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PERFORMANCE OF SOLID DESICCANT COOLING WITH SOLAR ENERGY IN HOT AND HUMID CLIMATE

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Abstract: The study investigated the solid desiccant cooling systems. The system is regenerated by solar energy and electricity heater. This work assesses the energy saving possible from developing solar assisted desiccant air conditioning system and makes recommendations for further research on the concept. This system is designed to satisfy space cooling demand. In this paper simulation/ theoretical analysis and experimental analysis of this component is presented, with particular attention to the variation of the performance as a function of the process and regeneration air flow rates. The experimental results were comparable with the results obtained from the theoretical.The experimental results obtained by the authors and data provided by the simulation have been used to calculate some performance parameter, and a satisfactory agreement has been obtained. The experimental results indicated that the average thermal COP cycle is 0.6 and the cooling capacity in the range of 5.6 kW under hot and humid ambient conditions. The results show that higher influence on the dehumidification process is due to the regeneration of temperature rather than to the regeneration of air flow rate.

KEYWORDS: Solid desiccant, performance, solar, desiccant cooling.

Introduction

Desiccant cooling system powered by vacuum-tube solar collectors is an interesting option for cooling application. In solar desiccant cooling cycle, solar energy is used to regenerate a desiccant that dehumidifies the moist air, the resulting dry air is cooled in heat recovery wheel and then in an evaporative cooler. The technique uses water as refrigerant and solar energy; electricity is only used in the auxiliaries, so the technique is environmentally friendly.

In the context of Malaysia the ability of renewable energy source issues is underestimated, consequently we do not see widespread commercial solar applications in the society. For space cooling requirement, availability of solar energy coincides with the need for cooling. Similarly the summer peak demand of electricity due to extensive use of air conditioners matches with the peak solar irradiance, thus offering an opportunity to use solar energy in the space cooling system. Desiccant cooling system requires medium temperature heat for regeneration about 60^{o}C to 80^{o}C of desiccant wheel part of which can be supplied from solar collector or auxiliary heater.

Desiccant cooling systems show great energy saving potential by using low-grade heat source, such as solar energy. A lot of study on solar assisted desiccant cooling has been concluded; Dai *et al.,* [3] conducted a comparative study of a standalone Vapour Compression System (VCS), the desiccant-associated VCS, and the desiccant and evaporative cooling associated VCS. They found an increase of cold production by 38.8-76% and that of COP by 20–30%. Henning *et al.,* [6] Conducted a parametric study of a combined desiccant/chiller solar assisted cooling systems and showed not only their feasibility but also the primary energy savings of up to 50% with low increased overall costs. Kodama *et al.,* [7] investigated the impact of the desiccant wheel speed, air velocity and regeneration temperature on the COP. The authors showed the existence

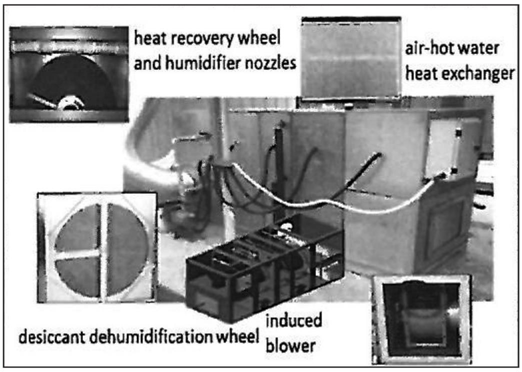

Figure 1: Solid Desiccant Cooling System with Solar Energy.

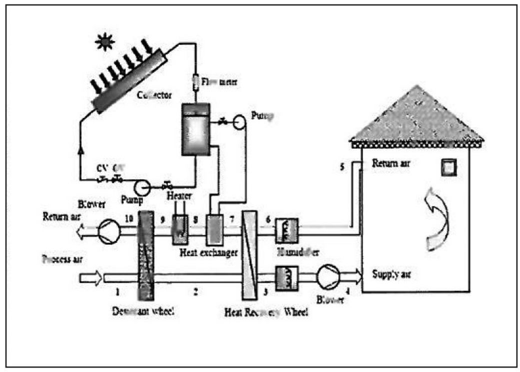

Figure 2: Solid Desiccant Cooling System.

