The Use of Solar Energy in Desiccant Wheels Systems in Cuba

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ABSTRACT

In Cuba the climate is tropical, with average solar radiation of 5.5 kW-h/m^{2}and an annual average temperature of 25 °C. The relative humidity is high all of the time, with an annual average between 75 % and 85%.

Because of this it is very interesting to test and develop technologies for dehumidification of the air and control of air humidity in different industrial applications. Desiccant wheel systems have been discussed during the past 10 years as an interesting option for air dehumidification and humidity control. A model running under TRNSYS is developed for a desiccant wheel and a solar heater.

The study shows that it is technically feasible to use solar energy as a heat source for regeneration of a dehumidification and cooling system using silica gel. The designed system guarantees the temperature and humidity conditions necessary in the buildings.

KEYWORDS
Desiccant cooling, Simulation study, Solar energy, Desiccant wheel

INTRODUCTION

Cuba is the largest Island of the Antilles group; it is located at the entrance of the Gulf of Mexico, in the middle of the Caribbean Sea. Cuba has a tropical climate, mostly very sunny, with an annual average temperature of 25 °C. During summertime, the average temperature is 27 °C. During wintertime it drops to 21 °C. The relative humidity is high with an annual average between 75 % and 85 %.

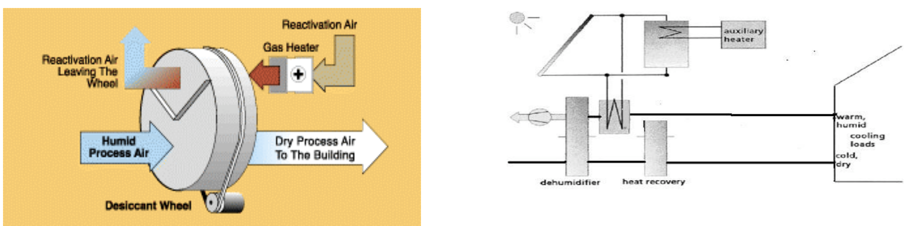
Solar energy is the most readily available source of energy. It does not belong to anybody and is, therefore, free. It is also the most important of the non-conventional sources of energy because it is non-polluting and, therefore, helps in reducing the greenhouse effect. Solar energy has been used since prehistoric times, but in a most primitive manner. The applicability of solar equipment is strongly influenced by the characteristics of the solar radiation. The intensity of the solar radiation in Cuba has a value between 900 and 1000 W/m^2 when it impacts perpendicularly on a surface, which represents an approximate average of 400 W/m^2 on the surface of the earth and more of 5kW/h a day per square meter, as average value yearly. The variation of the intensity of the radiation over different zones in country is not significant, due to the geographical position of the island of Cuba, stretching from East to West and located between the 20 and 23 degrees of north latitude. Neither is the variation of the intensity of the radiation between the summertime and the wintertime significant. This makes solar energy an option that can be used all over the country. The diffuse radiation has an average value above 40% of the direct normal radiation. There are more a 10 cloudy days per month, although there is almost always sunshine at least for a short period of time. The characteristics of the solar radiation in Cuba allow an advantageous use of these types of equipment that use both diffuse and direct solar radiation.

DESICCANT COOLING

Relative humidity control is an essential aspect of maintaining indoor air quality in an air conditioned space. Air conditioning consumes a large amount of electrical energy, especially in hot and humid climatic areas. The cooling load of a building is the sum of the sensible and latent heat loads. While the former is due to the difference between indoor and outdoor temperatures, the latter is caused by the difference between indoor and outdoor humidity content. Both types of loads may also be generated within the building. Normally dehumidification of air is achieved by bringing the temperature below the dew point a cooling coil to condense water vapor and then reheating it to the required temperature (ASHRAE,1996).

Humidity control, though with certain limitations, can be achieved by air bypass control, variable speed fans and capacity control of a compressor. Reheat and desiccant based systems including hybrid systems can be used to lower the humidity. The energy efficiency of desiccant enhanced air conditioners is more than other systems at low sensible heat ratios. Even though various studies have been reported on the development of novel desiccant cooling systems and also on conventional desiccant wheel dehumidifier for humidity reduction in the conditioned space, it is observed that no system is identified which produces low humidity conditions in the conditioned space by utilizing accessories like a desiccant wheel in conjunction with conventional AC system (ASHRAE, 1996).

