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The experimental study of dehumidification and regeneration processes in a fin and tube liquid desiccant system

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ABSTRACT

Significant focus has been placed on improving Indoor Air Quality (IAQ) due to the emergence of the large-scale severe acute respiratory syndrome (SARS) virus epidemic in the air conditioning system of buildings. There is also a need for an adequate air ventilation system that balances energy needs with air quality. This led to the discovery of liquid desiccants which have the ability to enhance air quality and lower primary energy usage as an alternative to the standard air dehumidification technology. Therefore, this study was conducted to investigate the dehumidification and regeneration processes in a Fin and tube liquid desiccant system. This involved flowing air horizontally while the ionic liquid flowed through the cooling or heating coil vertically downward to create a cross-flow fin and tube configuration. In the testing process, we obtained measurements of relative humidity and dry bulb temperature inlet and outlet from ducting by varying the input parameters. Moreover, the differential humidity ratio of the inlet and output process for the dehumidification and regeneration was observed to be essential for the dehumidifier performance indices. The experimental result showed that the system absorbed a humidity ratio of 5.5 g/kg during the dehumidification process and released 10.7 g/kg during regeneration.

1. Introduction

Hot and humid air is one of the reasons excess energy is required to operate the HVAC system [1] which consumes approximately 20%–40% of the total energy used in a building [2–4]. Meanwhile, the vapor compression systems designed based on ASHRAE 62 and 90 standards are commonly used in HVAC dehumidifiers [5–7]. This is associated with the ineffectiveness of traditional systems in managing latent loads in buildings with high moisture content because of the difficulty they have in dealing with humid and hot environments, thereby, making the air in the room become moist when the cooling coil is turned off. Moreover, much attention has been placed on improving Indoor Air Quality (IAQ) at the end of the last decade due to the large-scale outbreak of the Severe Acute Respiratory Syndrome (SARS) virus in the air conditioning system of buildings [1,8]. It is also considered important because 374,329 confirmed cases of COVID-19 and 12,064 deaths were recorded in the U.S by the U.S. CDC as of April 7, 2020 [9] and the figure continued to increase. Scientific briefs reported that the particle of the virus was predominantly transmitted through exhalation sneeze and contact routes [10]. Moreover, existing data showed that the virus was also discovered in the ventilation systems of the hospital rooms COVID-19-infected patients are placed in China [9,10].

The contacts through the virus particles or droplets from human sneeze into the environmental flow were found to be playing an

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essential role in the transmission of the infection. This led to a current study on one of the mass transfers between the droplets and the surrounding air as well as the investigation of droplet longevity under different ambient variables such as temperature and relative humidity [11]. The findings showed that the ambient relative humidity plays an important influence in calculating droplet longevity [12] such that an increase in the humidity did not necessarily cause a reduction in the lifetime of the droplet [12–14]. Moreover, an efficient air ventilation system that balances low energy requirements with excellent IAQ is required when the relative humidity in the air is low [3,12]. This led to the development of liquid desiccants as one of the most promising alternative technologies for efficient dehumidification in the heating and cooling industries [15]. Furthermore, it is possible to dry air using this innovation instead of traditional dehumidification methods which require cooling the air below the dew point temperature.

Several studies have been conducted on the impact of using air conditioning systems with a liquid desiccant to dry air [16–18]. The findings showed that this method absorbs moisture content from the air [19] and does not require cooling below the dew point temperature like the vapor compression cooling system. The liquid desiccants are also not harmful to the environment compared to the application of CFC and HCFC systems because they only require a small amount of energy. This means this technology is a potential addition to the cooling process. Moreover, LiBr and LiCl solutions can be used as liquid desiccants [17]. LiBr solution has been discovered to have a higher density and lower specific heat capacity [20] while the LiCl solution’s dehumidification process is better at the same flow rate. It was also reported that they both nearly have identical regeneration performances [21]. However, there are other novel types of liquid desiccant in addition to LiBr, LiCl, and CaCl₂ [21], thereby, increasing the interest of several scholars in concentrated bittern solutions as a by-product of salt solution acting on sunlight [20].

