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Moisture Removal Rate in A Solar Powered Liquid Desiccant Air Conditioning System

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Abstract: Air conditioning is an energy intensive process, especially in hot and humid climates. Therefore, more research and development of solar alternatives to conventional space conditioning technique are desirable both in terms of overall cost saving and minimizing the environmental impact. The main disadvantage of vapor-compression air-conditioning systems is that they are thermodynamically inefficient. The handling of the latent load requires cooling of the air below its dew point, and thus additional energy is needed to reheat the air to the delivery temperature. Liquid desiccant air-conditioning systems remove the latent load directly from the air by absorbing the moisture using liquid desiccant solution. The liquid desiccant is then regenerated again using low grade heating source like solar energy. In addition to dehumidification, an added benefit of some desiccants is their ability to absorb inorganic and organic contaminants in air. Moreover, the absorption process has the potential to remove biological pollutants such as bacteria, fungi, and viruses, improving indoor air quality. This paper experimentally 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. 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.

Keywords: *Liquid desiccant; Dehumidifier; Moisture removal rate*

1. INTRODUCTION

A liquid desiccant system basically consist of a dehumidifier where moisture is removed from the air and a regenerator where moisture is removed from the liquid desiccant by using heating source like solar heating. They are used as an alternative to the conventional vapour compression systems. These systems are that the electrical energy consumption can be reduced [1], [2]. Thus there is potential for cost savings by using desiccant cooling, especially in applications where the latent cooling load comprises a large portion of the total cooling load. For example, Burns *et al* [3] found that utilizing desiccant cooling in a supermarket reduced the cost of air conditioning by 60% compared to conventional vapor compression system. Therefore, research leading to reliable, energy efficiency, and cost competitive desiccant system is warranted.

Desiccant technology has become a valuable tool in the industry's arsenal of space conditioning options. The use of desiccant cooling and dehumidification systems for building comfort conditioning has increased steadily during the past few years. In addition to dehumidification, an added benefit of some desiccants is the ability to absorb inorganic and organic contaminants in the air. Moreover, the absorption process has the potential to remove biological pollutants such as bacteria, fungi, and viruses improving indoor air quality [4], [5].

One of the most efficient types of dehumidifiers is the inner cooled dehumidifier using cooling coils to remove the heat generated from dehumidification. Yoon *et al.* [6] used a dehumidifier with one channel flowing air and desiccant solution and another channel flowing cooling water from the cooling tower. Khan and Sulsona [7] chose an apparatus similar to the one used by Yoon, except that the cooling water is replaced by refrigerant in their hybrid system to realize the dehumidification of the process air giving the profiles of humidity and temperature of the process air, the concentration and temperature of the desiccant solution, as well as the quality of refrigerant in the cooling coil. An air dehumidifier where the air is brought in contact with a desiccant (TEG) film falling over a finned tube heat exchanger was analyzed by Peng and Howell [8]. Chebbah [9] presented results from performance modeling of a finned tube coil desiccant air contactor operating at nearly isothermal conditions. He found that both temperature and humidity of the air leaving the dehumidifier increased with the increasing inlet desiccant temperature. He also found that increasing the inlet desiccant concentration resulted in a lower humidity of the air leaving the dehumidifier. Jain *et al.* [10] experimentally tested the performance of the internally cooled dehumidifier, in which the flow direction of air to desiccant was parallel. LiBr aqueous solution is taken as liquid desiccant and cooling water from cooling tower is used as cooling fluid to cool the desiccant in a counter-flow direction. Zhao [11] tested a dehumidifier in which the flow direction of air to desiccant is counter- flow and the flow direction of cooling fluid to desiccant is cross- flow. Lowenstein *et al.* [12], [13] tested the performance of a cross-flow dehumidifier, in which the cooling water was in parallel-flow to the desiccant.

This paper aims at investigating experimentally, the performance of an internally cooled dehumidifier using Triethylene Glycol (TEG) as a desiccant and a solar energy as a heating source in the regeneration process. The effects of the dehumidifier inlet parameters such as air flow rate, air humidity ratio, desiccant flow rate, and desiccant concentration on the performance of the dehumidification process are to be studied. The performance of this process will be evaluated in terms of moisture removal rate.

