Journal of Engineering Science and Technology
Special Issue on Development of Sustainability Systems - II, 40 - 56

DEHUMIDIFICATION USING LICL, $CdCl_2$, AND NACL INORGANIC LIQUID DESICCANT MATERIALS WITH CELLULOSE AND PLASTIC PACKING

FARAH G. FAHAD[1,*], SHUROOQ T. AL-HUMAIRI[1], AMGED T. AL-EZZI[2,3], HASAN S. MAJDI[4], AUWAL ALIYU[5]

[1]Chemical Engineering Department, University of Technology- Iraq, Baghdad, Iraq
[2]Electromechanical Engineering Department, University of Technology- Iraq
[3]American University of Iraq, Baghdad, Iraq
[4]Chemical Engineering Department, Al-Mustaqbal University, Hillah 51001, Babil, Iraq
[5]Chemical Engineering Department, Ahmadu Bello University, Zaria 810211, Nigeria
*Corresponding Author email: che.21.08@grad.uotechnology.edu.iq

Abstract

Moisture removal to regulate the indoor humidity and improve the comfort level of indoor buildings is essential in the air conditioning system. This study investigates a packed bed to evaluate the dehumidification efficiencies of diverse salt solutions in liquid desiccant dehumidifiers (LDD). Three distinct dehumidification liquids, LiCl, $CdCl_2$, and NaCl, at concentrations of 400, 600, and 800 g/L, with flow rates of 2, 3, and 4 L/min, at two inlet air relative humidity of 60% and 90% were investigated. Additionally, two types of packed beds, namely cellulose and plastic beds, were selected for assessment. Elevating the concentration of the inlet LDD results in a decreased vapour pressure on the LDD surface, thereby amplifying the difference in water vapour pressure between the desiccant and the humid air. Augmenting the LDD flow rate corresponds to an increase in moisture removal. The cellulose-packed bed exhibited superior performance. Furthermore, lithium chloride exhibited greater efficiency compared to cadmium chloride and sodium chloride in the dehumidification process. Despite lithium chloride yielding optimal results among the inorganic liquid desiccants studied, it is noteworthy that cadmium chloride and sodium chloride are economically viable and readily accessible. Dehumidification efficiency of 80% and 31.6% were achieved with $CdCl_2$ and NaCl, respectively, with a concentration of 800 g/L, 4 L/min flow rate, with a cellulose-packed bed. The optimal conditions for maximum dehumidification efficiency of 88.3% with LiCl, 800 g/L concentration, 4 L/min flow rate, and an inlet relative humidity of 90%, coupled with a cellulose-packed bed.

Keywords: Anhydrous salt, Capture moisture, Cross current, Hygroscopic properties; Liquid desiccant absorber, Removal efficiency.

1. Introduction

Utilising liquid desiccants for dehumidification leverages their ability to absorb moisture directly from the air, leading to reduced energy consumption. The core function of liquid desiccant dehumidification (LDD) systems is their moisture absorption capability. Liquid desiccants, with hygroscopic properties, effectively absorb atmospheric moisture, thus dehumidifying air upon contact [1]. This is particularly advantageous in hot, humid regions and also aids in removing pollutants from the air stream [2]. Controlling indoor humidity significantly affects human comfort and health. Many industrial processes emit gases containing water vapour.

Petrochemical operations like steam cracking and steam reforming and industries such as iron and steel processing or natural gas production, release substantial water vapour [3]. Moisture removal is critical in air-drying and separation processes to prevent corrosion, hydrate formation, hydrolysis, and condensation-related issues [4, 5]. Water vapour may also act as a catalytic toxin or induce unwanted reactions, prompting the use of catalytic methods for moisture elimination [6]. As industries demand higher quality and energy efficiency, the necessity for moisture removal has intensified [7]. Various dehydration techniques such as adsorption, absorption, and compression are employed, with air dehumidification being more complex than temperature regulation [8, 9].

Dehumidification involves removing water vapour through cooling, increasing air pressure, or using solid or liquid desiccants. Cooling and pressurisation are energy-intensive processes [10]. Thus, selecting the appropriate liquid desiccant for LDD systems is crucial for dehumidification and regeneration. Desiccants must possess low surface tension, high heat transfer, low viscosity, low equilibrium vapour pressure, non-corrosiveness, and be cost-effective [11, 12].

Common desiccants include calcium chloride, magnesium chloride, lithium bromide, and lithium chloride, with their applications widely studied in modern engineering [13]. Inorganic salts like potassium formate, calcium chloride, lithium chloride, and lithium bromide are often used in LDD systems. The efficiency of these systems is influenced by the vapour pressure difference between the air's water content and the desiccant solution [14]. Lower vapour pressure improves desiccant effectiveness, producing drier air. Lithium chloride (LiCl), with the lowest vapour pressure and dehydration concentration of 30%-40%, is the most stable liquid desiccant [15].

While lithium bromide (LiBr) is about 20% more expensive than LiCl, it offers similar properties. Calcium chloride ($CaCl_2$), though the least costly and most accessible desiccant, has variable stability depending on concentration and air quality [13]. Saline desiccants can cause severe metal corrosion in dehumidifiers, prompting research into alternative solutions. LDDS dehumidifiers use external cooling sources to lower solution temperatures, enhancing dehumidification capacity. Liquid desiccant air conditioning (LDAC) systems are recognised for their energy efficiency in cooling applications [16]. Unlike conventional systems that overcool air below the dew point and reheat it for moisture removal, LD systems absorb moisture without excessive cooling [17, 18].

However, LD requires regeneration to maintain performance [19]. Key properties of LDAC systems include low vapour pressure, high solubility, low viscosity, low corrosiveness, chemical stability, non-toxicity, and odorlessness

[20]. While LiCl is highly effective, its cost limits widespread use. More affordable alternatives like sodium chloride (NaCl) and cadmium chloride ($CdCl_2$) are readily available, though their dehumidification capacities are less explored [21-23].

Liquid desiccants fall into two main categories: triethylene glycol (TEG) solutions and inorganic salts like LiCl, LiBr, and $CaCl_2$ [24]. However, TEG desiccants evaporate quickly due to their boiling points being close to water's [23]. Among halide salts, LiCl remains the most stable and effective but is costly. LiBr is similar in performance but more expensive, while $CaCl_2$ is cheaper but less stable. Magnesium chloride ($MgCl_2$) is less popular due to its low working concentration and high cost, driven by the need for further technological development [25]. Extensive studies have investigated the dehumidification performance of LiCl [26-28], LiBr [29, 30], and $CaCl_2$ [29]. Research also explores mixtures, such as 31.2% LiCl with 20% $CaCl_2$ [31] and composite desiccants combining silica gels with LiCl, $CaCl_2$, and polyvinyl alcohol [32].

