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# Investigation on the regeneration performance of liquid desiccant by adding surfactant PVP-K30

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ABSTRACT

The liquid desiccant cooling system (LDCS) is a promising alternative for the conventional vapor compression system due to its high energy efficiency. To enhance the mass transfer between the regeneration air and liquid desiccant in the regenerator, the paper firstly introduced a kind of surfactant called polyvinyl pyrrolidone (PVP-K30) which was added into the LiCl solution for better desiccant regeneration performance. The falling film characteristics and regeneration performance were investigated and compared with and without surfactant. The results indicated that the contact angle of desiccant solution on plate decreased from 58.5° to 28.0° by adding surfactant with 0.4% of concentration. The average wetting area increased from 0.174 $m^2$ to 0.209 $m^2$ with a relative increment of 20.1% with the addition of surfactant. Correspondingly, the film thickness had a reduction of 0.103 mm from 0.696 mm to 0.593 mm averagely. The regeneration rate had an average enhancement of 26.3% under the same working conditions, resulting from the decrement of solution contact angle with the addition of the surfactant. Finally, correlations to predict the mass transfer coefficient were proposed with and without surfactant and the mean absolute relative deviation between the results of correlations and the experiments were kept within 8%. The results and findings of present paper could be applied to guide the design of compact regenerator for higher regeneration performance.



## 1. Introduction

The energy consumption of buildings accounts for a heavy proportion in the whole energy consumption, such as more than 60% in Hong Kong, 30% in America and 40% in European countries [1]. Among the building energy consumption, about 30–50% is consumed by the air-conditioning system [2]. In the traditional air-conditioning system, the sensible heat load and latent heat load are handled together by cooling the processed air below the dew point temperature. However, in most situations, reheating is adopted subsequently to achieve suitable supply air temperature. As a result, the coefficient of performance of the system would reduce. Moreover, the condensation water due to the low temperature may provide a necessary condition for breeding bacteria [3]. Researchers try to find some alternatives for the conventional air conditioning system. By dealing with the sensible heat load and humidity load separately, the liquid desiccant cooling system (LDCS) is regarded as a prospective alternative among all the candidates.

Some previous investigation indicates that the LDCS has the potential to save up 40% energy compared with the traditional air conditioning system [4]. What is more, the regenerator in the LDCS can take advantage of solar thermal energy for regeneration so as to conserve energy and reduce $CO_2$ emission. Other merits, such as accurate humidity control ability and environmental friendly, are also possessed by the promising LDCS. Consequently, it draws more and more attention in recent years.

Dehumidifier and regenerator are two main components in a typical LDCS. In a dehumidifier, the concentrated liquid desiccant, such as lithium bromide (LiBr) and lithium chloride (LiCl) solution, absorbs water vapor from the processed air and becomes weak. The weak solution is then regenerated in a regenerator. The mass transfer driving force for both of the two processes are the partial water vapor difference between the air and the solution. In order to make the dehumidifier or regenerator more compact and efficient, various methods for heat and mass transfer enhancement have been proposed. The methods can be classified into two categories, namely structure improvement and solution modification. Researchers have put forward different structures for improvement, such as tube-fin [5], plate-fin [6,7], constant curvature surface [8] and super-hydrophilic coating [9,10]. The enhancement

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**Nomenclature**

| | | | |
|---|---|---|---|
| $A$ | wetting area ($m^2$) | *Greek symbols* | |
| $D$ | diffusion coefficient ($m^2/s$) | $\varphi$ | relative humidity (%) |
| $d$ | absolute humidity (g/kg) | $\rho$ | density ($kg/m^3$) |
| $G$ | flow rate (kg/s) | $\mu$ | dynamic viscosity ($Pa \cdot s$) |
| $h$ | enthalpy (kJ/kg) | $\Delta$ | change value |
| $h_m$ | mass transfer coefficient ($kg/(m^2 \cdot s)$) | $\sum v$ | diffusion volume of molecule ($cm^2/mol$) |
| $l$ | characteristics length (m) | *Subscripts* | |
| *LDCS* | liquid desiccant cooling system | a | air |
| $M$ | molar mass (g/mol) | dry | dry bulb |
| $\Delta m$ | dehumidification rate (g/s) | e | equilibrium |
| $N$ | data points | i | inlet |
| *Re* | Reynolds number | o | outlet |
| *Sc* | Schmidt number | s | solution |
| *Sh* | Sherwood number | w | cooling water or water vapor |
| $T$ | temperature (°C) | pre | predicted value |
| $v$ | velocity (m/s) | exp | experimental valve |
| $X$ | concentration (%) | | |

mechanisms can be summarized into two types, i.e., disturbance generation and wetting area increment. The solution modification includes adding nano-particle and surfactant to the desiccant. For the former one, certain kinds of nano-particles are dispersed into the desiccant solution with different physical and chemical ways. Nano-particles such like CNTs, Fe, and $SiO_2$ have been employed in the existing studies [11,12]. Different degrees of heat and mass transfer improvement were observed from these studies. About adding the surfactant which is the research interest of present study, detailed review is conducted as follows.

