A SIMULATION MODEL AND SOFTWARE FOR THE PERFORMANCE SIMULATION OF A HYBRID LIQUID DESICCANT COOLING SYSTEM

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ABSTRACT

This paper presents a simulation model and software for the performance of a liquid desiccant system and a conventional vapor compression system. The simulation model uses a finite difference analysis for heat and mass transfer in a packed absorber-regenerator type of liquid desiccant cooling system, and energy balance in the evaporator of the vapor-compression system. The software makes it easy to find the optimal values of the variables for the application that is being analyzed for it allows trying different combinations of the variables involved. This software was validated using the performance results presented by Mago and Goswami, (2000), based on experiments conducted at a test house at the University of Florida's Energy Research and Education Park. These tests consisted of operating the air conditioning system at the test house in two configurations: the conventional vapor compression system and the hybrid desiccant system. The simulation results agree with the experimental results with an error of less than 5%.

1. INTRODUCTION

One of the greatest needs for comfort in hot and humid regions of the world is air conditioning. A large share of the energy consumption in these regions during the summer time is for air conditioning. The total air conditioning load consists of sensible cooling load and latent cooling load. The load due condensation and removal of moisture from the air is called the latent load. In hot and humid regions where the relative humidity is high, this load becomes a big problem. Conventional vapor compression systems sometimes cannot even meet this load.

A combination of a desiccant dehumidification system and a vapor compression system (also known as hybrid desiccant cooling system) may not only meet the load but also save energy.

In a separate study, the authors (Mago and Goswami, 2000) showed that a hybrid liquid desiccant system using lithium chloride is better than a conventional vapor compression system for maintaining thermal comfort conditions.

The objective of this research was to develop a software tool to assist in further investigations of hybrid desiccant air conditioning systems. The developed software can simulate the performance of a conventional vapor compression system as well as the performance of a liquid desiccant system. The software makes it easy to find the optimal values of the system variables for the application that is being analyzed for it allows trying different combinations of the variables involved.

The advantages of having a tool like this is that by simulation a combination of the system parameters can be found to give the best effectiveness of the system, in a very short time. The software was developed using Visual Basic 5.0 and it needs Windows 95 or higher version to operate. The operation of the software is user friendly.

* This work was done at University of Florida, while he was a Graduated Student.

Some researchers such as Dai et al. (1998), Khan and Martinez (1998), among others, have also developed mathematical models and software for system simulations.

2. SIMULATION MODEL FOR HYBRID LIQUID DESICCANT SYSTEM

This part presents a finite difference model for heat and mass transfer in a packed bed absorber-regenerator and energy balance in the evaporator of the vapor-compression system.

2.1 Heat and Mass Transfer Model for the Tower

For the present study, a finite difference model presented by Oberg and Goswami (1998) and later modified by Fumo and Goswami (2000) is used. The assumptions made in this model are: only water is transferred between the desiccant and the air; the interfacial area for the heat and mass transfer is equal to the total surface area of the packing; the heat of mixing is negligible compared to the latent heat of condensation; and the resistance to the heat transfer is negligible in the liquid phase, resulting in the interfacial temperature being equal to the bulk temperature.

Figure 1 shows a representation of the tower, divided into small segments, dZ, to develop the governing equations. For each segment the mass and energy balance are solved, from the bottom to the top of the tower.

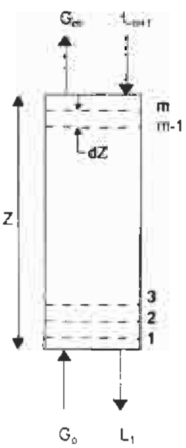


Fig. 1: Packed bed absorption tower divide in small segments

Equation (1) gives the change in air humidity across the segment as

$$\frac{dY}{dZ} = -\frac{M_w F_G a_w}{G} \ln\left(\frac{1-y_i}{1-y}\right) \qquad (1)$$

where a_w is determined using the equations proposed by Fumo (2000):

$$\frac{a_w}{a_t} = 1 - \exp\left[-1.45\left(\frac{\gamma_c}{\gamma_l}\right)^{0.75}\left(\frac{L}{a_t \mu_L}\right)^{0.1}\left(\frac{L^2 a_t}{\rho_L g}\right)^{-0.05}\left(\frac{L^2}{\rho_L a_t \gamma_L}\right)^{0.2}\right] \qquad (2)$$

