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A Review on Recent Development in Liquid Desiccant Dehumidification Assisted Cooling Systems

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Abstract: *The building uses a substantial amount of energy, much of it for air conditioning (AC) systems. Due to its technique of humidity regulation and usage of refrigerants with potential for global warming, conventional air conditioning based on vapour compression refrigeration (VCR) is neither energy efficient nor environmentally benign. VCR is being replaced by the liquid desiccant air conditioning system (LDAS), which shows promise. This review study offers a thorough summary of LDAS's recent advancements. This also includes discussion of the advancements in dehumidifier, regenerator, desiccant material, and applications. The viability of systems in variable climate, performance measurement and interior air quality are also discussed. This communication will be helpful in identifying the research needs and opening up new avenues for future study to boost LDAS effectiveness.*

Keywords: Dehumidification, Liquid desiccants, Performance, Regeneration

I. INTRODUCTION

Desiccant systems merely dehumidify the air; conventional vapour compression systems (VCSs) simultaneously chill and dehumidify it. To regulate the temperature and moisture of the air, desiccant systems can be used in tandem with evaporative cooling or other traditional coolers. The need for air conditioning and the energy crisis increased interest in desiccant systems as a practical solution [1-3]. Based on the type of desiccant utilised, desiccant systems may be categorised:

- Liquid desiccant systems, solid desiccant systems, and advanced desiccants are listed in that order (like, polymeric desiccant, bio-desiccant, etc.). While liquid desiccant consists of lithium chloride, lithium bromide, tri-ethylene glycol, calcium chloride, etc.,
- Solid desiccant includes activated silica gel, titanium silicates, alumina, zeolite, etc.

Liquid desiccant systems have been thoroughly covered in this review. Due to their expanding population and growing human requirements, they are now obliged to interact with nature and its resources. The human race needs air conditioners to live comfortably, but conventional air-conditioning systems consume the majority of conventionally generated electricity and have a negative environmental impact as well. To satisfy their unnecessary needs, they are less concerned about the harm they are causing to nature and using much conventional energy. India, a hot country, needs air conditioning all year round for comfortable working conditions. Latent heat factor regulates the moisture content of the space to be conditioned, whereas sensible heat factor regulates the different temperature variations in enclosed spaces. In the summer, when humidity levels are greater and temperatures must be kept well below the dew point, more conventional energy is needed to maintain a comfortable environment. Therefore, liquid desiccant air cooling may substitute conventional air conditioning in this situation with little to no environmental impact. In the desiccant dehumidification process, water vapour is taken out of the air by being absorbed in the hygroscopic desiccant. Due to its greater capacity to hold moisture, lower air side pressure drop, low regeneration temperature, suitability for adopting simultaneous cooling and dehumidification, air sterilisation capability, and operational flexibility in utilising solar energy, the liquid desiccant is preferred over the solid. For the purpose of cooling both the desiccant and the air, the desiccant system is frequently coupled with a sensible cooling system. A hybrid liquid desiccant air conditioning system is what is used when sensible cooling and desiccant systems are combined in this way (LDAS). Completely reviewing all of the material that is currently accessible is a challenging endeavour. However, the current study carefully evaluates a number of significant studies that aid in obtaining a thorough picture of the advancements in LDAS up to this point [4-6].

The major goal of this work is to provide a thorough analysis of LDAS advancements that can be used to pinpoint research gaps and offer potential directions for future studies [7-8]. The LDAS classification and concept are covered first in the review. The creation of dehumidifiers, regenerators, desiccant materials, climatic viability, mathematical modelling, operating and performance parameters, performance control techniques, and indoor air quality are then covered [9-10].

