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Experimental Analysis of a Flat Plat Liquid Desiccant Dehumidification System

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Abstract: -- **The continuously increasing energy demand in building space cooling and depleting conventional energy resources have provoked the need for generating renewable and sustainable energy technologies. Pre-eminent among the air conditioning technologies are absorption cooling that works on the low grade energy which is mostly delivered by solar energy. Liquid desiccant dehumidification technologies are the most optimistic option because of their lower regeneration temperature, higher coefficient of performance and ability to be used during night hours. But problems like desiccant carryover, process air pressure drop and incomplete wetted walls needs to be further investigations. The desiccant system investigated in the present study includes a flat plate energy exchanger for mass and heat transfer between process air and desiccant solution. It imparts high contact surface area and minimises the air pressure drop and carryover of desiccant droplets as there is a film contact between air and desiccant instead of direct intermixing which is associated with spray tower and packed bed dehumidifiers. It also provides a complete film over an entire surface of the flat plate which is the limitation of falling film absorbers. The diluted desiccant is heated into a heater tank consists of a heating coil and reactivated in the regenerator. The system comprises of an absorber, a regenerator, a solution heat exchanger to precool and preheat the solution and a cooling tower and a set of solution pumps. Calcium chloride was used as a desiccant material with 40 % by wt. concentration. Experiments were conducted by varying concentration of the desiccant solution and process air flow rates. Performance of the dehumidification system is represented in terms of dehumidification and regeneration effectiveness and moisture absorption rates.**

I. INTRODUCTION

In the last few decades, the demand or need of air conditioning has been escalate for residential as well as commercial buildings due the rapid progress on technology and society. Now a day, traditional vapour compression systems are used to meet the air conditioning requirements of the buildings. But these systems consume large quantity of high grade electrical energy which has several adverse effects on economy and environment. So, there is a great compulsion for the scientists and researchers to find out an alternative solution to tackle the problems arises by the vapour compression systems. Research on renewable and sustainable energies only can serve clean, sustainable, eco-friendly and cost effective alternate to society such as solar energy or desiccant air conditioning technology. Researchers believe that if only a very small amount of 0.01 % [1] of the total solar radiations incidents on the surface of earth is tapped, it would fulfil all the energy needs for that particular time. Air conditioning load can be divided into two parts. One is sensible load due to temperature rise or fall and another is latent load due to humidity content in the process air. Vapour compression system consume large amount of energy to handle the latent load. So, to handle latent load is a challenging task for energy efficient systems. Latent load can be control by utilising desiccant materials. Desiccants are the materials which have strong attraction towards the moisture content of the ambient air. Surface vapour pressure difference plays an important role to absorb the water vapour from the process air. Liquid desiccant are more beneficial than solid desiccant material due to several advantages: 1) Pressure drop for air to be processed is lower 2) Lower regeneration temperature is required 3) Multiple system can be join together to increase performance of the system 4) Concentrated liquid solution can be stored for non-sunshine hours etc.

Possibilities of using liquid desiccants in air conditioning systems are first investigated by Bichowsky et al. [2]. Lot of research has been done form the last two decades in the area of liquid desiccant air conditioning technology and improvement could be seen in practicing the commercialization of these systems. Various reviews and investigations have been reported in the literature during past few years, some of which are described in this section.

Fumo and Goswami [3] experimentally investigated and modelled a packed bed absorber for mass and heat transfer with the use of polypropylene packing. LiCl was used as a desiccant solution and results shows that LiCl desiccant solution wet the polypropylene packing in a non-uniform manner due to high surface tension of the solution. For the estimation of total wetted surface area of packing, an

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empirical correlation was developed and theoretical results were holds good agreement with the experimental results. Enteria et al. [4] performed a parametric analysis of a modelled twin rotor desiccant air conditioning system and Khouki et al. [5] made an experimental investigation for twin rotor desiccant air conditioning system. A comprehensive study for different types of thermally activated desiccant air conditioning systems was performed by Enteria et al [6] and found that the performance of the system depends upon the design variables and climate conditions. Liu et al. [7] and Liu and Jiang [8] established an analytical correlation for the coupled mass and heat transfer for a packed bed desiccant cooling system by assuming very small change in the concentration of desiccant solution and Lewis number used as one. They found analytical results holds good agreement with experimental results and exact numerical solutions.

