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Application of Renewable Solar Energy in Liquid Desiccant Powered Dehumidification and Cooling

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Abstract

Presently the air conditioning industry is confronted with some major challenges regarding use of halogenated Liquid desiccant based building cooling technology is an environment friendly which can be used to condition the outdoor air to produce thermal comfort. Unlike traditional vapor compression based air conditioning systems, which completely rely on use of high grade electricity to drive the cooling cycle, liquid desiccant cooling is a freely available renewable solar energy heat driven cycle. Liquid desiccant based air conditioning systems have been used successfully in many parts of the world exposing hot and humid climate conditions especially in tropical region since very long time. The present review enables use of solar energy to drive liquid desiccant cooling in various applications. The study demonstrates the application of solar energy is feasible in many parts of the world, provided that the latent heat gains experienced are excessive. To this extent use of freely available renewable solar energy for dehumidification and cooling applications is desirable. It is appreciated that this source of energy can at best be complementary rather than being competitive to conventional energy sources.

Keywords

Dehumidification, Desiccant Cooling, Regeneration, Solar Energy

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1. Introduction

As energy shortage emerges as an issue of growing concern in the world, coupled with the threat to environment posed by the conventional refrigerants, the need to come up with the new-fangled energy-saving as well as environmental-friendly air-conditioning systems has been more urgent than ever before. The liquid-desiccant dehumidification systems driven by low-grade heat sources can satisfactorily meet those needs; meanwhile, they provide an ideal area for the application of waste heat discharged from local factories, and the employment of brine solution as absorbent brings no damage to environment. The earliest liquid-desiccant system was suggested and experimentally tested by Lof et al. [1] using triethylene glycol as the desiccant.

Desiccant dehumidification has long been adopted for both industrial and agricultural purposes, such as humidity control in textile mill and post harvest low-temperature crop-drying in stores, and is now taking a more and more prominent role in the air-conditioning field.

Its economical and effective humidity control at low and moderate temperature really dwarfs the conventional method of humidity control, which is generally by lowering the air temperature to around the dry bulb temperature.

The desiccant cooling technology had been intensively investigated earlier and its performance is well established, while a few papers have been published previously for the various applications of different forms of the desiccant dehumidifiers. Among these papers is the work of Nelson et al. [2] who studied the feasibility of two configuration open cycle air conditioning systems using desiccants and solar energy as regeneration energy. The two configurations are

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the ventilation mode, in which ambient air is continually introduced into the room; and the re-circulation mode, in which room air is re-circulated. Kafui [3] developed a numerical model to estimate the transport of heat and moisture in thin beds of micro porous silica gel. Ahmed et al. [4] used a desiccant cooling system model to investigate the unglazed transpired solar collector for regeneration of the desiccant and compared its performance with an ordinary flat plate collector. Majumdar [5] investigated the performance of adsorption and desorption processes during a single blow operation in a dehumidifier made of a composite mixture of silica gel and inert materials. Simonson and Besant [6] presented an effectiveness correlation which allows the designers to predict the sensible, latent and total effectiveness of energy wheels when the operating conditions are known. Although Farooq and Ruthven [7] showed that the dehumidifier is the main component of the desiccant based cooling system and the system COP can be significantly improved by improving its performance, the existing works are not sufficiently detailed on the effect of the design and operating parameters on the dehumidifier performance.

As a result, the dehumidified air by such an approach is cooler than that required indoor comfort level, which in turn causes the reheat of energy loss. Meanwhile, the condensed water provides a breeding ground for indoor bacteria. Desiccant dehumidification avoided the above problems in handling the humidity of process air, since it makes full use of surface vapour pressure difference to realize moisture transfer between the process air and the liquid desiccant [8]. Solar cooling of the buildings is a significant application of solar energy. Cooling load and availability of solar radiation are approximately in phase. The combination of solar cooling should improve economics of cooling with desiccant cooling. Thus, solar cooling application can achieve the required regeneration energy for a solar assisted desiccant cooling system [9].

