International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435(Online) Volume 3, Issue 3, September 2014)

Performance of the Cross Flow Regenerator Used in Liquid Desiccant Dehumidification.

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***Abstract*-The regeneration of the desiccant solution used in the dehumidification process is very important to further dehumidify the air. The process of regeneration was carried out in packed structure regenerator. For the regeneration process, the vapor pressure in the desiccant solution should be higher than the vapor pressure in the air. The flow here is cross-flow between the solution and the air. The performance of the regenerator is expressed in terms of various parameters like mass evaporation rate, concentration change and regenerator effectiveness. The desiccant solution used is TEG and the packing used in the regenerator is PVC frill.**

***Keywords*-TEG, regenerator, desiccant & PVC packing**.

I. INTRODUCTION

Liquid desiccant cooling system is one of the emerging technologies in the present time. It can replace the conventional system of cooling. Dehumidification and regeneration are two important processes of this system. In first process, moisture is replaced from the humid air in packed structure column called dehumidifier by the desiccant solution. Where as in the second process, regeneration of the diluted desiccant is done in a packed structure column called regenerator.

For the regeneration process, the vapor pressure in liquid desiccant solution should be higher than the vapor pressure in the air used for the regeneration. So after the dehumidification process, the desiccant solution is heated to raise the vapor pressure. So the regeneration can be done by many methods. Regeneration by using the solar energy is popular. Also the regeneration can be done by heating the liquid desiccant directly with the help of heater as in this paper. In packed structure regenerator, mass and heat transfer happen only between air and the desiccant.

Desiccant is a material which absorbs moisture. It has strong affinity for moisture. These materials absorb moisture due to difference in vapor pressure. Desiccants are of two types namely solid desiccant and liquid desiccant. Some of the solid desiccants are silica gel, calcium chloride. A liquid desiccant is a hygroscopic liquid used to remove water. Some liquid desiccants are glycols (diethylene, tri ethylene, tetra ethylene). The selection of the desiccant depends on their ability to hold large quantities of water, their ability to be reactivated and cost.

There are different types of desiccant cooling systems namely solid desiccant system, liquid desiccant system hybrid desiccant system and Solar based desiccant systems. In solid desiccant systems, solid desiccant is used. It is used generally in industries. In liquid desiccant cooling system, liquid desiccant is used. It has two chambers, one is for dehumidification and other is for regeneration of the desiccant.

II. LITRATURE REVIEW

M. M. Bassuoni et al. [29] in this paper presented an experimental investigation on the performance of the structured packing cross flow desiccant dehumidification system. Calcium chloride ($CaCl_2$) solution is used as the working desiccant material in this system. The structured packing has a density (specific surface area) of 390 m^2/m^3, corrugation angle of 60° and void fraction of 0.88. The effect of relevant parameters such as air flow rate, desiccant solution flow rate, desiccant solution temperature and concentration and packing thickness on the performance of the system is studied. The performance of the system is evaluated using the mass transfer coefficient, moisture removal rate (MMR), effectiveness and the coefficient of performance (COP). The remarkable increase of mass transfer coefficient and MRR for both deh/reg is observed by increasing both air and solution flow rates. Eventually, the payback period (PP) of the DDS is 11 months with annual running cost savings (ΔC_{RC}) of about 31.24% compared with vapor compression system (VCS) dehumidification. The overall environmental impacts of DDS are nearly 0.63 of VCS. This may emphasize the need of incorporating a desiccant system along with air conditioning applications.

A.M. Ahmed et al. [4] studied the moisture removal rate in a solar powered liquid desiccant air conditioning system using Triethylene Glycol (TEG) as a desiccant. An evacuated tube solar boiler was used for desiccant regeneration. During the experimental investigation, inlet parameters, including air flow rate, humidity ratio, desiccant flow rate, and concentration were varied. The effect of these variables on the moisture removal rate was studied.

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It was found that the moisture removal rate increases with increasing the inlet air flow rate, inlet air humidity ratio, desiccant flow rate, and desiccant solution concentration.

