Experimental Analysis on Chemical Dehumidification of Air by Liquid Desiccant and Desiccant Regeneration in a Packed Tower

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This paper presents the experimental tests on the chemical dehumidification of air by a liquid desiccant and desiccant regeneration carried out in an absorption/desorption tower with random packing. The experimental set-up is fully described together with measurements, procedures, data reduction, and accuracy. The experimental tests include 46 dehumidification runs and 38 desiccant regeneration runs carried out with the traditional hygroscopic solution $H_2O/LiBr$ and the new solution $H_2O/KCOOH$ in the typical operative ranges of air conditioning applications. The experimental results are reported in terms of humidity reduction, desiccant concentration change, and tower efficiency. The experimental tests show that chemical dehumidification of air by liquid desiccants ensures consistent reduction in humidity ratio, which is suitable for the application to air conditioning or drying processes. The experimental results are also compared to a one-dimensional simulation code of a packed tower: a fair agreement was found between experimental and calculated performance. [DOI: 10.1115/1.1637642]

1 Introduction

The sorption dehumidification of air by liquid desiccants could represent an interesting alternative to traditional dehumidification processes by air cooling below the dew point which involve both cooling and heating capacity. Chemical dehumidification by solid or liquid desiccants allows consistent humidity reduction and its energy cost, due to desiccant regeneration, can be significatively reduced by proper heat recovery. This process is also useful in reducing airborne microbial contamination.

Chemical dehumidification had till now few applications. The most widespread systems are desiccant wheels, which use solid sorbents (adsorption), whereas dehumidifiers using liquid desiccants (absorption), as a packed column, seem to be more interesting, as they allow heat recovery on desiccant regeneration. These dehumidification units could be usefully integrated within innovative HVAC plants, particularly with high latent and ventilation loads or when a high indoor air quality is required. The authors of the present paper have designed HVAC plants based on chemical dehumidification for an educational building [1] and for an infectious disease hospital [2]. Recently an innovative HVAC system based on chemical dehumidification by liquid desiccants has also been proposed by [3]. Dehumidification units based on liquid desiccants have been commercially available since about 1935, and have been used in a variety of industrial and institutional HVAC systems [4]. More recently, in 1997, a compact air conditioning system, which includes a dehumidification and a regeneration unit integrated with a regenerative heat pump, was commercialized [5].

In open literature it is possible to find several works on the theoretical analysis of heat and mass transfer in the packed columns for chemical dehumidification of air [6–8] together with experimental data on the performance of absorption/desorption packed towers [9–14].

This paper presents the experimental tests on the sorption dehumidification of air by a liquid desiccant and desiccant regeneration carried out in an absorption/desorption tower with random packing by using the traditional hygroscopic solution $H_2O/LiBr$ and the new solution $H_2O/KCOOH$ in the typical operative ranges of air conditioning applications. The new desiccant, usually used as brine, is less corrosive and expensive than the traditional ones ($H_2O/LiCl$, $H_2O/CaCl_2$, $H_2O/LiBr$). The experimental data reported are useful for the design of the liquid desiccant systems.

2 Experimental Apparatus and Procedures

The experimental rig, shown in Figs. 1(*a*) and 1(*b*), consists of an air loop and a desiccant loop. In the first loop ambient air is heated and humidified to achieve the set conditions at the inlet of the packed column. The power of the heating element can be varied from 0 to 2000 W by a PID controller, while the steam humidifier provides a vapor flow rate from 0 to 5 kg/h. The air goes through the packed tower where the heat and mass transfer with the desiccant takes place and then it is discharged. An air dehumidification process or a desiccant regeneration process occurs depending on the relative values of the partial vapor pressure on the air and solution side. The tower shell, made of stainless steel, 725 mm in height and 400 mm in diameter is filled with randomly packed 25 mm plastic Pall Rings supported by a stainless steel net and sprinkled with a liquid distributor. A large chamber at the bottom of the tower provides a good air distribution entering the column, whereas a stainless steel wire mesh at the top removes desiccant droplets carried out by the air at the highest velocities. The air duct, manufactured from a 160 mm diameter PVC tube, contains two measurement sections located at the inlet and at the outlet of the tower to measure temperature and humidity ratio.

