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Experimental Analysis of inlet variables effecting the performance of Cross Flow Liquid Desiccant Air Dehumidifier

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Abstract - A Dehumidifier is a one of essential components in liquid desiccant air conditioning system. In summer the air contain more amount of moisture as compared to winter in Indian subcontinent environment. This moisture is the latent heat load of air which is to be removed by air conditioning system. In the vapour compression air conditioning system the air is cooled below its dew point temperature for removing this latent heat load then reheated for removing the sensible heat load. This paper is an experimental study of a cross flow air dehumidifier using triehtylene glycol (TEG) as liquid desiccant. The affect of inlet parameters were studied on some outlet parameters. It is concluded that dry bulb temperature, wet bulb temperature and enthalpy of air increases with increasing the air inlet temperature and humidity ratio, wet bulb temperature, specific enthalpy, moisture removal rate decreases on increasing the air mass flow rate. It is found that the higher mass flow rate of air does not effect on moisture removal rate significantly.

KEYWORD- Desiccant, dehumidification system, humidity ratio, triethylene glycol (TEG).

1 INTRODUCTION:

Liquid desiccant cooling systems is the alternatives to the conventional vapour compression cooling systems. In the hot and humid areas the humidity is more. The humid air having two types of heat load first sensible heat load and second latent heat load in the form of moisture. In the conventional vapour compression cooling system the sensible cooling load is removed in the evaporator by extracting latent heat from its surroundings by changing the refrigerant phase from liquid to vapour in the evaporator coil tubes [7]. And for second latent cooling load is removed by lowering the temperature below dew point temperature so that moisture present in the air changes its phase from vapour to liquid as condensate which is we often see the water coming out from back side of conventional air conditioner. Then refrigerant is reheated to get the desired temperature. So some extra amount of energy is consumed which is wastage. Earlier researches shown that by employing desiccant cooling before conventional cooling system the 25% electrical energy can be saved [7].

In addition the desiccant dehumidification system is environmentally safe in comparison with conventional vapour compression systems. Vapour compression systems are responsible for green house gas emissions and they increasing the pollutions as well as global warming. The refrigerants used in the vapour compression cooling systems are itself greenhouse gases. During maintenance, servicing, repairing and manufacturing there is possibility of some refrigerant to escape into the atmosphere, the refrigerant has the potential to contribute global warming. So desiccant cooling avoids or prevents the environments from such kind of dangers.

Air conditioners are operated by electrical energy, which is generated by burning of fossil fuels like burning of coals and burning of diesel and petroleum products. This burning of fuels produces huge amount of carbon dioxide and other pollutants which are contribute to global warming and depletion of ozone layer. In addition the desiccant cooling and dehumidification system for building comfort conditioning has increased steadily during the past several years. In addition to dehumidification the liquid desiccant cooling has ability to absorb inorganic and organic contaminants in the air, the absorption process has the potential to remove biological pollutants such as bacteria, fungi and viruses, improving indoor air quality [8].In view of these limitations the desiccant cooling is one of the energy efficient and environmentally safe method.

Desiccants are of two types namely solid desiccants and liquid desiccants. Solid desiccants include silica gel, activated alumina, lithium chloride salt, molecular sieves, titanium silicate and synthetic polymers. Liquid desiccants include lithium chloride, lithium bromide, calcium chloride and triethylene glycol (TEG).More details about desiccants properties and desiccants types are given by Kinsara et al. [9]. Liquid desiccants have several advantages over solid desiccants. The pressure drop through the liquid desiccant is lower than that through a solid desiccant system and can be stored for regeneration by some inexpensive or low grade energy such as solar energy and waste heat. Liquid desiccant system can reduce the area of evaporation and condensation by 34% [7].

The aim of the present study has been to design, build, test and evaluate a fully-instrumented liquid desiccant cooling system, to provide a demonstration under varying conditions. Humidity control is also important in many engineering applications such as storage warehouses; process industries Zurigat al. [10] investigated the performance of an air dehumidifier using triethylene glycol (TEG). Many researchers have developed analysis of the coupled heat and mass transfer dehumidifier processes in steady state. This paper presents a experimental study on results of various inlet parameters such as effect of mass flow rate and inlet dry bulb temperature of air for different inlet solution temperature is studied upon the change in humidity, change in wet bulb temperature, change in specific enthalpy, moisture removal rate and air outlet dry bulb temperature with pvc structured packed bed liquid desiccant cross flow dehumidifier in steady state condition.

