Journal of Applied Mechanics Research
Vol. 7, No. 4, pp 9-14, Spring, 2016
Received 03 July. 2014, Accepted 14 October, 2015

Optimum Selection of Liquid Desiccants as Working Fluid for Solar Air Conditioning Systems

S. Alizadeh, the Faculty of Engineering, Mech. Eng., Islamic Azad University, Branch of Takestan
H.R. Haghgou, Division of Energy, Materials and Energy Research center
Email: sh_alizadeh@gmail.com

Abstract: Desiccants are chemical materials used for air dehumidification, which have applications in air conditioning, drying of agricultural products and in the industry such as pharmaceutical processes. Their effectiveness in air dehumidification differs based on their chemical compounds. Lithium chloride is the most effective salt in air drying and is used in liquid desiccant air conditioning systems. Calcium chloride is an alternative salt for air dehumidification but is less effective and less expensive than lithium chloride. As a consequence a 50-50% mixture of the two substances are usually used as a cost effective liquid desiccant (CELD), which has a good affinity in air dehumidification and at the same time can be purchased at a lower cost compared with lithium chloride. In this paper characteristics of desiccant as a function of temperature, humidity and concentration are studied and desired solution for solar air conditioning system are introduced.

Keywords: Desiccants, dehumidification, solar air conditioning, and cost effective liquid.

انتخاب بهینه مواد جاذب رطوبت مایع بعنوان سیال عامل سامانه‌های تهویه مطبوع خورشیدی

شهاب علیزاده- دانشکده مهندسی مکانیک، دانشگاه آزاد اسلامی واحد تاکستان
حمیدرضا حقگو- پژوهشکده انرژی – پژوهشگاه مواد و انرژی

چکیده: مواد جاذب رطوبت موادی شیمیایی هستند که به عنوان ماده رطوبت گیر در سامانه های تهویه مطبوع و سرمایشی و خشک کردن تولیدات کشاورزی و در بعضی صنایع مانند صنایع دارویی استفاده می شوند. کارآیی این مواد در رطوبت زدایی با توجه به ترکیب شیمیایی آنها متفاوت است. در رطوبت زدایی از هوا، نمک لیتیوم کلراید از کارآترین موادی است که در سیستم های تهویه مطبوع بکار می رود. کلسیم کلراید ماده دیگری است که در این سیستم ها مورد استفاده قرار می گیرد ولی کارآیی کمتری داشته و ارزانتر است. ترکیب ۵۰درصد از این دوماده نیز به عنوان ماده جاذب مطلوب و ارزان در سیستم های تهویه مطبوع مورد استفاده قرار می گیرد. در این مقاله مشخصه های جاذب رطوبت مختلف بر اساس دما، رطوبت و غلظت ماده مورد بررسی قرار گرفته و مناسب ترین محلول برای سیستم های سرمایش خورشیدی معرفی می شوند.

واژه‌های کلیدی: ماده جاذب رطوبت، رطوبت‌زدائی، سامانه تهویه مطبوع خورشیدی و مایع با هزینه پائین.

1. Introduction

Desiccants can be either solid, like silica gel, zeolites, synthetic zeolites, carbon, activated alumina and synthetic polymers, or liquid, like calcium chloride, lithium chloride, glycol and lithium bromide. Solid desiccants have a greater drying capacity in comparison to the liquid desiccants. Due to this reason, they have wider applications to dehumidify the supply air in various air-conditioning applications than the liquid desiccants. Factor and Grossman (1980), however, listed the following advantages for liquid desiccants: ease of manipulation and mobility, low pressure drop of air-flow across the desiccant material, can be used in filtration to remove dust, and finally they require a lower regeneration temperature compared to solid desiccants.

In this paper, properties of different sorbent solutions and their characteristics in terms of temperature, humidity ratio and solution concentration will be discussed.

2. Selection of the Desiccant

In order to select a desiccant material, toxicity, corrosively, stability, boiling and melting points, and mutual solubility in water should be considered as criteria (Mansoori and Patel, 1979). The maximum allowable melting point of the desiccant depends on the possibility of crystallization.

