ISSN 2395-1621

Thermodynamic Analysis of Desiccant Assisted Hybrid Air Conditioning System

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ABSTRACT

This paper deals with the concept of desiccant assisted hybrid air conditioning. The hybrid air conditioning system combines the merits of moisture removal by desiccant dehumidifier and cooling coil for removal of sensible latent heat, which provides the thermal comfort to the human being. Desiccant cooling system (DCS) is an alternate suitable option against conventional cooling system in a hot and humid climate. Desiccants are natural or synthetic substances capable of absorbing moisture present in the outdoor air. Desiccant cooling system is the environmental protection technique for cooling purpose of the building. This thermodynamic system may save 30-40% of total power consumption. The heat rejected from the condenser can be utilized to the heat energy which required for regeneration of desiccant material. From the literature survey, it has been observed that this technology is economically possible and optimizes with low cost. In this paper, we have designed the hybrid air conditioning system by using solid desiccant and then evaluated the performance on psychometric chart.

***Keywords*— Desiccant cooling system, Dehumidification, modeling of desiccant wheel, Sensible heat ratio**

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I. INTRODUCTION

One of the important aspects of air conditioning system is to provide the thermal comfort to the human being in all conditions. For thermal comfort, the relative humidity must be within specific range. Desiccant assisted hybrid air conditioning system is an alternative solution in hot and humid climatic condition for thermal comfort. Conventional vapour compression system has many drawbacks; this requires high electricity for the compression process of refrigerant in the compressor results in a high operating cost. This operating cost increases at a very fast rate if the outside air humidity level increases. For effective use of evaporative cooling techniques in humid climate, a desiccant material can be used as a dehumidifier. Desiccants are natural or synthetic substances capable of absorbing moisture present in the outdoor air.

Now a day, many researchers have used solar energy to regenerate the desiccant wheel. From number of years many authors have investigated the design and operation of such systems. Q. Ma(et al) [2], studied performance analysis on a hybrid air-conditioning system according to the hybrid building energy system, which consists of vapor compression, desiccant, dehumidification and adsorption refrigeration predicted. The result shows that the performance of this system is 44.5% higher than conventional vapor refrigeration system at a latent load 30% and the improvement can be achieved by 73.8% at a42% latent load. The optimal ratio of adsorption refrigeration power to total cooling load of this kind of hybrid system is also studied. (C.X. Jia, Y. J. Dai) [4], carried out the experiment on a hybrid desiccant air –conditioning system, which is an integration of a rotary solid desiccant dehumidification and a vapor compression air-conditioning unit. It is found that, the hybrid desiccant cooling system economizes 37.5% electricity power as compared with the conventional Vapor Compression (VC) system; when the process air temperature and relative humidity are maintained at 30˚C and 55% respectively. From experiment it is found that the SHF of the evaporator is increased and 75% of evaporator tube segment will operate under the dry condition and electric power consumption of the hybrid desiccant system is reduced.

G. Panaras(et al) [4], in terms of performance level and environmental protection, solid desiccant air-conditioning systems present a promising solution. In this work, a methodology is proposed for definition of the system's achievable working range under specific set of space requirements. Considering a solid all- desiccant air-conditioning system, the proposed approach of working, for steady environmental conditions, with acceptable sensible and latent load rather than a fixed set-point value, sets the concept of system's achievable working range in terms of space requirements. G. Panaras (et.al) [6], in this work, a model for a desiccant air conditioning system has been developed and experimentally validated on an actual installation. The analysis has proved the validity of the assumption for the proposed efficiency factor presenting constant values, which characterize the operation of each subsystem. The investigation of the performance of a typical desiccant air conditioning system, on the basis of the model, verifies the ability of these systems to satisfy actual cooling loads, on temperature levels that enable the use of flat plate solar collectors. The results confirm the potential of the examined technology to satisfy actual cooling loads, and at the same time they lead to specific conclusions for the operation of these systems.

In this paper, we have designed the solid-desiccant assisted hybrid air conditioning system and checked the various indoor and outdoor DBT/WBT conditions and evaluated the performance of system on psychometric chart. The main purpose of this study is to study the feasibility of using cycle that combines sorptive dehumidification with heat recovery to create thermal comfort in hot-humid climate.

