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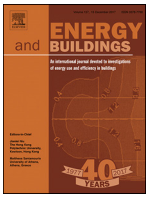

Enhancing the dehumidification performance of LiCl solution with surfactant PVP-K30

Tao Wen, Lin Lu[*], Chuanshuai Dong

Department of Building Services Engineering, Hong Kong Polytechnic University, Hong Kong, China

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ABSTRACT

Adding additives into liquid desiccant cooling system (LDCS) can enhance its mass transfer performance. However, the additives proposed by previous researchers are volatile and odorous which is a great threat to the indoor air quality. Therefore, this study introduced a new kind of non-volatile, odorless and non-toxic additive, i.e. polyvinyl pyrrolidone (PVP-K30), into LDCS for better dehumidification performance. Comparative studies were carried out to investigate the dehumidification performance of LiCl solution with and without the additive PVP-K30. The mass fraction PVP-K30 was chosen to be 0.4%. The results show that the dehumidification rate and dehumidification effectiveness have an average relative increment of 22.7% and 19.9% respectively with the addition of surfactant. The enhancement is attributed to the reduction of surface tension of liquid desiccant which is demonstrated by the decrement of contact angle from 58.5° to 28.0°. Correspondingly, the wetting ratio of desiccant falling film on plate has a relative increment of 16.9% from 82.7% to 96.7%, and the film thickness of falling film decreases from 0.681 mm to 0.583 mm. To sum up, the adding of additive PVP-K30 into LDCS provides an effective and practical way to enhance the vapor absorption performance in an absorber and so does the system efficiency.

1. Introduction

According to the statistics, people spend 70%–90% of their life time inside the buildings nowadays [1]. In this point of view, the indoor thermal comfort, which is closely related with the indoor temperature and humidity, plays a vital role in determining the quality of people's life. The traditional way to deal with the indoor heat and humidity load is vapor compression cooling system. However, this system has been criticized by its energy wastage, limited ability of humidity control and so on [2,3]. To make the situation even worse, it has the possibility of breeding bacteria because of the water condensation on the surface of cooling units [4]. As a promising alternative for the traditional vapor compression system, the liquid desiccant cooling system has been attracting attentions in recent years.

As a key component in the liquid desiccant cooling system, dehumidifier or absorber has the ability to absorb water vapor from processing air via the partial water vapor difference between liquid desiccant and moist air. Due to the different water vapor removal principle, the liquid desiccant system does not need to cool the processing air under dew point temperature for the purpose of moisture removal. On one hand, it can greatly reduce the possibility of bacteria breeding. On the other hand, it can avoid the process of reheat which usually occurs in the conventional cooling system to achieve higher efficiency. Moreover, compared with the traditional system, the liquid desiccant system can control the humidity more accurately by handling the heat load and moisture load separately with the help of cooling unit and absorber.

To make the dehumidifier compact, it is necessary to enhance the heat and mass transfer between liquid desiccant and process air or dehumidification ability in a dehumidifier. Some researchers tried to add certain kind of surfactant into the liquid desiccant to increase the water vapor absorption efficiency [4–15]. Such exploration started from the 1990s, when Cosenza and Vliet [5] studied the water vapor absorption characteristics in a tube falling film absorber. By employing 2-ethyl-1-hexanol as an additive, the mass transfer rate was three to four times bigger than that without additive. After that, 2-ethyl-1-hexanol was widely adopted by other researchers both in tube and plate absorbers [6–9]. Different degrees of absorption enhancement ranging from 20% to 500% were observed in their studies. Hozawa, Inoue [10] employed two kinds of surfactants, namely n-octanol and n-decanol, to investigate the static absorption performance of lithium bromide (LiBr) in 1991. They found that the initial absorption rate increased up to 2.5 times with the addition of n-octanol. They also measured the

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[*] Corresponding author.
E-mail address: vivien.lu@polyu.edu.hk (L. Lu).

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Nomenclature

d	Absolute humidity(g/kg)
G	Flow rate(kg/s)
h	Enthalpy(kJ/kg)
LDCS	Liquid desiccant cooling system
Δm	Dehumidification rate (g/s)
T	Temperature(°C)
X	Concentration(%)
Greek symbols	
φ	Relative humidity(%)
ρ	Density(kg/m^3)
ξ	Dehumidification effectiveness (Dimensionless)
Δ	Change value
Subscripts	
a	Air
dry	Dry bulb
e	Equilibrium
in	Inlet
out	Outlet
s	Solution
w	Cooling water

surface tension under different concentrations of n-octanol. It was found that the surface tension decreased with the increase of additive concentration to a certain degree and then kept constant. In 1996, Ziegler and Grossman [11] presented a review related to the recent progress of heat and mass transfer enhancement by additives. From this review, some commonly used additives, such as n-octanol, n-heptanol, 2-ethyl-1-hexanol and 6-methyl-2-heptanol, were introduced and so did the influence of their addition amount on absorption enhancement. Generally, the above studies could be classified into four categories: field test, horizontal and vertical falling film absorber (both on tubes and plates) and stagnant pool absorption experiments. Then other kinds of surfactant were also investigated by latter researchers. The attempts included 2-methyl-1-pentanol [12], Alkyl Glucoside [13] and Triton X-100 [14] and other multicomponent solutions such like LiBr + 1, 3-propanediol + water solution [15] and LiBr + CHO_2Na + water solution [16]. Various degrees of absorption increment were detected in these studies.

