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Effect of Fresnel lens as cover in a passive solar water heater with some air gap between cover and absorber plate

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Abstract. A passive solar heater can be used to heat air in a room or water for some household needs. Passive solar heater can reduce the energy consumption by converting solar radiation energy to be thermal energy. Basically, a simple passive solar heater consists of absorber plate, thermal insulation, working fluid, cover, and structure to hold everything. This paper will discuss about the effect of Fresnel lens used as the cover and the air gap between cover and absorber plate on a passive solar water heater. The results of the experiment are that the commercial Fresnel lens could not give the highest water temperature nor efficiency for passive solar water heater. The highest efficiency with glass cover and five-cm air gap was 22.8%. The smaller the air gap, the higher the water temperature in a passive solar water heater. The highest water temperature with glass cover and five-cm air gap was 63.8°C. The result of this experiment gives new challenge for the next research: we do the experiment in a solar water heater where water is circulated in a pipe and design until manufacture the new Fresnel lens.

1. Introduction

Indonesia is located in Tropics and gets a lot of Sunshine almost all the time in a year. Yet, in some countries that experience severe winter usually do not get much Sunshine. The heating process in there is required to maintain life, but it consumes much energy. Whereas, the radiation emitted by the Sun can be converted into thermal energy using solar collector. Passive heater is basically a very simple solar collector with water or air as the working fluid. The benefit of passive heating is no energy consumption for mechanical driven equipment. Since water is a good thermal storage, the working fluid used is usually water. The solar passive water heater is placed such that it is exposed to the Sun. So, the water inside get warmer and then it will warm the room. Although the building still needs to be heated, but the heating load is less and we can save energy consumption. While in tropics countries, passive heating could be used to produce hot water for bath or washing dishes.

A solar passive heater generally consists of absorber plate, thermal insulation, working fluid, cover, and structure to hold everything. The absorber plate is made of metal that has good conductivity and usually painted black to absorb more heat. Thermal insulation is used only when it is necessary. When the passive heater used for warming air inside a room, then no insulation is needed. Yet, when it is



used for producing hot water, then insulation is required to prevent heat loss. The cover could be made of glass or plastic to prevent heat transfer from the absorber plate or the fluid to the ambient air.

The cover was usually made of glass and sometimes plastic. Plastic is much lighter than glass. To overcome the lower transparency of plastic, Fresnel lens is used. Fresnel lens could be used for three application, i.e.: as collimator, collector, and condenser or diverger. Collimator produces parallel ray out of lens. Collector is focusing collimated beam to a focal. Condenser or diverger makes collimated beam disperse to a wider area. In general, Fresnel lens is classified as imaging and non-imaging. Imaging lens will produce image of object, while non imaging could not. Fresnel lens is much lighter and easier to manufacture than plan-convex lens (Leutz & Suzuki, 2001). The lens material since the official invention of Fresnel lens in 1822 is polymethylmetacrylate (PMMA) which has a good transmissivity and resistance for sunlight. Imaging Fresnel lens solar concentrators are designed as focusing devices. While non-imaging Fresnel lens solar concentrators are well suited for the collection of solar energy, because the goal is not the reproduction of an accurate image of the sun, but instead the collection of energy. Non-imaging Fresnel lens concentrators are thought to be very competitive solar collectors because of their high optical efficiency, light-weight and cost effectiveness (Xie, Dai, Wang, & Sumathy, 2011).

