PERFORMANCE PREDICTION OF LiCl ROTOR

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ABSTRACT

A finite-difference method is presented for predicting performance of lithium chloride rotor under both desiccant dehumidification and enthalpy exchange mode. The implicit numeric model was based upon analysis of heat and mass transfer between desiccant bed and air streams. Good agreements were observed between experiment data and calculated values. The work in this paper can help the use of LiCl rotor in air-conditioning engineering.

1. INTRODUCTION

Lithium chloride (LiCl) rotor, which makes use of the hygroscopic characteristic of LiCl to transfer moisture from one stream of air to the other stream, has long been used in air-conditioning systems. It plays important role in solar-energy based air-conditioning systems as desiccant dehumidifier. And it can also be used in recovering energy from exhaust as enthalpy exchanger [1]. A typical LiCl rotor consists of several main components: supporting structure, rotating matrix impregnated with lithium chloride and driving motor etc. (as illustrated in Fig. 1a). Across flow area of rotating matrix two physically separated air streams are arranged in counterflow pattern to achieve favorable heat/mass transfer results. Driven by a motor the matrix is exposed to different air streams alternatively in a cycle.

LiCl rotor can work under two different modes: desiccant dehumidification and enthalpy exchange. When the rotational speed is lower, a stream of air (called process air) passes through one part of the matrix, with the moisture being absorbed into the desiccant matrix. When the matrix is in the other stream of air (called regeneration air, always hot and comparatively dry), the absorbed moisture can be removed and the desiccant matrix becomes reactivated. In this operation mode – sometimes termed as “active dehumidification”, the process air is dried at the expense of heat for heating up regeneration air. LiCl rotor for dehumidification purpose is always called “rotary dehumidifier” or “desiccant wheel” or “regenerative dehumidifier”. While the matrix rotates at higher speed, return air from air-conditioned room, drier and cooler, is always used to take place of regeneration air and to pass through the regeneration side to exchange moisture and heat – enthalpy – with process air. This operation mode is usually called “passive dehumidification” and for this recovery purpose LiCl rotor is called “enthalpy wheel”.

Under both dehumidification and enthalpy exchange mode, the performance of LiCl rotor is controlled by combined heat and mass transfer within desiccant matrix. A series of models can be found related with active dehumidification mode [2-4]. But performance under enthalpy exchange mode has always been described by the definition of effectiveness for the sake of simplicity. In addition, most researches [2-4] with regard to desiccant dehumidification were targeted at the well-defined physisorption such as those in silica gel. For the case of LiCl, there has not been a widely-accepted conclusion whether the sorption process is a physical one or a physical one. Hence experimental data provided by manufacturers are widely used for design [5].

A numeric model based upon analysis of heat/mass transfer within desiccant matrix was set up and implicitly solved to predict the performance of LiCl rotor. Good agreements between numeric work and experiment data observed show that the work in this paper can be used to predict the performance of LiCl rotor under both desiccant dehumidification mode and enthalpy exchange mode.

2. NUMERIC MODEL DESCRIPTION

2.1 Derivation of Governing Equations

A balanced rotor, half section for process air while the other half for regeneration air (or return air), is used for analysis. The schematic of an adiabatic rotor is illustrated in Fig. 1a.
The following assumptions are employed to simplify analysis of combined heat and mass transfer process within desiccant matrix:

- LiCl rotor can be modeled as parallel passage design and all channels in the matrix are made of the same materials in the same configuration.
- All channels are assumed to be adiabatic. The air passage is surrounded by desiccant bed impregnated with lithium chloride.
- Thermal properties of dry air, water vapor and desiccant bed are assumed to be constant.
- The accumulations of energy and moisture in air streams are neglected. All the carry-over effect (from one side to the other side) is assumed to be undertaken by desiccant bed. It must be pointed out that this assumption will introduce great error when rotational speed is increased and the rotor is changed into enthalpy exchange mode because of the increasing carry-over effect by air stream. As it can be seen in following sections, some correcting measures has been taken to take into account the carry-over effect by air stream.
- There are no temperature and moisture gradients within the thickness of desiccant bed. And there is no radial temperature and moisture gradients in either the air stream or desiccant bed. In other words, the heat/mass transfer process is essentially one-dimensional.
- The heat/mass transfer coefficients between desiccant bed and air stream can be related by Lewis relationship [6], i.e.: 
  \[ h = \frac{K \cdot U}{\rho \cdot \frac{d\alpha}{dx} \cdot A_{cross}} \]
  and they are assumed to be linear functions of rotational speed. For dehumidification mode at lowest speed, heat and mass transfer coefficient are calculated by convective correlations. For enthalpy exchange mode at highest speed, heat transfer coefficients are determined by comparing with experimentally measured humidity ratio and temperature of air. For the rotational speed within this range, heat transfer coefficient is assumed to be a linear function of rotational speed.

