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STUDY ON THE CHARACTERISTICS AND THERMAL PERFORMANCE OF A SIMPLE SOLAR BOX COOKER FOR BOILING WATER

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ABSTRACT

In this study, experimental and numerical works have been performed to investigate characteristics and thermal performance of a simple solar box cooker for boiling water. In the experiment, a simple solar box cooker with absorber area of 0.835 m × 0.835 m has been designed and fabricated. The solar box cooker has been employed to boil water by exposing to the solar radiation in Medan city of Indonesia. Numerical method, where heat capacity of the material of solar box cooker is taken into consideration, has been developed. Numerical and experimental results show a good agreement. The results show that the simple solar cooker can be used to boil water up to 6 kg. The analyses show that the heat loss, useful energy, and hidden heat can be up to 57%, 15%, and 28%, respectively. The hidden heat stored in the solar box cooker material is very significant and it should be considered in the analysis and designing of solar cooker. The correlation to estimate boiling time as a function of water mass is proposed.

Keywords: solar energy, solar cooker, water heater, box.

1. INTRODUCTION

According to the International Energy Outlook 2006 [1], total World marketed energy consumption grows from 421 quadrillion British thermal unit (Btu) in 2003 to 613 quadrillion Btu in 2020 and 722 quadrillion Btu in 2030. The average growth is 2.0% per year. Since the main share of this energy consumption is fossil fuel, it will produce Green House Gases (GHGs) emission and results in Global Warming. Many countries have addressed their target in reducing GHGs emissions. In order to achieve the target, utilization of renewables or green energy resources must be enhanced. One of the potential resources of renewable energies is solar energy. The world is blessed with abundant solar energy. In one year, the world accepts 3, 400, 000 Exa Joule solar radiation from the sun. The yearly present global energy consumption can be filled with 1 hour and 20 minutes of solar irradiance. The use of solar energy in recent years has reached a remarkable edge due to the reduction of GHGs emissions target. Solar energy can be harvested in photovoltaic and thermal energy form. The solar thermal energy applications typically divided into solar drying, solar cooker, solar cooling, solar power plant, solar desalination, etc. [2]. Many countries, such as Egypt, India, Spain, and Indonesia, are enhancing the researches on utilization of solar energy.

In particular, Indonesia has big potency of solar energy. According to Ministry of Energy and Mineral Resources of Indonesia, the potency of solar energy in Indonesian archipelagos varies from 16 to 18 MJ/m^2/day [3]. Several studies on applying technologies for harvesting solar irradiance have been found in literatures. Ambarita *et al.* has reported their studies on application of solar energy for drying agricultural products [4], solar adsorption refrigeration [5], and natural vacuum desalination powered solar energy [6]. In addition, El-Maghlany [7] reported a study on solar still and Ghorab *et al* [8] studied performance evaluation of solar water heater. And many more studies on solar thermal utilization can be found in literature [9, 10].

One of interesting utilizations of solar energy is solar cooker. The solar cooker can be divided into solar cooker with thermal storage and solar cooker without thermal storage. The solar cooker without thermal energy storage consists of direct cooking and indirect cooking. In the direct cooking system, the insolation directly used to heat the material cooked. This solar cooker segregated into box type and concentrator type of solar cooker. In this study, we focus on solar box type cooker (hereafter shortened as solar box cooker). Numerous studies on solar box cooker have been found in literature. Saxena *et al* [11] reviewed studies on solar box cookers based on the thermodynamics overview. Lahkar and Samdarshi [12] carried out a review of the thermal performance parameters of solar box cookers and identification of their correlations. Those literature reviews showed that a wide range of studies of solar box cooker has been carried out by many researchers.

The main focus of the studies on solar box cooker varies from the material, configuration, collector type, container of the load, and the method of analysis. Ghosh *et al* [13] studied the thermal performance of solar box cooker with focus on special cover glass of low-e antimony doped indium oxide (IAO) coating. Kahsay *et al* [14] experimentally and theoretically studied the comparison of solar box cookers with and without internal reflector. Terres *et al* [15] used mathematical model to study solar box cookers with internal reflector. Mirdha and Dhariwal [16] investigated theoretically various design of solar box cookers to optimize their performance. Here, booster mirror was proposed. In order to collect more solar irradiance, to the solar box cooker is proposed to be equipped with additional solar collector and tracking system. Harmim *et al* [17] proposed solar box cooker equipped with a fixed asymmetric compound parabolic concentrator (CPC) as booster-reflector and its absorber-plate is in a form of step. The solar box cooker was

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optimized by testing it at Ardrar of Algerian Sahara. Joshi and Jani [18] proposed a small-scale box type photovoltaic and thermal hybrid solar cooker system. Five solar panels each of 15 W are attached to the box cooker. Farooqui [19] proposed power free tracking system to improve the performance of box type solar cooker. The tracking system uses gravitational potential energy stored in a water container connected to a pair of springs.