Xie et al. explained that solar energy concentration technology using Fresnel lens is an effective way to make full use of sunlight (Xie, Dai, Wang, & Sumathy, 2011). Fresnel lens could be used in solar concentrator in Photovoltaic/Thermal applications, because it becomes a promising alternative due to its potential to overcome techno commercial constraints associated with conventional reflector based Concentrated Solar Power. Non-imaging type of Fresnel lens allows optimal transfer of light ray from source to target at spot and does not attempt to form any image of source. Widest possible acceptance angles, higher tolerances both in manufacturing and operation, less precise tracking, misalignment compensation are the parameters of non-imaging optics which makes it most efficient and best suitable for CSP technology (Kumar, Shrivastava, & Untawale, 2015). Luminosu et al. has setup an experiment with Fresnel lenses tested for solar thermal. The results obtained were average efficiency of the installation equipped with linear focus Fresnel lens of 13.98% and an average efficiency of the installation equipped with point focus Fresnel lens of 16.48%. (LUMINOSU, DE SABATA, & JURCA, 2017). Berin and Lionel use Fresnel lenses as solar radiation concentrator to generate power. The non-imaging system give more merits, such as larger accept angles, higher optical efficiency (Aniesh N. B & Beneston , 2017). Fresnel lenses could be used in solar collector to heat water for desalination process (Mahmoud & Mohamed, 2011). Alibakhsh et al. did the review on parabolic trough/Fresnel based photovoltaic thermal systems and explained that trough collectors and Fresnel lenses are more significant in case of concentrating devices (Kasaeian, Tabasi, Ghaderian, & Yousefi, 2018). Fresnel lens could also be used with receiver module and tracking system to remove all direct radiation of the sun into a greenhouse for pot plant (typical shadow plant who does not like direct radation) (Sonneveld, Swinkels, van Tuijl, Janssen, & Gieling). Compared with parabolic troughs, linear Fresnel collectors suffer from lower optical efficiency. In addition, the linear Fresnel structure is particularly suitable for the combination of CSP, solar heating/cooling, photovoltaic (PV) and/or concentrating photovoltaic (CPV) technologies (Zhu, Wendelin, Wagner, & Kutscher, 2014). In Indonesia, Fresnel lens was used to focus the sunlight to heat up stove (Asrori, Soeparman, Wahyudi, & Widhiyanuriyawan, 2014).

Another variable beside the cover that affects the solar collector's performance is the air gap between the absorber plate and the cover. Arsham et al. did exergy analysis of solar flat plate air collector and found that exergy destruction in the glass cover is largest and unavoidable (Mortazavi & Amari, 2018). Ferahtaa et al. found that the absorber temperature varies with the thickness of the air gap, consequently the temperature of the heated fluid varies in the same way (Ferahtaa, Bougoula, Ababsaa, & Abid, 2011). Ralph has constructed analytical model for convective heat loss across the air gap between absorber and cover plate in flat plat solar collector (Eismann, 2015). Alison Subiantoro also constructed analytical model for the glazing flat plate solar collector with air gap spacing. The result is that for both single and double glazing, the air gap spacing that give Rayleigh

number near to its critical value of 1708, the heat loss thru glazing will be minimum (Subiantoro & Kim, 2013). Abbas and Azat has investigated experimentally the effect of width of the channel in a solar passive using Trombe wall. They used six different widths of air gap channel, i.e. 10, 15, 20, 25, 30, and 35 cm. They found that the mass flow rate is proportional directly to the width channel and the highest efficiency obtained was at depth of 30 cm (Abbas & Azat, 2018).

Fresnel lens is used a lot in many solar power concentrators or photovoltaic, but not many used in solar collector. So, it is an opportunity to study the effect of installing Fresnel lens as cover on solar collector, which is passive heater, experimentally. Since the air gap in a solar collector is important, then the effect of air gap will also be studied.

2. Experimental Setup

The experiments were conducted between April – June 2019 in Surabaya – Indonesia which is located at the latitude $7^{\circ}17'$ - $7^{\circ}21'$ of the South. Since it was conducted outdoor, the experiments shall be conducted simultaneously on horizontal plane. So, three solar passive heater were set-up. All of passive heater will heat the same amount of water, i.e. 500 ml. The Fresnel lenses used in this experiment is the commercial ones. The dimension of the solar passive heater box will follow the dimension of commercial Fresnel lens, i.e. 26 cm x 18 cm. The absorber plate is made of 0.7-mm aluminium.

In this experiment, the performance of the passive heater with different covers will be studied. The covers used are clear glass, one piece and two pieces of Fresnel lens with some certain air gap. The cross section of the solar passive heater and its photograph are shown in figure 1. The air gap was chosen such that the focal point of Fresnel lens will be on the absorber plate. From the measurement, the focal point of one piece of Fresnel lens is 25 cm and of two pieces put together is 9 cm. The air gap effects the heat loss from the absorber plate to the ambient. To study the effect of air gap, the height of the passive heater will be adjusted. The air gap used were 5 cm, 9 cm, 15 cm, 20 cm, and 25 cm.