Innovations include scalable 3D-printed electro-dialytic cells for deep eutectic solvent (DES) regeneration, achieving current efficiency ratings up to 65.82% [33]. Promising DES combinations include choline chloride with ethylene glycol and 1-butyl-3 imidazolium chloride with ethylene glycol, both potential alternative desiccants for air conditioning systems [34]. These binary DESs meet green chemistry standards and are environmentally benign working fluids suitable for heat and mass transfer systems [35].

Dependent on ambient humidity, either evaporation or vapour absorption occurs, causing fluctuations in salt concentration within the droplet. This variation in salt concentration alters the vapour pressure difference between the droplet surface and the surrounding air, consequently influencing the interfacial mass flux [36] and droplet dynamics. The behaviours of hygroscopic salt solution droplets encompass both evaporative and absorptive mass fluxes, hinging on the thermos physical properties of the salt solution and the environmental conditions.

Excess moisture fosters mould, mildew, and bacterial growth, causing health issues and structural damage while making indoor environments uncomfortable. This study evaluates LiCl, $CdCl_2$, and NaCl at concentrations of 400, 600, and 800 g/L, with flow rates of 2, 3, and 4 L/min, under inlet relative humidities of 60% and 90%, to assess dehumidification performance in hot, humid regions. The research contributes to sustainability by addressing challenges and potential barriers to using desiccant agents in various industries.

2. Materials and Methods

2.1. Materials

The main chemical materials used were Lithium chloride (>99%) purchased from Fluka Switzerland, Cadmium chloride (>98%) purchased from Thomas Baker India, and Sodium chloride (≥97%) from commercial.

2.2. Preparation of concentrated LD solution

Brine solutions were prepared based on the solubility of each salt: lithium chloride (800 g/L) [37], cadmium chloride (119.6 g/100 mL) [38], and sodium chloride (395 g/100 mL) [39]. Using LiCl's solubility, the law of dilution was applied to achieve

600 g/L and 400 g/L concentrations. Equivalent ratios of $CdCl_2$ and NaCl were prepared for consistent results. Densities were measured with a pycnometer, and salts were mixed with 15, 20, and 30 L of water for 20 minutes. LiCl, $CdCl_2$, and NaCl solutions at 800, 600, and 400 g/L were placed in a tank. A 0.75 kW water pump directed the solution through a pipeline to the shower, with flow rates measured via a flow meter and controlled by a valve. The used solution was redirected to the evaporative cooler basin for cooling. The system included pipes, valves, tanks, and other accessories.

2.3. Experimental setup

The schematic representation of the experimental setup is delineated in Fig. 1. The principal focus is on the dehumidifier section. In adherence to the experimental design, two distinct types of packing materials were chosen: cellulose papers and a plastic bed. These materials were strategically positioned within the dehumidifier to augment the heat and mass transfer interface between the air and the liquid desiccant. Additionally, the system incorporates a regenerator section featuring adiabatic cooling for the salt solution, an electrical air heater, and a centrifugal pump of model SJGW75.

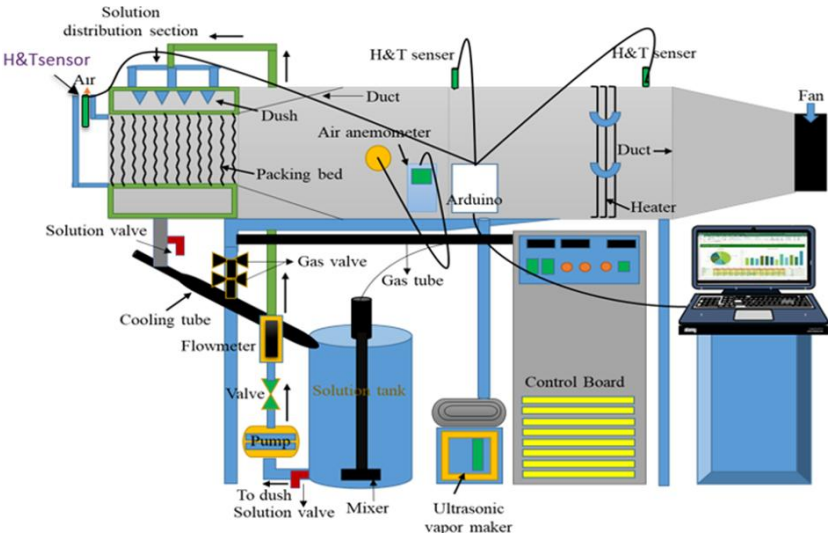

Fig. 1. Schematic diagram of the experimental setup of the liquid desiccant cross-flow dehumidifier.

Fan centrifugal blower type (C80/15/2SO), ultrasonic vapour maker /China, solution tank, and collection tank. While designing and fabricating the experimental test rig, all possible problems and requirements are taken into consideration. The absorber-dehumidifier section is the core of the LDDS system. They transfer heat and moisture between air and liquid desiccant solution and are functionally identical.

This work describes the preparation of liquid-desiccant dehumidification samples, each composed of distilled water contaminated with

(i) salts at different concentrations of 400, 600, and 800 gm/L,

(ii) salt solution flow rate at 2, 3 and 4 L/min, and inlet air RH% of 60 and 90% were investigated using two types of bed, cellulose and plastic beds.

Cellulose paper and Plastic (Hexagonal Honeycomb Tube Settler Packing) are used to make dehumidifier pads, as shown in Fig. 2. The dimensions and manufacturers of the packed beds are mentioned in Table 1.

Table 1. Provide the dimensions and manufacturers of packing pads.

TYPES	HEIGHT (CM)	LENGTH (CM)	WIDTH (CM)	MANUFACTURE
Cellulose Paper	50	50	50	China
Plastic	50	50	50	China

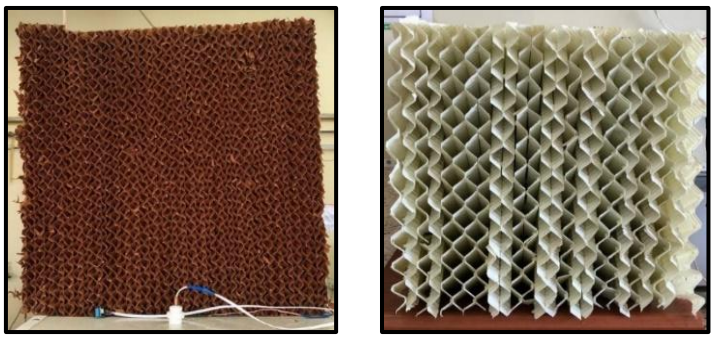

Fig. 2. Pictures of the packed beds: Left: Cellulose paper, Right: Plastic.

