Study on Liquid Desiccant Dehumidification And Regeneration Process – Review Article

Dr. Mercy Vasan.A[1], Ajai.S[2], Ashwin.S[3], Mohana Sundharam.B[4], Sukesh.V[5]
[1]Associate Professor, Dept of Mechanical Engineering
[2, 3, 4, 5]Dept of Mechanical Engineering

Abstract- *Cooling demand for India increases to 8- 11 times the present year within a decade. Energy requirement for meeting the cooling demand also increases which lead to more consumption of non- renewable resources & emission related to it. Performances of cooling system have to improve to reduce the energy consumption. Upon usage of the low grade heat and improved effectiveness in dehumidification, the liquid desiccant dehumidification technology is becoming more popular nowadays. By this technology air conditioning systems have been developed which is energy efficient, also demonstrated superiority over the traditional vapour compression system due to the controlling of temperature and humidity ratio independently.*

Keywords- Liquid desiccant, Dehumidification, hybrid Liquid desiccant air conditioning (LDAC), multistage internal circulation liquid desiccant dehumidifier (MICLDD)

I. INTRODUCTION

Desiccants are chemical substance that absorbs water vapour (moisture) from ambient air due to vapour pressure difference between desiccant & air. Humidity ratio of air decreases as water vapour is absorbed, during the process latent heat of vaporization is released consequently the temperature of air may increase depend on rate of dehumidification.

Desiccant will absorb or adsorb water vapour from the ambient air, until its vapour pressure becomes equilibrium with that of the air. In case of liquid desiccant, there is exponential increase in the equilibrium vapour pressure with respect to the temperature of the desiccant. Desiccant will absorb water vapour to certain limit it becomes saturated for given condition, will not absorb further more. This moisture have to be removed from the desiccant to use for a cyclic process, this done by supplying heat energy by means of solar thermal collector or any other heat sources to desiccant will increase temperature consequently vapour pressure also increase. Due to pressure difference water vapour will transfer from desiccant to air, this process of removing water from desiccant using heat energy is known as Regeneration. Desiccant-based cooling systems are more economical than the conventional refrigeration systems which works at lower temperatures and lower humidity ratio. A Desiccant dehumidification system is utilized in tropical and humid climatic conditions. Desiccant are classified into 2 types

1. Solid Desiccant
2. Liquid Desiccant.

II. LITERATURE REVIEW

1. **T wen et al** (2021) studied the performance between lithium chloride (LiCl) and potassium formate (KCOOH) and his experimental results indicated that 70.3% KCOOH solution had the same vapour pressure as 35% LiCl solution, also the absolute moisture removal of same number of solutions KCOOH is slightly higher than that of LiCl as a result of increased wetting area.
2. **B Guan et al.** (2021) studied deep dehumidification below the specific humidity of 7g/Kg of dry air can't be attained with existing analytical solution. The deviations between the modified analytical results and experimental results were around 10% under the same solutions, air flow rates, NTU_m, humidity ratio.
3. **M Bhowmik et al.** (2021) proposed a hybrid system for regeneration of liquid desiccant using solar tube collector as the source. Higher the solution to airflow (S/A) higher is the dehumidification and lower the S/A ratio higher the desiccant regeneration rate. Coefficient of performance was found out to be 1.1 by experimental method
4. **B Guan et al.** (2021) simulated a hybrid Liquid desiccant air conditioning (LDAC) under the typical summer condition of Guangzhou of China. This hybrid system is built by cascading both dehumidifier and regenerator together. The coefficient of performance of the proposed system is found out to be 13.0% higher than the conventional LDAC System.
5. **H Lu et al.** (2021) had simulated the dehumidification performance by user-defined function (UDF) codes based on the penetration theory. Dehumidification performance is increased by 30.9% for a rough plate when compared with a smooth plate when the inlet air velocity is 0.5 m/s and desiccant concentration is 30%.

