Liquid Desiccant System Component Models in the Sorption System Simulation Program (SorpSim)

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Abstract

Liquid desiccant systems (LDS) are known for their capability to effectively address latent cooling load in air conditioning application by utilizing renewable energy and waste heat. While there has been an increase in research and development in LDS during the past decade, and many LDS component models have been presented in literature, evaluation of LDS systems still requires a laborious process of building a model from scratch. Meanwhile, the Sorption system Simulation program (SorpSim) has been developed by Oak Ridge National Laboratory and Purdue University to provide a convenient platform for absorption system simulation studies. In this study, based on the LDS models available in literature, adiabatic LDS components were developed in SorpSim, extending the capability of SorpSim to liquid desiccant systems. A finite difference-based and an effectiveness-based component model was implemented, and each was verified against published data in the related literature. The SorpSim LDS models demonstrated the versatile capability to predict and analyze the performance of LDS dehumidifier and regenerator. As a reliable, convenient, and open-source simulation platform, the expanded SorpSim now has the LDS capability to facilitate LDS simulation at both the component and system level.

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1. Introduction

In the U.S., buildings account for over 36% of total energy use, 65% of electricity consumption, and 30% of greenhouse gas emissions [1], with air conditioning (A/C) systems as major contributors. A/C systems using liquid desiccant technology are able to address latent cooling load separately and effectively by using low grade renewable energy sources such as solar and waste heat. Therefore, liquid desiccant systems (LDS) have the potential to greatly improve the energy efficiency of A/C systems, especially in humid climates where latent cooling load is significant.

LDSs take advantage of the hydrophilic property of materials such as LiCl/H_2O solution to achieve

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dehumidification. Typically, a stream of strong solution is cooled and pumped into the dehumidifier to contact the process air and absorb moisture from it; then the diluted solution is heated and pumped into the regenerator to be re-concentrated by evaporating water content into the exhaust air stream. Such LDS cycles are able to address the entire latent cooling load with minimum pumping electricity consumption, and since the solution is regenerated using renewable energy source, the primary energy and carbon emission of such LDS are very low.

Although not as mature as vapor-compression systems, LDS has seen a significant increase in research over the past decade [2-7]. To facilitate the research, many LDS models have been built since 1980s [3, 5, 8-15], and these models have proven to be very helpful in their designated researches. However, to build upon successful LDS modelling works from others' research can be challenging, as the source-code of these published models is usually not readily available, and it requires much skill and effort in programming to implement and adjust the code to the new research scenarios.

Through the effort to promote the research and development of energy-efficient systems using sorption technology, Sorption system Simulation program (SorpSim) has been developed under DOE sponsorship as a reliable, user-friendly, and openly-accessible simulation software where a variety of sorption-based systems models can be constructed, simulated, and analysed with minimal effort from users [16]. Based on the legendary modular absorption simulation code ABSIMW Version 5.0, SorpSim enables convenient and effective simulation and analysis of absorption systems on modern computer platforms. Furthermore, successful simulations in SorpSim can be easily shared.

In order to provide a reliable and easy-to-use simulation tool for LDS research and development, this study presents the development of LDS component models in SorpSim. In the following sections, the SorpSim program is briefly introduced. Then the literature on the component models of adiabatic LDS dehumidifiers and regenerators is reviewed and discussed. The two types of LDS component models newly implemented in SorpSim are described. Finally, these LDS components models in SorpSim are verified by comparing them to the data published in literature.

2. Introduction of SorpSim

SorpSim was developed to provide a sorption system simulation tool that is reliable, flexible, and publicly accessible for promoting sorption system research [12]. The simulation engine of SorpSim was based on the legendary code of ABSIMW Version 5.0 (shortened as ABSIMW below) developed by the Oak Ridge National Laboratory in the 1990s. Although ABSIMW was capable of flexible and reliable calculation for absorption system simulation, due to a lack of continued development and maintenance since 2000, ABSIMW is only compatible with Windows XP and earlier Window operating systems. Its interface is menu-based and requires repetitive operations. The summary of system parameters and calculation results are in text files, lacking visualization capability such as tables and charts. It is difficult to carry out a system-level simulation and parametric studies without a flexible setting platform.

