

INVESTIGATIONS ON VAPOR COMPRESSION AIR CONDITIONER WITH DIRECT CONTACT DESICCANT LOOP OVER CONDENSER AND EVAPORATOR

J. Ravi, Shaligram Tiwari and M.P. Maiya*
Department of Mechanical Engineering
Indian Institute of Technology Madras
Chennai – 600036, India,
Phone: +91 44 2257 4665; *Email: mpmaiya@iitm.ac.in

ABSTRACT

Perceived air quality increases when relative humidity is decreased till about 30% in the range of comfort temperature. In the present scenario, humidity is considered as a pollutant. Hence, a controlled environment not only at low temperature but also at low humidity is desired for many applications such as archives, data centers, etc. Either a separate dehumidifier or a precision air conditioning (AC) system needs to be employed for such an application. In fact, the latter forms a reheat AC system which happens to be energy inefficient. In view of this, a vapor compression window air conditioner is investigated with a superimposed liquid desiccant loop harnessing the advantages of both the compression system (high COP) and desiccant system (low humidity). Operation of such a novel system is explained, elucidating the operational feasibility. The results presented consider the characteristics of such a system with respect to changes in the evaporator inlet air temperature and humidity. The change in the specific humidity of air is compared for vapor compression system and the direct contact hybrid system for different values of inlet air temperature.

Keywords: Air conditioning, Compression system, Liquid desiccant, Energy efficiency, Low humidity

INTRODUCTION

The objective of the present study is to analyze and characterize the performance of a coupled column of hybrid air conditioner for different inlet conditions of air and desiccant solution and for various possible configurations. The total air-conditioning cooling load can be divided into *sensible load* and *latent load*. Liquid desiccant solutions have the property of holding water vapor which confirms their suitability to be effectively used to overcome the latent part of the air-conditioning cooling load. In the present work, an energy-efficient configuration is proposed to reduce energy consumption in air-conditioning

systems using lithium chloride (LiCl) solution as the liquid desiccant.

The latent load of air-conditioning is the cooling load which removes the required amount of water vapor from the supply air. In hot and humid areas, the high air relative humidity is not desirable for human comfort. Supply air is therefore passed over a low-temperature cooling coil to remove some of its water vapor by condensation. This can be achieved by using desiccants without any extra increase of cooling load. Thus, latent load gets shifted from cooling coil to the desiccant resulting into reduced power consumption.

DESICCANT SYSTEMS

Desiccants are materials that have high affinity for water vapor. Low humidity is essential for many applications and for human comfort also. The main reason happens to be the freshness of the supplied air with decrease in its humidity. The compression based air conditioning system only cools the air with limited dehumidification. Energy consumption due to conventional air-conditioning is very high, especially in hot, humid areas. Liquid desiccant solutions have the property of holding water vapor and hence they can be used to overcome the latent part of the air-conditioning cooling load.

Conventional air-conditioning is accomplished by vapor-compression equipment. The air-stream must be cooled to a degree sufficient to provide lowering of both the air-temperature and humidity. The final comfortable space temperature can be achieved by reheating the cold air sensibly. As a result, the air-conditioning equipment must normally operate at a temperature colder than the supply air dew point temperature to meet the latent part of the cooling load and then the air is reheated sensibly to the required comfort temperature. Energy is needed to cool the air to its dew point temperature across the cooling coil and also to reheat the off-coil air to the desired space temperature.

Air conditioning systems are considered as a major energy consumer. In view of the increasing global attention towards energy conservation, there is an urgent need to review the prevalent energy conservation techniques in air conditioning systems. However, preservation of our eco-system always puts an important constraint on the economy of energy savings.