2.4. Moisture capture experiment steps

Using a Digital Anemometer with an accuracy of ±0.025 m/s, the fan and ultrasonic vapour generator are turned on to create steam in the air, confirming the system's operation. In the dehumidification portion, saline solutions at concentrations of 800, 600, and 400 g/L are pumped into the LDD solution tank and sprayed onto the packing bed, allowing air to flow through. After cooling, the diluted solution is regenerated for 30 minutes at 55 °C. Two K-type thermocouples monitor the temperature of the air and solution, and five DHT11 sensors measure the humidity and temperature of the air at strategic locations. An Arduino system collects data and sends it to a computer for analysis.

Upon completion of the dehumidification system measurements, the data logger is deactivated, and the fan is switched off. Subsequently, the brine in the tank is emptied, the pump is cleaned to eliminate any remaining salt, and the drain valve is opened to evacuate the brine. Finally, the pump is switched off.

The following presumptions were taken into account when creating the experimental setup's parts [40]:

- There is no desiccant carryover, and the regenerator and dehumidifier are adiabatic.
- Throughout the entire segment, the desiccant solution and air dispersion are thought to be uniform.
- There is no discernible pressure reduction across connected pipes.
- The area of contact between desiccant and air is the same.

Meanwhile, the definition of relative moisture removal efficiency is as follows in Eq. (1) [41].

$$Dehumidification\ Efficiency\% = [\frac{RH\%\ in - RH\%\ out}{RH\%\ in}] * 100 \quad (1)$$

where: $RH\%_{in}$ is the percentage relative humidity of inlet air and $RH\%_{out}$ of outlet air.

3. Results and Discussion

3.1. System analysis at various concentrations

The variation in inlet air relative humidity significantly influences the dehumidification process when employing inorganic liquid desiccant materials. The transition from 60% to 90% relative humidity results in an enhancement of dehumidification efficiency. This phenomenon is attributed to the decrease in outlet humidity as the incoming air relative humidity rises from 60% to 90%, owing to an increase in the water vapour pressure difference between the processed air and the salt solution [42]. These findings align well with the observations reported by Kavasoğulları et al. [41]. As air relative humidity climbs from 60% to 90%, dehumidification efficiency increases. This is because a larger water vapour pressure differential between the air and salt solution lowers exit humidity.

After removing moisture from the air, desiccant materials are heated to eliminate any moisture that has been absorbed so they can be used again. Desiccants include salt solutions such as lithium or cadmium chloride. The desiccant absorbs water vapour from the air until it reaches saturation as part of the counter current dehumidification process. The desiccant is then regenerated to regain its ability to absorb moisture.

The findings clearly indicate that, across all utilised liquid desiccants at a concentration of 800 g/L, the dehumidification performance surpasses that observed at concentrations of 600 g/L and 400 g/L, utilising both cellulose and plastic packings. Notably, at the 800 g/L concentrations, the cellulose packing demonstrates superior dehumidification performance compared to the plastic packing, as illustrated in Fig. 3 ($CdCl_2$), Fig. 4 (LiCl), and Fig. 5 (NaCl). This observation aligns with the findings of Das et al. [43]. It suggests that it is necessary to elevate the desiccant concentration in the liquid solution or increase the contact time between the air and the desiccant to offset higher inlet air humidity ratios. Similar ascending trends and explanations are applicable to salt solutions utilising plastic packing.

Consistent with the prior observations, the absolute moisture removal of the LiCl solution slightly exceeded that of the $CdCl_2$ solution and significantly surpassed that of the NaCl solution, attributable to the thermophysical and hygroscopic properties of brine solutions. Among brine solutions, 800 g/L LiCl emerges as the optimal choice for a liquid desiccant, as the vapour pressure of water above a saturated LiCl solution is lower than that of $CdCl_2$ and NaCl desiccants [26]. According to Eq. (2), a lower vapour pressure translates to improved desiccant performance, resulting in drier outlet air [44].

$$RH = \frac{P_w}{P^s} \quad (2)$$

where RH is relative humidity, p_w is the ambient vapour pressure of water, and p^s is the saturation water vapour pressure.

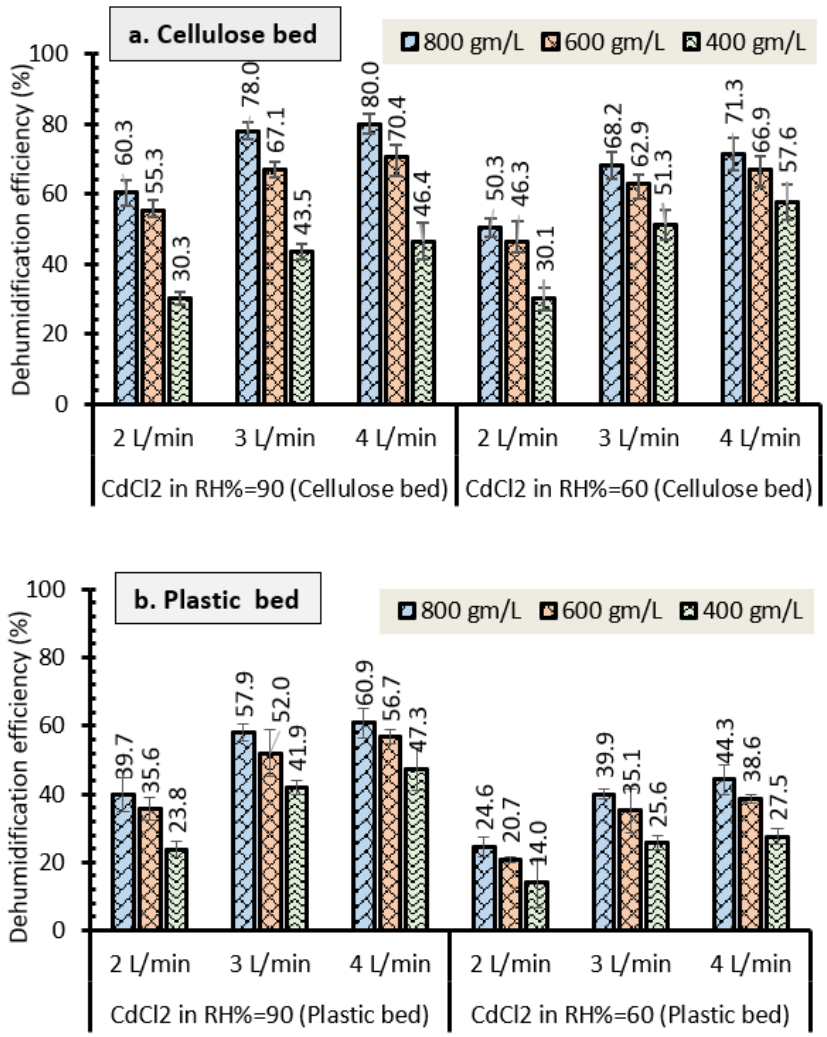

Fig. 3. Dehumidification efficiencies at various concentrations 800, 600, and 400 gm/l and flowrates 2, 3 and 4 L/min of $CdCl_2$ solution using a cross-flow dehumidifier with (a) cellulose bed and (b) plastic bed.