The interfacial gas phase concentration is

$$y_i = 1 - (1-y)\left(\frac{x}{x_i}\right)^{F_L/F_G} \qquad (3)$$

Empirical correlations by Onda and Okumoto (equations 4) were used for the k-type mass transfer coefficients which can be converted to F-type coefficients by equations 5 and 6:

$$k_L = 0.0051\left(\frac{\mu_L g}{\rho_L}\right)^{1/3}\left(\frac{L}{a_w \mu_L}\right)^{2/3}\left(\frac{\rho_L . D_L}{\mu_L}\right)^{1/2}(a_t D_P)^{0.4} \qquad (4)$$

$$k_G = 5.23\left(\frac{a_t D_G}{RT_a}\right)\left(\frac{G}{a_t \mu_G}\right)^{0.7}\left(\frac{\mu_G}{\rho_G D_G}\right)^{1/3}\left(\frac{\rho_L D_L}{\mu_L}\right)^{1/2}(a_t D_P)^{-2}$$

$$F_L = k_L x_M c \qquad (5)$$

$$F_G = k_G P \qquad (6)$$

The logarithmic mean partial pressure difference between the bulk air and interface values is defined as

$$P = \frac{P'_a - P'_{ai}}{\ln\left(\frac{P'_a}{P'_{ai}}\right)} \qquad (7)$$

The logarithmic mean desiccant mole fraction difference between the bulk air and interface values is defined as

$$x_M = \frac{x - x_i}{\ln\left(\frac{x}{x_i}\right)} \qquad (8)$$

The change of air temperature across the segment can be determined by

$$\frac{dT_a}{dZ} = \frac{h'_G a_t (T_i - T_a)}{G(c_{pa} + Y c_{pv})} \qquad (9)$$

where $h'_G a_t$ is the heat transfer coefficient corrected for simultaneous heat and mass transfer.

$$h'_G a_t = \frac{-G c_{pv} \dfrac{dY}{dZ}}{1-\exp\left(\dfrac{G c_{pv} \dfrac{dY}{dZ}}{h a_t}\right)} \tag{10}$$

The gas phase heat transfer coefficient is

$$h_G = F_G M_a \left(c_{pa} + Y c_{pv}\right) \frac{Sc^{2/3}}{Pr^{2/3}} \tag{11}$$

The change in desiccant concentration across the segment is

$$\frac{dX}{dZ} = -\frac{G}{L} X \frac{dY}{dZ} \tag{12}$$

The change in liquid flow rate as a function of the change in air humidity across the segment is

$$dL = G dY \tag{13}$$

The change in desiccant temperature across the segment is

$$\frac{dT_L}{dZ} = \frac{G}{c_{pL} L}\left\{\left(c_{pa} + Y c_{pv}\right)\frac{dT_a}{dZ} + \left[c_{pv}\left(T_a - T_0\right) - c_{pL}\left(T_L - T_0\right) + \lambda_0\right]\frac{dY}{dZ}\right\} \tag{14}$$

2.2 Energy Model for the Evaporator

After getting the conditions of the air that leave the tower the following equations are used to determine the final conditions of the air after passing through the evaporator. Figure 2 shows a control volume for a energy analysis of an evaporator.

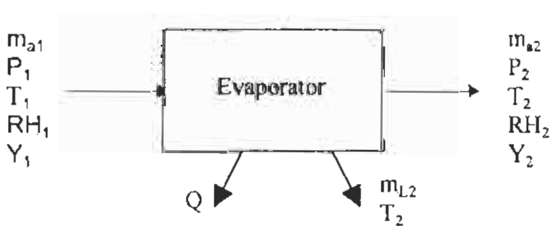


Fig. 2: Control volume of the evaporator analyzed in this system

Applying continuity for the air and water we get

$$m_{a1} = m_{a2} \tag{15}$$

$$m_{v1} = m_{v2} + m_{L2} \tag{16}$$

Applying the First Law of Thermodynamics, we get

$$Q + m_{a1} h_{a1} = m_{a2} h_{a2} \tag{17}$$

In this model the capacity of the evaporator is considered to be its nominal capacity.
The saturation pressure of water can be determined using ASHRAE (1996)

$$Ln(Ps) = \frac{C_1}{T} + C_2 + C_3 T + C_4 T^2 + C_5 T^3 + C_6 \ln T \tag{18}$$

Where
C_1=-5.8002206E3
C_2=1.3914993
C_3=-4.8640239E-2
C_4=4.1764768E-5
C_5=-1.4452093E-8
C_6=6.5459673

To use this equation, the temperature T has to be in Kelvin, and the saturation pressure Ps in Pascals.