Early in the 1960s, Beutler et al. [13] had found that the absorption rate of refrigeration vapor was enhanced by the adding of certain kinds of alcohols and other hydrocarbon chains compound with polar groups. Then in 1990s, Cosenza and Vliet [14] added 2-ethyl-1-hexanol into the desiccant solution to investigate the water vapor absorption characteristics. They found that the absorption rate was increased up to 4 times with the adding of surfactant. Different degrees of absorption enhancement were also observed by adding 2-ethyl-1-hexanol [15,16]. The enhancement mechanism could be partly explained by the model proposed by Kashiwagi in 1988 [17]. The Kashiwagi model held the view of point that there were additive islands on the surface of solution. The surface tension gradient caused by the presence of additive islands triggered the Marangoni convection in the solution. However, other studies pointed out that the additive islands were not the prerequisites [18] for Marangoni convection. In 1991, Hozawa et al. [19] employed n-octanol and n-decanol as additives in lithium bromide (LiBr) solution to investigate the static absorption performance. They found that the initial absorption rate increased up to 2.5 times with the addition of n-octanol even under unsaturated additive concentration, which could not be explained by the Kashiwagi model. In order to explore the enhancement mechanism, Ziegler et al. [20] conducted a review based on the papers presentated in an academic conference in 1996. The commonly employed additives, such as n-octanol, n-heptanol, 2-ethyl-1-hexanol and 6-methyl-2-heptanol, were introduced and so were the influence of their addition amount on absorption enhancement. They also classified the related studies into four categories based on different applications, i.e., stagnant pool absorption, horizontal and vertical falling film absorber (both on tubes and plates) and filed test. Regrettably, they just summarized the research status rather than uncovered the mechanisms under the enhancement phenomenon. After that in 1997, Daiguji et al. [21] developed a new model called salting-out model to figure out the initial cause of Marangoni convection. They indicated that the hydration force between water molecules and electrolyte ions of $Li^+$ and $Br^-$ was stronger than that between water molecules and additive molecules. The absorption of the water vapor at the surface of solution broke the balance of original status. The absorbed water molecules had to be combined with electrolyte ions in bulk solution rather than the additive molecules at the surface, which caused the segregation of additive molecules from bulk solution. Consequently, Marangoni convection occurred because of the surface tension imbalance. Nevertheless, the model did not work when the additive was over-saturated. For example, absorption enhancement was reported even at oversaturated solubility by Beulter et al. [13]. As a supplementary, Kang et al. [22] proposed the solubility model which could be applied to the situations of oversaturated solubility in 1999. When the concentration of surfactant exceeded the solubility, the inducement of Marangoni convection was the imbalance of surface tension and interfacial tension. All of the above models focused on the solution itself. Differently, Kulankara and Herold [23] focused on the additive vapor and proposed the vapor surfactant theory. But the theory has its limitation because certain kinds of surfactants, such as Triton X-100, have negligible volatility, while the absorption enhancement by adding Triton X-100 was detected by Kang et al. [24]. Accordingly, we can conclude that the mechanisms of the mass transfer enhancement of various surfactants are still not clear as each model has its limitations for the explanation of absorption enhancement regarding the variety of surfactants.

Previous researches of surfactant are mainly focused on absorption refrigeration. In the absorption cooling system, working pairs of refrigerant and absorbent were certain binary solvents that circulated in a closed loop. Therefore, it does not matter if the surfactants have odour, toxicity and volatility as they are in the closed type system. As a matter of fact, nearly all the adopted surfactants in existing studies are some kinds of alcohols or something similar, n-octanol, n-heptanol and 2-ethyl-1-hexanol and so on. They are more or less odorous, volatile or toxic. However, different from the absorption refrigeration system, the LDCS works in an open loop in which the processed air should contact directly with the desiccant solution. Therefore, the foregoing surfactants cannot be applied to the LDCS directly due to their odour, toxicity and volatility which might threat to the indoor air quality as the processed air can carry the droplets and pollutants into the indoor environment.