ENERGY-SAVING TECHNOLOGIES AND EQUIPMENT

The paper discusses the comparison of the performance of steam generators in large and small receivers, using a Fresnel lens concentrator.

The goal is to get the best value from the efficiency of a steam generator between large and small receivers, with the following task details:

a) design a conical cavity receiver that has the most efficient geometric concentration ratio;

b) compare the thermal efficiency of conical cavity receivers that have different geometric concentration ratios;

c) analyze the potential of the steam energy from the conical cavity receiver produced by the PMMA Fresnel lens concentrator based on the amount of average radiation directly at the study site.

The study uses an experimental field research method, which is conducted outdoors. This research was conducted in the energy conversion laboratory, Universitas Brawijaya (Latitude: 7.9553° S and Longitude: 112.6145° W), in September 2019. The PMMA Fresnel lens is used for the solar thermal concentrators. The two receivers with a conical cavity that were compared were made of copper with a volume of 2 litres and 0.25 litres, respectively. They are coated with a glass wool insulator with a thickness of 10 mm. Direct Normal Irradiance (I_b) is measured by a solar power meter. The cup anemometer is used to measure wind speed (v_w) around the receiver. Digi-Sense 12 Channel Scanning Benchtop Thermometer connected to the laptop is used to measure temperature. The positions of the four K-type thermocouples are as follows:

1) ambient temperature (T_a);

2) focal point temperature (T_f);

3) receiver wall temperature (T_r);

4) steam/water temperature (T_w).

A pressure gauge to measure the pressure of the steam that goes to the measuring cup was used. After saturation pressure (P_{sat}) has been reached, it will be known from the condensation process through the copper coil, which functions as a condenser.

From the results of the study, the large receivers have specifications CR_g=8 and a volume of 2 litres of water. Whereas, the small receiver is CR_g=30 and 0.25 L. The large receivers can produce steam latent heat energy Q_s=1.37 MJ per cycle with useful efficiency (utilization efficiency) η_{Th}=31.81 %. Whereas the small receiver can produce steam energy, Q_s=579.17 kJ per cycle with useful efficiency, η_{Th}=33.31 %. Hence, from the two types of conical cavity receivers, small receivers have that higher effectiveness than large ones can be recommended

Keywords: steam performance, Fresnel lens, solar concentrator, conical cavity, receiver, temperature, direct normal irradiation, geometric concentration ratio, latent heat, efficiency

INVESTIGATION OF STEAM GENERATION PERFORMANCE ON CONICAL CAVITY RECEIVER BY DIFFERENT GEOMETRIC CONCENTRATION RATIOS FOR FRESNEL LENS SOLAR CONCENTRATOR

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1. Introduction

One alternative to reduce the level of energy demand in the household sector today is the development of solar thermal energy for the solar water heater and solar cooker applications. In general, the working principle in the utilization of solar thermal energy consists of three mechanisms of heat transfer. First, direct solar rays, i. e., sunlight, is directed directly to the material/object that is heated (solar cooker). Second, through convection, the object is heated with hot air in an isolated chamber, for example, in a food drying system. Third, conduction is the heat transfer due to sunlight absorbed by the collector/absorber/receiver, which will then be delivered to the object to be heated (water heater). The development of the combination of these three combinations of heat transfer was carried out by many researchers for various applications of solar thermal technology.

The type of solar collector used today still uses conventional types from both the material and the type. Parabolic type solar collector is made of glass, so it requires strong

construction and expensive costs. Therefore, the development of solar thermal collectors is a challenge for researchers. Currently, one of the trends to generate high heat is using a Fresnel lens solar concentrator. This Fresnel lens is made of Polymethyl Methacrylate (PMMA). Its light shape and large diameter ($1\,\mathrm{m}^2$) can collect more light coming from the sun. Fresnel lenses can be designed with very low focal lengths and small focal point diameters, making them suitable for application in solar thermal technology.

Solar energy is converted to heat by a receiver. The receiver is designed with a small, lightweight, and simple shape so that the heat losses are as little as possible. Variations in the form and dimensions of efficient receivers are also a challenge for researchers today. One of the parameters in the discussion of solar receivers is the geometric concentration ratio (CR_g). It is the ratio between the capture area of the Fresnel lens and the surface area of the receiver. Therefore, the receiver design in this study is in the form of a conical cavity receiver. A small geometric concentration ratio (CR_g) has more potential for thermal generation with a fast time and higher efficiency. The results of the thermal characteristics of the comparison of receivers with different CR_g can be a reference for the use of solar thermal energy for solar water heater applications, solar cookers, or solar steam-generating.

2. Literature review and problem statement

Solar thermal energy is renewable energy. The use of solar thermal energy does not produce pollutants and emissions. Therefore, solar thermal energy is one of the potential energy sources of fossil energy reserves [1–3]. Solar radiation is divided into two types, namely, beam radiation/direct radiation and diffuse radiation. Direct radiation is also called Direct Normal Irradiation (DNI). DNI is the amount of solar radiation received by a surface area that is always perpendicular (or normal) to the rays coming from the direction of the sun when in the sky [4–6]. DNI is a source of solar energy in the application of solar thermal technology for Concentrating Solar Collectors (CSC), such as Concentrating Solar Cooker and Concentrating Photovoltaic (CPV) [7]. One of the uses of thermal technology applications is a solar cooker. Geometry types and solar stove designs are classified into three, namely: 1 – concentrator type, 2 – box-type designs, and 3 – indirect types [8–11].