Each measuring station consists of two temperature taps, instrumented with T-type thermocouples, and two humidity taps, con-

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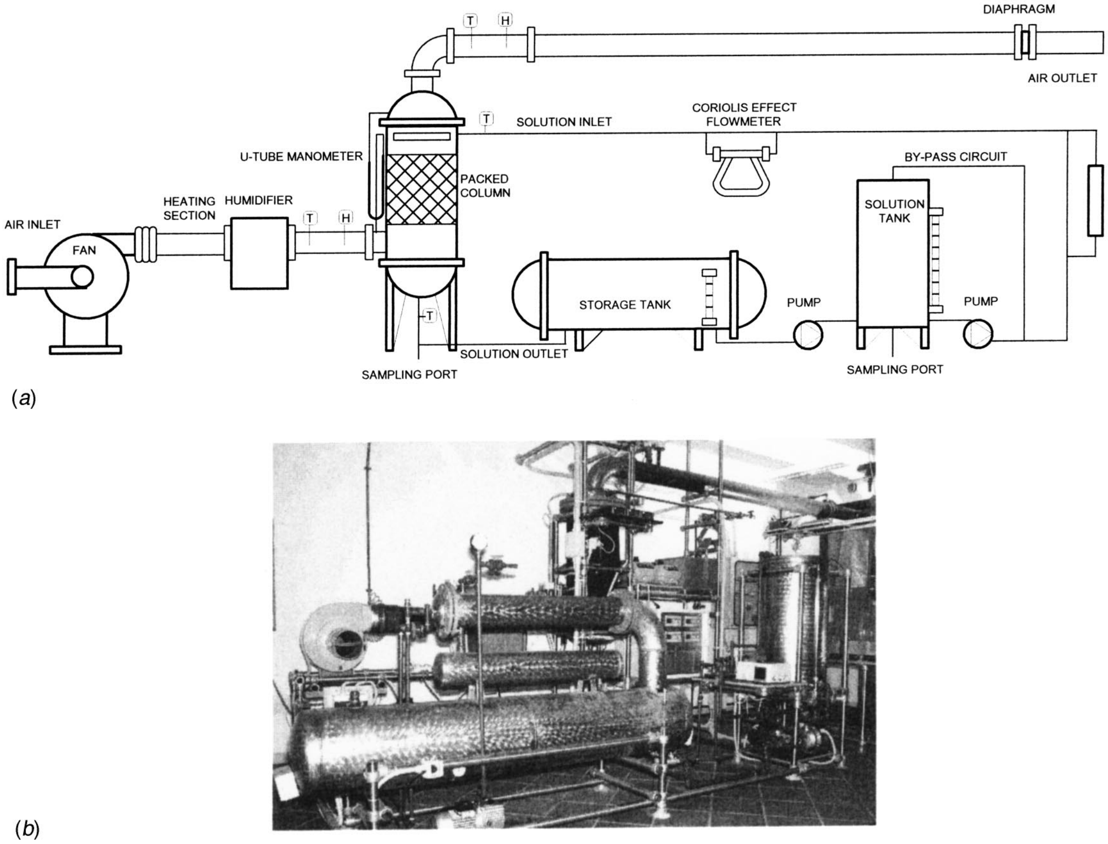