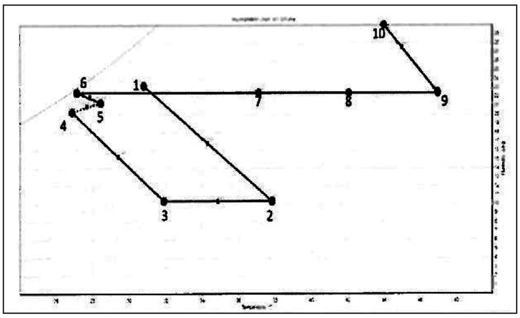

Figure 3: Desiccant Cooling System and Its Process Representation on Psychometric chart.

of an optimal speed and established that the COP decreased when the airflow rate increased and, on the contrary, the temperature of regeneration and the cooling capacity had the same evolution tendency. Eicker *et al.,* [4] study the component performance and seasonal operational. The seasonal performance monitoring carried out in the German installation showed that average seasonal COP was close to 1.0.

In this paper desiccant cooling performance is investigated focusing on the types of rotary desiccant cooling system. The mode desiccant based on air conditioning system was designed and tested experimentally to improve the indoor air quality and reduce energy consumption.

Materials and Methods

The solar assisted desiccant cooling system was designed and established near the test room located in Solar Green Park, UKM Malaysia. Figure 1 shows the experimental setup of the system. The test room has a length of 3 m, width of 2 m, and height of 3 m. The solar desiccant cooling system consists of three main units: a) solid desiccant wheel which used silica gel as absorber, (b) heat sources which used evacuated tube collector and auxiliary heater (c) cooling unit which used heat recovery heat exchanger, and direct evaporative cooling/humidifier.

Table 1 shows specification components of solar assisted desiccant cooling system. The desiccant wheel is designed to operate in both a 50% area for reactivation and 50% for process (50/50). The diameter of the wheel is 250 mm and its width is 533 mm. The heat recovery wheel is an aluminum honeycomb structure with 77.8% efficiency. It rotates at 12 Rev min^{-1}. The cooling capasity/energy recovery is 5.6 kW (1.6 TOR).

The diameter of the regenerator is 700 mm and its width is 700 mm. The electrical consumption of the blower motor and electrical heater is about 150 W and 1500W respectively. Hot water with 70-100^{o}C temperature is produced by using 12m^2 solar evacuated tubes while electrical heater is installed as an auxiliary heater in cloudy time.

Figure 2 shows schematic of desiccant cooling system. This system has 9 stages of procedure or with suitable temperature and humidity (comfort thermal) for test room that operate by following process: (1) is

Table 1: Specification of Desiccant Cooling Components.

Desiccant wheel	Specification
Desiccant wheel	WSG 250x200 model, 1/80 HP, 200 scfm flow rate
Heat recovery wheel	HRW-500 model, 800 CFM (supply side), 800 CFM (exhaust side) flow rate, 415 V/3PH/50Hz
Blower	ASF 604 model, 240V, Single phase 50 Hz
Heat exchanger	Radiator from Perodua Kancil
Heater	WFH -24065 model, 240V, 1.5 m/s Air Velocity
Hot water tank	Termomax model, capacity 120 liter
Solar Collector	Vacuum tube
Pump	JP Basic 3 GF-model, 50m Max head, 45 L/min Capacity
Hot water pump	815-BR-C Magne-Boost mode, 4.1 Max head, 2850 RPM

dehumidified in a desiccant wheel (2); it is then cooled in the heat recovery wheel (3) by the return cooled air before being further cooled in the humidifier, as an evaporative process (4), finally, it is introduced into condition room. The operating sequence for the return air (5) is as follows: it is cooled to its saturation temperature of the evaporative cooler (6) and then it cools the fresh air in the heat recovery wheel (7). It is then heated in the heat exchanger by solar collector or heater (8) and finally regenerates the desiccant wheel (9) by removing the humidity before exiting the system.

