Experimental Investigation of Solar Hybrid Desiccant Air-Conditioning System Using Heat Pipe Heat Exchanger

Zuraini Mohd Enggsa, Arfidian Rachman, M. Mehdi, Sohif Mat, Kamaruzzaman Sopian

1Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, MALAYSIA.

2Heating, Ventilation and Air-Conditioning Department, University Kuala Lumpur- Malaysia France Institute, Bandar Baru Bangi, Malaysia 43650

Abstract: In this study, experimental investigation of solar hybrid desiccant air-conditioning system was designed, fabricated and analysed under the humid and hot weather conditions of Malaysia. In the system, latent load is removed by the silica-gel solid desiccant wheel and cooling coil of conventional vapour compression (VAC). Sensible heat load is removed by vertical heat pipe as replacement of conventional heat recovery wheel. As a result of significant energy saving is recorded. Thermal unit was consisting of 120m$^2$ evacuated tube (solar collector) and axillary heater is used. Supply air mass flow rate and regeneration air mass flow rate for the system were 0.028(kg/s) and 0.120(kg/s) respectively. The COP, effectiveness of desiccant wheel, and heat pipe heat exchanger of the system are 0.6, 0.7 and 0.80 respectively. Therefore, output qualified supply air with 22°C temperature, and 7.7 (gr/kg) was achieved by using solar hybrid desiccant air-conditioning system in hot and humid weather of Malaysia.

Keywords: desiccant cooling, heat pipe heat exchanger, solar thermal energy, hot and humid.

INTRODUCTION

Malaysia is hot and humid country. In United states, K.R. Grosskorp reported that a lot of defect in buildings due to humidity problems(1). Due to high humidity, it is recommended that tropical HVAC systems should be installed with heat pipe heat exchangers for dehumidification enhancement according to Yat H. Yau (2). The use of heat pipe save a lot of energy. Research by A.M Alklaibi(3) showed for low room sensible heat factor, using loop heat pipe can improve the COP by approximately 2.1-fold over that when heating element is used. The author has suggested possible configurations of incorporating the loop heat pipe into the air-conditioning systems. The application of Heat Pipe Heat Exchanger offered major improvements in humidity control and overall efficiency(energy saving) when compared to the usual practice of utilizing a specially designed cooling coil in combination with reheat. Mathur (4) analyzed the performance enhancement of an existing 5-ton(17.7kW) air conditioning system with an air-to-air two phase natural circulation heat recovery loop heat exchanger by simulation. It was found that the two-phase heat recovery loop would pay for itself in less than a year.

Worek and Moon (5) have modeled the performance of a desiccant integrated hybrid vapour air conditioning system. The wasteheat
rejected from a vapour air conditioning cycle is utilized to activate a solid desiccant dehumidification cycle directly. The performance sensitivity of a first generation prototype hybrid vapour air conditioning system to variable outdoor conditions has been studied and compared to the performance of conventional vapour air conditioning systems. Results showed that the performance improvement over vapour air conditioning systems could be 60% at the same level of dehumidification under ARI summer conditions. Simulation study by Thibaut Vitte on desiccant system show substantial energy savings for summer period, with satisfactory thermal comfort of the occupants(6). Reduction in humidity will reduce air conditioning load and provide good indoor air quality simultaneously. Investigation by C.X.Jia(7) showed hybrid desiccant cooling system economizes 37.5% electricity powers when the process air temperature and relative humidity are maintained at 30˚C, and 55% respectively. Sheridan and Mitchell(8) have analyzed the performance of a hybrid desiccant cooling system and found the energy savings ranged from 20% to 40% in high sensible heat load applications. Based on previous and existing research, it is highly believe that this design of advanced solar hybrid desiccant cooling systems with heat pipe heat exchanger will produce good indoor air quality and save energy consumption substantially.