Abdul Wahab et al. [2] discussed the performance of air dehumidifier using triethylene glycol (TEG) as a desiccant. Three differently structured packing densities were used (77, 100 and 200 m2/ m3). The performance of the dehumidifier was evaluated and expressed in terms of the moisture removal rate and the dehumidifier effectiveness. The experimental work was undertaken to study the effects of several influencing design factors on this performance. The design factors covered included the air and TEG flow rates, air and TEG inlet temperatures, inlet air humidity and the inlet TEG concentration. The desiccant flow rate investigated was much less than that covered in previous studies and the range of the inlet temperatures of air and desiccant was significantly wider. The objective of this study was to use the multiple regression method and the principal component analysis to obtain statistical prediction models for the water condensation rate and the dehumidification effectiveness in terms of these design factors.

V. O Berg et al. [28] discussed the experimental investigation of the heat and mass transfer between a liquid desiccant (triethylene glycol) and air in a packed bed absorption tower using high liquid flow rates. A high performance packing that combines good heat and mass transfer characteristics with low pressure drop is used. The rate of dehumidification, as well as the effectiveness of the dehumidification process is assessed based on the variables listed above. Good agreement is shown to exist between the experimental findings and predictions from finite difference modeling. In addition, a comparison between the findings in the present study and findings previously reported in the literature is made. The results obtained from this study make it possible to characterize the important variables which impact the system design.

C. K. Chau et al. [3] discussed the sorption characteristics of water and toluene vapors in various concentrations of triethylene glycol (TEG) solution flowing through a packed-bed dehumidifier are investigated in this paper. A multi-component model was constructed using the reported equilibrium relationships of toluene and water vapors in TEG solutions together with the Krishna-Standart multi-component mass transfer correlation.

The effects of liquid-to-air ratios, TEG inlet temperatures, air inlet temperatures were reported on the moisture and toluene removal rate as well as the moisture and toluene removal efficiency of the packed dehumidifier.

Running the packed dehumidifier in a higher liquid-to-gas flow ratio generally increased the removal rates and efficiencies of both water vapor and toluene vapor from the airstream. Increasing inlet temperatures of the TEG solution led to a decrease in the removal rate of water vapor when running the packed dehumidifier at a high liquid-to-gas flow ratio. However, there was no significant change in the toluene vapor removal rate or toluene removal efficiency when the flow rate of the inlet TEG solution was increased.

Esam Elsarrag et al. [26] discussed structured packing which represents the newest development in high efficiency, high capacity packing for heat and mass transfer in contrast to the traditional, randomly placed packing material. The main objectives of this study are to develop design guidelines and to assess the performance of a structured packed liquid desiccant-evaporative cooling system in the modified comfort zone. Theoretical and experimental studies of the simultaneous heat and mass transfer between air and desiccant in a packed absorption tower are conducted. Triethylene glycol (TEG) is used as a desiccant and cellulose rigid media pads are used as structured packing.

III. Experimental Set Up

The experimental set up consists of two rectangular packed towers, one for dehumidifier and other for regenerator. The two rectangular towers of size (1 foot x 1 foot x 2 feet) are made of sheet metal in sheet metal shop. After that towers are packed with PVC frill of size (1 foot x 1 foot x 1 foot), which is a packing material. Two rectangular ducts of size 1 foot and 5 inches x 5 inches in cross-section are attached on both sides of the dehumidifier (one for inlet & one for outlet) and regenerator. The top of the dehumidifier and regenerator is provided with a plate having a large number of holes and act as sprayer. A heat exchanger is made of sheet metal and covered with thick sheet of thermo Cole to avoid the heat loss.

Heat exchanger is used to exchange the heat between desiccant after passing through dehumidifier & after passing through the regenerator.

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The procedure was very simple. We run the set up for 20-25 minutes to achieve steady flow condition. After the achievement of steady flow condition, readings were taken.