Fix the actual axis coordinate x onto one of the channels shown in Fig. 1b. Considering moisture balance of air stream within dx control volume, one can write:

\[
\frac{\partial Y}{\partial x} = \frac{K \cdot U}{\rho \cdot \frac{d\alpha}{dx} \cdot A_{cross}} (Y_w - Y_a) \quad (1)
\]

Similar equation can be derived if considering energy balance for moist air within dx control volume:

\[
\frac{\partial H}{\partial x} = \frac{K \cdot U \cdot H_w}{\rho \cdot \frac{d\alpha}{dx} \cdot A_{cross}} (Y_w - Y_a) + \frac{h \cdot U}{\rho \cdot \frac{d\alpha}{dx} \cdot A_{cross}} (T_w - T_a) \quad (2)
\]

For desiccant bed within dx control volume, changing rate of water content with time can be given as follows:

\[
\frac{\partial W}{\partial t} = \frac{K}{f \cdot \rho_w \cdot a_w} (Y_a - Y_w) \quad (3)
\]

And changing rate of enthalpy of desiccant bed with time is:

\[
\frac{\partial H_w}{\partial t} = \frac{K \cdot H_w}{\rho_w \cdot a_w} (Y_a - Y_w) + \frac{h}{\rho_w \cdot a_w} (T_a - T_w) \quad (4)
\]

Equations (1) to (4) are the well-known governing equations for combined heat/mass transfer of adiabatic dehumidifier [7,8]. An additional equation, so-called sorption isotherm, is necessary to make the system close since there are only four equations for five unknown variables. The underlying mechanism for applying isotherm equation is that at every moment of sorption the driving potential for mass transfer is vapor pressure difference between adsorbent and adsorbate.

![Fig. 1a: Illustration of a typical LiCl rotor](image1)

![Fig. 1b: Schematic of a specific channel within LiCl rotor](image2)
Gibbs’ assumption [9] is helpful to understand physical principle of above equation: there is a special phase named adsorption phase between adsorbent and adsorbate (here lithium chloride and water respectively). Even if the precise location of this phase boundary may be uncertain, it can be treated as a distinguishable phase in the thermodynamic sense.

It has been publicly accepted that for physisorption the driving potential for mass transfer can be attributed to vapor pressure difference between adsorbent and adsorbate. Therefore isotherm equation, or equilibrium assumption, can be used for calculating adsorption process. But it is quite doubtful whether such isotherm remains valid for LiCl sorption wherein predominant factor is polar affinity for water molecule rather than molecular attraction resulting from large specific surface area. Following results will demonstrate that isotherm equation method is also a powerful tool for LiCl sorption so long as appropriate isotherm is adopted.

2.2 Simplification of Governing Equations

The enthalpy of desiccant bed is a concept which likely leads to confusion. For physisorption such as in silica gel rotor, enthalpy of desiccant bed is a summation of following three parts [10]: enthalpy of supporting structure, enthalpy of silica gel itself and “integral heat of wetting”, the last of which is a function of water content of silica gel and temperature. For LiCl sorption, enthalpy of desiccant bed also consists of three parts [11]: sensible heat of desiccant bed itself (including supporting material and LiCl), sensible heat of moisture contained within desiccant and “integral heat of binding”. These two concepts, heat of wetting and heat of binding, have different underlying sorption mechanism. The former corresponds to physisorption while the latter corresponds to the binding process of water molecule to Lithium Chloride.