2. MATERIALS AND METHODS.

2.1 Experimental setup

The solar hybrid 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 system. The test room has a length 3 m, width of 2 m, and height of 3 m. The hybrid desiccant cooling system consist 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) and cooling unit which used heat pipe heat exchanger, and vapour compression air conditioning.

Table 1 shows specification components of solar hybrid desiccant cooling system. The desiccant wheel is designed to operate with 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 pipe consist of 95 tubes bundle with 0.7 m height each tube. The capacity is calculated at 1 Kw.

Table 1: Specification of solar cooling components.

<table>
<thead>
<tr>
<th>Desiccant wheel</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desiccant wheel</td>
<td>WSG 250x200 model, 1/80 Hp, 200 scfm flow rate</td>
</tr>
<tr>
<td>Heat pipe</td>
<td>95 bundle tubes with 1 kW capacity</td>
</tr>
<tr>
<td>Blower</td>
<td>ASF 604 model, 240V, Single phase 50 Hz</td>
</tr>
<tr>
<td>Heat exchanger</td>
<td>Radiator from Perodua Kancil</td>
</tr>
<tr>
<td>Heater</td>
<td>WFH -24065 model, 240V, 1.5 m/s Air Velocity</td>
</tr>
<tr>
<td>Hot water tank</td>
<td>Termomax model, capacity 120 liter</td>
</tr>
<tr>
<td>Solar Collector</td>
<td>Vacuum tube</td>
</tr>
<tr>
<td>Pump</td>
<td>JP Basic 3 GF-model, 50m Max head, 45 L/min Capacity</td>
</tr>
<tr>
<td>Hot water pump</td>
<td>815-BR-C Magne-Boost model, 4.1 Max head, 2850 RPM</td>
</tr>
</tbody>
</table>
2.2 Experimental procedure

Figure 2 show a desiccant cycle operates as follows: (1) is dehumidified in a desiccant wheel (2); it is then cooled in the heat recovery wheel (3) the air is cooled by cooling coil of vapour compression system (4), finally, it is introduced into condition room. The operating sequence for the return air (5) 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.

![Figure 2: Schematic diagram of advance solar hybrid desiccant air conditioning system](image)

The desiccant wheels are designed to operate with both a 50% area for reactivation and 50% for process (50/50). The diameter of the wheel is 250 mm and the width is 533 mm with the angular velocity of 8 rev h\(^{-1}\) for a nominal air-flow rate of 6000 m\(^3\) hr\(^{-1}\). The heat recovery wheel is an aluminium honeycomb structure. It rotates at 12 rev min\(^{-1}\). The diameter of the regenerator is 700 mm and its width is 700 mm. The installed cooling coil of vapour compression unit is 10,000 btu/hr max air flow 400 m\(^3\) hr. The electrical consumption of the motor blower is about 150 W. The system mainly includes 120 m\(^2\) solar air collectors with temperature range of between 80 – 120\(^\circ\)C, feeding 3 storage tank of 1000L. This central heating system also supply hot water to various projects in Green Energy Park, UKM.

ADAM data acquisition has been used to do monitoring. Temperature, Humidity, Air flow rate and radiation intensity has been monitored and recorded. The system consist of three adam 4018 to monitor temperature and humidity. One adam 4018-12 to monitor air flow rate and radiation intensity. The data is strengthen using adam 4510 before sending to adam 4520 and finally to computer for recording.

2.3 Determinations of performance, and effectiveness.

The Coefficient of Performance (COP) of the solar hybrid desiccant cooling system can be calculated by rate of heat extracted divide heat of air conditioning and heat regeneration.