The main drawback of solar box cooker is the low heat transfer rate. In order to provide a better heat transfer rate from the absorber to the material cooked in the vessel (or container), several innovations of the container and collector plate have been proposed and investigated. Harmim *et al.* [20] proposed a solar box cooker equipped with a finned absorber plate. The performance comparison with conventional solar box cooker has been made and show enhancement. Reddy and Rao [21, 22] reported the prediction and experimental verification of performance of box type solar cooker. To improve the performance, the designs of cooking vessel with a central cylindrical cavity was proposed. The experiments were carried out for the case vessel kept either on the floor of the cooker or on lugs. In addition, the effect of depressed lid of the cooking vessel was investigated. Rao and Subramanyam [23] also investigated the effect of cooking vessel on lugs in solar cookers. Geddam *et al* [24] studied the performance of a solar cooker with fin installed in its vessel.

The above studies focus on the solar box cooker modifications. However, not only studies related to the modification of solar box cooker, several researches also focusing their study on modelling the operational characteristics and method of analysis. Mahavar *et al* [25] introduced a concept to evaluate an optimum load range (OLR) for solar box cookers. The OLR concept is based on the dependence of rate of rise of load temperature on different heat transfer process between load and cooker interior. Verdugo [26] employed experimental data to obtain the equation to model convective coefficient of the heat transfer. The solar box cooker was tested and modelled during long time period in Madrid, Spain.

The above brief literature review showed that study on solar box cooker has come under scrutiny in recent years. This is due to its simplicity and easily manufactured. In the present work, characteristics and thermal performance of a simple solar box cooker will be investigated. Here, we propose a new analysis method where the heat capacity of the solar box cooker material is taken into account. The objectives are to investigate the effect of the solar box cooker material on the performance and to propose a performance equation. It is the correlation of boiling time as a function of load of the solar box cooker. This equation is specific for the designed solar box cooker and in the climate condition of Medan city, Indonesia. To the best knowledge of the authors such study has not reported in literature. The results of the present study are expected to supply the necessary information in development of high performance and low cost solar box cooker.

2. METHODS

In order to provide the data for analysis two approaches will be carried out, experimental and numerical approaches. In the experimental work, a simple solar box cooker is designed, fabricated and tested. On the other hand, in the numerical work a set of governing equations will be developed and solved numerically. The methods are explained in the followings subsections.

2.1 Experimental apparatus

A simple solar box cooker with absorber area of 0.835 m × 0.835 m has been designed and fabricated as shown in Figure-1. It is a flat plate solar collector with double glasses cover in the top. To minimize the heat loss, the envelop of the solar box cooker made of a series of insulation material rock wool, styrofoam, and wood. The dimensions and configurations of this material are shown in the figure. The load of the box solar cooker is water and it is placed in a cylindrical cooking vessel. The vessel is made of aluminum with diameter and height of 30 cm and 12 cm, respectively.

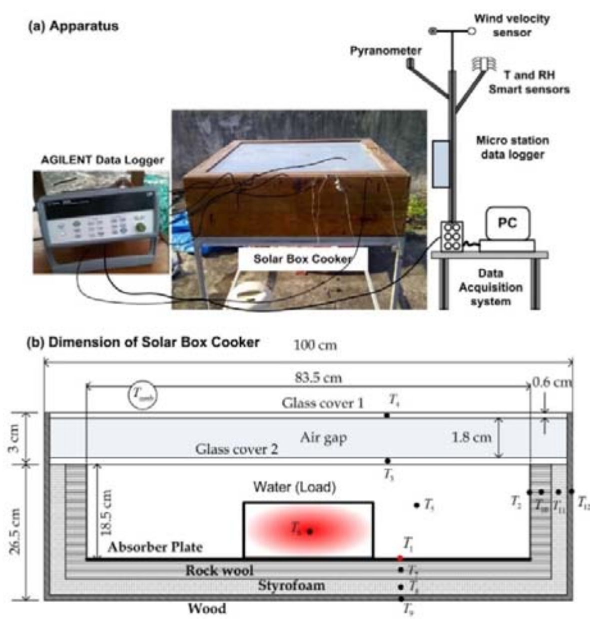

Figure-1. Experimental apparatus and data acquisition system.