The hygroscopic salts found in these goods such as magnesium, calcium, and sodium chloride can be used as a desiccant liquid [20]. Therefore, this study was conducted to identify the content of these salts, except for sodium chloride, to be used in cooling systems [1]. Several studies have been conducted on the properties of liquid desiccants and a large body of literature has experimental and theoretical data on air conditioning systems designed using desiccants [8]. This led this study to focus on heat and mass transfer in a cleansed dehumidifier or regenerator through an experimental test and theoretical study. Moreover, the dehumidification of air using a consistent solution has been demonstrated through experiments and theoretical research. The findings showed that the liquid containing hygroscopic salts have a consistent salt reduction which is suitable for air conditioning applications or drying processes [22,23].

The development of a new liquid desiccant dehumidifier with ionic liquid as well as fin and tube for internal cooling and heating process at different configurations in buildings was shown in literature reviews to have the ability of improving performance and reducing energy consumption in HVAC systems. However, its application is still required in several other systems.

The goal of this experiment is to investigate the utilization of an ionic liquid in the internally cooled dehumidifier and internally heated regeneration fin and tube liquid desiccant at HVAC. The specific focus is to understand the effectiveness of the dehumidification and regeneration process as well as the influence of different inlet parameters such as the ionic liquid temperature, airflow rate, and

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Fig. 1. The schematic diagram for Liquid Desiccant Dehumidifier.
liquid desiccant flow rate on their performance.

2. Materials and methods

2.1. Experimental setup

The materials used for the experiment include measurement devices, a fresh airflow duct, centrifugal blower input, condenser, exhaust stream duct, fin and tube, and heater as indicated in Fig. 1. The absorber and regenerator processes required installing a cooling coil and a heating coil in the middle of the duct such that the heating coil was maintained at 150 W electric heaters and the cooling coil at 300 W condenser. Moreover, Type K thermocouples were attached to the NI 9213 module and a data logger device was also applied to measure air temperatures in each section (NI-cDAQ -9174). The accuracy of the temperature sensor was ±0.01°C. Furthermore, the fresh air velocities across the cooling and heating coils varied between 0.1 and 0.3 m/s and were measured at the center of the duct using a hot wire anemometer Lutron AM-4234 with an accuracy of ±0.3 m/s. At each point, the air relative humidity was also measured using the Rh sensor PR-3002-WS-N01 with an accuracy of ±3% and recorded using the NI 9203 module connected to a data acquisition device (NI cDAQ-9174). The experimental setup is presented in Fig. 4 while the detailed information on the device is indicated in Table 4. The ranges of the operational parameters used in this study are also listed in Table 2. It is important to note that the system was first operated at its original condition for each group of the experiment and data were later collected by changing the condition of a parameter within its range while the others are kept constant.

The fresh air absorber (process) side was cooled and dehumidified by passing through a cooling coil device with flowing chilled water and a strong liquid desiccant solution sprayed over the whole cooling coil surface. The combined heat and mass transfer process occurred in the air and desiccant solution flow direction such that the sprayed desiccant solution absorbed moisture from the process air when they were in contact in the cooling coil. It is important to note that the design supply airflow rate for both the dehumidifiers and regenerators in this experiment was 0.225 m²/s. Meanwhile, on the regenerator side, the air from the centrifugal blower was heated and regenerated by passing through a heating coil device containing flowing heated water, and the entire surface of the heating coil was sprayed with a weak liquid desiccant solution and this released the moisture from the liquid desiccant in the regeneration air when they were in contact.

2.2. Thermophysical ionic liquid properties

Common desiccants, such as trimethylene glycol, are flammable and detrimental to the surrounding environment. The apparent disadvantages of common desiccants such as CaCl₂, LiCl, LiBr, and their mixtures, including their tendency to crystallize, corrosiveness towards metals, and environmental pollution, outweigh the advantage of their relatively low vapor pressure. Due to their characteristics, ionic liquids (IL) are currently the subject of extensive research [24]. IL are molten salts containing organic cations and inorganic anions that exist at room temperature. Researchers have examined numerous applications, such as synthetics, catalysts, lubricants, separating agents, and electrolyte materials. However, ionic liquids have not been the subject of any research to date. IL remain liquid at room temperature and exhibit excellent fluidity over a wide temperature range. In addition, they have very low vapor pressure, and some of them are non-corrosive. All of these characteristics make IL useful for dehumidification in liquid desiccant air conditioning systems [24]. This experiment utilized IL possessing the thermophysical properties shown in Table 1. In general, IL had excellent solubility with a variety of organic compounds, low volatility, and high thermal and chemical stability, which made them suitable for absorption processes such as those found in liquid desiccant systems.