SorpSim was developed to meet the needs for a flexible and powerful simulation platform. SorpSim inherited the flexible and verified calculation capabilities from the ABSIMW, while it was also equipped with enhanced features at each step of system simulation. Based on drag-and-drop operation and multiple dialogs, cycle manipulation in SorpSim is intuitive and responsive. All parameters in the cycle can be monitored and edited in the master panel, providing a convenient system overview. Calculation results can be visualized in a table, on a cycle diagram, and on fluid property charts. Parametric tables and plots can be easily generated, managed, and exported, which greatly facilitate post-simulation sensitivity analysis and system optimization. Furthermore, SorpSim was developed in C++ programming language, and it can be compiled and run on all latest operation systems including Windows, Mac OS and Linux.

With these enhanced features, SorpSim provides a better sorption simulation platform compared with general-purposed thermal system simulation tools such as Engineering Equation Solver (EES), which provides property subroutines of many sorption system working fluids and is widely used for thermodynamic calculations. In EES all governing equations of each component, connection, and inquiry of working fluid property in the cycle must be manually typed in, which requires a fair amount of effort to correctly build the system equation set. Moreover, if the system configuration needs to be adjusted (e.g. insert/remove components and re-wire connections), the variables in equations would also need to be manually changed, which can be both laborious and probable to introduce error. In contrast, SorpSim enables users to build, adjust, and simulate system cycles by simply operating on graphical modules of pre-programmed standard components, while the fluid property inquiries are made automatically during calculation. Moreover, fluid property charts such as Dühring Chart can be automatically generated and managed in SorpSim to analyze the cycle, while in EES they have to be created by manually generating each background line.

SorpSim provides 12 standard components for absorption systems including absorber, desorber, heat exchanger, condenser, evaporator, rectifier, analyzer, and auxiliary components such as valve, splitter, and pump. Also, SorpSim has the property library containing thermophysical correlations of 11 different working fluids including aqueous solutions of LiBr, LiCl, NaOH, and $LiNO_3/KNO_3/NaNO_3$ mixture, as well as other fluids used in absorption systems such as H_2O/NH_3 mixture, CH_3OH, and moist air.

These decoupled and modular subroutines of the component and working fluid in SorpSim enable a wide range of robust and flexible investigation of sorption systems: from a convenient inquiry of the working fluid property at a certain given condition to building and simulating systems with a large variety of user-defined cycle configurations. Moreover, such a modular framework allows continuous expansions of additional component models and working fluid properties into SorpSim, enabling it to provide an all-around simulation platform for even more and newer sorption technology systems. Based on this framework, new models of LDS components including dehumidifier/regenerator of various flow arrangements, as well as new fluid properties such as isotherms of LDS desiccant solutions including $LiCl/H_2O$ and ionic liquids can be implemented in SorpSim. This paper provides the description of the development and verification of the new LDS capability of SorpSim for the needs of LDS research in the following sections.

3. Liquid Desiccant Models

3.1. Model Overview

The dehumidifier and the regenerator are the two key components in a LDS where the heat and mass transfer process between desiccant solution and air takes place. The dehumidifiers and the regenerators in adiabatic configurations, namely spray tower/packed tower, are the simplest and most widely installed as well as investigated. There have been a number of mathematical models developed in literature to predict the performance of the adiabatic LDS dehumidifier and regenerator. These models can be categorized into three types as shown in Table 1: effectiveness model, finite difference model, and simplified model.

The finite difference models divide the component into a series of control volumes, and then list the conservation and heat/mass transfer differential equations for each control volume [4, 5, 10, 11, 17]. These differential equations are solved using numerical integration along the height of the component. The effectiveness model assumes that the saturated air enthalpy at the solution surface changes linearly with temperature, and that the change in solution concentration is negligible. Then it describes the heat and mass transfer between solution and air using correlations analogous to the NTU-effectiveness method in heat exchanger analysis, avoiding numerically solving the differential equations [15]. Some of the simplified models apply assumptions to help solve the differential equations analytically [3, 18, 19], some introduce dimensionless parameters and analytically link them to the performance [8, 14], and others use curve-fitted correlations from detailed simulations or empirical experiments to directly estimate the performance [9, 13].

