SIMPLE SOLAR COOKING BOX DESIGN FOR BOILING WATER

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Abstract
A simple solar cooker box was designed and constructed in this paper. The main objective is to make solar heating that can be used to boil water, as an alternative fuel for housewives in cooking. The main dimension of solar cooker design is 117 cm x 117 cm nd 30 cm height. Cooking experiment was conducted with different load (3, 4, 5 and 6 liters of water) in the field with the coordinates of 3°35' north latitude and 98°40' east longitude, starting at 09.00 am to 15.00 pm. The results show that the solar cooker box was able to boil 3 liters of water which can be increased up to 5 liters under better weather conditions.

Key words: solar, cooking, design, water.

INTRODUCTION

During this time the housewives in Indonesia always used kerosene or LPG as a fuel source in the cooking of food, especially rice and water. This is due to the lack of alternative fuel that can be used in cooking as well as equipment energy conversion technology is still limited. MEANWHILE, LUBIS (2007) and KHOLIQ (2015) described that the potential of renewable energy such as biomass, solar energy, wind energy, geothermal and so has not been widely used, although the potential of renewable energy is quite a lot in Indonesia. Renewable energy resources will be offered a choice of fuel that is cleaner than the kerosene and LPG. The resources are less or even not pollute or produce gas pollution, and these resources will remain available. According to SEPTIADI AND NANLOHY (2009), one source of renewable energy that can be exploited in Indonesia is solar energy. Solar energy can be converted into other energy forms in accordance with the needs, for example electrical energy, mechanical energy or thermal energy which can be used directly through an intermediary medium. Indonesia as an archipelagic country located in equator line has a bigger potential of solar energy. Estimated solar energy in Indonesia has been investigated by several agencies and research institutions. Based on a white paper published by the MINISTRY OF RESEARCH AND TECHNOLOGY OF INDONESIA (2006) states that regions in Indonesia have the potential of solar energy is 4.8 kWh·m^{-2}·day^{-1} or a total of 17.28 MJ·m^{-2}·day^{-1}. AMBARITA (2012) has conducted radiation measurements in the city of Medan and the result is daily radiation varies from 0.53 kWh·m^{-2}·day^{-1} until to 5.64 kWh·m^{-2}·day^{-1} with an average value of 3.54 kWh·m^{-2}·day^{-1} and radiation is on average 11.9 hours per day.

The considerable potential is still largely wasted. YANDRI (2012) had described that only a small fraction has been utilized, either to produce electricity with photovoltaic systems as well as to generate heat for heating the thermal system as reported by FAUZI ET AL. (2012). Therefore, the authors saw an opportunity to use solar energy to reduce dependence housewives in Indonesia to kerosene and LPG, where the cooking stove with a solar thermal system can be one alternative. For cooking water to boil it takes a minimum temperature of 100 °C. Therefore, solar cooker box must be able to exceed this temperature. PANWAR ET AL. (2012) made some reviews about solar cooking as renewable and sustainable energy, and AKOY AND AHMED (2015) had designed, constructed and evaluated the solar cookers performance. KRISHNAN ET AL. (2012) designed and constructed the residential solar cooker used of the thermal storage media and using reflector by BUDHI ET AL. (2015). MUTHUSIVAGAMI ET AL. (2010) and MAHAVAR ET AL. (2011) constructed and evaluated solar cooker without thermal of heat storage media. Based on the evaluation results of previous studies, as well as view factor to the overall economy and ease to use, the aim study of this research is to make solar heating that can be used to boil water, as an alternative fuel for housewives in cooking.

MATERIALS AND METHODS

In designing the solar cookers box need to be understood first heat transfer mechanism, the capacity of water to be cooked as well as the assumptions used in the calculation. The heat obtained from the calculation is then converted into the design of the heater box in the shape, dimensions and type of material to be used. According to AMBARITA (2013) the working principle of solar cookers box is as follows. Solar energy that comes from solar radiation will be absorbed by the absorber. At this energy absorber will be turned into heat because the temperature of the plate will go up. High temperature absorber plate which will be used for cooking or raise the temperature of the water is cooked. In other words, the solar energy will go into the water cooked as useful energy. Because the temperature rises, they absorb part of the energy will be emitted again out by radiation. While some of them to the environment in combination convection and conduction through the walls, the floor, and the glass layer.

