

A STUDY OF THE PERFORMANCE OF A HYBRID LIQUID DESICCANT COOLING SYSTEM USING LITHIUM CHLORIDE

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ABSTRACT

A hybrid desiccant system using aqueous lithium chloride was studied by simulation, laboratory test, and field tests. This paper presents field test of a hybrid solar liquid desiccant cooling system 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. For each configuration the system was operated in two modes: recirculation, and 100% ventilation air.

Experiments were conducted to study the influence of the air mass flow rate, temperature of the inlet air, temperature of the desiccant, and desiccant mass flow rate on the performance of both system configurations.

Based on the field test results it was found that the hybrid desiccant system improves the air conditioning performance in the field test house by decreasing the outlet humidity and temperature of the air. It was also found that the hybrid desiccant cooling system is more cost effective for the case 100% fresh air ventilation than recirculation.

INTRODUCTION

A large share of the electricity consumption in hot and humid regions of the world during the summer time is for air conditioning. The total air conditioning load consists of the sensible load and the latent load. In hot and humid regions where the relative humidity is high, the latent load becomes a big problem. Conventional vapor compression systems sometimes cannot even meet this load. Consequently, oversized compressors are installed to dehumidify the incoming air. To meet humidity requirements, vapor-compression systems are often

operated for long cycles and at low temperatures, which reduce their efficiencies and require reheating the dry, cold air to achieve comfort conditions. Both consequences are costly. However, 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 hybrid desiccant air-conditioning system, moisture is removed from the air by bringing it in contact with the desiccant; followed by sensible cooling of the air by a vapor compression cooling system, vapor absorption cooling systems, or evaporative cooling system. The driving force for the dehumidification process is the water vapor pressure. When the vapor pressure in air is higher than on the desiccant surface, moisture is transferred from the air to the desiccant until an equilibrium is reached. In order to regenerate the desiccant for reuse, the desiccant is heated, which increases the water vapor pressure on its surface. If air with a lower vapor pressure is brought in contact with this desiccant, the moisture passes from the desiccant to the air, thus the desiccant is recharged or brought back to its original dry state. The regeneration process can use thermal energy from natural gas, electricity, waste heat, or the sun.

Commercially available desiccants include silica gel, activated alumina, natural and synthetic zeolites, titanium silicate, lithium chloride, calcium chloride, triethylene glycol and synthetic polymers. In this study, an aqueous solution of lithium chloride was used as the desiccant. Fumo and Goswami (2000) had earlier studied the heat and mass transfer performance for this desiccant for air dehumidification.

A detailed review of liquid desiccant cooling system was given by Oberg and Goswami (1998). Ertas et al. (1992) presented an analysis of the properties of a liquid

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desiccant solution. He found that lithium chloride is the most stable liquid desiccant, but it is expensive. On the other hand, calcium chloride is much cheaper, but unstable depending on the air inlet conditions and the concentration of the desiccant in the solution (Ertas et al., 1992). The performance of the desiccant can be measured by its vapor pressure. The lower the vapor pressure, the better the desiccant performance. The calcium chloride has high water vapor pressure compared with the lithium chloride. A mixture of these two materials provides a stable desiccant, with lower vapor pressure than calcium chloride, and that is less costly than lithium chloride. Ahmed et al. (1998) studied some of the properties of this mixture for concentrations of 20, 30 and 40%.

In recent years, Kinsara et al. (1996), Khalid et al. (1997), Brandemuehl and Khattar (1997) and Beggs and Halliday (1999) have conducted research in hybrid desiccant cooling systems. All these studies found that hybrid desiccant systems perform better than vapor compression systems.

Some researchers such as Dai and Zhang (1998), Khan and Martinez (1998), Kessling et al. (1998) among others, have developed mathematical models and software for system simulations. These are important tools to predict the performance of a system.

This paper presents experimental results for the performance of a hybrid desiccant system and a vapor compression system.

