EXPERIMENTAL STUDY OF COUNTER FLOW AIR DEHUMIDIFIER FOR DIFFERENT PACKING HEIGHTS

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Abstract

An experimental study has been conducted to study the performance of a liquid desiccant counter flow air dehumidifier equipped with PVC zig-zag packing for three different packing heights using calcium chloride as desiccant. Three different packing heights used are 150 mm, 300 mm and 450 mm. The performance of the dehumidifier was expressed in terms of moisture removal rate, humidity ratio, air outlet temperature, solution outlet temperature under different air and desiccant parameters i.e air flow rate, air inlet temperature, desiccant flow rate, desiccant solution inlet temperature, desiccant solution concentration.

Keywords: *Dehumidifier, Calcium chloride, Desiccant.*

1. Introduction

Dehumidification is the process of removing the water vapour from the air. The outside humid air consists of sensible heat load and latent heat load [1]. In conventional system the dehumidification is done by vapour compression system. The sensible heat of the air is removed by reducing the temperature of the air but the latent heat load is removed by cooling the air below dew point temperature. The disadvantage associated with vapour compression system is that it is an insufficient thermodynamic process and it requires the air to be cooled below its dew point, which lowers the temperature than needed to meet the sensible heat load. Thus, some source of additional energy is required to reheat the air to the desired delivery temperature. Also use of CFC's in refrigeration and air-conditioning applications results into ozone layer depletion and global warming which is a very serious problem.

Thus there is a need for adoption of some another method for dehumidification of air. Desiccant dehumidification is one of such methods. A desiccant is a substance having low surface vapour pressure. When the desiccant is cool and dry, its surface vapour pressure is low and it can attract moisture from the air which has a high vapour pressure when it is moist. As the desiccant absorbs moisture it becomes wet and hot its surface vapour pressure increases and it will give off water vapour to the surrounding air. Vapour moves from the air to the desiccant and back again depending on the vapour pressure difference. The benefit of liquid desiccant system is the ability to remove a number of pollutants from the air stream [2].

There are two types of desiccant dehumidification systems: solid desiccant and liquid desiccant dehumidification system. 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.

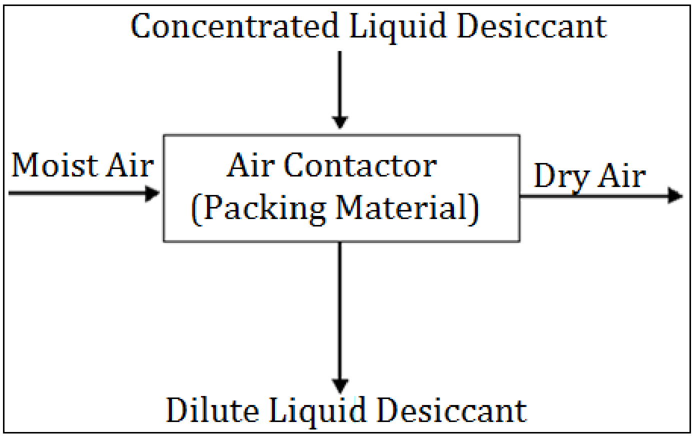

Fig. 1 Liquid Desiccant Dehumidification Technology

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. The usually used ones are flexi rings, berl saddles, intalox saddles, raschig rings [3]. Various liquid desiccants and their composites [4] can be used for dehumidification of air.

