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Comparison Study of Solar Flat Plate Collector with Two Different Absorber Materials

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Abstract

The major component of a flat plate solar collector consists of an absorber which is basically made of several narrow metal strip and pipe. They act as a conductive material that absorb heat from the incoming solar energy and then transfer it to the circulating fluid in the pipe to increase the temperature of the working fluid. The thermal performance of the collector is usually depending on the types of absorber material. The aim of this study is to determine the effect of different types of material absorber on the thermal performance of solar collector. The use of the same tube diameter size for risers and header were considered in the present study. The two types of absorber materials used in the current work are copper and aluminum. Both materials have thermal conductivity values of 386 W/mK for copper and 201 W/mK for aluminum respectively. The thermal performance characterization was performed under steady state condition according to the European Standard EN 12975. Collected data was processed by least square method (*Multiple Linear Regression*) to get collector performance parameters such as collector efficiency and heat losses. The test results show that there is no a significant difference of the collector thermal performance values in the use of the copper and aluminum material as an absorber. Furthermore, aluminum material provides an advantage in terms of thermal performance and production costs due to the higher thermal conductivity value and the lower material price and lower material density.

Keywords: solar collector, absorber plate, thermal performance

1. Introduction

Flat-plate collectors are the most common type of solar hot fluid panels. They are useful in meeting hot fluid needs for residential water, space heating, industrial application, etc. In principle, flat-plate collectors are more simple design, low maintenance and easy to operate. This type collector consists of an absorber, a transparent cover, a heat transport fluid and a heat insulating material.

Regarding the absorber, this material is a major component of the flat plate solar collectors, which play an important role in heat transfer between the absorber and the transport medium. Correspondingly, materials of high thermal conductivity are widely used in heat sink applications. The absorber acts as a conductive material that absorb heat from the incoming solar energy and then the heat is transferred to the transport medium in the fluid conduit. Copper, aluminum, brass and steel are the common material used in the absorber due to their high thermal conductivity.

Several studies have been reported regarding the performance of flat-plate collectors. Ekramian et al. (2015) simulated the use of the different absorber plates of copper, aluminum and steel with various thermal conductivities. The result showed that by increasing the absorber conductivity, the collector efficiency increases. The large difference value in the thermal efficiency between copper and steel (35 %) and slight difference between copper and aluminum (3.4%) was reported, respectively. The results were validated using those obtained by Cruz et al. (2014).

Nahar (2002) also investigated the effect of different absorber material by replacing copper in combination with aluminum and galvanized steel material. Furthermore, copper tube material replaces with galvanized steel tube and copper plate with aluminum plate. The result reported that there is no significant difference of thermal efficiency from the use of these kind of materials. While the price of the materials are large difference each other's.

In general, based on the tubing configuration there are two types of flat-plate collectors namely parallel tube collectors and serpentine tube collectors. The parallel tube collectors are most common type of flat-plate collectors available on the market and this collector has small parallel tubes connected to a larger main carrier pipes. These small parallel tubes are called riser tubes, while the larger ones are header tubes and so that the diameter size of both risers and header are different. Majority of studies reported here investigated the use of conventional collectors (parallel flat-plate collectors) in which the diameter dimension between riser tubes and header tubes are not the same. Facao (2012) also investigated the thermal efficiency of flat-plate collector based on the diameter of header and riser tubes. The result concluded that the outlet header should have a higher diameter compared to the diameter of the inlet header.

Most of the flat plate thermal collectors as in the market have risers and header of tubes with different diameter size. Unfortunately, in practice, this kind of flat plate thermal collector with different tubes geometry need a special design and much effort to attach it underneath of a surface of Photovoltaic/Thermal (PV/T) collectors. In this case, the flat plate thermal collectors will act as a heat exchanger for PV/T collector system. Meanwhile, the PV/T collectors are combination between a photovoltaic module and a solar thermal collector, forming a single device that converts solar energy into electricity and heat at the same time. In order to improve the electrical performance of PV modules, the heat from the PV can be removed and converted into useful thermal energy. It is well known that PV/T systems enhance the PV efficiency through a cooling effect.

The aim of this work is to study the effect of using different material as an absorber on the thermal efficiency of flat plate solar collectors. The use of the same tube diameter size for risers and header were considered in the present study. There is a lack information on the literature available on the use of different material as absorber associated with geometry of riser and header tubes. Therefore, it was necessary to carry out an experimental study on a flat plate solar collector and investigate on improvement of thermal efficiency.