Table 1 Summary of component models for adiabatic LDS dehumidifier and regenerator

Model Type	Flow Pattern	Desiccant	Operating mode and desiccant	Literature
Effectiveness Model	Counter-flow	LiCl	Dehumidification	Stevens et al [15]
Finite Difference Model	Counter-flow	LiBr	Dehumidification/regeneration	Factor and Grossman [10]
	Counter-flow	LiCl	Dehumidification/regeneration	Fumo and Goswami [11]
	Counter-/Co-flow	LiBr	Regeneration	Liu et al [5]
	Cross-flow	LiBr	Dehumidification/regeneration	Liu et al [4]
Simplified Model	Counter-flow	LiCl & TEG	Dehumidification	Chung [9]
	Counter-flow	LiCl & TEG	Dehumidification/regeneration	Martin and Goswami [14]
	Cross-/Counter-flow	LiBr	Dehumidification	Liu et al [13]
	Counter-flow	LiBr, LiCl, $CaCl_2$	Dehumidification/regeneration	Ren et al [8]
	Counter-flow	LiCl	Regeneration	Haim et al [18]
	Counter-flow	LiCl	Dehumidification/regeneration	Hellmann et al [19]

Counter-flow	LiCl	Dehumidification/regeneration	Gommed and Grossman [3]

Among all the available models, the finite difference model is the most generic with least assumptions, and the effectiveness model is more calculation-friendly while still quite accurate over a wide range of operation conditions. Therefore, these two models were implemented into SorpSim for performance prediction of adiabatic LDS components.

3.2. Finite Difference Model

The finite difference model divides the component into a number of control volumes and solves the differential conservation and heat/mass transfer equations within each control volume. As an example, Liu et al. [5] developed a finite difference model for a counter-flow regenerator as shown in Figure 1, where an overview of the regenerator is on the right, and a differential control volume at a certain height in that regenerator on the left. Energy, desiccant salt mass and moisture mass conservation can be established in each control volume:

$$m_s \cdot dh_s + h_s \cdot dm_s - m_a \cdot dh_a = 0 \tag{1}$$

$$m_s \cdot x_s - (\mathrm{m}_s + dm_s) \cdot (x_s + dx_s) = 0 \tag{2}$$

$$dm_s - m_a \cdot dw_a = 0 \tag{3}$$

As shown in Eq. (4), the change in air enthalpy includes both the sensible heat transferred due to the temperature difference from solution and the latent heat transferred due to moisture exchange with the solution. In Eq. (4), r is the condensation heat of water, A is the surface area per unit height, Z is the total height of the device, and $\mathrm{h_C}$ is the heat transfer coefficient.

$$m_a \cdot dh_a = h_C \cdot A \cdot \mathrm{dZ} \cdot (t_a - t_s) + r \cdot m_a \cdot dw_a \tag{4}$$

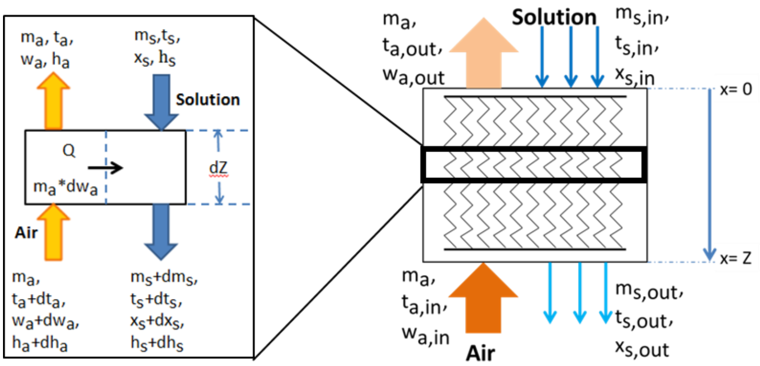


Figure 1 overview (right) and differential control volume (left) of a counter-flow LDS component

The change of moisture content in air is driven by the vapor partial pressure difference between air and the solution surface, which is represented in Eq. (5) by the difference between air humidity ratio (w_a) and equilibrium air humidity ratio at the solution surface ($w_{s,eq}$). The equilibrium air humidity ratio at the solution surface ($w_{s,eq}$) is calculated from solution temperature and concentration. h_D is the mass transfer coefficient.

$$m_a \cdot dw_a = h_D \cdot A \cdot \mathrm{dZ} \cdot \left(w_a - w_{s,eq}\right) \tag{5}$$

