PERFORMANCE OF SAND FOR HEAT STORAGE IN SOLAR COOKER

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ABSTRACT
Sand is environment friendly and easily available low cost heat storage material. The heating tests on sand were performed in a small scale photo voltaic and thermal hybrid solar cooker. The performance was observed for constant load and variable input power and for constant input power and variable load. The empty cooker test was performed for comparison. The results were compared and the maximum heat retention was found for 200gm sand at 42 watt input power. Sand can be used as a thermal energy storage material in solar energy devices like solar cooker, solar dryer and solar hot water system.

Key Words: Solar cooker, Thermal energy storage system, Dryer, Hot water system, Biomass

INTRODUCTION
The potential of renewable energy sources was recognized in India only in the beginning of last quarter of the 20th century. In the recent decades, efforts have been made for the development of renewable energy sources like solar, wind, biomass and biogas. Solar energy has wide potential and can be used in energy devices like solar cooker, hot water systems and solar dryers. Solar energy is intermittent, unpredictable and available only during the day. Its optimum utilization requires efficient thermal energy storage systems. Thermal energy is one such energy which is of interest to researchers worldwide. The most popular applications of thermal energy storage materials found in solar-energy storage systems are for water heating, greenhouses, space heating, cooling and cooking. The use of solar cookers is limited due to lack of energy storage facility. It cannot be used on cloudy days or in the late evening or night time. Solar cookers with sand as heat storage devices can be used during day time as well as night time too.

Sand as heat storage material
Sand, specifically the ordinary silica sand is an inexpensive heat storage medium and is also a type of TES (Thermal Energy Storage System). Obviously, heat exchange is needed in any such devices like solar cooker, solar hot water system, solar dryer etc. in which different heat collection and storage media are used. Heat transfer coefficient is one of the most important parameters for selection of TES. The heat transfer coefficient of flat and finned silica is in the range of 310-400W/m²-K and 212-405 W/m²-K respectively. Mathew et al. studied the effect of heat transfer on flat plate collector. Patton et al. has reviewed the similar work for the use of sand as TES with the parameters like the size of the fine sand, packing ratio, conductivity, specific heat, flow velocity and layer thickness. The temperature profile of solar cooker with sand as TES is discussed. Heat transfer has been studied by using granular materials.

In present work, the heat storage capacity of sand was tested by putting it in a solar cooker. For comparison, an empty cooker test was also conducted. In the earlier work, a very small photo voltaic and thermal hybrid solar cooker was developed and tested for its maximum utilization. The effect of tracking of solar PV module was tested to study the increase of its efficiency. Development of heat storage system for solar cooker was studied to test the performance of ionic liquids.

MATERIAL AND METHODS
100gm and 200gm sand was tested in the developed solar cooker with 12W, 30W and
42W input power supply. The weight of the sand was measured with Reptech RB-6005 precision balance having 5% accuracy. For comparison, an empty cooker test was also conducted. A variable power supply was connected with photovoltaic and thermal hybrid solar cooker. With the help of inbuilt voltmeter and ammeter, voltage and current were measured. Power $P$ was calculated by equation (1).

$$P = V \times I$$  \hspace{1cm} (1)

RESULTS AND DISCUSSION

Heat storage capacity of 100 gm sand

The solar cooker performance test were conducted with 100gm and 200gm sand with different input power viz. 12W, 30W and 42W. The ambient temperature and hot sand temperature were measured at an interval of 10 minutes. For comparison, an empty cooker test was also conducted with 12W and 42W power supply.

**Sand test with 12 W power**

Fig. 1 to Fig. 3 shows the temperature profile of photovoltaic and thermal hybridized solar cooker with 100gm sand at 12 Watt, 30 watt and 42 watt power respectively. The test was started with 100gm of sand at 2:40 p.m. in the laboratory. Initially ambient temperature and sand temperature were 31°C and 30°C respectively. To increase the sand temperature, power supply was switched on. It was allowed to heat sand for 90 minutes. As a result, the sand temperature was raised to 107°C, then the supply was switched off and temperature of sand was measured after 180 minutes to get the idea of heat retained by 100gm sand. It was observed that the sand temperature was dropped to 41°C while the ambient temperature was 29.7°C.

![Fig. 1: Temperature v. Time plot (100gm sand, 12W input power)](image1)

![Fig. 2: Temperature v. Time plot (100gm sand, 30W input power)](image2)
Fig. 3: Temperature v. Time plot (100gm sand, 42W input power)

Sand test with 30 W power
Initially, the sand temperature and the ambient temperature were 35°C and 33°C respectively. The power supply was switched on and the sand temperature was allowed to increase. The supply was switched off on 12:30 p.m. i.e. after 90 minutes. At that time the sand temperature was 175°C which was further increased to 178°C even after switching off the power supply then gradually it started to decrease and fall down to 65°C by 90 minutes, while the ambient temperature was 28.2°C.

Sand test with 42 W power
Initially, the sand temperature and ambient temperature were 30°C and 29.7°C respectively. When 42 watt power was supplied, the sand temperature increased to 209°C after 90 minutes and then it started to fall and dropped to 49°C at this time the ambient temperature was 28.2°C. Table 1 shows the temperature profile of solar cooker with 100gm sand as TES. It contains initial temperature when the power supply was switched on, highest temperature after 90 minutes and temperature after 180 minutes and 240 minutes are mentioned here.