HYBRID VAPOUR COMPRESSION LIQUID DESICCANT SYSTEMS

In the hybrid system, liquid desiccant system is superimposed on a vapor compression system. Liquid desiccant system consists of two parts, namely absorber and regenerator. The absorber/ dehumidifier desiccant stream is sprayed directly on the evaporator and regenerator stream is sprayed directly on the condenser. In view of the above, a vapor compression window air conditioner is investigated with a superimposed liquid desiccant loop harnessing the advantages of both compression system (high COP) and desiccant system (low humidity). The role of the desiccant, with low flow rate, is limited only to reduce the humidity by transferring it from supply air to ambient air. The cooling responsibility altogether lies with the vapor compression system in such a way that overall hybrid system becomes more efficient.

Dehumidification

Dehumidification is the process of removal of water vapor from moist air. It can be achieved by either cooling or increasing the pressure of air or by adsorption/ absorption of moisture by a solid or liquid material (called a desiccant). The removal of moisture from the air depends on the difference in water vapor pressure held by the desiccant and that of water vapor present in the air. Hence the driving force for dehumidification is the partial pressure difference between the vapor pressure of bulk air and the vapor pressure at the interface of air desiccant solution. Therefore, the lower vapor pressure at interface means better performance of dehumidification. The interface vapor pressure is taken as the saturation pressure corresponding to the temperature and concentration of the desiccant solution. The functioning of the desiccant cycle is based on difference in the moisture vapor pressure of the desiccant and the vapor pressure in the surrounding air. Moisture absorption takes place when humid air comes into contact with a desiccant. This is due to the fact that the partial pressure of water vapor in air is higher than the moisture partial vapor pressure of the desiccant. Desiccant can hold

up water until the moisture vapor pressure of the desiccant and the vapor pressure of surrounding air are equalized. The vapor pressure of a liquid desiccant solution varies directly with its temperature and inversely with its concentration. The dehumidification process is improved by increasing the surface area of the desiccant exposed to the air being dehumidified and increasing the contact time. The dehumidification of air generally proceeds without input energy, other than the requirement of fan and pump.

Regeneration

The moisture that get transferred from the air to the liquid desiccant in the dehumidifier causes a dilution of the desiccant resulting in reduction of its ability to absorb more water. Therefore, the desiccant must be regenerated to its original concentration to enable continuous operation. This can be achieved by bringing the vapor pressure of water in the desiccant to a value greater than the water vapor pressure in the air. Usually this is done by heating the desiccant solution. As the temperature of the desiccant solution increases, the water vapor pressure in the solution increases.

The partial water vapor pressure of the solution is the pressure of water vapor at solution interface, which is assumed to be in equilibrium with the solution at a given temperature. It is a function of temperature and concentration of the solution. The moisture vapor pressure of the desiccant decreases with increasing desiccant concentration and increases with increasing desiccant temperature. For air, the partial pressure of water vapor increases with increasing air dry-bulb temperature and absolute humidity. As a result, there is a limit at which a given desiccant system can work as a dehumidifier. When the partial pressure of water in the desiccant becomes higher than that of the surrounding air, a desiccant system starts to work as a regenerator, releasing out the previously absorbed moisture from the desiccant. So it is needed to find out the solution flow rate and air flow rate at which the dehumidification of air as well the regeneration of the desiccant solution become maximum. Figure 1 shows the block diagram of the spray type desiccant system in which the solution used for dehumidification is directly sprayed on the evaporator while the one used for regeneration is directly sprayed on the condenser. Both the evaporator and condenser are suitably modified with extra finning and then wrapped with cotton threads to enhance the heat and mass transfer area.

EXPERIMENTAL SET-UP

The experimental setup built for performance

evaluation of direct contact liquid desiccant vapor compression hybrid air-conditioner consists of the vapor compression system integrated with a desiccant spray system. The conventional vapor compression part of the system consists of the compressor, the evaporator, the condenser and fans. The desiccant system consists of dosing pumps, piping system, container and spraying equipments for both absorption and regeneration parts of the system. Both the evaporator and condenser have similar fin arrangement with identical wrapping of cotton clothes around them. The cotton is wrapped around the fins to improve wettability. Figure 2 shows the evaporator with cotton wrapped around the fins.

