A TECHNICAL REVIEW ON LIQUID DESICCANT REGENERATION SYSTEM

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Abstract: Increasing population, expanding economy and craving for higher comfort has led to rapid rise in demand of electrical power. Air conditioning is a major contributor to this rise in demand. It is pertinent to find technologies which consume less electrical energy and are more environments friendly. Liquid desiccant based air conditioning system is one such system which can use solar thermal or waste heat as energy input. Regeneration and dehumidification of LD is the important process in this system, once the LD dehumidified then it is necessary to increase its concentration level by regenerating liquid desiccant using suitable heating source. This work basically focus on Regeneration of LD using solar energy, for that study of proper selection of LD, Solar collector, operating parameter like temperature of LD, Concentration level of LD, Types of LD are important. So this paper combined the information about different liquid desiccant and their properties, different solar collectors, different regeneration system and their operating parameter like concentration level and operating temperature.so in a future proper optimum system can be design and develop for LD regeneration system.

KEYWORDS: Liquid desiccant, solar collector cum regenerator, dehumidifier, indirectsolar regenerator, direct solar regenerator, Air scavenging regenerator, Solar still, Reflector.

1. INTRODUCTION

Nowadays the consumption of electricity is increasing day-by-day. And air conditioners, refrigerators, household appliancesconsuming more power. The consumption of electricity is drastically increasing with respect to their applications in small and large industries and which in turn has bad effect on the environment. And the cause is that it increases the depletion of the ozone layer and the green-house gases. As the primary energy consumer sector accounts for 40% of the world's primary energy consumption and which is responsible for one third of the global CO_2 emissions [1].The major concern for consumption of much electricity is the population and the economy which is increasing at a tremendous rate. And in that having low cost of the air-conditioning is imposing a great stress on us [2]. Solar energy can be utilized for air conditioners as in summer as available in plenty [3-7]. Around 67% of total production of electricity comes from non-renewable energy resource such as fossil fuel etc. Conventional VCRS is solar directed Liquid desiccant dehumidification followed by the evaporative cooling of water [8].

Major option to the conventional VCRS is solar operated Liquid Desiccant (LD) dehumidification followed by evaporative water cooling. In LD based air conditioning, after the adsorption of moisture from process air LD needs to be regenerated. This weak LD solution can be regenerated by heating with the help of solar radiation [9]. This heat can be supplied by solar heated air in the stripping column or with the help of various process solarequipment's e.g. solar still [10–12], solar collector [13], falling film [14,15], spray [16–18], packed bed [19–25], solar dryer [26–28], solar pond [29–32] etc. As in summer season we have much availability of the solar energy which in turn saves the electricity and reduces the green-house gas emissions by using of the solar powered air conditioner [33]. Liquid desiccants such as Li-Cl, Li-Br, $CaCl_2$ and newly desiccants can be used in the liquid desiccants in the air-conditioning system attracted many of the researchers [34].

Liquid desiccant cooling systems (LDCS) is an environmentally-friendly technique which reduces the cause by using the solar energy and the liquid or the solid desiccants [35].

2. REVIEW BASED ON LIQUID DESSICANT

- Liquid Desiccant is a hygroscopic solution [33] which absorbs moisture from the closed system. It can also be defined as that it has an attraction towards the water particles present in the closed system. Basically two types of desiccants are available, (1) Solid desiccant 2) Liquid desiccant, Solid desiccants includes silica gel, hydrate salts, alumina. And liquid desiccants are Lithium chloride, Lithium bromide, Calcium Chloride. Basic properties of Liquid desiccants are like they should have low vapour pressure which minimize evaporation losses during regeneration, the desiccant should be non-toxic, non-corrosive, and odourless and non-flammable. The desiccant should be chemically and structurally stable and should not be affected by impurities. Liquid solutions should not crystallize within the operating range of temperature and concentration, and should have low viscosity and good heat transfer properties,Water vapor pressure characteristics of the desiccant should be suitable for the required degree of dehumidification and for regeneration at temperatures economically available from solar collectors or waste heat.

2.1 Properties Of Different Liquid Desiccants [36]:

- Lithium chloride (Li-Cl) and Lithium Bromide (Li-Br): It has good dehumidification with regeneration temperature about 80°C. And it does not require high circulation rate between dehumidifier and the regenerator. In these there are high chances of corrosion to the system and so it requires inhibitors and PH control. It does not evaporate at working temperature of the system. And its cost is high as compared to other desiccants.
- Calcium Chloride ($CaCl_2$): It has poor dehumidification, and its regeneration is possible at temperature of about 60°C.During the regeneration process it does not evaporate and has moderate effect of corrosion and so to prevent this we require inhibitors and PH control. Its cost is low as compared to (Li-Cl) and (Li-Br).
- Mono-ethylene glycol: It has moderate dehumidification when regenerated at 65°C to 80°C. It requires high circulation rate between dehumidifier and regenerator. It has greater losses during the regeneration and dehumidification processes.
  But on the other side it has moderate corrosion and requires inhibitors and PH control to prevent it. And its cost is moderate as compared to ($CaCl_2$).

Lithium chloride is the most stable liquid desiccant because it has low vapour pressure but on the other side it has high cost [36].

Calcium chloride is the desiccant which is easily available and the cheapest one but at a given temperature it has high vapour pressure and it becomes unstable depending on the inlet conditions of the air conditioning [36].

2.2 Principle Of Desiccant Cycle:

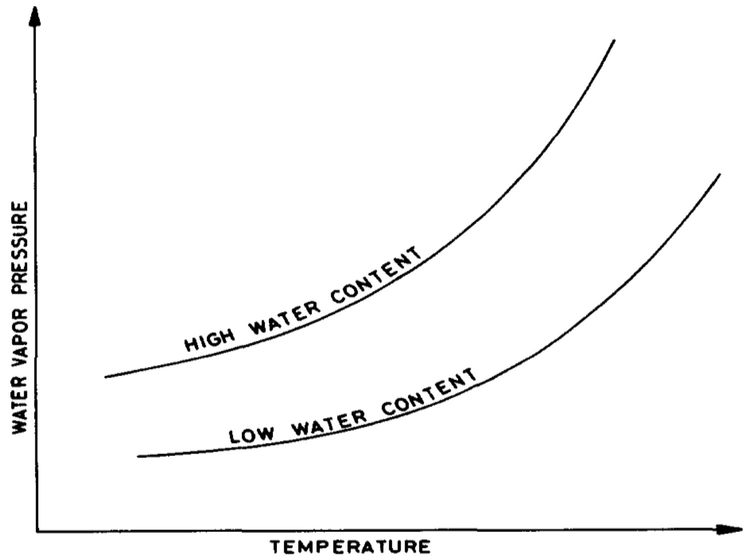

Figure 1: curves of water vapour pressure at desiccant surface as a function of temperature [37]

The Desiccant cycle working is possible due to its water retaining capacity from the surrounding at a lower temperature and discharging it to the air at a higher temperature.And this exchange of water vapour between the desiccant and the air purely depend on the surface of the desiccant and the water vapour pressure of the air.Vapour pressure is a function of temperature and water content at the surface of the desiccant. It is shown in the figure 2 and the curves shows that as the temperature increases the vapour pressure also increases and vice-versa. And it is known that as if temperature is very high then we get the higher vapour pressure [37].