The technology of solar energy concentration using Fresnel lenses is an effective way to convert solar energy in the form of thermal. The use of Fresnel lens solar concentrators for various applications has been described in the review paper [12, 13]. The paper [13] makes a review of the latest developments in the implementation of concentrated solar energy using Fresnel lenses. The paper mentioned that the Fresnel lens is arranged in the form of a circular groove in the shape of a prism with a certain tilt angle to form a focus (Fig. 1).

The working principle of Fresnel lenses is almost the same as conventional lens types in producing focal point distances or being used as magnifiers. Thinner lens thickness is illustrated in Fig. 2. Fresnel lenses have many advantages compared to conventional types of burner lenses, such as convex lenses.
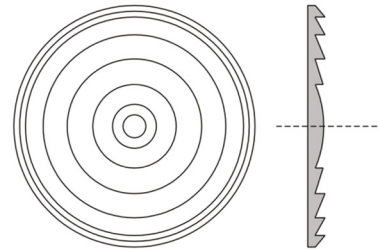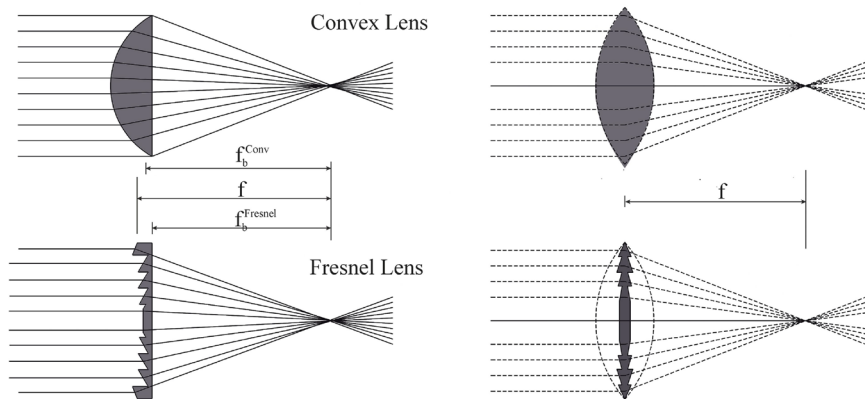

Fig. 1. Surface shape of a Fresnel lens

Fig. 2. Comparison of Fresnel lenses with convex lenses

The advantages of Fresnel lenses compared to conventional lenses as concentrators of sunlight are: Fresnel lenses can be produced in large sizes, light weights, a thickness of less than 4 mm, low prices compared to conventional magnifying glass lenses. For 1 meter in diameter, the lens needs to be up to 200 mm thick, weighing more than 50 kg. Large-diameter Fresnel lenses can collect more sunlight than conventional lenses. Fresnel lenses with short focus and small focal point diameter are suitable for solar thermal technology because they can convert solar heat into small receivers, so that heat losses are minimal.

In [14], the use of Fresnel lenses is the primary choice for focusing on solar energy. It is made of plastic, so it is widely used, while its advantages: small volume, transparent, light weight, easy to produce, stable polymer with optical characteristics such as glass, large capacity, low production costs, and effectively increase energy density. These can be created using CNC machines and new injection plastic moulding techniques. The effectiveness of the solar heat conversion Fresnel lens is in the form of focused heat, able to be absorbed by the receiver. Therefore, currently, the development of receiver design for the Fresnel lens concentrator continues to be carried out by researchers. The installation of Fresnel lenses and receiver forms is the primary key in the application of solar thermal concentrated technology. The author of [20] compared the thermal efficiency experimentally and numerically with three receiver forms, namely conical, spherical, and cylindrical. This receiver is fed with oil, which functions as a heat transfer fluid. The PMMA Fresnel lens is used to concentrate sunlight. The results show that the conical receiver has a higher thermal efficiency compared to spherical and cylindrical, and lower heat loss than others.

The paper [15] performed a simulation of the performance of a PMMA Fresnel lens shown in the form of optical efficiency, which could reach between 68.94 % to 70.38 %. Furthermore, the same author [16] developed the use of Fresnel lenses for solar cookers. Cooking pot/vessel uses three variations of receiver form. The result is that the average optical efficiency of the spherical, cylindrical, conical shapes is 72.23 %, 68.37 %, and 76.40 %, respectively. So far, the application of receivers as concentrators of Fresnel lenses is only limited to sensible heat generation (solar water heater & direct solar cooker). Research on the generation of steam from solar energy for power plant scale and using large and heavy conventional type solar collectors, namely glass-based parabolic is given [17, 18]. Whereas for latent heat generation in the form of steam for household-scale is still rarely done [19, 20].

Based on the background of the problem above, the problem can be formulated, namely the comparison of the performance of the steam generated by the conical cavity receiver.

Based on the geometric concentration ratio (CR_g) parameters. So the results of this steam performance study can be used for the application of indirect solar cooking with a steam transfer system.

3. The aim and objectives of the study

The aim of the present research is an investigation of steam generation performance on the conical cavity receiver with different geometric concentration ratios for the Fresnel lens solar concentrator.