Then we have following equations for enthalpy of desiccant bed in LiCl rotor:

\[
H_w = c_w \cdot T_w + f \cdot W \cdot c_{H_2O} \cdot T_w + f \cdot \int_0^W (H_{fg} - Q) \, dW
\] (6)

Substituting equation (6) into (4) and making some mathematical simplification will give:

\[
(c_w + f \cdot c_{H_2O} \cdot W) \frac{\partial T_w}{\partial t} = \frac{h}{\rho_w a_w} (T_a - T_w) + \frac{K}{\rho_w a_w} (Y_a - Y_w) + \frac{h}{\rho_w a_w} \left( \frac{U}{\rho_w a_w} \right) (T_w - T_a)
\] (7) where \( Q = H_{fg} + H_{binding} \)

Recalling that \( H_s = c_{da} T_a + Y_a \cdot H_s \) will result in another form of equation (2), as follows:

\[
(c_{da} + Y_a c_v) \frac{\partial T_s}{\partial x} = \frac{h \cdot U}{\rho_{da} u_a A_{cross}} (T_w - T_s)
\] (8)

2.3 Normalization

Two normalized coordinates were adopted to simplify the calculation, as follows:

Normalized time: \( \tau = \frac{h \cdot A \cdot t}{M_{wr} c_{ref}} \) (9)

Normalized axis coordinate: \( z = \frac{h \cdot A \cdot x}{m_{da} c_{da} X_L} \) (10)

Two different \( z \) were taken for process air side and regeneration air side respectively. And normalized time indicates the tangential position of a specific channel at different moment of sorption or desorption.

By the use of normalized coordinates as equations (9) and (10) and noticing that \( M_{wr} = \rho_w a_w A \), finally normalized equations to be numerically solved can be written as follows:

\[
\frac{\partial W}{\partial \tau} = A3(Y_a - Y_w)
\] (11)

\[
A4 \frac{\partial T_w}{\partial \tau} = A5(Y_a - Y_w) + (T_a - T_w)
\] (12)

\[
\frac{\partial Y_a}{\partial z} = A6(Y_w - Y_a)
\] (13)

\[
A7 \frac{\partial T_a}{\partial z} = (T_w - T_a)
\] (14)

where coefficients \( A3 \sim A7 \) are as follows:

\[
A3 = \frac{c_{ref}}{f c_{da} L e^{2/3}}
\] (15)

\[
A4 = \frac{c_w + f \cdot c_{H_2O} \cdot W}{c_{ref}}
\] (16)

\[
A5 = \frac{Q}{c_{da} L e^{2/3}}
\] (17)

\[
A6 = \frac{1}{L e^{2/3}}
\] (18)
\[ A7 = \left(1 + \frac{c_v}{c_d} \right) Y_a \]  

(19)

### 2.4 Boundary Conditions and Initial Conditions

The essential idea of the numeric model in this paper is to follow a specific channel within desiccant matrix and to record what happens to it during its residential period in process air stream and regeneration stream alternatively. Therefore it is not difficult to turn the actual boundary conditions and initial conditions into a suitable mathematical description: the temperature and water content profile of desiccant bed at the beginning of sorption (or desorption) cycle are identical to those at the end of desorption (or sorption) cycle.

For process air side, initial condition can be given as:

\[
T_a(0,z) = T_a(T_{pf}, NTU_{ad} - z) \\
W(0,z) = W(T_{pf}, NTU_{ad} - z)
\]

(20)

Boundary condition is as follows:

\[
Y_a(\tau,0) = Y_{a,ad}(\tau) \\
T_a(\tau,0) = T_{a,ad}(\tau)
\]

(21)

Similarly for regeneration air side, one can derive:

\[
T_a(0,z) = T_a(T_{pf}, NTU_{re} - z) \\
W(0,z) = W(T_{pf}, NTU_{ad} - z)
\]

(22)

\[
Y_a(\tau,0) = Y_{a,re}(\tau) \\
T_a(\tau,0) = T_{a,re}(\tau)
\]

(23)

NTU_{ad} and NTU_{re} are the numbers of transfer unit for process air side and regeneration air side respectively, as follows:

\[
NTU_{ad} = \frac{h_{ad} A_{ad}}{(m_{ad} c_{ad})_{ad}}
\]

(24)

\[
NTU_{re} = \frac{h_{re} A_{re}}{(m_{re} c_{re})_{re}}
\]

(25)

While TF_{ad} and TF_{re} are normalized cycle periods, which can be given by the following formulae:

\[
TF_{ad} = \frac{h_{ad} A_{ad} \cdot t_{ad}}{m_v c_{ref}}
\]

(26)

\[
TF_{re} = \frac{h_{re} A_{re} \cdot t_{re}}{m_v c_{ref}}
\]

(27)

The residential time of desiccant matrix in process air stream and regeneration air stream, i.e. t_{ad}, t_{re} can be calculated from rotational speed and rotor structure.