3. DIFFERENT REGENERATION METHODS FOR LIQUID DESICCANT:

3.1 Methods Of Regeneration Of LD

Regeneration method for LD can be divided into indirect method or direct method. In indirect method, the air is heated in solar collector and LD is heated in heat exchanger, hot air absorbs the moisture from LD. And in direct method LD is heated in the solar collector and water vapour is directly removed by evaporation.

3.2 Indirect Methods:

3.2.1 Air Scavenging Regenerator [37]

Water is heated in a solar air collector. The heating of air can be done by using heat exchanger in which hot water is supplied. The types of collector can be used are flat plate collector, ETC (Evacuated Tube Collector) collector, parabolic collector etc. It's a scavenging type regeneration system. In this type of regenerator hot air is passed over LD in regenerator and takes away the moisture from LD.

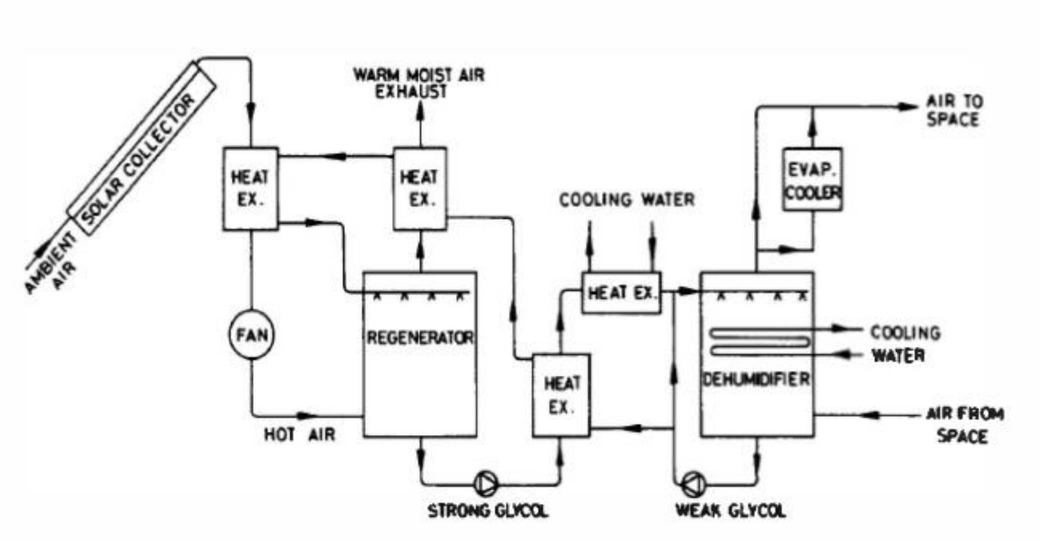

Figure 2:indirect method of ld regeneration [37]

As shown in figure the air is heated in solar collector. Hot air is used to heat the LD in heat exchanger and then supplied to regenerator. The preheated LD is sprayed in regenerator where it comes in contact with hot air which absorbs the moisture from LD due to vapour pressure difference.

3.2.2 Liquid Desiccant-Vapor Compression Hybrid System

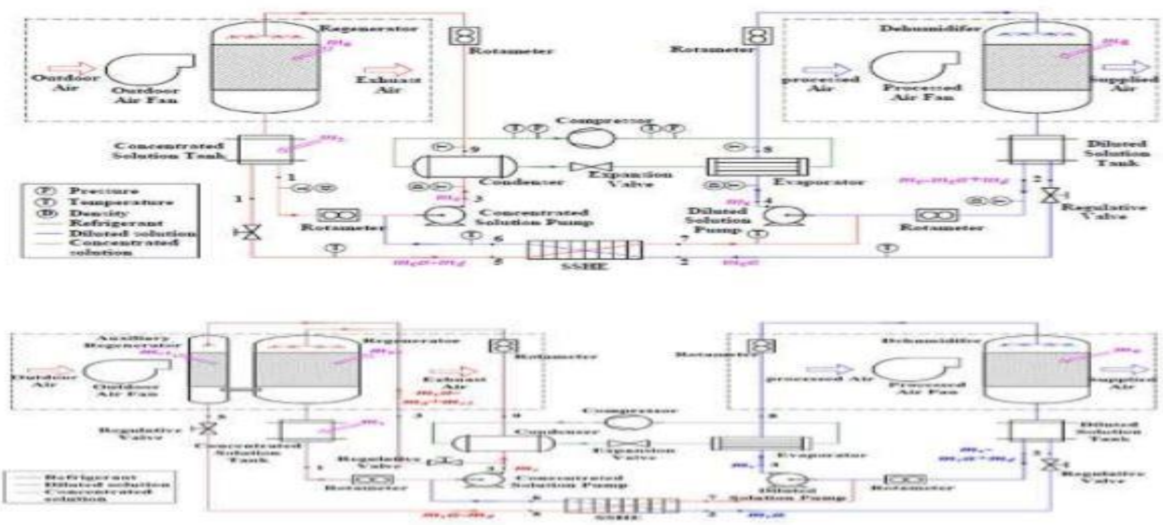

Figure 3: block diagram of system [62]

Li Yinglin et all [62] This paper suggest design for hybrid system by using auxiliary regenerator and also tests a conventional LDCH air-conditioning experimental setup and established the corresponding mathematical model to analyze the effect of the concentrated solution branch in the SSHE (solution solution heat exchanger) on the cooling capacity of the evaporator. The results show that the percentage of cooling capacity loss of the evaporator exceeds 10% with the small concentration difference of 1.5% in the conventional LDCH air-conditioning system. For this reason new system is proposed.

For the new LDCH air-conditioning system, there is a big drop of temperature of concentrated solution branch after being pre-treated by the auxiliary regenerator. Under the condition of concentration difference of 2.65%,

The inlet temperature of concentrated solution branch from the regeneration side in the SSHE can decrease over 60C, the extra heat load entering the dehumidification side from the regeneration side obviously decreases, and the loss percentage qc of cooling capacity lowers from 8.2% to about 1.5%. So auxiliary regenerator provide Reduction temperature and difference of inlet and outlet of heat exchanger.

