Parametric Analysis of a Cross-Flow Liquid Desiccant Dehumidification System

Satwinder Singh[1], Vikas Gupta[2], Swarn Singh[3]

[1, 2, 3]*Department of Mechanical Engineering, Chandigarh Group of Colleges-College of Engineering, Landran (Punjab), India*

Abstract- **An experimental analysis of a packed bed liquid desiccant dehumidifier has been conducted. Calcium chloride was used as desiccant in the experiment. PVC packing with density of 150m^2/m^3 used to facilitate the interaction of liquid desiccant with air. The performance of the dehumidifier was measured in terms of moisture evaporation rate, specific humidity, change in humidity ratio, air outlet temperature under different air and desiccant parameters i.e air flow rate, air inlet temperature, desiccant solution flow rate, desiccant solution inlet temperature.**

Keywords: **Dehumidifier, Calcium chloride, Desiccant. Packing material height, Regenerator.**

I. INTRODUCTION

Dehumidification of air is the process of removing the water vapor from the air. The atmospheric humid air consists of both sensible heat load and latent heat load. A conventional vapor compression system reduces the sensible heat by reducing the temperature of the air and reduces the latent heat load by cooling the air below dew point temperature. The major problem associated with vapor compression system is that it causes the depletion of ozone layer and it also requires a lot of electricity for its operation. Desiccant cooling systems have been considered as an alternative and effective method of controlling moisture content in supply air. Moisture from the air is removed in the desiccant systems due to difference in vapor pressure of desiccant and water vapor present in air. The vapor pressure of a desiccant is directly proportional to its temperature and inversely proportional to its concentration. A desiccant is a substance having low surface vapor pressure. When the desiccant is cool and dry, its surface vapor pressure is low and it can attract moisture from the air which has a high vapor pressure when it is moist. As the desiccant absorbs moisture it becomes wet and hot its surface vapor pressure increases and it will give off water vapor to the surrounding air. Vapor moves from the air to the desiccant and back again depending on the vapor pressure difference.. There are two types of desiccant dehumidification systems used in practice namely solid desiccant and liquid desiccant dehumidification system. But solid desiccant systems are not economical as they regeneration of the solid desiccant is a cumbersome method. Solid desiccant dehumidification uses a desiccant wheel through which a solid desiccant like silica gel circulates and it absorbs moisture from the air. Liquid desiccant dehumidification system uses desiccants like calcium chloride, lithium chloride, lithium bromide etc. A liquid desiccant air dehumidifier removes moisture and latent heat from process air through a liquid desiccant solution. In a liquid desiccant system, the desiccant is distributed in an absorber or dehumidifier. In the dehumidifier, the desiccant comes in direct contact with the process air to absorb the moisture from the air. As the moisture is absorbed into the desiccant liquid, the desiccant solution becomes diluted. This diluted solution is then pumped to regenerator where heat is supplied to remove the water from the desiccant into an exhaust air stream.

Liquid desiccant dehumidification systems are widely used in various industrial applications. The essential component in a liquid desiccant dehumidification system is the dehumidifier. The dehumidifier is packed with packing material. Different materials and sizes of packings are generally used in the dehumidifier.

