Box type and Panel type solar cookers which can be used as cartons to contain the emergency stuffs.

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Abstract

This study aims to design and construct solar cookers which can also be used as containers for emergency stuffs such as water, foods, medical kits, flash lights, etc. in order to prepare for the probable disconnection of the public services by an unpredictable disaster. The requirements for the cookers are that either of them can serve for two at least when it is clear regardless of the sun elevation for the use in mid-latitude countries such as Japan. Specifically we designed them to have the performance to heat 500mL of water to more than 95 degrees centigrade within 90 minutes when the average direct solar radiation is above 700 watts per square meter. The understanding for the practical availability of the solar cookers is still not common in Japan but these kind of solar cookers can alleviate this problem because people will have at least one container type solar cooker for each emergency kit automatically and they will have good chances to use them when they have to replace the stuffs inside every year.

The panel type cooker has the same shape with the existing solar cooker of ours which has been on the market for nearly ten years when it is developed and reassembled into the cooker. On the other hand, the box type cooker has high concentration and robustness compared with conventional box type solar cooker when reassembled from the container, which makes it possible to be used without any insulating material between the inner and outer boxes. Both two types of cookers can be returned to the containers after the usage as solar cookers. Solar energy is the most abundant form of energy on earth but some still have dissenting opinions to employ them for the preparatory measures because their performance is affected by the weather. We would like to place stress that these devices can really cook foods and can warm preserved foods in a short time without any possibilities to start fires even in the flammable rubbles. In addition, employing solar cookers will be particularly useful in situations where minimal fuel consumption is important, and the period while we wait for the recovery of the public service after a natural disaster is one of such typical situations.

The proposed two types of solar cookers are made of commonly available materials such as cardboard, multi-wall plastic, aluminized films, etc. so they are easy to fabricate and have

economically affordable costs. They are designed carefully by the ray tracing technique and tested through experiments for efficiency and capacity to realize the desired features.

Keywords
Solar Cookers, Emergency Kit, Panel type, Box type, Thermal Performance

1. Introduction

Organizations, consultants and governments constantly urge that each household or individual ought to have stores of extra food, clean containerized water, first aid supplies, clothing, backup power sources, money (cash) etc. set aside for the eventuality of uncontrollable disasters or events, whether they be natural or man-made.
For a country like Japan in which natural disaster such as earthquake, tsunami, flood etc. occur frequently, having a kit which allows cooking after these events is important for surviving.
Ashikaga Institute of Technology (AIT) in Japan has designed several solar cookers of different types through the researches with the student, and the Collaborative Research Center attached to AIT has employed them in the activities of civic educations including lecture deliveries to schools. Some of the cookers were made into products as educational materials by Showa Rikagaku Kikai Co. Ltd. (SRK) for the teachers to prepare large quantity easily.
In this study, we decided to design, construct and test a box and a panel type solar cooker. Our box type solar cooker is a container with a transparent plastic cover. The performance of the box type solar cookers depends on the insulation of the heat as well as the concentration of the light. Cardboard panels covered by aluminized plastic film are used for the booster mirrors and walls of the cooking chamber to direct the lights towards the pot as much as possible. The panel type solar cooker has the same shape and design with the Educooker 003. The difference is that the panel type can also be used as a container for emergency stuffs by adding supplemental folding lines and panels to the existing design. In testing the solar cooker, the procedures followed to evaluate the performance criteria we employed to be the practical cooking tool in Japan throughout the year: heating a quantity of 500 mL of water up to 90°C within a reasonable time. The test of the panel type followed the same process as the one for the box type.
On the other hand, we realize the continued demand for alternative sources of energy in developing countries to sustain their current lives. In many countries, for example, urbanization has created a great demand for structural wood, firewood, and charcoal resulting in an increasing loss of forests. Deforestation accelerates the acute demands of wood in the area and it expands to the neighbouring areas. Cooking with sun is a potentially viable substitute for the conventional fuels for cooking, but still most people do not aware its practicality because they do not have chances to see them work actually. Where the urbanization starts, there always exist logistics. If they can obtain their own solar cookers utilizing abundant, clean and safe energy easily from general distribution sources, the chance they start to use solar cookers will gradually and constantly increase. The box made of the cardboard with aluminized plastic film will shut the heat and the light from outside and keep the contents in the box undamaged for long time. The carton box with such added value will be a little costly so in many cases it is used to contain relatively valuable items such as chemicals, medicines, or expensive foods. By adding the further function transforming into a solar

cooker, the price of the carton box will increase but when considering the usage of such special boxes, the increase in price will be still affordable. The affordability strongly depends on the price of the content so we made the prototype with two materials. One is less expensive ordinary corrugated cardboard and the other is the PP multi-wall sheet, or corrugated plastic board. When it is used as a box containing the emergency kit, plastic material will be desirable because you need to keep it for long time. By employing the plastic material, the content is also safe from the humidity as well as the heat and the light. If you are trying to put the contents and the cooker in circulation, the period it is used as a container is short so the ordinary cardboard material will be suitable. For the emergency use, you may not be able to find suitable insulator for the box type solar cooker so we examined the performance without any thermal insulation materials relying only on the insulating characteristics of the corrugated materials themselves.