2. INSTRUMENTATION

The inlet, outlet temperature and relative humidity of the dehumidifier were measured by KOBOLD AFK-E Humidity/Temperature meter (made by KOBOLD Instruments Inc – Germany). This meter operates in the range of (0-100%) for relative humidity and (-40^{o}C to +180^o C) for temperature. The inlet and outlet air flow rate of the dehumidifier were measured by a portable digital anemometer CFM Master 8901 Vane Digital Anemometer (obtained from Omega Engineering). It measures volume flow rate, air velocity, free area, and temperature. The inlet and outlet temperatures for cooling water and desiccant solution were measured by digital thermometers operating in the range of (0 to +100^{o}C). The flow rate for cooling water was measured by flow meters (made by AMI) operating in the range of (0 to +130) liter per minute. The flow rates for strong solution were measured by flow meters (made by Blue White Industries CADADA), operating in the range of (0 to +280) liter per minute. The flow rate control of the cooling water and strong desiccant during the experiments were done via valves fixed after each of the four pumps. The air flow rate control in the dehumidifier and cooling tower was done by an adjustable speed switch made by FILUX. The TEG concentration was determined by a calibrated hand refractometer (made by ATAGO China) which has an operating range of (1.445-1.52).

3. EXPERIMENTAL SETUP

Fig. 1 shows the schematic diagram of the system used in this research. The whole system was fabricated in the AlGhaya electromechanical workshop -Khartoum, and assembled on the roof of the Northern Building of the Faculty of Engineering, University of Khartoum, Sudan. The dehumidifier composed of inner cooled finned tubes heat exchanger as a packing material, intake –inlet air ducts, cooling tower, strong desiccant storage tank, and circulating pumps. The regenerator is composed of inner cooled finned tubes heat exchanger as a packing material, intake air ducts, solar boiler, weak desiccant storage tank, and circulating pumps.