II. SYSTEM OPERATION

Fig. 1 depicts a straightforward LDS-containing dehumidifier and regenerator. Due to the difference in vapour pressure between the surface of the desiccant solution and the air, moisture from the air is absorbed by the desiccant. Dehumidification continues until the desiccant's vapour pressure equalises with that of the surrounding air. After dehumidification, air is transferred to an evaporative cooler to cool to the desired temperature, while the desiccant solution is diluted and supplied to a regenerator [11-14]. The desiccant is first sent via a sensible heat exchanger where its temperature is elevated before going straight to the regenerator. The moisture is then transported from the solution to the air because to the change in vapour pressure when the liquid is exposed to ambient air. Prior to being transferred to the dehumidification unit, this concentrated solution is once again passed via a heat exchanger and a cooling coil. Here, the weak solution is pre-heated, and the strong solution is pre-cooled using heat exchangers [15-17].

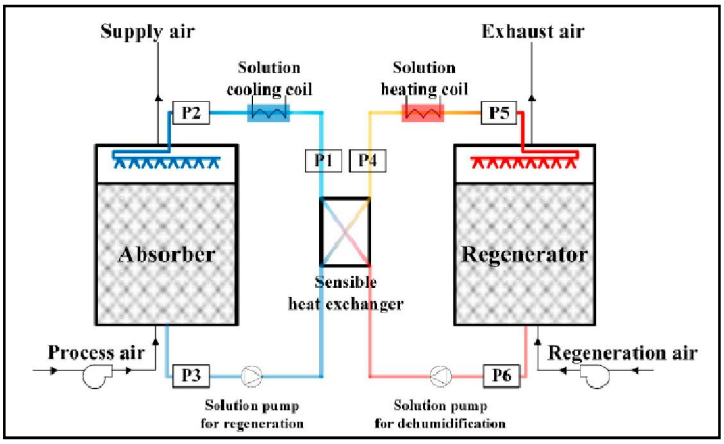

Fig. 1 Schematic layout of liquid desiccant cooling system.

In dehumidification, the mass concentration is selected in such a way that vapour pressure of desiccants is less than air to be processed for effective heat and mass transfer. Higher concentration is more favourable for dehumidification process. But corrosive nature increases with higher concentration and it can damage storage tank and desiccant unit air outlet [18-23]. Thus, an optimum range of concentration is selected for different liquid desiccants. It is shown in the Table 1.

TABLE 1: Concentration range for different desiccant materials

Liquid desiccant	Concentration range (%)
Lithium chloride	30-36
Lithium bromide	45-55
Potassium formate	65-70

III. LIQUID DESICCANTS AND THEIR PROPERTIES

Since desiccant are hydroscopic materials, employed in air conditioning and refrigeration systems to remove moisture from humid air for air conditioning [24-29]. Two different forms of desiccants may exist are as following:

- Solid dehydrator
- Liquid dehydratants.

The concentrated and diluted desiccants may be conveniently stored to give a large energy storage capacity for air dehumidification and cooling with an absorption capability of up to 1000 MJ/m^3. The liquid desiccants can be regenerate at temperatures below 80^oC.

Qualities of effective desiccants:

- Low regeneration temperature and a large saturation absorption capacity
- High coefficients of heat and mass transfer
- Reduced viscosity
- Non-flammable
- Non-Volatile
- Non-Corrosive
- Odourless
- Non-Toxic

Liquid desiccants are the most crucial component of the system in terms of LDSs. Its ability to be employed in a desiccant cooling system depends on a variety of factors. Conductivity, dynamic viscosity, specific heat capacity, density, elevation of the boiling point, regeneration temperature, etc. are examples of properties. Surface vapour pressure is one of the most crucial factors among all the others that govern heat and mass transport in a dehumidifier [30-37]. Liquid desiccants are also frequently odourless, non-toxic, non-flammable, and affordable. Some of the most often used liquid desiccants include lithium chloride (LiCl), lithium bromide (LiBr), and calcium chloride ($CaCl_2$). $CaCl_2$ is the most economical of the three salts, but LiCl is the most stable. The performance of two widely used liquid desiccants, LiCl and LiBr. They came to the conclusion that lithium bromide (LiBr) had higher regeneration performance than lithium chloride (LiCl) at equal desiccant volumetric flow rates because lithium bromide (LiBr) had a lower vapour pressure (LiCl). Additionally, because all aqueous solutions are extremely corrosive, any carryover during dehumidification might have a negative impact on occupant health. A novel desiccant potassium formate has a negative crystallisation temperature, is less corrosive than previous aqueous salts, and is more affordable. Potassium formate was used to investigate a novel air dehumidifier [38-39]. When a highly concentrated solution was used, it was successful in dehumidifying air with a high moisture content (75% RH), but less successful in dehumidifying air with a low moisture content (43% RH).