The typical air conditioning process consists of two components; one is moisture removal (latent cooling) and another one is to reduce the temperature (sensible cooling). The energy required for this process can be expressed as,

$$Q_l = m\, hfg\, (w_a - w_b)$$

where m is the air mass flow rate, h_{fg}, the heat of vaporization, and w is the absolute humidity ratio. The air must also be sensibly cooled to some temperature requiring an energy spending of, $Q_s = m\, Cp\, (Ta-Tb)$

where, Cp is the specific heat of air, and T is the air temperature. By adding these two components gives the fraction of the total load required for moisture removal which is called as the latent load ratio,

$$LLR = Q_l/Qt = Q_l/(Q_s + Q_l)$$

Room Sensible Heat Factor:

$$RSHF = \frac{RSH}{RSH + RLH}$$

II. BASIC PRINCIPLE OF DESICCANT AIR CONDITIONING SYSTEM

Figure 1 represents the basic principle of typical desiccant cooling system.

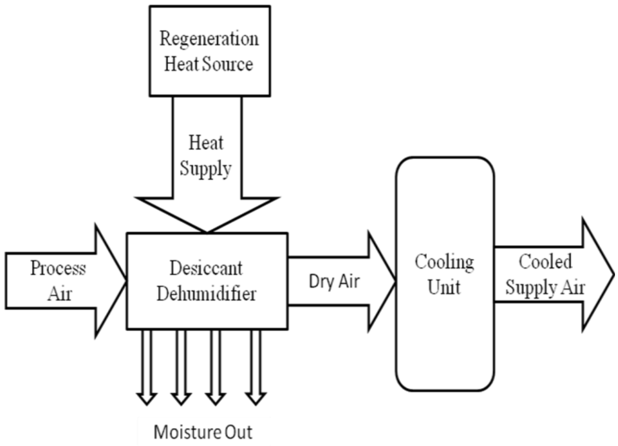

Fig 1- Principle of Desiccant Cooling Systems

This system dehumidifies the incoming air stream by means of a desiccant dehumidifier. Then it cools down the process air stream to the desired temperature, if required. For the continuous working, water vapor must be removed. The removal of moisture is achieved by heating the desiccant up to a suitably high temperature (regeneration process), which is depends on the type of desiccant material used. Desiccant dehumidifier removes some quantity of moisture from the process air, which has to be rejected to provide a continuous and effective dehumidification process.

The desiccant cooling system has one the major advantage that the sensible and latent heat can be processed separately and uses different low grades thermal energy sources such as waste heat recovery, solar energy etc. The efficiency of this system is mainly depends on sensible heat ratio.

III. EXPERIMENTAL SETUP AND PROCEDURE

A. *Experimental setup:*

Figure 2 and figure 3 illustrates schematic representation of this system and the process involved in hybrid air conditioning system respectively. The main components of the hybrid air conditioning consist of desiccant dehumidifier wheel, heat recovery wheel and heater. The performance of this whole system is depends on the performance of all the components [8]. The solid desiccant dehumidifier rotor of speed 15 rph is an important component of hybrid air conditioning system. The solid desiccant material is the most widely used in desiccant cooling system due to its simple handling. Desiccant rotor was selected from existing model. This rotor is connected to the heat recovery wheel. More care was taken to avoid mixing of primary and secondary air. The heat recovery wheel is connected to the blower through the cooling coil. The whole set up is properly instrumented to measure the temperature, relative humidity at different location. Energy consumption is measured by energy meter.

DW=Desiccant wheel; HRW= Heat Recovery Wheel; CC= Cooling Coil

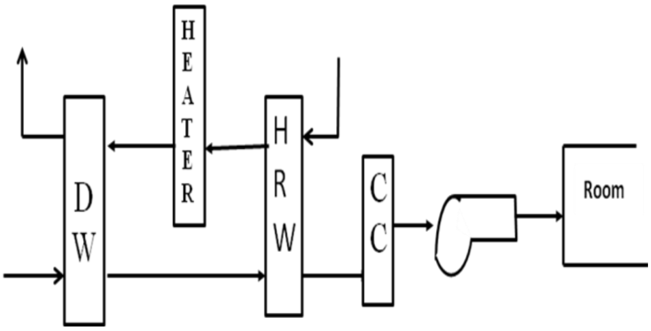

Fig 2- Schematic of Hybrid Air Conditioning System

Figure 3 shows all the processes involved in this system i.e. Vapour Compression air conditioning (1-4-5-6), desiccant cooling (1-2b-3b-5-6) and hybrid system (1-2a-3a-5-6) on psychometric chart. In hybrid air conditioning system the dehumidification process (1-2a) is achieved by applying the layer of solid desiccant on the dehumidifier. State 2a to 3a shows the sensible cooling of dry and heated air which is achieved by the application of cold water in the indirect evaporative cooler [11]. The further sensible cooling from 3a to supply state 5 is achieved in cooling coil of conventional VCRS.