Fig. 1 (***a***) **Schematic view of the experimental test rig.** (***b***) **Photographic view of the experimental test rig.**

nected to dew point temperature probes, placed at different positions in the gas flow. The pressure variation of the air flow across the tower is measured by a U-tube manometer and by a straingage pressure transducer, while the air flow rate is measured by a diaphragm inserted in the air duct at the outlet of the tower after 3000 mm of straight tube. The desiccant is maintained at a constant temperature and at a uniform concentration in a stainless steel tank by a PID controller. From there it is pumped into the tower and sprinkled onto the packed matrix. The solution, after the heat and mass transfer with air, flows due to gravity into a storage tank. The flow rate of the desiccant, varied by the by-pass valve of the solution tank, is measured by a Coriolis effect mass flow meter and also by evaluating the variation of the liquid level in the tank at any fixed time. The temperature of the solution is measured at the inlet and outlet of the tower by T-type thermocouples, whereas the concentration at the inlet and outlet is derived from density measurements on samples. The readings of the thermocouples and of hygrometers are scanned and recorded by a data logger, whereas the measurements of the air and desiccant flow rates and the solution concentration are taken manually and then implemented into the computer. Table 1 gives the main features of the different measuring devices in the experimental rig.

In the present work both air dehumidification and solution regeneration tests were carried out. Before starting each test the solution in the tank was recirculated through the by-pass circuit to ensure uniform conditions. The air and desiccant flow rates were then established at set values, while temperature and humidity readings were recorded. Once temperature and humidity steady state conditions were achieved, readings were collected. Flow and pressure drop measurements were repeated three times, samples of the solution were taken at the inlet and outlet of the tower to measure its concentration. From the measurements collected, a computer code calculated the heat and mass balances over the tower to determine the moisture content change and the temperature variation for both the air and the solution. A detailed error analysis indicated an overall accuracy within ±10% of humidity change and within ±20% of solution concentration change.

3 Results

Two different sets of experimental tests were carried out: the first included 20 dehumidification runs with H_2O/LiBr and 26

Table 1 Specification of the different measuring devices

Devices	Type	Accuracy	Range
Thermometers	Thermocouple T	0.1°C	0–60°C
Dew point probes	Mirror probe	0.1°C	−50/+50°C
Solution flow meter	Coriolis effect flow meter	0.1%	0–1600 kg/h
Density meter	Oscillator cell	0.1 kg/m^3	1–9999 kg/m^3
Manometer	U-tube	0.5 mmH_2O	0–200 mm H_2O
Pressure transducer	Strain gage	0.1% f.s.	0–40 mbar
Air flow meter	Diaphragm	2%	0–800 m^3/h

Table 2 Operative conditions under experimental tests

Test	Desiccant	Runs	T_{ai} (°C)	Y_i (g/kg)	T_{si} (°C)	X_i (%salt)	G/S (kg/m^{2}s)	L/S (kg/m^{2}s)	L/G
Dehumidification	H_2O/LiBr	20	23.6–36.7	8.2–22.8	23.7	53.9–51.9	0.44–0.47	0.16–1.39	0.35–3.0
Dehumidification	H_2O/KCOOH	26	22.6–35.8	8.8–20.7	21.9–24.8	72.8–74.0	0.48–0.52	0.09–1.23	0.20–2.5
Regeneration	H_2O/LiBr	26	50.0	3.0–15.4	48.0–49.5	51.3–50.1	0.40–0.44	0.16–1.46	0.45–3.5
Regeneration	H_2O/KCOOH	12	50.0	2.8–14.5	46.9–50.6	75.5–75.9	0.41–0.44	0.13–1.32	0.31–3.0

with H_2O/KCOOH; the second, 26 regeneration runs with H_2O/LiBr and 12 with H_2O/KCOOH. When the partial vapor pressure on the air side was higher than that on the desiccant side a dehumidification process occurred, on the contrary a desiccant regeneration process was obtained. Table 2 gives the main operative conditions under experimental tests: air inlet temperature T_{ai} and humidity ratio Y_i, solution inlet temperature T_{si} and concentration X_i, air mass flux G/S and solution mass flux L/S, ratio between solution L and air G mass flow rates. The air mass fluxes investigated during experimental tests are set to ensure zero-carryover conditions and they result lower than the values usually applied in commercial units. As can be seen, regeneration conditions during experimental investigation were obtained by increasing solution and air inlet temperature up to values around 50 °C.