Performance Index

The efficient working of a desiccant cooling system depends on the performance of its constituting component, the calculation procedure for the determination of effectiveness of rotary heat exchanger, and direct evaporative cooler. The system performance depends on the performance of individual components. A discussion of determining important component relations of individual components is given here.

Desiccant cooling units are heat driven system sand the coefficient of performance is defined as:

$$COP = \frac{Q_{cool}}{Q_{regen}} = \frac{m_a(h_5-h_4)}{m_a(h_8-h_7} \quad (1)$$

Where:

Q_{cool} = Rate of heat removed from the cooled room

Q_{regen} = Rate of regeneration heat supplied to the unit

m_a = Mass flow rate of air

h = Enthalpy of moist air and the state number refer to Figure 1.

Considering that the mass flow rates are equal in process and regeneration lines, the effectiveness of rotary regenerator may be expressed as:

$$\varepsilon_{HRW} = \frac{T_2-T_3}{T_2-T_6} \quad (2)$$

Where, T is temperature of moist air. The effectiveness of desiccant wheel may be expressed in a similar way:

$$\varepsilon_{DW} = \frac{T_2-T_3}{T_2-T_6} \quad (3)$$

The moisture removal capacity, MRC, represents the mass flow rate of moisture removed by wheel [8]:

$$\text{MRC} = \rho_1 \dot{V}_{proc}(\omega_1 - \omega_2) \quad (4)$$

The dehumidification Coefficient of Performance. DCOP, represents the ratio between the thermal power related to the air dehumidification and the thermal power supplied to the regeneration process [5]:

$$DCOP = \frac{\rho_1 \dot{V}_{proc} \Delta h_{vs}(\omega_1 - \omega_2)}{\rho_1 \dot{V}_{reg}(h_4 - h_1)} = \frac{\dot{V}_{proc} \Delta h_{vs}(\omega_1 - \omega_2)}{\dot{V}_{reg} C_p (t_4 - t_1)} \tag{5}$$

The effectiveness relations for the evaporative cooler air:

$$\varepsilon_{EC,1} = \frac{T_3 - T_4}{T_3 - T_{wb,3}} \tag{6}$$

$$\varepsilon_{EC,2} = \frac{T_5 - T_6}{T_5 - T_{WB,5}} \tag{7}$$

Where, T_{WB} is wet-bulb temperature of moist air. Also, a mass balance on the two evaporative cooler gives:

$$m^{\cdot}_{w1} = \dot{m}_a(W_4 - W_3) \tag{8}$$

$$\dot{m}_{w2} = \dot{m}_a(W_6 - W_5) \tag{9}$$

Where $m^{\cdot}_{w1}$ dan $\dot{m}_{w2}$ are the rates of moisture added to air in the evaporative coolers in the process and regeneration lines, respectively.

Result

The figures reported in this section are the experimental result obtained by the authors and the simulation. The experimental data, is related to the on-going modeling activity. The results are reported in the paper, as follows: the values of the outside air constant thermal hygrometric conditions (temperature and humidity ratio) are reported in each figure caption.

In Figure 4, the moisture removal capacity MRC is reported as a function of the process air thermal-hygrometric properties. The adsorption process is exothermic, so favored by low temperature [1], the rise in the process of air temperature that causes a decrease in the Desiccant Wheel (DW) dehumidification capability. The experiment data show better performance compared to the simulation result.

In Figure 5, the rise in ω_{out} causes an increase in the Desiccant wheel dehumidification capability [2]. The effect of $\omega_{out} = \omega_1$, t_2 increase significantly with process air inlet humidity ratio, as the wheel removes a greater quantity of water vapour.

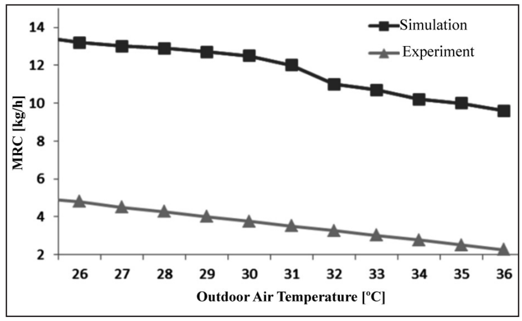

Figure 4: MRC as a Function of Outdoor Air Temperature (ω_{out}= 23.3 g/kg).