In order to reveal the mechanism of absorption enhancement by adding additives, some studies concentrated on the measurement of physical properties, mainly surface tension and viscosity. Daiguji, Hihara [17] stated that the surface tension of solution had an effect on the absorption performance in the falling film absorber. However, they also indicted that the absorption enhancement could not result from the reduction of surface tension alone. Some other reasons, Marangoni convection for example, might be the contributor. The surface tensions of aqueous lithium bromide with and without additives were measured by a drop weight method by Kulankara and Herold [18]. It showed that the addition of additives reduced the surface tension up to a critical level with the increase of additive concentration. Then, the surface tension kept almost the same for all four kinds of additives, namely 2-ethyl-1-hexanol, 3,5,5-trimethyl-1-hexanol, 2-methyl-1-hexanol, 3-phenyl-1-propanol. They also mentioned that the additive vapor around the liquid interface was of great importance to the reduction of surface tension. Different from Kulankara and Herold [18], Carazzo, Wohlfeil [19] measured the dynamic surface tension of LiBr solution with surfactant 1-octanol. In their mind, the contact time between vapor and solution was pretty short and the equilibrium of solution could hardly reach the steady state. They also gave a correlation to predict the dynamic surface tension.

Even so, the foregoing literature related to the measurement of surface tension can just give a guidance rather than convincing explanation to understand the enhancement mechanism. There is a general consensus that the absorption enhancement is caused by the Marangoni convection. But, the trigger mechanism under this phenomenon is still unclear. Some models developed previously tried to uncover the truth. Firstly, Kashiwagi [20] put forward a model called Kashiwagi model. He thought that the surface tension gradient caused by the presence of additive islands was the reason. However, the additive islands was shown to be unnecessary for Marangoni convection observed by subsequent researchers [21,22]. After that, Daiguji et al. [17] developed a salting-out model for the initial cause of Marangoni convection. They indicated that the absorption of water vapor broke the balance of original solution due to the stronger hydration force between water molecules and electrolyte ions of Li^+ and Br^-. It caused the segregation of additive molecules from bulk solution. As a result, Marangoni convection occurred in the solution. Nevertheless, this model could not be applied to the situation when the concentration of surfactant exceeded the solubility limit. For example, absorption enhancement was reported even at oversaturated solubility by Beutler et al. [23]. To be a supplement, Kang et al. [24] proposed the solubility model in 1999. They indicated that the salting-out model was the trigger for inducement of Marangoni convection before solubility limit of additives, while after the limit, the trigger could be contributed to the imbalance of surface tension and interfacial tension. Different from the abovementioned three models, Kulankara and Herold [25] put their concentration on the additive vapor and proposed the vapor surfactant theory. They explained that the inhomogeneous distribution of additives on the solution surface caused by the non-uniform absorption at the interface resulted in surface tension gradients, and then produced Marangoni convection in the solution. However, additives, such like Triton X-100, have negligible volatility. In such situation, the additive vapor is unlikely to exist in the gas phase. It can conclude that certain model can only give reasonable explanation for absorption enhancement for some additives, but there is no general criterion for all additives.

In addition, most researches are about the additives used in the absorption refrigeration system. In such systems, the aqueous solution circulates in a closed loop. The odour and volatility of the additives, such as n-octanol, n-heptanol and 2-ethyl-1-hexanol, do not make much difference in these systems. However, different from the closed type absorption refrigeration system, the liquid desiccant system works in an open loop, in which the moist processing air contacts directly with the liquid desiccant. Therefore, almost all of the additives mentioned above cannot be applied to the liquid desiccant system due to their odour, volatility and toxicity which is a great threat to the indoor air quality.

Therefore, the present study newly introduced a surfactant, namely polyvinyl pyrrolidone (PVP-K30), to the liquid desiccant system. Compared with those abovementioned surfactants, the odorless, non-volatile and nontoxic PVP-K30 [26] is improbable to pollute the processing air which is suitable for the open loop liquid desiccant cooling system. Comparative experiments were conducted in a single channel plate dehumidifier with the size of 500mm*500 mm (Length*Width). In order to avoid the influence of corrosion caused by LiCl solution on dehumidification performance, the stainless steel 316 L with excellent corrosion resistance performance was adopted for plate dehumidifier. In fact, researcher used plastic for the production of dehumidifier [27]. However, the complex processing technologies, weak structure strength and poor wettability greatly restricts its practical application. Therefore, metals are still the most suitable and promising material to produce plate type dehumidifier. The influences of various parameters,