Experimental Facilities

Field tests of a hybrid solar liquid desiccant cooling system were 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 of the house in two configurations—the conventional vapor compression system, and the hybrid desiccant system. Figures 1a and 1b show the air conditioning system in a hybrid desiccant configuration. Figure 1a shows the arrangement for recirculation air and figure 1b shows the arrangement for 100% ventilation air. Both systems were operated in the two configurations (vapor compression system with and without the liquid desiccant system) and the data was collected to compare the performance of the two arrangements. For the “vapor compression system only” mode the desiccant system was bypassed as shown by the dotted lines in figures 1a and 1b.

The desiccant system was constructed as a tower of 56 cm diameter and 60 cm height. The tower was packed with Rauschert Hiflow[®] rings made with polypropylene and with a specific surface area of 210 m²/m³. To distribute the desiccant over the packings three spray heads were used. The system had two tanks and two pumps; one tank stores the unused desiccant, which is pumped to the tower, and the other tank stores used desiccant, which is pumped by the second pump from the

bottom of the tower. This arrangement ensures constant temperature and concentration condition of the desiccant going into the tower. Temperatures were measured using copper - constantan thermocouples, with an accuracy of $\pm 0.5^{\circ}\text{C}$ and relative humidities were measured by humidity transmitters HMD 20 UB, with an accuracy of $\pm 2\%$ RH (0-90% RH) and $\pm 3\%$ RH (90%-100%). Humidity ratio of air was determined from the relative humidity and temperature measurements. The air velocity was measured using a Velometer ALNOR with an accuracy of $\pm 2\%$.

Desiccant concentration was determined by the Karl Fischer titration method. This is a quantitative method for determining water concentration by titrating the desiccant solution with anhydrous alcohol containing iodine and sulfur dioxide.

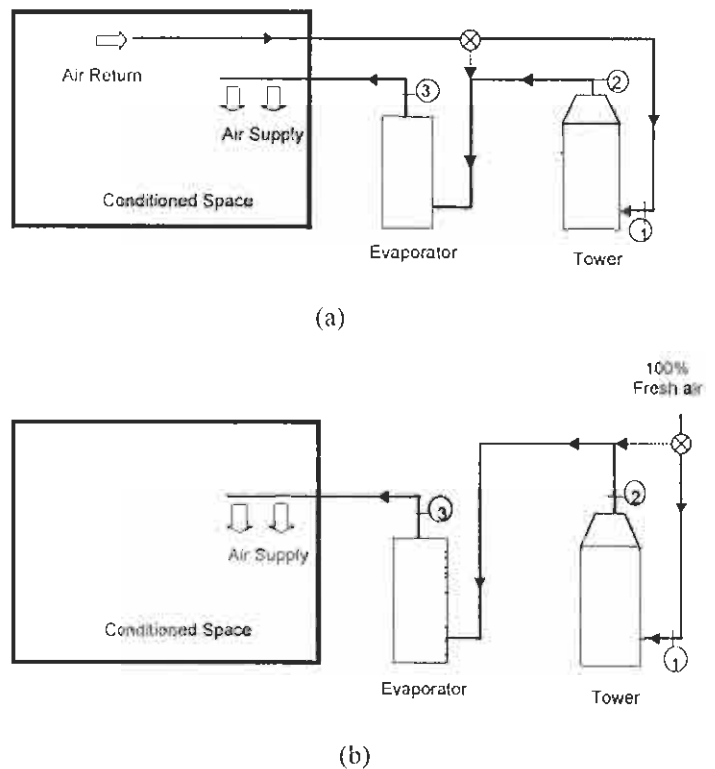


Figure 1. (a) liquid desiccant system with re-circulating air
(b) liquid desiccant system with 100% fresh air

Experimental Procedure

Both experiments were conducted under the same air inlet conditions for approximately one hour each. The following data were measured using a PC-based data acquisition system:

- Temperature and relative humidity of the air at the inlet and outlet of the evaporator.
- Temperature of the liquid desiccant in the tower.

- Temperature and relative humidity of the air at the inlet and outlet of the tower.
- Time.
- Air flow rate.

To ensure steady state before recording the data, air and desiccant conditions (temperature and RH of inlet and outlet air, temperature of the desiccant) were monitored. It took approximately 45 minutes to achieve steady state conditions.