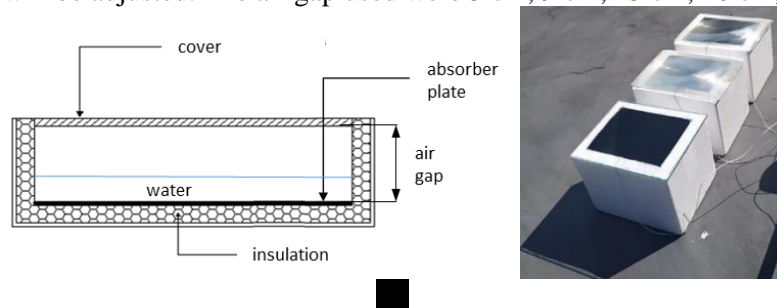


Figure 1. The schema and photograph of the passive solar heater used.

Data measured during the experiments were temperature of water, solar radiation intensity in the location, wind speed, and ambient temperature. Solar radiation intensity was measured using a pyranometer (Kipp&Zonen type SP Lite2). Temperature was measured using K-type thermocouple with Pico data logger TC-08. Wind speed was measured using Lutrin AM-4203 digital anemometer. The experiment was conducted from 09:00 am to 15:00 pm. The solar heater with three kinds of cover were tested together with the same air gap as in figure 1 for one day.

3. Result and Discussion

From the experiments conducted, the highest water temperature inside solar passive heater was obtained when the cover was clear glass at all the air gap used. Figure 2 shows the effect of cover and solar radiation intensity on water temperature. There are four graph in figure 2, i.e. when the air gap or distance between absorber plate and the cover is (a) 5 cm, (b) 9 cm, (c) 15 cm, and (d) 20 cm. The water temperature was rather symmetry, because all passive heaters were located in a horizontal plane, not tilted. The highest water temperature, 63.8°C , got during experiments happened when glass cover used with 5 cm air gap between cover and absorber plate. The water got warmed and produced some water vapor inside the solar heater. These water vapor goes up and wet the inside cover. The

commercial Fresnel lens is serrated and not smooth. This serrated surface keeps more water vapor and less sunlight reach the water and absorber plate. This cause the water temperature with commercial Fresnel lens was lower than clear glass.

The Fresnel lens is much used to concentrate solar radiation for generating electricity or used in concentrator, but it is not used as cover in passive heating (Aniesh N. B & Beneston , 2017) (Asrori, Soeparman, Wahyudi, & Widhiyanuriyawan, 2014) (Kasaeian, Tabasi, Ghaderian, & Yousefi, 2018) (Kumar, Shrivastava, & Untawale, 2015) (Sonneveld, Swinkels, van Tuijl, Janssen, & Gieling) (Xie, Dai, Wang, & Sumathy, 2011) (Zhu, Wendelin, Wagner, & Kutscher, 2014). Yet, Fresnel lens has better benefit compares to clear glass. It is able to focus the solar radiation to absorber plate and lighter than glass.