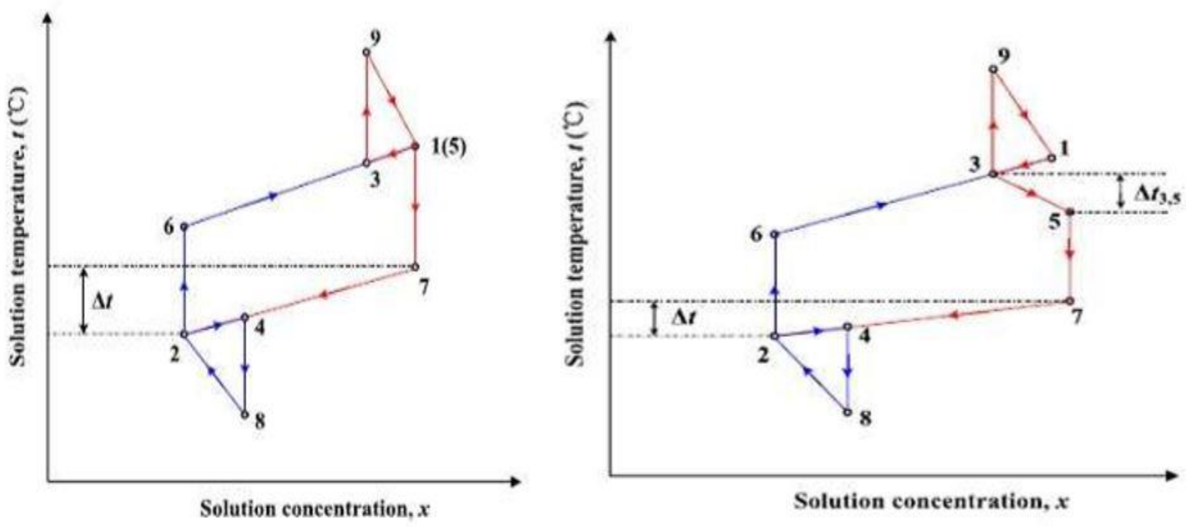

Figure 4: t-x diagram [62]

3.3 Direct Methods (Collector cum Regenerator, C/R)

In the direct method or the collector cum regenerator, the LD gets heated with the help of the collector or regenerator. Water content in the LD gets evaporated and removed.

Flat Plate C/R: Natural convection and forced convection

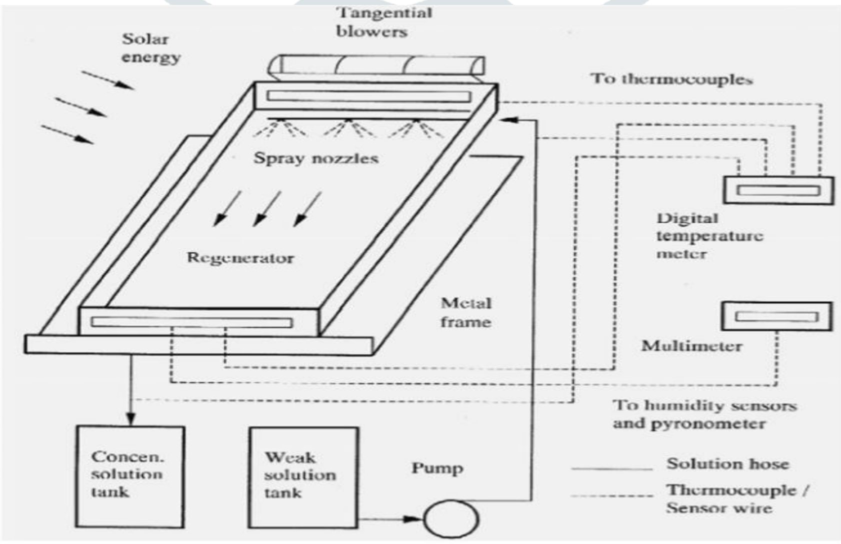

Figure 5: flat plate solar collector [38]

The system is shown in the figure:5. It is forced parallel flow type flat plate collector/regenerator. In this method collector is used directly for heating the LD instead of heating air as it was in the case of indirect regeneration. Here ambient air is passed over the desiccant, which is sprayed over the surface of the collector/regenerator and it has shown in the figure. And the air takes the water vapour which is evaporated from the LD.

3.3.2ETC used as C/R in Two Stage Regeneration Process

Figure 6: evacuated tube collector [39]

ETC is used to achieve higher temperature and it has been shown in the figure:6.In this LD gets regenerated in two stage regeneration. First the LD gets heated in the glass tube and then it gets boiled. At the outlet of regenerator, LD is regenerated and steam is received. And this steam can be used to preheat the LD or regeneration [39].

3.3.3 Solar still type regenerator

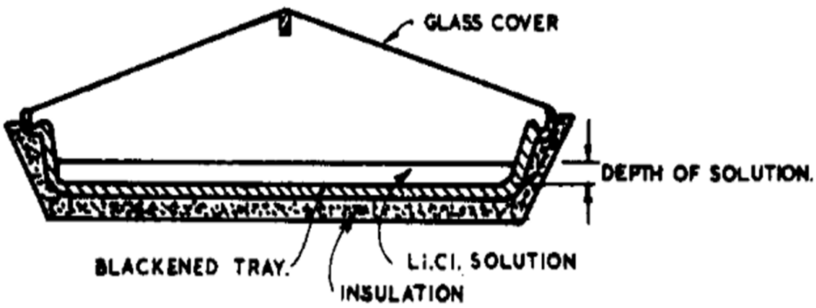

Figure 7: double slope solar still [40]

3.3.4 Tilted Solar Still As The Regenerator

Gandhidasan [41] has also showed the use of tilted solar still for the regeneration of LD (Fig. 8). He derived that solar energy for the regeneration of LD would be feasible in hot and humid climate rather than dry climate. Also, Gandhidasan et al. [42] had simulated the open solar regeneration system for the humid climate and discussed the various parameters affecting the performance of the system.

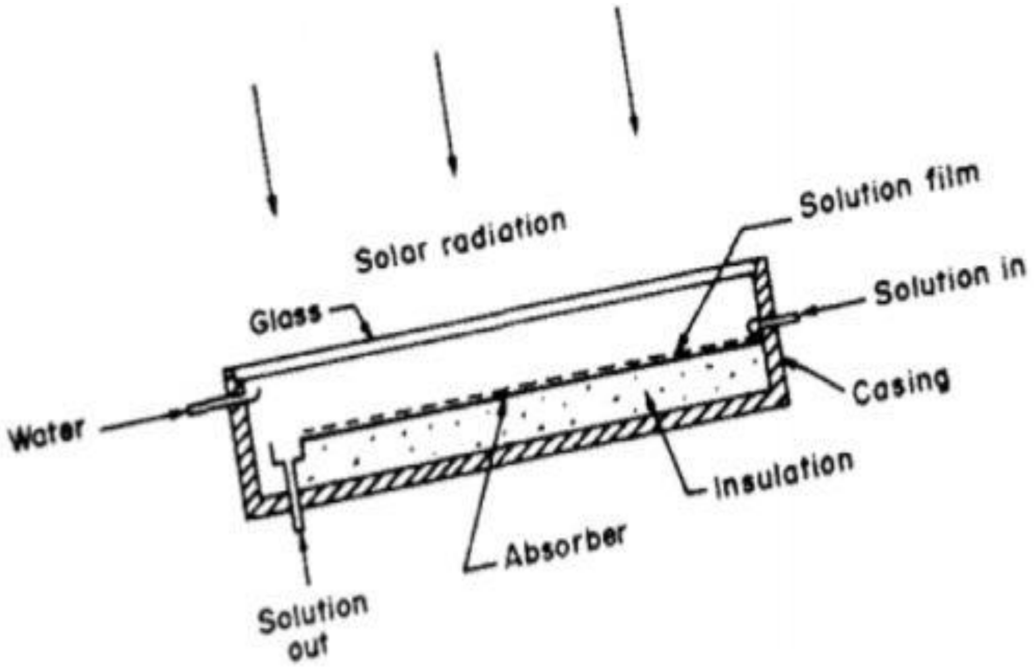

Figure 8: tilted solar still as the regenerator [41]