3.2. Liquid desiccant concentration

The impact of salt concentrations (LiCl, $CdCl_2$, and NaCl) at varying relative humidity ratios (90% and 60%) and utilising two types of packing materials (cellulose and plastic) across different liquid desiccant flow rates on dehumidification efficiency is illustrated in Fig. 3 ($CdCl_2$), Fig. 4 (LiCl), and Fig. 5 (NaCl). A pronounced reduction in the relative humidity of the outlet air stream is observed with escalating inlet desiccant concentrations, resulting in enhanced dehumidification efficiency. This phenomenon can be attributed to the reduction in desiccant surface vapour pressure as the inlet desiccant concentration increases, thereby amplifying the average water vapour pressure difference between the desiccant and the air within the dehumidifier. Consequently, the air outlet humidity

ratio diminishes, leading to a lower relative humidity. This interpretation aligns with the findings of Das et al. [43] and Katejanekarn et al. [45].

Thus, an elevated inlet desiccant concentration from 400 g/L to 800 g/L induces a more substantial reduction in relative humidity for air entering the dehumidifier at 90% humidity compared to 60%. Because desiccants have a high affinity for water, they are employed to remove moisture from the air. As a result of water vapour shifting from greater vapour pressure in the air to lower vapour pressure in the desiccant, dehumidification takes place. The vapour pressure of the desiccant decreases with increasing concentration, which increases the vapour pressure differential and improves the absorption of moisture.

Higher concentrations of adsorption sites enhance the rates of water vapour absorption and desorption, accelerating the elimination of moisture. In general, faster and more effective dehumidification is the result of increased desiccant concentrations.

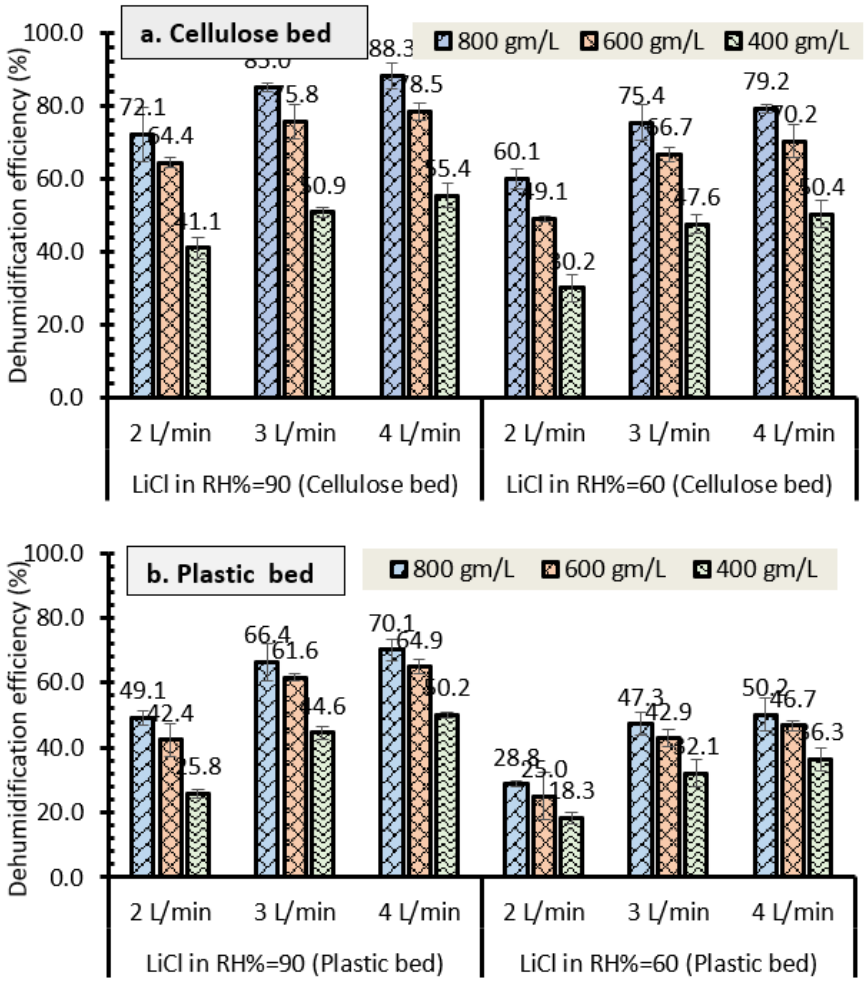

Fig. 4. Dehumidification efficiencies at various concentrations (800, 600, and 400 gm/l) and flowrates 2, 3 and 4 L/min of LiCl solutions using a cross-flow dehumidifier with (a) cellulose and (b) plastic packed bed.

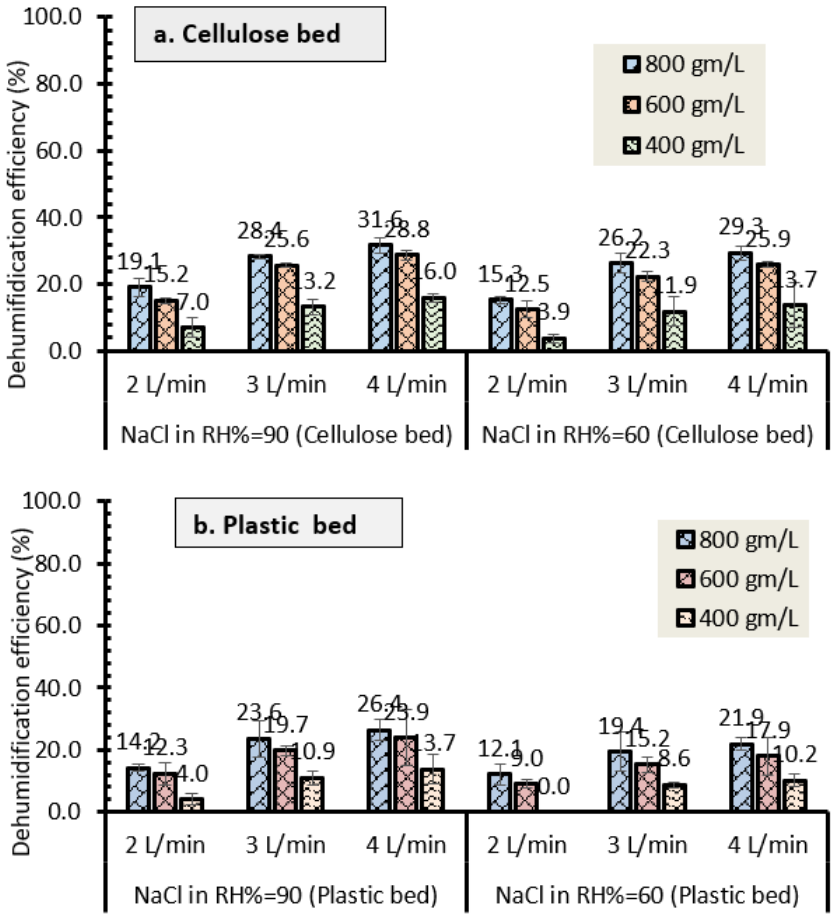

Fig. 5. Dehumidification efficiencies at various concentrations (800, 600, and 400 gm/l) of and flowrates 2,3 and 4 L/min NaCl salt solutions using a cross-flow dehumidifier with (a) cellulose and (b) plastic packed bed.