The Lewis number and number of mass transfer unit NTU are defined by Eq. (6) and (7), where $C_{p,m}$ is the specific heat of humid air.

$$\mathrm{NTU} = \frac{h_D \cdot A \cdot Z}{m_a} \tag{6}$$

$$\mathrm{Le} = \frac{h_C}{h_D \cdot C_{p,m}} \tag{7}$$

The enthalpy of moist air can be written as the sum of two products: the moist air specific heat and air temperature, and the humidity ratio and the evaporation heat of water.

$$h_a = C_{p,m} \cdot t_a + w_a \cdot r \tag{8}$$

Substituting Eq. (6) into (5) yields Eq. (9):

$$\frac{dw_a}{dZ} = \frac{\text{NTU}}{Z} \cdot \left(w_a - w_{s,eq}\right) \tag{9}$$

Substituting Eq. (6) (7) (8) (9) into Eq. (4) yields Eq. (10), where $h_{s,eq}$ is the equilibrium air enthalpy above solution surface calculated from solution temperature (t_s) and the equilibrium air humidity ratio ($w_{s,eq}$).

$$\frac{dh_a}{dZ} = \frac{\text{NTU} \cdot Le}{Z} \cdot [\left(h_a - h_{s,eq}\right) + (\frac{1}{Le} - 1) \cdot r \cdot \left(w_a - w_{s,eq}\right)] \tag{10}$$

Eq. (1) - (3) and Eq. (9) (10) are the governing equations of the heat and mass transfer processes in one control volume. In order to solve for the entire component, calculations have to be carried out for all control volumes along the flow direction, using output of one control volume as the input for the next.

3.3. Effectiveness Model

The effectiveness model for counter-flow dehumidifier was derived by Stevens et al. [15] based on the finite difference model, and the analogy to the effectiveness-NTU method for sensible heat exchangers was applied to help integrate the heat and mass transfer differential equations and avoid solving those equations numerically. In the effectiveness model, Eq. 1, 2, and 3 for each control volume can be directly integrated along the component height:

$$m_{s,o} = m_{s,i} - m_a(w_{a,o} - w_{a,i}) \tag{11}$$

$$m_{s,o} \cdot x_{s,o} = m_{s,i} \cdot x_{s,i} \tag{12}$$

$$h_{si}m_{si} - h_{so}m_{so} = m_a(h_{a,o} - h_{a,i}) \tag{13}$$

Analogous to the heat capacitance ratio used in heat exchanger analysis, define a capacitance ratio m^* for air and solution streams in the component:

$$m^* = \frac{m_a C_{p,eq}}{m_{s,i} C_{p,s}} \tag{14}$$

where $C_{p,eq}$ is the specific heat of air in equilibrium at desiccant solution's surface, which is assumed to be constant. In SorpSim, this $C_{p,eq}$ is calculated using the average temperature and enthalpy difference between solution inlet and outlet. Then Eq. 10 can be integrated assuming Lewis number equals one for moist air:

$$h_{a,o} = h_{a,i} + \mathcal{E}(h_{eq,si} - h_{a,i}) \tag{15}$$

where the effectiveness $\mathcal{E}$ is defined as:

$$\mathcal{E} = \frac{1 - e^{-NTU(1-m^*)}}{1 - m^* e^{-NTU(1-m^*)}} \tag{16}$$

In order to solve for the air outlet humidity ratio, an "effective" heat and mass transfer process is assumed where the temperature, enthalpy, and humidity ratio of the equilibrium air at solution surface are constant values that result in the same outcome as the actual varying values. In this case, the corresponding m^* in equation (16) can be deemed as 0, and the "effective" equilibrium air enthalpy can be calculated by substituting Eq.16 into Eq.15 with $m^* = 0$.

$$h_{eq,eff} = h_{ai} + \frac{h_{a,o} - h_{a,i}}{1 - e^{-NTU}} \tag{17}$$

And assuming the change of solution concentration can be neglected, the "effective" equilibrium air humidity ratio $w_{eq,eff}$ can be calculated based on $h_{eq,eff}$ and solution inlet concentration. Then substituting w_{eq} with $w_{eq,eff}$ and integrate Eq. 4, the processed air outlet humidity ratio can finally be calculated as:

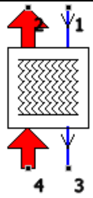
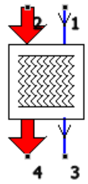
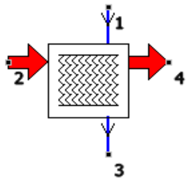
$$w_{a,o} = w_{eq,eff} + \left(w_{a,i} - w_{eq,eff}\right)e^{-NTU} \tag{18}$$

Eq. 11, 12, 13, 15 and 18 are the five governing equations of adiabatic liquid desiccant heat and mass exchangers. During simulation, the intermediate parameters are calculated before these five equations are evaluated for residuals.