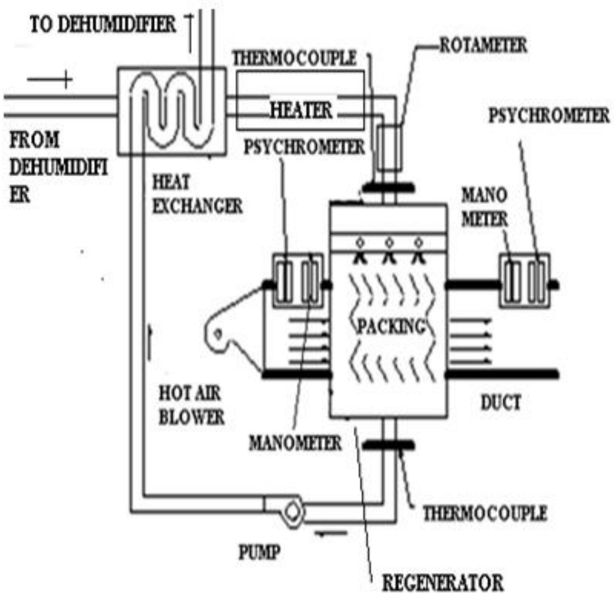

Fig. 1 shows the schematic diagram of regenerator.

Fig. 2 shows the actual experimental set up

IV. THEORITICAL ANALYSIS

The desiccant solution gets diluted after the dehumidification of air. Its regeneration is necessary for further dehumidification of air. The regeneration of the desiccant solution is done in packed column structure called regenerator.

For the regeneration process, the vapor pressure in the desiccant solution should be higher than the vapor pressure in the air so that water can evaporate from the air. If the vapor pressure in the desiccant solution will be less than the vapor pressure in the air, then there will be no evaporation and no regeneration of the solution. Instead of this, there will be dehumidification of the air i.e. moisture will transfer from air to water. So for this reason, the desiccant is heated with the help of heater before entering the regenerator to raise the vapor pressure in the desiccant solution. The change in concentration, moisture removal rate and the regenerator effectiveness are the parameters to judge the performance of the regenerator.

The change in concentration can be measured by using the hydrometer. Hydrometer measures the concentration at the outlet of the regenerator. Hydrometer measures the specific gravity. Specific gravity is defined as the ratio of the density of the liquid to the density of the water. By taking the value of specific gravity, we can calculate the value of concentration.

The moisture removal rate can be calculated by measuring the humidity of air at inlet and the outlet. The moisture removal rate can be calculated by

$$M_{evap} = (Y_{out} - Y_{in}) .A$$

Last parameter is the regenerator effectiveness. It is defined as the ratio of the actual change in moisture content of the air stream to the maximum possible change in its moisture content under a given set of operating conditions.

$$\varepsilon = \frac{(Y_{out} - Y_{in})}{(Y_{equil} - Y_{in})}$$

Where Y_{out} and Y_{in} are the specific humidities of the air at the outlet and inlet conditions, respectively and Y_{equil} is the specific humidity of the air at equilibrium with the desiccant solution at the desiccant inlet concentration and temperature. Where A is the cross-sectional area of the column.

The vapor pressure of the TEG desiccant solution can be calculated by using Antoine's equation and is given by

$$\mathrm{Log}_{10}(P_{sol}) = A - \frac{B}{T + C}$$

Where A, B & C are constants and their values depend upon liquid desiccant temperature and concentration. T is liquid desiccant temperature in °C.