2. Parallel Tube Collector Design

The tested of solar collectors with the two types of absorber materials, that is, copper and aluminum were designed and made in the current work. While the copper material almost provide the value of thermal conductivity 2 times higher than aluminum material as given in the characteristic of the solar collector. The configuration of the parallel tubes collector with aluminum as absorber was identical to that of the copper material. Both solar collectors were built under the same tube diameter size of riser and header. The tested solar collector used in this study has the characteristic:

- The number of risers is 7 tubes
- The diameter of header and risers is 0.00953 m
- Tube spacing is 0.08 m
- Absorber plate materials are copper (k = 386 W/m°C) and aluminum (k = 201 W/m°C)
- Area of absorber plate is 0,8 m^2
- Thickness of absorber plate is 0.003 m

Fig. 1: The tested solar collectors with (a) aluminum absorber plate (b) copper absorber plate

3. Experimental Procedure

The two different absorber material types of the collectors as presented in Figure 1 were tested indoors using a solar simulator based on European Standard EN 12975 (2006). According to this standard for indoors testing, the collector must be tested under incident radiation more than 700 W/m^2. Data collection were made for inlet and outlet fluid temperatures, ambient temperature and incident radiation, respectively. Then, all the temperature data and radiation data were measured using K-type Thermocouples with TM 947SD Thermometer and a Solar Power Meter SPM 1116SD, respectively. The mass flow rate of the working fluid was regulated by using a valve at a constant flow rate of 0.02 kg/m^{2}s (EN 12975). The mass flow rate was applied constant for all the measurement tests performed in the current work. To vary inlet fluid temperatures during the test, electrical heaters were used. All measurement data were recorded every 10 seconds.

In the current work a simple model based on the energy balance for the useful heat power is presented in the Equation (1), Dufie et al. (2006):

$$Q_u = A_{abs}(\tau\alpha)K_\theta(\theta)R_s - A_{abs}U_L(T_{pm} - T_a) \quad (1)$$

The mean temperature of the absorber plate (T_{pm}) as shown in the Equation 1 is difficult to calculate since this temperature is a function of the collector design, the entering fluid conditions and the incident radiation. Furthermore, it is convenient to relate the performance of the solar collector to the temperature of the heat transfer fluid, as the plate temperature is usually not known.

In view of simplification purpose, the whole mass (the tube, absorber plate, cover and insulation of the collectors) can be represented by a single temperature that refers to the mean temperature of the working fluid (T_m). By rearrangging Equation 1, an efficiency factors of the collector F' is introduced to allow the use of the mean inlet fluid temperature (T_m) as presented in Equation 2:

$$Q_u = A_{abs}F'(\tau\alpha)_e K_\theta(\theta)R_s - A_{abs}F'U_L(T_m - T_a) \quad (2)$$

Since the tested solar collectors are performed perpendicular to solar simulator radiation, furthermore the function of $K_\theta(\theta)$ incident angle modifier can be eliminated and then Equation 2 can be rewritten as presented in the Equation 3:

$$Q_u = A_{abs}F'(\tau\alpha)_e R_s - A_{abs}F'U_L(T_m - T_a) \quad (3)$$

From the above equation, the Q_u as the useful heat power is determined by the following equation:

$$Q_u = \dot{m}\, c_p(T_m - T_a) \quad (4)$$

As stated in EN 12975, curve fitting and least square method can be implemented in order to calculate the performance of solar thermal collector. A number of such tests should be carried out for at least four different values of the fluid inlet temperature T_i and led to the collection of 16 experimental points. Computations were applied using Multiple Linear Regresion (MLR) method to further identify the collector parameters as reported by Amrizal et al. (2010,2012,2013).

4. Results and Discussion

Several thermal performance tests were conducted associated with different absorber materials and the same diameter of riser and header tubes. The solar thermal parameters as shown in Table 1 are zero loss efficiency $F'(\tau\alpha)_e$ and heat loss $F'U_L$ respectively.