Liu et al. [9] experimentally investigated the performance of a cross-flow dehumidifier by using structured packing and LiCl as a desiccant solution. They represented the results in the form of moisture absorption rate and performance of the absorber for different values of desiccant solution and process air flow rates, temperatures and concentration of desiccant solution and temperature and humidity ratio of process air. A compilation of the experimental performance of various liquid desiccant cooling systems has been made by Jain and Bansal [10] and represented an overview and present scenario of the cooling technology based on liquid desiccant system. Hwang and Rademacher [11] suggested that the absorption cycle is better than adsorption cycle and thermal COP of liquid desiccant system is higher than that of solid desiccant system. Wang et al. [12] made a comparison for performance and economic viability for different types of liquid desiccant systems and found that carryover of desiccant droplets with the process air is an unavoidable problem related to liquid desiccant system and should be removed with some appropriate methods. For wetting the surface of the dehumidifier to increase the mass and heat transfer between the desiccant solution and the process air, surface tension of the solution plays a very important role in it. Generally used desiccant materials for desiccant solutions are halide salts like LiCl, CaCl2, LiBr, mixture of salts and glycols such as TEG etc. The selection of such desiccant materials directly affects the design and performance of the dehumidifier system.

Lof [13] investigated experimentally and suggested the earliest liquid desiccant cooling system by using TEG as the material for desiccant solution and found that the desiccant system performed more effectively for hot and humid climates. A packed bed liquid desiccant cooling system was developed by Patnaik et al. [14] with the use of LiBr as a desiccant solution and found that by using such systems, cooling capacities of 3.5 to 14 kW may be achieved. Hassan et al. [15] made a comparison for the performance of calcium chloride and calcium nitrate by taking different composition of two. The results showed that low stability of calcium chloride can be enhanced by adding calcium nitrate in it and the composition of 20 % and 50 % by weight of calcium nitrate and calcium chloride respectively deliver maximum possible vapour pressure depression.

Kumar [16] made an investigation for the performance of liquid desiccant system and developed new cycles for the enhancement of the system performance and studied the significance of various design parameters on the performance of absorber and regenerator. To avert the problem of desiccant droplet carryover with process air, mist filters are used but it increased the pressure drop of incoming air which in turn required more maintenance. Ertas et al. [17] determined the properties of LiCl and CaCl2 with three different composition (70-30, 50-50, 30-70 %) respectively and found that 50-50 % composition of Lithium chloride and calcium chloride gives the best results for the dehumidification system. Longo and Gasperella [18] made a comparison between conventional liquid desiccant solution of LiBr and LiCl with a novel liquid desiccant solution of KHCO2 and concluded that KHCO2 has poor dehumidification performance but have better performance in regeneration process than LiCl and LiBr. They also proposed KHCO2 as a better choice over conventional desiccant materials due to less corrosive and cost effective qualities.

Several research works have been done in the recent years to analyse the performance of different types of liquid desiccant air conditioning systems. Bero and chiari performed a study on hybrid cooling systems and use LiCl as a liquid desiccant solution. The results showed that under given conditions hybrid cooling system consumes 50 % less energy as compared to convention cooling systems. Saman and Alizadeh [19] proposed a new kind of absorber which is internally cooled with the help of evaporative cooler. In this system, secondary air stream is used with water spray to cool the liquid desiccant solution which is flowing in adjacent channel. Niu et al. [20] analysed the effect of different ambient air ratios on the performance of dehumidification system. A new two stage liquid desiccant cooling system was developed by Xiong et al. [21]. Thermal COP rises from 0.24 to 0.73 as compared to conventional cooling system by using CaCl2. Jain and Bansal [10] analysed the performance of packed bed dehumidification system using TEG, LiCl and CaCl2 as a desiccant materials. They concluded that the effectiveness of dehumidification system varies between 10 to 50 % and suggested that a solution heat exchanger in between dehumidifier and regenerator can improve the performance of

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Vol 3, Issue 1, January 2018

the system. Effect of design variables such as temperature and concentration of desiccant solution, temperature and humidity ratio of process air, flow rates of desiccant solution and process air on the effectiveness of dehumidification system was studied by Seenivasan et al. [22] by using CaCl2 as a desiccant material. They found that optimized values of these variables to achieve high effectiveness of the system are as follows: desiccant solution temperature, concentration and flow rate were 25 oC, 40 %, 2.25 kg/m2s respectively, process air flow rate and relative humidity were 1 kg/m2s, 85 % respectively. The major problems related to liquid desiccant cooling systems are carryover of solution droplets with process air, air side pressure drop. Falling film or wetted wall dehumidifiers are most compromising methods to overcome these two problems. The main advantages of the falling film design are low air pressure drop, high surface contact area, and easy design with low cost and negligible solution carryover problem. But the main problem related to falling film dehumidification systems is the incomplete film formation over the entire surface of the walls and the less contact time between desiccant solution layer and process air layer due to action of gravity. This can be removed by the flat plate flowing film design of the dehumidification system.