### 2.5 Thermal Properties and Heat Transfer Coefficient

Listed in Table 1 are equations used to calculate related thermal properties.

The error resulting from neglecting carry-over effect by air stream from one side to the other side increases with increasing rotational speed. The following method was adopted to correct the error: a minimum (h = 0.008 kWm^{-2}oC^{-1}) and a maximum (h = 0.04 kWm^{-2}oC^{-1}) heat transfer coefficient were taken for the lowest (20 RPH) and highest (600 RPH) rotational speed respectively. When rotational speed falls between lowest and highest rotational speed, heat transfer coefficient was calculated by linear interpolation. The minimum heat transfer coefficient was evaluated according to convective correlations, while the maximum heat transfer coefficient was determined by comparing exit air humidity ratio and temperature with experimentally measured values.

<table>
<thead>
<tr>
<th>Table 1: Thermal properties equations</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Parameters to be calculated</th>
<th>Calculation formula used</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Saturated water vapor pressure</td>
<td>[ P_s = 610.7 \times 10^{1 \cdot 6.866 + 0.130896 T + 0.2524939 \times 10^{-7} T^2} ] (Pa)</td>
<td>[12]</td>
</tr>
<tr>
<td>2 Latent heat of water</td>
<td>[ H_{fg} = 2502.68 - 2.34 T (kJkg^{-1}) ]</td>
<td>[10]</td>
</tr>
<tr>
<td>3 Sorption isotherm of LiCl</td>
<td>[ W = (2.832291 - 2.0639 \times 10^{-2} T) \cdot (\ln RH) \cdot \frac{1}{2.07915 + 3.3 \times 10^{-7} T} ] (kJkg^{-1})</td>
<td>[12]</td>
</tr>
<tr>
<td>4 Integral heat of binding</td>
<td>[ H_{Binding} = 88.94 e^{2.514 - 1.0475 W} ] (kJkg^{-1})</td>
<td>[11]</td>
</tr>
</tbody>
</table>
2.6 Numeric Algorithm

Equations (11) to (14), a set of non-linear, hyperbolic partial-differential equations with periodically changing boundary and initial condition equations (20) to (23), are governing equations for combined heat and mass transfer within LiCl rotor. If the isotherm equation is linear, analytical solution can be achieved with appropriate assumptions [13]. But for LiCl isotherm equation is strongly nonlinear. Furthermore, coefficients $A_4$, $A_5$, $A_7$ are functions of primitive variables, increasing the inherent complexity.

First-order finite difference method (FDM) was used in this paper to derive discrete equations. Then implicit scheme was adopted to keep numerically stable solution. Iterative method was employed to calculate time-resolved humidity ratio and temperature at every normalized moment. For a given process air and regeneration air (or return air) condition, calculation was initiated from a casually selected moment. After several computational cycles, the time-resolved humidity ratio and temperature at the exit of rotor changed periodically, and then the iterative process terminated. Recalling we have equal numbers of channels at different tangential position at the same actual time, the average humidity ratio and temperature over normalized sorption period and desorption period are exit humidity ratio and temperature for process air and regeneration air, respectively.

A Fortran program was compiled to fulfil the above-mentioned algorithm.

3. EXPERIMENTAL SET-UP AND MEASUREMENT SYSTEMS

Illustrated in Fig. 2 are the experimental facilities and relevant measurement systems. The return air from an air-conditioned room (Room 1) passed through a heating coil which is supplied by the heat water from a cogeneration plant (not shown). Then it flowed through one side of a LiCl rotor and passed into another room (Room 2) at higher humidity ratio and lower temperature. The air then was pumped through the duct to the other side of the LiCl rotor and consequently a cooling coil whose chilled water comes from a chiller driven by the electricity from the cogeneration plant.

When the experimental facilities started, it would take about half an hour for the humidity ratios and temperatures of both sides to become almost constant.

The temperature and relative humidity of air at inlet and outlet of LiCl rotor were recorded and sent into a central computer. Sampling software were used to calculate the humidity ratios simultaneously.

The rotational speed of rotor was controlled by an inverter (not shown) and could be changed from 0~700 RPH. The airflow rates through the rotor were varied by changing voltages to the two fans.