6. **W Li et al.** (2021) has proposed Internally-cooled membrane-based liquid desiccant dehumidifier (IMLDD) in which a semi permeable membrane separates both air and desiccant solution. By the mathematical model the counter flow arrangement for air and desiccant flow fetches the best dehumidification performance.
7. **B Guan et al.** (2021) introduced the thermal capacity ratio (*m**) of air to desiccant. *m** value cannot be simultaneously equal to 1 in deep dehumidification conditions (for specific humidity lesser than 5g/Kg of dry air). Two strategies were proposed by which the exergy loss is reduced by 10.6% - 26.8%.
8. **MI Ahmed et al.** (2021) analysed a 3D computational model spray type dehumidifier with counter flow configuration. Specific humidity is increased from 4.2 to 6.3g/Kg of dry air by increase in desiccant flow rate and reducing the air flow rate. Solution concentration is decreased due to moisture absorption during dehumidification. Adding a cooling unit for liquid desiccant system increases the moisture transfer rate.
9. **YZ Chou et al.** (2021) proposed a system which preheats the inlet air by the heat energy without any moisture transfer in the air. By this system the air flow is increased to 2600 CMH than the system without heat recovery which has only 1600 CMH. So, the optimal dehumidification and regeneration is obtained with the air flow rates.
10. **R Qi et al.** (2020) investigated about the insufficient wet ability. To increase the wet ability author has proposed the usage of hollow fibre membrane dehumidifier instead of plate type ones which has lesser surface area. The tube-shaped fibre membranes are assembled from 200 to 1200 in one module with diameter ranging from 0.1-3mm diameter.
11. **N Bleibel et al.** (2020) examined the performance of hybrid system combining evaporative-cooled window (ECW) with desiccant dehumidification system (DDS) at Jeddah, Saudi Arabia. The inner window temperature was reduced by 5 °C, 7 °C, 4 °C, and 5 °C in June, July, August, and September respectively also resulting in an 11% decrease of the total cooling load compared with only ECW system.
12. **K Manusuriya et al.** (2020) investigated the performance of hybrid system by combining liquid desiccant dehumidification and vapour compression refrigeration with a 5Kw capacity. The results reveal in the coefficient of performance of about 27.54% due to 54.93% of latent load is being covered by the liquid desiccant dehumidifier. This energy saving method reveals the payback period of this system is reduced to 4 years compared to the stand-alone system.
13. **J D Liang et al.** (2020) integrated the traditional liquid desiccant dehumidification system with shallow geothermal energy (water at 20-22°C) to cool the outdoor air before entering the dehumidifier to reduce the sensible load. This proposed system reduces 86% on power consumption.
14. **R Niu et al.** (2020) Simulated and experimentally studied about the falling film liquid dehumidifier. Results were obtained with a decrease in dehumidification with a increase in air velocity, Increase in the amount of dehumidification by increase in solution concentration, air inlet moisture and solution flow rate.
15. **Zhang et al.** (2020) investigated about the exergy loss on the system due to high heat source temperature (120°C) for regeneration. It is found that the decrease in heat source temperature due to increase in regeneration air flow rates. Then a heat pump cycle is combined with a system hence high heat source temperature is lowered to 45.6°C which also reduces the exergy loss. Exergy efficiency of the system is improved 17.7% to 28.6%.
16. **H Bai et al.** (2020) Investigated dehumidification performance and energy requirement of a membrane-based liquid desiccant dehumidification system. System performance is considerably affected by the number of heat transfer units in the dehumidifier side. System performance is not affected by the heat transfer units in the regenerator side.
17. **M Bhowmik et al.** (2020) studied experimentally about the counter flow desiccant dehumidifier with Lithium bromide and calcium chloride as the liquid desiccants. The optimised results were obtained at Air flow rate of 0.766 kg/m^2-s, Ambient temperature of 30.745 °C, Specific humidity of 0.023 kg_{wv}/kg_{da}, Solution flow rate of 1.812 kg/m^2-s, Solution temperature of 24.01°C, and relative humidity of 48.1%.
18. **Z Yang et al.** (2020) investigated an improved method of dehumidification process using a standing-wave ultrasound, by which desiccant droplets are vibrated in humid air and thus increases the mass transfer. This improved standing wave ultrasound method increases the dehumidification performance by 56% on average than the conventional way.
19. **J Guo et al.** (2020) proposed the usage of photo voltaic thermal (PV/T) collector as the main heating source. Regeneration process operates at low temperature ranging from 43°C to 62°C by the use of PV/T collector. Annual cooling performance of the shows up the coefficient of performance ranging from 9.6 to 16.3 with the energy saving of about 87% than a conventional dew point air dehumidification and cooling process.
20. **X Cheng et al.** (2020) proposed a multistage internal circulation liquid desiccant dehumidifier (MICLDD)

where the packing bed and cooling module are layered separately inside each stage. The heat and mass transfer area increases with the increase of packing series, thus the dehumidification efficiency is increased. MICLDD improves 9.3% with the same pump power consumption.