The solar box cooker is equipped with a data acquisition system which consists of Agilent data logger and Hobo micro station data logger. The Agilent data logger with 20 channels and thermocouples are used to measure the temperatures in the solar box cooker such as absorber temperature, glass temperature, water temperature, etc. The used thermocouples are *J*-type with uncertainly equal to 0.1 ºC. The temperatures are measured with interval of 1 minute. The ambient temperature and relative humidity (RH) is measured using HOBO temperature RH smart sensor with an accuracy of 0.2 ºC and ± 2.5% RH, respectively. The wind speed around the experimental apparatus is measured with

HOBO wind speed smart sensor with accuracy ± 1.1 m/s. The solar radiation is measured using Silicon Pyranometer Smart Sensor with resolution and accuracy of 1.25 W/m^2 and ± 10 W/m^2, respectively.

2.2 Numerical approach

In the numerical approach, the solar box cooker is divided into 12 components. The dimensions and temperature notation of every components are shown in Figure-1(b). A set of governing equations is developed for each component. The energy conservation for absorber plate gives the following equation.

$$m_p C_p \frac{\partial T_1}{\partial t} = \tau^2 \alpha I A_p - FC_{15}\left(T_1 - T_5\right) - FR_{13}\left(T_1 - T_3\right) - FR_{12}\left(T_1 - T_2\right) - \frac{1}{R_{17}}\left(T_1 - T_7\right) \quad (1)$$

where m_p [kg] and C_p [J/kg K] are mass and specific heat of absorber plate. Furthermore, I [W/m^2], α , and τ are solar irradiance, absorptivity and transmission coefficients of the glass cover, respectively.

In the present numerical approach, the air inside the solar box cooker is assumed to be one substance with a homogeneous temperature of T_5. The application of energy conservation to the air inside solar box cooker gives:

$$\left(\rho V_{ol}\right)_{air} \frac{\partial T_5}{\partial t} = FC_{15}\left(T_1 - T_5\right) - FC_{52}\left(T_5 - T_2\right) - FC_{53}\left(T_5 - T_3\right) - FC_{56t}\left(T_5 - T_6\right) - FC_{56w}\left(T_5 - T_6\right) \quad (2)$$

Where FC [W/K] is factor for convective heat transfer from any surface. The subscript 1, 5, 2, 3, 6 refer to surfaces shown in Figure 1. While 6t and 6w refer to top surface and container wall surface of the cooking vessel, respectively.

The double glasses cover is made of glass with similar emissivity (ε) and thickness. Application energy conservation to the top and bottom glassed yield to

$$m_g C_g \frac{\partial T_4}{\partial t} = \left(1 - \tau\right) I A_g + FR_{34}\left(T_3 - T_4\right) + FC_{34}\left(T_3 - T_4\right) - FR_{4s}\left(T_4 - T_{amb}\right) - h_w A_g\left(T_4 - T_{amb}\right) \quad (3)$$

$$m_g C_g \frac{\partial T_3}{\partial t} = \left(1 - \tau\right) \tau I A_g + FC_{53}\left(T_5 - T_3\right) + FR_{13}\left(T_1 - T_3\right) + FR_{23}\left(T_2 - T_3\right) - FC_{34}\left(T_3 - T_4\right) - FR_{34}\left(T_3 - T_4\right) \quad (4)$$

Where h_w [W/m^2 K], A_g and T_{amb} [ºC] are convective heat transfer coefficient from the top glass to the ambient air and temperature of the ambient air, respectively.