2. Materials and Designs

2.1 Box type solar cooker

Among various solar cookers, the box type is one of the common and popular variety. To adapt for the low sun elevation in Japan, we employed slanted top cover and large enough booster mirrors. When designing the shape of the box type cooker, we used our experience when designed the panel type solar cooker in reference to obtain the high concentration and robustness. Because we are expecting the use in emergency situations, the usage of an insulation material is optional. If you can find something which is available for the heat insulation material, you can put it between the inner and outer boxes. Even without the insulator, it can work as a cooker but in this case its characteristics are close to a panel type solar cooker which does not rely on the use of plastic bags. The two booster mirrors which expand in triangle shape concentrate the sun's rays toward the cooking pot and food for higher cooking temperatures and effectiveness.

The box type cooker consists of a multi-wall transparent PP lid to be used on the inner box, cooking tray, and an additional cardboard to reinforce the insulation of the inner walls. The cooking tray can be insulated on the bottom when a suitable material is available, but the feature of this box type is that it can cook food without using additional insulation materials other than cardboard itself. Under the inner box of the box cooker, it has enough space which can contain insulation material. When using as a carton, this inner part is reversed in order to strengthen the structure of the carton box. The two booster mirrors placed on the upper side of the box work as two lids from different direction when the cooker is used as a container.

The cooker has to be placed facing the sun. The reflectors are inclined at an angle according to the sun elevation. Because the front of the cooker is a corner of the diagonal and the two booster mirrors are adjacent with the right angle, the robustness to the direction of the incident light is relatively high despite of the high concentration. In most cases, the position of the reflectors and the direction of the cooker can be remained unchanged throughout the working period. A very common steel cooking pot with dark colour is used for the experiments.

2.1.1 Construction of the Box-Type Solar Cooker

There are mainly three types of materials that have been used in the construction of the solar box cookers.

A. Structural material : Cardboard / Plastic
B. Transparent material: multi-wall plastic for green houses
C. Reflector : Aluminized cardboard or Aluminized plastic
D. Insulation : optional (cotton clothes, wool blanket, rock wool, etc.)

Specification of the box cooker

Cardboard / Plastic box = Length 420 mm x Width 420 mm x height 315 mm
Thickness 3 mm
Plain glass = Length 425 mm x Width 425 mm x Thickness 3 mm
Aluminized surface: 1.0 m^2
Black aluminium vessel = 0.5 litres
Volume of inner box: 0.54 m^3