3.4 A Concept- Hybrid Solar System

3.4.1 Hybrid Conventional And Liquid-Desiccant Subsystem

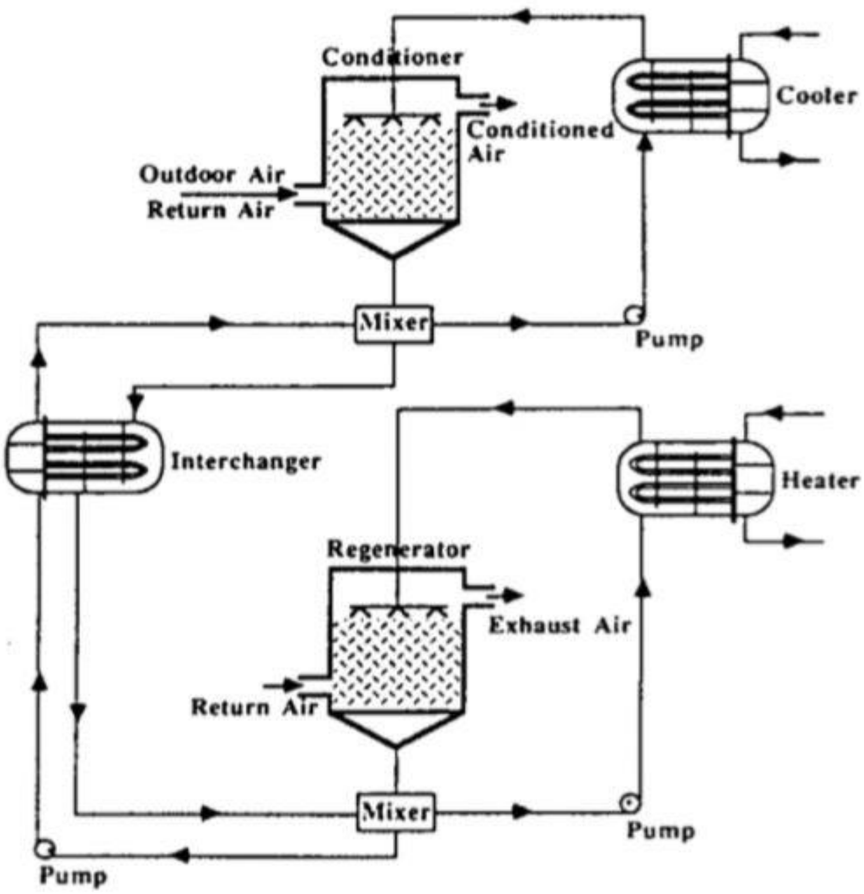

Figure 9: hybrid conventional and liquid-desiccant subsystem [43]

In last few decades, a Hybrid solar system concept is getting more popular and popular due to its ability to achieve more required condition of air rather than LDAC alone. In the hybrid solar system, either two sources of heat are used for regenerating LD or solar energy is used for regeneration along with other application (mainly as a combination of solar powered LD system and conventional VCRS or absorption refrigeration system) [44]. Sick et al. [43] analysed the performance of hybrid LD cooling system comprising of conventional and LDAC equipment as shown in Figure 10. They had calculated that if initial costs are not taken into account, this system has lowest operational cost when operated at solar mode having regeneration with the help of flat plate collectors.

3.4.2 Hybrid Solar System

Mohan et al. [45] have designed a Liquid Desiccant Vapour Compression (LDVC) hybrid system consist of a 0.8 TR vapour compression air conditioning system and LiBr liquid desiccant loop as shown in Fig.11. They have carried out an experiment on the hybrid system in balanced ambient room type calorimeter. This kind of work was also found in other research papers [46-49]. In the study, liquid desiccant was regenerated with the use of waste heat. The authors have investigated the effect of varying room air temperature and specific humidity on performance of hybrid system. The main attention of the system is that very low LD to air flow ratio (~0.01) is used in whole experiment. The authors have concluded that dehumidification of process air and regeneration of liquid desiccant reduces as room temperature increases and increases with increase in room specific humidity.