The results from this study indicate that cellulose packaging outperforms plastic packaging in dehumidification across all three liquid desiccants ($CdCl_2$, LiCl, and NaCl) due to cellulose's higher moisture absorption capacity [46]. Cellulose, being a natural and biodegradable material derived from plant fibres, possesses an enhanced capacity for absorbing moisture owing to its porous structure. This superior moisture absorption capability of cellulose, as depicted in Figs. 3-5 establish it as an effective desiccant material in the dehumidification process. Conversely, plastic packaging lacks the same moisture absorption capacity as cellulose, being a non-porous material that restricts the easy passage of moisture [47]. Consequently, plastic packaging is less effective in absorbing moisture from the air, rendering it suboptimal for utilisation as a desiccant in the dehumidification process.

Observations from the experimental results in Figs. 3-5 highlights that Lithium chloride exhibits superior efficiency compared to cadmium chloride and sodium chloride in the dehumidification process, attributed to its heightened

affinity for water molecules and greater moisture absorption capacity [48]. Lithium chloride's highly hygroscopic nature, indicating a robust tendency to absorb water vapour from the air [14], renders it an efficacious desiccant material for dehumidification applications.

In contrast, cadmium chloride, while also hygroscopic, demonstrates lower efficiency in moisture absorption compared to lithium chloride due to its diminished affinity for water molecules. Consequently, higher quantities of cadmium chloride are necessary to achieve an equivalent dehumidification level as lithium chloride. Additionally, lithium chloride is acknowledged as a safer and more environmentally friendly desiccant material compared to cadmium chloride, as also mentioned by Gu et al. [49].

Moreover, sodium chloride (NaCl) exhibits some ability to absorb water from the environment due to its hygroscopic nature, albeit to a significantly lesser extent compared to the two salts investigated in this research. The findings indicate the effective absorption of water vapour by the liquid desiccant. Despite the incorporation of heat insulation in the system, there is minimal heat loss observed between the experimental setup and the ambient air, contributing to the observed disparities in heat transfer. Dehumidification efficiencies were assessed at concentrations of 800, 600, and 400 g/L and flow rates of 3, 4, and 5 L/min using $CdCl_2$, LiCl, and NaCl solutions, shown in Figs. 3-5, respectively, with both cellulose and plastic beds.

3.3. Liquid desiccant volumetric flow rate

Figures 3-5 display three salts (LiCl, $CdCl_2$, and NaCl) in cellulose and plastic packings at 60% and 90% relative humidity to show how the flow rates of salt solutions affect dehumidification. The pump capacity determines the maximum flow rate limit, while the lower limit guarantees that the dehumidifier packing is continuously wet. With cellulose packing, the best moisture removal rate was 4 L/min, which was closely followed by 3 L/min for all desiccant concentrations. Although 4 L/min is optimal, 3 L/min removes moisture at a comparable rate, indicating effective functioning at somewhat lower flow rates. These findings align with the work of Wen et al. [50]. They found that, despite doubling the flow rate, the absolute moisture removal by 35% LiCl remained constant because it had little effect on the falling film's wettability.

By increasing interaction with humid air and accelerating the removal of moisture, higher flow rates improve dehumidification. Higher flow rates enable the processing of more air in less time, lowering the risk of saturation because desiccants lose efficiency upon saturation. This increases overall efficiency in cyclic systems by shortening absorption-regeneration cycles.

Particularly for cellulose packing, measurement uncertainty had a minor impact on the moisture removal patterns, highlighting the importance of carefully interpreting data. Because cellulose and wet air had a longer contact duration, cellulose packaging performed somewhat better than plastic packing. Longer contact times remove more moisture, which is caused by the vapour pressure difference between the desiccant and water. LiCl, at equal concentrations, demonstrated a marginally better dehumidification effectiveness than both $CdCl_2$ and NaCl [50-52].

3.4. Dehumidification time

Dehumidification time and effectiveness are greatly influenced by operational factors such as air inlet relative humidity, desiccant concentration, solution flow rate, desiccant type, and packing material. More air-desiccant contact during an extended dehumidification period improves moisture removal. Longer periods, however, can eventually decrease efficiency because of desiccant saturation and diminishing returns as equilibrium is reached [11, 53]. Dehumidification of LiCl solutions at 800 g/L required five minutes for both plastic and cellulose packaging at 60% and 90% relative humidity, as shown in Fig. 6. The strong hygroscopicity of LiCl causes this speedy process, which results in rapid saturation and loss of moisture absorption ability. However, because of their poorer hygroscopic qualities, $CdCl_2$ and NaCl solutions required more than 15 and over 20 minutes, respectively (Figs. 7 and 8) [43, 54].

Long drying times use more energy, and the slight improvements in moisture removal might not be worth the extra expense. To determine their effect on overall system performance, factors like (i) air inlet relative humidity (60% and 90%), (ii) desiccant concentration (400, 600, 800 g/L), (iii) flow rates (2, 3, 4 L/min), and (iv) dehumidification time were thoroughly evaluated.