To use these two types of models, the NTU value which defines the component's design and dimension (mass transfer capacity and surface area for heat and mass transfer) is required. Then from the temperature, concentration/humidity ratio, and flow rate of each of the 4 state points, 5 variables can be set as unknown and calculated when the rest state point parameters are given. For example, given the status of air and solution inlet, as well as the air outlet flow rate (dry air flow rate equals to inlet), the air outlet temperature, humidity ratio, and solution outlet temperature, concentration, and flow rate can be calculated using both the finite difference model and the effectiveness model.

Besides the two models for counter-flow LDS components, in total six more models of both types were implemented in SorpSim with different flow arrangements and component types, as shown in Table 2.

Table 2 Summary of LDS component models in SorpSim

Flow Arrangement	 Counter-flow		 Co-flow	 Cross-flow
Component Type	Dehumidifier/Regenerator		Dehumidifier/Regenerator	Dehumidifier/Regenerator
Model type	Finite Difference Model	Effectiveness Model	Finite Difference Model	Finite Difference Model
Reference	[5]	[15]	[5]	[4]

4. Liquid Desiccant Model Verification

The finite difference model and effectiveness LDS models introduced above have been implemented in SorpSim. In order to verify their accuracy, the performance of a LDS dehumidifier and a LDS regenerator were modeled and compared under operation conditions presented by Stevens [20] and Khan [21]. After verification, a brief parametric analysis was carried out for both components to evaluate the influence of various NTU and air/solution status on the component performances.

4.1. Dehumidifier Model Verification and Performance Analysis

In Stevens et al. [20], a series of simulations were carried out using both finite difference model and effectiveness model on a counter-flow LDS dehumidifier. Aqueous lithium chloride solution was the working fluid in a counter-flow adiabatic dehumidifier. We used the data of the simulation #14 based on the finite different model for our model validation. The condition was: air inlet fixed at 35°C and 0.03 kg/kg humidity ratio; desiccant solution inlet fixed at 15°C and 40% concentration; solution mass flow kept at 2 kg/s; and air mass flow rate kept at 1 kg/s. The Lewis number was kept at 1, and the mass transfer NTU value from 0.01 to 10 was assumed to reflect dehumidifiers of different sizes and designs. The air outlet temperature and humidity ratio, as well as the solution outlet temperature, were calculated by the model.

Table 3 summarizes results of SorpSim compared to results in Stevens' thesis. The RMSDs shown are generally small. Both models in SorpSim tend to over-predict the air outlet humidity ratio, and consequently under-predict the solution outlet temperature due to less condensation and smaller flow rate. This difference could be attributed to the different working fluid property correlations that were used in Stevens calculation and in SorpSim. SorpSim uses the LiCl/H_2O isotherm property correlation from Conde [22], which was published well after Stevens' thesis.

Figure 2 shows a brief sensitivity analysis on the dehumidifier performance based on operation conditions described above. In the left chart, both the air outlet temperature and humidity ratio declines quickly when NTU increases from 0.1 to 2, and then their slope become very flat as the NTU continues to increase. This indicates that the marginal size of NTU to effectively improve the dehumidification performance under current operation condition is around 2. That means increasing the size of the dehumidifier would have only trivial effect on its performance of drying and cooling air.

In the right chart, the solution inlet temperature and concentration was varied while the NTU value was kept at 1. The dehumidification performance increases with higher solution concentration, and decreases with higher solution temperature. These trends reflect the property of the desiccant solution: the equilibrium vapor pressure of the solution decreases with concentration and increases with temperature. With a lower vapor pressure at solution surface, the driving force of dehumidification, namely the vapor pressure difference between air and solution, becomes stronger, leading to a better performance of the component.