Liquid desiccant dehumidification systems are widely used in various industrial applications. Many research works have been carried out in this field where these desiccants are referred to as composite desiccants. Ani et al. [5] discussed about a hybrid system consisting of vapour compression unit, a liquid desiccant system, and a flat solar hot water collector. This combination allowed for a separate control of humidity and temperature without energy penalty. Various packing heights of the absorber component were tested to determine the optimal performance of the combined unit. A 1000 mm packing height with cross-sectional area of 600 × 600 mm, proved to be the best height that gives promising improvements in the coefficient of performance of the vapour compression unit. The size and performance of a dehumidification tower were studied by simulating varying operating conditions by Hesamoddin Salarian et al. [6] presented the performance of a packed tower absorber for a lithium chloride desiccant dehumidification system. They showed the effects of the main variables like air flow rate, liquid desiccant flow rate and inlet air temperature on the rate of dehumidification. D. Seenivasan et al. [7] investigated the performance of an adiabatic dehumidifier by using calcium chloride as desiccant. They employed MATLAB genetic algorithm (GA) to enhance the performance of the dehumidifier. Zegenhagen et al. [8] presented experimental results of an internally cooled and heated, open liquid desiccant system working with an ionic liquid. Zurigatet al. [9] investigated the performance of an air dehumidifier using triethylene glycol. They evaluated the performance of the dehumidifier and expressed in terms of the moisture removal rate and the dehumidifier effectiveness. Jradi et al. [10] 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. Ahmed et al. [11] experimentally studied the moisture removal rate in a solar powered liquid desiccant air conditioning system using triethylene glycol as a desiccant and using an evacuated solar boiler as regenerator. Bouzenada et al. [12] evaluated the performance of a solar driven, low-flow study was carried out to evaluate the performance of a solar thermally driven, low-flow, falling-film, internally-cooled parallel plate liquid desiccant air-conditioner using lithium chloride solution as desiccant. Koronaki et al. [13] studied the performance of a counter flow liquid desiccant dehumidifier. They developed the heat and mass transfer theoretical model of an adiabatic packed column based on the Runge-Kutta fixed step method, to predict the performance of the device under various operating conditions. Hyun Lee et al. [14] studied a desiccant cooling technology with plate type dehumidifier using a liquid desiccant of lithium chloride solution. The plate was treated with hydrophilic coating and the wettability 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. Pradeep Bansal et al. [15] compared the performance of an adiabatic and an internally cooled structured packed-bed dehumidifier using calcium chloride as desiccant. The moisture removal from the air, the effectiveness of the dehumidifier and the mass transfer coefficients between air and solution have been compared for the dehumidifier operation with and without internal cooling. They found that the optimum liquid to gas flow rate ratio for maximum effectiveness is about 1.0. Bassuoni [16] investigated the performance of the structured packing cross flow desiccant dehumidification system. It is used to meet a latent heat load by air dehumidification. Calcium chloride solution is used as the working desiccant material in this system. The performance of the system is evaluated using the mass transfer coefficient, moisture removal rate, effectiveness and the coefficient of performance. Y. Zhao et al. [17] 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

In the present study, the effect of packing height on the performance of air dehumidifier using calcium chloride as liquid desiccant is studied the There are several parameters that influence the performance of a desiccant dehumidifier. These parameters include inlet air flow rate, desiccant solution flow rate, air inlet temperature, solution inlet temperature. The performance of the dehumidifier is measured in terms of moisture removal rate.

2. Experimental Set up

The layout of experimental setup is shown in Fig.2. Various components are desiccant solution tank, a pump, rotameter, dehumidifier, liquid distributer tray, gate valve, packing, air inlet duct, air blower, air outlet duct, DBT and WBT thermometer, U-tube manometer, orifice plate, desiccant collection tank at outlet, thermocouple and electric heater to increase the temperature of the solution. The solution of calcium chloride is contained in desiccant solution tank. The rotameter is used to measure the solution flow rate. The solution tank is connected to the liquid distributer through a pipe and rubber hose. A PVC packing of honey comb structure is used in the dehumidifier. The size of the packing is 600mm×300mm×150mm. The air blower 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. The air enters the dehumidifier at the bottom and comes out at the top through an air outlet duct. An orifice plate of diameter 50 mm is placed in the outlet air duct to measure the pressure head across the dehumidifier. The pressure head is measured in terms of water column with the help of a U-tube manometer.