Many research works have been carried out in this field where these desiccants are referred to as composite desiccants. Minaal Sahlot et al. (2016) provided an extensive review of liquid desiccant systems along with all the components of liquid desiccant system such as dehumidifier, regenerator, packing material and liquid desiccant properties. Hesamoddin Salarian et al. (2011) explained the performance of a packed tower absorber for a lithium chloride desiccant dehumidification system. The effects of the main variables like air flow rate, liquid desiccant flow rate and inlet air temperature on the rate of dehumidification are discussed. Lun Zhang et al. (2018) conducted an experimental analysis of heat and mass transfer ability of counter-flow packing tower and liquid desiccant dehumidification system. Bassuoni et al. (2011) investigated the performance of the structured packing cross flow desiccant dehumidification system. In this calcium chloride solution was used as the desiccant material and the performance of this system is evaluated using the mass transfer coefficient, moisture removal rate, effectiveness and the coefficient of performance. S. Patnaik et al. (1990) studied an experimental solar open-cycle liquid desiccant air dehumidification system. D. Seenivasan et al. (2016) studied the performance of dehumidifier using calcium chloride as a liquid desiccant. C.R. Hiremath et al. (2017) gave an experimental and theoretical study on dehumidification potential of clay-additives based $CaCl_2$ composite desiccants. They expressed the exit air humidity ratio relative to inlet air humidity ratio in terms of percentage reduction in moisture and also compared the experimental results for percentage reduction in moisture with theoretical mass transfer model. Sanjeev Jain et al. (2007) presented a comparative parametric analysis of packed bed dehumidifiers for three commonly used desiccant materials viz. triethylene glycol, lithium chloride and calcium chloride. Lingshi Wang (2016) presented an experimental study of the dynamic heat and mass transfer characteristics of a counter-flow packed-type liquid desiccant dehumidifier. Experiments were carried out to investigate the dynamic responses of the outlet air and desiccant solution to various changing inlet conditions. Koronaki et al. (2013) studied the performance of a counter flow liquid desiccant dehumidifier. A theoretical model of an adiabatic packed column based on the Runge-Kutta fixed step method was developed to predict the performance of the device under various operating conditions. Hyun Lee et al. (2016) studied a desiccant cooling technology with plate type dehumidifier using lithium chloride solution as desiccant. The plate was treated with hydrophilic coating and the wetability was improved by giving a groove shape. They concluded that the air velocity has the greatest effect on the improvement of the absorption rate and heat and mass transfer. Y. Zhao et al. (2014) developed and investigated the performance of a desiccant dehumidification unit with silica gel coated fin-tube heat exchanger. In this unit, two silica gel coated heat exchangers are adopted and switched to provide continuous dehumidification capacity. Kokouvi Edem N'Tsoukpoe et al. (2015) gave a short analysis of the general physical and chemical properties of calcium chloride. . M. Mujahid Rafique et al. (2016) presented different commercially available liquid desiccants and their composites which combines the properties of two or more desiccant materials for better performance. S. Bouzenada et al (2016) presented a comparative study on dehumidifier/regeneration process using $CaCl_2$ and LiCl under the same operating conditions and the effect of air velocity and relative humidity on these processes has been analyzed. Muhyiddine Jradi et al. (2014) numerically investigated an innovative micro-scale liquid desiccant dehumidification system using potassium formate as liquid desiccant. They studied the effect of various operational parameters on the overall performance of liquid desiccant dehumidifier

In the present study, calcium chloride is used as liquid desiccant and the performance of liquid desiccant dehumidification system is studied by varying the various inlet parameters like air flow rate, air inlet temperature, desiccant flow rate and desiccant temperature. The performance of the dehumidifier is measured in terms of moisture removal rate, specific humidity at outlet, change in humidity ratio, air outlet temperature.

II. EXPERIMENTAL SET UP

The layout of experimental setup is shown in Fig.1. The setup consists of a desiccant solution tank, desiccant pump, rotameter, dehumidifier, gate valve, PVC packing, air inlet duct, air blower, air outlet duct, psychrometer, U-tube manometer, orifice plate, solution tank at outlet. The solution of calcium chloride is contained in desiccant solution tank. The rotameter of range 40 LPH to 500 LPH is used to measure the flow rate of desiccant solution. The PVC packing of size is 600mm×300mm×150mm is used in the dehumidifier. The air blower of 0.75 HP is used to force the air to the dehumidifier through the inlet air duct. The flow rate of the air is controlled by varying the speed of the air blower. An orifice plate of diameter 50 mm is used in the outlet air duct to measure the pressure head across the dehumidifier. To note down the pressure head a U-tube manometer is used which measures the pressure head in terms of water column. The pressure head is measured in terms of water column with the help of a U-tube manometer.

The solution of calcium chloride is prepared in the desiccant solution tank. The pump and the air blower are started. The whole system is allowed to run for some time to achieve the steady state condition. The pump supplies the desiccant solution to the dehumidifier. The desiccant enters at the top of the dehumidifier where it is uniformly distributed over the packing. The air enters at the bottom of the dehumidifier through the inlet air duct. The air and the desiccant solution flow in a counter flow manner and both come in direct contact with each other. During this contact the air losses its moisture to the desiccant solution due the difference in vapor pressure. The air gets dehumidified and it leaves at the top of the dehumidifier through outlet air duct. The desiccant solution after absorbing moisture gets diluted which is collected in another tank at outlet. The flow rate of the solution is measured by the rotameter and it is varied by operating the gate valve. The results are noted for different air and solution flow rates. The solution temperature at inlet and outlet are also noted.