Figures 2(*a*) and 2(*b*) show the humidity reduction measured during the dehumidification runs against the mass flow rate ratio L/G. The dehumidification rate depends on the flow rate ratio with a logarithmic trend, the slope of which increases, in absolute value, with the air inlet humidity ratio. The solution H_2O/LiBr shows better dehumidification performance than the H_2O/KCOOH solution. The measured humidity reductions are interesting for the application to air conditioning or drying processes.

Figures 3(*a*) and 3(*b*) show the solution concentration increase measured during the regeneration runs versus the mass flow rate ratio L/G. The regeneration rate depends on the flow rate ratio with a logarithmic trend, the slope of which decreases with the air inlet humidity ratio. The solution H_2O/KCOOH shows better regeneration performance than H_2O/LiBr solution.

The performance of a dehumidification/regeneration tower can be evaluated by a specific tower efficiency as the ratio between the absolute value of the actual humidity change on the air side and the absolute value of the maximum humidity change possible under given conditions:

$$\varepsilon_{\text{tower}} = |Y_i - Y_o| / |Y_i - Y_{o.\text{min/max}}|$$

The maximum humidity change is achieved when the partial vapor pressure of the air at the outlet is equal to the saturation pressure of the solution at the inlet of the tower. This efficiency is valid both for dehumidification and regeneration tests.

Figures 4(*a*) and (*b*) show the tower efficiency for the experimental tests carried out. The efficiency increases with the mass flow rate ratio, with a similar trend for dehumidification and regeneration tests but with a different absolute value. Dehumidification efficiency ranges between 40 and 80–90% with a flow rate

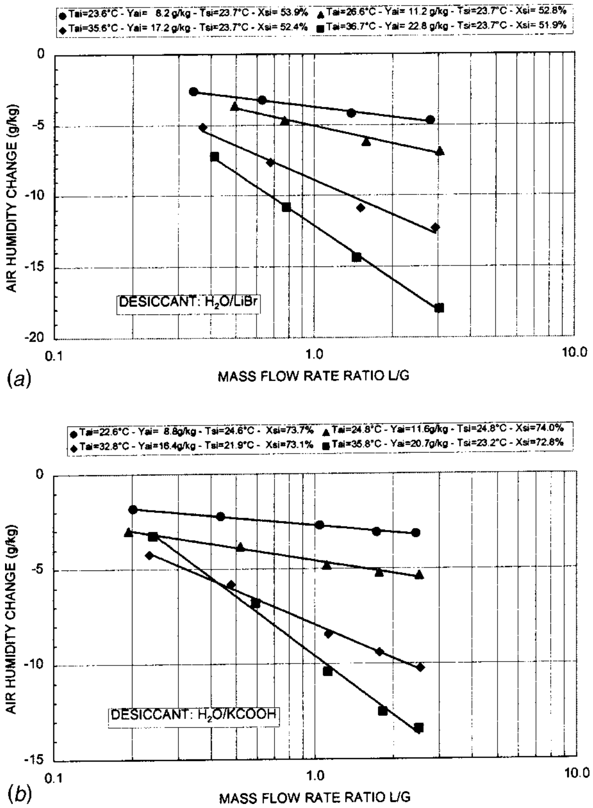

Fig. 2 (***a***) **Humidity reduction versus mass flow rate ratio L/G under dehumidification tests with desiccant H_2O/LiBr.** (***b***) **Humidity reduction versus mass flow rate ratio L/G under dehumidification tests with desiccant H_2O/KCOOH.**