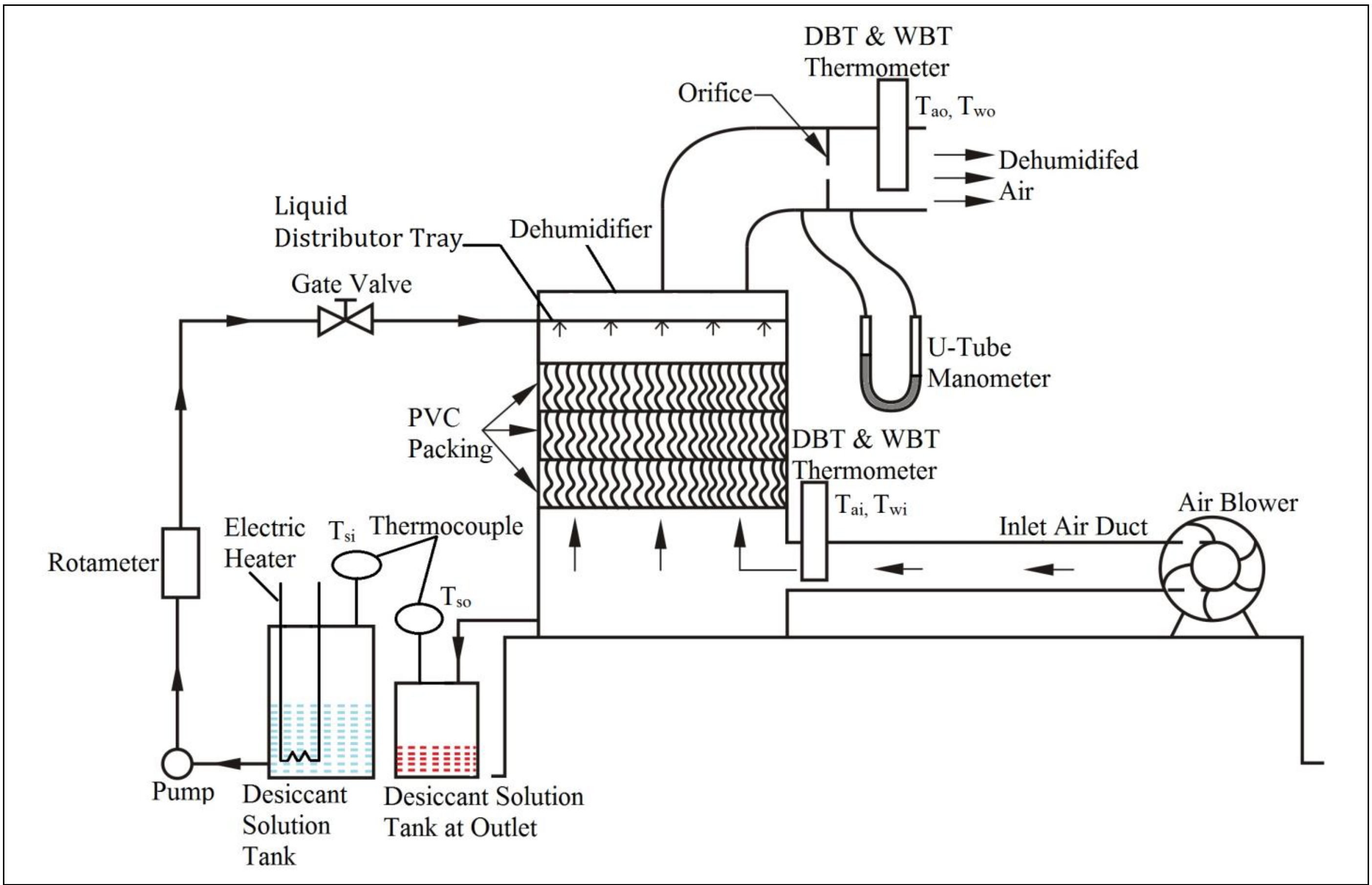

Fig. 2 Experimental Set up

3. Operation Procedure

A solution of calcium chloride is prepared in the desiccant solution tank. The pump and the blower are started and the operation starts. The system is allowed to run for some time till the steady state condition is achieved. The desiccant enters at the top of the dehumidifier and the liquid distributer tray distributes the solution uniformly over the packing. The air blower forces the air to enter at the bottom of the dehumidifier through inlet air duct. The air flows upwards and desiccant flows in the downward direction. As the desiccant comes in direct contact with the air, it absorbs the moisture from the air due to difference in vapour pressure. The air gets dehumidified and it leaves at the top of the dehumidifier through outlet air duct. As the desiccant solution absorbs moisture from the air it becomes diluted. This diluted solution is then collected in the desiccant solution tank at outlet. The flow rate of the solution is measured by the rotameter and it is varied by operating the gate valve. The flow rate of air can be varied by varying the speed of the blower. The results are noted for different air and solution flow rates. The solution temperature at inlet and outlet are noted by the thermocouples. The operation is repeated for different packing heights.

4. Results and Discussion

A series of experiments were performed on the set up at various inlet parameters. The output parameters were measured for three different packing heights. 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, specific humidity or humidity ratio, solution outlet temperature, moisture removal rate, air outlet temperature.