The equilibrium specific humidity is given by

$$Y_{equil} = 0.62185 \frac{P_{sol}}{P_{atm} - P_{sol}}$$

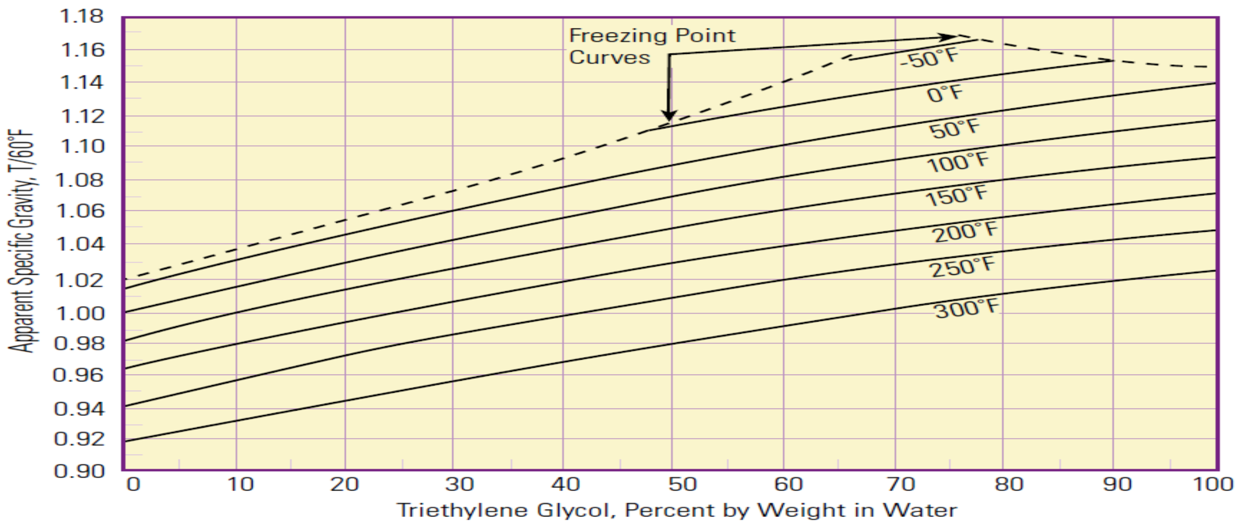

Fig. 3 shows the specific gravity vs. concentration graph.

Triethylene Glycol Antoine Constants for Calculating Vapor Pressure
3-Constant Antoine Equation $\text{Log}_{10}(P) = A - B/(T + C)$
P = mm Hg, T = °C

TriEG, Wt%	A	B	C
0	7.959199	1663.545	227.575
50	7.922294	1671.501	228.031
70	7.878546	1681.363	228.237
80	7.837076	1697.006	228.769
90	7.726126	1728.047	229.823
95	7.620215	1806.257	236.227
97	7.495349	1841.522	238.048
98	7.404435	1881.474	240.666
99	7.211145	1926.114	242.799
99.5	7.042989	1970.802	242.865
100	7.472115	2022.898	152.573

Fig. 4 shows the Antoine's equation & values of constants

V. RESULTS & DISCUSSIONS

The performance of the regenerator is generally expressed in terms of mass evaporation rate, change in concentration and regenerator effectiveness. So we have studied the effect of some inlet parameters like mass flow rate of air, mass flow rate solution, inlet air temperature. The results are shown and discussed below.

A. Effect of mass flow rate of air on performance parameters.

The effect of mass flow rate of air was studied on these parameters. The mass flow rate was varied from 0.95 x 10^{-2} kg/s to 1.25 x 10^{-2} kg/s.

Here the other parameters like inlet air temperature and mass flow rate of solution were kept constant. Inlet air temperature was 22°C& mass flow rate of the solution was 0.02 kg/s. After study, it was found that mass evaporation rate increased with increase in mass flow rate of air. The reason was that with increase in mass flow rate of air, more air comes in contact with the solution and solution released more moisture to the air. Also the experiment shows that stronger desiccant solution was available at higher desiccant's temperatures for the same air flow rate.

International Journal of Recent Development in Engineering and Technology
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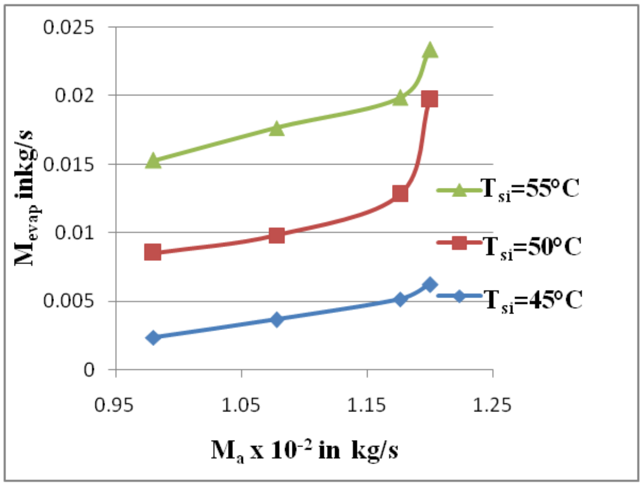

Fig. 5 shows the variation of evaporation rate with mass flow rate of air at different inlet solution temperatures.