To achieve the set aim, the following objectives had to be accomplished:

– to design a conical cavity receiver that has the most efficient geometric concentration ratio;

– to compare the thermal efficiency of a conical cavity receiver that has a different geometric concentration ratio;

– to analyze the potential steam energy from a conical cavity receiver produced by a PMMA Fresnel lens concentrator based on the number of direct normal irradiance at the study site.

4. Materials and methods of research

4. 1. Conical cavity receiver design used for heat generation by Fresnel lens concentrator

The concentration ratio that is explicitly discussed for the Fresnel lens as optical is called the optical concentration ratio (CR) where the CR value is only viewed from the perspective of energy losses in optical losses due to the lens material factor (refraction & absorption index) or the manufacturing factory of the Fresnel lens itself. Therefore, to be able to take into account the thermal performance of the receiver, the receiver area is very influential. The receiver surface area is related to thermal losses, so the parameter geometric concentration ratio (CR_g) needs to be taken into account.

Fig. 3 shows the form of the receiver in this study using large and small receivers. It is shown in Table 1. The receiver is placed precisely at the focal point of the Fresnel lens (88 cm) below the Fresnel lens concentrator.
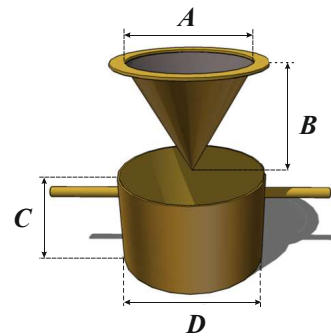

Fig. 3. Scheme of conical cavity receiver

Table 1

Specifications of conical cavity receiver

Parameter	Large receiver (mm)	Small receiver (mm)
Cone diameter (A)	75	50
Conical height (B)	75	75
Receiver height (C)	125	50
Tube diameter (D)	150	85
Material	Copper plate	Copper plate
Plate thickness	2	2

The geometric concentration ratio (CR_g) is the ratio of the area of the Fresnel capture lens (A_{FL}) to the surface area of the cone cavity receiver (A_{cr}). The equation for the ratio of geometric concentrations of CR_g is as follows:

$$CR_g = \frac{A_{FL}}{A_{cr}}. \tag{1}$$

So based on the results of the conical cavity receiver design in Table 1 and equation (1), we obtain two forms of large receivers and small receivers, which have CR_g of 8x and 30x, respectively. From the results of this design, it can be seen that the volume of large receivers ($CR_g=8$) and small receivers ($CR_g=30$) is 2 L and 0.25 L, respectively. Furthermore, two receivers with different CR_g will be tested under the Fresnel lens concentrator to see the resulting thermal performance.

4. 2. Experimental setup of generating steam on the conical cavity receiver by Fresnel lens concentrator

This research uses the Field Experimental Research method, which is conducted outdoors. The study was conducted in September 2019 in the energy conversion laboratory, Brawijaya university (Latitude: 7.9553° S and Longitude: 112.6145° W) Fresnel lens concentrators were used with specifications: Material: PMMA (Polymethyl Methacrylate), Structure: plano-convex, Size: 1000×1000 mm, Thickness: 3 mm, Groove pitch: 0.5 mm, Focal length: 880 mm. Conical cavity receiver is made of copper with a volume of 0.25 Liter of water. The receiver wall is coated with a glass wool insulator with a thickness of 10 mm. Solar radiation is measured by a solar power meter that functions like a pyrheliometer. The amount of available solar energy captured by the Fresnel lens is direct radiation or also known as Direct Normal Irradiance. Variations in DNI readings over 5-minute intervals do not exceed 100 W/m². The direct radiation reading range (I_b) is between 450-1,100 W/m². An anemometer cup (ABH-4224) with a measurement accuracy of 0.9–35.0 m/s is used to measure wind speed (v_w) around

the receiver. Digi-Sense 12 Channel Scanning Benchtop Thermometer connected to a laptop is used to measure temperature, 4 K-type thermocouples with a temperature range of 200–1,350 °C are used to measure:

1) ambient temperature (T_a);

2) focal spot temperature of Fresnel lens (T_f);

3) receiver wall temperature (T_r);

4) steam/water temperature in the receiver (T_w). Steam flowed into the measuring cup, after reaching saturated pressure (P_s) as indicated by the pressure gauge.