Amongst the liquid desiccants, lithium bromide solution has been in common use. Other solutions, such as lithium chloride and calcium chloride, have also been used by many researchers, (Hollands, 1963; Novak, 1985; Kaushik and Kaudinya, 1989). A mixture of lithium chloride and calcium chloride is also reported to be cost-effective and suitable for air dehumidification applications (Ertas et al., 1990).

Most organic desiccants such as ethylene glycol were not considered due to the fact that a proportion of the vapors will always migrate to the air during the dehumidification and regeneration processes. Even traces of these organic vapors could be harmful. Hence, inorganic salts, which are highly soluble in water, were taken as the suitable candidates for air dehumidification. The following are the most important properties of the candidates likely to be suitable as liquid desiccant (Farid and Mohammad, 1997):

1. High solubility in water.
2. Very low water vapour pressure in equilibrium with the saturated solution at ambient temperature.
3. High vapour pressure at temperatures between 60 $°C$ and 80 $°C$, so that the salt solution can be regenerated at these temperatures, easily obtained from flat plate solar collectors.
4. Low density and viscosity to minimize pressure drop in the dehumidifier and regenerator.
5. Low cost, non-poisonous and non-corrosive.
6. Does not undergo undesirable phase transition, which may lead to salt crystallization in the columns.

Search for suitable materials showed that zinc chloride may be included with the salts which have been previously studied (Farid and Mohammad, 1997). These salts are lithium chloride, lithium bromide and calcium chloride. Sulphuric acid and sodium hydroxide, two of the most effective liquid desiccants were eliminated due to their strong smell, high corrosively, safety and health hazards.

3. Evaluation of Materials Used as Liquid

Desiccants

To evaluate desiccant solution candidates for use in liquid desiccant dehumidification systems, an understanding of the simultaneous heat and mass transfer process occurring in the absorber is necessary. Changes in refrigerant absorption rates per unit area of the absorber brought on by a change of sorbent solution can be very significant in terms of system cost and power requirement. Conversely, Wood et al. (1984) have shown that the collector / regenerator area can be increased or decreased significantly as a result of a change in sorbent solution, without significantly affecting system cost or power requirements. To evaluate the sorbent solution candidates chosen, an analytical absorber model was utilized by Ameel et al.(1995) to estimate the cooling capacity per unit of the absorber area for each candidate at conditions likely to be encountered in the liquid desiccant system. Experimental studies were not considered since, in general, these studies did not consider a wide enough range of solution parameters to be useful.

Of those liquid desiccant candidates possessing the minimum qualifications to be considered, desiccant cost is of primary concern. Salts such as calcium chloride and zinc chloride cost much less than salts which have traditionally been used in absorption systems such as lithium bromide and lithium chloride. Unfortunately, calcium chloride does not possess the necessary solubility characteristics and zinc chloride is considered to be too viscous and corrosive. However, Heath and Minger (1939) have shown that by combining salts such as calcium chloride and lithium chloride, improved solubility characteristics can be expected as well as a possible reduction in viscosity, while achieving a considerable cost reduction relative to pure lithium chloride. Also, Easteal et al. (1974) indicate that mixtures of lithium chloride and zinc chloride display significant minima in viscosity at a composition corresponding to a double salt di-Lithium Zinc Chloride.

Ameel et al.(1995) further indicated that mixtures of chlorides of zinc, calcium, and lithium might exhibit more of the desirable characteristics for sorbent solutions than the single salts from which they are comprised. In light of the reduced cost of these mixtures, the solutions of di-Lithium Calcium Chloride, di-Lithium Zinc chloride and calcium zinc chloride were chosen as sorbent solutions candidates. Also, for the purpose of comparison, the solutions of Lithium Bromide, Lithium Chloride and Zinc Chloride were investigated.

The sorbent solution physical properties required by Grossman's (1983) absorber model were: (a) vapor pressure as a function of concentration and temperature, (b) solubility of the solute as a function of temperature, (c) viscosity as a function of concentration and temperature, (d) density as a function of concentration and temperature, (e) specific heat as a function of concentration, (f) thermal conductivity as a function concentration and temperature, and (h) heat of absorption as a function of concentration.