2 LITERATURE REVIEW :

C. K. Chau et. al. [3] investigeted the triethylene glycol (TEG) solution flowing through a packed-bed dehumidifier. 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.

S.A. Abdalla et. al. [4] described the proposed solar-driven liquid desiccant evaporative cooling system and the method used for investigating its performance in providing cold water for a radiant air-conditioning system using LiCl-Water as desiccant. The results of the investigation show that the system can operate in humid as well as dry climates and that employing such a system reduces air-conditioning peak electrical demands as compared to vapour compression systems. The parametric study conducted to investigate the system performance shows that the system dehumidifies about 1.6 kg/sec of process air, at the design conditions defined earlier by this work (about 30.1^{0}C dry-bulb temperature and 6.6g/kg humidity ratio, which is equivalent to 17^{0}C wet-bulb temperature). At these conditions a 1.2 water-to-air ratio cooling tower (evaporative water cooler) using this process air can produce 1.92 kg/sec of water at about 22^{0}C.

V. Oberg et. al. [5] 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.

Esam Elsarrag et.al. [6] performed experimental study on a structured packing represents the newest development in high-efficiency, high-capacity packing for heat and mass transfer in contrast to the traditional, randomly placed packing material. An experimental study for evaluating the heat- and mass-transfer coefficients in an air-desiccant contact system employing triethylene glycol and cross-corrugated cellulose structured packing (Celdek type) is carried out. The important design variables found to have the largest effect on the mass-transfer coefficient are as follows: the air and liquid flow rates, the air vapor pressure, and the solution vapor pressure. It is found that high liquid flow rates do not have

The performance of the dehumidifier has been expressed in terms of the moisture removal rate by SA Abdul Wahab et. al [1]. The experiments covered a wide range of parameter space that included the air and TEG flow rates, air and TEG inlet temperatures, inlet air humidity and inlet TEG concentration. The liquid flow rate investigated is much less than that covered in previous studies. The trend of the dehumidifier performance was similar to that reported in the literature using high density and random packing. The results were compared to the Chung and Luo correlation, which over predicted the effectiveness. In the present study, it was found that the moisture removal rate increased with TEG flow rate and air flow rate. In addition, the moisture removal rate is increased with increasing the inlet air temperature for the structured packing only. The effectiveness of the column was increased by increasing the TEG flow rate.

The performance of air dehumidifier using triethylene glycol (TEG) as a desiccant was investigated by SA Abdul Wahab et. al [2] . 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.

3 EXPERIMENTAL SET-UP :

A prototype is fabricated to perform experiments on it. Dehumidifier tower's over all dimensions are 305mm X 305mm X 450 mm. One PVC packing of size 300mm X 300mm X 300mm are stacked in such a manner that their effective height is 300 mm. packing's cross section is shown in figure 1, it is arranged in zigzag manner to reduce the desiccant carry over rate and provides proper mixing of air with the desiccant at the same time. Two ducts for air flow having cross-section 154mm X 154 mm are fitted at dehumidifier's both ends as shown in figure1.A desiccant circulation pump, which pumps the weak desiccant from tank to the dehumidifier top, so that it can flow downwards in the dehumidifier.

The air is fed through duct by blower at right angle to make contact with the liquid desiccant coming from the top of dehumidifier. A perforated tray is used for the proper distribution of desiccant is fitted over the packing. A rotameter is fitted at the top of dehumidifier before liquid spraying to measure the mass flow rate of liquid desiccant. Two manometers are fitted in the duct to measure the mass flow rate of air. Two venturies having square cross-sectional area 89mmx89mm fitted before and after the dehumidifier for measuring the mass flow rate of air. Two psychometers are fitted before and after the dehumidifier in the duct to measure the dry bulb and wet bulb temperature of the fresh and dehumidified air. A hydrometer is used to measure the specific gravity of the liquid desiccant, which is further calculated for liquid desiccant concentration. Two PT-100 type thermocouples are used for measuring the inlet and outlet solution temperatures. A electrical heating element is fitted between blower and dehumidifier in the duct for supplying the air at different temperatures.

