PERFORMANCE STUDIES FOR DESICCANT COOLING SYSTEM

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Abstract - *In recent years, with the change in climatic conditions, the demand for air conditioning is spreading over the entire world. Due to this reason an increase in primary consumption of energy in high quantity has been recorded. Desiccant cooling system is one of the options in our daily life to provide the best indoor air quality and thermal comfort with the minimum consumption of energy. In this paper, basically the principles of desiccant cooling systems have been discussed and studied. Through performance studies of desiccant cooling system, it has proven its feasibility and advantages of energy and cost saving in different climatic conditions. Desiccant cooling system could replace other cooling systems such as traditional vapour compression air conditioning system, the evaporative cooling*

Key Words: Desiccant cooling, Desiccant material, COP

Nomenclature

Twb Wet Bulb Temperature [K]
Tdb Dry Bulb Temperature [K]
IEC Indirect Evaporative Cooling
DEC Direct Evaporative Cooling
PHE Plate Heat Exchanger
HX Heat Exchanger
COP Coefficient of performance
CFC Chloro Floro Carbon
LDAC Liquid desiccant air conditioning

1.INTRODUCTION *(Size 11 , cambria font)*

The desiccant cooling with its significant accessibility, economical and cleaner air conditioning could be a perfective supplement or an alternative over the traditional vapor compression system for air conditioning as it has many drawbacks like it consumes more power and increases the CFC level which depletes ozone layer. The desiccant cooling can be used with energy source such as solar energy and waste heat resulting in the reduction of the operating cost and increase the accessibility to the air conditioning for the population of urban areas.

The desiccants are natural or synthetic substances which are capable of absorbing or adsorbing water vapor due the difference of water vapor pressure between the surrounding air and the desiccant surface. The desiccants could be in both liquid and solid states. Each of liquid and solid desiccant systems has its own advantages and disadvantages. Some commonly used desiccant materials include lithium chloride, triethyleneglycol, silica gels, aluminum silicates (zeolites or molecular sieves), aluminium oxides, lithium bromide solution and lithium chloride solution with water, etc. In addition of having lower regeneration temperature and flexibility in utilization, liquid desiccant have lower pressure drop on air side. Solid desiccant are compact, less subject to corrosion and carry over.

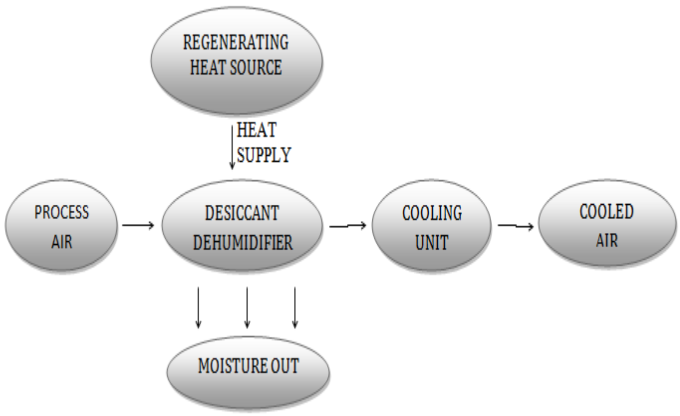

Fig. 1.Principle of desiccant cooling.

The desiccant materials are used in various arrangements. Rotating wheel coated with the desiccant is one of typical arrangements in which the wheel rotates at 8–10 revolutions/h, with part of it intercepting the incoming air stream while the rest of it is being regenerated.

A type of arrangement is made in which solid desiccants are packed to form a sort of adsorbent beds exposed to the incoming air stream which takes up its moisture. The beds are periodically moved in the direction of the regeneration air stream and then returned to the process air stream. Liquid desiccants are often sprayed into air streams or wetted onto contact surfaces to absorb water vapor from the incoming air which latterly like the solid desiccants, regenerated in a regenerator where water vapors previously absorbed is evaporated out from it by heating. To eliminate the overcooling and the reheat, the desiccants can also be coupled with the traditional air conditioning system, thus reducing the equipment size and their costs. Their most frequent use remains, however, their employ with the evaporative cooling. Indeed, the evaporative cooling is the oldest technique of cooling. The current more efficient and conveniently operated conventional air conditioning subsequent technology has suppressed this old technique. But due to the energy costs and the concerns related to environmental harms engendered by the refrigerants used in this system, the researchers began looking back at the old cooling technique and trying to solve their main drawbacks. These techniques mainly drawbacks due to the operating inefficiency in very humid climate, and even for the tropical and dry climate, their seasonal operating inefficiency (even in tropical climates, they become inefficient in rainy seasons). Desiccant cooling emerged as a solution to this problem. By dehumidifying the incoming air forcing it through the desiccants, the evaporative cooler can achieve greater efficiency rather on the dry air stream.