Samples of the liquid desiccant were taken before and after the experiment to measure the concentration.

The maximum airflow rate was the maximum that the air handler of the actual system could attain. Lower flow rates were obtained using dampers. Valves were used to regulate the mass flow of the liquid desiccant.

RESULTS

Experiments were conducted to study the influence of air mass flow rate, temperature of the inlet air, temperature of the desiccant, and desiccant mass flow rate on the performance of both system configurations. The air conditioning system was operated in both hybrid and conventional configurations, and for re-circulating air and 100% percent fresh air modes. Each variable was studied for three different values while the others were held constant. The results of the experiments are plotted in figures 2 to 13. An explanation of the data points plotted in these figures is given below. After reaching a steady state, the data listed in the previous section were taken each minute during the experiment, which was continued for additional 15 minutes. The minute-by-minute data was averaged to give one experimental data point for this study. The experiment was repeated for each condition three times to give three experimental data points. These three experimental data points for the same set were averaged to provide a data point to plot in the figures. A standard deviation was also calculated. The average of the standard deviation of three points for a curve were plotted as the error bars in each plot.

Influence of Airflow Rate Over Other Parameters in the Systems:

Experiments were conducted for airflow rates of 0.6, 0.65 and 0.70 kg/s while keeping other conditions constant to study the influence of airflow rates over various performance parameters in the system. This experiment was done for re-circulating air.

Figure 2 shows that for the vapor-compression system (VCS), water condensation rate is constant with airflow rate for the range analyzed. In this experiment the change of humidity ratio decreases with the airflow rate. However, the product of the airflow rate and the change of humidity ratio remain constant. In the hybrid-desiccant system (HDS), rate of condensation (sum of condensation

in the desiccant tower and the evaporator) increases with the airflow rate. The water removal from air was estimated based on measurements of humidity ratio and air mass flow rate.

Figure 3 shows that change of enthalpy is constant for both systems with the airflow rate. The change of enthalpy is higher in the hybrid-desiccant system than it is in the vapor-compression system, which means that the hybrid-desiccant system can improve the coefficient of performance over the vapor compression system alone, unless increased parasitic power negates the gains. In a companion paper by Mago and Goswami (2001), was found that COP indeed increases, while taking into account increased parasitic power.

Figure 4 shows that outlet air temperature increases for both systems with the airflow rate. It is important to note that outlet temperature of air for the hybrid-desiccant system is always lower than that for the vapor compression system alone for the same inlet conditions.

Influence of Inlet Desiccant Temperature in Hybrid Desiccant System:

Experiments were conducted to study the influence of inlet desiccant temperature over other parameters in the hybrid desiccant system using 100 % fresh air mode. The inlet desiccant temperatures used were 28, 29 and 30 (°C) and the other conditions were maintained constant.

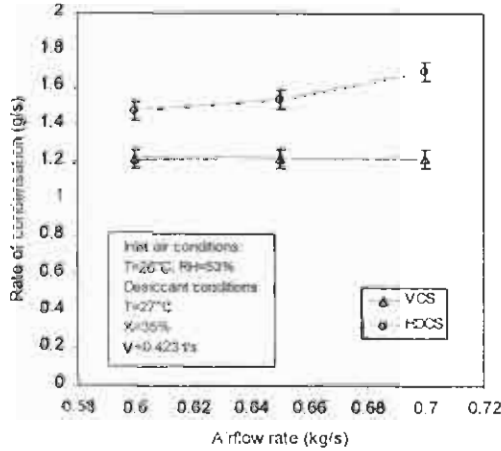


Figure 2 Influence of the airflow rate on the water rate of condensation

Figure 5 shows that water condensation rate decreases when the inlet desiccant temperature increases. The reason is that the water vapor pressure in the liquid desiccant surface increases with temperature, which decreases the driving force for dehumidification.

Figure 6 shows that the outlet air temperature increases with the inlet desiccant temperature. It was seen in Fig. 5 that the rate of water condensation decreases with the increase in desiccant temperature. Since the air entering the evaporator is now humid, the evaporator is unable to decrease the air temperature much. It is important to note that if the water condensation rate in the desiccant tower decreases, the evaporator has to take up more latent load, which defeats the purpose of a hybrid desiccant system.