The relative humidity is

$$RH = \frac{Pv}{Ps} \tag{19}$$

For air-water vapor mixture the humidity ratio is given by

$$Y = 0.622 \frac{Pv}{Pa} \tag{23}$$

Finally the enthalpy of the air can be determined using

$$h = T + Y(2501.3 + 1.86T) \tag{24}$$

where h is in kJ/kg and T is in degree Celsius.

All these equations were used to develop the software used to simulate the process. The software was developed using Visual Basic 5.0 and it needs Windows 95 or higher version to operate. This software can simulate the performance of a conventional vapor compression system as well as the performance of a liquid desiccant system.

3. DESCRIPTION OF THE SOFTWARE

In this part the functionality of the simulation software that was developed is described. This is done by presenting the different screens that appear during the executions of the software.

3.1 Initial Screen

When the software is started it shows the initial screen as follows:

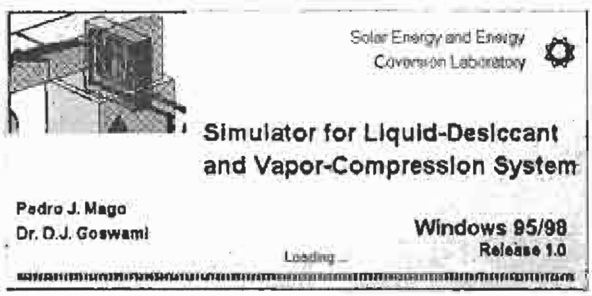


Fig 3: Initial screen.

3.2 Main Menu

After that, Main Menu appears. The user has to choose the kind of system that is going to be evaluated, input the data and the results. This is the screen that allows the users to simulate their systems. It is shown in figure 4.

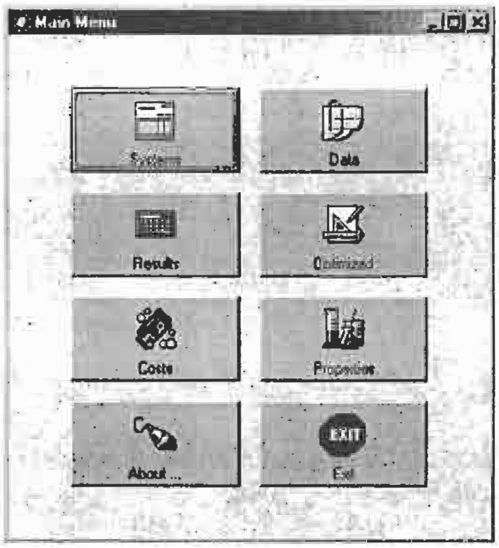
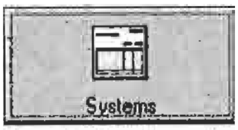


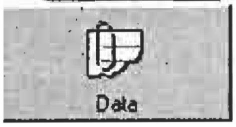
Fig: 4: Main menu.

3.3 Command System:



In this part the user can choose what kind of system to be evaluated: liquid desiccant system or vapor compression system. There is also the option to give the final conditions of the air to perform the simulation.

3.4. Command Data:



In this section the user has to enter the data for the system that is to be analyzed. There are two different screens: the first screen is for the data of vapor compression system and the other one is for liquid desiccant system. The screen for the data of the Liquid desiccant system is shown in figure 5.