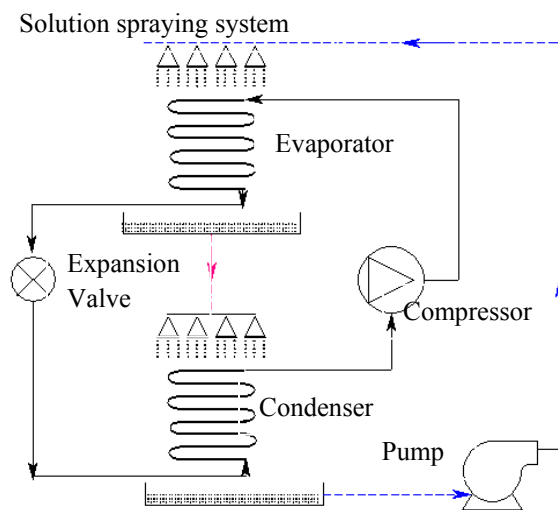


Figure 1. Schematic of direct contact LDVC hybrid AC



Figure 2. Evaporator with cotton wrapped around fins

Desiccant Distribution System

For spraying the desiccant uniformly over the fins of the coil of the evaporator and condenser, a spraying arrangement as shown below is used. The desiccant enters the middle hub and then forced through a

number of small 0.5mm diameter holes. This arrangement sprays the desiccant solution uniformly over the fins of the coil. The schematic for this arrangement is shown in Figure 3. The spraying system utilizes the force of gravity at condenser and a dosing pump used to pump at evaporator.



Figure 3. Distribution system

Air Heating System

The air heating system including resistance air heater and a rheostat to control the heat output is used to vary the inlet air temperature before entering desiccant column, air heaters have been used to heat the air by forced convection method is shown in Figure 4. Forced convection moves air past a heat source with a fan or blower. Heater of the rating 500W has been used. The figure shows the air heater arranged in the space to be heated. The input voltage needs to be monitored according to the requirement of the experiment. The heater is fin type and can get the quick heating of the air as the heat transfer rate is higher. Rheostat used to change the voltage has to give to air heater. By changing the voltage we can change the input voltage to heater and corresponding output of the air heater. Thereby we can maintain the room at different temperature.

Figure 4 shows the complete experimental set up. The evaporator and spraying system on the evaporator have been enclosed in test room. Desiccant solution is pumped with the help of a dosing pump on to the evaporator and utilizing force of gravity to distribute the solution on condenser. The readings of the thermocouples and pressure transducers are noted down with the help of data logger and computer. In data logging device we can set the interval at which experiment readings have to be taken which will be logged automatically.

RESULTS AND DISCUSSION

The experimental set-up described above has been run by varying input parameters like, inlet air specific humidity, inlet air temperature of both evaporator and condenser. Experiments are carried out by varying one parameter while keeping other parameters at their mean values. Possible explanations for the trends observed by varying the parameters have been discussed below.

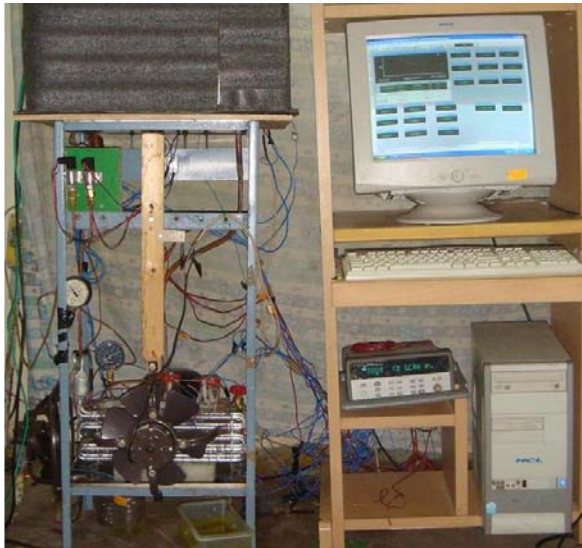


Figure 4. Experimental set up

Five different parameters, listed in Table 1 are varied and their effect on the rate of dehumidification and heat and mass transfers is studied.