Table 3. Comparison between SorpSim results and Stevens [20]:

	Air Outlet Temperature (°C)			*Air Outlet Humidity Ratio (kg/kg)*			*Solution Outlet Temperature(°C)*		
NTU	Stevens	SorpSim		Stevens	SorpSim		Stevens	SorpSim	
		EFF	FD		EFF	FD		EFF	FD
0.01	34.802	34.81	34.81	0.02972	0.0297	0.0297	15.186	15.18	15.17
0.1	33.178	33.27	33.27	0.02732	0.0273	0.0274	16.765	16.72	16.62
0.5	28.318	28.48	28.48	0.01901	0.0191	0.0192	22.038	21.85	21.46
1	24.892	25.07	24.95	0.01244	0.0126	0.0127	26.073	25.77	25.17
1.5	22.602	22.82	22.59	0.00841	0.0086	0.0088	28.554	28.16	27.46
2	20.841	21.12	20.82	0.00591	0.0062	0.0063	30.15	29.69	28.93
4	16.72	17.1	16.89	0.00237	0.0026	0.0027	32.701	32.17	31.34
6	15.38	15.62	15.55	0.00184	0.002	0.002	33.223	32.74	31.89
8	15.064	15.17	15.15	0.00176	0.0019	0.0019	33.32	32.89	32.02
10	15.006	15.04	15.04	0.00175	0.0019	0.0019	33.336	32.92	32.06
RMSD	-	0.202	0.10	-	1.7×10^{-4}	2.4×10^{-4}	-	0.37	1.04

*EFF = effectiveness model; FD = finite difference model

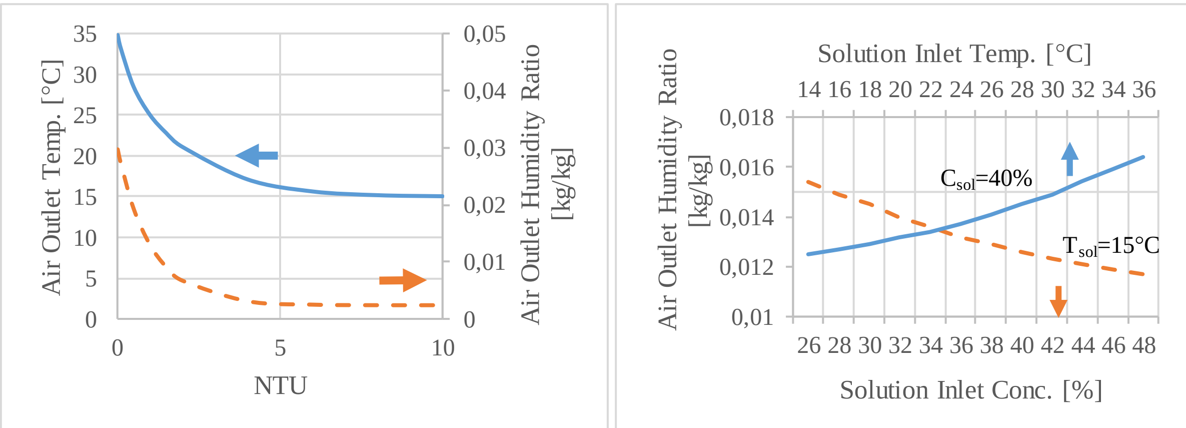


Figure 2 The effect of dehumidifier NTU (left) and solution status (right) on the dehumidification performance

4.2. Regenerator Model Verification and Performance Analysis

In Khan's paper [21], a group of simulation results of a packed-type counter-flow LDS regenerator using LiCl-H_2O as the working fluid were reported using finite difference model. Through these simulations, the values of the NTU was kept at 1.0, the Lewis number was kept at 1.0, and solution inlet concentration was fixed at 44%. Various cases using a range of solution and air temperatures, humidity, and solution-air-mass-ratio (SAMR) were simulated. The ranges of variables in Khan's simulations are summarized in Table 4:

Table 4. Summary of the operation condition range in Khan [21]