With the exception of [EMIm]Ac from F.F. Zhang et al. and [BMIm][Cl] from Anuja Jain et al. the IL used in the present study has a lower density than other IL listed in Table 1. Except for [EMIM][FSI] and [BMPYR][FSI] from F.F. Zhang et al. the viscosity of the IL in this study is lower than all of those listed in Table. Due to its low density and viscosity, the IL utilized in this experiment has a low pumping expense.

2.3. Performance dehumidification and regeneration

Fig. 2 shows the structured fin and tube used as a control volume (CV) with heat and mass transfer interactions between the liquid

| Ionic Liquid | IL mass fraction X, % | Temperature T, °C | Density ρ, kg.m⁻³ | Viscosity μ, Pa.s | Thermal Conductivity λ, W.m⁻¹.K⁻¹ | Specific Heat C_p, kJ.kg⁻¹.K⁻¹ |
|--------------|------------------------|--------------------|-------------------|-----------------|-------------------------------|-------------------------------|
| Present work | 0–80                   | 25                 | 997.1154          | 0.001–0.032     | 0.607–0.274                   | 1.7–4.2                      |
| [HEA]La [25] | –99                    | 25                 | 1201.785          | –               | 0.255                         | 1.8                          |
| [BHEA]La [25] | –99                    | 25                 | 1218.433          | –               | 0.236                         | 1.78                         |
| [THEA]La [25] | –99                    | 25                 | 1235.933          | –               | 0.226                         | 1.75                         |
| [EMIm][Ac] [26] | 80                    | 20                 | 1100.82           | 0.022           | 0.27                          | 2.35                         |
| [EMIM][FSI] [27] | –99                  | 15                 | 1451.11           | 0.026           | –                             | –                            |
| [BMPYR][FSI] [27] | –99                  | 15                 | 1314.74           | 0.078           | –                             | –                            |
| [MPEG₅₀(bim)][Tf₂N] [28] | 70                  | 25                 | 1285.4            | 0.28            | –                             | –                            |
| [MPEG₅₀(bim)][Tf₂N] [28] | 70                  | 25                 | 1251.5            | 0.37            | –                             | –                            |
| [BMIm][PF₆] [29] | 98                    | 20                 | 1371.1            | –               | –                             | –                            |
| [BMIm][Cl] [30] | 98                    | 20                 | 998.2             | –               | –                             | –                            |
| [Mmim][MeO][PO₄] [31] | 55                    | 59.85             | –                 | 0.65            | –                             | –                            |
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The enthalpy of the air regeneration and process was calculated using EES (Engineering Equation Solver) as follows:

$$h_a = f (T, \omega, P)$$

(1)

The humidity ratio for in-process and regeneration was also later determined as follows:

$$\omega_a = f (R_h, T)$$

(2)

The specific heat of solution and chilled water were determined using the following equations:

$$C_p_s = f (T, X)$$

(3)

$$C_p_{water} = f (T, x)$$

(4)

The concentration of ionic liquid was calculated as follows [32,33]:

$$X = f (EC, T)$$

(5)

The moisture removal and regeneration rates also known as the performance analysis of dehumidification process and regeneration presented in Equations (6) and (7) respectively are the indices commonly used to evaluate the dehumidification and regeneration processes associated with the use of liquid desiccants [16,17,34]. Detail dimensions of the fin and tube heat exchanger were described

Table 2
The fin and tube dehumidifier and regenerator experimental range.

| Condition   | $m_a$ (g/s) | $t_{in}$ (°C) | $m_s$ (kg/s) | $t_{in}$ (°C) | $X_a$ (%) | $T_{chw, in}$ | $T_{hw, in}$ | $V_{in}$ |
|-------------|-------------|---------------|--------------|---------------|-----------|---------------|---------------|---------|
| Dehumidification | 3-11        | 27-28         | 0.4-0.6      | 15-20         | 50-60     | 12-19         | -             | 0.1-0.3 |
| Regeneration  | 4-9         | 26-29         | 0.5-0.6      | 38-60         | 50-60     | -             | 30-60        | 0.1-0.3 |

Table 3
Dimensions of fin and tube heat exchanger.