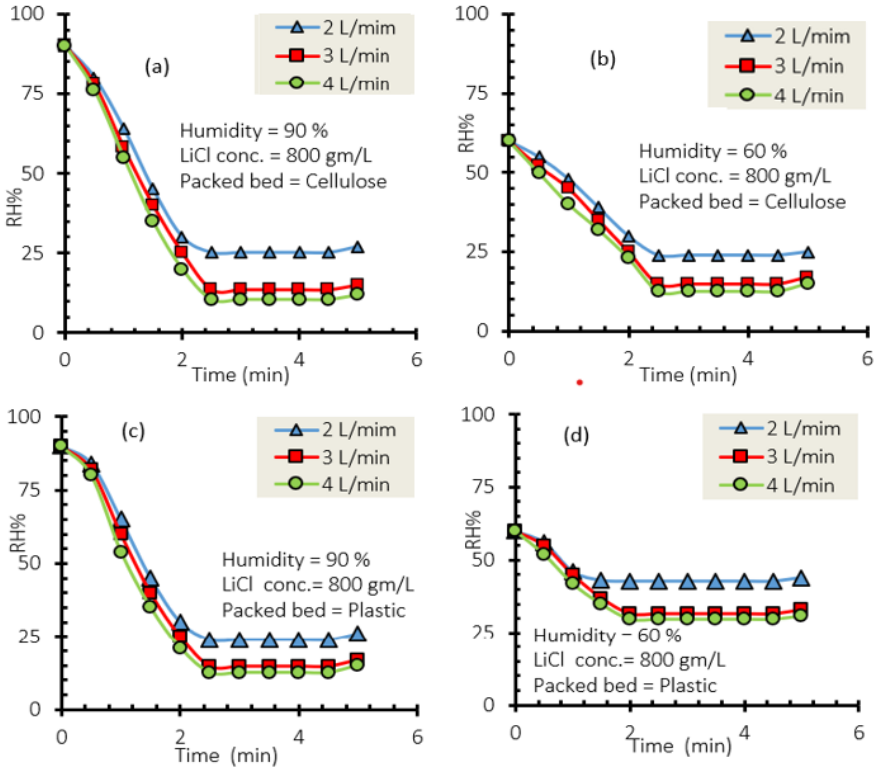

Fig. 6. The effect of humidity removal time with LiCl solution at a concentration 800 gm/L at desiccant solution flow rates for inlet air RH in cellulose packing (a) 90% humidity, (b) 60% humidity, and in plastic packing (c) 90% humidity and (d) 60% humidity.

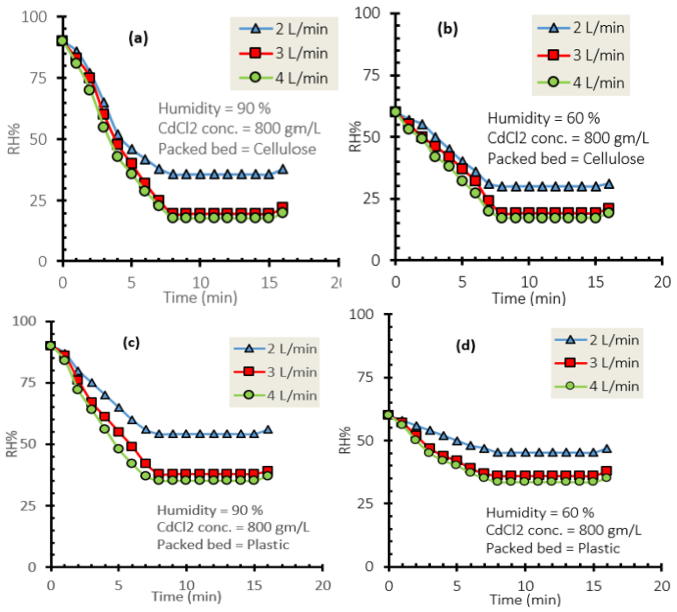

Fig. 7. The effect of humidity removal time with $CdCl_2$ solution at concentration 800 gm/Lat different desiccant solution flow rates for inlet air RH, (a) 90 % and (b) 60 % in CP in cellulose packing (c)at inlet air relative humidity =90% and (d) at inlet air relative humidity = 60% in plastic pack.

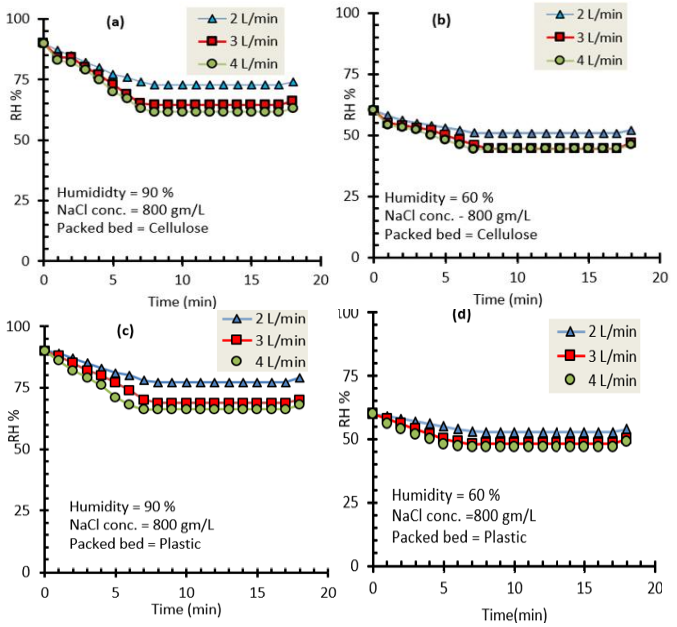

Fig. 8. The effect of humidity removal time with NaCl solution at concentration 800 gm/Lat different desiccant solution flow rates for inlet air RH, (a) 90 % and (b) 60 % in CP in cellulose packing (c)at inlet air relative humidity =90% and (d) at inlet air relative humidity = 60% in plastic pack.

4. Conclusions

This study focused on the dehumidification performance of LiCl, $CdCl_2$, and NaCl solutions at different concentrations (400, 600, and 800 g/L) and flow rates (2, 3, and 4 L/min) and effectively built and executed a liquid desiccant-based absorber-dehumidifier system. The effect of flow rate, liquid desiccant concentration, and air inlet relative humidity on dehumidification efficiency was assessed. Lithium chloride (LiCl) outperformed $CdCl_2$ and NaCl as the most effective desiccant.

The findings showed that raising the liquid desiccant concentration from 400 to 800 g/L decreased the vapour pressure at the desiccant surface, improving moisture removal because of a larger pressure differential. Additionally, the cellulose-packed bed performed better when the flow rate was increased from 2 to 4 L/min, resulting in better moisture extraction. A concentration of 800 g/L, a flow rate of 4 L/min, and an inlet relative humidity of 90% were the conditions that produced the best dehumidification efficiency of 88.3% using LiCl.

However, the efficiency of $CdCl_2$ and NaCl solutions was much lower at 90% relative humidity. The results demonstrate how lithium chloride's exceptional hygroscopic and thermophysical characteristics help explain its high capacity to absorb moisture. The natural, biodegradable, and porous structure of cellulose packing further improves moisture retention. The results of this study will be helpful to researchers and industry professionals alike in optimising liquid desiccant-based dehumidification systems.

Acknowledgement

The authors extend their gratitude to the Department of Chemical Engineering, University of Technology in Baghdad, Iraq, for generously providing access to laboratories and facilities, as well as for conducting all the necessary technical tests required for the experiments. Special thanks are also extended to Ali Hussein Al-Suray for his invaluable assistance in configuring the experimental system.