In this study, the box solar cooker is used to boil water. Thus, the load here is the water inside the coking vessel. The cooking vessel and water receive convective heat transfer from the air inside the solar box cooker through side wall and top wall of the vessel. The top surface of the cooking vessel acts as a solar collector and the insolation on the top surface is considered as heat flux. The conductive heat transfer rate from the absorber floor to the bottom and radiative heat transfer from the wall of the cooking vessel are neglected. The temperatures of the cooking vessel and water inside are assumed homogenous. Based on these assumptions, energy conservation in the cooking vessel gives

$$\left(m_f C_f + m_c C_c\right) \frac{\partial T_6}{\partial t} = FC_{56w}\left(T_5 - T_6\right) + FC_{56t}\left(T_5 - T_6\right) + \tau^2 \alpha I A_{ct} \quad (5)$$

Where the subscript f and c represent water and container, respectively.

The temperature difference in each material of the wall of the solar box cooker is taken into account. As a note, the temperature of every material of the bottom wall of the solar cooker is shown in Figure-1. Energy conservation in the rock wool, styrofoam, and wood will give the following equations.

$$m_{rw} C_{rw} \frac{\partial T_7}{\partial t} = \frac{1}{R_{17}}\left(T_1 - T_7\right) - \frac{1}{R_{78}}\left(T_7 - T_8\right) \quad (6)$$

$$m_{st} C_{st} \frac{\partial T_8}{\partial t} = \frac{1}{R_{78}}\left(T_7 - T_8\right) - \frac{1}{R_{89}}\left(T_8 - T_9\right) \quad (7)$$

$$m_{wd} C_{wd} \frac{\partial T_9}{\partial t} = \frac{1}{R_{89}}\left(T_8 - T_9\right) - FC_{9a}\left(T_9 - T_a\right) \quad (8)$$

Where the subscript rw, st, wd, and a refer to rock wool, styrofoam, wood, and ambient, respectively. On the other hand, the energy conservation for each material of the wall of the solar box solar cooker (inner plate, rock wool, Styrofoam, and wood) will give the following equations:

$$m_p C_p \frac{\partial T_2}{\partial t} = FR_{12}\left(T_1 - T_2\right) + FC_{52}\left(T_5 - T_2\right) - FR_{23}\left(T_2 - T_3\right) - \frac{1}{R_{210}}\left(T_2 - T_{10}\right) \quad (9)$$

$$m_{rw} C_{rw} \frac{\partial T_{10}}{\partial t} = \frac{1}{R_{210}}\left(T_2 - T_{10}\right) - \frac{1}{R_{1011}}\left(T_{10} - T_{11}\right) \quad (10)$$

$$m_{st} C_{st} \frac{\partial T_{11}}{\partial t} = \frac{1}{R_{1011}}\left(T_{10} - T_{11}\right) - \frac{1}{R_{1112}}\left(T_{11} - T_{12}\right) \quad (11)$$

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$$m_{wd}C_{wd}\frac{\partial T_{12}}{\partial t}=\frac{1}{R_{1112}}\left(T_{11}-T_{12}\right)-\frac{1}{R_{12a}}\left(T_{12}-T_{a}\right) \quad (12)$$

The factors to calculate convective heat transfer (FC), radiative heat transfer (FR) and conductive thermal resistance (R) are defined as follows.

$$FC=\frac{Nu\times k}{L_c}A \quad (13)$$

$$FR_{12}=\frac{\sigma\left(T_1^2+T_2^2\right)\left(T_1+T_2\right)}{\frac{1-\varepsilon_1}{A_1\varepsilon_1}+\frac{1}{A_1F_{12}}+\frac{1-\varepsilon_2}{A_2\varepsilon_2}} \quad (14)$$

$$R=\frac{d\times A}{k} \quad (15)$$

Where Nu, k and σ are Nusselt number, conductivity, and Stephan-Boltzmann constant, respectively. The Nusselt number equations are calculated using correlations documented by Cengel [27].

All of the governing equations, equation (1) to equation (12), are converted from partial differential equation form into linier equation system by using discretization technique. The used technique is forward time step marching. Due to stability consideration, the values of Δt must be relatively low. In this work, the value of $\Delta t=1\text{sec}$ is used. This value shows stability. Here, a FORTRAN code program is written to solve the transient governing equations which are coupled with all of the heat transfer coefficient equations.