T_{si} (°C)	T_{ai} (°C)	w_{ai} (kg/kg)	SAMR
55-80	25-50	0.008-0.012	1.5-5.0

Two parameters were introduced to evaluate the performance of the regenerator: the humidity effectiveness (ε_w) and enthalpy effectiveness (ε_h) of the component are defined as the ratio of actual air humidity/enthalpy change before and after regeneration over the maximum humidity/enthalpy difference in the component:

$$\varepsilon_w = \frac{w_{a,i} - w_{a,o}}{w_{a,i} - w_{eq,si}} \tag{19}$$

$$\varepsilon_h = \frac{h_{a,i} - h_{a,o}}{h_{a,i} - h_{eq,si}} \tag{20}$$

In Eq. 19 and 20, $w_{eq,si}$ and $h_{eq,si}$ are the equilibrium air humidity ratio and enthalpy at the solution inlet. In Khan's paper, each humidity and enthalpy effectiveness provided was the average value for a group of cases using the same SAMR and solution temperature, while varying the air inlet temperature and humidity within the given range with intervals of 5°C and 0.005 kg/kg. The same calculations were carried out using the LDS component models in SorpSim following the same procedure. Table 5 shows the comparison between results of two SorpSim models and results from Khan as well as the RMSDs of the comparison. The finite difference model results were in good agreement with Khan's results. However, the effectiveness model in SorpSim tended to slightly over-predict the humidity and enthalpy effectiveness in a few cases when the effectiveness was the lowest. Nevertheless, the maximum difference was below 20% compared to Khan's results. Both models were therefore verified with good accuracy simulating LDS regenerators.

A brief performance analysis using these two SorpSim models on a regenerator is shown in Figure 4. By default, the solution inlet temperature was set to 70°C, and the air inlet conditions were 30°C and 0.012kg/kg. In the left chart, the solution outlet concentration increased with higher regenerator NTU, which can be explained by the increased evaporation of water content from the solution due to a larger heat and mass transfer surface indicated by a high NTU. The increased water evaporation is also the reason behind the decreasing solution outlet temperature, as heat was taken from the solution stream with evaporation. Similar to the dehumidifier analysis, the effect of enlarging the component size diminished after the NTU reached 4. The right chart in Fig. 4 illustrates the solution concentration difference before and after regeneration with varying solution inlet temperature and concentration while the NTU was kept at 1. The concentration difference was determined by the amount of water evaporated in the regenerator, which in turn was influenced by the vapor pressure difference between solution and air. As shown in the chart, a lower concentration or higher temperature led to a larger concentration difference in the solution. This can be explained similarly to the analysis for the dehumidifier: the vapor pressure above solution was higher for hotter and weaker solution, which enhanced the evaporation driving force and resulted in the solution losing more moisture and becoming more concentrated.

When solution temperature was too low, for instance below 50°C, moisture actually is absorbed into the solution. This is because at such low temperature, the solution vapor pressure was lower than that in the air, and moisture was driven from air into the solution. In this case, the regenerator was in effect turned into a dehumidifier, and the desiccant solution passing through became more diluted instead of concentrated.

Table 5. Summary of operation conditions in Khan [21]

		Humidity Effectiveness			*Enthalpy Effectiveness*		
SAMR	Tsi (°C)	Khan	SorpSim EFF	SorpSim FD	Khan	SorpSim EFF	SorpSim FD
1.5	55	0.464444	0.4764	0.465106	0.509272	0.53175	0.520363
	60	0.456208	0.480033	0.464309	0.487204	0.518324	0.503941
	65	0.437292	0.470724	0.450169	0.460722	0.503167	0.484946
	70	0.41025	0.45628	0.430439	0.434052	0.486419	0.463219
	75	0.38168	0.439391	0.407022	0.40721	0.468193	0.438739
	80	0.352996	0.421019	0.380778	0.377544	0.448748	0.411628
2	55	0.500988	0.511337	0.50145	0.536388	0.55508	0.544398