Nomenclature

		Subscripts	
ω	humidity ratio (g/kg)	a	air
$\Delta\omega$	change in humidity ratio (g/kg)	in	inlet port
m	mass flow rate (kg/s)	out	outlet port
T	temperature (ºC)	eq	equilibrium
p	partial pressure (kpa)	d	dehumidifier
h	specific enthalpy (kJ/kg)	r	regenerator
φ	mole fraction of solute particle	s	solution
x	concentration of desiccant solution	*Abbrevations*	
ε	effectiveness	$CaCl_2$	calcium chloride
Å	rate of moisture absorption	LiCl	lithium chloride
		LDAC	liquid desiccant air conditioning

II. EXPERIMENTAL PROCEDURE/METHODOLOGY

There are mainly three major associated to the liquid desiccant dehumidification system which are as follows:

a) The absorber
b) The regenerator
c) The evaporative cooler

The absorber or dehumidifier composed of a flat plate long channel with one inlet and one outlet port. Ambient air enters into the absorber through the inlet port with the help of an induced draft fan which has varying speed and exists from the outlet port and then passes through the evaporative cooler. The outlet port of air is the inlet port for liquid desiccant solution. The desiccant solution flows over the entire flat plate in the form of a film at very low flow rates. The regenerator consists of a solution heat exchanger and an induced draft fan at the outlet and all dimensions similar to that of dehumidifier. The cooling tower comprises of honey comb structure packing with various layer for direct evaporative cooling of process air. Some other components of the dehumidification system are cold solution pump in dehumidifier, hot solution pump for regenerator and one water pump for evaporative cooler, desiccant solution storage tanks, heater .The absorber in made up of a flat plate so that liquid desiccant solution flows evenly over the entire surface of the plate. The process air from another side flows over the desiccant film in a counter flow manner. There is a surface contact between the two films of desiccant solution and process air to minimise the carryover of desiccant droplets. In this process there is no intermixing of two films which eliminates the air side pressure drop problem related to packed bed dehumidifiers. The surface vapour pressure of the solution is kept below the ambient air by maintaining the temperature below 25 oC so that vapours from the ambient air get condensed into the desiccant solution. The fabricating material used for the construction of dehumidification system is of acrylic with suitable thickness because of the corrosive nature of the halide salts. Initially the desiccant solution is stored into the storage tank and cooled at 25 oC by the help of cooling tower. After achieving the required temperature for dehumidifier, valve of storage tank opens and the desiccant solution starts flowing through pipes and enters into the absorber and then flow over the entire surface of the plate. The diluted desiccant collected at the outlet port of the absorber is passed through the solution heat exchanger and preheated before entering the regenerator. The regenerator has the same configuration as that of the dehumidifier. The diluted desiccant solution after heated up by an electric heater in a storage tank flows through the regenerator. The storage tank for heating the solution has the capacity of 80 L and consists of a two electric heaters of 1 kW rating. The schematic diagram showing the details of the experimental set up is given in Fig.1. The concentrated desiccant solution leaving the regenerator also passes through the solution heat exchanger to get precool and again cooled with the help of cooling water circulates through the cooling water cycle.

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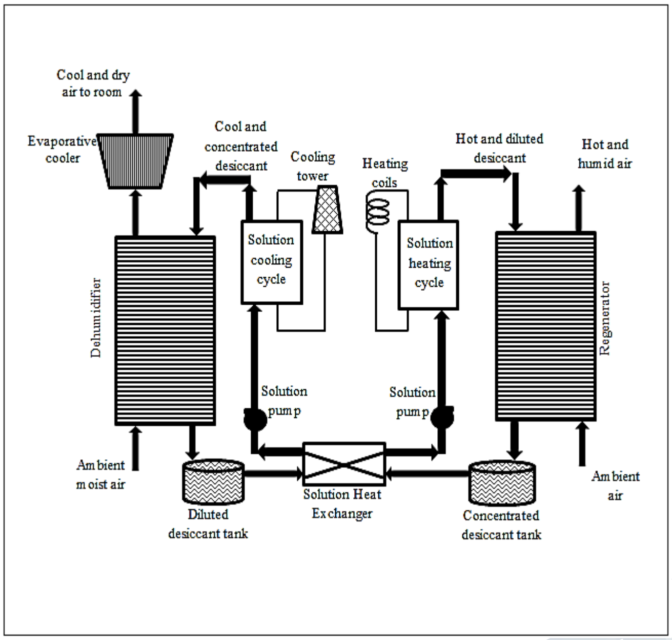