Figure 1. Experimental set up of cross flow dehumidifier**.**

4 METHODOLOGY:

First of all equipment is run for 30 minutes for steady state conditions. All leakages were prevented by applying m-seal adhesive as per requirement. Mass flow rate of air was varied with varying the rpm of blower with the help of regulator. An electric heater was fitted just after the blower in the duct with regulator, so that temperature of air can be changed as per requirement. Two psychrometers were fitted before and after the dehumidifier for checking the wet bulb temperature and dry bulb temperature of the inlet and outlet air respectively. The trays of psychrometers were filled with water for wetting the wick as per requirement.

Mass flow rates of air was varied by varying the rpm of blower to measure the humidity ratio of air, outlet wet bulb temperature of air, outlet specific enthalpy of air, moisture removal rate and outlet dry bulb temperature of the air. Also inlet air dry bulb temperature varied with the help of electric heater and regulator to measure humidity ratio of outlet air, wet bulb temperature of outlet air, specific enthalpy of outlet air, moisture removal rate of air and dry bulb temperature of outlet air as shown in the graphs. Following instruments were used for measuring the observations i.e. PT-100 type thermocouples for solution temperature, thermometers for dry bulb and wet bulb temperature of air at inlet and outlet, Rotameter for measuring the mass flow rate of the desiccant, U-tube manometers for measuring the differential pressures at before and after the dehumidifier, a hydrometer was used to measure the density/concentration of desiccant. Majority of observations were taken on the same day, however some were taken on different days/ in different environment conditions to get different levels of humidity. Variable inlet parameters for this experiment were m_a tdb_{ai} and to check the performance, outlet parameters were $\Delta\omega_a$, Δtwb, Δh, $m_a x \Delta\omega$, and tdb. The objective of dehumidification process is to transfer the water vapor from humidified air to the strong desiccant to dehumidify the air.

5 RESULTS AND DISCUSSION:

5.1 Effect of mass flow rate on output parameters:

The performance of the dehumidification system was evaluated by conducting a series of runs with structured pvc packing. The parameters considered in this study included air flow rate, air inlet temperature, humidity ratio, change in wet bulb temperature, change in specific enthalpy, moisture removal rate and change in dry bulb temperature of air. The performance of the dehumidifier was evaluated by calculating the above said parameters with cross flow orientation of dehumidifier i.e. air was contacting the liquid desiccant at right angle. Figure 2,3,4,5 and 6 show the affect of mass flow rates of air on humidity ratio of air, change in wet bulb temperature of air, sp. enthalpy of air, moisture removal rate and dry bulb temperature of air at solution temperature 21°C,24°C and27°C. Figure 2. shows as the mass flow rate of air increases, moisture removal rate decreases, this is due to the fact that the contact time between air and desiccant reduces because air velocity is increased. Findings of this study are in agreement with Esam Elsarrag et. al. [5] Figure 3 shows the increased mass flow rate of air reduces the wet bulb temperature at different constant solution temperatures, this is due to the fact that as latent heat load of air reduced the wet bulb temperature drops. This is also agreed with Esam Elsarrag et. al. [5]. Figure 4 shows as the air mass flow rate increases the enthalpy of air reduces because latent heat of air reduces hence enthalpy of air decreased. Figure 5 shows at low temperature as 21°C the moisture removal rate increases but when the temperature of desiccant solution increased to 24°C the moisture removal rate reduced slightly decreased, and when temperature of solution is further increased up to 27°C the moisture removal rate decreased rapidly this is due to the fact that as the temperature of desiccant increases the corresponding partial pressure of desiccant increases the partial pressure of desiccant is slightly more than previous condition and hence moisture removal rate is decreased. Figure 6. Shows as the mass flow rate of air increased the dry bulb temperature of air decreased this is due to the fact that as moisture quantity reduced the latent heat reduced in the air, as the latent heat reduced the dry bulb of air reduced. There is some slight difference to this result of M.M. Bassuoni [6], in that study calcium chloride was used as desiccant as compared to triethylene glycol in this study[6].