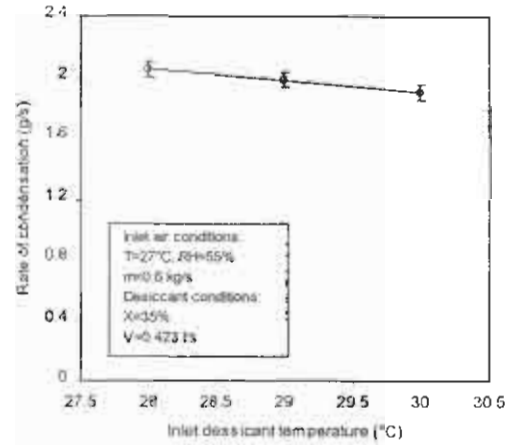


Figure 5 Influence of inlet desiccant temperature on water condensation rate

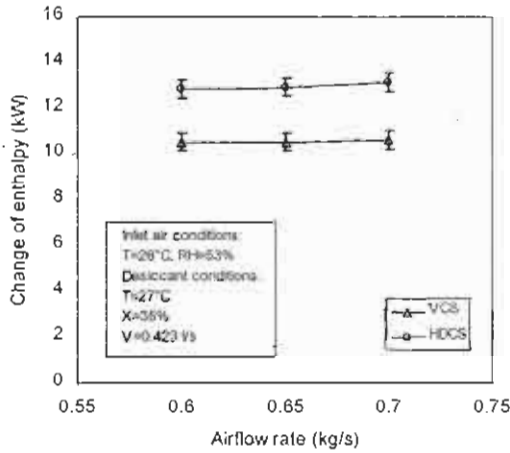


Figure 3 Influence of the airflow rate on the change of enthalpy in the system

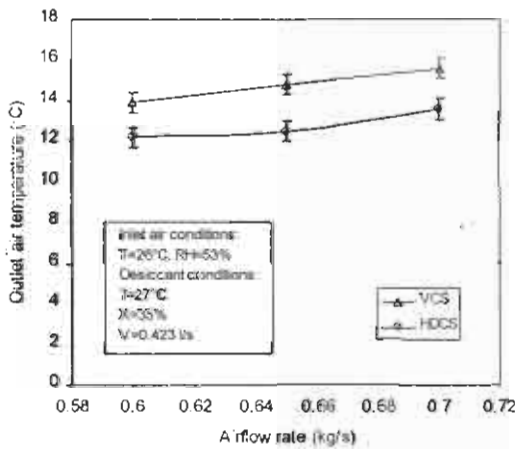


Figure 4 Influence of airflow rate on the outlet air temperature

Figure 7 shows that the change in enthalpy decreases with the increase in the inlet desiccant temperature.

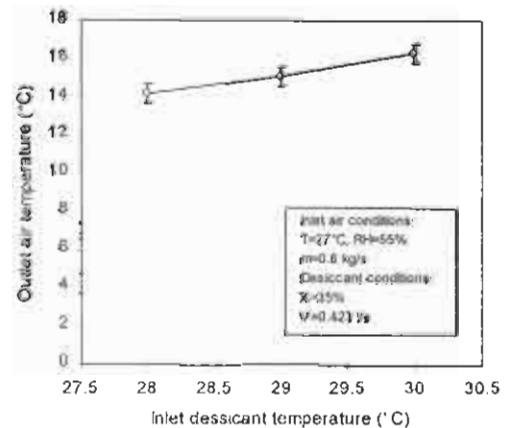


Figure 6 Influence of inlet desiccant temperature on the outlet temperature of the air

Influence of Inlet Air Temperature Over Other Parameters in the Systems:

Experiments were conducted for inlet air temperatures of 26, 28 and 29°C, to study the influence of the inlet air temperature over different performance parameters in the system. This experiment was done using re-circulation air mode.