The power saving in the hybrid air conditioning system is depends on following two factors:

1. The temperature of cooling water applied to the process 2a-3a. At state 3, lower cooling water temperature decreases the temperature of air, which decreases the power consumption over the cooling coil.
2. If the value of RSHF increases, the power consumption in VCRS increases, but in hybrid system decreases the power consumption.

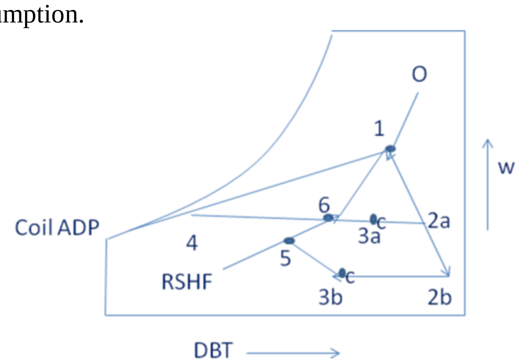

Fig 3- Process of Hybrid Air Conditioning System

B. *Experimental Procedure*

To start the experiment, initially the dehumidifier has to be adjusted to humidify the air upto required level. At the starting cooling coil and blower kept off. It takes atleast 10-20 minutes to initialize the dehumidification process in the dehumidifier. First ambient conditions were recorded. After starting the dehumidification process of the incoming process air stream, cooling coil and blower is switched on. The fresh air from the atmosphere and recirculated air from the air conditioned space mixes in the desired portion before circulated through the blower at the inlet of the dehumidifier. The ratio of this air is depends on ventilation level required in the conditioned space. The inlet air is passed through a solid desiccant dehumidifier. The dehumidification is achieved due to the lower water vapour pressure at the surface of the desiccant. Hence due to condensation, specific humidity falls and this heat of condensation increases the temperature of air, which increasing its dry bulb temperature (DBT). The hot and dehumidified air from dehumidifier is sensibly cooled. Now the desired supply temperature of air to the conditioned space is achieved by passing this air over the cooling coils of conventional vapour compression refrigeration system.

Based on recorded data, the performance of desiccant dehumidifier was plotted on psychometric chart. Results and discussion are explained in next chapter.

III. RESULTS AND DISCUSSION

The performance of this system for hot and humid climate has been carried out and plotted on psychometric chart which is illustrated in figure 4. During the summertime hot moist air at 35 ºC and 20 g/kg moisture content is drawn through the desiccant wheel so that it is at say 48 ºC and 18 g/kg moisture content. The process air stream is then passes through the desiccant dehumidifier where it is sensibly cooled upto 25 ºC. On the return air side, air from the conditioned space at 27 ºC and 24 g/kg moisture content enters the thermal wheel. As the return air stream passes through the thermal wheel, it is sensibly heated. In order to regenerate the desiccant coil, the air is then heated up to approximately 52˚C. It should be noted that in order to reduce system operation costs approximately 20% of the return air flow by-passes the regenerating oil and the desiccant wheel.

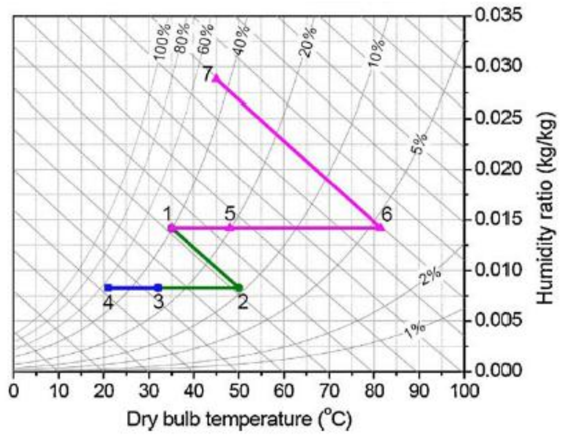

Fig 4- Psychometric process in Hybrid air conditioning system

RSHF is the function of room sensible heat and room latent heat. Both have absorbed by the process air at the inlet conditioned space. Consider four values of RSHF for analysis such as 0.6, 0.5, 0.5 and three values of this ratio as 4:1, 3:2 and 1:1. The results of variations of power consumption are represented in figure 5.