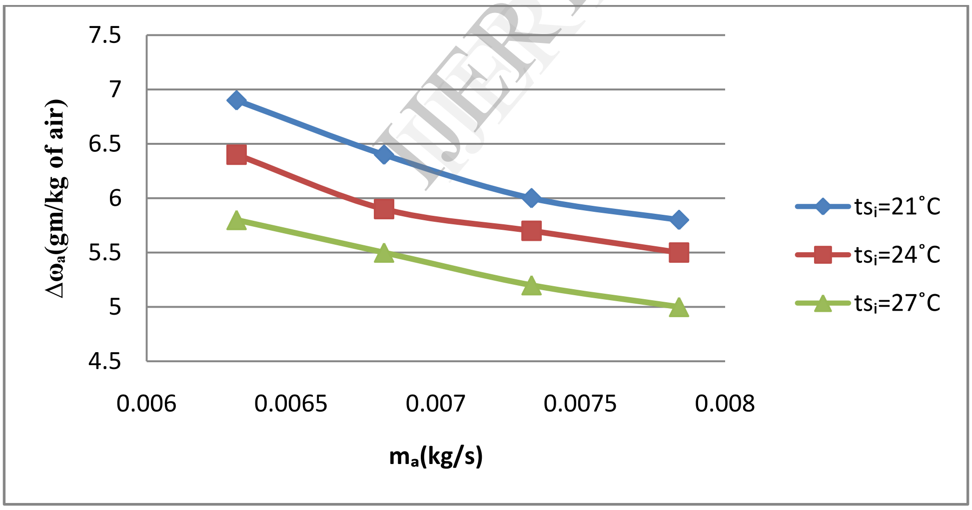

Figure 2 Effect of mass flow rate of air on specific humidity at different solution temperature

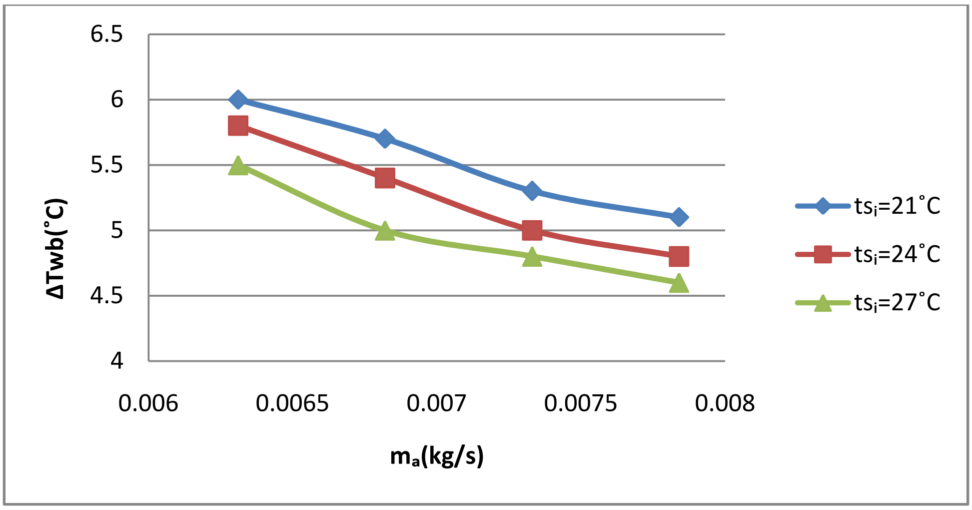

Figure 3 Effect of mass flow rate of air on wet bulb temperature at different solution temperature