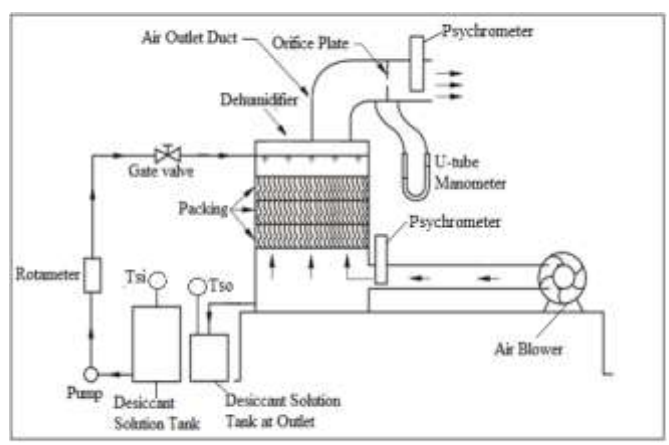

Fig. 1 Experimental Setup

III. RESULTS AND DISCUSSION

A series of experiments were performed on the set up at various inlet parameters. The input variables used in the experiment are air inlet temperature, solution inlet temperature, solution flow rate, air flow rate. The measured outlet parameters are air outlet temperature, change in humidity ratio, solution outlet temperature, moisture removal rate, air outlet temperature.

A. Effect of air flow rate:

In these experiments, mass flow rate of air (M_a) is varied and its effects are studied upon various outlet parameters. Mass flow rate of air is varied from 0.00071kg/s to 0.0012 kg/s and the readings are noted for different solution inlet temperature of 55°C, 65°C and 70°C.

Fig. 2 shows how specific humidity at outlet changes with mass flow rate of air. With lesser desiccant temperature i.e. 55°C, specific humidity changes from just 0.021 kg/kg of air to 0.026 kg/kg of air. Specific humidity increases from 0.028 to 0.035 kg/kg of air for T_{si} of 65°C and it changes from 0.031 to 0.036 kg/kg of air for T_{si} of 70°C.

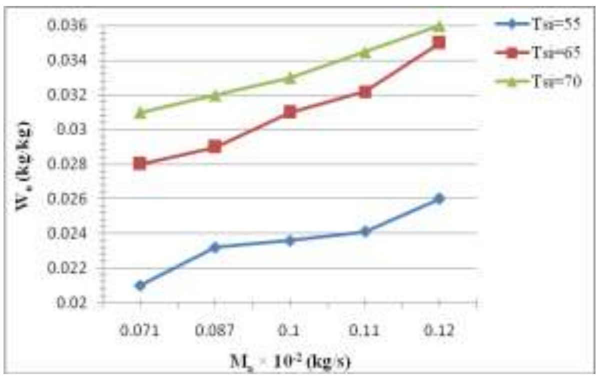

Fig. 2 Mass Flow Rate of Air vs Specific humidity at outlet

Fig. 3 shows the variation of moiture evapoartion rate with mass flow rate of air for different soluiton inlet temperatures of 55°C, 65°C and 70°C. Moiture evaporation rate increases with increase in air flow rate.

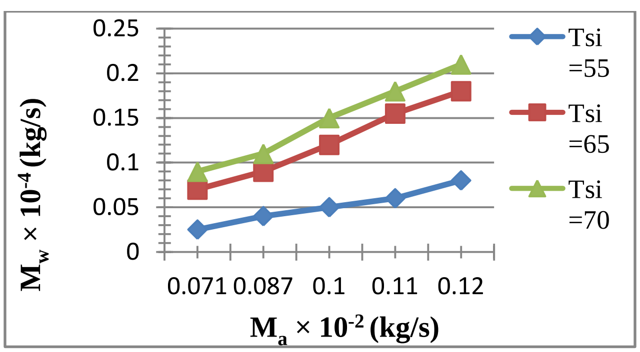

Fig. 3 Mass Flow Rate of Air vs Moisture Evaporation Rate

The Fig. 4 shows the variation of air outlet temperature of air with air flow rate for different solution inlet temperature. It is clear from the figure that for a given inlet temperature of solution, the air outlet temperature increases with the increase in air flow rate. This is due the reason that the air loses its latent heat to the solution due to which the temperature of the air coming out of the dehumidifier increases. For solution temperature of 65°C the air outlet temperature increases from 38.4°C to 39°C.