The desiccant materials are used in diverse technological arrangements. One of typical arrangements consist of using a slowly rotating wheel impregnated or coated with of desiccant, with part of it intercepting the incoming air stream while the rest of it is being regenerated. The operation principle is illustrated in Figure 1(a).



(a) (b)

Figure 1: Principle of operation of desiccant wheels.

As cooling loads are highest in the summertime, where there is the greatest amount of solar energy available, the use of the sun to drive cooling systems would seem logical. Solar desiccant systems which use water heated in solar collectors are not available commercially but many research projects have evaluated the potential for such systems. The feasibility of solar driven desiccant cooling in the UK has been demonstrated by Beggs and Halliday *et al*. (2002) using real data for the United Kingdom, they have shown that a significant proportion of the total heat required to power a desiccant cooling system can be provided from solar heating. Nelson *et al* (1978) have modeled desiccant systems to investigate the suitability for solar powered applications, but do not discuss the solar collector in detail.

This paper has the purpose to show the technical feasibility of the use of the solar energy in the desiccant wheel system for the treatment of the air in Cuba. The dynamic behavior of the system is simulated, which was not studied deeply in the past. The solar assisted desiccant cooling system is shown in Figure 1(b).

SIMULATION MODEL

The system was studied using the simulation software TRNSYS. For the design of desiccant cooling systems, one new component was programmed that simulates the behavior of the desiccant wheel using silica gel.The overall simulation consists of the desiccant cooling system and the heat supply system witch consists of the solar collector. A flat plate solar collector was chosen from the TRNSYS data base (component Type 73).

The desiccant dehumidifier model uses nonlinear analogy methods, proposed by Banks (1985) and used by MaClaine –Cross (1972), Niu *et* al (1995), Zhang *et al* (2003) and other authors for modeling similar systems. In this method the regenerator or dehumidifier is represented by superposition of two regenerators, in each of which transfer is driven by a combined potential F_i, analogous to temperature for heat transfer alone. The storage capacity in the matrix of each superposed regenerator is described by a combined specific capacity ratio γ_i , analogous to the ratio of the matrix material specific heat to the air specific heat for heat transfer alone. The F_i and γ_i depend on temperature, air specific humidity, and the thermodynamic properties of matrix and air.

The γ_i are given by Eqn 1.

$$\gamma_i = \left(\frac{\delta H}{\delta h}\right)_{Fi} = \left(\frac{\delta W}{\delta w}\right)_{Fi}$$

For the silica gel the potential equations are Eqn 2 and Eqn 3:

$$F_1 = \frac{-2865}{T^{1.49}} + 4.244W^{0.8624} \qquad F_2 = \frac{T^{1.49}}{6360} - 1.127W^{0.07969}$$

T is temperature in K and W is the humidity ratio in kg/kg.

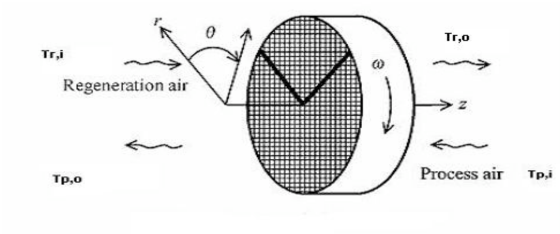


Figure 2: The rotary desiccant wheel

Regenerator performance prediction by the analogy methods involves first the evaluation of the F_i for the inlet air stream and the regeneration stream. By choosing the transfer efficiencies of each of the two regenerators the outlet air state can be determined by Eqn 4 and Eqn 5:

$$\eta_{F1} = \frac{F_{1p,o} - F_{1p,i}}{F_{1r,i} - F_{1p,i}} \qquad \eta_{F2} = \frac{F_{2p,o} - F_{2p,i}}{F_{2r,i} - F_{2p,i}}$$