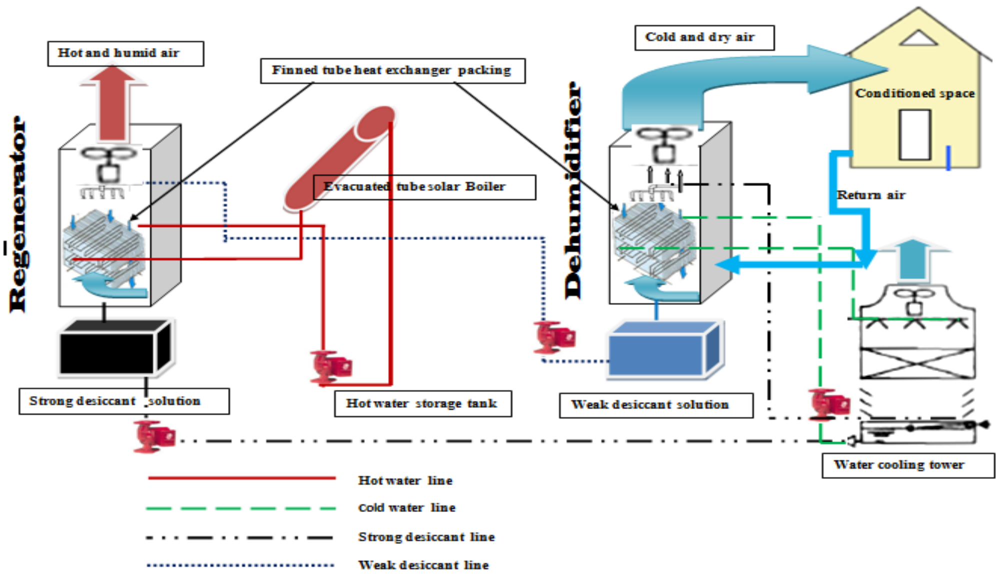

Fig. 1. Schematic diagram of the experimental setup

The system used a 95% Triethylene Glycol (TEG) solution as desiccant. The TEG solution was distributed uniformly over the heat exchanger. The solution was passed by the cold water pump through the fins of a plate heat exchanger which held cold water from the cooling tower. The solution was cooled while passing through the fins and was sprinkled down in a laminar flow configuration. The processed fresh air, which was drawn by the axial fan was introduced from the bottom of the vertical section of the dehumidifier in a counter manner to the desiccant and flew over the cold surface of the heat exchanger fins. The contact between the humid air under a high vapor pressure and the cold desiccant solution under very low vapor pressure drove water vapor from the air to the desiccant solution. In addition, cooling of the air occurred due to the contact with the cold solution. The final result of the activity in this section was that the air was dehumidified and cooled down before being supplied to the conditioned space. The diluted desiccant was circulated to a regenerator which used hot water from a solar boiler. The hot concentrated desiccant was cooled to a certain temperature by passing it through the cooling water tank before distributing it again over the finned tube heat exchanger in the regenerator. The desiccant temperature and concentration were measured before running each experiment.

The performance of the dehumidifier is evaluated by moisture removal rate. The moisture removal rate in this paper is calculated using a theoretical numerical model proposed by Ahmed M. A [14]. The moisture removal rate from the air is calculated using the following equation:

$$\dot{m}_{cond} = (Y_{in} - Y_{out}).A \qquad (1)$$

where Y_{in} and Y_{out} are the absolute humilities of the air at the inlet and outlet conditions, respectively, and A is the column cross-sectional area. The moisture removal rate is also calculated using the correlation developed by Abdul- Wahab *et al.* [15].

4. RESULTS AND DISCUSSION

The moisture removal rates found from the experimental data were presented graphically with the design variables. The parameters that were varied during the experiments included the inlet air flow rate, inlet air humidity ratio, desiccant solution flow rate, and desiccant solution concentration.

4.1 Effect of air flow rate

The variations of moisture removal rate as a function of the air flow rate are shown in Fig. 2. A higher air flow rate will remove the dehumidified air more rapidly away from the interface, thereby reducing the humidity gradient between the solution and the air stream at the interface. It will enhance the mass transfer coefficient.

4.2 Effect of Inlet Air inlet humidity ratio

The influence of air inlet humidity ratio on the dehumidifier performance is shown in Fig. 3 Moisture removal rate increases with increasing air inlet humidity ratio. In fact, increasing the air inlet humidity ratio caused an increase in the