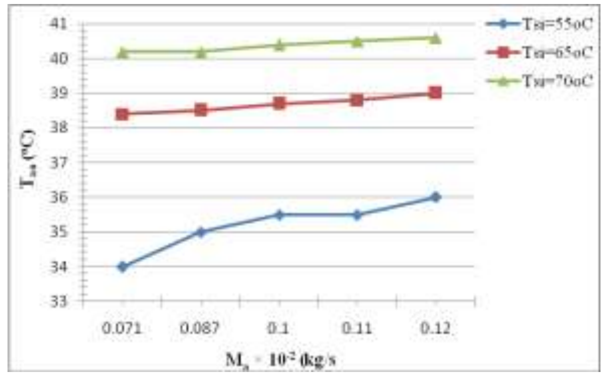

Fig. 4 Mass Flow Rate of Air vs Air Outlet Temperature

B. Effect of Dry Bulb Temperature of Air at Inlet

The experiment is carried out to study the effect of air inlet temperature on outlet parameters like change in humidity ratio, moisture removal rate, air outlet temperature. The experiment is carried out for different solution inlet temperature keeping solution flow rate and air flow rate as constant. The temperature of air is varied from 29°C to 45°C for a solution flow rate of 0.0623 kg/s, air flow rate of 0.00071 kg/s. The concentration of solution is kept as 34 %. The effects of air inlet temperature upon various outlet parameters are shown via various graphs.

The effect of air inlet temperature on ΔW is shown in the Fig. 5. For desiccant temperature of 65°C, ΔW changes from 0.0143 kg/kg to 0.032 kg/kg and it changes from 0.016 kg/kg to 0.034 kg/kg for solution inlet temperature of 70°C.

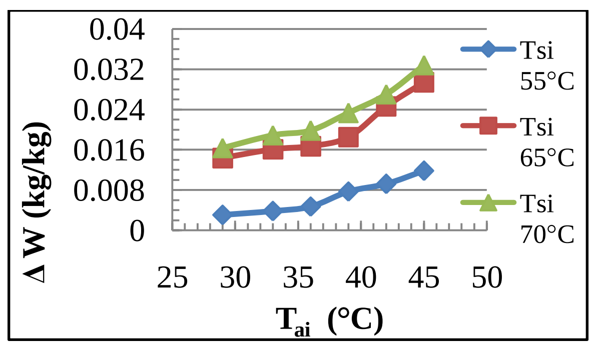

Fig. 5 Dry Bulb Temperature of Air at Inlet vs Change in Humidity Ratio

Moisture evaporation rate also increases with increase in air inlet temperature. From the Fig. 6 we see that moisture evaporation rate increases from 0.0000022 kg/s to 0.0000084 kg/s for solution inlet temperature of 55°C and it varies from 0.0000102kg/s to 0.000023 kg/s for solution inlet temperature of 65°C. This may be due to the reason that an increase in air inlet temperaure leads to increase in vapor pressure difference on solution surface, which results in increase in evaporation rate.

Also we see that the moitusre evaporation rate increases with increase in solution inlet temperature. For air inlet temperature of 29°C the moisture removal rate is increased from 0.0000022 kg/s 0.0000102kg/s as T_{si} changes from 55°C to 65°C. In this case also the rate of heat transfer is from hot solution to the air stream which results in raising the the air outlet temperature. For higher values of desiccant's temperature, the vapor pressure on the solution surface is also higher due to which the moisture evaporation rate increases.