III. RECENT DEVELOPMENT AND FUTURE SCOPE

The recent development in field of liquid desiccant materials shows improvement in efficiency of the desiccant cooling system as a whole depends heavily on the liquid desiccant materials, which are its fundamental component. In order to choose the best candidates for the system, it is important to analyse the characteristics of the liquid desiccants. There are two main categories of liquid desiccant materials: inorganic aqueous salt solutions like calcium chloride, lithium chloride, lithium bromide, and calcium bromide; and aqueous solutions of organic solvents like triethylene glycol, diethylene glycol, and ethylene glycol. A solar-powered liquid desiccant cooling system using triethylene glycol (TEG) solution. Despite the fact that the testing findings showed TEG to be an excellent desiccant for the cooling system, TEG may readily evaporate into the processed air because of its boiling temperature, which is extremely near to that of water. TEG is therefore inappropriate for applications using liquid desiccant cooling due to the liquid carryover issue. Numerous liquid desiccant dehumidification devices use inorganic salt solutions, such as calcium chloride, lithium chloride, lithium bromide, and potassium formate, which have been the subject of much research. The vapour pressure of a desiccant dehumidification method has a significant impact on its effectiveness. The primary driving force behind the moisture absorption process in the dehumidifier or the moisture desorption process in the regenerator is the difference between the partial pressure of water in the air and the vapour pressure of water above the desiccant solution. A desiccant works better when the vapour pressure is lower because the output air is dryer [40-42].

Liquid desiccant cooling systems have various limitations and issues, while being more effective and ecologically benign than traditional VCSs. They would become more competitive in the market if these issues were resolved. Reverse dehumidification, desiccant unit corrosion, and desiccant carry-over are significant issues. Conventional air conditioners can come in small sizes. However, desiccant systems that include an evaporative cooler are often large. Research has shown several important solutions. When process air is humidified rather than dehumidified, reverse dehumidification takes place. Even when the liquid desiccant has a positive vapour pressure, reverse dehumidification can still happen. Utilizing plastic materials in the storage tank and dehumidifier solves the corrosion issue. When desiccant solution particles combine with the process air, carry-over happens. Carry-over can cause ducts and pipes near air outlets to corrode in enclosed environments, which is bad for tenant health [43-44].

The introduction of micro-porous membrane is one remedy for this issue. The contact between the process air and the liquid desiccant would be prevented by allowing moisture to pass through these semi-permeable barriers. As a result of the low moisture content at the membrane-air interface, it also offers a distinct and continuous surface area that would be free of air and desiccant flow rates and would prevent the spread of germs in the working environment. Reducing the carry-over of liquid desiccant in supply air by an experimental inquiry employing micro-porous semi-permeable hydrophilic membranes as desiccant cores. In order to evaluate membrane contractors made from hydrophobic PP, PVDF, and Tyvek membranes, lithium chloride was utilised as a liquid desiccant. The findings showed that although the carry-over issue had been resolved, the efficacy of dehumidification was low, ranging between 23% and 45% since membranes add to resistance. Two unique individual liquid desiccant cycles are simulated and studied parametrically. Based on the falling film concept, both cycles made use of several absorbers, because it has low-pressure dips, falling film-based absorber was used. When used with larger concentrations of desiccant solution, the proposed cycles not only increased the system's performance coefficient but also managed the carryover issue. The crystallisation of liquid desiccant is another issue. When a liquid desiccant solution is kept at a high concentration and the temperature drops, crystallisation can happen. For a membrane-based dehumidifier and regenerator, the major findings demonstrated agreement between the experimental dehumidifier results and the model's projected outcomes. The model and the findings of the regenerator experiment did not, however, remain in accord. The crystallisation of lithium chloride aqueous solution in the membrane openings during the regeneration process is what led to discrepancies between the model and experimental results. These crystals decreased moisture transmission, which led to inaccuracies in the experimental findings [45-46].