Nomenclatures

$CaCl_2$	Calcium Chloride
CP	Cellulose Packing
DEG	Di Ethylene Glycol
LiBr	Lithium Bromide
LiCl	Lithium Chloride
$MgCl_2$	Magnesium Chloride
NaCl	Sodium Chloride
PP	Plastic Packing
psw	Saturation vapour pressure of pure water, N/m^2
pT	Total Pressure, N/m^2
T4EG	Tetra Ethylene Glycol

Abbreviations

DAs	Desiccant Agents
IEQ	Indoor Environment Quality
LD	Liquid Desiccant

LDD	Liquid Desiccant Dehumidifier
LDDS	Liquid Desiccant Dehumidification system
LDS	Liquid desiccant system
LDAC	Liquid desiccant air conditioning
SLA	Stereolithography

References

1. Fahad, F.G.; Al-Humairi, S.T.; Al-Ezzi, A.T.; Majdi, H.S.; Sultan, A.J.; Alhuzaymi, T.M.; and Aljuwaya, T.M. (2023). Advancements in liquid desiccant technologies: A comprehensive review of materials, systems, and applications. *Sustainability*, 15(18), 14021.
2. Mohamed, A.S.A.; Ahmed, M.S.; Hassan, A.A.M.; and Hassan, M.S. (2016). Performance evaluation of gauze packing for liquid desiccant dehumidification system. *Case Studies in Thermal Engineering*, 8, 260-276.
3. Lalik, E.; Kosydar, R.; Tokarz-Sobieraj, R.; Witko, M.; Szumełda, T.; Kołodziej, M.; Rojek, W.; Machej, T.; Bielańska, E.; and Drelinkiewicz, A. (2015). Humidity induced deactivation of Al_2O_3 and SiO_2 supported Pd, Pt, Pd-Pt catalysts in H_2 + O_2 recombination reaction: The catalytic, microcalorimetric and DFT studies. *Applied Catalysis A*: *General*, 501, 27-40.
4. Taresh, H.; Abdul-Zahra, A.; and Saleh, A. (2022). Study the performance of a novel desiccant heat exchanger. *Engineering and Technology Journal*, 41(1), 45-59.
6. Alassi, A.; Burgass, R.; and Chapoy, A. (2022). Water content measurements for liquid propane in equilibrium with water or hydrates: New measurements & evaluation of literature data. *Journal of Natural Gas Science and Engineering*, 108, 104732.
7. Ghaffour, N.; Soukane, S.; Lee, J.-G.; Kim, Y.; and Alpatova, A. (2019). Membrane distillation hybrids for water production and energy efficiency enhancement: A critical review. *Applied Energy*, 254, 113698.
8. Wu, Q. (2017). *Modeling and control of dehumidifier in distributed operating liquid desiccant dehumidification system*. PhD Thesis, Interdisciplinary Graduate School Energy Research Institute, Nanyang Technological University.
9. Ezzi, A.A.; Ismael, L.; Fayad, M.A.; Jaber, A.A.; Jubori, A.M.A.; Al-Jadir, T.; Dhahad, H.A.; Ma, H.; and Yusaf, T. (2022). Experimental investigation of dehumidification and regeneration of zeolite coated energy exchanger. *International Journal of Thermofluids*, 15, 100164.
10. Mohamed, A.S.A.; Ahmed, M.S.; Hassan, A.A.M.; and Hassan, M.S. (2016). Performance evaluation of gauze packing for liquid desiccant dehumidification system. *Case Studies in Thermal Engineering*, 8, 260-276.
11. Giampieri, A.; Ma, Z.; Ling-Chin, J.; Bao, H.; Smallbone, A.J.; and Roskilly, A.P. (2022). Liquid desiccant dehumidification and regeneration process: Advancing correlations for moisture and enthalpy effectiveness. *Applied Energy*, 314, 118962.
12. Guan, B.; Zhang, T.; Liu, J.; Liu, X.; and Yin, Y. (2022). Review of internally cooled liquid desiccant air dehumidification: Materials, components, systems, and performances. *Building and Environment*, 211, 108747.

13. Salikandi, M.; Ranjbar, B.; Shirkhan, E.; Priya, S.S.; Thirunavukkarasu, I.; and Sudhakar, K. (2021). Recent trends in liquid desiccant materials and cooling systems: Application, performance, and regeneration characteristics. *Journal of Building Engineering*, 33, 101579.
14. Song, R.; Zou, T.; Chen, J.; Hou, X.; and Han, X. (2019). Study on the physical properties of LiCl solution. *IOP Conference Series*: *Materials Science and Engineering*, 562(1), 012102.
15. Fumo, N.; and Goswami, D.Y. (2002). Study of an aqueous lithium chloride desiccant system: Air dehumidification and desiccant regeneration. *Solar Energy*, 72(4), 351-361.
16. Abdel-Salam, A.H.; Ge, G.;and Simonson, C.J. (2013). Performance analysis of a membrane liquid desiccant air-conditioning system. *Energy and Buildings*, 62, 559-569.
17. Kalpana; and Subudhi, S. (2022). Developments in liquid desiccant dehumidification system integrated with evaporative cooling technology. *International Journal of Energy Research*, 46(1), 61-88.
18. Dai, Y.J.; Wang, R.Z.; Zhang, H.F.; and Yu, J.D. (2001). Use of liquid desiccant cooling to improve the performance of vapor compression air conditioning. *Applied Thermal Engineering*, 21(12), 1185-1202.
19. Cheng, Q.; and Zhang, X. (2013). Review of solar regeneration methods for liquid desiccant air-conditioning system. *Energy and Buildings*, 67, 426-433.
20. Bhowmik, M.; Naik, B.K.; Muthukumar, P.; and Anandalakshmi, R. (2023). Performance assessment and optimisation of liquid desiccant dehumidifier system using intelligent models and integration with solar dryer. *Journal of Building Engineering*, 64, 105577.
21. Duong, H.C.; Hai, F.I.; Al-Jubainawi, A.; Ma, Z.; He, T.; and Nghiem, L.D. (2017). Liquid desiccant lithium chloride regeneration by membrane distillation for air conditioning. *Separation and Purification Technology*, 177, 121-128.
22. Bouzenada, S.; Kaabi, A.N.; Frainkin, L.; Salmon, T.; and Léonard, A. (2016). Experimental comparative study on lithium chloride and calcium chloride desiccants. *Procedia Computer Science*, 83, 718-725.
23. Chen, X.; Riffat, S.; Bai, H.; Zheng, X.; and Reay, D. (2020). Recent progress in liquid desiccant dehumidification and air-conditioning: A review. *Energy and Built Environment*, 1(1), 106-130.
24. Guo, Y.; Ma, Z.; Al-Jubainawi, A.; Cooper, P.; and Nghiem, L.D. (2016). Using electrodialysis for regeneration of aqueous lithium chloride solution in liquid desiccant air conditioning systems. *Energy and Buildings*, 116, 285-295.
25. Namvar, R.; Pyra, D.; Ge, G.; Simonson, C.J.; and Besant, R.W. (2012). +Transient characteristics of a liquid-to-air membrane energy exchanger (LAMEE) Experimental data with correlations. *International Journal of Heat and Mass Transfer*, 55(23-24), 6682-6694.
26. Chen, Y.; Zhang, X.; and Yin, Y. (2016). Experimental and theoretical analysis of liquid desiccant dehumidification process based on an advanced hybrid air-conditioning system. *Applied Thermal Engineering*, 98, 387-399.