Fig. 1: *Technical drawing of the constructed box-type solar cooker*

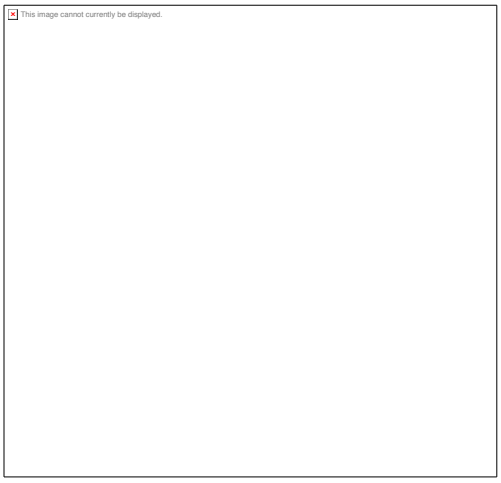


Fig. 2 : *The constructed box-type solar*

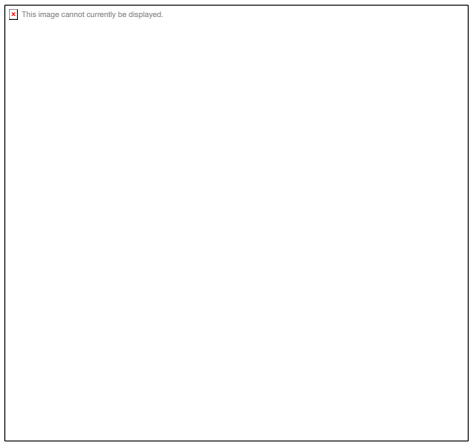


Fig. 3 : *The constructed box-type solar cooker as container*

2.2 The Panel type solar cooker

The panel type solar cooker Educooker 003 was designed and made into product in 2007 as a teaching material to be used in science classes in elementary or junior high schools by enlarging the size 10% from the previous version 002. To adapt to the use in Japan where the sun elevation changes largely with the seasons the shape was designed carefully calculating the concentration and the robustness by ray-tracing software. Its dimensions were determined to meet the size of the cylindrical mess kit which is available all over Japan. The shape of the body before set-up is a 1m by 1m square with four slits and folding lines. The leftovers coming from the processing is little. The total number we produced and sold reaches three thousand.
Using the same characteristics of the Educooker 003, we made a panel type solar cooker which can be set as carton in order to stock emergency stuffs. When folded, the carton has the following dimensions: Length = 370 mm, Width = 275 mm, Height = 270 mm.

2.2.1 Construction of the Panel-Type Solar Cooker

The material of the original panel type cooker is made of cardboard with aluminum-metallized film. It can boil 500ml of water averagely in 90 minutes from spring to fall in Japan and can bring the temperature of it above 85 centigrade in 90 minutes in winter.
The panel type cooker which can be set as carton was designed modifying the plan of the Educooker 003. We added the bottom part as shown in the following drawing. When it is assembled the shape is exactly same with the Educooker 003.

Figure 5 *Constructed Panel-Type.*

Fig. 4 *Design of the constructed panel-type solar cooker.*

Fig. 6 *Constructed Panel-Type as carton.*

3. Experiments

Experiments were conducted on the constructed solar cookers outdoors during different seasons especially for the panel type, in order to observe their behaviours and to study the effect of seasons on the cookers performances. For the box type the experiments concerns only the November month. For the panel type solar cooker, the experiment took place during the whole year. During all experiments, the digital type of thermometers, were used to measure the temperature of the water contained inside the black pots located in the cookers; the ambient temperature were also measured. Using an insulation meter, the solar irradiation was also recorded. In addition, graduated jar was used to measure 500 ml of water for all the experiments.
So, the measured parameters were: ambient temperature, initial water temperature, maximum water temperature and solar irradiation. The recorded data were used for a clear understanding of the constructed solar cookers by calculating the thermal performance especially the cooking power and for constructing data curves in order to analyze and interpret.

3.1 Thermal Performances of Solar Cookers

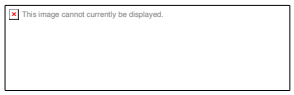
A simple procedure[1] was adopted to evaluate the thermal performance of the two solar cookers. The performance testing procedure consisted of a water heating tests. It was about the requiring time to achieve 95°C.
A series of tests were also conducted for comparison purposes between cookers.

3.2 Energy efficiency of the solar cookers

Energy input to the solar cookers from the sun had been calculated as follows:

where
E_i : the energy input in W
I_t : the total solar energy incident upon plane of the solar air being heated in W/m^2
A_{sc} : the surface area of the solar cooker in m^2

Energy output from the solar cookers was found as shown below:



where
E_o : the energy output in W
m_w : the mass of water in kg
c_{pw} : the specific heat of water in J/kgK
T_{wi} : the initial temperature of the water in K
T_{wf} : the final temperature of the water in K
t : the time in seconds

[1] used by El-Sebaii and Ibrahim (2005)

Energy efficiency of the solar cookers had been found as shown below:

Table 1. ***The cooking power of the constructed solar cookers for the first 60 minutes.***

Solar Cooker	**Cooking power (W)** ***in Novewmber 2016***
Box Type	31.2
Panel Type	25.0

4. Results and Discussion

4-1. *Water temperature variation with time in the box type cooker.*

Figure 7 shows the measured temperature of water, the ambient temperature and the solar irradiance plotted versus time. In the figure, the water temperature rises fast in the first half of the experiment, and then becomes flat. That is because of the unstable weather as can be seen from the values of the direct irradiation in the graph. However, still the figure 7 gives us some promising features of this cooker. Within 50 minutes, it can bring the water temperature above the sterilization temperature and within 70 minutes it reached the cooking temperature for the most meats (74 centigrade) even the irradiation is gradually weakening down to 300 W/m^2. Although it had no additional insulation material inside the box, it maintained the temperature of 82 centigrade for the last 30 minutes of the experiment, while the panel type solar cooker which was being measured at the same time showed a drop of the temperature.