2. System Description

Air-desiccant contactors use a distributor [10] for micro-quantities of liquid, to ensure a good wetting of the contacting surfaces. The absorber is internally cooled by water and the desorber is internally heated by hot water at a temperature in the range 60 - 80°C. The direct contact of process air with the Li-Cl aqueous solution warrants the benefits of the bacteriostaticity of the desiccant, although the generation of Li-Cl containing aerosols is also probable. No reports are available to the author in this respect at this point, though. Figure 1 depicts the schematic of a solar driven plant using LDCS equipment.

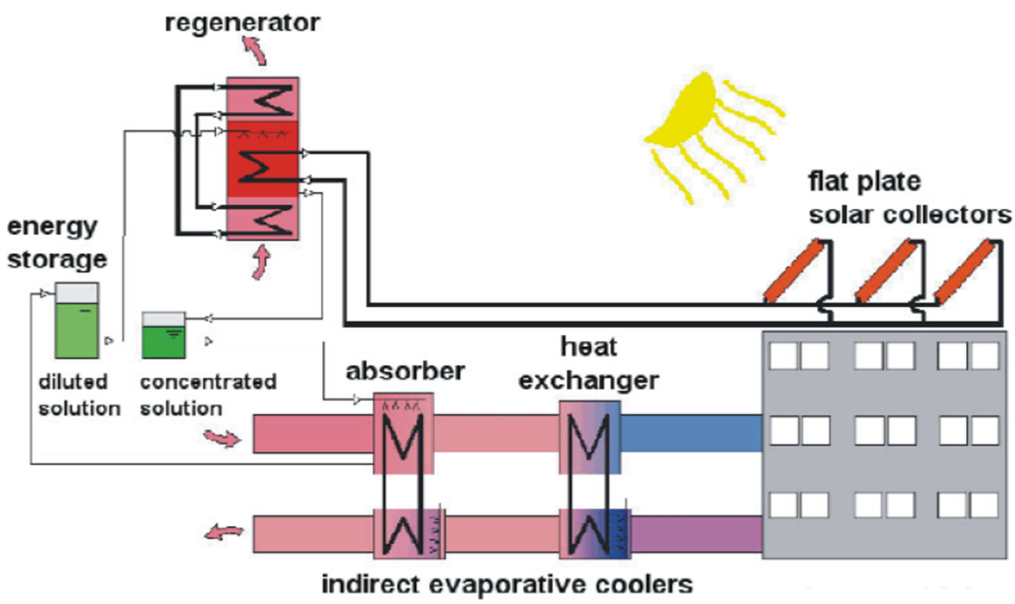

Figure 1. Solar driven desiccant cooling system.

The system generally made up of four major units, namely, dehumidification unit, regeneration unit, liquid-desiccant storage unit, and sensible heat handling unit. The task of dehumidification unit is to remove the moisture of the inlet air by bringing into contact with sprinkled liquid desiccant. The regeneration unit is used to regenerate the diluted solution flowing from dehumidification unit to an acceptable concentration (near the desiccant's initial concentration); thus, the continual operation of the cycle can be maintained. The liquid storage unit is aiming at realizing energy storage by storing strong solution as shown in Figure 2. The sensible heat handling unit is to remove the sensible heat load of the process air flowing from the dehumidification unit according to indoor air comfort standards. The other such systems can be made through different arrangements, replacements and additions of components based on this system.

Figure 2. Structured packing material.

In the refrigeration unit, the surface vapour of diluted hot liquid desiccant is higher than that of inlet ambient air, so the direction of mass (water) transfer is from sprayed liquid film to process air; the weak solution is concentrated near to the initial concentration of the desiccant solution pumped into the dehumidifier. The surface vapour pressure difference between liquid-desiccant film and air is acting as the driving force for mass transfer; therefore, the diluted solution flowing from dehumidification unit need preheating to increase its surface vapour pressure to improve refrigeration efficiency [11].