21. **B.K. Naik et al.** (2019) studied on liquid desiccant dehumidification/regeneration system. Increase in inlet humidity ratio reflects on both dehumidification and regeneration process, latent energy exchange is predominant between ambient air and desiccant in dehumidifier whereas sensible energy exchange is predominant in regeneration process.
22. **T Wen et al.** (2019) had done investigation on potassium formate. It shows using potassium formate solution (KCOOH) solution for a falling film type arrangement, the indicated air temperature and solution flow rate had negligible influence on mass transfer performance.
23. **X Wang et al.** (2019) modelled an independent mass and heat transfer unit for both regeneration and dehumidification and also proposed a batch-wise operation strategy for lesser power consumption. Results show that dehumidification rate and regeneration rate can be improved to an average of 5% and 3.5% respectively. It shows considerable energy savings up to 16.81% and 18.6% from dehumidifier and regenerator respectively.
24. **H.J. Cho et al.** (2019) has compared cross flow and counter flow type dehumidifier experimentally. The counter flow dehumidifier performance is highly affected by the inlet air flow an inlet humidity ratio. The results shows better dehumidification in counter flow than the cross-flow type dehumidifier.
25. **Y. Gu et al.** (2019) done a feasibility study of applying a counter-current-flow RPB (rotating packed bed) for air dehumidification. From the experimental data, both dehumidifier effectiveness and moisture removal rate can be improved significantly by increasing the rotating speed of the RPB, solution flow rate and solution inlet concentration.
26. **B. Guan et al.** (2019) has proposed a hybrid dehumidification system which assures a compact structural system. The proposed system achieves a superior cop of 3.3 with an improvement of 13.8% when compared with a conventional liquid desiccant dehumidification system.
27. **J. Lin et al.** (2018) proposed a desiccant enhanced evaporative cooling system. Under hot and humid climate (30.0 °C and 20.0 g/kg), the hybrid system is able to deliver the product air at 18.3 °C temperature and 10.9 g/kg humidity. A mathematical model is developed and had a difference of ±5.0% with respect to the experimental results.
28. **R.P. Singh et al.** (2018) studied on different solid, liquid desiccant and feasibility of formation of composite desiccant .The composite desiccant of silica gel and LiCl has adsorption capacity 2-3 times higher than that of pure silica gel. The limitation faced by desiccant system is availability of regenerating heat to regenerate desiccant material.
29. **C. Dong et al.** (2018) experimentally tested plate dehumidifier with distinctive surface properties and the results show positive effect on dehumidification performance by increasing wetting area and reducing falling film thickness.
30. **M.R. Islam et al.** (2018) have developed a simplified mathematical model for liquid desiccant dehumidifier. The hybrid water cooled desiccant system shows an energy saving of up to 25% . The developed model can also be rationally modified to study the performance of adiabatic dehumidifiers.
31. **X Chen et al.** (2018) proposed novel hollow fibre liquid desiccant system. The porous feature of the hollow fibre module can help to eliminate any liquid desiccant droplets carryover into the process air. Experimentally obtained latent effectiveness are in the range of 0.25–0.43 and the sensible effectiveness are in the range of 0.31–0.52, which is validated with the empirical correlation of effectiveness-NTU model results.
32. **B Su et al.** (2018) proposed a two stage liquid desiccant dehumidification system. Stimulation shows that this system decreases 30.63% percentage of power consumption with respect to the conventional cooling dehumidification system. The heat and power are used effectively in a cascaded way.
33. **S.A. Nada et al.** (2017) has done a numerical analysis on air-cooling dehumidification for different configuration. Among the counter, parallel and cross flow arrangement the result shows that parallel flow arrangements give relatively more cooling and dehumidification. Derived a governing equation which relates all major process parameter using finite difference technique.
34. **Z Chen et al.** (2017) done a feasibility study on the hot and humid region is assessed with calcium chloride solution .The regeneration performance is increased by increasing mass flow rate and hot water temperature, but the required thermal input power increases accordingly. From steady state experiment, supply air temperature of 20.4 °C and system COP of 0.70 are achieved at a solution concentration ratio of 36%.
35. **S Bouzenada et al.** (2016) has done a comparative experiment using LiCl and CaCl. In dehumidification process the mass transfer potential of lithium chloride is better than calcium chloride in case of regeneration