Fig. 2: Schematic illustration of experimental facilities and measurement systems
4. RESULTS AND ANALYSES

4.1 Exit Air Humidity and Temperature – Dehumidification Mode

Fig. 3 and Fig. 4 are calculated values of time-resolved humidity change for process air side and regeneration side. The mass flow rate for both side is 820 kghr⁻¹ and humidity ratio for inlet of both side is 14 gkg⁻¹. Inlet temperatures of process air and regeneration air are 28°C and 70°C respectively. Accordingly the exit humidity ratios are 8.1 gkg⁻¹ and 19.9 gkg⁻¹. The diameter of rotary matrix is 650 mm with depth of 450 mm. Rotational speed is 20 RPH.

4.2 Comparison with Experiment Data – Dehumidification Mode

In order to evaluate the validity of numeric work, a lot of experiments have been carried out to measure the performance of LiCl rotor as dehumidifier under different rotational speeds. Some of the results are listed in Tables 2 to 5. The operational parameters in first two columns were input into the numeric program and corresponding calculated results were listed in the third column. Good agreements can be found between measured values and calculated values.

Since our main interest is on process air side, only comparisons of process air side were listed.

The uncertainty of sorption isotherm and mass transfer coefficient can be used to explain the discrepancy between measured values and calculated values. The isotherm used in this paper was taken from Ref. [12] which was determined from equilibrium sorption curve of lithium chloride solution at different temperatures. This practice may give rise to some errors. More importantly, mass transfer coefficient was calculated from Lewis relationship in combination with heat transfer coefficient. For temperature prediction, the maximum difference between calculated values and measured values is about 5°C (10%). While for humidity ratio the maximum difference is 0.5 gkg⁻¹ (9.3%). For the sorption process of LiCl, Lewis relationship can only be regarded as an approximation in engineering sense.

In general, performance prediction of LiCl under dehumidification mode can be considered quite good and reliable.

<table>
<thead>
<tr>
<th>Inlet conditions of regeneration air side</th>
<th>Inlet conditions of process air side</th>
<th>Exit conditions of process air side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y (gkg⁻¹)</td>
<td>T (°C)</td>
<td>m_d (kgs⁻¹)</td>
</tr>
<tr>
<td>1</td>
<td>7.3</td>
<td>54.0</td>
</tr>
<tr>
<td>2</td>
<td>6.4</td>
<td>53.7</td>
</tr>
<tr>
<td>3</td>
<td>6.5</td>
<td>54.2</td>
</tr>
<tr>
<td>4</td>
<td>6.1</td>
<td>62.9</td>
</tr>
<tr>
<td>5</td>
<td>5.2</td>
<td>63.7</td>
</tr>
<tr>
<td>6</td>
<td>4.9</td>
<td>62.9</td>
</tr>
</tbody>
</table>
Table 3: Comparison of measured and calculated values (22.5 RPH)

<table>
<thead>
<tr>
<th>Inlet conditions of regeneration air side</th>
<th>Inlet conditions of process air side</th>
<th>Exit conditions of process air side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y (g/kg)</td>
<td>T (°C)</td>
<td>m_{da} (kgs⁻¹)</td>
</tr>
<tr>
<td>1</td>
<td>5.9</td>
<td>65.3</td>
</tr>
<tr>
<td>2</td>
<td>5.9</td>
<td>65.1</td>
</tr>
<tr>
<td>3</td>
<td>6.1</td>
<td>65.0</td>
</tr>
<tr>
<td>4</td>
<td>5.6</td>
<td>55.5</td>
</tr>
<tr>
<td>5</td>
<td>5.7</td>
<td>54.6</td>
</tr>
<tr>
<td>6</td>
<td>6.4</td>
<td>55.0</td>
</tr>
</tbody>
</table>

Table 4: Comparison of measured and calculated values (30 RPH)

<table>
<thead>
<tr>
<th>Inlet conditions of regeneration air side</th>
<th>Inlet conditions of process air side</th>
<th>Exit conditions of process air side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y (g/kg)</td>
<td>T (°C)</td>
<td>m_{da} (kgs⁻¹)</td>
</tr>
<tr>
<td>1</td>
<td>7.0</td>
<td>53.0</td>
</tr>
<tr>
<td>2</td>
<td>7.3</td>
<td>54.5</td>
</tr>
<tr>
<td>3</td>
<td>5.8</td>
<td>51.5</td>
</tr>
<tr>
<td>4</td>
<td>5.9</td>
<td>52.2</td>
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<tr>
<td>5</td>
<td>6.1</td>
<td>55.4</td>
</tr>
<tr>
<td>6</td>
<td>6.4</td>
<td>55.3</td>
</tr>
</tbody>
</table>