Equations used are:

Volumetric flow rate of air, $Q = C_v . C_d . \frac{\pi}{4} d^2 \sqrt{2gH}$

Mass flow rate of air, $M_a = \rho_a . Q$

Moisture removal rate, $M_w = M_a . \Delta W$

4.1 Effect of Desiccant Solution Flow rate

The experiment was conducted to study the effect of desiccant solution flow rate on the moisture removal rate and change in humidity ratio for different packing heights. The experiment was carried for an air flow rate of 1.023 g/s and solution concentration of 40%. The solution flow rate is varied from 19.5 g/s to 77.8 g/s. From the study, it was found that the moisture removal rate and change in humidity ratio increases with increase in desiccant flow rate (shown in Fig. 3 and 4).

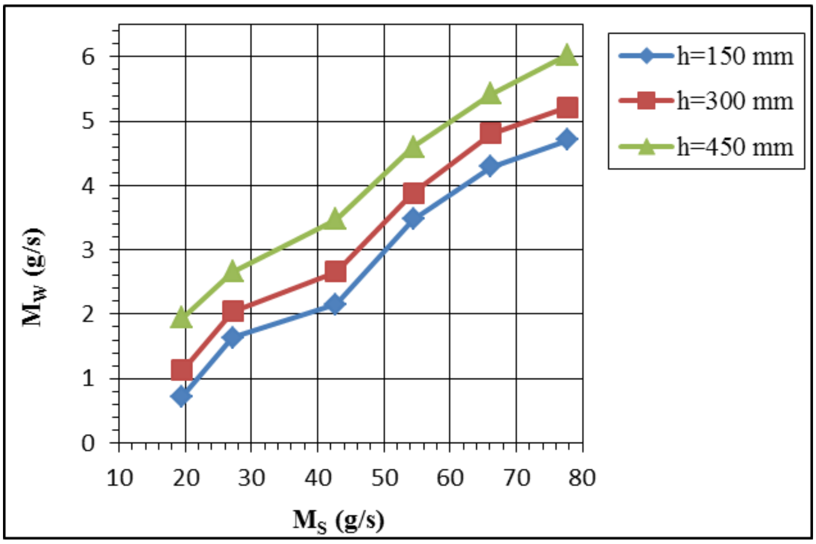

Fig. 3 Effect of Solution flow rate on moisture removal rate

This is because of the reason that a better contact between the desiccant and air is attained with the increase in desiccant solution flow rate. This ensures a better mass transfer. Also it has been found that moisture removal rate and change in humidity ratio increases with increase in packing height. From the figure we see that for a packing height of 150 mm the moisture removal rate increases from 0.716 g/s to 0.4706 g/s as the solution flow rate is increased from 19.5 g/s to 77.8 g/s. But for the packing height of 300 mm the moisture removal rate increases from 1.125 g/s to 5.217 g/s for the same change in solution flow rate. For the solution flow rate of 42.8 g/s, the moisture removal rate increases by 24% when the packing height is increased from 150 mm to 300 mm, but as the packing height is increased from 300 mm to 450 mm the moisture removal rate increases by 31%.