The assumptions of heat transfer used in the design of solar cooker box are as follows:

- Air temperature and items cooked T_a in the solar box is considered uniform.
- Outside air temperature changes according to the daily temperature of air measured by the data logger
- The intensity of sunlight changes according to data logger measured
- The intensity of the incoming radiation to the absorber was partially obstructed by two layers of glass is turned into heat by 90%. Usually the glass transmissivity was 95%.
- Temperatures are distinguished on the current temperature calculation T' and the previous temperature T.

The radiant energy into the heating box is:

$$Q\text{rad} = IxAx\ \Delta tx\ 90\% \quad (1)$$

Δt is the time interval of observation and A is the area of the absorber plate. The energy required to heat the air inside the solar heater is:

$$Q\text{a} = m\text{a}\ x\ c\text{a}\ x\ (T'\text{a} - T\text{a}) \quad (2)$$

m_a is the mass of air, c_a is the specific heat of air in the heater box and *T'*a is the current air temperature calculation in the heater box. Due to differences in temperature difference that occurs very small time interval Δt measurement is small, then the nature of the temperature difference can be evaluated using the initial temperature T_a. The energy used to boil the water or rice is:

$$Q\text{c} = m\text{c}\ x\ c\text{c}\ x\ (T'\text{a} - T\text{a}) \quad (3)$$

m_c is the mass of water that is cooked and c_c is the specific heat of water is cooked. The energy required to heat the solar wall material is:

$$Q\text{m} = \sum m\text{m}xc\text{pm}\ x\ (T'\text{am} - T\text{am}) \quad (4)$$

$\Sigma m_m x c_{pm}$ is the sum of the product of the respective weight of the material with a specific heat of solar box wall materials. Planned wall layer consists of aluminum, rock-wool, stereo-foam and wood. While T_{am} is the average temperature of the material, calculated by the equation:

$$T\text{am} = \frac{1}{2}(T\text{a} + T\text{ao}) \text{ and } T'\text{am} = \frac{1}{2}(T'\text{a} + T'\text{ao}) \quad (5)$$

This happens because the wall temperature is not the same as the air temperature in the solar box but varies between T_a and T_{ao}. The energy required to heat the absorber plate is:

$$Q\text{b} = m\text{b}\ x\ c\text{b}\ x\ (T'\text{b} - T\text{b}) \quad (6)$$

m_b and c_b are the mass and heat absorber plate type of material used. While the heat is lost from the double glass roof is calculated by the equation:

$$Q\text{r} = U\ x\ A\ x\ (T'\text{a} - T\text{a} \quad (7)$$

$$\frac{1}{U} = \frac{1}{h\text{i}} + \frac{d}{k} + \frac{1}{h\text{c}} + \frac{d}{k} + \frac{1}{h\text{o}} \quad (8)$$

U is the total heat transfer resistance coefficient, h_i is the coefficient of convection in the inner surface (natural convection bottom horizontal plate), *k* is the material coefficient of conductivity, h_c is air convection coefficient between the first glass and the second glass (natural convection in a confined space), h_o is the coefficient of convection in the outer surface (natural convection upper horizontal plate). All these equations are calculated using the formula Nusselt numbers and that the settlement was not a trial and error, we recommend physical properties are analyzed at the temperature T_a. The heat loss from the walls of solar cookers is calculated using the equation:

$$Q\text{w} = U\ x\ A\ (T'\text{a} - T\text{a}) \quad (9)$$

$$\frac{1}{U} = \frac{1}{h\text{i}} + \frac{d}{k\text{Al}} + \frac{d}{k\text{rockwool}} + \frac{d}{k\text{stereoform}} + \frac{d}{k\text{wood}} + \frac{1}{h\text{o}} \quad (10)$$

h_i is the coefficient of convection in the inner surface (convection natural on the plate vertical) and is calculated on the nature of the air temperature T_a, h_o is the coefficient of convection in the outer surface (convection natural on the plate vertical) and is calculated on the nature of the air in the outdoor air temperature T_{ao}, A is the total area of the four side walls. All of these equations are calculated using the formula Nusselt numbers.