The initiation and development of desiccant technology started by Shelpuk and Hooker [1] under the scheme of US solar heating and cooling program. In the open cycle adsorption system, the basic operating principle of dehumidifier are explained and compared. Dhar et al [2] have been evaluated thermodynamic analysis of desiccant augmented evaporative cooling cycles for the Indian climatic conditions. They analyzed the different desiccant cooling cycles and suggested the most efficient cycle for Indian conditions.

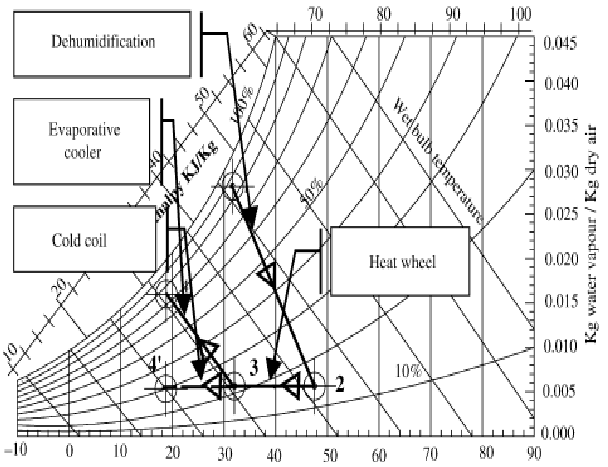

Fig. 2. Psychrometric chart illustrating the principle of desiccant cooling.

1.1 Solid Desiccant Cooling System

There are two ways of implementing the evaporative cooling system these are Indirect Evaporative Cooling mode (IEC) and Direct Evaporative Cooling mode (DEC). Water is sprayed directly into the process air stream in DEC while on the other hand the indirect evaporative cooling consists in using another air stream (called secondary air) cooled directly and evaporative as the heat sink to cool the process air (called primary air) inside a plate heat exchanger (PHE). In DEC, the temperature of process air is lowered only at the expense of higher moisture content in the air making it an adiabatic process. This cycle of evaporative cooling can operate efficiently in dry climates. When a relatively more humid climate prevails, however, the IEC would rather be suited more since it enables a real cooling (reduction of enthalpy) without adding moisture into the process air. It also allows the use of reduced air volume in comparison with that would be required in direct desiccant cooling.

The IEC is composed of several chambers separated by a heat conductor plate. In one of the chamber, in the secondary air stream water is sprayed which thus cool down the stream by direct evaporative cooling. The primary air is circulated inside the chamber adjacent to which the cooled secondary air is circulated. The heat is transmitted to the secondary air through the separating plate from the primary stream resulting in the indirect evaporative cooling. Thus, the primary air is used to maintain the temperature of the space at lower temperature and the secondary air is dumped into the environment. Where Tdb is the dry bulb temperature, Tout is the outlet temperature, and Twb is the wet bulb temperature.

The efficiency of the indirect evaporative cooling would be inferior to the direct evaporative cooling because of the fact that, the direct evaporative cooled secondary air is used to cool indirectly the primary air. The effectiveness of heat transfer from the secondary air to the primary air which, by no means, can equal 100% plays a reductive role in the overall process.

In general, evaporative cooling systems are best applied where the ambient wet bulb temperature does not frequently exceed 25◌̊C. According to Munters, they feature an effectiveness of 90% for the DEC and 70–80% for the IEC. They are very effective cooling technologies and have been demonstrated to operate with a COP reaching up to 5 in dry climate. However, in humid climates their effectiveness declines because of already nearly saturation of surrounding air. Therefore, in order to make their utilization possible in humid climates thereby extending their climatic applicability's scope, resort made to the adjunction of a desiccant dehumidifier, which removes part of moisture of processed air and thus creates the conditions of effective functioning. The scheme thus formed is a desiccant cooling system.