3. RESULTS AND DISCUSSIONS

The experiments will be performed using the fabricated solar box cookers at a location in Medan city of Indonesia. The latitude and longitude Medan city are 3° 35'N and 98° 40'E, respectively and the elevation of experimental is 54 m above sea level. All experiments were carried out during July, 2016. In the experiments, the solar cooker is used to boil water as the load; the tested loads are 2 kg, 3 kg, 5 kg, and 6 kg. The experiments were performed during clear sky conditions. The temperatures of the solar box cooker, ambient and solar irradiation are measured. The results are discussed in the following subsections.

3.1 Solar irradiance and ambient temperature

The measured solar irradiance and ambient temperature will be used to model solar energy input to the solar box cooker and ambient temperature. The measurement of solar irradiance in July 11, 2016 at Medan city at the experiment location is shown in Figure-2. The figure also shows the theoretical clear sky radiation.

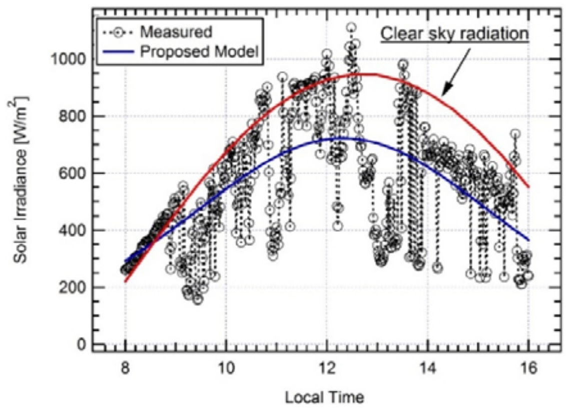

Figure-2. Measured, clear sky, and modelled solar irradiance.

The measurement results show that the actual solar irradiances are lower than theoretical clear sky radiation. This is because the effects of cloudy in the sky during experiments. It can be seen from the figure that maximum solar irradiance is 1018 W/m^2, occurred at 12.00 local time. The total solar energy resulted by the solar irradiance during experiments is 16.2 MJ/m^2. By using these measurement data, an equation to predict solar input to the solar box cooker is developed by using Gauss equation. The proposed model is shown by blue line in Figure 2. In this model, the maximum solar irradiance is 721.9 W/m^2 and it occurred at 12.19 local time. The total solar energy resulted by the solar radiation by the proposed model is 16.2 MJ/m^2. This reveals that the solar energy from measurement and from the proposed model is the same. This model will be used in the numerical simulation as heat flux to the absorber plate of the solar box cooker.

3.2 Numerical validation

A numerical validation test is carried out by comparing temperature history of the water in the cooking vessel resulted by experimental and numerical methods. In the experimental results the temperature history of cooking vessel for loads of 3 kg, 5 kg, and 6 kg water are selected for comparison. Temperature history from numerical results and measurements are shown in Figure-3. The figure shows that for all cases, the temperature history from measurement and numerical simulation do agree very well. It can be seen that the temperature value and the boiling time of the water can be predicted by numerical simulation with a very good accuracy. Based on this comparison, it can be said that the numerical method can be used to analyze the characteristics and the performance of the solar box cooker.

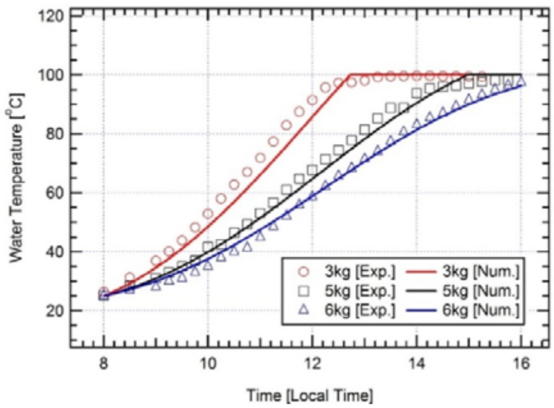

Figure-3. Comparison of numerical and experimental results.

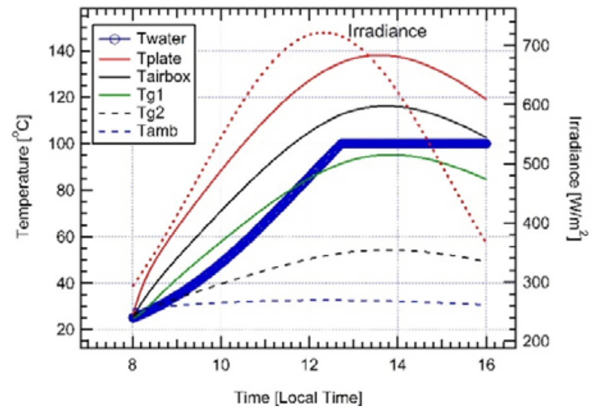

Figure-4. Temperature characteristics for load 3 kg water.