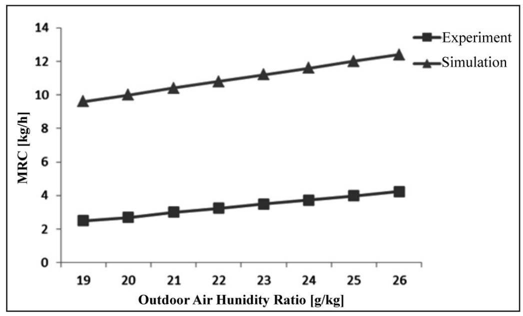

Figure 5: MRC as a Function of Outdoor Air Humidity (t_{out}= 37.8).

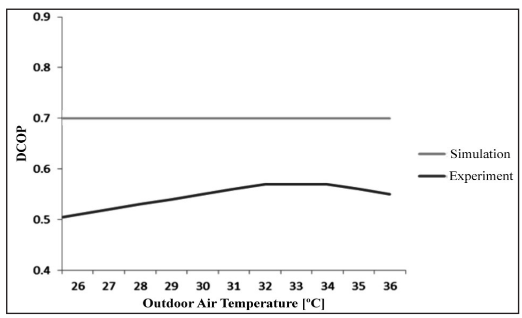

Figure 6: DCOP as Function of Outdoor Air Temperature (ω_{out}=23.3 g/kg).

In Figure 6, the rise in $t_{out} = t_1$ determines a reduction of Δh_{vs} of dehumidification capability [2], but also an increase in $h_{out} = h_1$. DCOP show a nearly constant value for simulation data and experimental result.

Figure 7, shows the efficiency of the heat recovery wheel and other component at

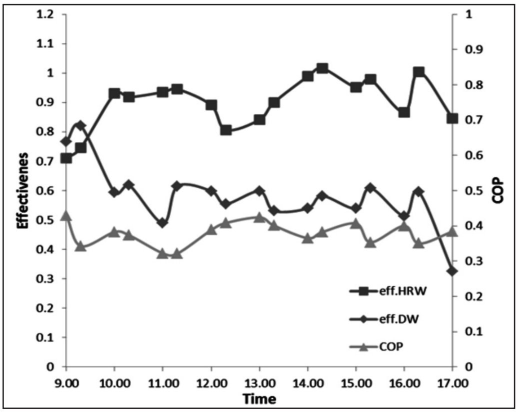

Figure 7: The Performance of Component Desiccant Cooling System.

various times. The lower differences are those of direct evaporative cooling and the higher differences which involve the desiccant mode. The efficiency of the heat recovery wheel is constant independently of the temperature difference and is always higher than 0.7. This result is predictable since efficiency does not vary significantly with the conductance unless there are important heat losses which is not the case here. This efficiency of 0.7 is crucial for the desiccant cooling system. Based on these results, to achieve a trade-off between the system energy performance (COP) and the supply of the air condition, regeneration temperature between 65^{o}C and 80^{o}C is more reasonable for the system operation under hot and humid climatic condition.

Conclusion

The performance of desiccant cooling system regenerated by solar energy has been obtained by means of an experimental investigation carried out in UKM-Malaysia. It can be concluded as follows:

- Desiccant wheel properties of the process of the air entering the wheel and the regeneration temperature strongly influence the performance of the desiccant;
- High heat recovery wheel effectiveness values (greater than 0.7) are desirable for better performance.
- Under given conditions, the increase in inlet humidity of process air results in obvious increase of moisture removal as well as COP. Lower inlet temperature and humidity ratio of regeneration air lead to better system performance.

The results obtained herein are useful for the development of desiccant cooling systems that are free from CFCs, and which require much less electric power consumption.

Acknowledgment

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