The condensate (V_c) will be known from the condensation process through the copper coil, which functions as a condenser. Fig. 4 shows the experimental setup for investigating steam performance on the conical cavity receiver.
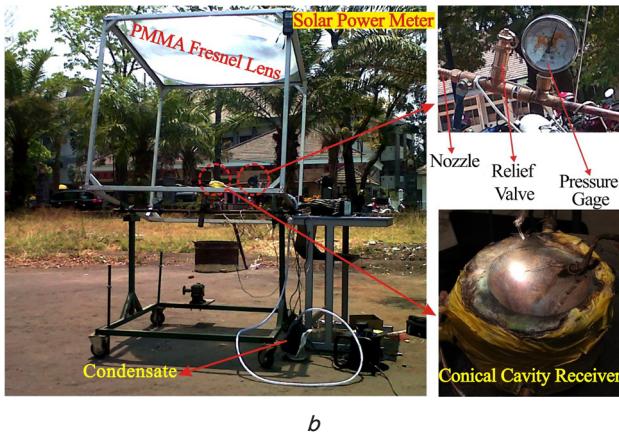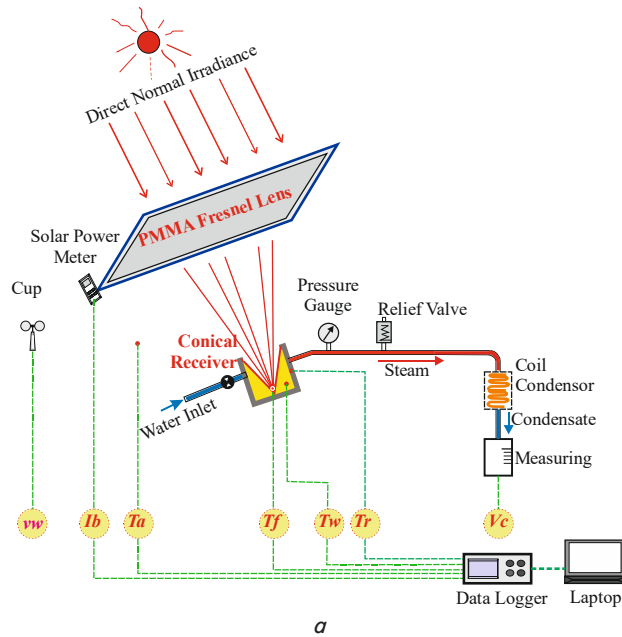

a

b

Fig. 4. Steam generation on conical cavity receivers by Fresnel lens solar concentrating: *a* — schematic of the experimental setup; *b* — photograph of experimental setup

In this study, two receivers with different volumes are used. This volume difference parameter is known as the geometric concentration ratio (CR_g). The large and small receivers each have a capacity of 2 L and 0.25 L, with CR_g=8 and 30. Indicators that this receiver will be able to be developed as

an indirect solar cooker with the steam transfer method. It must be able to function as a boiler to produce steam (latent heat) in a short duration of time to be used as a source of thermal cooking energy.

This receiver performance is influenced by several factors: solar radiation, concentrator type (PMMA Fresnel lens), receiver material and shape, treatment of the receiver (isolator and surface coating), wind speed, ambient temperature, receiver temperature, initial and final water temperature. Fig. 4, *a* shows the experimental setup scheme for conical cavity receiver testing. Fig. 5, *b* shows the photograph of the device settings for testing steam generation on a Fresnel Lens solar concentrator system. Steam generation carried out in this study is saturated steam for medium temperature level, where the required temperature is between 100–150 °C and low-pressure steam where the gauge pressure measurement is between 2–4 barG [21]. The test is carried out under clear sky conditions with relatively sunshine duration to obtain a stable DNI so that maximum saturation temperatures can be obtained. When the temperature in the receiver has reached the required saturation temperature (>100 °C), the steam will be flowed by the relief valve through the nozzle and the condenser hose to the condensate reservoir. The volume of condensate water during the test is measured to determine the energy produced by the vapour.

4. 3. Basic theory of steam generating performance

The amount of steam produced by the receiver during the test period is a form of latent heat energy used for cooking. So that the useful saturation steam energy formula (Q_s) is [19],

$$Q_s = m_s h_f, \tag{2}$$

where is the mass of evaporated water or condensate water during the test period (kg), h_f is a specific enthalpy of saturation steam (kJ/kg). While the rate of the mass of steam produced by the receiver can be measured from the weight of condensate water (kg) and the time during testing (s). So the formula can be written,

$$\dot{m}_s = \frac{m_s}{\Delta t}. \tag{3}$$

The efficiency of the receiver steam generation (η_s) is the ratio of saturated steam energy (Q_{sat}) to the direct solar radiation energy absorbed by the receiver (Q_{in}). The heat absorbed by the receiver during the test is direct solar radiation energy (I_b), which is concentrated by the Fresnel lens (Q_F) for the time (Δt), the formula is [20],

$$Q_{in} = Q_F = \eta_o I_b A_F \Delta t, \tag{4}$$

where is the total time of the process reaches saturation temperature and evaporation process. So from Eq. (2) and Eq. (3), the equation of the efficiency of steam generation by receiver cycles can be written,

$$\eta_s = \frac{m_s h_f}{\eta_o I_b A_F \Delta t}, \tag{5}$$

where η_s is the efficiency of the receiver steam generation; η_o is the optical efficiency of the Fresnel lens.