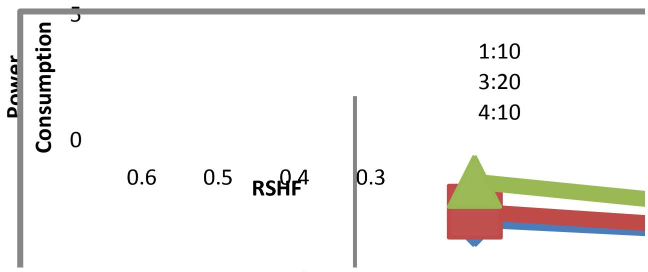

Fig 5 - Variation of power consumption

The power consumption of hybrid air conditioning system increases with increasing mixing ratio R. Higher is the mixing ratio decreases the dehumidification load on the cooling coil and also the heating load. This is because of the constant value of RSHF increasing mixing ratio decreases the DBT and increases RH of supplying air to the conditioned space.

IV. CONCLUSION

From experimental investigation and results obtained from this, it was observed that the desiccant cooling system presented in this paper can be a suitable solution for hot humid climate to provide thermal comfort to the human being. The desiccant dehumidifier system is the most cost effective as well as reduced the power consumption significantly. The hybrid air conditioning system save high grade electric energy which is a very good potential air conditioning system.

REFERENCES

1. K. Daou, R.Z. Wang, Z. Z. Xia, “Dessicant cooling air conditioning: A Review” Renewable and Sustainable Energy Reviews, 10 (2006) 55–77.
2. Q. Ma, R.Z. Wang, Y.J. Dai, X. Q. Zhai **,** “Performance Analysis On a Hybrid Air-Conditioning System Of a Green Building”, Energy and Buildings 38 (2006) 447-453.
3. L. Bellia, P. Mazzei, F. Minichiello and D. Palma, 2001, “Air Conditioning Systems With Dessicant Wheel For Italian Climates” International Journal on Architectural Science, Volume 1, Number 4, p.193-213, 2000
4. C.X. Jia, Y. J. Dai**,** J. Y. Wu, R.Z. Wang, “Analysis on a Hybrid Desiccant Air- Conditioning System”, Applied Thermal Engineering 26 (2006) 2393-2400.
5. Ritunesh Kumar, “Studies on standalone liquid desiccant based air-conditioning system”, PhD Thesis, IIT Delhi, Sep 2008.
6. G. Panaras, E. Mathioulakis, V. Belessiotis, N. Kyriakis, “Theoretical and Experimental Investigation of the Performance of a Desiccant Air Conditioning System” , Renewable Energy 35 (2010) 1368-1375.
7. V. C. Mei and F. C. Chen, Z. Lavan, R. K. Collier, G. Meckler, “An Assessment Of Desiccant Cooling and Dehumidification Technology”, ORNL/CON-309, July 1992.
8. Jain S, Dhar PL. “Evaluation of solid desiccant-based evaporative cooling cycles for typical hot and humid climates”. Int J Refrig 1995; 18(5):287–96.
9. K. Gommed, G. Grossman, “Experimental investigation of a liquid desiccant system for solar cooling and dehumidification” Solar Energy 81 (2007) 131–138.
10. Jain S, Dhar PL, Kaushik SC. “Experiments studies on the dehumidifier and regenerator on a liquid desiccant cooling system” Applied Engineering 2000;20:253–67.
11. Dr. S.P.S Rajput, Shankar Kumar, “Thermodynamic Performance Analysis of Hybrid Air Conditioning System” International Journal of Research in Engineering and Technology (IJRET) Vol. 1, No. 6, 2012 ISSN 2277 – 4378.
12. H. Parmar, D.A.Hindolia, “Desiccant Cooling System for Thermal Comfort: A Review”, International Journal of Engineering Science and Technology (IJEST), Vol. 3 No. 5 May 2011, ISSN : 0975-5462.
13. A Zendehboudi , R Hashemi, A zendehboudi, “ Performance assessment of a Solid Desiccant Based on Dehumidifier System Coupled with Air Conditioning System in a Tropical Climate” , International Journal of u- and e- Service, Science and Technology Vol.7, No.2 (2014), pp.167-178.
14. N. Enteria and K. Mizutani, “The role of the thermally activated desiccant cooling technologies in the issue of energy and environment,” *Renewable and Sustainable Energy Reviews*, vol. 15, pp. 2095-2122, 2011.