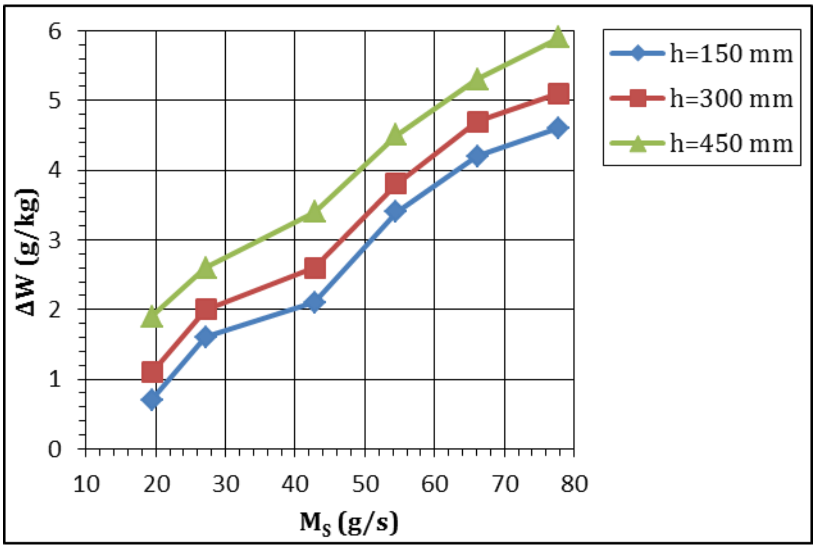

Fig. 4 Effect of Solution flow rate on change in humidity ratio

From figure 5 we see that percentage of moisture removed also increases with rise in solution flow rate and packing height.

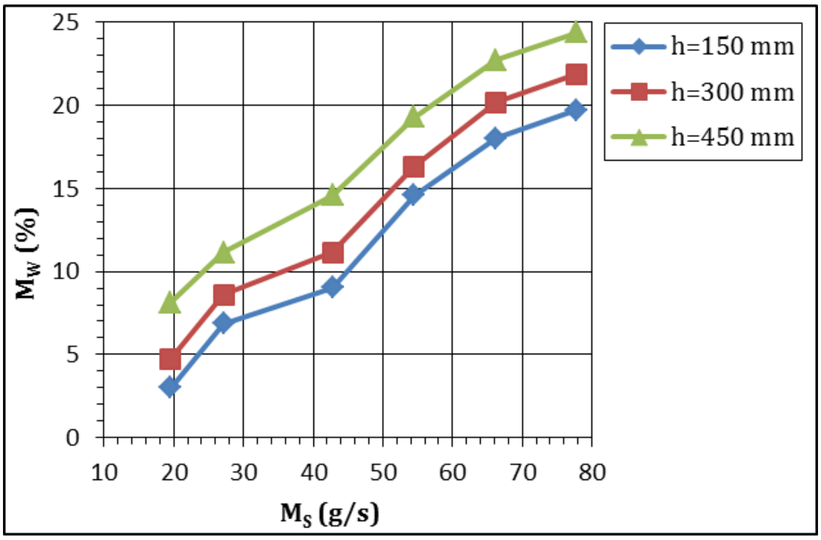

Fig. 5 Effect of Solution flow rate on percentage of Moisture removed

Effect of solution flow rate on air outlet temperature for different packing heights and air flow rate of 1.023 g/s is shown in Fig. 6. The air outlet temperature increases with increase in solution flow rate. This is due to the reason that as the solution flow rate increases the latent heat absorption capacity of the desiccant also increases which increases the solution temperature. Thus the temperature of the air that interacts with the solution also increases. Also the air outlet temperature as the packing height is increased. This is because of the increase in wetting surface as the packing height increases.