where η_{F1} and η_{F2} represent the regenerative F_1 and F_2 potential efficiencies, respectively, and the subscripts *o* and *i* mean outlet and inlet respectively and *p* and *r* mean process and regeneration air stream respectively. The outlet process air temperature and moisture content can be obtained by solving Eqn (2) and (3) combined with the results from Eqn. (4) and (5) respectively (Figure 2). One pair of (η_{F1}, η_{F2}) values was selected, η_{F1}=0.3 and η_{F2}=0.85, as recommended by Niu. *et al* (2002). The desiccant wheel effectiveness mainly depends on the material, wheel structure and rotary wheel speeds. Our model assumes: honeycombed desiccant wheel, effective material fraction equal 0.7, 0.2m of wheel length, diameter of 0.4 m, duct geometry sinusoidal, desiccant material is silica gel and rotary speed of 30 rph. The air is sensibly cooled by water in a cross flow heat exchanger. The outlet state of the process air from the heat exchanger was simulated with component Type 52 of Trnsys .The temperature of cooled water entering the heat exchanger was assumed to be equal to 14ºC. The reference value of heat exchanger effectiveness was taken at 0.85.

RESULTS AND DISCUSSIONS

Comfort air-conditioning involves treating the environmental air to control its temperature, humidity, cleanliness and distribution for the comfort of the occupants of the air-conditioned space. In Cuba for human comfort in Hotels, Buildings, Conference Centers, the relative humidity must be within a specified range of temperature at 24 ºC and relative humidity between 50-55%. The ranges of relative humidity between 45–55% and temperature of 20–24 ºC have been recommended for library and museum considering both human comfort and shelf life of the objects. For hospitals in cleaning areas is very necessary to keep temperatures in the range of 17- 21 ºC and relative humidity in 50% or less.

In this work the following working conditions were set

- Inlet temperature of regeneration air , Tr = 70 ºC
- Inlet relative humidity of regeneration air , 50 %
- Inlet temperature of process air, Ti= 32 ºC
- Inlet relative humidity of process air, 75 %

- Outlet temperature of process air , Troom = 20- 22 ºC
- Outlet relative humidity of process air, 50-55%.

Figure 3 shows the variations of air outlet temperature in the dehumidifier, the regeneration temperature given for the solar flat –plate collector and the temperature in the conditioned room. The temperature of the regeneration air changes between 70-77 ºC. A 5 solar flat-plane collectors system, with an efficiency =0.7 and an area of 20 square meters can supply enough heat for the desiccant reactivation process, as for silica gel the regenerating air temperature is recommended in the span 70-100ºC. In the case of the humidifier outlet air temperature it can see that the values oscillate between 57- 63 ºC, which can be explained by the exothermic characteristics of the adsorption dehumidification process, that takes place in the desiccant wheel. Similar values have been reported in several papers for this desiccant substance and similar system, Techajunta *et al* (1999), Neti and Wolf (2000) , Khalid and Nabeel (2001).

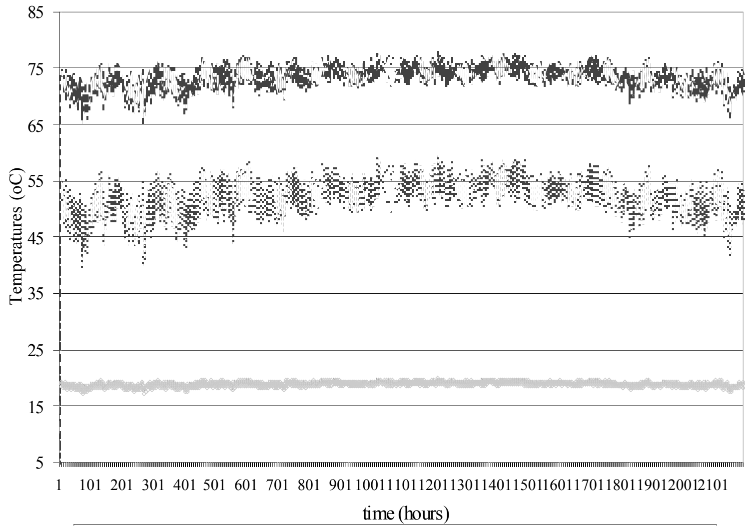


Figure 3: Annual performance of Temperatures in the solar desiccant cooling system