Heat lost from the base of the box cookers is:

$$Q\text{f} = U\ x\ A\ (T'\text{a} - T\text{a}) \quad (11)$$

$$\frac{1}{U} = \frac{1}{hi} + \frac{d}{k\mathrm{Al}} + \frac{d}{k\mathrm{rockwool}} + \frac{d}{k\mathrm{stereoform}} + \frac{d}{k\mathrm{wood}} + \frac{1}{ho} \quad (12)$$

So that the energy balance in the box of this solar heater can be written as:

$$\sum Q\mathrm{in} = \sum m.c.\Delta t + \sum Q\mathrm{losses} \quad (13)$$

which if translated would be the equation:

$$Q\mathrm{rad} = [Q\mathrm{a} + Q\mathrm{c} + Q\mathrm{m} + Q\mathrm{b}] + [Q\mathrm{r} + Q\mathrm{w} + Q\mathrm{f}] \quad (14)$$

These equations were solved every minute to obtain the temperature of the heater box.

This research was conducted in the field with the coordinates of 3°35' north latitude and 98°40' east longitude. In the process of designing the solar intensity measurement results on location will be used as a reference. At the beginning of the measurement of the intensity of radiation and daily temperature for five days, starting at 09.00 am to 15.00 pm and found that the intensity of the radiation can reach 800 W/m^2 for at least 30 minutes in a day. The observation of this intensity is used as a basic assumption in the calculation and design.

Solar cooker box designed to be able to cook up to five liters of boiling temperature. The energy balance of the heating box was calculated using equations (13) and (14). A form of solar cooking design results is shown in Fig. 1 in which the basic form is a simple box. In order to keep the temperature inside the box (T_a) reaches more than 100°C, the material composition and solar heating components must be designed and manufactured appropriately. On the floors and walls was used plate Aluminum painted black. This serves to be able to absorb all the energy radiation that comes to the surface. This will be called the absorber plate. At the top is made of two layers of glass separated. The aim is to ensure the solar radiation energy can get into the box, but the incoming summer detained to not get out too much. In other words, the function of the layer of air between the two glass plates is a heat resistant material. The wall is made of four layers, namely inside the aluminum layer, insulating layer consisting of rock-wool and stereo-foam, as well as a layer of wood on the outside. The function of the aluminum layer in the black paint is in addition to the energy-absorbing radiation coming from sunlight and heat radiation reflected by the floor. The function of the insulation layer is to inhibit heat transfer by conduction from the inner wall to the outer wall. Likewise, the wooden walls in addition to inhibiting the conduction transfer from the inside; it also serves as a holder construction of this cooker box.

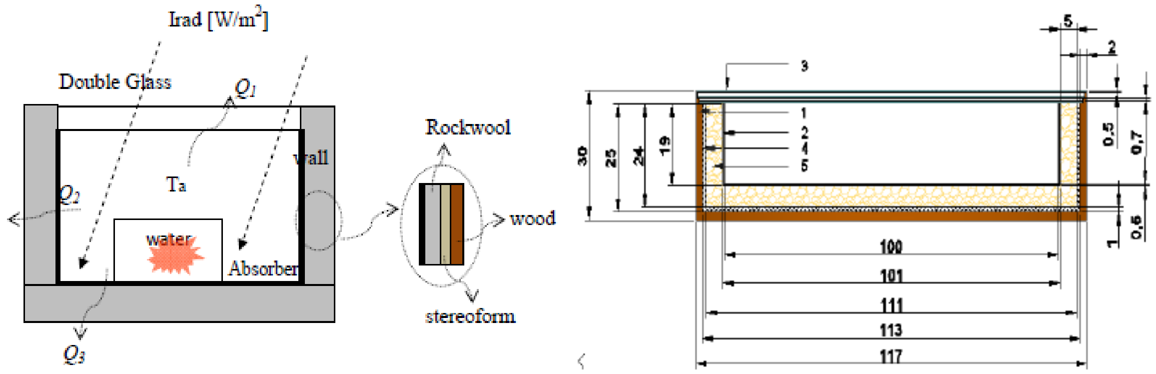

Fig. 1. – Thermal flow equilibrium and solar cooking box dimensions

By using the material and arrangement mentioned above, as well as dimensional calculation results as shown in Fig. 1, the solar heater box is made manually at the Laboratory Department of Mechanical Engineering University of HKBP Nommensen Medan. Solar cooker box that has been created is then used to boil water as shown in Fig. 2 below.