Fig.1. Schematic diagram for the dehumidification system

2.1 Parameters to analyse system performance

The parameters required to analyse the performance of the dehumidification system are mentioned below:

Effectiveness of absorber (εd) $=\frac{\omega_{a,in}-\omega_{a,out}}{\omega_{a,in}-\omega_{eq}}$ .... (1)

Effectiveness of regeneration (εr) $=\frac{\omega_{a,out}-\omega_{a,in}}{\omega_{eq}-\omega_{a,in}}$ .... (2)

where, ω is the humidity ratio and subscripts a,in and a,out are the process air entering and leaving the dehumidifier and regenerator. ωeq is the equilibrium humidity ratio for the desiccant solution and can be calculated by:

$$\omega_{eq} = \frac{0.622\{p_s(\varphi,T)\}}{\{p-p_s(\varphi,T)\}}$$ .... (3)

Rate of moisture absorption, Å $= m_{a,in}(\omega_{a,in} - \omega_{a,out})$ .... (4)

ma, in is the mass flow rate of air entering the dehumidifier.

Vapour pressure for the liquid desiccant solution of CaCl2, at a particular concentration and temperature is taken from Conde-Petit [22].

2.2 Instrumentation used for experimental measurements:

The properties of process air and liquid desiccant solution during the process of dehumidification and regeneration process are measured using the instrumentation described in Table 1. The parameters measured in the present experiments are such as:

- Velocity of process air entering the system
- Relative humidity to calculate humidity ratio
- Temperature of liquid desiccant solution
- Flow rate of liquid desiccant solution
- Concentration of liquid desiccant solution

Table 1: Specifications of the measuring instruments

Sr. No.	Instrumentation	Property measured	Accuracy
1	Anemometer	Process air velocity	+- 2 %
2	Hygrometer	Relative humidity and temperature of air	+-2 %
3	PT 100 RTD	Solution temperature	+- 0.3 ºC
4	Hydrometer	Solution density	+- .05
5	Stopwatch	Process time	+- 0.01 s
6	Rotameter	Solution flow rate	+- 0.45 lpm

III. RESULTS AND DISCUSSION

The process of dehumidification carried out using two sets of experiment with varying desiccant solution concentration and mass flow rate. The output of the results is in the form of moisture removal rate and dehumidification effectiveness. The experiments related to dehumidification process were performed at a volumetric flow rate for process air of 0.00576 m3/sec. The concentration of the CaCl2 was taken as 40 % by weight and the output results are shown in Table 2.

Table 2: Performance of dehumidification system using CaCl2 as a desiccant solution

S.No.	Solution mass flow rate (kg/s)	Solution Concentration (ᶻ)	Humidity ratio (air inlet, g/kg)	Humidity ratio (air outlet, g/kg)	Change in humidity ratio (Δ ω, g/kg)	M.R.R (g/s)	Dehumidification effectiveness (ε)
1	0.080	38.0	20.26	18.70	1.56	0.0088	0.0769
2	0.078	38.5	20.19	18.73	1.46	0.0078	0.0723
3	0.082	39.3	20.29	18.24	2.05	0.0073	0.1010
4	0.081	39.5	20.02	17.65	2.37	0.0085	0.1183
5	0.080	39.70	20.14	17.54	2.60	0.0105	0.1290
6	0.082	40.04	20.26	16.90	3.36	0.0120	0.1658
7	0.081	40.10	20.29	16.68	3.61	0.0113	0.1779
8	0.077	40.04	20.02	16.69	3.33	0.0119	0.1663
9	0.076	40.05	20.14	16.69	3.45	0.0123	0.1713
10	0.079	40.03	20.02	16.74	3.28	0.0103	0.1638

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3.1 Experimental results using calcium chloride as a desiccant solution

The performance of the dehumidification system is given in Table 2. The absorption rate of water vapour depends up on the ambient relative humidity and temperature which lies between 16 g/kg to 18 g/kg and equilibrium specific humidity for desiccant solution depends on the concentration and temperature of the solution. The dehumidifier effectiveness by using $CaCl_2$ lies between 0.07-0.16 which is low. Dehumidifier and regenerator both are in the direct contact with the desiccant solution but in surface contact only, so there is a little possibility of carryover of desiccant droplets with the process air. Performance of the regenerator was better than that of the dehumidifier and varies in the range of 0.31 to 0.69. The lower performance of the dehumidifier is due to the small vapour pressure difference and between solution and process air in dehumidifier and surface contact between the two.