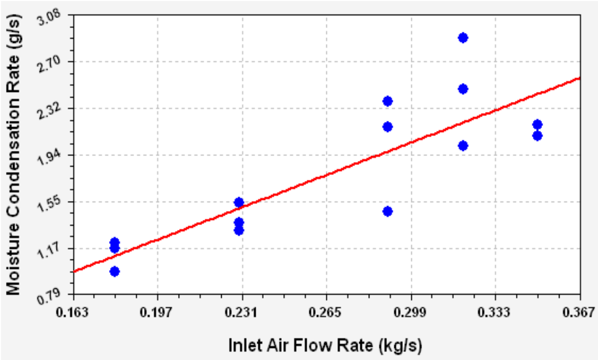

Fig. 2. The effect of air flow rate on the moisture condensation rate

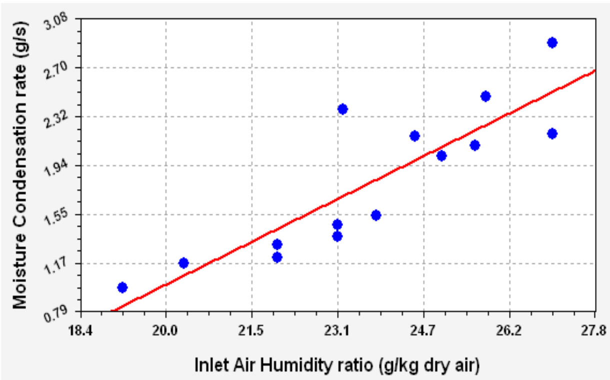

Fig. 3. The effect of inlet air humidity ratio on the moisture condensation rate

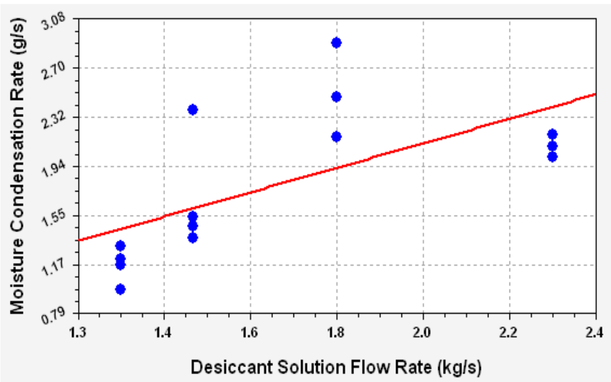

Fig. 4. The effect of desiccant solution flow rate on the moisture condensation rate

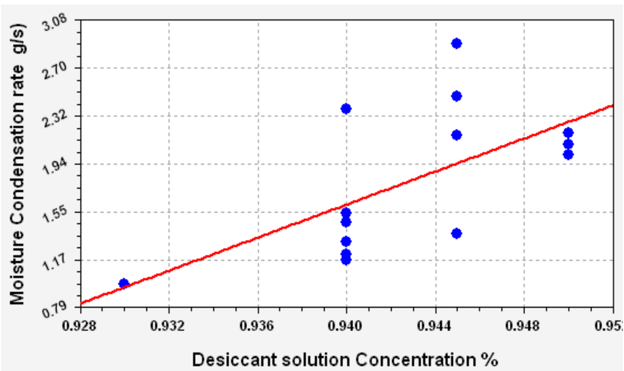

Fig. 5. The effect of desiccant concentration on the moisture condensation rate

driving force and hence increased the mass transfer potential within the dehumidifier resulting in an increase in the moisture removal rate.

4.3 Effect of desiccant solution flow rate

The influence of desiccant solution flow rate on the dehumidifier performance is shown in Fig. 4. Moisture removal rate is enhanced when the flow rate of solution is increased. This is due to the good wetting of the packing when high liquid flow rates were employed based on liquid to air flow rate ratios. The driving potential for heat transfer is greater when the temperature difference between solution and moist air remains high as a result of higher solution flow rate. Increasing the desiccant flow rate increased the mass transfer coefficient between the desiccant and the air in the dehumidifier.

4.5 Effect of Desiccant inlet concentration

Fig. 5 shows the effect of desiccant inlet concentration on dehumidifier performance. Moisture removal rate was increased significantly with increasing desiccant inlet concentration. The reason is that when increasing the desiccant inlet concentration decreases, the desiccant surface vapor pressure which increased the average water vapor pressure difference between the desiccant and air in the dehumidifier, leading to lower air outlet humidity ratio and, hence, higher moisture removal rate.

5. CONCLUSIONS

The performance of an internally cooled TEG liquid desiccant dehumidifier was investigated experimentally in this study. Results showed that as the inlet air flow increases the moisture condensation rate increases, whereas, the dehumidifier effectiveness decreased. The same results were obtained when the inlet air humidity ratio was increased, the moisture condensation rate increased, whereas, the dehumidifier effectiveness decreased. This suggests that, increasing the inlet desiccant flow rate and concentration increased both the condensation rate and the dehumidifier effectiveness. These results are in conformity with a number of studies in the literature [16], [17] and [18].

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Nomenclature

A	cross sectional area of dehumidifier (m^2)
F	Flow rate (kg/s)
M	water condensation rate (g/s)
P	Pressure (mmHg or kPa)
T	Temperature °C
X	Desiccant Concentration (kg TEG/kg solution)
Y	Air humidity ratio (kg water/kg dry air)

Abbreviations

TEG	Triethylene Glycol

Subscripts

a	Air
atm	Atmosphere
des	Desiccant
equ	Equilibrium
in	Inlet
out	Out let
sol	Solution
vap	Vapor