5. Results of investigation of steam generation performance on conical cavity receiver

5. 1. Results of generating steam saturation in large receivers

Fig. 5 shows the generation of saturation steam for wide receivers containing 2 kg of water carried out on September 15th, 2019. The results of measurement data carried out for 185 minutes obtained an average DNI, stagnation temperature, and ambient temperature are 714 W/m^2, 285.3 °C, and 32.9 °C while the results of the heating process from sensible temperatures to saturation temperatures can be seen in Fig. 6.
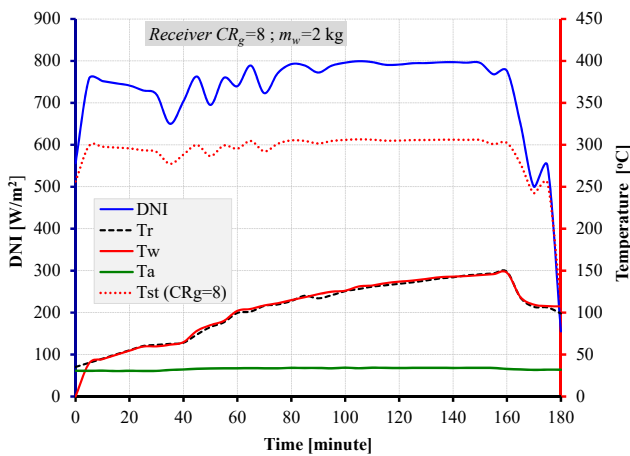

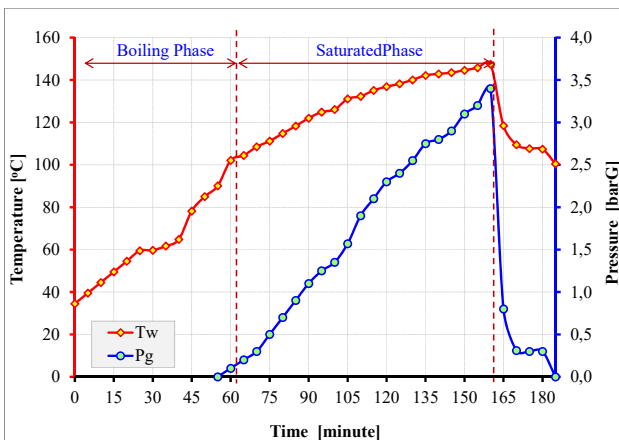Fig. 5. Steam generation performance of large receiver with CR_g=8; m_w=2 kg

Fig. 6. Relationship of temperature and saturation pressure with time for large receivers (CR_g=8; m_w=2 kg)

Fig. 5 shows the steam generation process that occurs in the receiver. The method of generating steam in this receiver is related to useful energy used for cooking purposes. This process will be known as useful thermal efficiency, which can be calculated for the cooking energy requirements. From the boiling phase test, the time to reach a boiling temperature of 100 °C (boiling time) is approximately 60 minutes. While the maximum saturation temperature of 147.5 °C can be reached in 160 minutes. The achievement of saturation temperature is very dependent on incoming solar radiation energy. During the test carried

out on 15/09/2019, a relatively stable DNI measurement is obtained, ranging from 700 W/m^2 (Fig. 5) so that in the test, a maximum saturation temperature is obtained. Furthermore, when conditions start to cloud, and DNI decreases, a condensation process is carried out. As is known, the condensation process is a latent heat dissipation process, and this is a test method to determine the steam energy content that can be used for cooking needs. From the condensation process for 25 minutes (0.42 hours), a 500 ml (m_s=0.5 kg) condensate water volume is obtained. So the steam flow rate is,

$$\dot{m}_s = \frac{m_s}{\Delta t}, \tag{6}$$

$$\dot{m}_s = \frac{0.5}{0.42} = 1.19 \, \text{kg/h}.$$

Steam energy estimation is useful at saturation temperatures, T_{sat}=147.5 °C is,

$$Q_s = m_s h_f, \tag{7}$$

$$Q_s = 0.5 \times 2742.89 = 1371.45 \, \text{kJ},$$

where, h_f=specific enthalpy at a saturation temperature of 147.5 °C (kJ/kg). While the energy absorbed by the big receiver for 160 minutes (9,600 seconds) is,

$$Q_{in} = \eta_o I_b A_F \Delta t, \tag{8}$$

$$Q_{in} = 0.7544 \times 758 \times 0.785 \times 9,600, \, \text{J},$$

$$Q_{in} = 4311.89 \, \text{kJ}.$$

So that the energy efficiency of steam,

$$\eta_s = \frac{m_s h_f}{\eta_o I_b A_F \Delta t} = \frac{Q_s}{Q_{in}}, \tag{9}$$

$$\eta_s = \frac{1371.45}{4311.89} = 0.3181 = 31.81 \%.$$

Thus, it can be concluded that from the results of tests for conical receivers that have CR_g=8 and contain water, m_w=2 kg under average conditions of direct solar radiation, DNI=714 W/m^2 can reach the maximum saturation temperature point T_{sat}=147.5 °C. The saturation temperature reached 160 minutes. At the same time, the steam energy that can be utilized for 25 minutes at the saturation temperature is Q_s=1.37 MJ per cycle. Assuming one cycle for 25 minutes, the mass flow rate of steam m_s=1.2 kg/hour. Steam energy efficiency is η_s=31.81 %. The resulting efficiency is the efficiency of steam generation from the development of Fresnel lens applications for indirect solar cooker systems with the steam transfer method.

The photograph of saturation vapour produced by the conical cavity receiver is shown in Fig. 7. Testing the solar concentrating system using a Fresnel lens can produce steam up to a saturation pressure of 3.5 barG with a temperature of around 150 °C. This saturation steam has the potential to be used for cooking using the steam pressure cooker method.