| Parameter                              | Dimension          |
|----------------------------------------|--------------------|
| Number of tube columns (horizontal array) | 2                  |
| Number of tube rows (vertical array)   | 5                  |
| Fin thickness                          | $2 \times 10^{-4}$ m |
| Fin pitch                              | $2 \times 10^{-2}$ m |
| Tube outer wall diameter               | 1.4 $\times 10^{-2}$ m |
| Tube wall thickness                    | 1.3 $\times 10^{-3}$ m |
| Tube horizontal pitch                  | 3 $\times 10^{-2}$ m |
| Tube vertical pitch                    | 3 $\times 10^{-2}$ m |

Table 4
Specification of parameters and different measurement devices.

| Parameters                              | Devices     | Accuracy                  | Resolution and Range          |
|-----------------------------------------|-------------|---------------------------|------------------------------|
| $V_{a,r, out}, V_{a,p, out}$            | Lutron AM - 4234SD | ± (1% + 0.3 m/s)          | 0.1 m/s, 0.2 m/s - 5 m/s     |
| $T_{chw, in}, T_{hw, in}, T_{a,p,out}, T_{a,p,in}, T_{a,r, out}, T_{a,r, in}, T_{s,p,out}, T_{s,p,in}$ | Thermocouple K | ±2.2 °C                 | -270 °C-1370 °C              |
| $RH_{a,r, in}, RH_{a,r, out}, RH_{a,p, in}, RH_{a,p, out}$ | PR-3002-WS-N01 | ±3% RH                 | 0%RH-100%RH                   |
| $T_{a,p, in}, T_{a,p, out}, T_{a,r, in}, T_{a,r, out}$ | PR-3002-WS-N01 | ±0.5 °C                | -40 °C-+80 °C               |
| $F_{chw, in}, F_{chw, out}, F_{s,r, in}$ and $F_{s,r, out}$ | YFS - 301      | ±3%                     | 0.3-10 (L/min)              |
| $E.C._{p}, E.C._{r}$                    | Conductivity Probe K 1.0 | ±2%                   | 5-200,000 μS                |

The energy balance of the structured fin and tube used as a control volume of a. Regeneration b. Process.

![Fig. 2. The energy balance of the structured fin and tube used as a control volume of a. Regeneration b. Process.](image-url)
in Table 3, and Fig. 3 Shown the fin and tube at using in this study.  

\[
\begin{align*}
    m_{w,p} &= m_{a,p} \cdot (\omega_{a,p,\text{in}} - \omega_{a,p,\text{out}}) \\
    m_{w,r} &= m_{a,r} \cdot (\omega_{a,p,\text{out}} - \omega_{a,p,\text{in}})
\end{align*}
\]  

(6) \hspace{1cm} (7)

2.4. Uncertainty analysis and repeatability

The uncertainty analysis was conducted to assess the consistency of the dependent parameters, and the measurement points were based on the standard deviation of each sensor. Moreover, the calculated parameters associated with the mass flowrates of each operating parameter were determined through Eq (9) [35], and the measuring point was determined through Eq (10) [36] values obtained are presented in Table 5.

\[
U = U(U_x, U_y)
\]  

(8)

\[
\sigma_u^2 = \left(\frac{\partial U}{\partial U_x}\right)^2 \sigma_{U_x}^2 + \left(\frac{\partial U}{\partial U_y}\right)^2 \sigma_{U_y}^2
\]  

(9)

\[
U(x_i) = \frac{i_x}{\sqrt{3}}
\]  

(10)

where \(U_x \ldots U_y\) are different independent parameters while \(U\) is the dependent parameter, and the accuracy of each sensor device is \(i_x\).

The Reapitibility of the experiments has also been checked, and one of the observations of Rh \(p,\text{out}\) for two different runs is shown in Fig. 5 [37].

3. Results and discussion

3.1. Fin and tube liquid desiccant performance

The chilled water temperature in the experiment was set to be constant at 10 °C for the dehumidification process while the input hot water was constant at 36 °C for the regeneration process. The solution and air outlet temperature slightly decreased due to heat transfer into chilled water which increased its output temperature compared to its inlet temperature. Moreover, the relative humidity output also slightly decreased due to mass transfer from the air inlet to the solution inlet as indicated in Fig. 6c and Fig. 6e.

The solution and air outlet temperature for the regeneration slightly increased due to heat transfer from hot water to solution and air, thereby, leading to a reduction in the output temperature of the hot water compared to its inlet temperature. Meanwhile, the relative humidity output slightly decreased due to mass transfer from the air inlet to the solution inlet as presented in Fig. 6d and f.