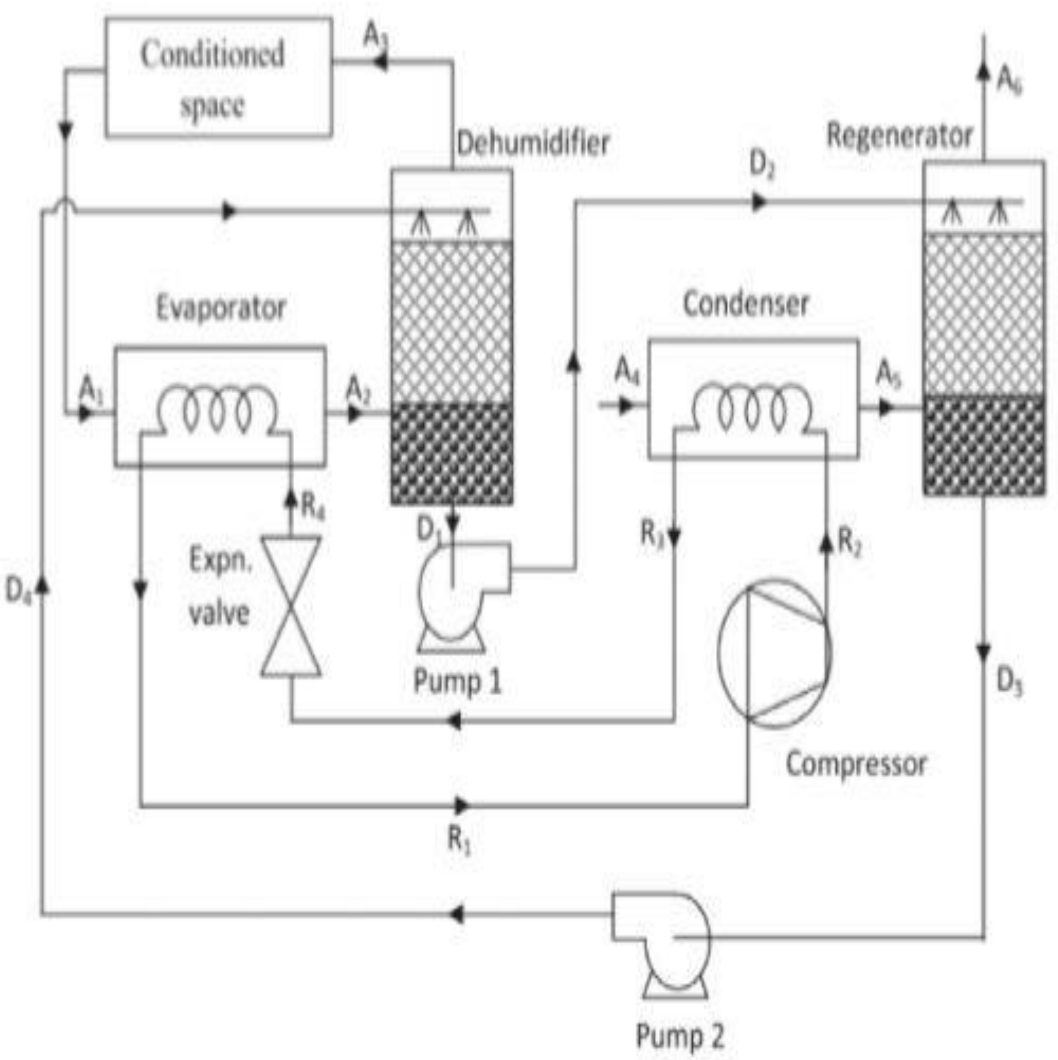

Figure 10: block diagram of hybrid solar system [45]

4. REGENERATION OF LIQUID DESSICANT USING SOLAR ENERGY:

Solar Collector is classified as:

1. Concentrating type of solar collector and,
2. Non-concentrating type of solar collector

The application of collector is according to its field like the air collectors is used for air conditioning, some collector collects solar radiation to produce electricity, or to produce hot or cold water generation [50].

Concentrating type of solar collector is that collector which concentrates the solar energy to a point with the help of the reflective surface where it is absorbed and the solar energy is converted into the heat with the help of direct or the beam radiation.

Parabolic trough collector, solar tower, compound parabolic collector are the concentrating types of solar collector.

Non-concentrating type of solar collector is that type of collector in which the area collecting the solar energy is same as the area which is absorbing the solar radiation like the flat plate collector and the evacuated type of collector.

4.1 Flat Plate Collector

Flat plate collector is a fixed type of solar thermal collector which consists of a transparent cover, black absorber plate with fluid tubes,insulation on side and at the back to minimize the heat loss and air tight enclosure. When the solar radiation is incident on the collector the radiation passes through the transparent cover and then the radiation after passing through this is absorbed by the absorber plate which converts the solar radiation into the heat energy and passes this energy to the fluid passing through the tubes.

It came to be noted that the maximum collector efficiency without reflector is obtained around 51% and with reflector it was around 61%. So it was experienced that the presence of reflector increases the efficiency by 10% with the collector [51].

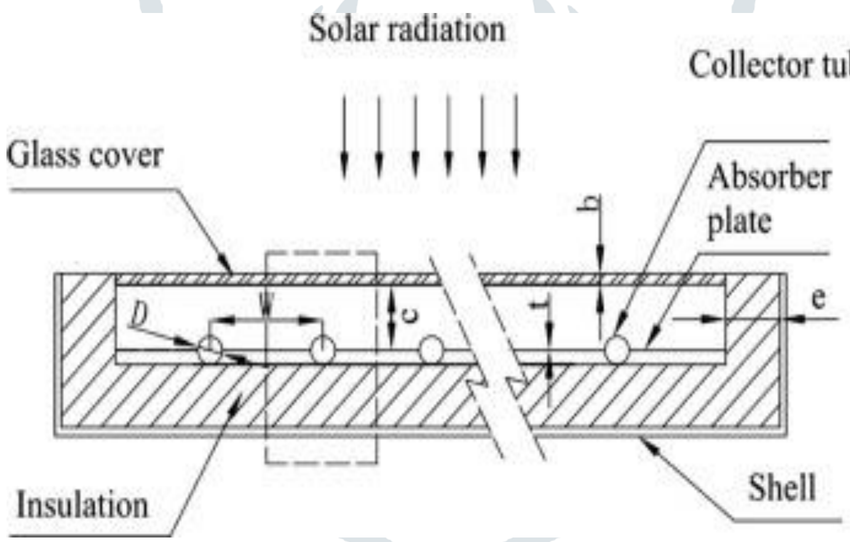

Figure 11: flat plate collector [52]

The efficiency of around 55% to 60% also obtained by [53-55] using different methods of improving the solar collector efficiency.

4.2 Evacuated Tube Collectors

Evacuated tube collector is made up of number of evacuated tube glass tubes. Each of the glass tube has an absorber plate in which the heat pipe is placed inside the tube. When the solar radiation falls on the evacuated tube, the absorber plate absorbs it and converts the solar radiation into the heat energy. And this heat is now transferred from absorber plate to the heat pipe and further it is utilised according to the process for which it is used. In this collector vacuum is created inside the glass tube and this reduces conduction and convection heat losses which generally occurs outside of the tube. And so we get efficient performance of evacuated tube collector as compared to flat plate collector [50].

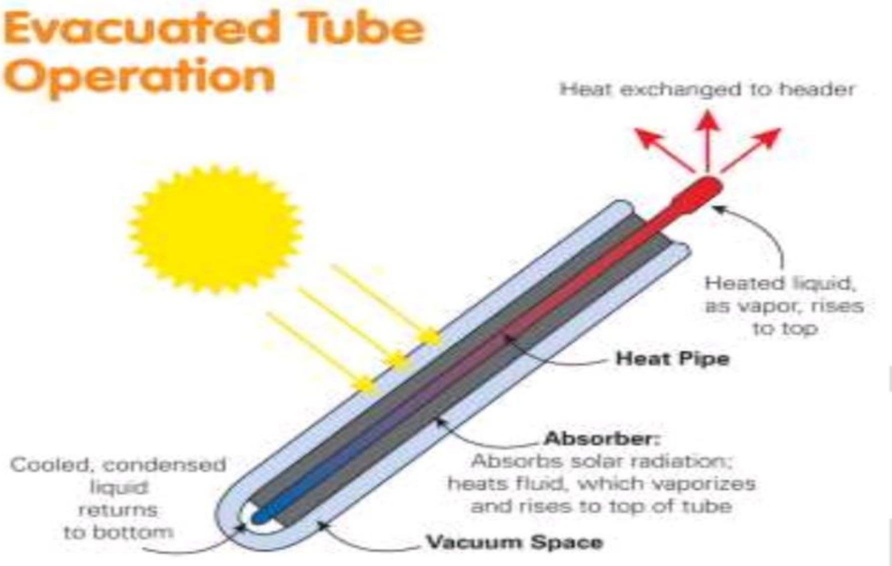

Figure 12: evacuated tube collector [50]

There are different types of evacuated tube collectors such as evacuated glass metal tube collector and evacuated glass to glass tube collector [50].

[56] had carried out the field performance with a 4m^2 flat plate collector and 3m^2 evacuated tube collector and it was found that the FPC was quite favourably with the ETC under the same weather conditions and when connected to a 300litre hot water tank.

