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Regeneration of Liquid Desiccant air-conditioning System
A brief review of Regeneration and dehumidification

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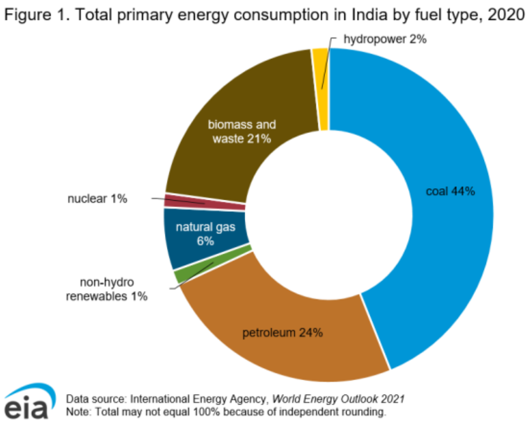
ABSTRACT: An efficient method of controlling moisture content in supply air is desiccant dehumidification systems. As they do not use ozone-depleting coolants but still consume less energy as compared to vapour compression system. In the hot and moist areas, the liquid desiccant air-conditioning systems depend on evaporative cooling which was put forward as an alternative to the old vapour compression system because of its superiority in, removing air latent load, friendly environment, removing of pollutants, from the air and reducing the electrical energy. This paper provides a large review of Liquid Desiccants Systems (LDSs). The factors of LDSs like dehumidifier, regenerator, packing material and liquid desiccant effects along with its energy storage capabilities is mentioned. Furthermore hybrid of LDSs with sensible cooling techniques is studied. Finally current problems in LDSs are also mentioned.

KEYWORDS: Desiccant System, Dehumidifier, Regenerator.

I. INTRODUCTION

According to research conducted by International Institute of Refrigeration, energy used by air conditioning during household and commercial application is about 45%. 15% of total energy of air conditioning system in world. Figure 1 shows energy consumption in India in2020. In India primary energy consumption has been decreased by 6% in 2020 and now it is returning to the average levels in 2021 by 10%. Coal is to most of 44% of India’s total consumption. Petroleum and liquids are holding 24% of energy whereas the old biomass and waste is 21%. The other atomic waste is 1% of primary energy consumption in India. Whereas, natural gas is contributing 6% for country’s energy consumption. Nowadays India is planning to boost the natural gas market by 15% till 2030.



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The issue with air conditioning systems that are in use is not only have less efficiency but also use refrigerants such as CFC, HCFC and HFC, which is responsible for ozone layer depletion. Global Warming Potential (GWP) is highest of CFC and Ozone Depleting Potential (ODP) and its effect last about 45-1000 years on environment. Conventional vapour compression systems (VCSs) at the same time cools and dehumidifies the air since a desiccant system only dehumidifies it. Desiccant system can be brought in implementation with combination of evaporative cooling to keep up the temperature and moisture of air. Energy disaster and air conditioning request led to increase of research in desiccant system as productive method to fulfill it.

Desiccant system can be classified on type of desiccant used:

1. Liquid Desiccant system
2. Solid Desiccant System
3. Advanced Desiccants (such as polymeric desiccant, bio-desiccant, etc.)

Solid Desiccants involve silica gel, titanium silicates, alumina, zeolite, etc. since liquid desiccant involve lithium chloride, lithium bromide, tri-ethylene glycol, calcium chloride, etc. In this review, liquid desiccant systems are discussed in detail.