The dehumidification performance was determined using Equation (6) and the moisture removal rate of the air inlet process was found to be 0.0018 g/kg. According to Liu et al. [16,17], the concentration of liquid desiccant can affect dehumidification and regeneration performance and this was further confirmed by the constant values of these parameters as presented in Fig. 6g and a. Meanwhile, the regeneration performance was determined using Equation (7) and the moisture release rate of the air inlet was found to be 0.039 g/kg with the concentration and performance of the regeneration process observed to slightly increase as shown in Fig. 6h and b.

3.2. Effects of inlet parameters on the humidity ratio regeneration and dehumidification process

3.2.1. Airflow rate

Fig. 7 shows the relationship between air mass flow rate and humidity ratio associated with the mass transfer performance during the dehumidification process. It was discovered that there is a difference between the humidity ratio input and output processes and the regeneration was also observed to have decreased due to the increase in air mass flow rate. Moreover, the decreasing moisture...
Fig. 4. Experimental setup.

| Measurement point | Value      | Calculated parameters | Value               |
|-------------------|------------|-----------------------|---------------------|
| T_s,p,in          | 15.5 ± 1.27| Mass flowrate Air (kg/s) | m_{s,p,in} 0.34 ± 0.4 |
| T_a,p,in          | 15.7 ± 1.27|                       |                     |
| T_s,p,out         | 15.7 ± 1.27|                       |                     |
| T_a,p,out         | 29.7 ± 1.27|                       |                     |
| T_c,hw,in         | 26.8 ± 1.27| Mass flow rate Ionic Liquid (kg/s) | m_{s,p,in} (0.5 ± 0.1) x 10^{-1} |
| T_c,hw,out        | 10.2 ± 1.27|                       |                     |
| T_tank,p          | 12.8 ± 1.27|                       |                     |
| T_tank,r          | 24.4 ± 1.27|                       |                     |
| T_{ht,in}         | 29.5 ± 1.27|                       |                     |
| T_{ht,out}        | 31.5 ± 1.27|                       |                     |
| T_{ht,in}         | 38.1 ± 1.27|                       |                     |
| T_{ht,out}        | 37.4 ± 1.27|                       |                     |
| T_{ht,in}         | 37.8 ± 1.27|                       |                     |
| T_{ht,out}        | 38.4 ± 1.27|                       |                     |
| T_{ht,out}        | 38.2 ± 1.27|                       |                     |
| T_{ht,out}        | 73.3 ± 1.7 | Relative Humidity (%) | m_{chw,in} (0.56 ± 0.008) |
| T_{ht,out}        | 62.4 ± 1.7 |                       |                     |
| Relative Humidity (%) | 72.6 ± 0.017 |                       |                     |
| Electrical Conductivity (mS) | 79.9 ± 0.017 |                       |                     |
| EC_p              | 11.1 ± 0.01|                       |                     |
| EC_r              | 21.5 ± 0.01|                       |                     |
| Flow (l/m)        | 2.57 ± 5.7 |                       |                     |
| F_s,p,in          | 3.42 ± 5.7 |                       |                     |
| F_c,m,in          | 2.88 ± 5.7 |                       |                     |
| F_s,r,in          | 6.52 ± 5.7 |                       |                     |
| V_{s,p,in}        | 0.1 ± 0.05 | Velocity (m/s)         |                     |
| V_{s,p,est}       | 0.3 ± 0.05 |                       |                     |
content in the air inlet caused the ΔHumidity ratio to reduce. Humidity ratio on the regeneration side decreases from the first variation of airflow rate with a value of 6.54 g/kg to the last variation of airflow rate with a value of 4.55 g/kg. In the dehumidification process, the Humidity ratio decreases from the initial variation of air flow rate with a value of 5.55 g/kg to the final variation of air flow rate with a value of 5.12 g/kg.

3.2.2. Desiccant flow rate

The effect of liquid desiccant flow rate on dehumidification and regeneration is presented in Fig. 8 and it was discovered that an increase in the flow rate of the solution used in the dehumidification process caused a significant increment in the difference between the humidity ratio of the incoming and outgoing air. Meanwhile, an increase in the flow rate of the solution used in the regeneration reduced the humidity ratio between the inlet and outlet air. Humidity ratio on the regeneration side decreases from the first variation of flow rate solution regeneration with a value of 10.74 g/kg to the last variation of flow rate solution regeneration with a value of 6.18 g/kg. Humidity ratio in the dehumidification process increases from the initial variation of flow rate solution process with a value of 2.06 g/kg to the final variation of flow rate process with a value of 4.6 g/kg.