Fig. 7. Steam saturation resulting from testing
a conical cavity receiver using Fresnel lens solar
concentrator

5. 2. Results of generating steam saturation in small receivers

The next steam generation test is carried out on a small conical receiver with CR_g=30 containing 250 mL of water (0.25 kg). The test, conducted on September 25th 2019, consisted of three tests. Fig. 10 shows the tests carried out in three local time frames, namely 8:30 am – 9:30 am, 9:35 am – 11:00 am, and 11:30 am – 13:00. This test is intended to find the maximum saturation temperature generated based on the weather conditions around the test. Test (Test#01) under the average direct radiation conditions DNI=761 W/m^2 can reach saturation temperature T_{sat}=133.1 °C with a duration of 50 minutes.

Furthermore, the second test (Test#02) with an average DNI=684 W/m^2 takes 60 minutes to reach the saturation temperature T_{sat}=134.4 °C. In the third test (Test#03), the average DNI=652 W/m^2 can achieve T_{sat} saturation temperature=134.0 °C in 75 minutes of heating time. When compared to large receivers, even smaller receivers achieve a slightly smaller saturation temperature. This is due to weather factors, especially the continuity of solar radiation and the influence of the disorientation of the position of the focus point on small receivers, which tend to be larger due to the inaccuracy of the manual tracker. Fig. 8 shows the DNI relationship to time on a small receiver until it reaches its maximum saturation temperature.
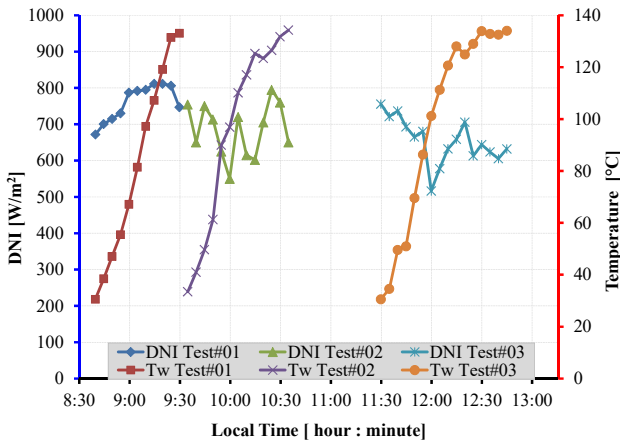

Fig. 8. Testing a small receiver to achieve maximum
saturation temperature

The small receiver performance analysis is based on the third test (Test#03), detailed test results are shown in Fig. 9.
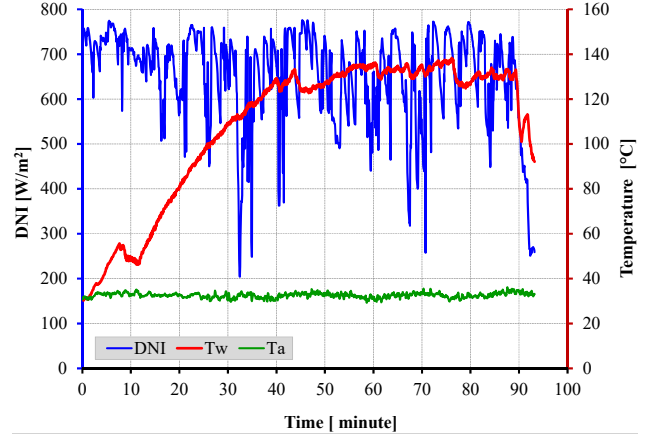

Fig. 9. Steam generation on a small receiver
(CR_g=30; m_w=0.25 kg)

Fig. 9 shows the generation of steam in a small receiver so that the average DNI obtained, saturation temperature, and ambient temperature is 652 W/m^2; 134.0 °C and 32.4 °C. The test results also showed that the time needed to reach the saturation temperature was 75 minutes (4,500 seconds). When the T_{sat} condition=134.0 °C and the measurement pressure is 2 barG. The steam energy utilization process is carried out with the condensation method with a time that can achieve of 10 minutes until the pressure returns to 0 barG. The volume of condensate water obtained was 212.5 mL (0.2125 kg). Furthermore, during this time (10 minutes) it can be predicted that the rate of flow of steam produced is,

$$\dot{m}_s = \frac{m_s}{\Delta t}, \text{ kg/h,} \qquad (10)$$

$$\dot{m}_s = \frac{0.2125}{0.1667} = 1.275 \text{ kg/h.}$$

If the specific enthalpy at a saturation temperature of 134 °C is h_f=2725.5 kJ/kg, the utilization of steam energy is,

$$Q_s = m_s h_f, \qquad (11)$$

$$Q_s = 0.2125 \times 2725.5 = 579.17 \text{ kJ,}$$

whereas direct solar radiation energy produced by Fresnel lens concentrations for 75 minutes (4,500s) is,

$$Q_{in} = \eta_o I_b A_F \Delta t, \qquad (12)$$

$$Q_{in} = 0.7544 \times 652 \times 0.785 \times 450 \text{ J,}$$

$$Q_{in} = 1738.56 \text{ kJ.}$$

So that the energy efficiency of steam,

$$\eta_s = \frac{m_s h_f}{\eta_o I_b A_F \Delta t} = \frac{Q_s}{Q_{in}}, \qquad (13)$$

$$\eta_s = \frac{579.17}{1738.56} = 0.3331 = 33.31 \%.$$

Based on the above calculation, it can be concluded for testing steam generation in small receivers that have a geo-

metric concentration ratio, CR_g=30 containing 250 mL of water, steam energy of Q_s=579.17 kJ with useful efficiency η_s=33.31 % in one cycle can be produced.