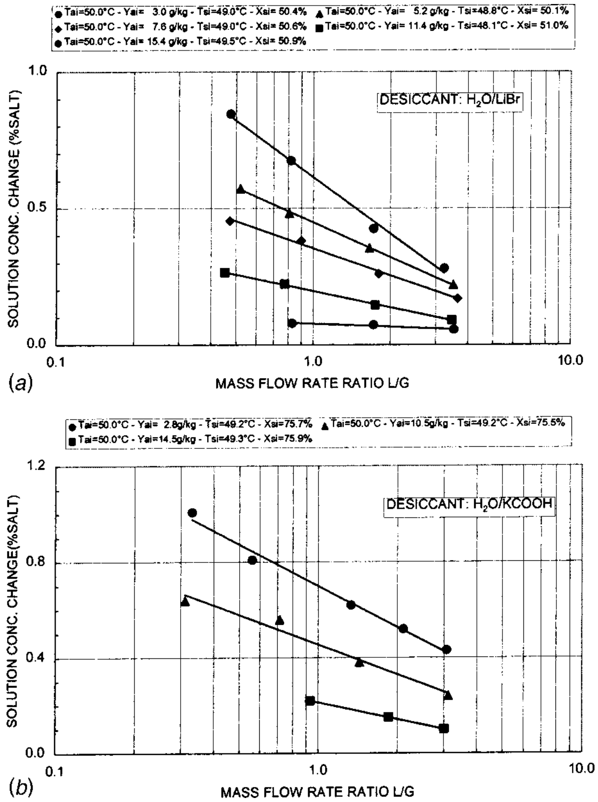

Fig. 3 (***a***) **Solution concentration increase versus mass flow rate ratio L/G under regeneration tests with desiccant H_2O/LiBr.** (***b***) **Solution concentration increase versus mass flow rate ratio L/G under regeneration tests with desiccant H_2O/KCOOH.**

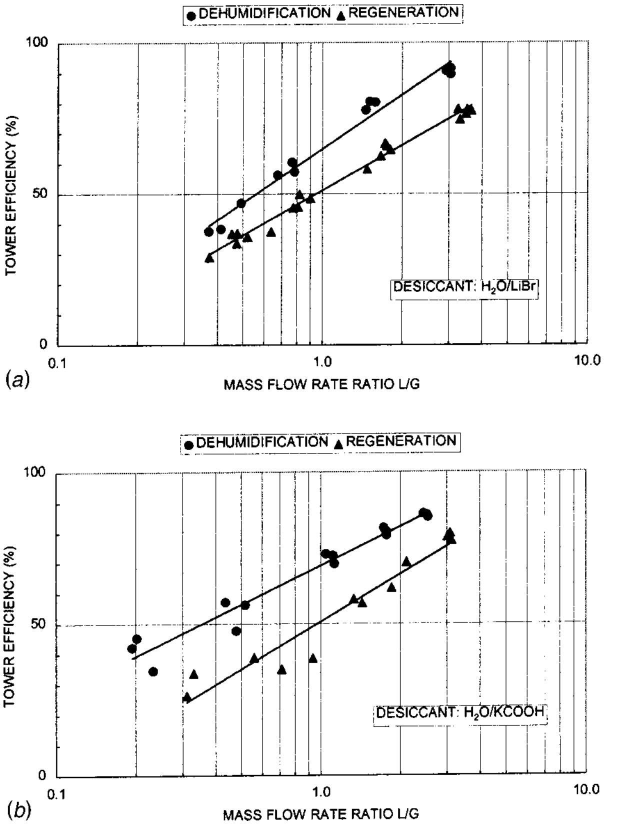

Fig. 4 (*a*) **Tower efficiency vs. mass flow rate ratio under experimental tests with desiccant H_2O/LiBr.** (*b*) **Tower efficiency versus mass flow rate ratio under experimental tests with desiccant H_2O/KCOOH.**

ratio ranging from 0.2 to 3.0, whereas regeneration efficiency varies from 25 to 75% with a flow rate ratio ranging from 0.3 to 3.0.