The change in concentration also increased with mass flow rate of air. This was due to the reason that with increase in mass flow rate of air, more air interacted with the solution and more moisture was released by the solution which increased the outlet concentration of the solution.

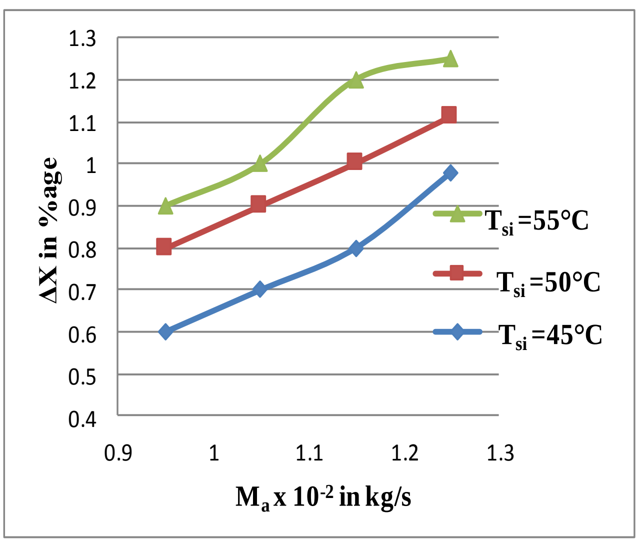

Fig.6 shows the variation of change in concentration with mass flow rate of air at different inlet solution temperatures.

The regenerator effectiveness increased with mass flow rate of air. The increase in regenerator effectiveness was due to the increase in outlet humidity of air as it absorbed more moisture with increase in mass flow rate of air.

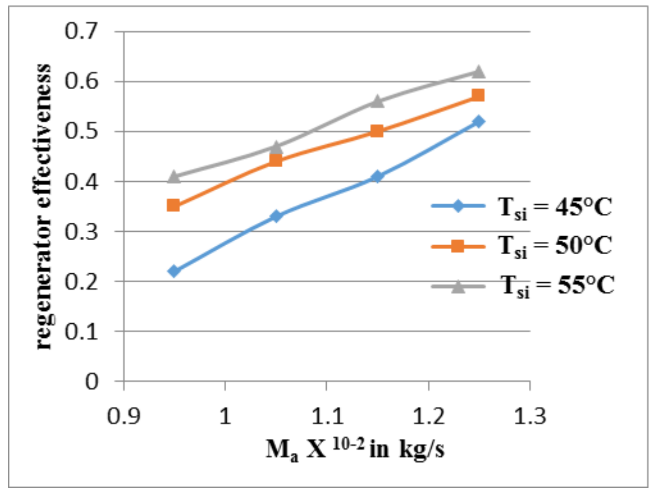

Fig. 7 shows the variation of regenerator effectiveness with mass flow rate of air at different inlet solution temperatures.

B. Effect of mass flow rate of solution on performance parameters.

The effect of mass flow rate of solution was studied on these parameters. The mass flow rate was varied from 0.02 kg/s to 0.04 kg/s. Here the other parameters like inlet air temperature and mass flow rate of air were kept constant. Inlet air temperature was 22°C& mass flow rate of the air was 0.95 x 10^{-2} kg/s.

Experimentally it was found that evaporation rate increased with mass flow rate of solution. This was due to the fact that, when the desiccant flow rate was increased, there would be a good wetting area, and hence a good contact area between air and desiccant which would increase the heat and mass transfer. When the contact was increase, more water vapor would be released and thus increasing the evaporation rate