5. 3. Comparison of steam generation performance in large receivers and small receivers

The test results show that the system efficiency of small receivers (CR_g=30) is relatively better compared to wide receivers (CR_g=8). However, the efficiency parameters of the steam generator of the two receivers are not enough to compare with each other. Therefore, it is necessary to have a study related to the effectiveness of using this receiver. The intended effectiveness parameter is the receiver's ability to produce steam energy use in the shortest possible time to be used as a source of cooking energy. Fig. 10 illustrates a comparison of large and small receivers' capabilities in the generation of steam at the same saturation temperature point, i. e., T_{sat}=134 °C. The small receiver (CR_g=30) at an average DNI=647 W/m^2 can produce a saturation pressure of P_{sat}>2 barG, for 70 minutes. Furthermore, the large receivers (CR_g=8) at an average DNI=747 W/m^2 under the same saturation pressure conditions (P_{sat}=2.1 barG) require approximately 115 minutes.
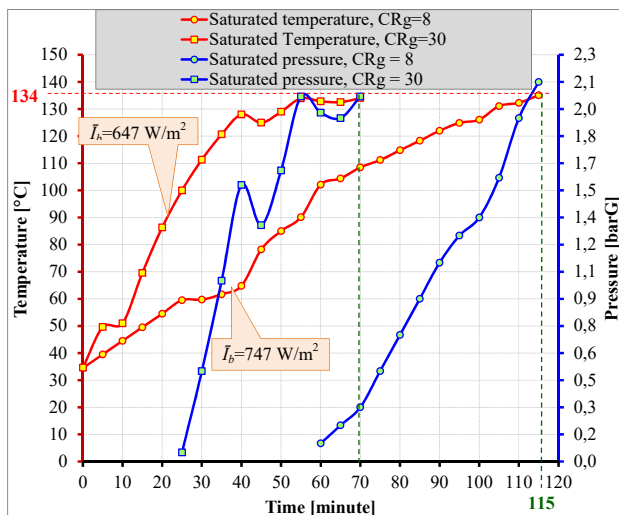

Fig. 10. Comparison graph of the effectiveness of steam generation

The test results show a small receiver even though the incoming direct radiation is smaller than ones, and it turns out that the time achieved is 45 minutes faster than a large receiver. Fig. 10 also provides information about the thermal performance of receivers with different CRg. The result shows the thermal efficiency (η_{Th}) of the receiver with CR_g=8 and CR_g=30 is 31.81 % and 33.31 %, respectively. So that in terms of steam generation, small receivers (CR_g=30) are more efficient compared to large receivers.

6. Discussion of the investigation of steam generating performance on conical cavity receiver

The greater the Geometric Concentration Ratio (CR_g) of a receiver, the higher the stagnation temperature (T_{st}) received. In this study, two conical receivers (conical cavity receiver) with different volumes are used. Small receiver (CR_g=30). Likewise, with the stagnation temperature re-

ceived, small receivers are higher than large receivers. The average stagnation temperatures received by large and small receivers for various DNI variations during the test were 267.35 °C and 478.94 °C, respectively. If the DNI parameter is assumed to be 700 W/m^2 (the average DNI during the test is 643 W/m^2), the ambient temperature range at the location is from 29.1 °C to 34.3 °C. The CR_g increases, the stagnation temperature and geometric efficiency will also increase.

It is beneficial in planning the form of receivers to be used for concentrated solar thermal (CST) applications. The CR_g factor will be a basic reference in terms of determining the estimated temperature of the solar cooker to be designed. The development of indirect solar cookers with the steam transfer method certainly requires high temperatures. Therefore, in this study, small receivers (CR_g=30) have more potential for steam generation than large receivers (CR_g=8). So that later CR_g limits can be recommended that are suitable for the application of solar cooker that uses PMMA Fresnel lens.

Fig. 10 shows that small receivers have higher effectiveness compared to large receivers. This is due to several factors:
– higher efficiency;
– potential for faster steam generation due to short cycle times;
– large receivers are more at risk of not generating steam because they have to take almost 2 hours to reach a saturation pressure of 2 barG (134 °C);
– a small receiver load is lighter than a large receiver, so when using an automatic solar tracker, the motor power of the movers is smaller.

In this study, water loads plus material weights for large and small receivers are ±4 kg and 1 kg. Thus, a conical receiver with CR_g=30 with a volume of 250 mL water is more suitable to function as a mini boiler for a steam generator in a complicated solar cooker system especially using a Fresnel lens concentrating technology. Whereas a large receiver with CR_g=8, which contains 2 litres of water, has more potential to function as a furnace in a direct solar cooker system. In bright day weather conditions, solar thermal energy is concentrated by the Fresnel lens on the large receiver. It can reach the saturation temperature point, so that the water in this large receiver can generate sensible heat energy and latent heat for use as cooking energy.

A comparison of the results of this study with the results of other studies regarding the performance of receivers in concentrated solar thermal technology is shown in Table 2.