Investigation on application of aluminium heat pipe in the solar collectors was done by [57].

4.3 Parabolic Trough Collector

Parabolic troughcollector is a collector which concentrates the incident solar energy about 70-100 times on the absorber tubes, achieves temperature of about 350°C to 550°C [58].

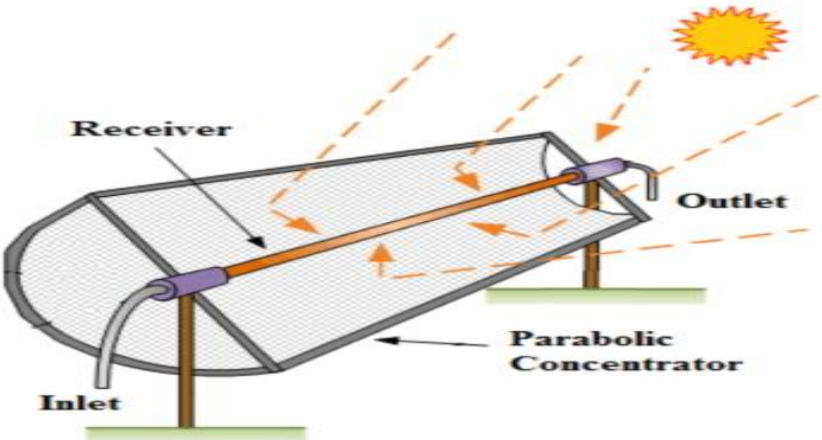

Figure 13: parabolic trough collector [59]

5. PERFORMANCE PARAMETER OF LD REGENERATION

5.1 Concentration AndCondensing Temperature

Xiaohui She et al: [60] this research paper suggest the relation between concentration level of liquid desiccant, condensing temperature & C.O.P for the different types of liquid desiccant like LiBr,CacL2,LiCl. It also show that at what level we maintain our concentration level for particular desiccant through analysis of curve fitting by empirical formula and also compare this analysis with computer programming result. Here in this proposed system they using total three heat exchanger separately.

(a) Sensitive study of solution concentration involved in the system is conducted at different condensation temperature. Under standard condensing temperature (50 C), the suggested solution concentration is around 0.31 for LiCl aqueous solution system, 0.45 for LiBr aqueous solution system and 0.42 for CaCl2 aqueous solution system.

(b) for LiCl and LiBr aqueous solutions, the correlation is linear, and can be easy to get, while it is nonlinear for CaCl2 aqueous solution,
For LiCiXs = 0.008 xTcon - 0.09
For LiBrXs = 0.008 xTcon + 0.05
For cacl2 Xs = -0.0001 xTcon3 + 0.0157 xTcon2 - 0.755 xTcon + 12.361

(c) For CaCl2 aqueous solution, Performance improvement increases at first, decreases later and achieves maximum value with the increase of solution concentration Xs.

(d) When Tcon is 45 C, the maximum Performance improvement 11.93% is achieved as Xs reaches 0.37;whileTcon is 47.5 C, the maximum value is13.19% and the corresponding solution concentration is 0.39; when Tcon is 50 C, the maximum Performance improvement is 15.09% as Xs arrives at 0.42; when Tcon is 52.5 C, the maximum value is 16.03%;when Tcon is 55 C, the maximum Performance improvement 17.04%is obtained as Xs is 0.45.

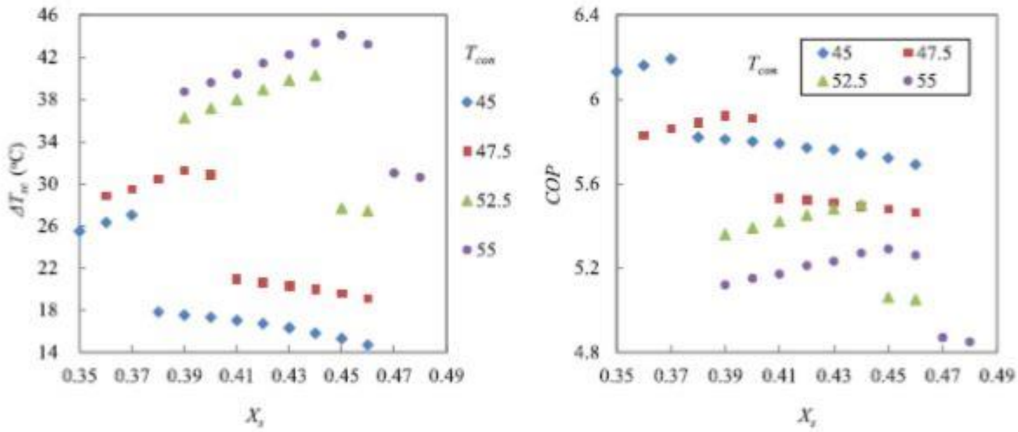

Figure 14: system performance for $cacl_2$ solution [60]

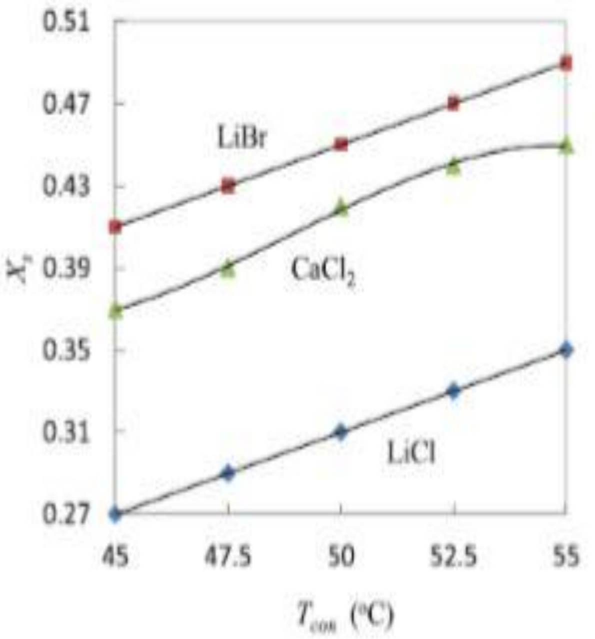

Figure 15: relations between the condensing temperature and concentration [60]

5.2 Effects Of Inlet Temperature Of The Desiccant On The Air Absolute Humidity Change [61]

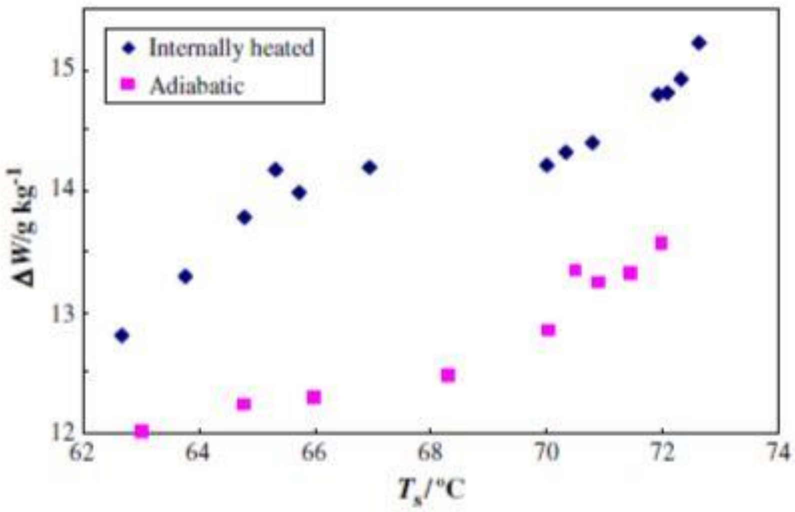

Figure 16: effects of inlet temperature of the desiccant on the air absolute humidity change [61]