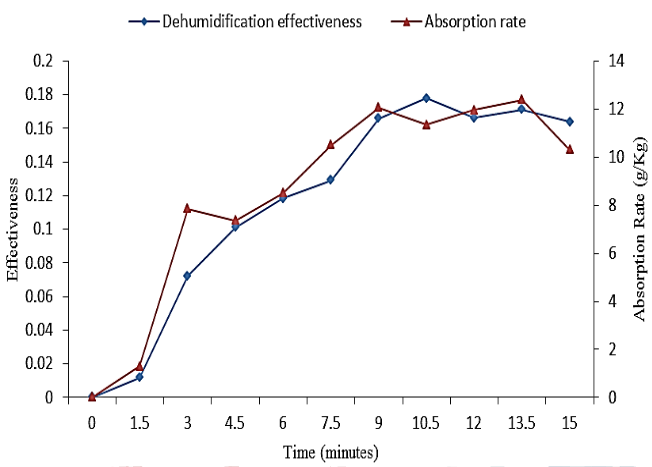

Fig.2. Variation of effectiveness and absorption rate with time

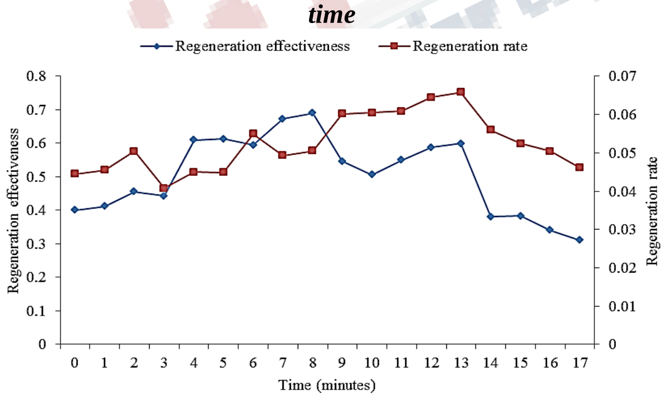

Fig.3. Variation of regeneration effectiveness and regeneration rate with time

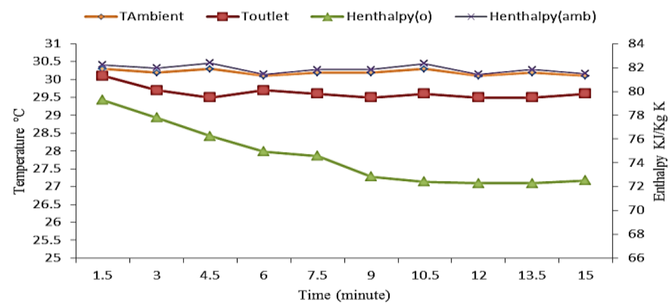

Fig.4. Variation of enthalpy change and temperature with time

Change in humidity ratio varied between 1.56 g/kg to 3.28 g/kg as shown in Table 2 and it depends upon the ambient temperature and humidity ratio as shown in Fig.2. The change in humidity ratio also increases by increasing the concentration of the desiccant solution from 38 % to 40 %. The effectiveness and moisture removal rate of dehumidifier also depends upon the inlet condition of the process air reach maximum to the 0.17 and 12.06 g/kg respectively as given in Fig.2. The regeneration effectiveness and regeneration rate showed better results than dehumidifier and achieve the maximum of 0.17 and 0.06 as given in Fig. 3. The flow rates in the regenerator are higher than dehumidifier. It is shown by Fig.4 that the temperature of inlet process air decreases slightly at the outlet of the dehumidifier and enthalpy of process air also gets decreased.