Table 1. Range of variable parameters

To study the characteristic of the system by varying different parameter, we need to take care that while studying the effect of one parameter, other parameters have to be set at their mean value. The range and mean value of the various parameters are given in the Table 1. To study the influence of inlet air specific humidity, it is needed to provide a continuous and varying humidity to the test room. For a given specific humidity the reading has been taken after reaching the steady state. After taking the first reading the system has been again fed with humidity with humidifier and again waited till the steady state to reach. The same procedure has been repeated for different inlet air specific humidity and the results been analyzed.

INLET AIR SPECIFIC HUMIDITY

The experimental procedure as discussed above, been

run till the system reached steady state and reading been analyzed. Figure 5 shows the effect of inlet air specific humidity (W_{air}) on change in specific humidity (ΔW_{air}). It is seen that as the inlet air specific humidity increases from 14 to 18 g/kg of dry air, the change in specific humidity (ΔW_{air}) also increases. This is because the increase in inlet air specific humidity causes increase in the vapor pressure of air and which in turn increase in the driving potential for the moisture transfer. The effect of inlet air specific humidity on change in specific humidity of air shows similar characteristics even for higher solution to air flow ratios (S/A). This is because for a given inlet specific humidity (W_{air}), the increase in the quantity of solution causes more absorption. It is seen that for the S/A ratio of 2% the dehumidification attains maximum and after which it start decreasing.

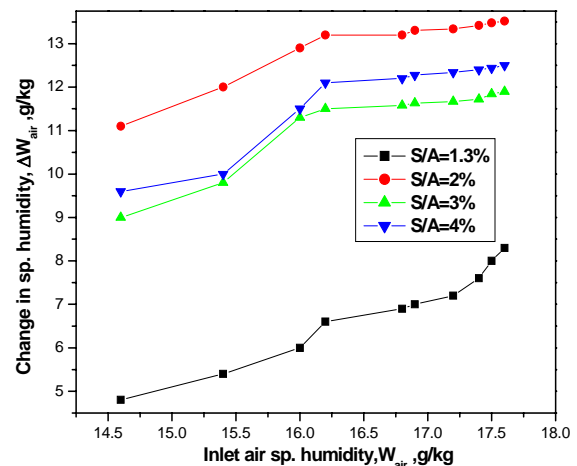


Figure 5. Variation of change in specific humidity

Parameter	Range	Mean value
Inlet air humidity (g/kg)	14.5-18	16
Inlet air temperature at evaporator ($^{\circ}$ C)	8-22	15
Inlet air temperature at condenser ($^{\circ}$ C)	22-35	28.5
Air flow rate (m^3/h)	50-250	150
Desiccant flow rate (ml/s)	0.23-0.7	0.5

with inlet air specific humidity at evaporator

Figure 6 shows the comparison between vapor compression system (VCS) and hybrid system. It is seen that for VCS system the dehumidification (ΔW_{air}) of 5g/kg, where as in hybrid system the dehumidification (ΔW_{air}) of 9g/kg without recycling of the desiccant and 6.5 g/kg with recycling of the desiccant solution. This additional dehumidification

has been achieved because of desiccant solution (LiCl).

INLET AIR TEMPERATURE

The inlet air temperature is varied and its effect on the rate of dehumidification is studied. The experiment been repeated for eight different values of inlet air temperature.