Low-grade energy hereby serves as the preheating source for weak desiccant as well as the driving force for the whole system. The ancillary heat exchanger here is necessary lest the low-grade energy is weak or unavailable. Similarly, the inlet liquid desiccant needs to be pre-cooled to lower its surface vapour pressure, thus better dehumidification efficiency can be achieved. The heat exchanger between the weak solution flowing out of the dehumidification unit and strong solution flowing in it can effectively preheat the former and pre-cool the latter. Besides, in order to maintain the low surface pressure of the desiccant solution, methods such as adding insulating layer to prevent the increase of solution temperature caused by heat transfer are taken to maintain the ideal mass transfer driving force. The desiccant storage tank is used for purpose of energy storage by storing the regenerated strong solution. It should be mentioned here that the storage tank is usually equipped with an ancillary heater to avoid crystallization, which will affect the normal operation of the system by clogging the pipe. It is self-evident that the main energy consumption occurs in the process of regeneration, which can be completed by low-grade energy, thus the application of attractive but not readily available low-temperature heat resources is greatly expanded. Additionally, their potential is enhanced by the energy storage [12].

The air dehumidification is generally effected by sprinkling the liquid desiccant from the top of the packing materials and bringing it in contact with the inlet process air. Packing materials is the place where mass transfer occurs between falling film of the liquid desiccant and inlet air. Hence, the selection of packing materials will undoubtedly exert influence upon the performance of the dehumidification unit. Packing materials can be categorized as random packing materials and structured packing materials, the former are materials without regular geometric forms and placed randomly in the packing tower, and opposite structured packing materials, which has fixed geometric form. Pall ring, rosette ring, ladder ring, etc. are among the widely used random packing materials in gas–liquid contacting industrial equipments, such as cooling towers.

The structured packing materials, by contrast, deciding the flowing direction of the liquid desiccant owing to their structured geometric patterns, are to some extent beneficial to the expansion of air-desiccant contacting area and meanwhile lower the liquid-desiccant resistance. Wavy plate packing materials, grid packing materials, and silk net packing materials belong to structured packing materials. Silk net packing materials own many advantages, such as high liquid gas separation rate, low-pressure drop, and flexible manipulation; however, they are vulnerable to corrosion and their channels are easily clogged. Therefore, considering the fact that the possible crystallization of the liquid desiccant solution may clog the channel, the currently technically mature wavy packing materials are a better alternative.

The irrigated pressure drop is one of the major criteria for choosing packing materials for liquid-desiccant system, since the pressure drop is closely connected with the energy required by the fan for blowing the inlet process air.

The selection of the liquid desiccant is decisive in the overall performance of the dehumidification system, and will exert an immediate influence on the mass of dehumidification. Its selection depends on various operating parameters, such as boiling point elevation, energy storage density, regeneration temperature, thermo-physical properties, availability, cost, etc. Among the above parameters, the surface vapour pressure is one of major concern and has been investigated extensively and thoroughly. Lithium bromide, lithium chloride, triethylene glycol are among the most widely used single desiccants, their surface vapour pressure at low temperature and high concentration are lower than that of the humid process air.

Investigations and experiments found that calcium chloride is the cheapest and most readily available desiccant, but its vapour pressure at a given temperature is relatively high, and its unstable conditions depending on inlet air conditions and desiccant concentration in solution limit its widespread use. Lithium chloride is the most stable desiccant with advantageously low vapour pressure, but its cost is slightly higher compared with others. The cost and vapour pressure of lithium bromide are intermediate. Triethylene glycol is the earliest used desiccant in liquid desiccant dehumidification systems, but the liquid residence caused by its high viscosity make the system operation unstable. Besides, triethylene glycol has a very low surface vapour pressure, which causes some of them to evaporate into the air flowing into the conditioned areas. Owing to the difference of the purity of the metal-salt, the surface vapour pressure of the liquid desiccants often varies. Experimental measurement is an important method but not a universal method due to the capital support. Lithium chloride and calcium chloride are the universal desiccants mostly used to get cost-effective mixture in different weight combinations in the open literature.