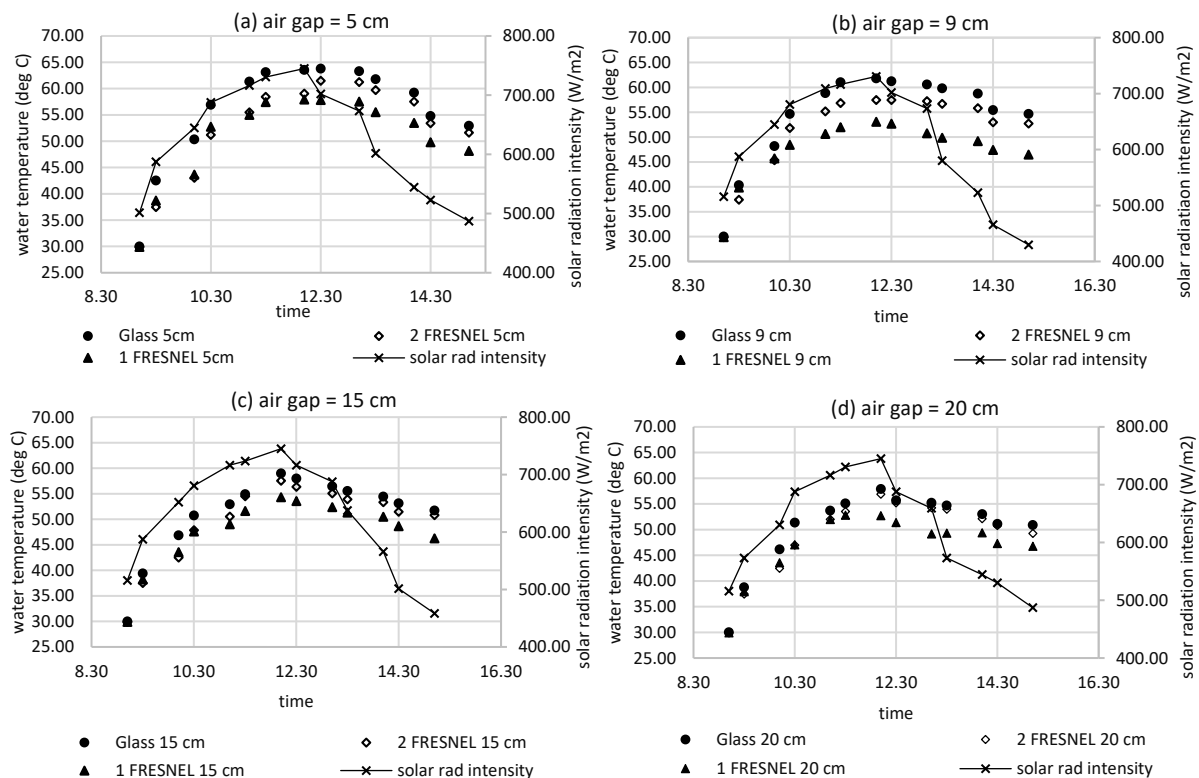


Figure 2. Average water temperature inside solar passive heater with some covers.

Figure 3 was made to show the effect of the air gap for a certain cover, i.e. glass and one piece of Fresnel lens. The smaller air gap gave higher water temperature for any cover. The less air gap means less air trapped above the water. The higher water temperature means less heat loss to the surrounding. Since the temperature of the absorber plate was almost the same with water, then convection will be more dominant than radiation. The trapped air in the gap will deliver heat by natural convection. The hot plate which was in the bottom increase the convection heat transfer from the water to the surrounding. Thus, thicker air gap will deliver more heat loss.

The glass cover gave the highest result and one-piece of Fresnel gave the least. For five-cm air gap, the water temperature could reach 63.8°C with glass cover and only 57.9°C with one-piece of Fresnel lens. This fact shows that the commercial Fresnel lens is not suitable for solar passive heater where water vapour could rise and block some sunlight. The next experiment will be on solar water heater where water is circulated in pipe arrangement. So, the water vapour problem could be avoided. Since the commercial Fresnel lens used is not giving good result for solar collector or passive heater, a Fresnel lens will be designed with expectation to improve the commercial one.

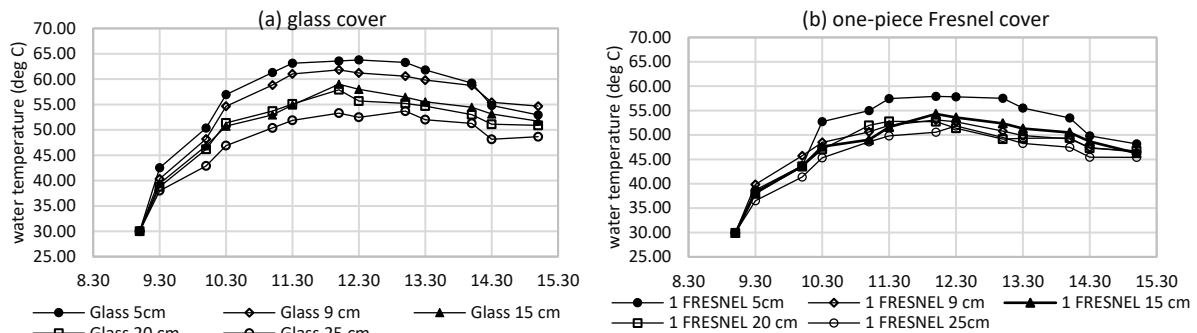


Figure 3. The effect of air gap for glass cover and one-piece Fresnel lens cover on water temperature.