Fig. 2. – Solar heater box for boiling water

To be able to do analysis of the equation (1) until (14), it is necessary to test and record all data changes in temperature and radiation. Data acquisition system was used for recording. Experimental set-up for the heating process with this simple solar box can be seen in Fig. 3.

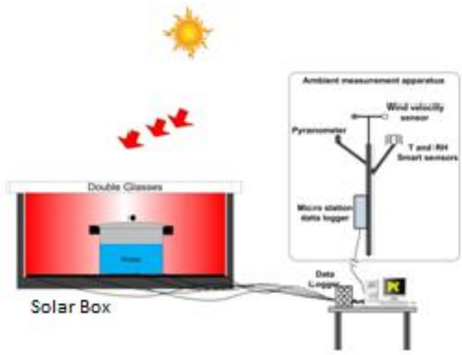

Fig. 3. – Experimental set-up of boiling water

RESULTS AND DISCUSSION

Testing was done with the cooking water as much as three, four, five and six liters for four consecutive days and the data of the temperature of the floor, walls and glass box constantly observed solar heating as well as pots and water temperature. The amount of radiation that comes to the surface of the solar cooker box and the ambient temperature were also observed, as shown in Fig. 4, 5, 6 and 7.

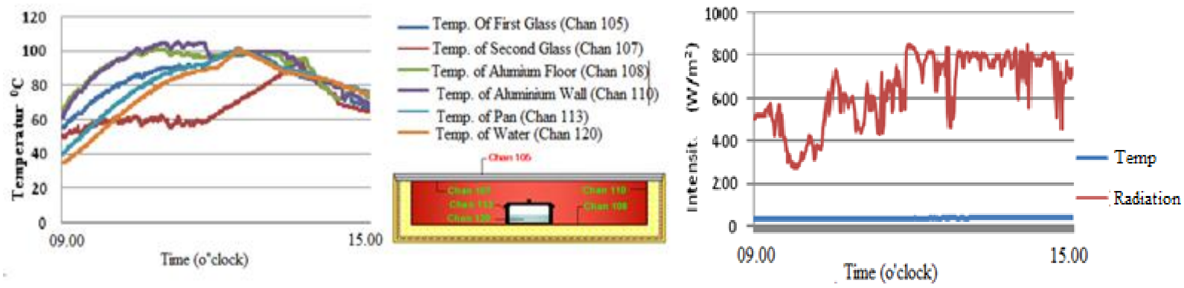

Fig. 4. – Temperature and radiation data for boiling three liters of water

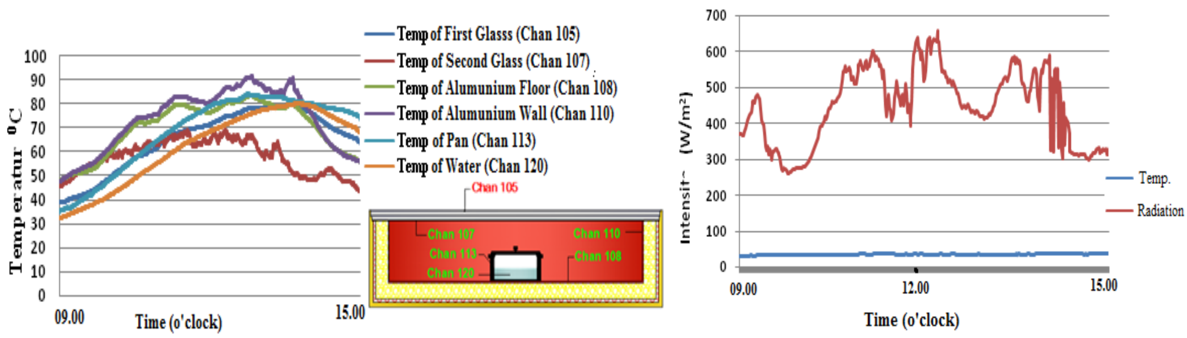

Fig. 5. – Temperature and radiation data for boiling four liters of water

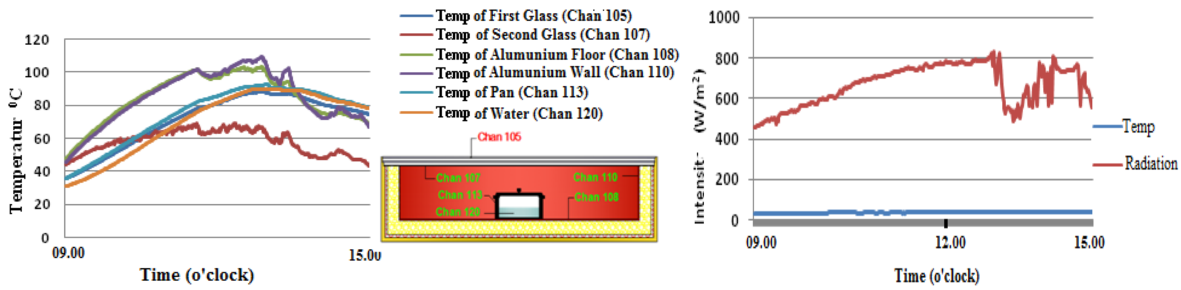

Fig. 6. – Temperature and radiation data for boiling five liters of water

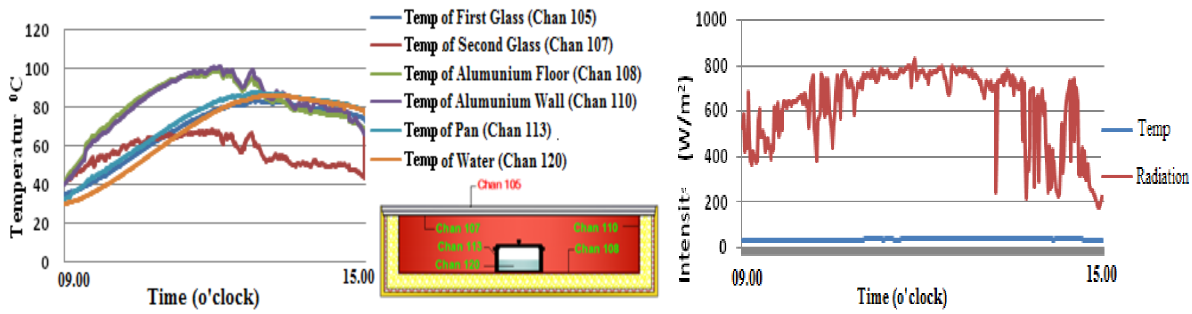

Fig. 7. – Temperature and radiation data for boiling six liters of water

Fig. 4, 5, 6 and 7 above shows that the boiling water reaches 100.97°C when the heat three liters of water. Meanwhile, when heat four liters of water, the maximum temperature that can be achieved is 79.84°C, the maximum temperature of heat five liters of water is 89.93°C and maximum temperature when heating six liters of water is 85.98°C, as shown in Fig. 8a.

This is understandable because in accordance with the equilibrium energy at the solar cooker box as shown by equation (14) that the energy required to heat the box cooker, the pot, and the water is proportional to energy radiation into the box cooker is reduced by energy lost in box heating. The value of energy radiation that comes also depends on the intensity of solar radiation, as stated in equation (1).

If we look at the magnitude of the average intensity of solar radiation received when heating the three, four, five and six liters of water from 09:00 am to 15:00 pm, it can be seen that the average intensity of solar radiation is highest during cook five liters of water that is equal 640 $W \cdot m^{-2}$, whereas the three liters of water when cooking in the amount of 601.33 $W \cdot m^{-2}$, and six liters of water when cooking in the amount of 611.5 W/m^2. Comparison of the amount of radiation that occurs for all four testing can be seen in Fig. 8b.