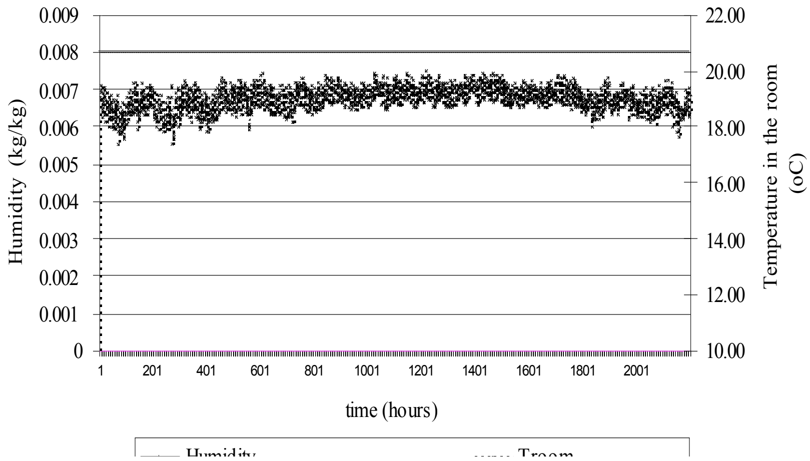


Figure 4: Temperature and Humidity ratio in the room.

Figure 4 shows the variations of air outlet temperature and humidity ratio from simulation for solar cooling desiccant systems in the conditioned room. In this figure it can be seen that the behavior of the temperature and the absolute humidity in the room air condition, the temperature is between 19-22 ºC and the humidity it kept constant value, 8 g/kg.

The cooling capacity of supply air, the COP and the required reheat energy were calculated, obtain the following results:

- Cooling capacity of process air, Q_c= 1.6 kW
- COP=1.9
- Q_r=0.84 kW

If we compare these results, with those that would be obtained with a conventional system for same condition: Q_c =1.86 kW, COP ~ 2.5 (Subramanyam *et al*, 2004), it can be seen that the cooling capacity of supply air in the desiccant wheel is less and hence the COP is marginally less. The electrical power necessary to obtain the cooling effect desired in case of using the conventional dehumidification system is 0.744 kW and in the desiccant system is 0.1 kW less, 0.64 kW. This proves that it is possible to obtain energy savings by using this system.

CONCLUSIONS

The study shows that it is technically feasible to use solar energy as a heat source for regeneration of a dehumidification and cooling system using silica gel. The designed system guarantees the temperature and humidity conditions necessary in the buildings. This type of system is proven to be very interesting for the specific conditions of the Cuban climate. The study suggested that it is possible to obtain with the implementation of this system savings of primary energy.

REFERENCES

ASHRAE Handbook.(1996).Chapter 22.Desiccant Dehumidification and Pressure Drying Equipment. American Society of Heating, Refrigerating and Air –Conditioning Engineers, Inc.

Banks.P.J. (1985).Prediction of Heat and Mass Regenerator performance using Nonlinear analogy Method: Part 1-Basis *Transaction of the ASME* 107, 222-229.

Banks.P.J. (1985). Prediction of Heat and Mass Regenerator performance using Nonlinear analogy Method: Part 2 Comparisons of Methods. *Transaction of the ASME*107, 230-238.

Dhar,P.L., Singh.K.(2001).Studies on solid desiccant based hybrid air conditioning systems, *Applied thermal Engineering* 21, 119-134

Halliday S.P, Beggs.C.B, P.A.Sleigh.(2002) The use of solar desiccant cooling in the UK:a feasibility study. *Applied Thermal Engineering* 22, 1327-1338

Mavroudaki. P,,C.B.Beggs, P.A.Sleigh, S.P.Halliday. (2002). The potential for solar powered single-stage desiccant cooling in Southern Europe*. Applied thermal Engineering* .22,1129-1140.

MaClaine-Cross I.L, Banks D.J, (1972), Coupled heat and mass transfers in regenerators-prediction using an analogy with heat transfers with transfers, *Int.J. Heat and Mass Transfers* 15, 1225-1242.

Niu.J.L, Zhang.L.Z, Zuo.H.G.(2002). Energy savings potential of chilled-ceiling combined with desiccant cooling in hot and humid climates. *Energy and Building s* 34 , 487-495.

Subramanyam.N, M.P.Maiya, S.Srinivasa Murthy.(2004) Application of desiccant wheel to control humidity in Air Conditioning Systems. *Applied thermal Engineering* 24 , 2777-2788.

Trnsys. Transient system simulation program (Version.16).Madison /Wisconsin, USA.

Zhang.X.J, Dai.Y.J, Wang.R.Z.(2003) A simulation study of heat and mass transfer in honeycombed rotary desiccant dehumidifier. *Applied Thermal Engineering.*23 , 989-1003.