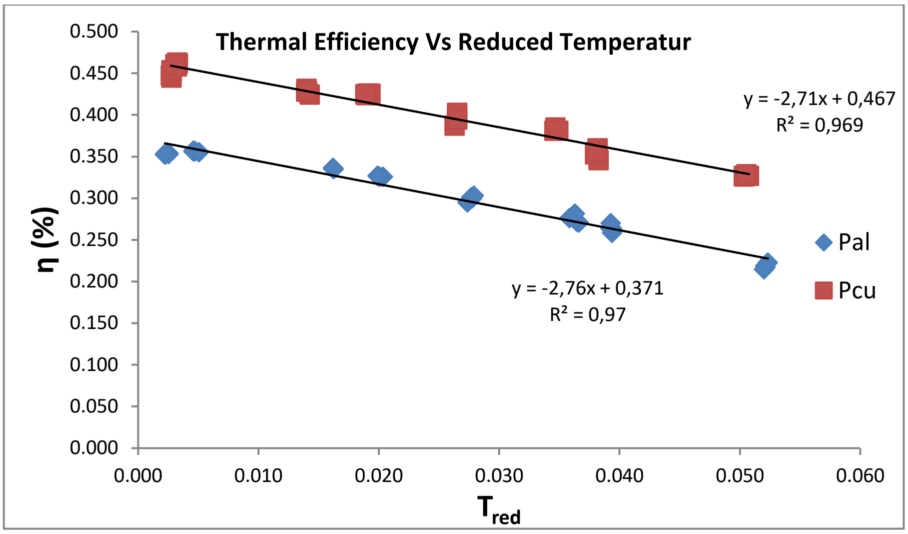

Fig. 2: The efficiency of the flat plate solar collector with different absorber materials

Table 1. Comparison between the two materials for price and thermal performance

Absorber Materials	**Price per m2 (IDR)***	**Zero Loss Efficiency $F'(\tau\alpha)_e$ (%)**	**Heat Loss ($F'U_L$) (W/m2 K)**
Cu	750.000,00	46,7	2.71
Al	55.000,00	37,1	2.76

*Price of materials based on the market in Bandar Lampung (Indonesian Currency-IDR)

Figure 2 presents variation of thermal efficiency against reduced temperature parameter ($T_{red} = \frac{(T_m - T_a)}{R_s}$) for different absorber materials. From Figure 2, it describes the effect of two absorber materials on thermal efficiency of solar collector. As shown in the Figure 2, it presents that at zero reduced temperature, the thermal efficiency levels of the solar collector is 46.7% for copper and 37.1 % for aluminum, respectively. Therefore, the copper as an absorber material has better thermal performance than the aluminum material. However, increasing the value of zero loss efficiency $F'(\tau\alpha)_e$ for copper is only 9.6 % compared to that of the aluminum material. This means that the copper material does not significantly increase the thermal efficiency of the solar collector in comparison with its thermal conductivity value. Meanwhile, heat losses $F'U_L$ parameters of the two materials are nearly the same as given in the Table 1.

Meanwhile, the experimental results were compared with those obtained by Ekremian et al. (2015) associated with conventional solar collector. There is a significant different between the thermal efficiency obtained from the two results. The zero loss efficiency (at zero reduced temperature) of the conventional solar collector is 80 % for copper material which is 33% higher than that of the present study. This may be affected by using the same diameter of header and risers, therefore the dwell time of the fluid circulation will be shorter than that of the conventional collector. Consequently, the working fluid also absorb the heat shorter than that of the conventional collector with the bigger header tubes.

Table 1 presents comparison between the two materials based on price and thermal performance of the solar collector. Concerning the absorber material, the price of copper is higher 14 times than the price of aluminum material. While, the difference of the thermal performance between the two material is only 10 %. Again, the price of materials is not proportional to increasing the thermal performance of the collectors. For this reason, the use of aluminum material as an absorber for solar thermal collector should decrease the material cost.

5. Conclusion

The different materials used as an absorber affect thermal efficiency of solar collectors. Comparing to the thermal performance of two absorber materials (between copper and aluminum) give different values of 10 % for zero loss efficiency and 0.05 W/m^2K for heat loss, respectively. These values are not proportional to the price difference between the two materials as shown in Table 2. While the price of copper is 14 times higher than the price of aluminum. Since the price of the two materials is large differences each others and it can be recommended the use of aluminum material is more suitable in terms of thermal performance and material cost. Regarding the use of the same geometry implemented in the present study, thermal performance decrease significantly compared to that of the conventional collector. This may be dwell time of the fluid circulation shorter than the dwell time of the conventional collector. The zero loss efficiency (at zero reduced temperature) of the present study is 33% lower than that of the conventional solar collector.

6. Acknowledgements

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7. Nomenclature

F'	collector efficiency factor	-
R	radiation	W/m^2
T	temperature	C
$\dot{m}$	mass flow rate	kg/s
Q	energy gain	W
k	thermal conductivity	W/mK
c	heat specific of fluid	kJ/kgK
U	overall heat loss coefficient	W/m^2K
A	area	m^2
Greek letter		
τ	transmissivity	-
α	absorptivity	-
θ	incident angle	deg
Subscript		
e	efficiency	
s	solar	
i	inlet	
o	outlet	
m	mean	
a	ambient	
u	useful	
p	pressure	
L	losses	
abs	absorber	

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