II. LIQUID DESICCANT SYSTEMS

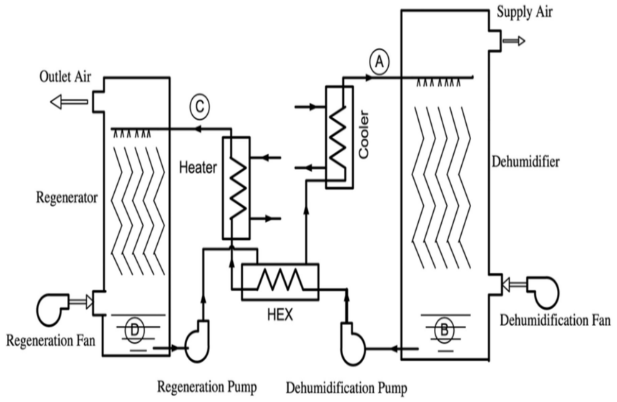

Fig.2. Schematic of an LDS [3] ,

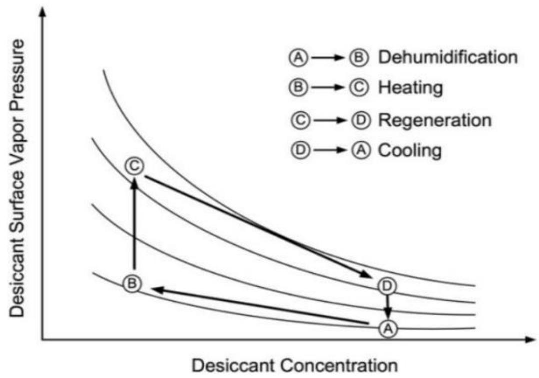

Fig.3. Desiccant dehumidification and regeneration process [3]

A simple LDS containing dehumidifier and regenerator as presented in figure 2. Moisture from air is preoccupied by the desiccant since difference in vapour pressure in the middle of air and the surface of desiccant solution. Dehumidification occurs till vapour pressure of desiccant reaches balance with air. Following dehumidification, air is transferred to evaporative cooler to cool down to the needed temperature since the diluted desiccant solution is given to regenerator. Before giving it to the desiccant directly to regenerator, it is first passed between a sensible heat exchanger where its temperature is increased. Later the liquid is reveal to regenerative air and because of difference in vapour pressure; the moisture is transmitted from solution to air. Then the concentrated solution is once more is passed between heat exchanger and a cooling coil before it is forwarded to dehumidification unit. Now the heat exchangers are given to pre-heat the fragile solution and pre-cool the powerful solution.

III. LIQUID DESICCANT PROPERTIES

As far as LDSs are concerned with liquid desiccants are the most vital part of the system. Several properties which decide its potential to be used in a desiccant cooling system. Properties involve conductivity, dynamic viscosity, specific heat capacity, density, boiling point elevation, regeneration temperature, and so on. Between all the properties, Surface Vapour Pressure is one the most crucial parameters that is supervise for heat and mass transfer in dehumidifier [4]. As well as liquid desiccants are fragrance free, harmless, non-flammable and cheap. $CaCl_2$ is more profitable while LiCl is more stable between the three salts [4].

Commonly used liquid desiccants like LiCl and LiBr was differentiated by Liu et. al. Lithium chloride (LiCl) is better dehumidifier than lithium bromide (LiBr) as it has less vapour pressure and thus regeneration performance of Lithium Bromide (LiBr) is superior to lithium chloride (LiCl), which was concluded under similar desiccant volumetric

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flow rates. As well as since all the running solutions are very corrosive so any carryover during dehumidification may bring out unpleasant effects on occupants health[5]. Potassium Formate(HCOOK) which is a new desiccant is less corrosive as differentiated with another aqueous salts and has negative crystallization temperature and less costly than others. Investigation by Qiu et al. using potassium formate was a novel air dehumidifier. At the same time a very concentrated solution got hold of it then it was up to effectively dehumidify the air with a highly moisture content (75% RH) but in sync it was very low in dehumidifying low moisture air (43% RH) [7].
Some important advantages and disadvantages pointed by Baniyounces et al. of liquid desiccant are as follows:

Advantages:
1.LDSs are acceptable for use with very low regeneration temperature since low pressure drop across it.
2.The capacity to uplift liquid desiccants make the whole unit small and close packed.
3.When heat source for regeneration is not available then the stored liquid desiccants can be used.

Disadvantages:
1.Lithium chloride, lithium bromide and others that have corrosive nature among all 2.liquid desiccants is the large threat for liquid desiccant system.
3.Serious issues to occupant's health can be caused by any carry-over of liquid desiccant across the air supply.
4.Desiccants of fluid salts get crystallized.
During dehumidification, the mass concentration is opted in a way where vapour pressure of desiccants is low than air to be processed for productive mass and heat transfer. Higher concentration is very good for dehumidification process. Still corrosive nature increases with more concentration and it may damage storage tank and desiccant unit air outlet. Hence the best range of concentration is selected for various liquid desiccants. It is shown in Table 1 [9].