The corrosion effects on the operating components of the systems should also be taken into account, the normal anti-corrosion methods mentioned in the open literature is adding additives to the liquid desiccant, or choosing parts made of synthetic plastic for the system, which can simultaneously lower cost compared with metal parts [13].

3. Use of Solar Energy for the Desiccant Regeneration

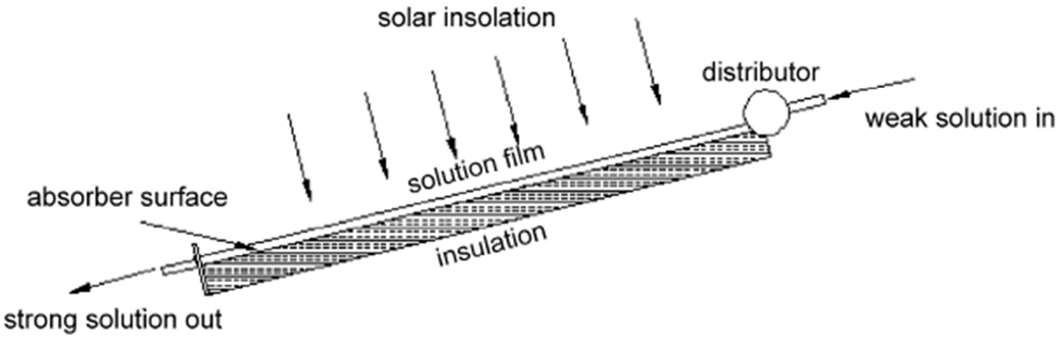

Figure 3. Open type solar collector desiccant regenerator.

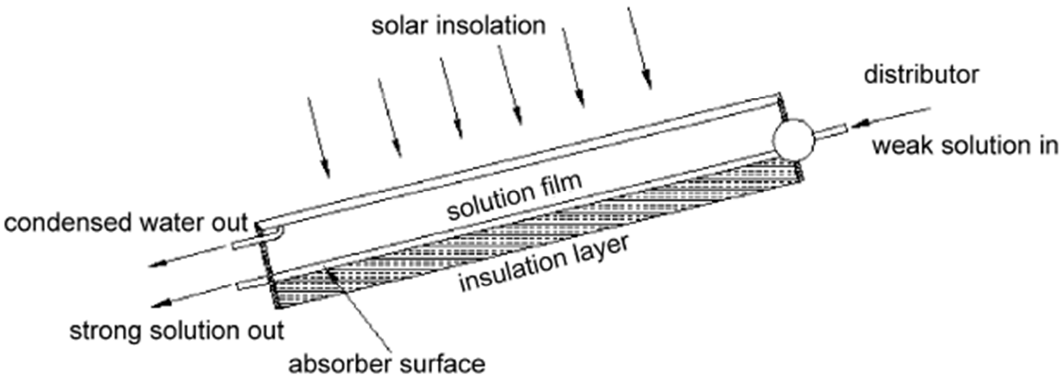

Figure 4. Closed type solar collector for desiccant regenerator.

The solar collector was widely used for regeneration purpose in liquid-desiccant dehumidification system, for the solar energy is readily available, especially when energy shortage has become an issue of wide concern around the world. The solar collector can be used directly and indirectly for regeneration. In the former mode, the heat-collecting fluid is the weak desiccant flowing from the dehumidifier. In the latter mode, the heat-collecting fluid in the solar collector is water, which is then used to preheat the weak desiccant solution flowing into the regenerator. The former is more effective in terms of solar energy utilization ratio, for the regeneration temperature is more or less equal to that of solar collector plate, besides, the regeneration chamber is eliminated. However, when the solar insolation is not ideal in overcast days, the solar collector itself cannot handle the regeneration of desiccant solution; as a result, auxiliary heaters should be equipped with the solar collector regenerators to heat the weak solution flowing into the solar collector to achieve the better performance of regeneration. The solar collector regenerators can be divided in different categories as follows: (1) open-type (Figure 3); (2) closed-type (Figure 4).