According to the analysis made by Jia et al. [3] on the integration of a rotary solid desiccant dehumidification and a vapor compression air-conditioning unit, it economizes 37.5% electric power in comparison to the conventional VC system when the temperature and relative humidity is maintained at 30◌̊◌̊C and 55% respectively. Such similar results were found when Yadav and Kaushik [4] studied hybrid solid desiccant refrigeration over a VC unit.

1.2 Liquid Desiccant Cooling System

An example of liquid desiccant cooling application is represented in here, through the spraying nozzle the cool strong desiccant solution is sprayed onto the top of the dehumidifier. Due to the gravitation, it trickles through the structure of the dehumidifier where it gets contact with the process air stream blown perpendicularly to its trickling flow direction. The water vapor migrates from the air stream to the desiccant solution and condenses therein because the vapor pressure of the desiccant solution is lass than that of air vapor pressure. As a result, the heat of condensation and mixing are liberated causing an increase in the solution's temperature. The temperature of the process air stream slightly decreases due to its contact with the cold desiccant solution. The dehumidified and rather warm process air stream then passes successively through the evaporative cooler and the evaporator of the traditional refrigerant vapor compression air conditioner, before been delivered into the conditioned space. The diluted desiccant solution, exited from dehumidifier, is circulated through the regenerator where it is heated and the moisture absorbed in the dehumidifier is now lost to the scavenger air stream. In order for the system to keep functioning continuously and effectively, an equal amount of water vapor absorbed from the humid air and condensed to the desiccant solution in dehumidifier must be evaporated from the desiccant solution in the regenerator. The hot and strong desiccant solution is thereafter cooled down in the pre-cooler and then cooled further in the heat exchanger (HX) before being ready again to dehumidify the incoming process air.

Liquid desiccant have several advantages over solid desiccant. The pressure drop through the liquid desiccant is lower than that through a solid desiccant system and can be stored for regeneration by some inexpensive energy such as solar energy and waste heat. Liquid desiccant system combined with vapor compression system can reduce area of evaporation and condensation by 34% and power consumption by 25%, compared with vapor compression system alone.

In a study of a hybrid desiccant vapor compression air conditioning system Khalid-Ahmed et al. [5] determined that it can achieve a 35 % reduction in electricity demand as compared to pure vapor compression system. Burns et al. [6] found that utilizing liquid desiccant cooling in a supermarket reduced the energy cost of air conditioning by 60% as compared to conventional cooling. Whereas also a simulation is made by Chengchao et al. [7] shows that the solar liquid desiccant air conditioning has advantages over vapor compression air conditioning system in its suitability for hot and humid areas and high air flow rates.

2. PERFORMANCE STUDIES

Mazzei et al. [8] using the computer simulation tool, compared the operational cost of desiccant cooling system and the traditional systems and predicted a reduction of Thermal power up to 52% and saving in operational cost of about 35%. The authors projected if the regeneration of the desiccant would be done by waste heat. They have also found, when the indirect evaporative cooling in conjunction with desiccant humidification i.e. used, the cooling power reduction and cost saving also increases. The operating cost will vary with the variation in the cost of electricity units, as it may vary from place to place.

Alizadeh et al. [9] experimented with a prototype of solar LDAC absorber unit over a commercial site of about 200m^2 area located on the Persian Gulf region, the performance of the solar LDAC unit in controlling the temperature and humidity was satisfactory. Experiment shows that the conditioner unit can have effectiveness of about 82% when used with liquid desiccant. The maximum electrical utilization for experimental units determined is 3KW with an electrical COP of about 7.

Kadoma et al. [10] investigated the impact of the desiccant wheel speed, air velocity and regeneration temperature on the COP. The authors showed the existence of an optimal speed and established that the COP decreased when the air flow rate increased and, on the contrary, the temperature of regeneration and the cooling capacity had the same evolution tendency.

Desiccant cooling systems can not only be used for comfort air conditioning but also for products in markets, warehouses as well as for the preservation of stored cereals. Thorpe et al. [11] developed and tested a desiccant cooling device, regenerated by solar energy employed to preserve stored grains. The device was able to produce a cooling energy upto 50 times the electrical energy input.