From the results of Table 2, we can see a comparison of the performance of the steam generator of the receiver with the previous researchers. For a large receiver with a Fresnel area that is almost the same as the area of the Vega Fresnel, the thermal efficiency (η_{Th}) of the large receiver is greater than the result of the author [20]. This is due to several factors including geographical location (tropical versus subtropics), weather, and time of solar energy absorption. The time of absorption of solar energy is very influential on saturation temperature. The difference in saturating temperature with a large ambient temperature makes the thermal efficiency even greater.

The challenges of future research are:
1) increasing the thermal efficiency of Fresnel solar concentrator equipment by adding automatic solar trackers;
2) on a small scale, the steam transfer system can be used as energy from the indirect solar cooker for households, while a larger scale of the steam can be used as a latent heat utility in the chemical industry;

3) increasing incoming solar energy by increasing the Fresnel lens area;

4) analyzing estimated production costs;

5) furthermore the giant Fresnel lens combined with a Stirling motor to drive an electric generator is also a very interesting topic to study.

Table 2

Comparison of the performance of steam generation on receivers

Author	Specification	DNI [W/m^2]	Δt [menit]	T_{sat} [°C]	P_{sat} [barG]	η_{Th} [%]
Asrori et. al.	Fresnel lens PMMA: A_p=0.785 m^2; CR_g=8; m_w=2 kg; $\dot{m}_s$=1.2 kg/jam	714	160	147.5	3.4	31.8
Asrori et. al.	Fresnel lens PMMA: A_p=0.785 m^2; CR_g=30; m_w=0. 25 kg; $\dot{m}_s$=1.3 kg/jam	652	75	134.0	2.0	33.3
Vega (2016)	Fresnel lens PMMA: A_p=0.83 m^2; m_w=1.2 kg	1098	69	126.8	N/A	21.8
Mahdi. et. al. 2014	Parabolic: A_p=2.98 m^2; m_w=6 kg; $\dot{m}_s$=2.1 kg/jam	750	80	170	9.8	40.0

7. Conclusions

1. The design of the receiver with a conical cavity is chosen. For large receivers with a CR_g=8 specification and a volume of 2 litres of water, a small receiver with CR_g=30 specifications and a capacity of 0.25 litres of water.

2. Large receivers (CR_g=8; m_w=2 kg) can produce steam latent thermal energy of Q_s=1.37 MJ per cycle with useful efficiency (utilization efficiency) of η_s=31.81 %. Whereas a small conical receiver containing an insulator (CR_g=30; m_w=0.25 kg) can produce steam energy of Q_s=579.17 kJ per cycle with useful efficiency of η_s=33.31 %.

3. From both conical receivers, it can be recommended that small receivers have higher effectiveness than large receivers. This is due to several factors:

1) higher efficiency;

2) potential for faster steam generation due to short cycle times;

3) large receivers are more at risk of not being able to generate steam because it must take almost 2 hours to reach a saturation pressure of 2 barG (134 °C).

4) the weight of the small receiver is lighter than that of a large receiver, so when using an automatic solar tracker the driving power of the motor is smaller.

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DEVELOPMENT OF A SOIL REGENERATOR WITH A GRANULAR NOZZLE FOR GREENHOUSES

The results of the development of a regenerative-type heat exchange unit for greenhouses are presented. The creation of a soil regenerator is conditioned by energy and economic expediency. In spring in the daytime, the air in greenhouses is intensely heated by solar radiation, and at night it can be cooled below the allowable temperature. Heat accumulation during the day and using this heat at night will reduce the need for heaters even to their complete exclusion. The soil regenerator contains a dense layer of granular material that is blown through by the air from the inner space of a greenhouse. This solution makes it possible to intensify significantly the heat exchange. To determine the mean intercomponent heat exchange factor, the empirical dependence, taking into consideration the effect of duration of the heat exchange process, was obtained. We developed the procedure of thermal design calculation of a regenerator, using which the main geometric characteristics of the heat exchange area are determined. The results of the calculation of the soil regenerator for a greenhouse with the surface area of 18 m^2 for the conditions of the warm continental climate were presented. The developed soil regenerator contains 5 channels that are 5.75 m long, filled with rubble. It was obtained that for the average solar radiation flow $Q_c=2,160$ W and the duration of operation of the soil regenerator $\tau_\Sigma=6$ hours, the accumulated heat at night can be consumed for 2.6 hours at the average ambient temperature $t_1=7$ °C. As the ambient temperature rises, the time of regenerator operation will increase. The proposed soil regenerator is characterized by the design simplicity and its application will lead to an increase in energy costs to maintain the temperature mode in a greenhouse

Keywords: solar radiation, heat accumulation, heat calculation procedure, factor of intercomponent heat exchange

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1. Introduction

The need to develop energy-efficient methods for heating and cooling the premises increases every year. The efforts of many researchers are aimed at finding effective solar energy batteries to heat the premises under conditions of a significant daily temperature difference. It is advisable to use a dense layer of granular materials as an accumulating body.

Due to the developed heat exchange surface, which is the cumulative surface of all particles in the apparatus, the heat exchange intensity increases significantly. A regenerator for maintaining the required temperature level in greenhouses is one of the applications of using a regenerative device with a granular nozzle in the form of a dense layer, for which the source of heat is solar radiation. The temperature in a greenhouse should be on average from +16 to +25 degrees,