Table 5: Comparison of measured and calculated values (37.5 RPH)

<table>
<thead>
<tr>
<th>Inlet conditions of regeneration air side</th>
<th>Inlet conditions of process air side</th>
<th>Exit conditions of process air side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y (g/kg)</td>
<td>T (°C)</td>
<td>m_{da} (kgs⁻¹)</td>
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<tr>
<td>1</td>
<td>6.4</td>
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<tr>
<td>2</td>
<td>6.7</td>
<td>49.5</td>
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<td>50.8</td>
</tr>
<tr>
<td>6</td>
<td>8.2</td>
<td>47.9</td>
</tr>
</tbody>
</table>

4.3 Comparison with Experiment Data – Enthalpy Exchange Mode

Listed in Table 6 are comparison results of LiCl rotor under reasonable rotational speed as enthalpy exchanger. And further comparison results under all available rotational speeds were listed in Table 7. It can be found that:

- For all cases, predicted humidity ratios are lower than measured ones. This is partly because mass transfer was over-estimated from heat transfer coefficient and Lewis relationship. On the other hand, when LiCl rotor works as an enthalpy exchanger, the residential times of desiccant matrix in both process and return air stream are so greatly reduced that it is impossible to achieve sorption equilibrium. Under this circumstance more errors have been introduced by the use of isotherm equations. But it is interesting to notice that such a model can give satisfactory prediction, even if whether isotherm cannot be applied in a strict sense remains questionable.

- The fact that predicted temperatures are higher than measured ones suggested actual heat transfer is stronger than that from Lewis analogy. In this paper, Lewis number for all cases was taken as constant 0.874, an appropriate and reasonable value for mass/heat transfer between air and water. It can be concluded that despite such a constant, Lewis number cannot describe the transfer process very precisely, the predicted values from Lewis relationship is accurate enough for engineering use.
Table 6: Comparison of calculated values and measured values – Enthalpy exchanger mode
(Commonly-used rotational speed)

<table>
<thead>
<tr>
<th>RPH</th>
<th>Inlet conditions of return air</th>
<th>Inlet conditions of process air</th>
<th>Exit conditions of process air side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$Y$ (gkg$^{-1}$)</td>
<td>$T$ (°C)</td>
<td>$m_{da}$ (kgs$^{-1}$)</td>
</tr>
<tr>
<td>525</td>
<td>11.2 23.3 0.6525</td>
<td>12.6 34.0 0.5722</td>
<td>12.0 10.9 24.7 26.2</td>
</tr>
<tr>
<td></td>
<td>11.1 23.4 0.6573</td>
<td>12.7 34.1 0.5677</td>
<td>11.9 10.4 24.9 26.0</td>
</tr>
<tr>
<td></td>
<td>10.9 23.6 0.6529</td>
<td>12.9 33.9 0.5669</td>
<td>11.8 10.4 24.9 26.0</td>
</tr>
<tr>
<td></td>
<td>11.4 23.4 0.5526</td>
<td>12.0 34.7 0.4960</td>
<td>12.0 10.9 24.9 26.1</td>
</tr>
<tr>
<td></td>
<td>11.7 23.5 0.5492</td>
<td>13.9 35.0 0.4897</td>
<td>12.3 11.0 25.0 26.4</td>
</tr>
<tr>
<td></td>
<td>12.0 23.3 0.5000</td>
<td>13.9 35.9 0.4883</td>
<td>12.7 11.2 25.6 26.6</td>
</tr>
<tr>
<td>562.5</td>
<td>11.3 23.5 0.5454</td>
<td>13.2 35.0 0.4928</td>
<td>12.0 10.6 24.8 26.5</td>
</tr>
<tr>
<td></td>
<td>11.4 23.7 0.5456</td>
<td>13.7 35.5 0.4885</td>
<td>12.1 10.9 24.9 27.5</td>
</tr>
<tr>
<td></td>
<td>11.6 23.6 0.5521</td>
<td>14.0 35.8 0.4938</td>
<td>12.3 10.9 25.2 26.7</td>
</tr>
<tr>
<td></td>
<td>12.0 23.5 0.6482</td>
<td>14.0 36.4 0.5638</td>
<td>12.6 11.1 24.9 26.7</td>
</tr>
<tr>
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Table 7: Comparison of measured values and calculated values – Enthalpy exchanger mode
(All rotational speeds)