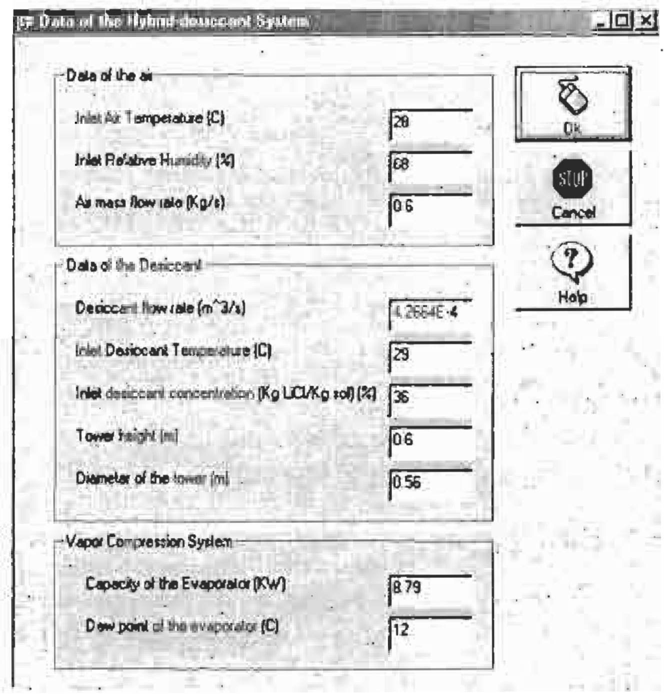
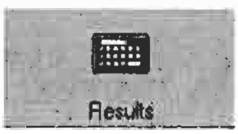


Fig 5: Screen to input the data of the system.

3.5 Command Results:



In this section the software provides the results of the simulation of the system that is being evaluated. The results for vapor compression system include the conditions of the air at the exit, the rate of condensation in the evaporator and the change of enthalpy and humidity ration in the evaporator. The results for the Liquid desiccant system include more information such as the outlet conditions of the air at the exit of the tower and the exit of the evaporator, the rate of condensation and change of enthalpy in the tower, in the evaporator and for the whole system. The screen is shown in figure 6.

3.6 Command Optimized:

In this section the user can choose between the height of the tower and the dew point in the evaporator to improve the evaluated system.

For example, for the height of the tower the system will provide the optimum height of the tower such that all the condensation takes place here and not in the evaporator. The dew point of the evaporator is based on the same principle.

After the software makes the calculations it displays a screen with the solution for the case analyzed.

3.7 Command Cost:

This command allows to make an economic analysis of both systems in order to compare the economic advantage of one system over the other. Also, the software calculates the simple pay back, which is an important factor at the time to choose a system.

3.8 Command Properties:

In this section of the software the user can get the properties of the Lithium Chloride just by knowing the temperature and the concentration.

3.9 Command About:

When the user clicks this command the software provides information about the authors of the application and information about the system under which is working the computer. It shows a screen as follows:

10. Command Exit:

This command allows the user exit to the operative system (Windows 95 or windows 98)

4. ANALYSIS OF THE COMPUTER MODEL DEVELOPED

In order to verify the performance of the software developed, this section compares the experimental results

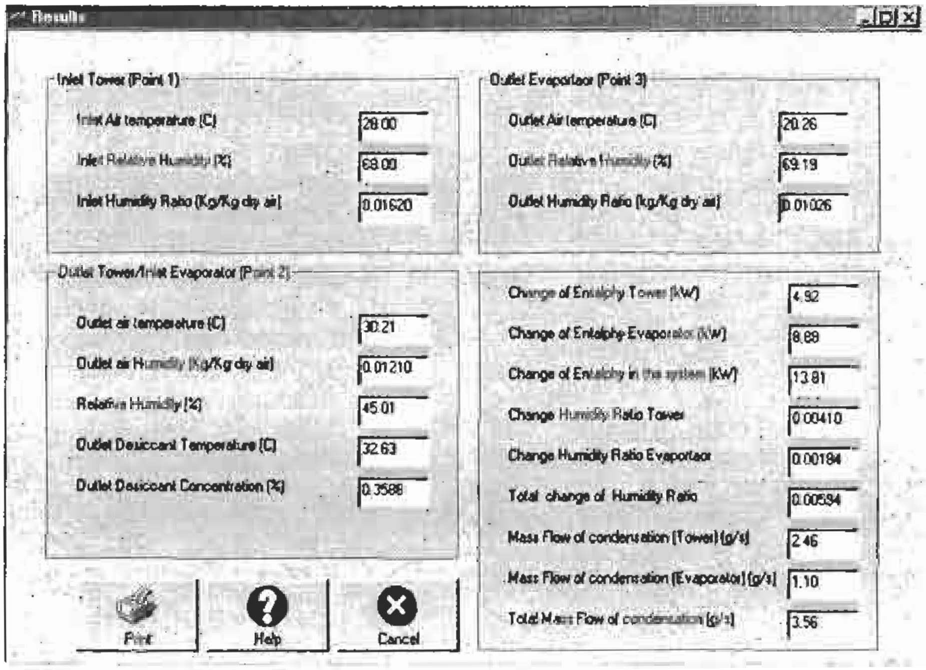


Fig 6: Screen with the results for the system.

done by Mago and Goswami (2000), with the software results. The analysis was performed for the following experiment. This experiment was conducted to study the influence of airflow rate over different parameters in the system. The airflow rates used were 0.6, 0.65 and 0.70 kg/s and the other conditions were held constant.