Yonggao Yin et al: [61] The research paper suggest new design of the internally cooled/heated dehumidifier/regenerator based on the plate–fin heat exchanger (PFHE). By the internally cooled dehumidification testing, effects of the cooling water temperature, the air flow rate and the desiccant temperature on the dehumidification performance and the cooling efficiency were presented. The behaviour of internally cooled dehumidification process was compared with that of the adiabatic dehumidification process.

During the desiccant solution dehumidification, because of the water vapour partial pressure difference the vapour in the air would become liquid water to enter into the solution, and release the vaporization heat which results in increasing temperature of the solution and air. The cooling water entering into the dehumidifier would bring away the heat to restrain the increase of the solution temperature. So the internally cooled dehumidifier could hold the low temperature of the solution to show good dehumidifying performance. If the cooling water is inactivated, the dehumidifier would be an adiabatic one, just the same as the packed bed.

The dehumidification performance could be promoted by increasing the air flow rate or decreasing the cooling water temperature. The outlet temperature of the desiccant solution increased with the increase of the temperature of cooling water, and the outlet temperature of the solution was very close to the outlet temperature of the cooling water, which indicated that the PFHE had good cooling performance for the desiccant.

During the internally cooled dehumidification process, the cooling efficiency of desiccant decreased with the increase of the cooling water temperature, which was very different from the only heat transfer process in the PFHE.

6. CONCLUSION

In this paper authors try to identify best suitable solution for liquid desiccant regeneration system, especially using solar energy. This LD regeneration system is a promising solution for future if correct method of regeneration with proper liquid desiccant is selected. Environmental parameter is also consider which affected the performance of regeneration LD system. After getting all the correct parameter optimal system could be design , manufacture, and experiment can be carried out in a future.

REFERENCES

1. Fernando M. Gomez-Castro Dietrich Schneider Tina Pabler Ursula Eicker., 2018,Review Of Indirect And Direct Solar Thermal Regeneration For Liquid Desiccant Systems, Renewable and Sustainable Energy Reviews 82, pp. 545-575.
2. Kalpesh V. Modi, Dhruvin L. Shukla., 2018,Regeneration Of LD For Solar Air Conditioning And Desalination Using Hybrid Solar Still, Energy Conversion and Management 171, pp. 1598-1616.
3. Grossman G. Solar-powered systems for cooling, dehumidification and air conditioning. Sol Energy 2002; 72: 53–62.
4. Grossman G. Solar cooling, dehumidification and air conditioning. In: Cleveland, C.J. (Ed.) Chapter in encyclopedia of energy; 2004, 5, p. 575–85.
5. Ani FN, Badawi EM, Kannan KS. The effect of absorber packing height on the performance of a hybrid liquid desiccant system. Renew Energy 2005; 30 (15): 2247–56.

6. Ma Q, Wang RZ, Dai YJ, et al. Performance analysis on a hybrid air conditioning system of a green building. Energy Build 2006; 38 (5):447–53.
7. Yonggao Y, Xiaosong Z, Zhenqian C. Experimental study on dehumidifier and regenerator of liquid desiccant cooling air conditioning system. Build Environ 2007; 42 (7):2505–11.
8. Shobha BS, Watwevilas, Rajesh AM. Performance evaluation of a solar still coupled to an evacuated tube collector type solar water heater. Int J InnovatEngTechnol 2012;1(1):72–84.
9. Cheng Q, Zhang X. Review of solar regeneration methods for liquid desiccant air conditioning system. Energy Build 2013; 67: 426–33.
10. Hollands KGT. The regeneration of Lithium chloride brine in a solar still for use in solar air conditioning. Sol Energy 1963; 7: 39–43.
11. Mullick SC, Gupta MC. Solar desorption of absorbent solutions. Sol Energy 1974; 16: 19.
12. Peng CSP, Howell JR. The performance of various types of regenerators for liquid desiccants. Washington D.C., U.S.A: Winter Annual Meeting of ASME; 1981.
13. Lodwig E, Wilke DA, Bressman J. A solar powered desiccant air conditioning system in: Proceedings of the 1977 annual meeting of the American section of the international solar energy society; 1977, p. 1:7.1−7.3.
14. Howell JR. A survey of active solar cooling methods. Prog Sol Eng 1987:171–82
15. Jain S, Dhar PL, Kaushik SC. Experimental studies on the dehumidifier and regenerator of a liquid desiccant cooling system. ApplThermEng 1999; 20: 253–67.
16. Scalabrin G, Scaltriti G. A liquid sorption–desorption system for air conditioning with heat at lower temperature. J Sol Energy Eng 1990; 112: 70–5.
17. Patnaik FS, Lenz TG, Lof GOG. Experimental studies with a solar open cycle liquid desiccant system. In: Proceedings of ISES solar world congress, Hamburg, Germany; 1987, p. 1013–8.
18. Chung TW, Lai C, Wu H. Analysis of mass transfer performance in an air stripping tower. Sep SciTechnol 1999; 34 (14):2837–51.
19. Factor H, Grossman GA. A packed bed dehumidifier/regenerator for solar air conditioning with liquid desiccants. Sol Energy 1984; 24: 541–50.
20. Lof GOG, Lenz TG, Rao S. Coefficients of heat and mass transfer in a packed bed suitable for solar regeneration of aqueous lithium chloride solutions. Trans ASME J Sol Energy Eng 1984; 106: 387–92.
21. Gandhidasan P, Ullah MR, Kettleborough CF. Analysis of heat and mass transfer between a desiccant air system in a packed tower. Trans ASME J Sol Energy Eng 1987; 109: 89–93.
22. Patnaik S, Lenz TG, Lof GOG. Performance studies for an experimental solar open-cycle liquid desiccant air dehumidification system. Sol Energy 1990; 44: 123–35.
23. Khan AY, Ball HD. Development of a generalized model for performance evaluation of packed-type liquid sorbent dehumidifiers and regenerators. ASHRAE Trans 1992; 98: 525–33.
24. Elsayed MM, Gari HN, Radhwan AM. Effectiveness of heat and mass transfer in packed beds of liquid desiccant system. Renew Energy 1993; 3: 661–8.
25. Sultan GI, HamedAM, Sultan AA. The effect of inlet parameters on the performance of packed tower regenerator. Renew Energy 2002; 26: 271–83.
26. Palaniappan C, Subramanian SV. Economics of solar air preheating in south Indian tea factories: a case study. Sol Energy 1998; 63: 31–7.
27. Purohit P, Kandpal TC. Solar crop dryer for saving commercial fuels: a techno economic evaluation. Int J Ambient Energy 2005; 26 : 3–12.
28. Purohit P, Kumar A, Kandpal TC. Solar drying vs. open sun drying: a framework for financial evaluation. Sol Energy 2006; 80: 1568–79.
29. Kalogirou SA. Seawater desalination using renewable energy sources. Prog Energy Combust Sci 2005; 31: 242–81.
30. Tabor H. Solar ponds. Sci J 1966; 66: 66–71.
31. Weinberger H. The physics of the solar pond. Sol Energy 1964; 8: 45–56.
32. Tabor H, Matz R. Solar pond project. Sol Energy 1965; 9: 177–82.
33. J.R.MEHTA., 2014, Regeneration of Liquid Desiccant Using Solar Energy, Proceeding of 2014 1st international conference on non-conventional energy.
34. G. Lychnos, J.P. Fletcher, P.A. Davies, Properties of seawater bitterns with regard to liquid-desiccant cooling, Desalination 250 (2010) 172–178.
35. S.Bouzenada, A.N.Kaabi, L.Fraikin,A.Leonard., 2014, Experimental study on dehumidification/regeneration of LD: LiBr Solution, 4th International conference on sustainable energy information technology (SEIT-2014).
36. L. Mei, Y.J. Dai,"A technical review on use of liquid desiccant dehumidification for air conditioning application",Renewable and Sustainable Energy Reviews12)2008 (662-689.
37. Gershon Grossman, Alec Johannsen, "Solar Cooling and Air Conditioning", Prog.Energy Combust. Sci., Vol. 7, pp. 185-228.