Liquid Desiccant	Concentration Range (%)
Lithium Chloride	30-37
Lithium Bromide	45-60
Potassium Formate	65-71

TABLE 1
*Temperature in the range of 30-35 degree Celsius.

IV. DEHUMIDIFICATION

Heat and mass transfer from the inlet air to the liquid desiccant occurs in dehumidifier, meanwhile the temperature difference leads the heat transfer among the air and desiccant solution. Due to vapour pressure difference it drives the mass transfer among air and desiccant. Finned-tube surface, coil-type absorber, spray tower and packed tower are mostly used dehumidification units [10]. Dehumidification can be divided into two types based on heat extraction process; which are adiabatic dehumidifier and internally cooled dehumidifier. Figure 4 describes two vertical spray towers with and without internal cooling unit [11].

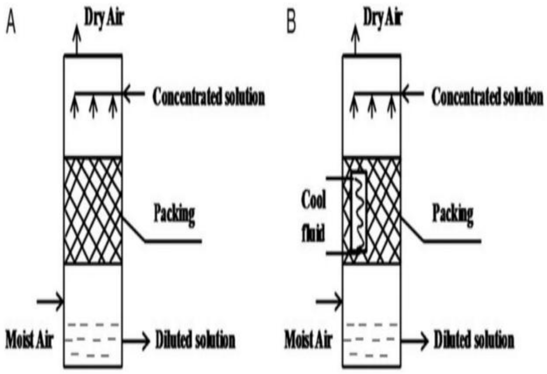

Fig.4. (A) Adiabatic dehumidifier, (B) internally cooled dehumidifier [11]

Xiong and his colleagues expanded a two stage liquid desiccant cooling system using a power analysis. In this kind of dehumidification process, process air has to pass along two-humidification units. Inlet air is transferred between calcium chloride solutions trailed by lithium chloride solution. Help to reduce irreversibility in dehumidification process is the vital advantage of pre-dehumidification process using calcium chloride. Further, during regeneration lithium chloride is regenerated top followed by calcium chloride. This is because regeneration capacity of calcium chloride is excessive than that of lithium chloride. The thermal co-efficient performance of the suggested system was 0.73 since energy efficiency was 23% was the outcome. Also the energy storage capacity of the desiccant solutions appeared over single-stage dehumidification [12].A medium for liquid desiccant to link with the process air stream to remove moisture is a packing material. A packing material must be motionless to liquid desiccant. Packing material and its configuration remarkably influence the show of dehumidification unit of the desiccant cooling system. They are commonly differentiated as regular/ structured packing and random packing build on their configuration. Regular packing expands the performance of the dehumidifier by giving low pressure drop for the air stream and is simple to install as compared with random packing. It also lowers the liquid desiccant resistance in the dehumidification unit. On the other side, random packing material cannot adapt to the variation in liquid desiccant flows and results in unequal distribution of desiccant solution above the surface of packing material, which lowers the performance of the dehumidification system. But, regular packing is costly than random packing [4, 13].The flow patterns of the humid air and liquid desiccant is shown in figure 5. The three common flow patterns in an adiabatic dehumidifier such as parallel flow, cross-flow and counter flow. The contact area and the process of Interaction between desiccant and inlet air is determine by flow pattern. They also determine the type of mathematical model that is acceptable for a specific desiccant system. Liu and his colleagues made analytical solutions of dehumidifier and regenerator based on the kind of flow using mathematical models from existing research. Analytical solutions of all cases are in great agreement with the experimental results from other researchers [14].