The amount of heating is varied by the heaters being employed in the test room. By varying inlet air temperature ($t_{air, evap}$), the variations in outlet parameters like air specific humidity (W_{air}), air temperature ($t_{air, evap}$) has been observed. The other inlet parameters of air and solution are kept at constant throughout the experiment. The effect of inlet air temperature ($t_{air, evap}$) on change in humidity (ΔW_{air}) and change in temperature (Δt_{air}) of the air is shown in Figs.7 and 8, respectively. The increase in inlet air temperature (t_{air}) from 7 to 22°C, results in decrease of change in specific humidity for various S/A ratios as shown in Fig. 8.

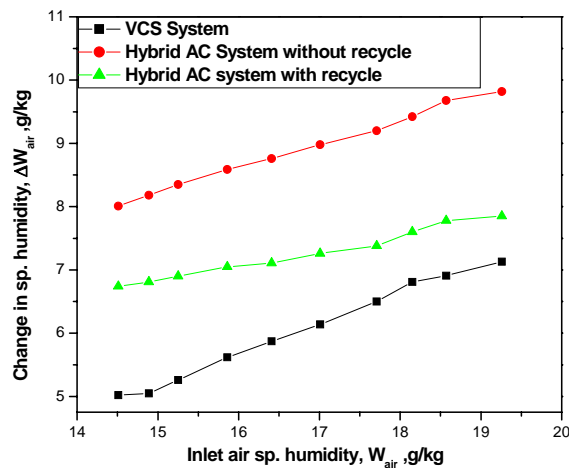


Figure 6. Comparison of change in specific humidity with inlet air specific humidity of VCS and hybrid system

Variation of change specific humidity

The increase in air temperature causes increase of solution temperature, which results of increase in the vapor pressure of the solution. The increase in vapour pressure of the solution reduces the potential for moisture transfer from air to solution, thereby the transfer of moisture. As the S/A ratio increases, for a given inlet air temperature, there is an increase in absorption because of increased solution flow rate. So for higher S/A the change ins specific humidity increases. The behavior of change in air temperature (Δt_{air}) with variation of inlet air temperature ($t_{air, evap}$) as shown in Fig.8 can be explained as follows.

As the increase in absorption by air causes release of absorption heat which in turn causes heating of the solution and air. For a given S/A ratio, with increase in inlet air temperature the change in the temperature of air decreases because of decreased moisture

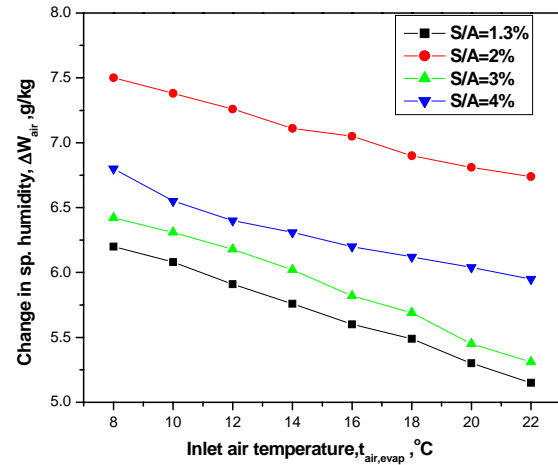


Figure 7. Variation of change in specific humidity with inlet air temperature

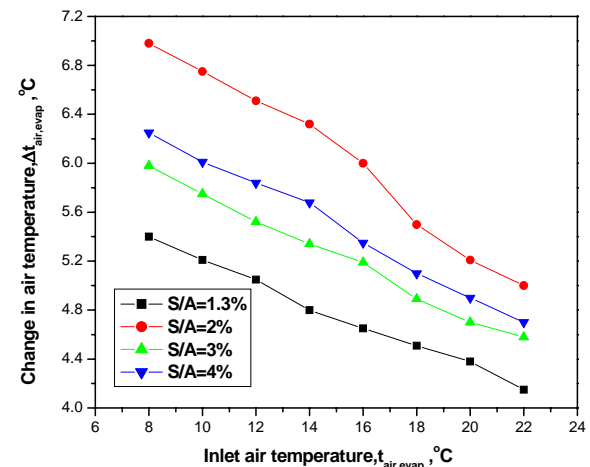


Figure 8. Variation of change in air temperature with inlet air temperature at evaporator

transfer and the corresponding decreased heat release. But increasing the solution flow rate (S/A) for a given temperature of inlet air has a direct effect on heating of air as shown in Fig.8. This is because of increased moisture transfer and the corresponding increased heat release.