3.3 Characteristics at low load

The characteristics of the box solar cooker will be analyzed at low and high load. In the case with low load, the cooking vessel with 3 kg water will be selected for discussions. The temperature history of the water, absorber plate, air in the box, glasses cover, and ambient temperature are shown in Figure-4. In the figure, the history of solar irradiance is also shown. The figure shows that temperature of the plate absorber is higher than other components. It starts from initial temperature of 25 °C at 8.00 am and increases with increasing time until reach a maximum value. The maximum value is 138.2 °C and it occurs at 13.35 local time. After reaching the maximum value, the temperature of the absorber plate decreases with increasing time. The hot absorber plate will heat the air in the solar box cooker. It can be seen in the figure, the temperature of the air in the box shows similar trend with temperature of the plate absorber. The maximum value of the air temperature and occurring time are 116.2 °C and 13.44 local time, respectively. As a note, there is a delay of 9 minute of the occurring maximum temperature of hot air in the box in comparison with absorber plate. This is the time needed to transfer the heat from absorber plate to the hot air. Furthermore, the temperature of the glass covers also show the same trend with absorber plate but the value is lower. It is clarified that temperature of the top glass cover is lower than the bottom glass. Temperature history of the water in the cooking vessel is shown by blue line with circle marker. The temperature of the water in the vessel increases with increasing time and reach its boiling temperature of 100 °C at 12.44 local time. After reaching the boiling point, the temperature is constant.

One of the main focuses in the solar box cooker research is to utilize solar irradiance efficiently by minimizing the heat loss from the box. The heat loss rate from the box for load 3 kg of water is shown in Figure-5. In the figure, the heat loss will be divided into 4 sources; they are heat loss from the bottom of the solar box cooker, from the side walls, convective and radiative heat losses from the top glass cover. The figure shows that heat loss from the top glass cover increases with increasing time and reaching a maximum value. The trend is similar to the temperature inside the box. On the other hand, the heat losses from the bottom and side walls show the different trend. It increases slightly with increasing time. This is because the wall of the present solar box cooker made of good insulation material. The maximum convective heat loss and radiative heat loss from the top glass cover are 220 W and 111 W, respectively. These facts suggest that the highest heat loss in the solar box cooker is the convective heat loss from the top glass cover and followed by radiative heat loss from the top glass. The heat loss from the bottom and the side wall are much lower.

Total cumulative history of heat input to the solar box cooker, total energy loss from the solar box cooker, total useful heat and thermal efficiency are shown in Figure-6. It can be seen that the total heat input to the solar box cooker, total energy loss, and total useful energy are 11.3 MJ, 6.44 MJ, and 1.65 MJ, respectively. Thus, total efficiency of the solar box cooker is 14.6%. This efficiency is low because the heat loss is very big. The implementation of energy balance to the solar box cooker show that there is a big amount of hidden heat. If the total useful heat and the total heat loss are extracted from the total heat input, the hidden heat will be 3.21 MJ or 28.41% of the input solar energy. The hidden heat is stored in the heat capacity of the solar box cooker material. In this case, the hidden heat is very significant. It is twice of useful heat. This fact reveals that the heat capacity of the solar box cooker material strongly affect the performance of the solar box cooker. It must be considered to choose the material with low heat capacity.

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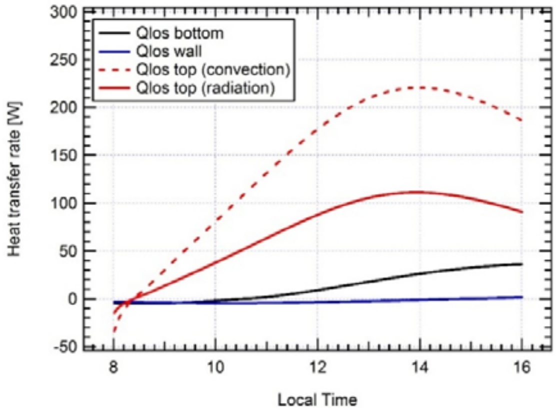

Figure-5. Heat loss from the solar collector for load 3 kg water.