4. Corrosively and wetting performance of the desiccants

As was already described, desiccants can be corrosive when subjected to metal surfaces such as ducts or pipes. This can be avoided either by selecting a less corrosive desiccant such as calcium chloride solution or substituting nonmetals such as polyester based materials for the metals. Another alternative is the use of corrosion inhibitors, such as lithium chromate in the desiccant solution (GRI, 1989).

The wetting characteristic of the absorber plates is another issue, which should be considered when selecting the desiccant and plate material. In order to increase the dehumidification efficiency of a liquid desiccant system good wetting properties of the desiccant on the absorber plates has to be maintained. Selecting the proper material for the plates can do this. Metals wet very well, but are not recommended, due to highly corrosive action of the desiccant. In addition to plate material, selection of the proper distribution mechanism (such as spray, etc.) may have a significant effect on the wetting.

According to experiments carried out by the Gas Research Institute (GRI, 1989) on corrosivity and wetting performance of desiccants, especially lithium chloride, 'Flocked' polyester films show the best behaviour among the plastic materials tested. Several other types of plastics have been proposed that are polyester based with flocking or similar surface treatment.

5. Hazardous effects of desiccants

Many desiccants can be harmful to human health and should be prevented from contact with the body and skin. In Chapter 2 different methods were described in order to prevent the desiccant droplets from entering the conditioned space. According to the ChemWatch Material Safety Data Sheet (2002), calcium-chloride is less hazardous than lithium-chloride and it is also less corrosive to the metals. Consequently, if a mixture of the two salts has to be used as the desiccant, it is desirable to use higher ratios of calcium chloride in the mixture to reduce the hazardous and corrosivity problems. Inorganic absorbents such as sulphuric acid, etc., have a hazardous nature and are not to be used. Due to the above reasons calcium chloride solution, which is less hazardous and less expensive has been selected as the liquid desiccant for experimental work.

6. Sanitizing effects of desiccant-based cooling

Airborne microorganisms (bio-aerosols) are responsible for numerous disease outbreaks (Wells, 1995). The relationship between bio-aerosols and airborne disease transmission in the medical community has been well established (Hugh-Jones, 1973). Outbreaks of tuberculosis, chicken pox, measles and small pox have confirmed the importance of airborne disease transmission (ACGIH, 1989). However, the impact of bio-aerosols on indoor air quality (US Environmental Protection Agency, 2001) has only recently been examined. Bacterial and fungal infections in health care facilities and research laboratories are often disseminated through HVAC systems (Pike, 1976). Similarly, indoor air quality (IAQ) studies are finding that bio-aerosols are a primary link to building-related illness (BRI), infections, toxic syndromes and hyper-sensitivity diseases (Etkin, 1994).

Since the early 1980s, illness and complaints associated with indoor air quality have been steadily climbing. Indoor air quality investigations conducted by the National Institute for Occupational Safety and Health (NIOSH, 1987) during the 1980's, found bio-contaminants to be responsible in 5% of problem buildings. Other investigators have found microorganisms to be the primary cause in as many as 35-50% of IAQ cases (Stetzenbach, 1994). The increase in both communicable disease rates and BRI is often attributed to insufficient ventilation or recirculated air. Many studies identify inadequate fresh air as a primary cause of IAQ problems (NIOSH, 1989).

However, increasing the amount of fresh air (without pre-conditioning) can also increase the level of humidity. Excess moisture (above 60% relative humidity) provides conditions, which allow fungi to proliferate. Since bio-aerosols are associated with moisture, maintaining relative humidity below 60% will aid in their control (ASHRAE, 1990). In addition to controlling bio-contaminants, maintaining the health of building occupants largely depends upon maintaining the proper range of temperature, humidity and ventilation (comfort criteria). Since comfort criteria are controlled by HVAC systems, an HVAC system, which combines these principles, may be useful in achieving this goal.