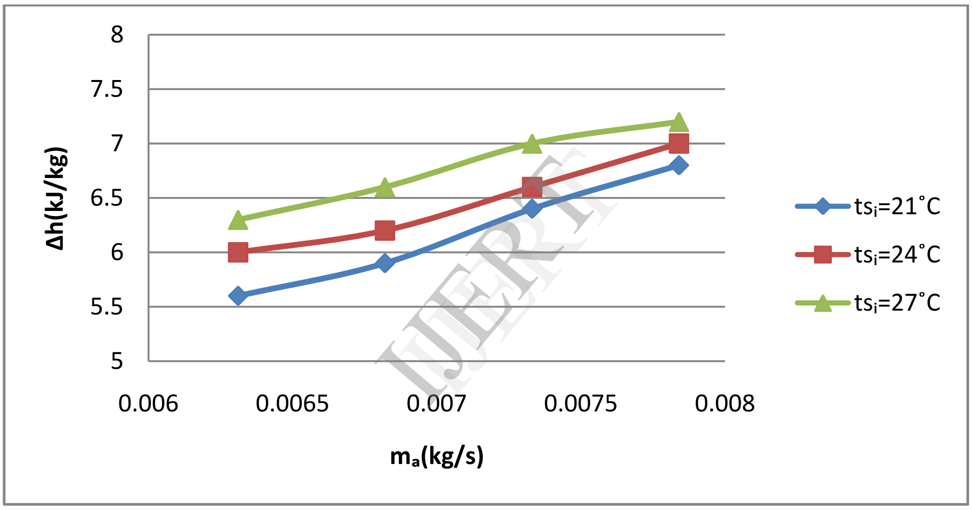

Figure 4 Effect of mass flow rate of air on change in specific enthalpy at different solution temperature

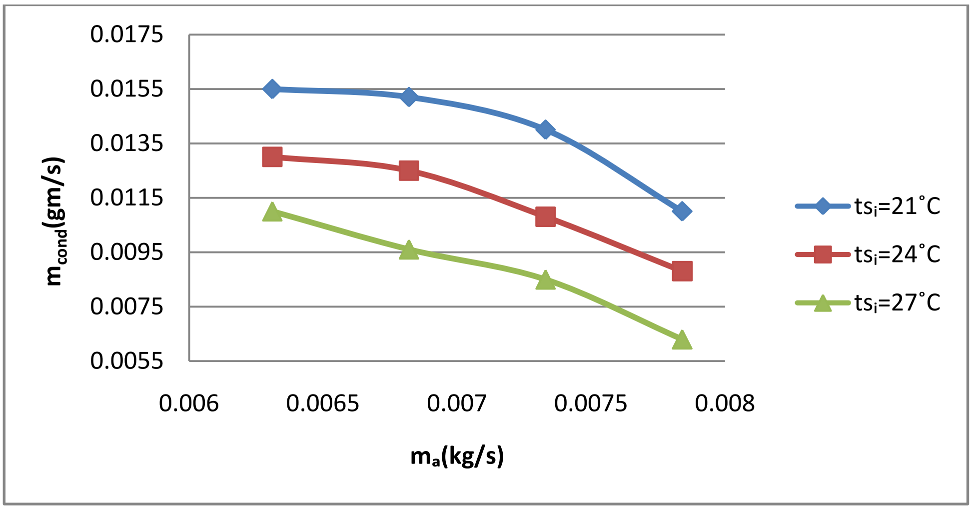

Figure 5 Effect of mass flow rate of air moisture removal rate at different solution temperature