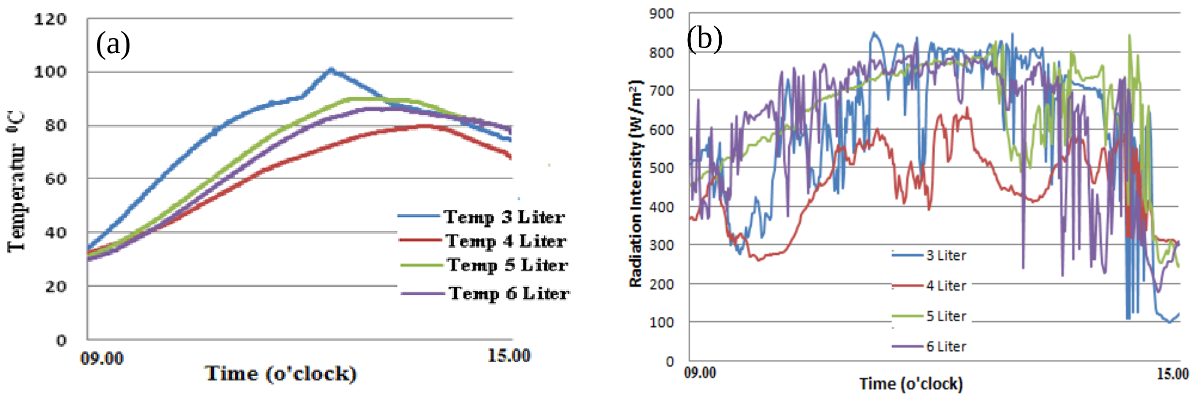

Fig. 8. – (a) Temperature and (b) radiation data for boiling all the liters of water

It is understood that three liters of water can reach a temperature of 100°C despite boiling average radiation intensity is lower than the heating five and six liters of water. This can happen because the energy generated from the radiation is able to satisfy the equation (14) above where the radiant energy received minus the energy lost from the cooker box is still able to heat the cooking box and pot to meet the energy needs for heating three liters of water.

As for testing the load five and six liters of water, although the intensity of the radiation received is greater than the test with a load of three liters of water, but the energy generated by the intensity of the radiation after subtracted by the heat lost from the box is not enough to heat up the box heater and pot to boil water to a temperature of 100°C. If we observe Fig. 6b, initially occurring radiation intensity has increased from 09.00 am to 13.00 pm approached the intensity value of 800 $W \cdot m^{-2}$. But when it was approaching the intensity, the weather began overcast so not reached an intensity of 800 W/m^2 as the initial planning heater box, where the assumptions used to the intensity of solar radiation at a minimum of 800 W/m^2 for at least 30 minutes. This is likely to cause the solar cooker box can't boiling five liters of water. It is necessary for further testing on the weather conditions. As for heating six liters of water, although Fig. 7 shows the intensity of the radiation that reaches $800 \cdot m^{-2}$ for a while, but because this box is designed for load testing five liters of water, then this box cannot afford to boil six liters of water.

AKOY AND AHMED (2010) research by using the solar box cooker uses a reflector system with dimensions of 0.25 by the design volume of this study can heat water up to temperature 52.36°C. A similar study conducted by UHUEQBU AND CHIDI (2011) using a solar heater box with black painted aluminum absorber plate and the dimensions of 0.3 by volume this study design can produce heat absorber plate at 72°C indicating not be able to boil the water. MAHAVAR ET AL. (2011) did a similar study using dimensions of 0.14 times of the design volume of this study, using a plate of aluminum painted black as an absorber and using a reflector, can heat the water of 1.2 kg until the temperature 94.5°C. If we see the test results of this solar cooker box, this indicates that the design of this solar heater box is in conformity with that required to be used by housewives to boil water.

CONCLUSIONS

The design of the box simple solar heater can already be used to boil water to boiling as much as three liters. The use of two layers of glass to forward incoming solar radiation and heat blocking out has been quite good. Plate wear aluminum painted black apart as the floor as well as wall heating box further enhance the ability to absorb heat. The use of two layers of insulation of rock-wool and stereo-foam also reduce the heat dissipated into the outside wall, and the use of wood in addition to as thermal insulation but also as construction makes the cooker box is quite sturdy.

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