As was described in the previous chapters in a desiccant-based air conditioning (DBAC) system a desiccant material, which can be either liquid or solid, is used to dehumidify air. Hines et al. (1991) noted that desiccant systems can enhance the quality of indoor air and reduce the level of microorganisms. Four desiccant-based air conditioning systems using solid desiccant wheels were evaluated by Phillips and Wagner (1994) to determine their effectiveness in reducing bio-aerosols. Field studies were conducted on three of the DBAC units to observe their performance under normal operational conditions. The three DBAC units were installed in health care facilities, where bio-aerosols (particularly bacteria and fungi) can be a constant problem. Two of the units were located in patient areas in local hospitals (sites 1 & 2) and, one unit was located in a commons room in a nursing home (site 3).

For the laboratory study, one DBAC unit was installed in a climate controlled isolation chamber in a university microbiology laboratory to evaluate the effects of the DBAC system on the seven selected microorganisms. In addition to testing the system on specific microorganisms, the laboratory study also isolated and examined the effect of the desiccant wheel. The results of the field and laboratory studies are presented in Figs. (1) and (2), respectively. As Fig. (1) shows, all three of the field study sites displayed reductions in both bacteria and fungi across the DBAC unit. An overall reduction was also observed in six of the seven organisms tested across the DBAC unit (Fig. (2)).

7. Conclusion

In selecting a desiccant absorbent for liquid desiccant dehumidification / cooling system different characteristics such as toxicity, corrosively, stability etc., should be considered as criteria. Of those liquid desiccant candidates possessing the minimum qualifications, desiccant cost is also of primary concern. However, it has been shown that by combining salts, improved characteristics can be expected while achieving considerable cost reduction relative to the pure salts.

Among the desiccants, lithium chloride and calcium chloride are in common use. Lithium chloride is the most effective in dehumidifying the air but the most expensive. Calcium chloride, which is the cheapest has less effectiveness in the air dehumidification and is less hazardous. A combination of these two salts can be used in order to increase the effectiveness of calcium chloride and decrease the high cost of lithium chloride. A 50% combination, known as Cost Effective Liquid Desiccant (CELD), has been proposed by Ertas et al. (1992) to be the best combination. However, in this study calcium chloride, due to being less expensive and less hazardous, has been selected as the desiccant.

The health hazard in liquid desiccant systems, despite the fact that they have sanitizing effects on airborne microorganisms, is an important issue and has to be taken into consideration. In the proposed system, a baffle can be incorporated in the final stage to capture any desiccant droplets, which may be carried over by the air. Alternatively, a demister could be used in the dehumidifier to capture the liquid desiccant droplets. The introduction of a direct evaporative cooling pad as a cooling stage will also ensure that traces of desiccant material are not carried into the conditioned space. It is notable that lithium chloride can be regenerated by temperatures as low as 40 °C. Therefore low cost flat plate collectors could be used which can produce high temperature hot water in summer.

8. References

[1] Ertas, A., Anderson, E.E. and Kiris, K, (1992), Properties of a New Liquid Desiccant Solution - Lithium Chloride and Calcium Chloride Mixture. *Solar Energy*, Vol. 49, pp. 205-212.

[2] Ertas, A., Anderson, E.E. and Kiris, K., (1990), Properties of a New Liquid Desiccant Solution - Lithium Chloride and Calcium Chloride Mixture, *Solar 90 : The National Solar Energy Conference : Proceedings of the 1990 Annual Conference, American Solar Energy Society, Inc.*, pp. 535-539, March 19-22, , Austin, Texas.

[3] Farid, M.M. and Mohammad, A.R., (1997), Air dehumidification using liquid desiccant, *CHEMECA 97, Rotorua, New Zealand, 29th September to 1st October.*

[4] Factor, M. and Grossman, G. (1980), A Packed Bed Dehumidifier / Regenerator for Solar Air Conditioning with Liquid Desiccants, *Solar Energy*, Vol. 24: pp. 541-550.

[5] Mansoori, G.A. and Patel, V., (1979), Thermodynamic Basis for the Choice of Working Fluids for Solar Absorption Cooling Systems. *Solar Energy*, Vol. 22, no.6, pp. 483-491.