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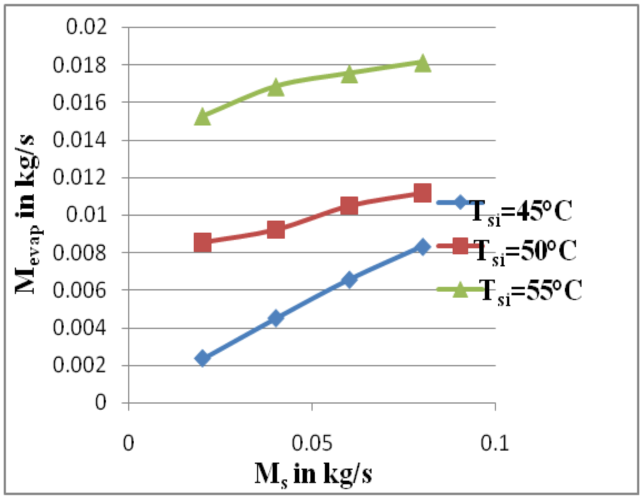

Fig. 8 shows the variation of evaporation rate with mass flow rate of solution at different inlet solution temperatures.

The change in concentration also increased with mass flow rate of solution. This was due to the fact as mass flow rate of solution increased, more solution comes in contact with the same amount of air for particular value of T_{ai} and it would increase the heat and mass transfer. When contact was increased, more water vapor would be released and concentration at outlet increased.

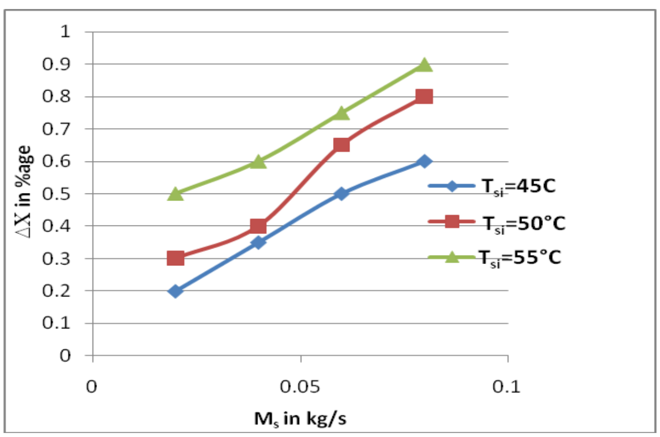

Fig. 9 shows the variation of change in concentration with mass flow rate of solution at different inlet solution temperatures.

The regenerator effectiveness increased with mass flow rate of solution due to the increase in evaporation rate which leads to increase in outlet humidity of air.

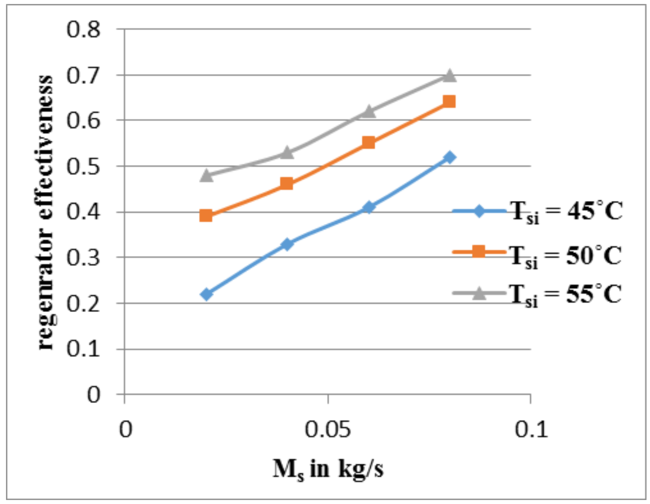

Fig. 10 shows the variation of regenerator effectiveness with mass flow rate of solution at different inlet solution temperatures.

C. Effect of inlet air temperature on performance parameters

The effect of inlet air temperature was studied on these parameters. It varied from 22°C to 31°C. Here the other parameters like mass flow rate of air and mass flow rate of solution were kept constant. Mass flow rate of the air was 0.95 x 10^{-2} kg/s & mass flow rate of solution is 0.02 kg/s.

The evaporation rate decreased with increase in inlet air temperature and this is due to the fact that by increasing inlet air temperature, there would be decrease in difference of vapor pressure in solution and in air and corresponding less water evaporates from the desiccant solution.