Another important variable discussed in passive heater is efficiency. Figure 4 and figure 5 shows the effect of the cover and air gap on efficiency of the passive heater. The efficiency was calculated using equation (1). The data needed are m , mass of water inside, c , the specific heat of water, T_w is water temperature, t is time for the increasing temperature, I is the solar radiation intensity, and A is the absorber plate area.

$$\eta = \frac{Q_{usefull}}{Q_{input}} = \frac{mc(T_{w,final} - T_{w,initial})}{I.A} \quad (1)$$

The efficiency of the solar passive heater was quite low. The maximum was only 22.8% and it happened at the beginning of the experiment. Around 9.00 am, which the experiments were started, the increasing of water temperature was tremendous and the solar intensity was still low. Thus, the combination produced high efficiency. Glass cover gave slightly higher efficiency compare to Fresnel lens cover. Figure 4 and figure 5 shows that the efficiency downed sharply as the solar radiation intensity increased. The Fresnel cover could not give better efficiency compare to glass. The possible reasons are first the emergence of water vapor stick to inside surface of the cover produced by water. Second, the commercial Fresnel lens has only one focal point and the heating process focused on that point only and this made the water temperature increase less. Thus, for next research a new designed Fresnel lens shall be used on a solar collector which water is flowing inside pipes.

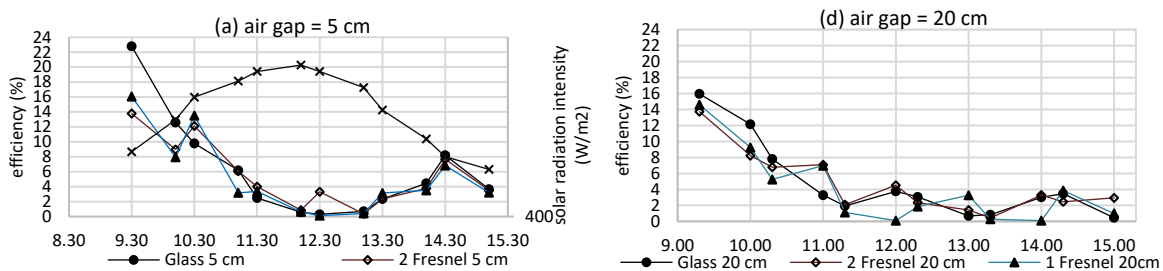


Figure 4. Efficiency of the solar passive heater using some cover with some air gap.

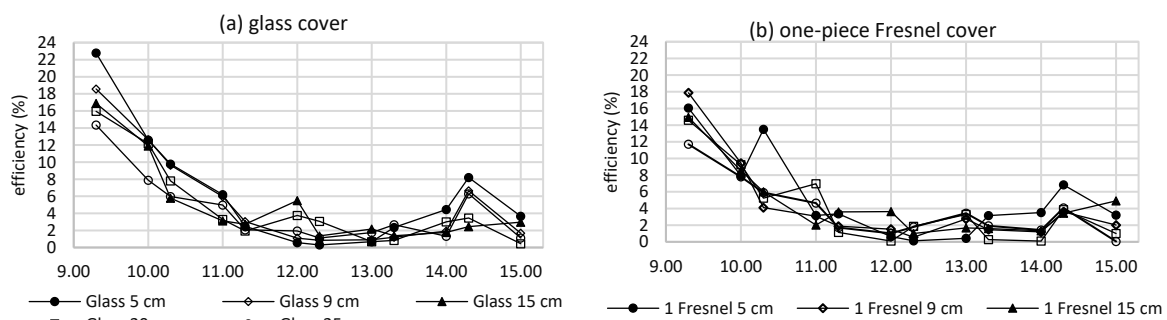


Figure 5. The effect of air gap for cover on efficiency of the passive solar water heater

4. Conclusion

From the experiments conducted, some conclusions are: the commercial Fresnel lens could not give the highest water temperature and efficiency for passive solar water heater. The highest efficiency with glass cover and five-cm air gap was 22.8%. The smaller the air gap, the higher the water temperature in a passive solar water heater. The highest water temperature with glass cover and five-cm air gap was 63.8°C. The result of this experiment gives new challenge for the next research: do the experiment in a solar water heater where water is circulated in a pipe and design until manufacture the new Fresnel lens.

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