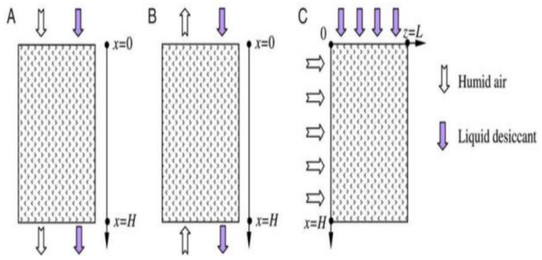

Figure 5, Flow patterns of air and liquid desiccant in dehumidification unit

V. REGENERATION

A regenerator is a unit which is uses to convert the low or diluted desiccant solution into a concentrated solution as shown in figure 2. The basic function and process of two units is contrast to each other but still regenerator is similar to the dehumidifier. A dehumidifier unit has a superfluous layer of insulation to lower the heat and mass transfer from the atmosphere is yet another difference. Regenerator is normally an adiabatic unit. Yet, Yin and his colleagues expressed that as the regeneration process carry on with the temperature of liquid desiccant that lowers and solution cannot provide latent heat of vaporization of that is needed to transfer water in the solution to the incoming air. Hence, the performance of the system reduces. So, they put forward an internally heated generator in which a heating coil supplies heat energy to keep the solution temperature [16]. Regeneration procedure using thermal energy is the most frequent method. But there are other methods for regeneration as shown in the Figure 6. Given as follows:

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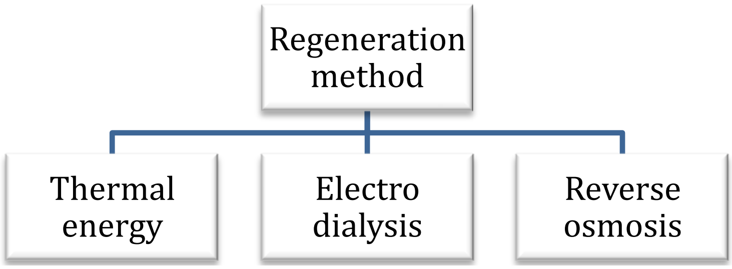

Fig. 6.Various methods of regeneration

Cheng and his fellow researchers investigated the performance of an electro dialysis regenerator for liquid desiccant during experiment. Ions are transferred through a selective membrane under the effect of electric field, during the electro dialysis process. A parametric analysis of electro dialysis regenerator was carried out on current utilization and solution mass transfer rate per unit area of anion exchange membrane. Outcomes showed that the highest current utilized by the system was 55%. Also higher in desiccant flow rate rises the mass flow rate and current utilization by powerful solution [17].

Commonly used method for desalination of seawater is reverse osmosis. Likewise weak solution can be transferred into a strong solution by separating the added water from the desiccant [18]. An MFI zeolite membrane was used by Al-Suleiman and his colleagues to unconnected the lower calcium chloride solution from water, while doing this process. They suggested this method for countries like Saudi Arabia where there is a shortage of soft water. They put together this method of regeneration with a two-stage evaporative cooling in which water needed by the evaporative coolers was provided by the reverse osmosis [18].

VI. HYBRID LIQUID DESICCANT AC SYSTEMS

Liquid desiccant systems are acceptable for removing latent heat from the air. But, a desiccant cooling system is helpless of removing sensible heat from air. So, desiccant systems are regularly used in fusion with direct or indirect evaporative cooling system, vapour compression refrigeration system or vapour absorption system to separate latent and sensible heat before putting it in space. A descriptive review of the system is shown in the figure 7 as follows:

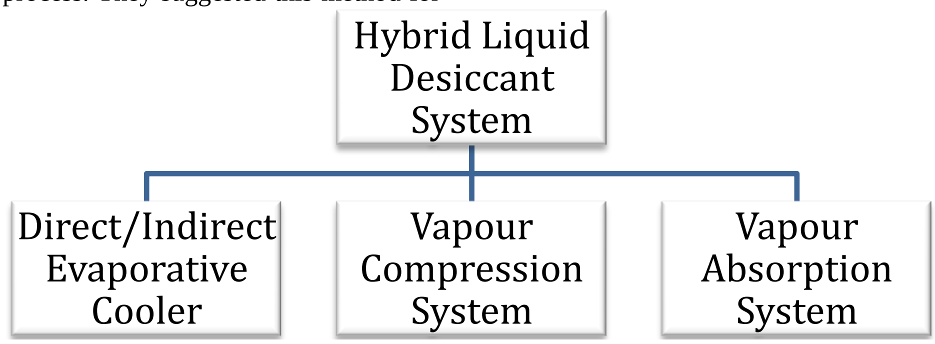

Figure 7, Hybrid of LDS with various systems.

