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Development of Solar Oven Incorporating Thermal Energy Storage Application

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***Abstract*— A functional solar oven integrated with thermal storage application was fabricated in a way to optimize the performance of solar cooking. This paper presents the characteristic, performance, and efficiency studies of the solar oven by evaluating different parameters; aluminum panel, aluminum wall inside the oven and aluminum wall contained with steel bar as test load with thermal energy storage. Temperature analysis towards four set of experiments showing that thermal energy storage application is the steadfast option in improving the solar oven performance.**

***Index Terms*— Solar oven; sensible heat storage; thermal energy storage application; Solar oven energy efficiency.**

I. INTRODUCTION

A solar oven or solar cooker is a device which exploits sunlight as its energy source, uses no fuel and involves no operation cost. It is a form of outdoor cooking and often used in situations where minimal fuel consumption is important, or the danger of accidental fires is high. Most low income families using fuelwood for cooking or difficulties in getting cooking gas supply may lead the shifting to solar cooker in much of the developing world [1,2]. Solar cooking has become a possible solution as a substitute for fuelwood in food preparation but its acceptance is limited partially due to some barriers. Solar cooker cannot cook the food under low radiation condition and solely dependent on the sun radiation which is an inconsistent variable causing the disabilities of oven to function at optimal performance [3]. To overcome this problem, solar oven with the application of thermal energy storage was developed with a goal that the heat distribution in the oven occurred even in sudden decrease of solar radiation. Capable to retain energy and maintaining well heat distribution inside the oven, the thermal energy system also can preventing the oven from losing heat during the drop of solar radiation due to changing weather condition [3,4]. Therefore this study attempts to contemplate the characteristic and performance of four sets of functional solar oven.

II. MATERIAL AND METHOD.

A. Designing and sketching process

The design of solar oven is in compliance with required aspects to ensure the parts are all functioning. The must considered aspects in designing are: (i) strength (ii) Ergonomic factors: user friendly, easy and convenient product (iii) Glass orientation: Appropriate orientation for greater solar heat gain. (iv) Reflector: multiple reflectors to gain more solar radiation incident. (v) Heat storage: additional heat storage application [4-6].

B. Material selection

Material selection is particularly done for four main parts of main body, container, reflector and a holder. The main body of this solar oven used plywood material. There are two bodies actually which is an inner and outer body with 3cm gaps for air spacing. Trapped air will be used as an insulation medium for the wall of the main body in term of convection loses reduction.

Double glasses have been used as the top cover since it can trap air between the glasses. The air filled space could reduce heat transfer across the solar oven body part and preventing heat from escaping to the outside. Container part is made using aluminum and it is placed in the main body for food placement and thermal energy storage application. There is separate column between food and thermal energy storage. The aluminum properties are good in thermal conductivity so as for thermal energy storage. The reflector made from aluminum as well due to the light weight criteria and easily to cutting and shaping. Aluminum sheet also is a good heat reflector from the sun direct to the oven and able to reflect additional heat to the oven. The solar oven can be aligned in horizontal axis and adjusted 90 degrees to the direct sun radiation. Technically, the principle of making solar oven stated that more glass facing perpendicular to sunlight will gain more solar incident into the solar oven [4].

C. Thermal energy storage application

Two types of energy storage, sensible heat storage and latent heat storage (phase change material, PCM) were considered for the thermal energy storage application. PCMs have a constant temperature to store heat energy in it, but sensible heat storage has no transition temperature to absorb large energy. Thus, sensible heat storage was chosen in this study with river rocks as a thermal energy storage application. The high melting point criteria makes possible for rocks to absorb much heat during heating process [3,4].

D. Glazing material

A double glazed box cooker and a double glazing with suitable thickness and gap in between were found better than a single thick glazing [7]. The transparent cover (glazing) is used to reduce convection losses from the food container through the restraint of the stagnant air layer between the food container and the glass. It also reduces radiation losses from the collector as the glass is transparent to the short wave radiation received from the sun but it is nearly opaque to long-wave thermal radiation emitted by the food container [7,8].

E. Experimental setup

The experiments were conducted in HVAC laboratory, Faculty of Mechanical UMP. There are four experiment sets tested in order to achieve optimum cooking process. The solar radiation was assumed to be constant at 1000W/m², equal to actual mean solar radiation in Malaysia during daytime. To achieve constant radiation, four sets of spotlights were used as sources of heat in replacement of sunlight. The spotlight radiation was measured using pyrometer. Each experiment took about 3 hours heating and 30 minutes cooling. 30 minutes cooling data is to determine the functionality of thermal storage application.

Set 1 (Oven only)
The first set (Fig.1) is a basic oven only to measure the temperature data. There are three measured parameters; oven temperature, aluminum tray temperature and steel bar temperature. All temperature parameters are measured using thermocouples. Steel bar is a test load to measure energy efficiency values of the solar oven.