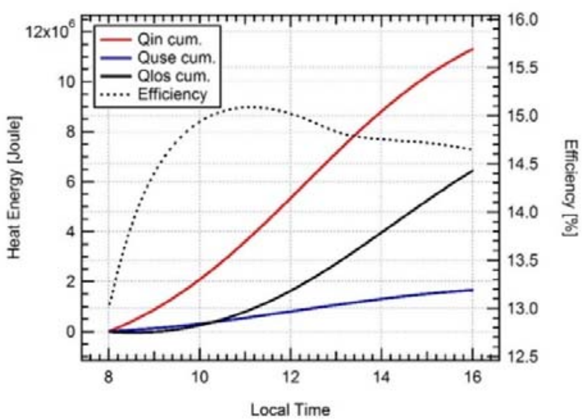

Figure-6. Heat energy and thermal efficiency for load 3 kg water.

As a note, the maximum thermal efficiency of the present solar box cooker is 15.1% and occurs when the temperature of the water inside the cooking vessel is around 60 °C. This is because at this time, temperature difference of the water and the air in the box is high. In addition, the higher temperature of the water results in lower heat transfer rate from the air to the water inside the cooking vessel. At the same time, solar irradiance increases with increasing time. This fact suggests that high operational temperature of the material cooked results in lower thermal efficiency. After the boiling temperature is reached, the temperature will be constant at 100 °C. The heat transfer rate from the air to the container will be used for heat evaporation. Here the thermal efficiency will fall down as shown in Figure-5.

3.4 Characteristics at high loads

The characteristics of the solar box cooker at high load will be discussed for the case with load of 6 kg water. Figure-7 shows the temperature history of the water, absorber plate, air in the box, glasses cover, and ambient temperature of the solar box cooker for load 6 kg water. The figure shows that boiling temperature is reached after 16.00 local time. The maximum temperature of absorber plate is 136.45 °C and it occurs at 13.36 local time. While, the maximum temperature of the hot air in the solar box cooker is 113.55 °C at 13.52 local time. In comparison with the case with low load 3 kg water, the maximum temperature of the plate and the maximum temperature of hot air in the solar box cooker are lower. This is because at high load in the cooking vessel, the load will absorb more solar energy input. This will affect the thermal performance of the unit and will be discussed in the next section. Similar with the temperature characteristics at low load, the temperature of the glass covers also show the same trend with hot air temperature but with lower value. And the temperature of the top glass cover is lower than top glass.

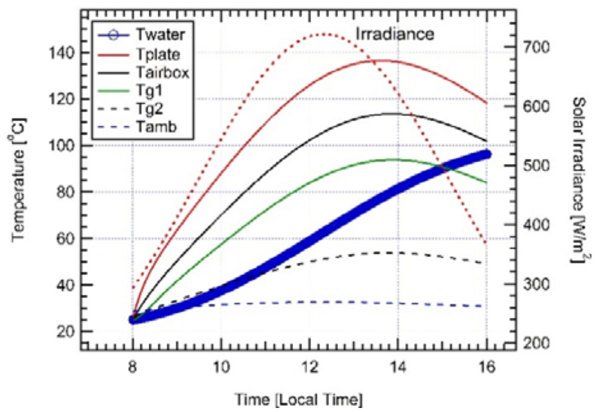

Figure-7. Temperature characteristics for load 6 kg water.

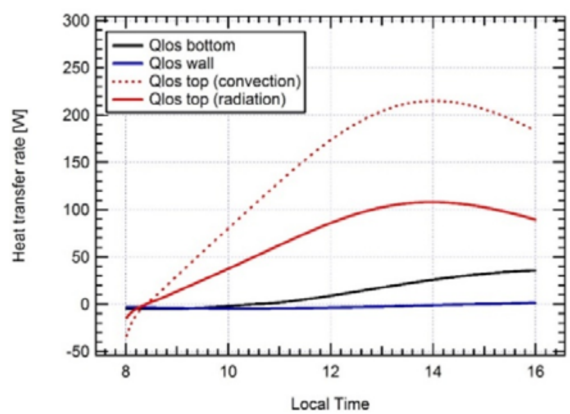

Figure-8. Heat loss from the solar box cooker for load 6 kg water.