27. Koronaki, I.; Christodoulaki, R.I.; Papaefthimiou, V.D.; and Rogdakis, E.D. (2013). Thermodynamic analysis of a counter flow adiabatic dehumidifier with different liquid desiccant materials. *Applied Thermal Engineering*, 50(1), 361-373.
28. Liu, X.H.; Yi, X.Q.; and Jiang, Y. (2011). Mass transfer performance comparison of two commonly used liquid desiccants: LiBr and LiCl aqueous solutions. *Energy Conversion and Management*, 52(1), 180-190.
29. Cao, B.; Yin, Y.; Zhang, F.; Tong, S.; Che, C.; Chen, W.; Ji, Q.; Xu, G.; and Li, X. (2022). Experimental study on heat and mass transfer characteristics between a novel ionic liquid and air under low-humidity conditions. *International Journal of Heat and Mass Transfer*, 198, 123373.
30. Cheng, Q.; and Pei, W. (2019). Performance comparison on different liquid desiccants in the liquid desiccant air-conditioning using electrodialysis regeneration: LiCl and LiBr aqueous solutions. *International Journal of Refrigeration*, 107, 1-10.
31. Giampieri, A.; Machado, Y.; Ling-Chin, J.; Roskilly, A.P.; and Ma, Z. (2023). A techno-economic investigation of conventional and innovative desiccant solutions based on moisture sorption analysis. *Heliyon*, 9(8), e18825.
32. Chua, K.J. (2015). Heat and mass transfer of composite desiccants for energy efficient air dehumidification: Modelling and experiment. *Applied Thermal Engineering*, 89, 703-716.
33. Oladosu, T.L.; Al-Kayiem, H.H.; Gilani, S.I.U.H.; Baheta, A.T.; and Horng, T.W. (2023). Performance enhancement of electrodialysis regeneration of deep eutectic solvent for liquid desiccant air conditioning systems. *Journal of Building Engineering*, 70, 106343.
34. Oladosu, T.L.; Al-Kayiem, H.H.; Gilani, S.I.U.; and Baheta, A.T. (2021). Dehumidification and thermal regeneration characterisation of binary deep eutectic solvents in liquid desiccant air conditioning systems. *Journal of Building Engineering*, 42, 103056.
35. Al-Kayiem, H.H.; Oladosu, T.L.; Gilani, S.I.U.; and Baheta, A.T. (2021). Molecular dynamics of binary deep eutectic solvents as biocompatible working fluids in heat and mass transfer systems. *Journal of Molecular Liquids*, 342, 117493.
36. Wang, Z.; Orejon, D.; Sefiane, K.; and Takata, Y. (2019). Coupled thermal transport and mass diffusion during vapor absorption into hygroscopic liquid desiccant droplets. *International Journal of Heat and Mass Transfer*, 134, 1014-1023.
37. Kamienski, C.W.; McDonald, D.P.; Stark, M.W.; and Papcun, J.R. (2004). *Lithium and lithium compounds*. In Kirk-Othmer (Ed.), *Kirk - Othmer Encyclopedia of Chemical Technology*. Wiley.
38. Haynes, W.M. (2014). *CRC Handbook of Chemistry and Physics*. CRC Press.
39. Kolafa, J. (2016). Solubility of NaCl in water and its melting point by molecular dynamics in the slab geometry and a new BK3-compatible force field. *The Journal of Chemical Physics*, 145(20), 204509.
40. Babakhani, D.; and Soleymani, M. (2009). An analytical solution for air dehumidification by liquid desiccant in a packed column. *International Communications in Heat and Mass Transfer*, 36(9), 969-977.

41. Kavasoğulları, B.; Cihan, E.; and Demir, H. (2016). Novel packing materials for open liquid desiccant system. *Energy Procedia*, 91, 785-791.
42. Tajeddini, F.; Eslami, M.; and Etaati, N. (2018). Thermodynamic analysis and optimisation of water harvesting from air using thermoelectric coolers. *Proceedings of the ISME*2018, 26th *International Conference on Mechanical Engineering*, Semnan, Iran, 24-26.
43. Das, A.; Das, R.S.; and Das, K. (2022). Performance enhancement of a liquid desiccant absorber with triangular corrugated structured packing. *Journal of Building Engineering*, 45, 103677.
44. Che, C.; Yin, Y.; and Zhang, F. (2020). A modified LIQUAC model for prediction of the vapor pressure of a single liquid desiccant at high concentration and regeneration temperature. *Fluid Phase Equilibria*, 514, 112558.
45. Katejanekarn, T.; Chirarattananon, S.; and Kumar, S. (2009). An experimental study of a solar-regenerated liquid desiccant ventilation pre-conditioning system. *Solar Energy*, 83(6), 920-933.
46. Sahu, P.; and Gupta, M. (2022). Water absorption behavior of cellulosic fibers polymer composites: A review on its effects and remedies. *Journal of Industrial Textiles*, 51(5_suppl), 7480S-7512S.
47. Liu, X.; Qu, M.; Liu, X.; and Wang, L. (2019). Membrane-based liquid desiccant air dehumidification: A comprehensive review on materials, components, systems, and performances. *Renewable and Sustainable Energy Reviews*, 110, 444-466.
48. Fumo, N.; and Goswami, D.Y. (2002). Study of an aqueous lithium chloride desiccant system: Air dehumidification and desiccant regeneration. *Solar Energy*, 72(4), 351-361.
49. Gu, Y.; Zhong, K.; Cao, R.; and Yang, Z. (2022). Aqueous lithium chloride solution as a non-toxic bactericidal and fungicidal disinfectant for air-conditioning systems: Efficacy and mechanism. *Environmental Research*, 212, 113112.
50. Wen, T.; Luo, Y.; Wang, M.; and She, X. (2021). Comparative study on the liquid desiccant dehumidification performance of lithium chloride and potassium formate. *Renewable Energy*, 167, 841-852.
51. Ashrae, A.H.F.; and Atlanta, G. (2009). 2009 *ASHRAE Handbook-Fundamentals*. American Society of Heating, Refrigerating And Air-Conditioning Engineers, Inc.
52. Hong, J.K.; Hwang, I.; Roh, C.W.; and Kim, M.S. (2022). Performance investigation on electrodialysis regeneration of potassium formate desiccant solution for liquid desiccant air-conditioning systems. *Energy and Buildings*, 266, 112112.
53. Charidi, M. (2018). *Investigation of a liquid desiccant enhanced evaporative cooling system for building application*. MSc dissertation, Eastern Mediterranean University (EMU)-Doğu Akdeniz Üniversitesi (DAÜ).
54. Zheng, X.; Ge, T.S.; Wang, R.Z.; and Hu, L.M. (2014). Performance study of composite silica gels with different pore sizes and different impregnating hygroscopic salts. *Chemical Engineering Science*, 120, 1-9.