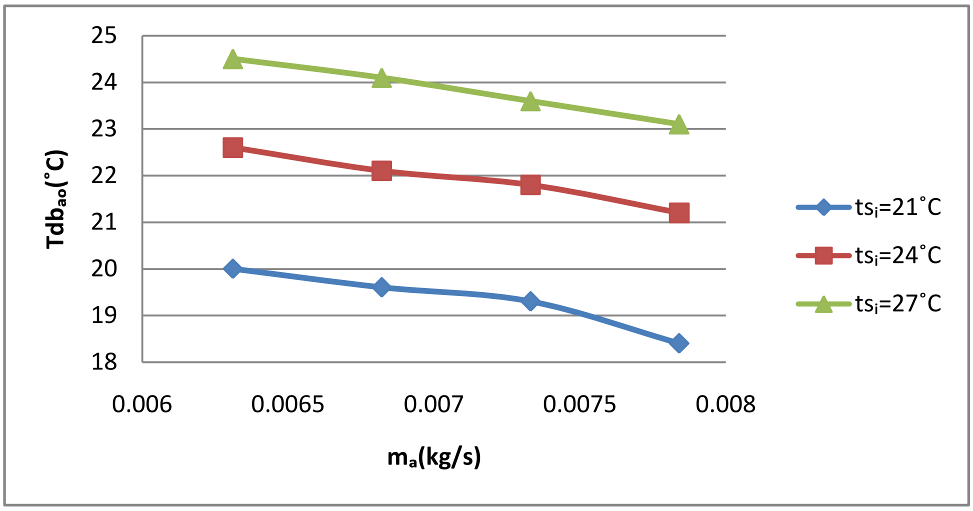

Figure 6 Effect of mass flow rate of air on outlet air dry bulb temperature

5.2 Effect of Dry Bulb Temperature on output parameters

In another set of experiments, the effect of inlet air dry bulb temperature on other output parameters studied. Figure 7 shows moisture removal rate slightly decreases with increase in inlet air dry bulb temperature. As the inlet air temperature is increased, the temperature of the liquid desiccant solution inside the dehumidifier is increased which in turn increases the partial vapor pressure on the desiccant surface. When the desiccant surface vapor pressure increases, the potential of the absorption process is decreased, causing air to become more humid and in turn low moisture removal rate. This is in agreement with M.M.Bassuoni 12]. Figure 8. Shows as the inlet air dry bulb temperature increases the change in outlet wet bulb temperature increases rapidly. Because as the temperature of air increases the air become more humid due to partial vapour pressure of liquid desiccant increases, hence wet bulb temperature increases. Figure 9 shows when air inlet temperature increases the change in enthalpy of air also increases this is due to the increasement in temperature of air and liquid desiccant. Figure10. Shows the effect of air inlet temperature on moisture removal rate. As inlet air temperature increases the moisture removal rate increases but on further increasement in temperature the moisture removal rate decreases. The partial vapor pressure is the driving force of the mass transfer occurs between process air and desiccant solution. As the inlet air humidity ratio increases with increase in temperature, the partial vapor pressure of air also increases which in turn enhances the difference between the partial vapor pressure in the inlet air-stream and that on the desiccant solution surface resulting in an increase in the moisture absorbing capacity of desiccant solution. This increase leads to high moisture removing capacity [12].This is in agreement with Y.H.Zurigat el.al.,Nelson Fumo, D.Y.Goswami. Figure 11. Shows with increasing the inlet air temperature the outlet air temperature also increases slightly, this is due to as the inlet air temperature is increased, the temperature of the liquid desiccant solution inside the dehumidifier is increased which in turn increases the partial vapor pressure on the desiccant surface. When the desiccant surface vapor pressure increased the moisture removal rate decreases and air become more humid, and due to this latent heat load of air increases enhancing outlet air temperature. This is in good agreement with M.M.Bassuoni [12].

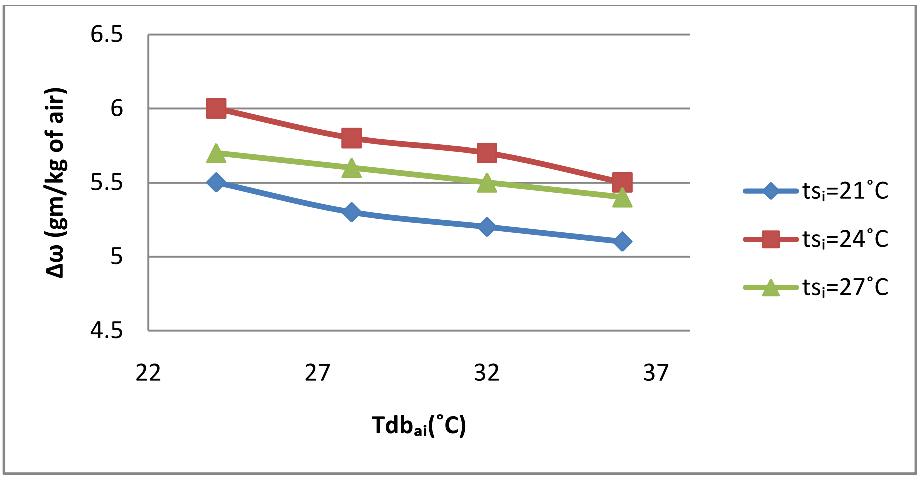

Figure 7 Effect of inlet air dry bulb temperatures on specific humidity at different temperature