Figure-8 shows the history of heat loss from the solar box cooker for load 6 kg water. The figure shows that the trend of the heat loss for this case is similar with the case with low load as shown in Figure-5. In this high load case, the maximum convective heat loss and radiative heat loss from the top glass cover are 215 W and 108 W, respectively. In comparison with solar box cooker with low load, there are slightly differences of heat loss from the solar box cooker. This is because at higher load, the solar box cooker will absorb more solar energy input into useful energy. The higher useful energy results in lower temperature inside the solar box cooker. The lower temperature will reduce the heat loss to the surrounding. This fact clearly shown in the Figure-8. This will affect the total heat absorbed and the thermal efficiency of the solar box cooker.

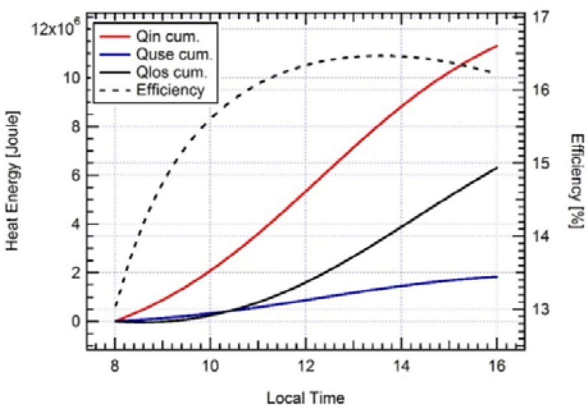

Figure-9. Heat energy and thermal efficiency for load 6 kg water.

Figure-9 shows the history of total cumulative heat input to the solar box cooker, total useful heat, and total heat loss, and thermal efficiency. The total cumulative heat input to the solar box cooker, total heat loss, and cumulative useful are 11.3 MJ, 6.3 MJ, and 1.83 MJ, respectively. The total efficiency of the solar box cooker is 16.22%. In this case the hidden heat is 3.17 MJ. In comparison with the case with low load, the characteristics of the solar cooker with high load shows the followings. The heat loss is lower due to the lower operational temperature of the solar box cooker. The useful heat is higher. This is because the load is higher and it absorbs more energy. Furthermore, even though the load is doubled, the useful load is not doubled. This is because at low load, after reaching the boiling temperature the water and container still absorb the heat for evaporating the water into vapor. As expected, thermal efficiency is higher. This is because the useful heat is higher.

3.5 Performance equation

The objective of the present solar box cooker is to boil the water. Here the main performance is the time needed for boiling the water, named as boiling time. In the above discussion, it is clearly showed that the boiling time strongly affected by the mass of the water. For practical use, it is important to develop a correlation of boiling time and mass of the water. Figure 10 shows the boiling time resulted from experiment and numerical simulation also the proposed correlation of the boiling time. The proposed correlation is developed by curve fitting technique using numerical results. The proposed correlation is given by the following equation.

$$t_b = 0.0859m^2 + 0.6279m + 9.943 \quad (16)$$

Where t_b [local time] and m [kg] are the boiling time and mass of the water, respectively. The value of R^2 is 0.99. As a note this equation can be applied for clear sky condition in Medan city of Indonesia and the cooking process starting at 8.00 of local time.

4. CONCLUSIONS

Experimental and numerical works have been used to investigate the characteristics and thermal performance of a simple solar box cooker. In the experimental work, a simple solar box cooker with absorber area of 0.835 m × 0.835 m has been designed and fabricated. The solar box cooker has been to boil water by exposing to the solar radiation in Medan city of Indonesia at a location 3°35'N and 98°40'E. In the numerical method, a set of transient governing has been developed and solved numerically by using forward time step marching technique. The conclusions of the present study are as follows. The numerical and experimental works show a good agreement. The absorber of the box solar box can reach maximum temperature from136°C to 138 °C. The higher load of the solar box cooker shows the lower maximum temperature. The heat transfer analysis shows that the input energy from solar irradiation can be divided into heat loss, useful energy, and hidden heat. For the present solar box cooker, the heat loss, useful energy, and hidden heat can be up to 57%, 15%, and 28%, respectively. The main conclusion can be drawn here is that the present simple solar box cooker can be used to boil water up to 6 kg. The correlation to estimate boiling time as a function of water mass has been developed.

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