Aly et al. [12] (1988) analyzed an integrated vapor compression and a waste heat dehumidifier air conditioning system. The waste heat of the vapour compression unit by the heat pump in a heat recovery system is entirely used to regenerate the drying matrix. For the design condition in Jedhah, Saudi Arabia, the overall cooling COP achieved by the combined system reaches 1.73, which is 25 % more than that of the vapor compression alone. Whenever the ARI conditions are applied, the combined system showed an overall COP of 1.76 with 27 % energy saving compared to vapor compression alone.

Ismail et al. [13] (1991) analyzed the performance of a solar regenerated open cycle desiccant bed grain cooling system. The experiments were performed to built a solar cycle grain cooling system. The device consisted of two beds of silica coupled with 95.85m2collector. Results from a experimental series suggest that the device may be used to cool up to 200 tons of grain. The electrical power consumption of the device is of the order of 0.3 watt per ton of grain cooled and the total electrical energy consumption is of the order of 0.7 KWH per ton of grain stored for a 6 months period.

3. CONCLUSIONS

The most important concluding remarks in this study are: Some desiccant cooling cycles have been analyzed and suggested a most efficient desiccant cooling cycle for selected climatic conditions. Direct and indirect evaporative cooling methods can be used for different cycles of desiccant cooling system.

Throughout this review, it has been seen that the desiccant cooling is a simple technology which can reduce the operating cost in comparison with the present system. Dessicant cooling can supplement them advantageously by extending their climatic applicability's scope. Experiments performed in Saudi Arabia and Persian Gulf Region have given remarkable results energy saving and effectiveness in controlling the temperature and humidity. Although the desiccant cooling has its penalty which is the energy required in regenerating the desiccant, it has been seen throughout this literature review that, its energy saving potential is significant. And the regeneration could be done with the help of free energy such as waste energy and solar energy.

Desiccant cooling is not only appropriate in comfort cooling but can also be used effectively in preservation of cereals and warehouses.

REFERENCES

[1] Shelpuk B.C. and Hooker D.W.,1979, "Development program in solar desiccant cooling for residential buildings", International Journal of Refrigeration,Vol.2, pp. 173 – 179.

[2] Dhar P.L, Kaushik S.C. and Jain S., 1995, "Thermodynamic analysis of desiccant – augmented evaporative cooling cycles for Indian conditions", ASHRAE Trans., Vol.101, pp. 735-749.

[3] Jia C.X, Dai Y.J, Wu J.Y, Wang R.Z, Analysis on a hybrid desiccant air-conditioning system, Applied Thermal Engineering 26 (2006) 2393–2400.

[4] Y.K. Yadav, S.C. Kaushik, Psychometric technoeconomic assessment and parametric studies of vapor-compression and solid/liquid desiccant hybrid solar space conditioning systems, Heat Recovery Systems and CHP 11 (1991) 563–572.

[5] C. Khalid-Ahmed, P. Gandihidasan, A. Al-Farayedhi, Simulation of a hybrid liquid desiccant based air-conditioning system, Appl. Therm. Eng. 17 (1997) 125–134.

[6] [6] Burns P. R., Mitchell J.W. and Beckman W. A. (1985) Hybrid desiccant cooling system in supermarket applications. ASHRAE Trans. 91(pt. 1b), 457–468.

[7] Chengchao F. and Ketao S. (1997) Analysis and modeling of solar liquid desiccant air conditioning system. TaiyanhnengXuebao/Acta Energiae Sinica 18(2), 128–133.

[8] Mazzei P, Minichiello F, Palma D. Desiccant HVAC systems for commercial buildings. Applied Thermal Engg. 2002;22:545–60.

[9] Alizadeh S, Haghgou H.R.,Performance prediction and experimental analysis of a solar liquid desiccant air conditioner. Solar Thermal Applications 2011;73(5):3953–60.

[10] Kadoma Daou, R.Z.Wang, Z.Z. Xia, Desiccant cooling air conditioning: a review, Renewable and Sustainable Energy Reviews 10, 55–77, 2006.

[11] Thorpe GR. The modeling and potential applications of a simple solar regenerated grain cooling device. Post harvest BiolTechnol 1998;13:151–68.

[12] Aly, S., Fathalah, K., 1988 "Combined absorption-desiccant solar powered air conditioning system" Wrne-und Stoffubertragung,Vol.23, 111.

[13] Ismail M.Z., Angus D.E., Thorpe G.R. (1991) "The performance of solar-regenerated open-cycle desiccant bed grain cooling system"Solar Energy, Volume 46, Issue 2, 1991, Pages 63-70.