VII. CURRENT PROBLEMS

Even though desiccants systems have demonstrated to be more well organized and environmental friendly than conventional VCSs, desiccant systems have some weakness and problems. Solving such problems would make them more ambitious in the market. Large problems include reverse dehumidification, desiccant unit corrosion, desiccant carry over. Also conventional air conditioners come in little sizes. But, the desiccants systems unite with an evaporative cooler are usually big [4]. Research has shown some significant solutions. Reverse dehumidification takes place when the process air is humidified rather than dehumidification. Reverse dehumidification can take place even when the vapour pressure of liquid desiccant is effective [19]. By using plastic material in the dehumidification unit and storage tank the problem of corrosion can be solved. When the particles of desiccant solution mix with the process air takes place carry over. In inner space, carry-over can be dangerous for health of occupants and can take to corrosion of ducts and pipes near air outlet. One condition to this issue is to introduce micro-porous membrane. Allowing moisture transfer between such semipermeable membranes would prevent communication between the process air and liquid desiccant [20]. Also it gives a distinct and constant surface area that would be free of air and desiccant flow rates and can inhibit the approach of microbes in working conditions because of low moisture content on membrane-air interface [20, 21]. Das and Jain did an experimental study using micro-porous semipermeable hydrophilic membranes as desiccant cores to decrease the carry-over of liquid desiccant in supply air. Lithium chloride was used as a liquid desiccant to test membrane contractors enlarged from hydrophobic PP, PVDF and Tyvek membrane. The outcomes indicated that even though the problem of carry-over was controlled, dehumidification benefit was low varying between 23% and 45%, as membranes create additional resistance [22].

Kumar and his colleagues proposed a simulation and parametric study of two innovative single liquid desiccant cycles. Both the cycles used many absorbers on falling film design. Falling–film design was the best option as it has low pressure drops. Suggested cycles not only improved the coefficient of performance of the system but also controlled the issues of carry-over when operated at very high concentration of desiccant solution [19]. Crystallization of liquid desiccant was another problem. Crystallization can take place in a liquid desiccant solution stored at high concentration with low temperature [4]. Ge and his colleagues did a comparison study among experimental data and; heat and mass transfer model for membrane based dehumidifier and regenerator. The results were that the predicted results from model agreed with experimental results of the dehumidifier. But the model did not hold the agreement with regenerator experiment results. Discrepancies through the model and experimental data that caused by the crystallization of lithium chloride aqueous solution is the slit of membrane at the time of regeneration process. These crystals lowered the moisture transfer and so produced errors in experimental data [23]

VIII. CONCLUSION

1. Desiccant cooling systems were studied in this communication. Conclusions are as follows:
Any ozone-depleting refrigerants are not used by desiccant cooling systems. Also, they can work successfully on low-grade heat from solar energy, combined heat and power plant or misused heat from factories or chimneys.
2. Mostly used desiccants are lithium chloride and calcium chloride. Lithium chloride is well liked as low vapour pressure and stability while calcium chloride is less costly and easily available. So, both the salts are corrosive nature and need require safety before use. Between all aqueous salts, potassium formate is less corrosive and can be used as a viable replacement.
3. Inside cooled dehumidification units help to decrease the heat discharge and allow the less flow rates, which improves the performance of system. Two-stage dehumidification unit can help to lower the irreversibility in the dehumidification process and increase the storage capacity of desiccant solutions.
4. Kind of packing material selected for dehumidification core is vital part. Structured packing let lower pressure drop than random packing but is costly. On the other side, random packing material has less performance as of uneven distribution of liquid desiccant. In dehumidifier central airflow resistance lowers with increase in void ratio. Mass transfer performance expands with increase in wetted area.
5. Liquid desiccant can be regenerated using thermal energy one of two by heating the weak solution or heating the regeneration air using air-water heat exchanger.
6. Using thermal energy to regenerate liquid desiccant is not one option. It can also be carried out by help of electro dialysis or reverse osmosis depending on condition and relevance.
7. Mostly suitable system for drying the air is an adiabatic desiccant system. If cooling is needed, then hybrid system has to be used. A LDS mixed with a VCS has a powerful coefficient of performance.
8. It can also be mixed with to an evaporative cooler direct or indirect. A hybrid LDS does not need any refrigerants and hence is more environmental friendly.

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