Figures 7 and 8 show plots for comparison of software results with the experimental results. These figures show that the software's results are very close to the experimental results with a difference of less than 5%. This shows that the software developed may be used as a powerful tool to get fast and reliable results for a hybrid liquid desiccant system using lithium chloride as a desiccant. This software can be used to design new systems.

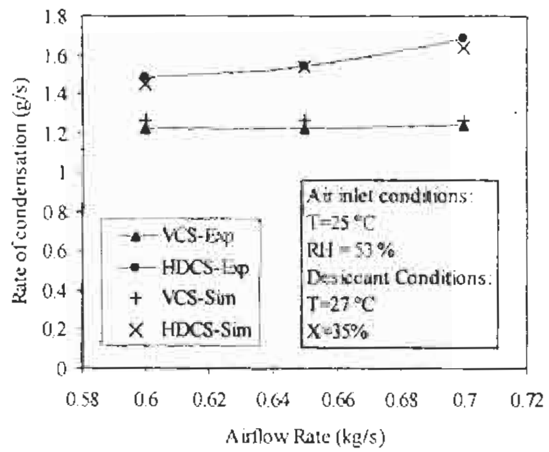


Fig 7: Rate of condensation for both cases.

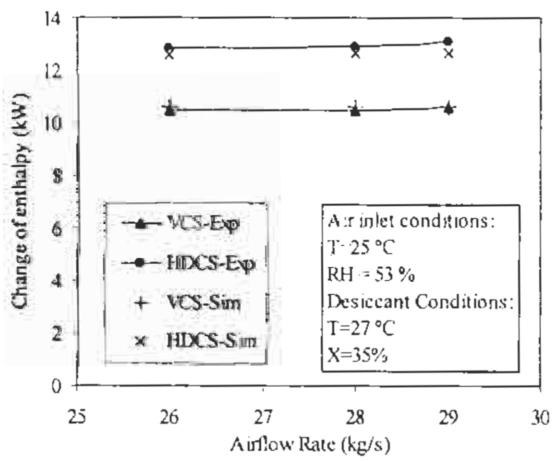


Fig 8: Change of enthalpy for both cases

5. CONCLUSIONS

A software package was developed for the simulation of a vapor compression system and a hybrid desiccant system. The simulation results agree with the experimental results done by Mago and Goswami (2000), with an error of less than 5%. This software is a powerful tool for getting faster and accurate results for liquid desiccant system using lithium chloride.

6. NOMENCLATURE

A	Area [m^2]
a_t	Total specific surface of packing [m^2/m^3]
a_w	Wetted surface area of packing [m^2/m^3]
c	Molar density [kmol/m^3]
c_p	Specific heat [kJ/kg-°C]
D	Diffusivity [m^2/s]
F_G	F-type gas phase mass transfer coefficient [kmol/s- m^2]
F_L	F-type liquid phase mass transfer coefficient [kmol/s- m^2]
G	Superficial air mass velocity [kg/s-m^2]
h_G	Gas side heat transfer coefficient [kJ/s-m^2-°C]
k_G	-type gas phase mass transfer coefficient [kmol/s-m^2-Pa]
k_L	k-type liquid phase mass transfer coefficient [kmol/s-m^2-Pa]
L	Superficial desiccant mass velocity [kg/s-m^2]
M	Molar mass [kg/kmol]
m	Mass flow rate [g/s]
P	Total pressure [kPa]
P'	Partial pressure
Pr	Prandtl number
Pv	Vapor pressure [kPa]
Ps	Saturation pressure [kPa]
Q	Capacity of the evaporator [kW]
Sc	Schmidt number
T	Temperature [°C]
X	Desiccant concentration [%desiccant by weight] or [kg desiccant/kg solution]
x	Desiccant mole fraction [kmol desiccant / kmol solution] or molar concentration of water in the desiccant [kmol water /kmol solution]
y	Water mole fraction [kmol water / kmol air]
Z	Tower height [m]

7. REFERENCES

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