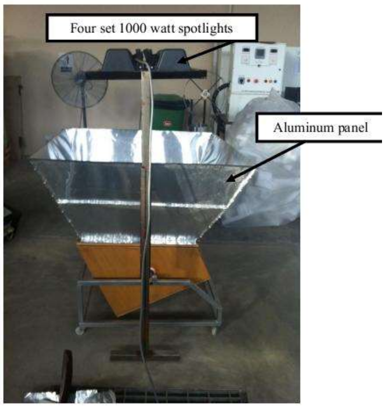


Figure 1. Set 1 (Oven only)

Set 2 (Oven with aluminum panel)

Meanwhile, Set 2 as in Fig. 2 designed with combination of oven and additional aluminum panel. The aluminum panel was installed to increase the heat incident directly to the oven and simultaneously increasing the oven temperature. The measured parameters are same as experiment 1.

Figure 2. Set 2 (Oven with aluminum panel)

Set 3 (Oven with aluminum panel and thermal storage)

Updating system in Fig. 3 is the third experimental setup that consists of an oven with aluminum panel and additional of thermal energy storage application. The thermal storage application was technically applied to determine the capability of oven in maintaining the

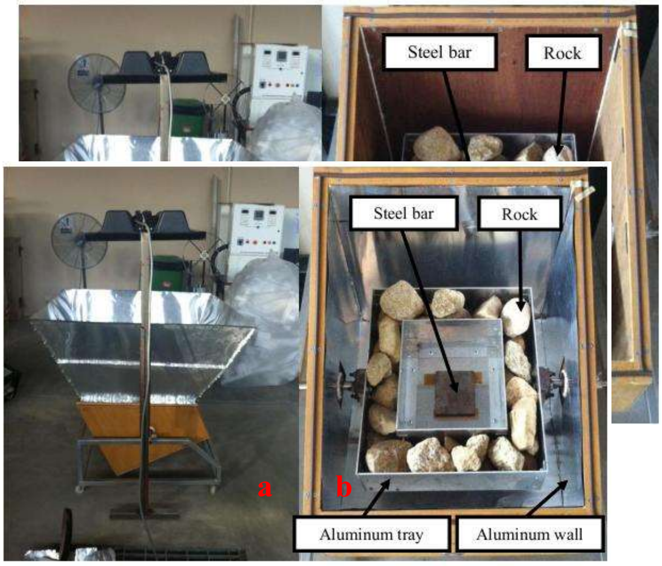


Figure 3. Set 3, (a) Oven with panel,(b) Inside the oven

Set 4 (Oven with panel, thermal storage and aluminum wall).

The combination system for Set 4 in Fig. 4 technically consists of additional oven parameter; aluminum panel, thermal energy storage application and aluminum wall. The aluminum wall is accounted since it is known that aluminum sheet is good at reflecting heat.

Figure 4. Set 4, (a) Oven with panel, (b) Inside the oven

III. RESULTS AND DISCUSSION

A. Temperature analysis

The temperature analysis for all systems is illustrated in the corresponding graph. The temperature trend in Fig. 5 for Set 1 clearly shows that the highest temperature is steel bar which is 88ºC. Aluminum tray reach maximum temperature at 85ºC and oven only reach 83ºC. Oven temperature increases almost at 100 minutes then slowly stable when reach 120 minutes during the experiment. Instead, the steel bar is continuously increased to the maximum value at 180 minutes as it has a higher capability to store energy than aluminum tray. Aluminum tray is good at handling and transferring heat from the oven to the steel bar.

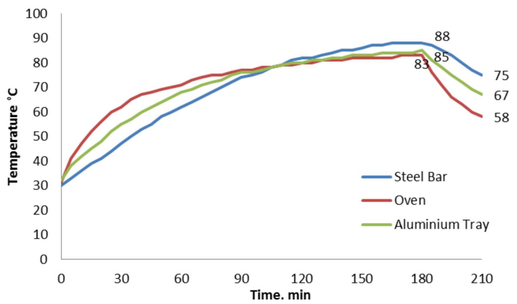


Figure 5. Temperature Analysis- Set 1

Meanwhile, temperature analysis for Set 2 that illustrated in Fig. 6 shows that the maximum temperature is steel bar which is 108°C. Then it followed by aluminum tray at 99°C and oven temperature at 94°C. It is clear that Set 2 absolutely increased the overall temperature of the parameter measured as the aluminum panel eventually supplies more heat incident to the oven. Oven temperature also increasing perpendicular to the time as compared to result for Set 1.