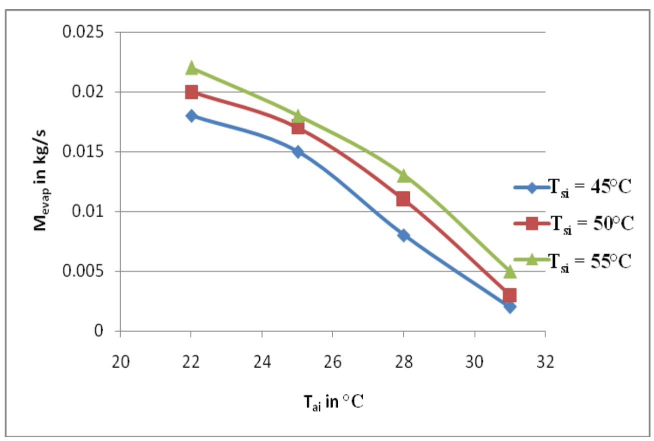

Fig. 11 shows the variation of evaporation rate with inlet air temperature at different inlet solution temperature.

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The next graph shows variation of change in concentration with inlet air temperature. It decreased with inlet air temperature. It evaporation rate decreases with inlet air temperature which leads to decrease in outer humidity and outlet concentration of solution.

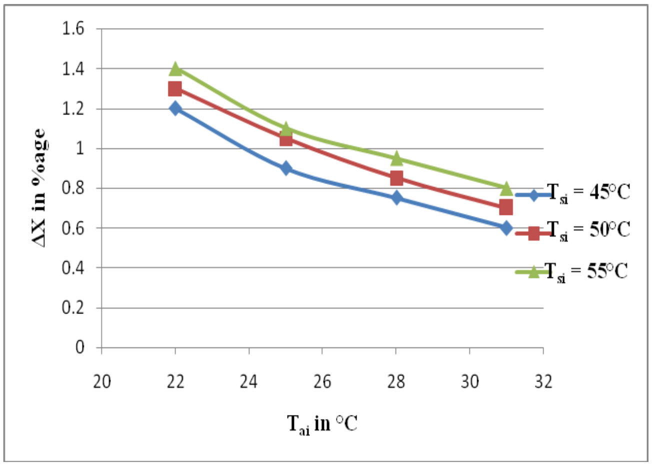

Fig. 12 shows the variation of change in concentration with inlet air temperature at different inlet solution temperatures.

Last graph shows the variation of regenerator effectiveness with inlet air temperature. Its value decreased with inlet air temperature as outlet humidity decrease.

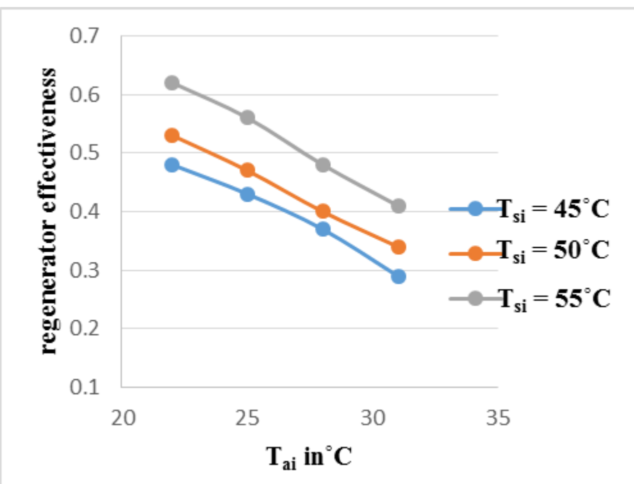

Fig. 13 shows the variation of regenerator effectiveness with inlet air temperature at different inlet solution temperatures.

VI. CONCLUSION

In this paper, the effect of various inlet parameters were studied on performance parameters namely evaporation rate, change in concentration & evaporator effectiveness. The results were formulated in the form of graphs. The results were satisfactory and in agreement with other research papers. Also the desiccant solution was regenerated for further dehumidification.

VII. NOMENCLATURE

M Mass flow rate in (kg/s)
T Temperature (°C)
ΔX Change in concentration in (%age)
TEG Triethylene glycol
a air
s solution
evap evaporation
i inlet
o outlet
ε regenerator efectiveness

Acknowledgement

We would like to thank Punjab Technical University, Kapurthala and IET, Ropar to give opportunity to carry out this research work.

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