3.2.3. Liquid desiccant inlet temperature

The effect of ionic liquid temperature on the humidity ratio in the dehumidification process is presented in Fig. 9 and the findings showed that a smaller ionic liquid temperature led to a greater Humidity ratio. This is due to the increase in the surface vapor pressure of the liquid and a reduction in the average vapor pressure difference between the air and ionic liquid in the dehumidifier as the temperature of the ionic liquid increases [34]. This phenomenon caused a high humidity ratio outlet and subsequently led to a low water vapor content. This simply means there was a decrease in water vapor levels when the ionic liquid temperature increased.

Fig. 9 also shows that higher regenerator temperature produced a higher humidity ratio because a lot of water vapor was released from the ionic liquid, thereby, increasing the outlet water vapor content. Humidity ratio on the regeneration side increases from the first variation of flow rate solution regeneration with a value of 4.59 g/kg to the last variation of flow rate solution regeneration with a value of 9.15 g/kg. Humidity ratio in the dehumidification process decreases from the initial variation of flow rate solution process with a value of 5.54 g/kg to the final variation of flow rate process with a value of 3.36 g/kg.

3.3. Psychometric profile diagram of dehumidification process and regenerator

3.3.1. Psychometric profile diagram in the dehumidification process

The psychometric profile diagram for the ionic liquid temperature of the dehumidification process at 15.5 °C is presented in Fig. 10 where the outlet parameters used when the experiment was first conducted are indicated in Point 1 and those after the experiment was completed at Point 11. The detailed information on this profile is explained in the following Table 6.

Points 1 to 11 show a decrease in the humidity ratio by 5.3 (g/kg) water vapor content as confirmed in Fig. 10 that the air entering $T_{a,p,\text{out}}$ at Point one has 19.1 (g/kg) humidity ratio and 76.5 (kJ/kg) enthalpy but 13.8 (g/kg) and 61.6 (kJ/kg) respectively at Point 11. Moreover, Table 6 shows that the enthalpy slightly decreased due to heat transfer from inlet air to inlet solution and chilled water.

3.3.2. Psychometric profile diagram in the regeneration process

The psychometric profile diagram for the ionic liquid temperature of the regeneration process at 38 °C is presented in Fig. 11. It is also important to note that Point one shows the outlet parameters when the experiment was first conducted while Point 11 indicates the parameters after the completion of the experiment. The detailed information on this profile is explained in the following Table 7.

Points 1 to 11 show an increase in the humidity ratio by 3.3 (g/kg) water vapor content and this was further confirmed by Fig. 11 that the air entering $T_{a,r,\text{out}}$ in Point one has a 19.5 (g/kg) humidity ratio and 77.9 (kJ/kg) enthalpy and these increased to 22.8 (g/kg) and 89.7 (kJ/kg) respectively in Point 11. It was also discovered that the enthalpy slightly increased due to the heat transfer from inlet
hot water to inlet air and solution.

3.4. Comparison of inlet and outlet humidity ratio in the dehumidification process

Table 8 summarizes the trends concerning the impacts of inlet parameters on the delta humidity ratio of the current cross-flow
Fig. 7. Effects of the airflow rate parameters on the dehumidification process and regenerator performance.

Fig. 8. Effects of the flow solution parameters on the dehumidification process and regenerator performance.

Fig. 9. Effects of the liquid desiccant temperature on the dehumidification process and regenerator performance.
absorber (process) as well as the experimental results reported for the counter-flow process in previous studies. The inlet settings generally have similar effects on the current cross-flow performance and counter-flow designs with exceptions mainly associated with the difference in the parameter range. For example, the delta humidity ratio increased with the desiccant flow rate in this study. It is also important to note that Richard Jayson Varela used a fin and tube with a larger volume and surface area and the comparison of the results to the present study showed that the application of a larger volume can increase the effectiveness of dehumidification in the liquid desiccant.