38. Dhruvin L. Shukla,Kalpesh V. Modi.,2017, A Technical Review On Regeneration Of Liquid Desiccant Using Solar Energy, Renewable and sustainable energy review 78, pp. 517-529.
39. J.R.Mehta M V Rane., 2013, Liquid Desiccant Based Solar Air Conditioning System With Novel Evacuated Tube Collector As Regenerator, Procedia Engineering 51, pp. 688-693.
40. K.G.T. Hollands., 1963,The Regeneration of Lithium Chloride Brine in a Solar Still, Commonwealth Scientific and Industrial Research Organisation, Engineering Section, Melbourne, Australia.
41. Gandhidasan P. Theoretical study of tilted solar still as a regenerator for liquid desiccants. Energy Convers Manag 1983; 23: 97–101.
42. Gandhidasan P, Al-Farayedhi AA. Solar regeneration of liquid desiccants suitable for humid climates. Energy 1994; 19: 831–6.
43. Sick F, Bushulte TK, Klein SA, Northey P, Duffl JA. Analysis of the seasonal performance of hybrid liquid desiccant cooling systems. Sol Energy 1988; 40 (3): 211–7.
44. Kumar R, Dhar PL, Jain S, Asati AK. Multi absorber standalone liquid desiccant air conditioning systems for higher performance. Sol Energy 2009; 83: 761–72.
45. Mohan BS, Tiwari S, Maiya MP. Experimental investigations on performance of liquid desiccant-vapor compression hybrid air conditioner. ApplThermEng 2015; 77: 153–62.
46. Dai YJ, Wang RZ, Zhang HF, Yu JD. Use of liquid desiccant cooling to improve the performance of vapor compression air conditioning. ApplThermEng 2001; 21: 1185–202.
47. Jain S, Dhar PL, Kaushik SC. Evaluation of solid-desiccant-based evaporative cooling cycles for typical hot and humid climates. Int J Refrig 1995; 18: 287–96.
48. Aly AE, Fathalah K, Gari HA. Analysis of an integrated vapour compression and a waste heat dehumidifier air conditioning system. Heat Recovery Syst 1988; 8: 503–28.
49. Worek WM, Chung JM. Desiccant integrated hybrid vapor-compression cooling: performance sensitivity to outdoor conditions. Heat Recovery Syst 1988; 8: 489–501.
50. Raghurajsinh .B. Parmar , KedarBhojak., May-June, 2016, Performance of an evacuated tube collector with heat pipe technology, International Journal of Engineering Research and General Science Volume 4, Issue 3, Gandhinagar,Gujarat, India.
51. HimangshuBhowmika, Ruhul Amin., 2017, Efficiency improvement of flat plate solar collector using reflector, Energy Reports 3, pp. 119-123.
52. Zhang Jiandong, Tao Hanzhong,ChenSusu a., 2015, Numerical simulation for structural parameters of flat-plate solar collector, Solar Energy 117 , pp. 192–202.
53. Hematian, A., Ajabshirchi, Y., Bakhtiari, A.A., 2012. Experimental analysis of flat plat solar air collector efficiency. Indian J. Sci. Technol. 5 (8), pp. 3183–3187.
54. Sarkar, J., 2013. Performance of a flat-plat solar thermal collector using supercritical carbondioxide as heat transfer fluid. Int. J. Sustain. Energy 32 (6), pp. 531–543.
55. Sivakumar, P., Christraj, W., Sridharan, M., Jayamalathi, N., 2012. Performance improvements study of solar water heating system. ARPNJ. Eng. Appl. Sci. 7(1), pp. 45–49.
56. L.M. Ayompe, A. Duffy, M. McKeever, M. Conlon, S.J. McCormack, 2011. " Comparative field performance of flat plate and heat pipe evacuated tube collectors (ETCs) for domestic water heating systems in a temperature climate," Energy, vol.36, pp. 3370-3378.
57. Boris Rassamakin, SergiiKhairnasov, VladilenZaripov, AndriiRassamakin, 2013. "Aluminium heat pipes applied in solar collectors," Solar Energy, vol. 94, pp. 145-154.
58. Solar Thermal Electricity Global Outlook 2016 (Solar Thermal Electricity Global Outlook Report).
59. SeyedEbrahimGhasemiAli Akbar Ranjbar., October 2016, Thermal performance analysis of solar parabolic trough collector using nanofluid as working fluid: A CFD modelling study, Journal of Molecular Liquids Volume 222, pp. 159-166, Qaemshahr, Iran.
60. Xiaohui She, Yonggao Yin, Xiaosong Zhang. "Suggested solution concentration for an energy-efficient refrigeration system combined with condensation heat-driven liquid desiccant cycle"RenewableEnergy83)2015 (553-564.
61. Yonggao Yin, Xiaosong Zhang, Geng Wang, Lei Luo , " Experimental study on a new internally cooled/heated dehumidifier/regenerator of liquid desiccant systems", international journal of refrigeration 31 (2008) 857 – 8 66.
62. Li Yinglin,,Zhang Xiaosong , Tan Laizai , Zhang Zhongbin , Wu Wei , Xia Xueying , "Performance analysis of a novel liquid desiccant-vapor compression hybrid airconditioning system"Energy109)2016(180e189.