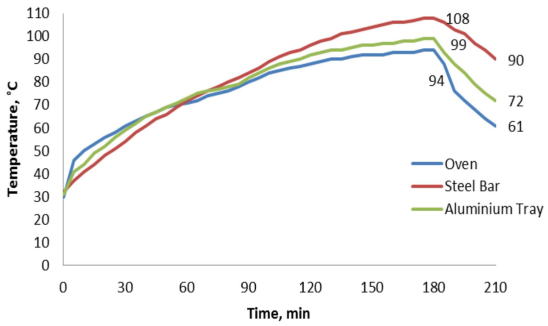


Figure 6. Temperature Analysis- Set 2

With the addition of thermal energy storage, temperature analysis for Set 3 in Fig. 7 indicated that the maximum temperature of oven is at 98°C. Steel bar followed with 95°C, aluminum tray at 89°C and rock at 77°C. It is also shown that oven temperature is instantaneously increased in comparison with the previous set due to the thermal energy storage application. The oven temperature is kept almost in stable with less fluctuation and temperature spike. Temperature of steel bar and aluminum tray dropped a little bit compared to previous set likely as the heat energy is absorbed by rock during heating process.

Figure 7. Temperature Analysis- Set 3

Eventually, temperature analysis for Set 4 presented in Fig. 8 shows that the maximum temperature in the oven obtained from the steel bar at 105°C. Oven at second highest with 102°C, followed by aluminum tray at 99°C and rock at 90°C. It is also shown that the oven temperature increased drastically within 30 minutes prior of the experiment likely happened due to the installed aluminum wall to reduce heat loses from the oven. The released heat then was directed to the center of the oven and kept the steel bar to reach the highest temperature and defeated the previous set.

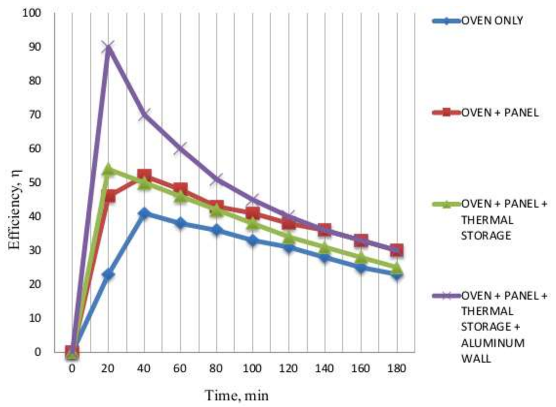
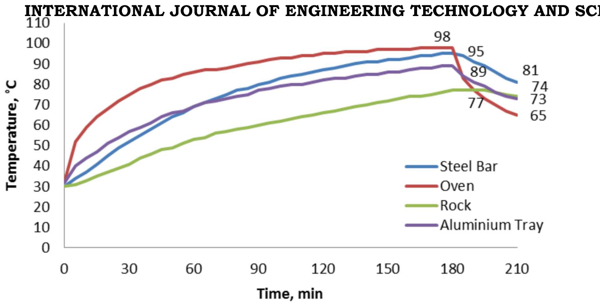


Figure 8. Temperature Analysis- Set 4

B. Solar oven energy efficiency

The solar oven instantaneous efficiency is calculated from the data collected from the steel bar as the test load. Energy efficiency of an oven can be defined as the ratio of energy output (steel bar) to the energy input (the energy of solar radiation). Thus the instantaneous energy efficiency of the oven was calculated as follows:

$$\eta = \frac{1 + m.cp\,(T_f - T_i)/\Delta t}{I.A} \qquad (1)$$



From the energy efficiency study, the experimental results are summarized in Fig. 9. The oven efficiency is calculated for each 20 minutes period of experiment. The maximum efficiency is at first 20 minutes for Set 4 with 90% of efficiency. The efficiency then drastically dropped in perpendicular with time meanwhile the temperature different slowly reaching the stability condition. Finally, Set 4 reached 35% of efficiency at the end of heating processes.

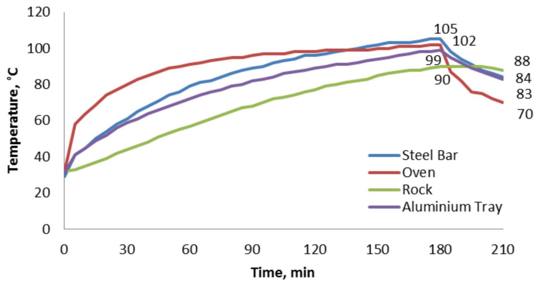


Figure 9. Solar Oven Efficiency

IV. CONCLUSION

In overall, the aluminum panel was specified to increase the oven and steel bar temperature. Meanwhile, aluminum wall increases heating rate to boost up oven, aluminum tray and rock temperature. Both materials are performing well in the oven efficiency studies. It was proven during the experimental study for Set 2 and Set 4 where the steel bar and oven temperature is highest in both experiments. Thermal storage application rises the temperature of oven, aluminum and steel bar steadily when the radiation started to drop proven that the using of thermal storage application is the steadfast option to improve the solar oven performance.

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