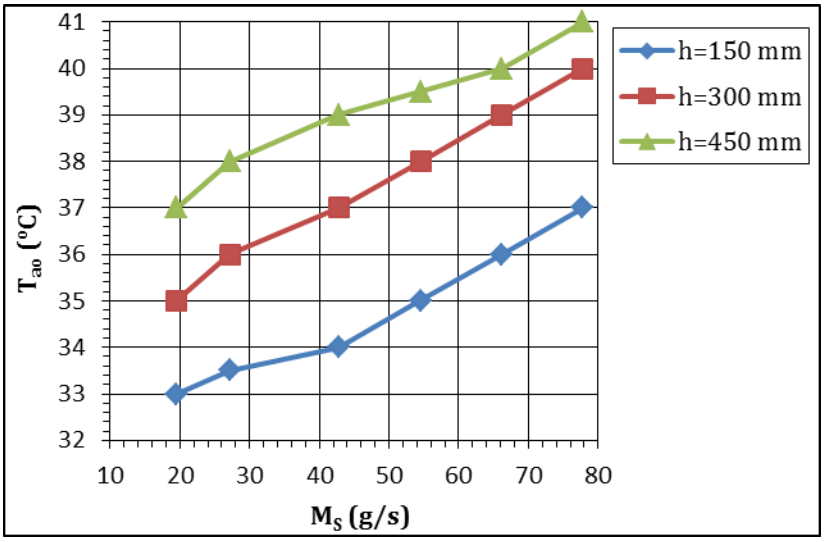

Fig. 6 Effect of Solution flow rate on Air outlet temperature

Fig. 7 shows the variation of solution concentration at outlet with desiccant flow rate for different packing heights. The results are plotted for an air flow rate of 1.023 g/s, solution concentration of 40% and the desiccant flow rate of 19.5 g/s to 42.8 g/s. It is observed that the concetration of solution at outelet decraeses with increase in desiccant solution flow rate and increase in packing height.

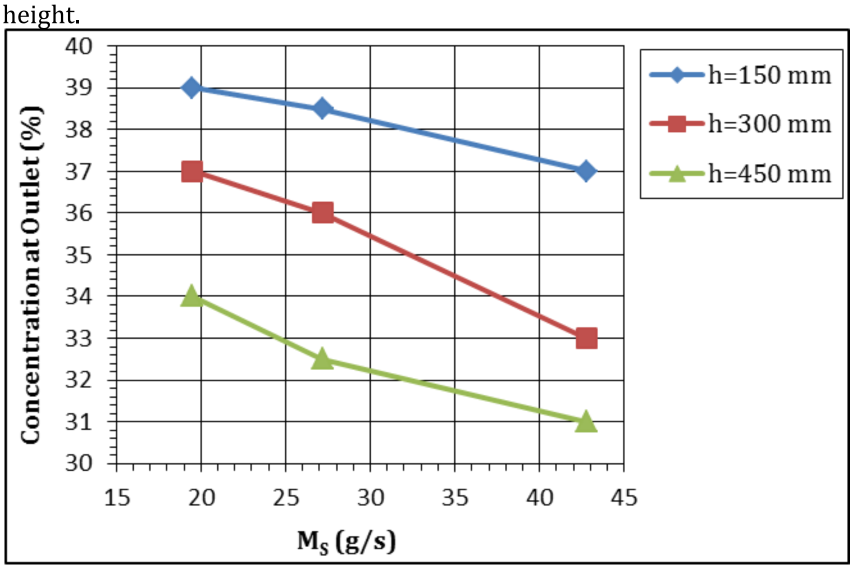

Fig. 7 Effect of Solution flow rate on solution concentration at outllet

This is because of the reason that the with incraese in solution flow rate and packing height, the moisture removal rate increases, desiccant absorbs more water vapour, thus the solution becomes diluted and concentration decreases.