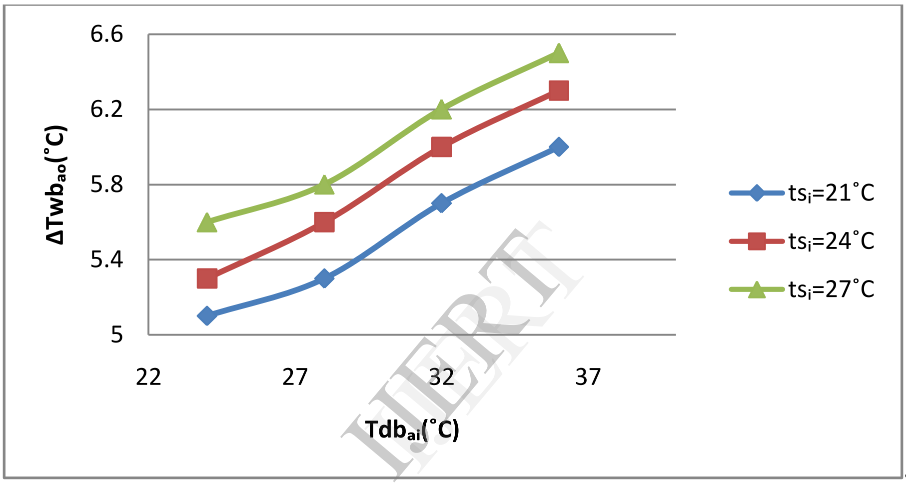

Figure 8 Effect of inlet air dry bulb temperatures on change in outlet wet bulb temperature