[6] Wood, B.D., Siebe, D.A and Collier, R.K., (1984), Design analysis of a residential solar open-cycle absorption cooling system, *report for Arizona Solar Energy Commission*, Arizona State University.

[7] Ameel, T.A., Gee, K.G. and Wood, B.D., (1995), Performance Predictions of Alternative, Low Cost Absorbents for Open-Cycle Absorption Solar Cooling, *Solar Energy*. Vol. 54, no. 2, pp. 65-73.

[8] Heath, S.B. and Minger, F.R., (1939), U.S. Patent 2,143,007.

[9] Easteal, A.J., Sare, E.J., Moynihan, C.T. and Angell, C.A., (1974), Glass-transition temperature, electrical conductance, viscosity, molar volume, refractive index and proton magnetic resonance study of chlorozinc complexation in the system $ZnCl_2$ +LiCl + H_2O, *J. Soln. Chem*., Vol. 3, no.11, p. 817.

[10] Grossman, G., (1983), Simultaneous heat and mass transfer in film absorption under laminar flow, *Int. J. Heat and Mass Transfer*, Vol. 26, no.3, pp. 357-370.

[11] Perry's Chemical Engineers Handbook, (1984), 6th *Edition*, McGraw Hill.

[12] Uemura, T., (1967), Studies on the lithium chloride-water absorption refrigeration machines. *Technol. Rep. Kansai Univ* Vol. 9, pp. 71-88.

[13] Dow Chemical Company, (1983), *Calcium Chloride Handbook.* Dow Chemical Company, Michigan, USA.

[14] Gas Research Institute, (1989a), Liquid Desiccant Technology Development, *Phase I, Final Report* (January 1988-April 1989), U.S. Department of Commerce.

[15] ChemWatch Material Safety Data Sheet (2002): http://www.chemwatch.net

[16] Wells, W.F., (1995), Airborne contagion and air hygiene: An ecological study of droplet infections, Harvard University Press, Cambridge, Massachusetts.

[17] American Conference of Governmental Industrial Hygienists, (1989): Guidelines for the assessment of bioaerosols in the indoor environment. Bioaerosols committee, ACGIH, Cincinnati, Ohio. ISBN: 0-936712-83-X.

[18] Gas Research Institute, (1989b), Liquid Desiccant Technology Development, *Phase II, Final Report* (October-December), U.S. Department of Commerce.

[19] Pike, R.M., (1976), Laboratory-associated infections. Summary and analysis of 3921 cases. *Health Lab Sci* Vol. 13: pp. 105-114.

[20] US Environmental Protection Agency (2001), Indoor Air Quality:

[21] Etkin, D.S., (1994): Biocontaminants in indoor environments. Microbial contaminants in indoor air. *Cutter Information Corp*., ISBN : 0-943779-87-1.

[22] National Institute for Occupational Safety and Health, (1987): Guidance for indoor air quality investigations, *Hazards Evaluation and Technical Assistance Branch*, Cincinnati, Ohio.

[23] National Institute for Occupational Safety and Health, (1989): Indoor air quality, selected references, *Division of Standards Development and Technology Transfer*, Cincinnati, Ohio, September.

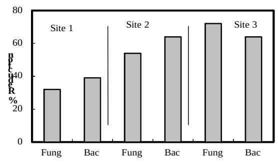

Fig. (1): Bacteria and fungi reduction in the field DBAC units. (Phillips and Wagner, 1994)

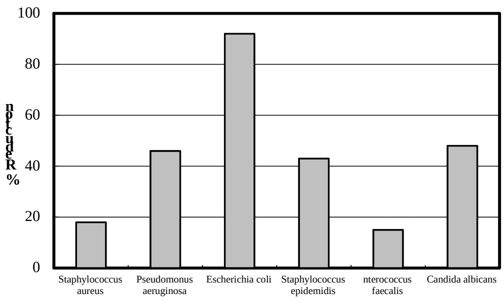

Fig. (2): Reductions of the seven organisms tested in the laboratory. (Phillips and Wagner, 1994)