Figure 8 shows the influence of inlet air temperature on the outlet air temperature in the two systems. It is obvious that outlet air temperature would be higher with an increase in the inlet air temperature, but the

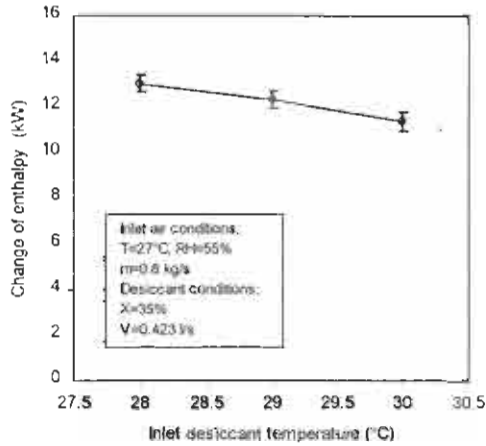


Figure 7 Influence of inlet desiccant temperature on change of enthalpy in the system

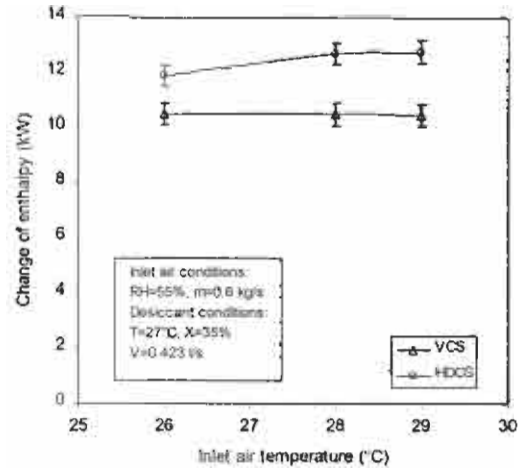


Figure 9 Influence of inlet air temperature on change of enthalpy of the system

purpose of this figure is to show that the hybrid-desiccant system is always able to give lower temperatures than the vapor compression system alone.

Figure 9 shows that change of enthalpy increases with inlet air temperature in the hybrid desiccant system but remains constant in the vapor compression system.

Figure 10 shows that for both systems, rate of water condensation increases when the inlet air temperature is increased for the same relative humidity. However, the rate of increase is higher for the hybrid-desiccant system.

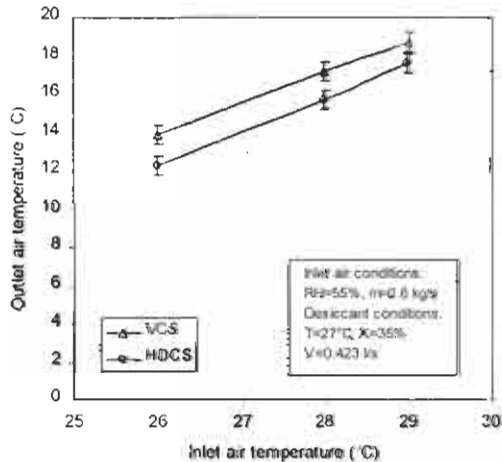


Figure 8 Influence of inlet air temperature on the outlet air temperature

Influence of Desiccant Mass Flow Rate in the Hybrid Liquid Desiccant System:

Experiments were conducted for desiccant mass flow rates of 0.35, 0.44 and 0.51 kg/s with the other conditions held constant, to study the influence of desiccant mass flow rate over various performance parameters in the system using 100% fresh air.

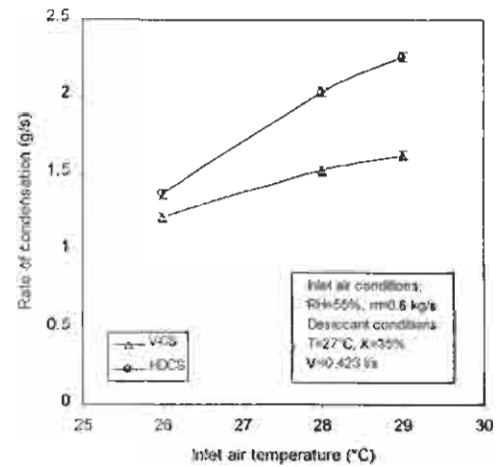


Figure 10 Influence of inlet air temperature with constant relative humidity on the water condensation rate.