<table>
<thead>
<tr>
<th>Time (minute)</th>
<th>Th12W (°C)</th>
<th>Tambient (°C)</th>
<th>Th30W (°C)</th>
<th>Tambient (°C)</th>
<th>Th42W (°C)</th>
<th>Tambient (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>31</td>
<td>30</td>
<td>35</td>
<td>33</td>
<td>30</td>
<td>29.7</td>
</tr>
<tr>
<td>90</td>
<td>107</td>
<td>28.6</td>
<td>178</td>
<td>28.5</td>
<td>209</td>
<td>28.5</td>
</tr>
<tr>
<td>180</td>
<td>41</td>
<td>29.6</td>
<td>65</td>
<td>28.2</td>
<td>49</td>
<td>28.2</td>
</tr>
<tr>
<td>240</td>
<td>34</td>
<td>29.7</td>
<td>35</td>
<td>27.9</td>
<td>35</td>
<td>29</td>
</tr>
</tbody>
</table>

In all the cases sand was heated for 90 minutes by connecting it with the power supply then the supply was switched off and heat retaining capacity was studied. The maximum temperature was observed for 42 W supply which was 209°C, 197°C for 30 W supply and 107°C for 12 W power supply. The final temperature was measured after 90 minutes which was 12°C higher than that for 30W and 102°C higher than for 12W supply.

Table 1 : Heat storage capacity of 100 gm sand

Heat storage capacity of 200 gm sand
Temperature profile of solar cooker with 200gm of sand for 12W, 30W and 42W is as shown in Fig. 4 to Fig. 6 respectively. Initial temperature of heater was 31°C, 34°C and 34°C for 12W, 30W and 42W respectively. The temperatures were increased to 111°C, 197°C and 245°C by connecting them with power supply. After 90 minutes the supply was switched off and temperatures were again noted down.
Table 2 shows the temperature profile of solar cooker with 200gm sand as TES. It contains initial temperature when the power supply was switched on, highest temperature after 90 minutes and final temperature after 240 minutes when the final temperature show the heat retained capacity of sand for different input power viz. 12W, 30W and 42W.
Table 2: Heat storage capacity for 200 gm sand

<table>
<thead>
<tr>
<th>Time (minute)</th>
<th>$T_{h12W}$ (°C)</th>
<th>$T_{h30W}$ (°C)</th>
<th>$T_{h42}$ (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>31</td>
<td>34</td>
<td>31</td>
</tr>
<tr>
<td>90</td>
<td>111</td>
<td>197</td>
<td>245</td>
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<td>180</td>
<td>50</td>
<td>65</td>
<td>75</td>
</tr>
<tr>
<td>240</td>
<td>37</td>
<td>41</td>
<td>46</td>
</tr>
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</table>

Empty cooker test
To compare the heat retained capacity empty cooker test were conducted by varying input power. Fig. 7 and Fig. 8 show the temperature profile for empty solar cooker with 20W and 42 W respectively. Both these plots show sudden fall of temperature as the cookers are empty and cannot retain heat.

Fix load variable wattage

Case: I
To get an idea of wattage requirement for fix load (100gm sand) a plot of Temperature v. time is plotted with 5% error bar as shown in Fig. 9 Temperature of sand was measured for different wattages viz. 12W, 30W and 42W.

Case: II
To get an idea of wattage requirement for fix load (200gm sand) a plot of temperature v. time is plotted with 5% error bar as shown in Fig. 10. Sand temperature and ambient temperature were measured at an interval of 10 minutes for different wattages viz. 12W, 30W and 42W.
Fix 100 gm sand with variable wattage

Fig. 9 shows the plot of temperature v. time for different input wattage viz. 12 W, 30W and 42W. The cooker was loaded with 100gm sand. There is very small change in ambient temperature throughout the time of experiment i.e. only 1.4°C while sand temperature was increased from 30°C to 209°C when cooker was loaded with 100gm sand. After 90 minutes of heating the sand temperature was increased to 209°C. The temperature of sand at that time was 49°C and the ambient temperature was 29.6°C. For empty cooker, the initial and final temperature after heating was 32°C and 203°C respectively. The temperature dropped to 48°C after the power was switched off.

Fix load 200 gm sand with variable wattage

Fig. 10 shows the plot of temperature v. time for different input wattage viz. 12 W, 30W and 42W. The cooker was loaded with 200gm sand. Initially, the sand temperature was 31°C and it was increased to 245°C by supplying 42 watt power for 90 minutes. Once the power was switched off, the temperature of sand started to fall and was dropped to 75°C. The heat retained by 200gm sand was higher than that in the case of 100gm and empty cooker.

Fig. 9: Temperature v. Time plot (100 gm sand, variable input power)

Fig. 10: Temperature v. Time plot (200 gm sand, variable input power)

Fix wattage with variable load

Fig.11 to Fig.13 shows the temperature v. time plot for 12 watt, 30 watt and 42 watt input supply (constant) for empty cooker, cooker with 100gm sand and cooker with 200gm sand with 5% error bars respectively. To compare these temperatures, an ambient temperature is also included in it. Table. 3 show the heat retention capacity of 100gm and 200gm sand.
Fig. 11: Temperature v. Time plot (12W input power, Variable load)

Fig. 12: Temperature v. Time plot (30W input power, Variable load)

Fig. 13: Temperature v. Time plot (42W input power, Variable load)
CONCLUSION
Heat retaining capacity for 42 watt input power
is higher for 200gm sand than for 100gm sand
i.e. the temperature of sand will be 45.4 °C higher than ambient temperature. Sand being
environment friendly material and easily available at low cost can be used for heat
storage in the solar energy devices like solar cooker, solar dryer and solar water heater.

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