Table 6
Dehumidification performance at different variations of $T_{a,p,\text{out}}$ 15.5 °C

| $T_{a,p,\text{out}}$ (°C) | $\text{Rh}_{a,p,\text{out}}$ (%) | $h_{a,p,\text{out}}$ (kJ/kg) | $\omega_{a,p,\text{out}}$ (g/kg) |
|--------------------------|-------------------------------|-----------------------------|-------------------------------|
| 27.6                     | 81.72                         | 76.5                        | 19.1                          |
| 27.4                     | 78.8                          | 74                          | 18                            |
| 26.8                     | 73.5                          | 68.6                        | 16.3                          |
| 26.7                     | 71.4                          | 67                          | 15.7                          |
| 26.6                     | 71.3                          | 66.6                        | 15.6                          |
| 26.5                     | 71.2                          | 66.2                        | 15.5                          |
| 26.5                     | 69                            | 64.9                        | 15                            |
| 26.4                     | 68.5                          | 64.3                        | 14.8                          |
| 26.4                     | 68.1                          | 64.1                        | 14.7                          |
| 26.3                     | 68                            | 63.7                        | 14.6                          |
| 26.2                     | 64                            | 61.6                        | 13.8                          |

Fig. 10. Psychometric profile at ionic liquid temperature 15.5 °C in the process outlet air.

Fig. 11. Psychometric profile at ionic liquid temperature 38 °C in the regeneration outlet air.
4. Conclusions

This study showed that a liquid desiccant dehumidifier with ionic liquid as well as fin and tube can be applied on a large scale as indicated by the experimental results. It was also discovered that a greater ionic liquid temperature in the dehumidification process led to a smaller $\Delta \omega_{a,p}$ as indicated by the different 15.5°C, 17.4°C, and 19.4°C temperatures that produced 5.27 g/kg, 3.42 g/kg, 3.36 g/kg humidity ratio respectively. Meanwhile, for the regeneration, an increase in the ionic liquid temperature was observed to have caused an increment in the $\Delta \omega_{a,r}$. This was evident in the 3.2 g/kg, 5.36 g/kg, and 9.15 g/kg humidity ratios recorded for 38.1°C, 40.9°C, and 55.4°C ionic liquid temperatures respectively. Moreover, a larger air mass flow rate in the dehumidification process produced a smaller humidity ratio as indicated by 5.55 g/kg, 5.25 g/kg, and 5.12 g/kg humidity ratios for 3.31 g/s, 5.88 g/s, and 10.44 g/s mass flow rates respectively. The situation is different for the regeneration process such that a higher air mass flow rate was observed to have led to a higher humidity ratio as evident by the 6.54 g/kg, 4.96 g/kg, and 4.55 g/kg humidity ratio values respectively recorded for 4.36 g/s, 6.86 g/s, and 8.66 g/s air mass flow rates. Furthermore, it was also discovered that a greater ionic liquid flow in the dehumidification process led to a better $\Delta \omega_{a,p}$ as indicated by the different 80 l/h, 100 l/h, and 150 l/h flow rate humidity ratio, respectively. Moreover, for the regeneration, an increase in the ionic liquid flow rate was observed to have caused a decrement in the $\Delta \omega_{a,r}$. This was evident in the 10.74 g/kg, 8.62 g/kg, and 6.18 g/kg humidity ratios recorded for 80°C, 100°C, and 150°C ionic liquid temperatures, respectively.

Credit author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
Data availability

Data will be made available on request.

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Nomenclature

ω  Humidity Ratio (g/kg)

\( m_a \)  Massflowrate air (kg/s)

v  Velocity of air (m/s)

\( \rho_{udara} \)  Mass jenis udara (kg/m\(^3\))

mS  Millisiemens

\( m_s \)  Mass flow rate solution (kg/s)

\( m_{(chw)} \)  Mass flow rate chilled water (kg/s)

\( m_{(hw)} \)  Mass flow rate hot water (kg/s)

T  Temperature (°C)

Δ  Delta (Difference of inlet and outlet, and vice versa)

Special Character

F  Flowrate (l/m)

EC  Electrical Conductivity (mS)

Subscript

a  (air)

a,p, in  (Fresh air process input)

a,p, out  (Fresh air process output)

a,r, in  (Fresh air regeneration input)

a,r, out  (Fresh air regeneration output)

s,p, in  (Solution process inlet)

s,p, out  (Solution process outlet)

s,r, in  (Solution process inlet)

s,r, out  (Solution process outlet)

tank, p  (Tank in process system)

tank, r  (Tank in regeneration system)

chw  (Chilled water inlet)

hw  (Hot Water inlet)

X  (Concentration)

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