IV. CONCLUSION

In the present experimental study, performance of a flat plate liquid desiccant air conditioning system was investigated using calcium chloride as a desiccant solution in which film of desiccant solution flowing over the absorber plate and process air film flowing over desiccant film in counter flow to overcome the problems associated to the conventional packed bed and spray tower dehumidifiers. Experimental studies were conducted by varying concentration of desiccant solution and flow rates of process air. The change in humidity ratio varies between 1.56 to 3.28 g/kg with respect to ambient humidity ratio. The dehumidification effectiveness lies in range of 0.07 and 0.177. The regeneration effectiveness shows better results than dehumidifier and varies between 0.01 and 0.69 due to higher vapour pressure difference between the process air and desiccant solution. Temperature and enthalpy of process air also shows a decrement at the outlet port. The dehumidification performance was limited due to only film contact between the air and desiccant. Scope of future research would include the use of various desiccant materials with this system and to investigate the performance of multilayer flat plate liquid desiccant system.

REFERENCES

1. Sukhatme Suhas, S., Solar Energy Principles of Thermal Collection and Storage2008: Tata McGra-Hill Publishing Company.

2. Bichowsky, F. and G.A. Kelley, Concentrated solutions in air-conditioning. Industrial & Engineering Chemistry, 1935. 27(8): p. 879-882.

3. Fumo, N. and D. Goswami, Study of an aqueous lithium chloride desiccant system: air dehumidification and desiccant regeneration. Solar energy, 2002. 72(4): p. 351-361.

4. Enteria, N., et al., Study of the conventional twin rotor desiccant cooling system. Part. 1: p. 1111-1012.

5. Khoukhi, M., et al., Study of the conventional twin Rotor desiccant cooling system. Part. 1: p. 1109-1010.

6. Enteria, N., et al., The experimental works and some parametric investigations of thermally activated desiccant cooling system. Proceedings of Clima 2007 WellBeing Indoors, 2007.

7. Liu, X., et al., Analytical solutions of coupled heat and mass transfer processes in liquid desiccant air dehumidifier/regenerator. Energy Conversion and Management, 2007. 48(7): p. 2221-2232.

8. Liu, X. and Y. Jiang, Coupled heat and mass transfer characteristic in packed bed dehumidifier/regenerator using liquid desiccant. Energy Conversion and Management, 2008. 49(6): p. 1357-1366.

9. Liu, X., et al., Experimental study on mass transfer performances of cross flow dehumidifier using liquid desiccant. Energy Conversion and Management, 2006. 47(15): p. 2682-2692.

10. Jain, S. and P. Bansal, Performance analysis of liquid desiccant dehumidification systems. International journal of refrigeration, 2007. 30(5): p. 861-872.

11. Hwang, Y., et al., Review of solar cooling technologies. HVAC&R Research, 2008. 14(3): p. 507-528.

12. Wang, R., et al., Solar sorption cooling systems for residential applications: options and guidelines. International journal of refrigeration, 2009. 32(4): p. 638-660.

13. Lof, G.O. Cooling with solar energy. in Congress on solar energy. 1955. Tucson, USA.

14. Patnaik, S., T. Lenz, and G. Löf, Performance studies for an experimental solar open-cycle liquid desiccant air dehumidification system. Solar energy, 1990. 44(3): p. 123-135.

15. Hassan, A. and M.S. Hassan, Dehumidification of air with a newly suggested liquid desiccant. Renewable Energy, 2008. 33(9): p. 1989-1997.

16. Kumar, R., et al., Multi absorber stand alone liquid desiccant air-conditioning systems for higher performance. Solar energy, 2009. 83(5): p. 761-772.

17. Ertas, A., et al., Experimental study on the performance of a regeneration tower for various climatic conditions. Solar energy, 1994. 53(1): p. 125-130.

18. Longo, G.A. and A. Gasparella, Experimental and theoretical analysis of heat and mass transfer in a packed column dehumidifier/regenerator with liquid desiccant. International Journal of Heat and Mass Transfer, 2005. 48(25): p. 5240-5254.

19. Saman, W.Y. and S. Alizadeh, An experimental study of a cross-flow type plate heat exchanger for dehumidification/cooling. Solar energy, 2002. 73(1): p. 59-71.

20. Niu, X., F. Xiao, and G. Ge, Performance analysis of liquid desiccant based air-conditioning system under variable fresh air ratios. Energy and buildings, 2010. 42(12): p. 2457-2464.

21. Xiong, Z., Y. Dai, and R. Wang, Development of a novel two-stage liquid desiccant dehumidification system assisted by CaCl 2 solution using exergy analysis method. Applied energy, 2010. 87(5): p. 1495-1504.

22. Seenivasan, D., V. Selladurai, and P. Senthil, Optimization of liquid desiccant dehumidifier performance using Taguchi method. Advances in Mechanical Engineering, 2014. 6: p. 506487.