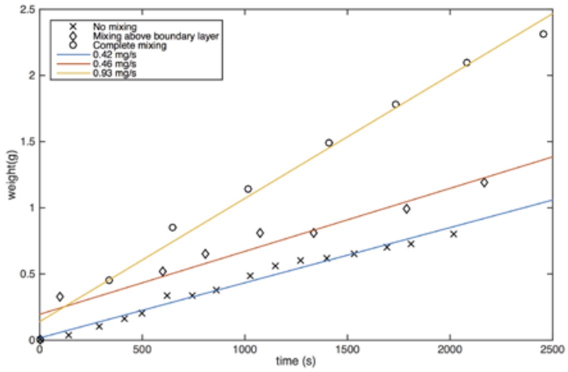

Fig. 1: Adsorption of liquid desiccant as a function of different airflows above contact surface.

Results on Figure 2 show the absorption for different mixing conditions of the desiccant: one with mixing and the other one without. It shows that for absorption of water vapour into the desiccant there are two distinct regimes, a resistance-limited regime and a contact-area limited regime. Initially when concentrated desiccant is exposed to humid air, we are in an area-limited regime as the desiccant is concentrated and the majority of the collisions between desiccant and water vapour will result in a successful absorption interaction (blue line in Figure 2). However, as the desiccant becomes saturated, fewer collisions will result in absorption (red line in Figure 2). This is the basis for a standard langmuirian adsorption kinetics model. As the surface area available for water molecules decreases with desiccant saturation, there will be fewer physical spaces available for effective collisions that lead to absorption. In this second regime, a resistance-limited regime, absorption rates are now limited by the frequency of effective collisions. While having more surface area would still increase rates, the dominant resistance is now a molecular phenomenon. Results point out that moving from limited resistance to limited contact area regime decreases slope almost 3 times from 0.93 to 0.32.

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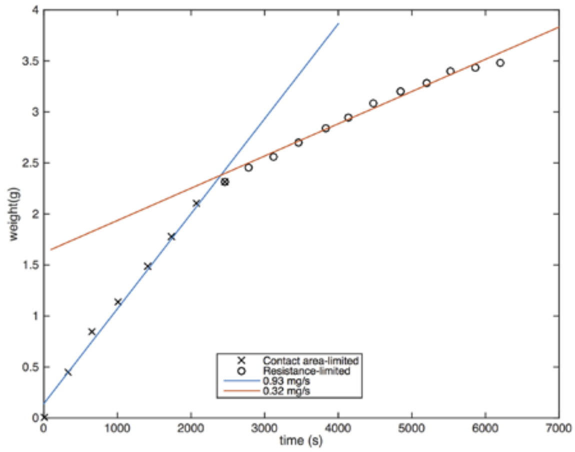

Fig. 2: Adsorption of liquid desiccant in limited resistance and limited contact area regime.

Results in Figure 3 show desorption rates for liquid desiccant in a beaker with fully mixed air above the free surface. Results suggest that desorption is slightly slower process when compared to adsorption where about 0.7 gram is removed per second for desorption and 1 gram is added per second for absorption, both for the faster resistance limited regime, but the desorption could also be limited by the boundary layer. The rate in the slower site limited regime is comparable for absorption and desorption so the desiccant kinetics are probably controlling for both with a rate of about 0.4 grams per second.

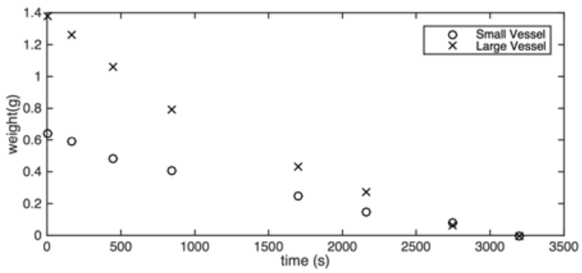

Fig. 3: Liquid desiccant desorption characteristics in two different vessels.

5 DISCUSSION

Based on the water vapour absorption and desorption rates we calculated necessary surface area to provide dry ventilation air in the tropics. It was assumed that outdoor air had to be dehumidified from humidity ratio of 20 g/kg to 10 g/kg. For single occupant ventilation requirement of 30 m^3/h required contact area is 3.8 m^2. If we deploy membrane tubes of 1 mm diameter with 0.5 m length 7600 tubes would be required to build such an exchanger. Based on the calculated area we considered development of absorber that will increase mass transfer coefficient compared to absorption from the mixed air above the contact surface. We intend to utilize increase of Sherwood number with the controlled flow of air over the air - liquid desiccant contact surface. This will reduce resistance introduced by the air boundary layer. Reduction of surface area required for dehumidification is very important factor for integration of this system. We considered hollow fibre membrane exchanger. Membrane will be made of hydrophilic material that has tendency to absorb water from air. Hydrophilic membrane was chosen as a material because it had high permeability, hence although it physically separates air from the desiccant it doesn't add to the system's resistance. Hollow fibre hydrophilic membrane exchange also prevents carryover issue hence supplied air will be safe for occupants and building materials.

6 CONCLUSION

From the results presented following conclusions can be derived:

- Air movement above free surface of liquid desiccant substantially affect mass transfer rate. Increase of the mixing above liquid desiccant free surface increases mass transfer rate.
- Absorption of water vapour into the desiccant show existence of two distinct regimes, a resistance-limited regime and a contact-area limited regime. Resistance limited regime has higher mass transfer rate compared to contact area-limited regime.
- Desorption rates are 50 % lower compared to absorption rates for liquid desiccant tested in our experiments.
- Based on per occupant ventilation requirement of 30 m^3/h and necessary removal of 10 g/kg of water per kilogram of air, we calculated that required air - liquid desiccant area is 3.8 m2. Our future research will be focused on methods to increase dehumidification and reduce necessary area.

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DOI 10.3218/3774-6_51, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

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