4.2 Effect of Air Flow Rate

The effect of air flow rate on moisture removal rate for different packing heights is shown in Fig. 8. The results were drawn for a solution flow rate of 42.8 g/s and constant solution temperature. The results show that the moisture removal rate increases with an increase in air flow rate. The higher flow rate increases the mass transfer coefficient.

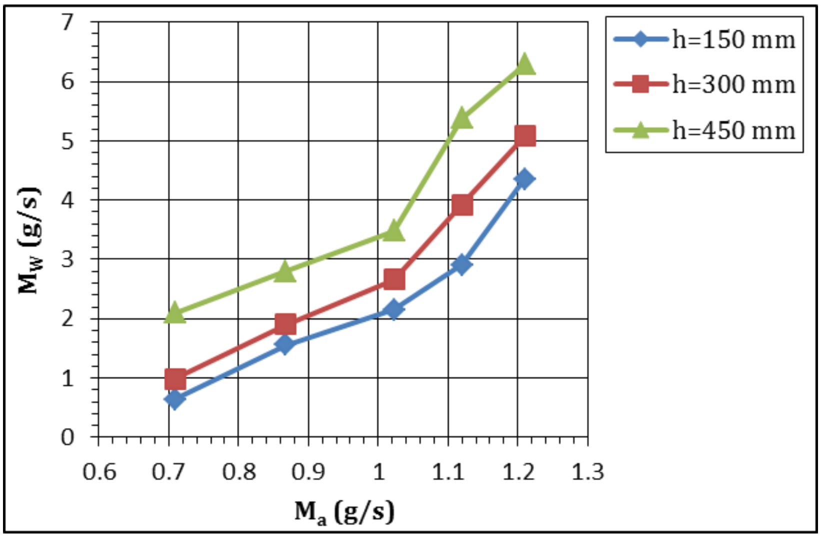

Fig. 8 Effect of air flow rate on moisture removal rate

This is because of the reason that on increasing air flow rate, more amount of moisture comes in contact with desiccant. This results in more amount of condensation of moisture in the solution, which results in to an increase in moisture removal rate. The moisture removal rate also increases with increase in packing height. For a packing height of 150 mm the moisture removal rate increases from 0.6377 g/s to 4.356 g/s and for packing height of 300 mm the moisture removal rate increases from 2.1 g/s to 6.292 g/s as the air flow rate changes form 0.7085 g/s to 1.21 g/s. For the solution flow rate of 1.12 g/s the moisture removal rate increases approximately by 34% as the packing height changes from 150 mm to 300 mm, but this increase is higher when the packing height is 450 mm. i.e when the packing height changes from 300 mm to 450 mm the moisture removal rate increases approximately by 38%.

5. Conclusions

From the experimental results it has been concluded that the the overall performance of liquid desiccant air dehumidifier depends largely on the packing height of dehumidifier. With incraese in packing height, the surface area exposed to the air increases which further increases the latent heat absorption capacity of the desiccant. Thus the moisture removal rate increases. It has also been observed that for a given packing height the moisture removal rate also incraeses with incraese in solution flow rate and air flow rate.

6. Nomenclature

M_s: Solution flow rate, M_w: Moisture removal rate, ΔW: change in humidity ratio, M_a: air flow rate, T_{ai},T_{ao}: Dry bulb temperature of air at inlet and outlet, T_{wi}, T_{wo}: Wet bulb temperature of air at inlet and outlet, T_{si}, T_{so}: Solution temperature at inlet and outlet, h: Packing height. H: Pressure head across orifice, d: Diameter of orifice, C_v: Coefficient of Velocity for orifice, C_d: Coefficient of discharge for orifice.

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