processes the calcium chloride shows better mass transfer potential than lithium chloride.

36. **F. Fakhrabadi et al.** (2016) proposed a hybrid air conditioner which consists of a liquid-to-air membrane energy exchanger (LAMEE) as a desiccant dehumidifier and a regenerative heat and mass exchanger (RHMX) as an evaporative cooler. The importance of various design and operating conditions on the optimal RCC (room cooling capacity) and the optimum set of design variables were studied.
37. **L Wang et al.** (2016) has done an experimental study on the dehumidification performance of a counter flow liquid desiccant dehumidifier using structured packing. A new empirical relation between moisture effectiveness and the enthalpy has been developed and compared with the previous experimental results. The deviations are found out to be ±10% and ±15% for the former and latter respectively.
38. **Y luo et al.** (2014) studied various mathematical models for calculating energy transfer. Different approach for heat & mass transfer is explained with their application, different methods are proposed for determining the outlet/ output of dehumidifier. Effectiveness NTU model is less iterative give better output of dehumidifier compare to finite volume method (more time consuming).
39. **K Keniar et al.** (2014) has done a feasibility study on solar coupled regenerative system. Membrane desiccant system and parabolic solar collector is modelled, it achieves indoor thermal comfort with minimal effect on room temperature. Payback period for initial cost of system is found to be 7 years.
40. **S.Bouzenada et al.** (2014) conducted an experiment on liquid desiccant in direct contact with the air at different operating conditions .An analysis of the mass transfer is made in order to prove LiBr material is the best liquid desiccant for LDCS. Experimental results showed the effect of air conditions on mass transfer. It stated that LiBr is able to absorb moisture and can be regenerated at low temperature.

III. PROBLEM IDENTIFICATION

To obtain the optimal result on liquid desiccant dehumidification and regeneration process, many problems were identified and the main problems are summarised as follows.

i. Mass transfer potential of different salts.
ii. Type of dehumidification system and effect on number of heat transfer unit.
iii. Type of flow on dehumidifier system.
iv. Number of stages in dehumidification is required.
v. Effect on dehumidification performance due to mass flow rates of air and solution, other influencing parameters.

IV. CONCLUSION

Based on the data and information cumulated from the literature review, it is found that inlet humidity, inlet temperature of desiccant and air, mass flow rate of ambient air are major deciding parameter for an optimum dehumidifier performance. In case of regeneration, regeneration heating temperature and type of desiccant used will determines the effectiveness of regeneration process and the following points are concluded.

1. Hybrid system i.e. combining liquid desiccant dehumidification and vapour compression refrigeration has shorter payback period.
2. In dehumidification process the mass transfer potential of lithium chloride is better than calcium chloride, In case of regeneration processes the calcium chloride shows better mass transfer potential than lithium chloride.
3. In membrane-based liquid desiccant dehumidification system, the number of heat transfer unit has greater influences in the performances of dehumidifier side but has no effect on regeneration process.
4. Potassium formate solution (KCOOH) indicates that the air temperature and solution flow rate had negligible influence on mass transfer performance.
5. Counter flow dehumidifier shows better dehumidification than the cross-flow and parallel flow type dehumidifier.
6. Two stage liquid desiccant dehumidification system demands lesser power input with respect to conventional dehumidification system.
7. The regeneration performance is increased by increasing solution mass flow rate and regeneration temperature.
8. The amount of dehumidification increases by increase in solution concentration, air inlet moisture and solution flow rate.

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