Theoretical Analysis:

\[
\eta_s = \frac{m(H_2 - H_1)}{P_{\text{d}} + P_{\text{ac}} + P_{\text{b}} + P_{\text{h}}}
\]

Where:

- COP/\(\eta_s\) = Coefficient Performance of System
- \(m\) = mass flow rate
- \(H\) = Air specific humidity ratio (kg\(_{\text{dry}}\)/kg air)
- \(I\) = Radiation intensity (kWh/M\(^2\))
- \(A_s\) = Solar collector area (m\(^2\))
- \(P_{\text{b}}\) = Blower motor capacity (kWh)
- \(P_{\text{h}}\) = Electrical heater capacity (kWh)
- \(P_{\text{ac}}\) = Desiccant wheel motor capacity (kWh)
- \(P_{\text{h}}\) = hot water pump capacity (kWh)
- \(P_{\text{ac}}\) = air conditioning system capacity (kWh)

Considering that the mass flow rates are equal in process and regeneration lines, the effectiveness of heat pipe rotary regenerator may be expressed as Eq. 2:

\[
\varepsilon_{\text{HPW}} = \frac{T_2 - T_3}{T_2 - T_6}
\]

Where, \(T\) is temperature of moist air. The effectiveness of desiccant wheel may be expressed in similar way Eq. 3:

\[
\varepsilon_{\text{DW}} = \frac{T_1 - T_2}{T_2 - T_8}
\]

3. RESULTS AND DISCUSSION
Results of experimental test as flow chart and psychrometric chart are shown in figure 3 and 4, respectively. In the first point ambient air with 33.8°C temperature and 27.1 (gr/kg) specific humidity enters to desiccant wheel, after absorbing humidity by dehumidifier in second point, the temperature increase to 41.2°C, and specific humidity reduces to 7.7 (gr/kg).

Afterward, the process air enters heat pipe (first part of cooling unit) resulting the third point temperature reduces to 28.9°C but specific humidity remains unchanged. The process only involving sensible cooling. When air passes through the cooling coil (second part of cooling unit) temperature reduces to 20.9°C, but as the specific humidity remains constant, so this air as supply air enter the rooms.

In return air process, air with 26°C and 9.8 (gr/kg) (fifth point) exhausts from the room and enters in other side of heat pipe. This condenser part of heat pipe reject heat resulting in temperature increase of regeneration air to 32°C. In the next step, air heated again by getting heat from solar thermal (evacuated tube collector) and auxiliary heater (seventh point). Therefore the seventh point increases to 48.8°C. Specific humidity of fifth, sixth, and seventh points remains constant. Lastly, the regeneration air absorbed moisture reducing temperature to 41.7°C. In this system latent load is removed by silica-gel solid desiccant wheel, and sensible heat load is removed by heat pipe and vapour compression air conditioning system. The process is illustrated in psychrometric chart as follow:

![Psychrometric chart of solar hybrid desiccant cooling systems.](image)

Figure 4: Psychrometric chart of solar hybrid desiccant cooling systems.

![Coefficient of Performance](image)

Fig. 5: Effect of regeneration temperature, Coefficient of Performance

Figure 5, shows the change of COP with respect to different regeneration temperature. It can be found that; COP could obtain a maximum when $T_r$ is between 70 and 80°C.

The influence of the increment of regeneration heat is much more significant, which leads COP to drops off.

Calculation done system performance, heat pipe performance and desiccant wheel performance is 0.8, 0.6 and 0.7 respectively.

4. Conclusion.

This paper presents experimental investigation of solar hybrid desiccant cooling system using heat pipe heat exchanger in hot and humid weather like Malaysia. Heat pipe is energy free device without external electricity required. Indoor condition: 20.9°C, 7.7 gr/kg, by using this system with COP: 0.8 was reached while outdoor conditions 33.8°C, 27.1 gr/kg. In this system heat pipe heat recovery, and cooling coil of VAC were used as cooling unit to remove sensible load. Latent load was removed by desiccant wheel. The results of this system shows that output qualified supply air can be achieved even without using evaporative cooling. It was found solar hybrid desiccant system provide substantial energy saving in comparison with conventional vapor compression in hot and humid area. Therefore, it is highly recommended to be used in hot and humid weather like Malaysia.

Acknowledgements.
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References.
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