The experimental results are also compared to a one-dimensional simulation code of an adiabatic packed tower described in [13]. The whole absorption/desorption column is subdivided into an appropriate number of sections, and suitable subroutines were realized to evaluate heat and mass transfer coefficient in accordance with [6,8,9]. Initial assumptions on outlet conditions can be verified and adjusted by iteration. The model can specify the main characteristics of the packing. Temperature, humidity ratio and specific flow rate are supplied for the air inlet. Temperature, concentration and flow rate at the inlet are given as regards the sorbent. The model computes the correspondent values at the outlet and also provides an insight into the process down the column. Thermodynamical, thermophysical, and transport properties of the desiccant H_2O/LiBr were calculated in accordance with [15–18], whereas the properties of desiccant H_2O/KCOOH were computed in accordance with [12]. Figure 5 shows the comparison between experimental and calculated air humidity change during dehumidification tests, whereas Fig. 6 shows experimental versus calculated solution concentration change during regeneration tests. The simulation code reproduces dehumidification runs with a mean absolute deviation of around 9.9% and regeneration tests with a mean absolute deviation of around 16.4%. Therefore the model reproduces the experimental data within their experimental accuracy and it appears adequate to simulate the investigated processes.

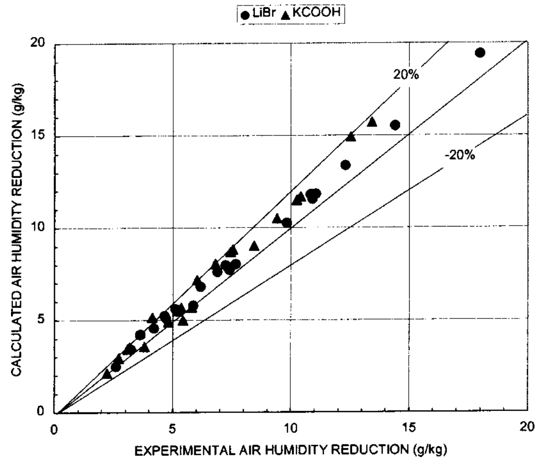

Fig. 5 Comparison between experimental and calculated dehumidification rate

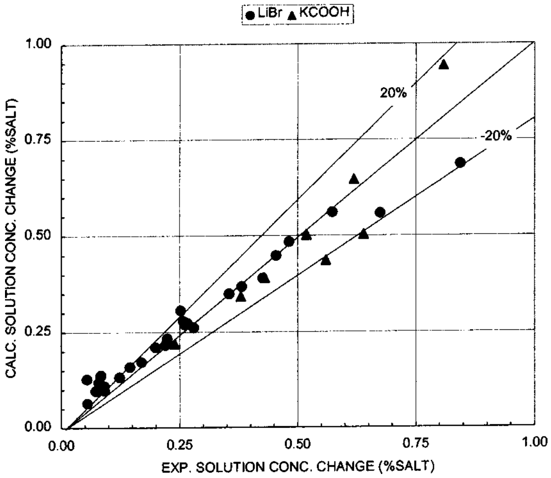

Fig. 6 Comparison between experimental and calculated regeneration rate

4 Conclusion

This paper presents the experimental tests on sorption dehumidification of air by liquid desiccant and desiccant regeneration carried out in an absorption/desorption tower with random packing using the liquid desiccants H_2O/LiBr and H_2O/KCOOH.

The traditional solution H_2O/LiBr presents better dehumidification performance than new solution H_2O/KCOOH which gives better performance in regeneration tests. However the new solution H_2O/KCOOH, less corrosive and expensive than traditional desiccants, allows humidity reductions which are suitable for the application to air conditioning or drying processes.

The comparison between experimental tests and a one-dimensional simulation code of the absorption/desorption tower shows a fair agreement.

The experimental data reported are useful for the design of dehumidification systems providing information concerning a new interesting desiccant, H_2O/KCOOH

Nomenclature

ε = tower efficiency [%]
G = air mass flow rate [kg/s]
L = desiccant mass flow rate [kg/s]
S = area of the cross section of the tower [m^2]
T = temperature [K]
X = desiccant concentration [%Salt]
Y = humidity ratio [$g/kg_{d.a.}$]

Subscript

a = air
d.a. = dry air
i = inlet
max = maximum
min = minimum
o = outlet
s = desiccant

References

[1] Lazzarin, R. M., Gasparella A., and Longo G. A., 1999, ''Analysis of an Innovative HVAC Plant Based on an Open Cycle Absorption System,'' *Proc. Int. Absorption Heat Pump Conf.*, Munich (Germany), March 24–26, 1999, pp. 151–156.