	60	0.496154	0.513369	0.499717	0.51942	0.543828	0.531054
	65	0.478416	0.504804	0.487352	0.500146	0.530819	0.515337
	70	0.45398	0.491507	0.470063	0.473452	0.516078	0.496926
	75	0.424954	0.47572	0.449141	0.448632	0.499596	0.475628
	80	0.400796	0.458076	0.425044	0.418948	0.481467	0.451341
3	55	0.541386	0.548402	0.539624	0.566698	0.579557	0.569394
	60	0.536314	0.549457	0.537663	0.552628	0.57117	0.559772
	65	0.520728	0.542557	0.528139	0.535648	0.561167	0.548239
	70	0.504676	0.531594	0.514739	0.521714	0.549526	0.534407
	75	0.48008	0.518274	0.498131	0.496866	0.536067	0.51792
	80	0.453228	0.502904	0.478359	0.471092	0.520709	0.498467
4	55	0.566906	0.568019	0.55937	0.584446	0.592244	0.582211
	60	0.562032	0.568689	0.557591	0.573622	0.585578	0.574706
	65	0.54809	0.563019	0.549954	0.56301	0.577507	0.565654
	70	0.534436	0.553857	0.539154	0.547494	0.567972	0.554656
	75	0.518746	0.542535	0.525574	0.535094	0.556726	0.541354
	80	0.493304	0.529246	0.509106	0.510204	0.543611	0.525335
5	55	0.591758	0.57988	0.571417	0.5937	0.60000	0.590004
	60	0.579284	0.580535	0.569846	0.58639	0.59448	0.583856
	65	0.573112	0.575874	0.563498	0.575756	0.587722	0.576387
	70	0.550634	0.568024	0.554472	0.563458	0.579669	0.567309
	75	0.536946	0.558244	0.543057	0.547854	0.570056	0.556191
	80	0.517812	0.546624	0.529046	0.534022	0.55867	0.542652
RMSD		-	0.031549	0.002554	-	0.034145	0.00313

*EFF = effectiveness model; FD = finite difference model

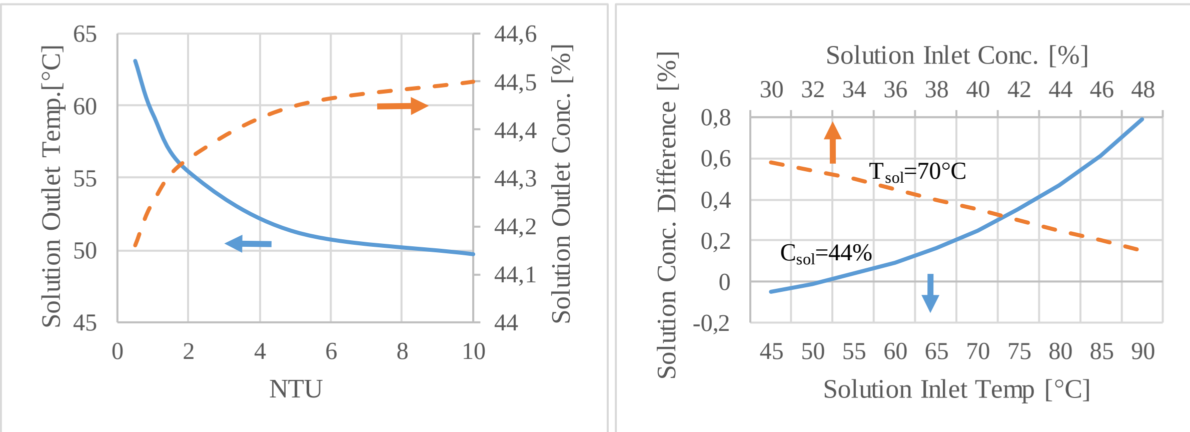


Figure 4 The effect of dehumidifier NTU (left) and solution status (right) on the component performance

In summary, both the finite different and effectiveness models in SorpSim were used to predict the performance of a dehumidifier and a regenerator, and their results were in good agreement with simulation results in literature. A brief analysis was carried out on both the dehumidifier and regenerator by using SorpSim, and the sensitivity of component performance against several operation condition parameters was illustrated. Therefore, the LDS component models in SorpSim were verified, and the LDS component modelling capability of SorpSim was demonstrated.

5. Conclusion

Liquid desiccant systems have received increasing interest for their ability to utilize renewable energy source to effectively provide latent cooling in air conditioning applications. In order to facilitate further research and development of LDS, a convenient and reliable LDS simulation tool is strongly called for. In this study, a finite difference model and an effectiveness model of adiabatic LDS components with various flow arrangements were developed in SorpSim. The two SorpSim components were verified against data published in the literature. The SorpSim LDS component models demonstrated good capability to predict and analyze the performance of LDS dehumidifier and regenerator in various operation conditions. With a library of fully functional LDS component models, SorpSim now can be used for various LDS systems simulations.

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