Among all these categories, the closed solar collector regenerator is presently proved to be the most effective and is widely used. The energy transfer taking place with the regenerator is in three forms, namely, radiation, convection, and evaporation-condensation. The bottom of the solar collector plate must be well insulated to avoid energy loss [14-16].

Although the close-cycle solar collector regenerator can effectively lower the energy loss caused by convection, the lack of ventilation will lower that driving force for regeneration, namely, the vapour pressure difference between the air and the solution film, because the limited vapour condensation on the underside of the glazing layer will inevitably contribute to the increase of the vapour pressure of the air in the regenerator. The multi-stage regenerator can be combined with solar collector regenerator which provides the inlet hot water, the low-grade energy source, such as water heat and gas could also act as the heating source for the hot water.

4. Future Needs

Innovations are required in the liquid desiccant dehumidification technique in industrial and residential applications as well as effectively ameliorating the system's performance. Finally, future study and application for liquid-desiccant dehumidification techniques are need following research and development [17-28]:

1. Solve basic problems of the system, such as avoiding corrosion of the system and plant components;
2. Improve the transport processes in the contacting columns (absorber and desorber), particularly at part load;
3. Combine open liquid absorption systems with conventional refrigeration, to reduce defrosting energy costs, for example, in food conservation and transport;
4. Combine open liquid absorption systems with conventional air conditioning systems to reduce, or eliminate, the latent load on the chiller;
5. Combine open liquid absorption systems with mobile air conditioning systems to reduce CO_2 emissions due to the operation of such systems in cars, busses and trucks;
6. Develop compact and modular components allowing the construction of autonomous (no chiller, no cooling tower) air handling units.

The development of liquid desiccant-based air-conditioning systems has attained a stage where it is reasonable to state that they are here to stay and their market share to grow. Although the manufacturers already on the market are not among the 'front pack' in the field, they are, nonetheless, the leaders of a 'new-old' technology, that brings along much needed new impulses and solutions to a real problem: Safe, reliable and environmentally sound satisfaction of our society's needs.

Research and development activities on solar powered liquid desiccant dehumidification and cooling is further required, as are educated people, familiar with the principles of these systems, from the design board through the shop floor, down to the installer.

5. Conclusions

Solar powered liquid-desiccant dehumidification techniques have made great strides in the past decades, and some are commercialized and employed to satisfy industrial and residential needs. A promising solar cooling method is through the use of a liquid desiccant system, where humidity is absorbed directly from the process air by direct contact with the desiccant. The desiccant is then regenerated, again in direct contact with an external air stream, by solar heat at relatively low temperatures. The liquid desiccant system has many potential advantages over other solar air conditioning systems and can provide a promising alternative to absorption or to solid desiccant systems. Growing demand for air conditioning in recent years has caused a significant increase in demand for primary energy resources. Solar powered cooling is one of the environmentally-friendly techniques which may help alleviate the problem. Although liquid-desiccant dehumidification system scan easily realize the independent control and temperature and humidity ratio of the process air, but it has the potential drawback in big dimension and unstable operation, which hinder its widespread applications, besides, its continuous operation and performance is influenced by the climate conditions, since the performance of solar collector is decided partly by the ambient air conditions and solar insolation. Therefore, the system performance is slightly unstable compared with that of conventional air conditioning units. It was found that the solar liquid desiccant system is an effective way of dehumidification and cooling in hot and humid climates and that the solar powered liquid desiccant system performance could be enhanced by using the optimum air and solution flow rates. The emergence of hybrid systems will partly lessen the system's instability, besides, hybrid system's capacity for handling the sensible cooling of the process air far outweigh that of evaporation coolers, which is commonly employed by the conventional liquid-desiccant dehumidification and cooling systems. Furthermore, the evaporation cooler's performance is limited by the areas climate conditions. Above all, hybrid systems should be lied emphasis on to widen the use of desiccant dehumidification techniques for space conditioning. Also, further analytical and experimental investigations should be made to deepen the understanding of mass and heat transfer occurring within the dehumidifiers to improve the system's overall performance.

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