Figure 9 shows the comparison between VCS and hybrid system. It is seen that for VCS system the dehumidification (ΔW_{air}) of 5g/kg, where as in hybrid system the dehumidification (ΔW_{air}) of 8.5g/kg without recycling of the desiccant solution and

6.5g/kg with recycling of the solution. This additional dehumidification has been achieved because of desiccant solution (LiCl).

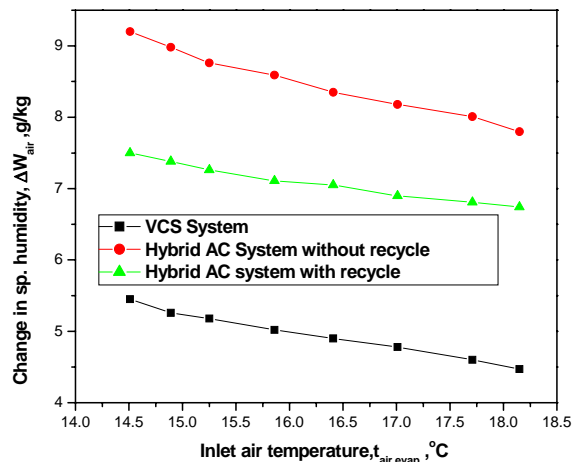


Figure 9. Comparison of change in sp. humidity with inlet air temperature of VCS and hybrid system

INFLUENCE OF INLET AIR TEMPERATURE ON OUTLET SOLUTION TEMPERATURE

Figure 10 shows the effect of inlet air temperature (t_{air}) on outlet solution temperature (t_{sol}) of evaporator. For a given S/A ratio, as the inlet air temperature is increased, the outlet solution temperature also gets increased. This is because of the direct heating of the solution by air at the evaporator, as shown in Fig.10. So the increase in inlet air temperature heats the solution causing the rise in the temperature of the solution. For a given inlet temperature the increase in solution flow rate causes increase in outlet solution temperature.

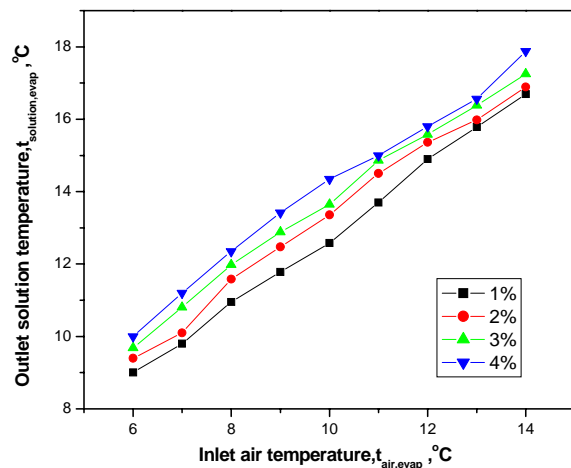


Figure 10. Variation of outlet solution temperature with inlet air temperature at evaporator

CONCLUSIONS

A vapour compression air conditioner with direct contact desiccant loop over condenser and evaporator is built and tested for enhanced dehumidification. The solution to air flow ratio is kept low at about 3%, just sufficient to transfer an extra bit of moisture from supply air to condenser air. The dehumidification capacity of the present hybrid air conditioning system is found to be superior to that of the conventional system thereby making it useful for low humidity applications. Further, the dehumidification capacity increases with increase in room air humidity.

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