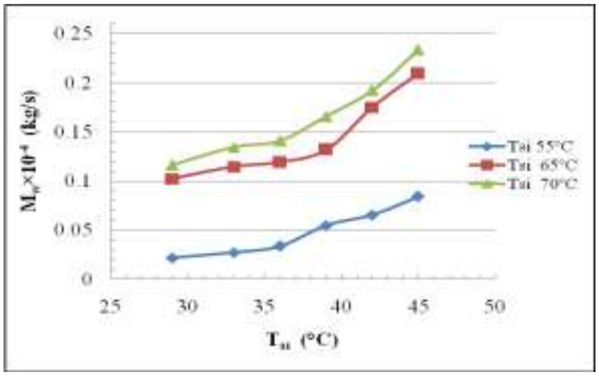

Fig. 6 Dry Bulb Temperature of Air at Inlet vs Moisture evaporation rate

The Fig. 7 shows the varaition of air outlet temperature (T_{ao}) with air inlet temperature (T_{ai}) for different solution inlet temperatures. We see that T_{ao} increases with T_{ai}. This is due the reason that with increase in air inlet temperature, the vapor pressure difference on solution surface increases and the air loses its latent heat to the solution and thus the dry bulb temperature of air increases at the outlet of the dehumidifier. For solution inlet temperature of 55°C, T_{ao} varies from 33°C to 44°C and for T_{si} 65°C & 70°C, T_{ao} varies form 37°C to 47°C & 39°C to 48°C as T_{ai} varies from 29°C to 45°C. Also as the air loses its latent heat to the solution, the solution outlet temperature increases.

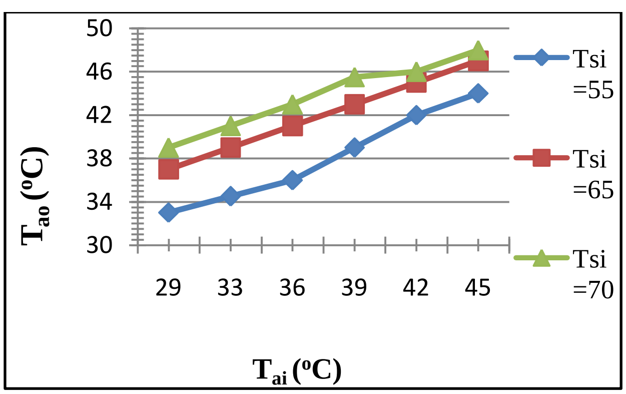

Fig. 7 Dry Bulb Temperature of Air at Inlet vs Dry Bulb Temperature of Air at Outlet

Also as the air loses its latent heat to the solution, the solution outlet temperature (T_{so}) increases. The variation of solution outlet temperature with dry bulb temperature of air at inlet is shown in the Fig. 8 and it is observed that the solution outlet temperature increases with desiccant's outlet temperature. T_{so} also increased with air temperature T_{ai}. For desiccant solution inlet temperature of 55°C, the solution outlet temperature increases from 43°C to 48°C as the air inlet temperature is changed from 29°C to 45°C. and for solution inlet temperature of 65°C, it increases from 48°C to 53°C for the same change in air inlet temperature.

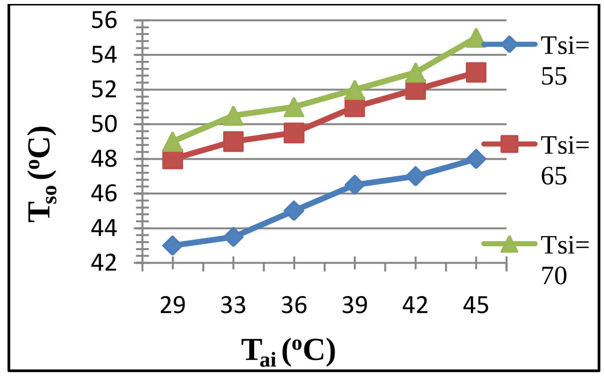

Fig.8 Solution outlet temperature vs Dry Bulb Temperature of air at inlet

IV. CONCLUSIONS

From the experimental results it has been concluded that the output parameters like moisture evaporation rate, solution outlet temperature, air outlet temperature, humidity ratio increases with increase in air inlet temperature, increase in air flow rate.

V. NOMENCLATURE

M_s: Solution flow rate, M_w: Moisture evapoartion rate, **Δ**W: Change in humidity ratio, M_a: Air flow rate, T_{ai},T_{ao}: Dry bulb temperature of air at inlet and outlet, T_{si}, T_{so}: Solution temperature at inlet and outlet.

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