[2] Lazzarin, R. M., Gasparella A., and Longo G. A., 1999, ''Analysis of an innovative HVAC System for a Hospital,'' *Proc. 20th Int. Congr. of Refrigeration*, Sydney (Australia), September 18–24, 1999.

[3] Oliveira, A. C., Alfonso, C. F., Riffat, S. B., and Doherty, P. S., 2000, ''Thermal Performance of a Novel Air Conditioning System Using a Liquid Desiccant,'' Appl. Therm. Eng., **20**, pp. 1213–1223.

[4] Kathabar technical information, www.kathabar.com, 2001.

[5] DryKor technical information, www.drykor.com, 2001.

[6] Treybal, R., 1980, *Mass Transfer Operations*, McGraw Hill, New York, pp. 187–219.

[7] Löf, G. O. G., Löf, P., Lenz, T. G., and Rao, S., 1984, ''Coefficients of Heat and Mass Transfer in a Packed Bed Suitable for Solar Regeneration of Aqueous Lithium Chloride Solution,'' J. Sol. Energy Eng., **106**, pp. 387–392.

[8] Gandhidasan, P., Kettelborough, C. F., and Rifat Ullah, M., 1986, ''Calculation of Heat and Mass Transfer Coefficients in a Packed Tower Operating with Desiccants-Air Contact System,'' J. Sol. Energy Eng., **108**, pp. 123–128.

[9] Factor, H. M., and Grossman, G., 1980, ''A Packed Bed Dehumidifier/regenerator for Solar Air Conditioning with Liquid Desiccants,'' Sol. Energy, **24**, pp. 541–550.

[10] Patnaik, P., Lenz, T. G., and Löf, G. O. G., 1990, ''Performances Studies for an Experimental Solar Open-cycle Liquid Desiccant Air Dehumidification System,'' Sol. Energy, **44**, pp. 123–135.

[11] Khan, A. Y., and Ball, H. D., 1993, ''Experimental Performance Verification of a Coil-type Liquid Desiccant System at Part-load Operation,'' Sol. Energy, **51**, pp. 401–408.

[12] Ertas, A., Gandhidasan, P., Kiris, I., and Anderson, E. E., 1994, ''Experimental Study on the Performance of a Regeneration Tower for Various Climatic Conditions,'' Sol. Energy, **53**, pp. 125–130.

[13] Lazzarin, R. M., Gasparella, A., and Longo, G. A., 1999, ''Chemical Dehumidification by Liquid Desiccant: Theory and Experiment,'' Int. J. Refrig., **22**, pp. 334–347.

[14] Gommed, K., Grossman, G., and Ziegler, F., 2002, ''Experimental Investigation of LiCl Water Open Absorption System for Cooling and Dehumidification,'' *Proc. Int. Absorption Heat Pump Conf.*, Shanghai (R.P. China), September 24–27, 2002, pp. 391–396.

[15] Mcnelly, L., 1979, ''Thermodynamic Properties of Aqueous Solutions of Lithium Bromide,'' ASHRAE Trans., **85**, pp. 412–434.

[16] Lower, H., 1961, ''Thermodynamische eigenschaften und warmediagramme des binaren systems lithiumbromid wasser,'' Kältetechnik, pp. 178–184.

[17] Lower, H., 1961, ''Dichte, spezifische warme, warmeleitzahl, dynamische viskosität der wasseringen lithiumbromid lösung,'' Kältetechnik.

[18] Hellmann, H. M., and Grossman, G., 1996, ''Improved Property Data Correlations of Absorption Fluids for Computer Simulation of Heat Pump Cycles,'' ASHRAE Trans., **102**(1), pp. 980–996.

[19] Riffat, S., 1998, Private communications.