Figure 11 shows that water condensation rate increases when the desiccant mass flow rate increases. The reason is that the packings are wetter (see Oberg and

Goswami, 1998) and the driving force of the desiccant increases as the desiccant mass flow rate increases.

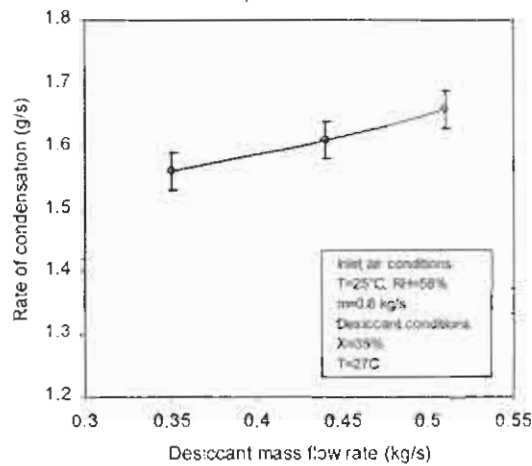


Figure 11 Influence of the desiccant mass flow rate on the water condensation rate.

Figure 12 shows that outlet air temperature decreases with the desiccant mass flow rate. The reason is that when water condensation rate in the desiccant tower increases and the evaporator has to take up less latent load.

Figure 13 shows that the change in enthalpy increases slightly with the increase in the desiccant mass flow rate.

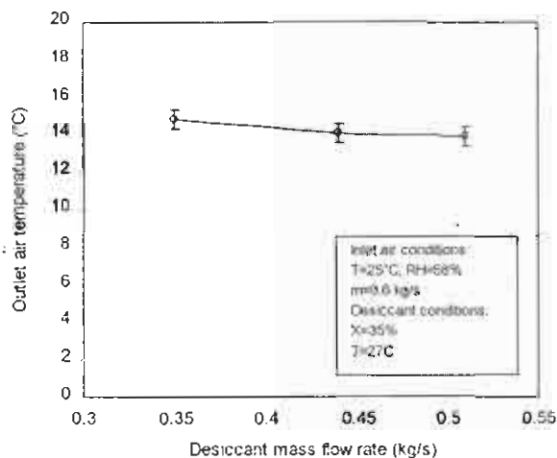


Figure 5.12 Influence of the desiccant mass flow rate on the outlet air temperature

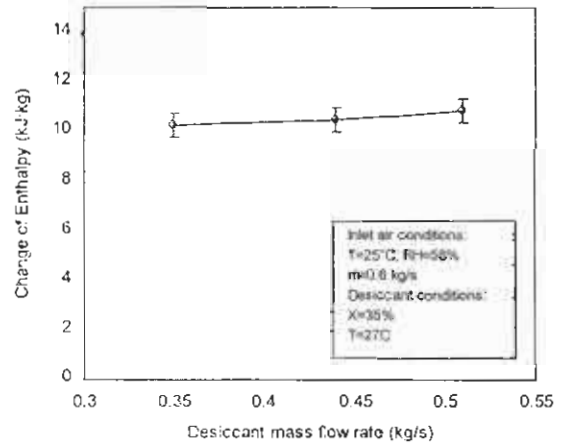


Figure 13 Influence of the desiccant mass flow rate on change of enthalpy of the system

CONCLUSIONS

- The hybrid liquid desiccant system improves the air conditioning performance over vapor compression system in the field test house by decreasing the outlet humidity and temperature of the air.
- In the hybrid liquid desiccant system, rate of condensation increases with: airflow rate, inlet air temperature or desiccant mass flow rate; and it decreases when the inlet desiccant temperature is increased.
- In the hybrid liquid desiccant system, outlet air temperature increases with: airflow rate, inlet air temperature or inlet desiccant temperature; and decreases when the desiccant mass flow rate is increased.
- In the hybrid liquid desiccant system change in enthalpy of air is almost constant with the change in airflow rate and with the desiccant mass flow rate or the inlet air temperature. However the change of enthalpy decreases when the inlet desiccant temperature increases.

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