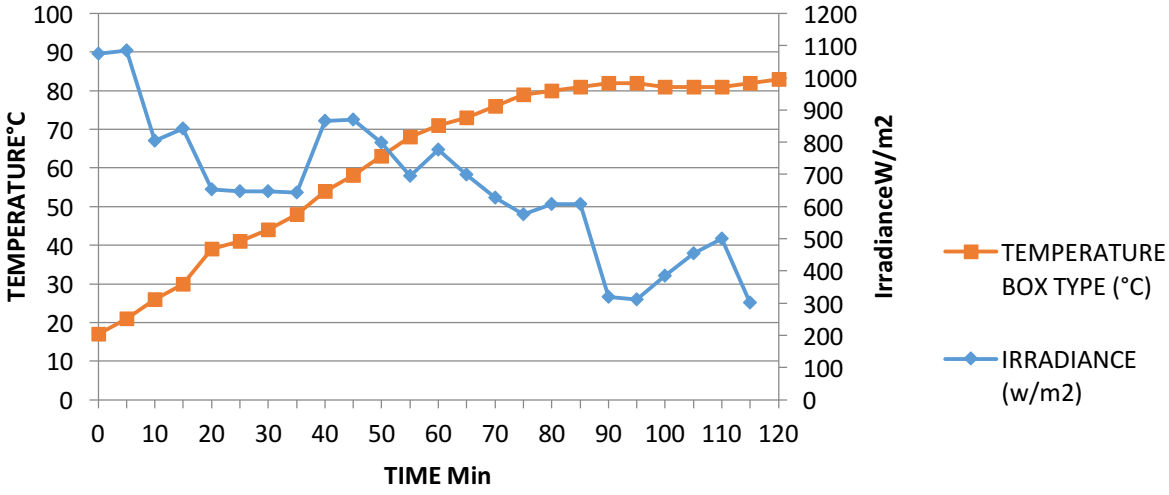


Fig.7 Water temperature variation with time in the box type solar cooker. (November 30 th, 2016)

4-2. *Water temperature variation with time in panel type solar cooker.*

Figure 8 shows the temperature of water in the black pot placed in the panel type solar cooker in winter. The highest temperature was 82 °C which is almost same with the one for the box type, but the irradiation is much better.

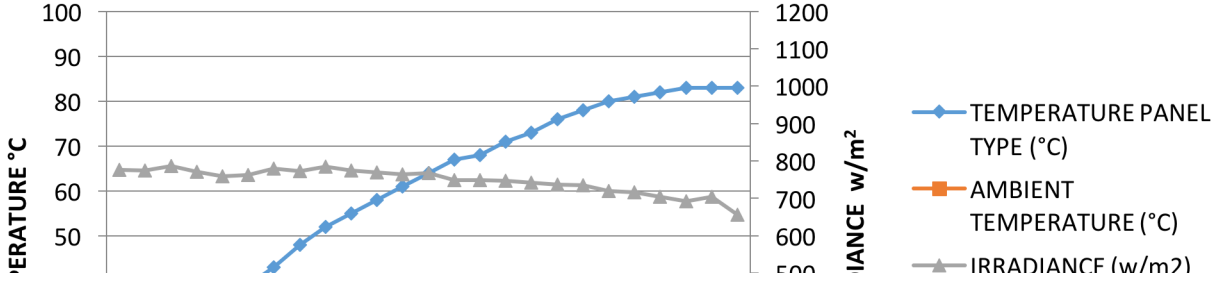


Table 2. ***The energy efficiency of the solar cookers***

Solar Cooker	**Energy efficiency (percent %)** ***in November 2016***
Box Type	15.60
Panel Type	13.84

Table 1 shows the calculated results for the cooking power of the two different types of solar cookers. Although the outputs of these two cookers are similar, the efficiency of the cooker shows that the box-type outperforms the panel-type cooker.

5. Conclusions

The constructed cookers can contain stuffs like water, foods, medical kits, flash lights which can be useful in emergency situations. The cookers have been designed to have enough capacity inside even packed with the separate parts necessary for the assembly. We employed two materials with the similar structure so that they can be chosen properly depending on the usage. Both material can be found everywhere and through our experiment, it was found that both material has fairly high heat insulation properties even without any additional insulation materials. However, if there is a need, any objet such as old cloths, papers etc. can be used to insulate the cooker. Also, the constructed solar cookers were satisfactorily used to heat water and to cook food such as rice, spaghetti, eggs, cake etc. In addition of using them as survival kit, the solar cookers can also be used to greatly reduce deforestation, air pollution, and family health problems especially in developing countries. Finally, the use of solar energy in cooking protect environment and solar energy is abundant and available everywhere without any cost.

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