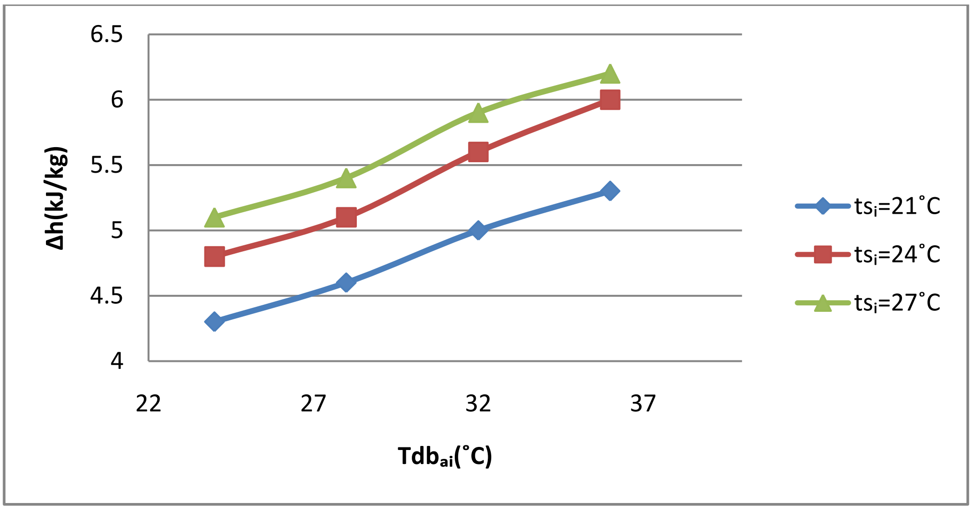

Figure 9 Effect of inlet air dry bulb temperatures on specific enthalpy

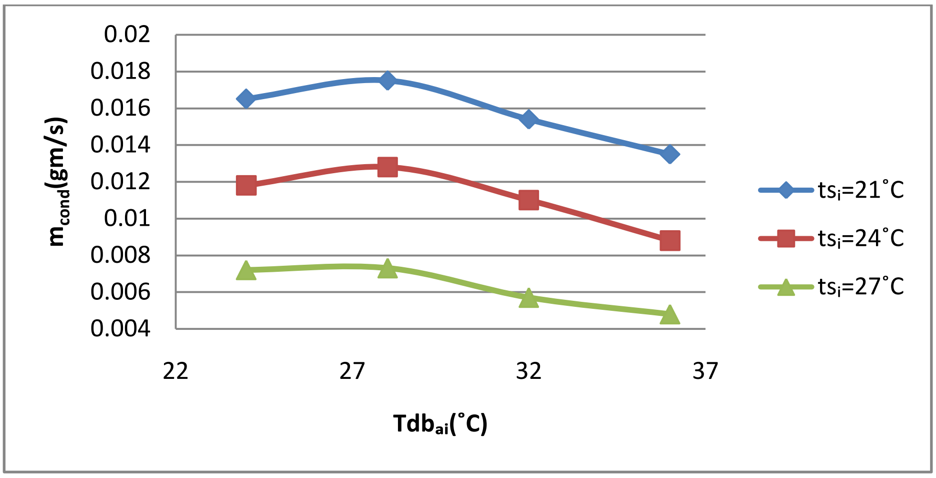

Figure 10 Effect of inlet air dry bulb temperatures on moisture removal rate

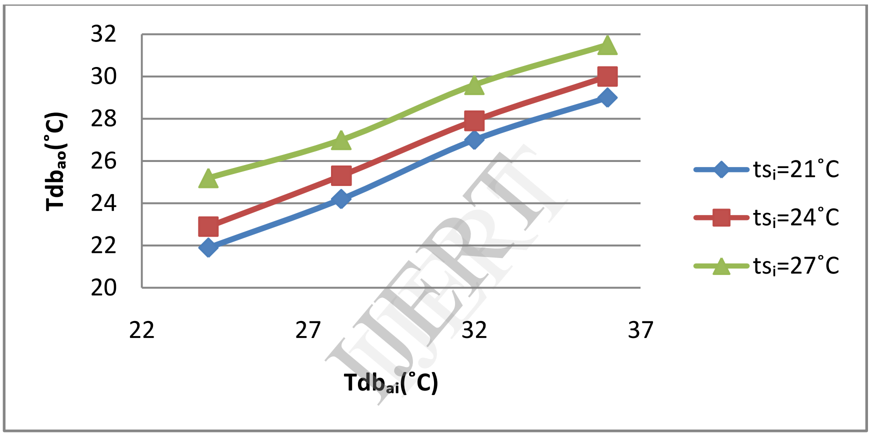

Figure 11 Effect of inlet air dry bulb temperatures on. outlet air dry bulb temperatures

5. CONCLUSION

In this paper, the effects of various inlet parameters i.e. air mass flow rate and inlet air dry bulb temperaure is reported upon the performance i.e. change in specific humidity, outlet air wet bulb temperature, specific enthalpy, moisture removal rate and outlet air dry bulb temperature of PVC packed dehumidifier. The objective was to dehumidify the air using tri ethylene glycol solution using PVC structured packing. The effects of inlet parameters were also studied on some outlet parameters as shown in figures above. It is concluded that specific enthalpy increases with increasing air mass flow rate while specific humidity, wet bulb temperature, dry bulb temperature and moisture removal rate decreases with increasing air mass flow rate. The moisture removal rate decreases because due to high velocity of air the time of contact between air and desiccant reduced.

It is also concluded that with increasing inlet air dry bulb temperature the wet bulb temperature, specific enthalpy and air outlet dry bulb temperature increases while specific humidity and moisture removal rate decreases. Specific enthalpy increases with increasing air inlet dry bulb temperature since heat energy is adding to the air also air outlet dry bulb temperature and wet bulb temperature also increasing due to this reason.

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6. Nomenclature

Tdb: Dry bulb temperature (°C)
Twb: Wet bulb temperature (°C)
m_a : mass flow rate of air (kg/s)
m_{cond}: evaporation rate (kg/s)
ω: humidity ratio (kg water/kg of air)
Δω : change in humidity ratio (kg water/kg of air)

Δh: Specific enthalpy of air (kJ/kg)

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