The mixed solvent desiccants are generating more scientific interest lately. Some salts, like Li-Cl have lower vapour pressure and are more stable, but they are more expensive than other salts, such $CaCl_2$. The dehumidification properties are anticipated to be improved by combining the salts, along with a substantial decrease in prices and energy usage. The flow pattern and different configurations of the dehumidifier have piqued the interest of researchers greatly since they are the most crucial part of the dehumidification process. The liquid desiccant in the dehumidifier interacts with the entering humid air to help remove moisture from the air. Dehumidifiers may be divided into four varieties based on how the incoming air interacts with the liquid desiccant solution: parallel flow, cross flow, counter flow, and counter-cross flow. The liquid desiccant cooling system may be divided into two types: adiabatic and internally cooled dehumidifiers, depending on whether there is or is not an internal cooling or heating source in the dehumidifier [47-48].

The right model must be used for the examination of the heat and mass transport mechanisms in order to completely comprehend the dehumidification and regeneration process. The difference in vapour pressure typically drives the mass transfer between the desiccant and the air. Moisture will migrate from the air to the desiccant and vice versa when the air's vapour pressure is higher than the desiccant's. Numerous academics have been focusing on choosing the best models and achieving amazing results. The finite difference model, the effectiveness-NTU model, the artificial neural network (ANN) model, and other unique heat and mass transfer models are the most widely used heat and mass transfer models utilised in the simulation among the most recent research [49-51].

Liquid desiccant systems can be integrated with other systems to enhance system performance due to their capacity to absorb moisture. In the past ten years, there have been several advances in hybrid system research, including solar-driven liquid desiccant systems and combinations of liquid desiccant with heat pumps, CHP systems, and vapour compression systems. One benefit of a liquid desiccant cooling system (LDCS) is that low-grade heat may be used to renew the diluted liquid desiccant. As a result, there have been several theoretical and practical advancements in the study of the sun aided liquid desiccant cooling system in recent years. In traditional LDCS, liquid droplets carry over because the process air comes into direct contact with the liquid desiccant. Applications of such systems are restricted to the industrial sector due to the corrosive characteristics of these desiccants. The hydrophobic membrane contactor in LDCS is used as the mass exchanger to separate the air and solution in order to get over this obstacle [52-54].

In the past several decades, there has been a lot of interest in the integration of liquid desiccant dehumidification systems with other systems including solar collectors, vapour compression systems, heat pump systems, and CHP systems. Numerous study groups have reported on the striking enhancements in the total system performance of the combined liquid desiccant and other types of systems (VC, heat pump, and CHP system). Though some experimental validations are available, the majority of these investigations are restricted to theoretical analysis. A fantastic opportunity for solar energy-powered regeneration of the diluted desiccant solution is provided by solar-driven liquid desiccant dehumidification systems. The intermittent nature of solar radiation, however, might prevent its practical and long-term utilisation. To increase the stability of the system, it would be required to further research suitable energy storage technologies that could be used in conjunction with solar-driven liquid desiccant systems.

IV. CONCLUSION

Traditionally used vapor compression based air conditioning system replaced by desiccant assisted dehumidification and cooling system as VCs humidity regulation and make usage of refrigerants with potential for global warming, is neither energy efficient nor environmentally benign. This evaluation offers a thorough summary of LDAS's recent advancements. This review provides a thorough explanation of the categorization and functioning principles. The several kinds of material innovation to improve system performance as well as the optimizations in the design configurations were also described. It is shown that the majority of the recent research work for liquid desiccant dehumidification systems has concentrated on numerical simulations, a considerable amount of works are still required for the practical investigations of innovative material (mixed solvents) and liquid desiccant integrated hybrid cooling systems. Through this communication it will be useful to identify the research gaps to explore new pathways for future research to further improve the efficiency of LDAS.

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