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<tr>
<th>RPH</th>
<th>Inlet conditions of return air</th>
<th>Inlet conditions of process air</th>
<th>Exit conditions of process air side</th>
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<tr>
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<td>$Y$ (gkg$^{-1}$)</td>
<td>$T$ (°C)</td>
<td>$m_{da}$ (kgs$^{-1}$)</td>
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<td>18.7 36.6 0.4047</td>
<td>13.4 12.1 25.4 26.2</td>
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</table>
5. CONCLUSIONS

- The numeric work set up in this paper, namely mass and heat transfer analysis in combination with empirical treatment for heat transfer coefficient, can predict quite accurately the performance of LiCl rotor under both dehumidification and enthalpy exchange modes.

- In order to improve accuracy of predicting based upon analysis of mass and heat transfer within LiCl under dehumidification mode, more research should be carried out on isotherm of lithium chloride.

- For enthalpy exchange mode, the improvement of predicting accuracy will depend mainly upon sorption kinetics development. Because residential times of desiccant matrix in air streams are so short that one cannot anticipate equilibrium between LiCl and moisture.

- The empirically-treated heat transfer coefficient can give reliable prediction enough for engineering use.

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tr>
<td>a</td>
<td>thickness of desiccant bed, m</td>
</tr>
<tr>
<td>A</td>
<td>area, m²</td>
</tr>
<tr>
<td>A1-A7</td>
<td>coefficients of normalized equations</td>
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<tr>
<td>c</td>
<td>specific heat, kJ kg⁻¹ °C⁻¹</td>
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<tr>
<td>f</td>
<td>mass fraction of desiccant within desiccant bed, kg LiCl/kg desiccant bed</td>
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<tr>
<td>h</td>
<td>heat transfer coefficient, kW m⁻² °C⁻¹</td>
</tr>
<tr>
<td>H</td>
<td>enthalpy, kJ kg⁻¹</td>
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<tr>
<td>K</td>
<td>mass transfer coefficient, kg m⁻² s⁻¹</td>
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<td>Le</td>
<td>Lewis number</td>
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<tr>
<td>m</td>
<td>mass flow rate of air in terms of dry air, kg s⁻¹</td>
</tr>
<tr>
<td>M</td>
<td>mass, kg</td>
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<tr>
<td>NTU</td>
<td>number of transfer unit</td>
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<td>Q</td>
<td>isosteric adsorption heat, kJ kg⁻¹</td>
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<td>RH</td>
<td>relative humidity</td>
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<td>T</td>
<td>temperature, °C</td>
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<td>TF</td>
<td>normalized cycle</td>
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<tr>
<td>t</td>
<td>actual time coordinate or period, s</td>
</tr>
<tr>
<td>u</td>
<td>velocity, m s⁻¹</td>
</tr>
<tr>
<td>U</td>
<td>hydraulic wetting perimeter, m</td>
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<tr>
<td>W</td>
<td>water content of Lithium Chloride, kg H₂O/kg LiCl</td>
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<tr>
<td>XₙL</td>
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<td>x</td>
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<tr>
<td>Y</td>
<td>humidity ratio of air, kg H₂O/kg dry air</td>
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<td>z</td>
<td>normalized axis coordinate</td>
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<tr>
<td>ρ</td>
<td>density, kg m⁻³</td>
</tr>
<tr>
<td>τ</td>
<td>normalized time coordinate</td>
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Subscripts

a moist air
ad process air side
Binding binding process
cross cross-sectional
da dry air
fg phase change process
H₂O liquid water
re regeneration air or return air
ref reference value
s saturated water vapor
v water vapour
w desiccant bed or air which should be in equilibrium with desiccant bed
wr rotor (including desiccant bed and water within desiccant bed)
z process air side or regeneration air side (of heat transfer surface area)

REFERENCES

1. Y.M. Qian, High-rise building air-conditioning system and energy conservation, Tongji University Press, Shanghai, pp. 528-537 (1990) - In Chinese.


