

THE EFFECT OF TUBE ARRANGEMENT ON A FLAT PLATE SOLAR WATER HEATER PERFORMANCE

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ABSTRACT

The function of the tube of a flat plate solar collector is to circulate the water from the tank to be heated in collector. The three possible arrangements are tube below of, tube between of and tube above of the flat absorber plate. This tube arrangement might cause different heat transfer mode and heat loss from collector. Thus, it might affect the performance of a flat plate solar water heater, i.e. the temperature difference of the water flowing at the inlet and outlet of the collector and its flow rate as well. A research is conducted to find out this effect.

Three models were developed to represent the three tube arrangements. From the experiment conducted on January – February 2008 in Surabaya, Indonesia, it is found that the tubes placed below of the flat plate are suitable for a cloudy and windy surrounding, tubes placed above of the flat plate are suitable for locations that are sunny and still air, and tubes placed between of the flat plate gives the best performance, i.e. the highest temperature of water stored in the tank (means highest flow rate) and the highest temperature difference of water flowing in and out of the collector.

KEY WORDS

Tube arrangement, flat plat solar collector, solar water heater.

1. Introduction

Indonesia is a tropical country laying in the equator. Therefore, in Indonesia the sun shines almost all the time in the whole year. This blessing shall be used as an alternative source to heat up fluids. The electromagnetic energy emitted by the sun is converted to be thermal energy in a solar collector.

One popular type of solar collector is a flat-plate collector. This collector is used in moderate working temperature. Thus, it is usually used for water heater, room heater and some drying process. It is simpler than a concentrating collector. According to Garg and Prakash [1], a flat-plat solar collector consists of two main parts, i.e. a flat plate absorbing the heat and tubes or passages of

the fluids. The plate absorbs most of the heat and transfer to the fluid flowing in passages or tubes. For a solar water heater, water is circulated from the insulated storage tank to the collector via the tubes. The top of the collector is covered with clear glass to trap the incoming electromagnetic waves reflected by the plate absorber. Cross section of a flat plat collector is shown in figure 1.

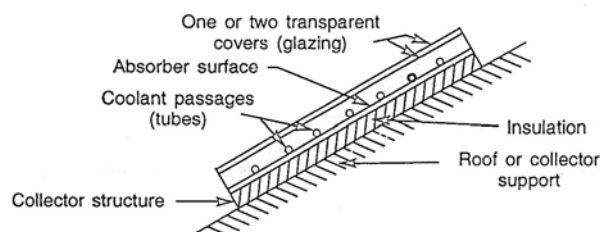


Figure 1. Cross section of a flat plat solar collector

Source: H.P. Garg & J. Prakash, *Solar Energy Fundamental and Applications* (New Delhi: Tata McGraw-Hill Publishing Company Limited, 1997) p. 47.

The temperature difference of the fluid flowing in and out of the collector shows the rate of heat radiation absorbed by the fluid as it flows across the collector. The flow rate of the fluid across the collector is hard to be measured. Yet, it is possible to measure the time needed to heat up the fluid in the storage tank. The longer the time needed, the smaller the flow rate of the fluid across the collector. These two are the collector's performance.

To design a flat-plate solar collector, some parameters need to be determined are its dimension, the tube spacing, the tube diameter, the thickness of the absorber plate, the insulation, the angle of collector to horizontal, the glass cover and the tube arrangement.

According to Duffie and Beckman [2], the general tube arrangements for a flat plate collector with a flat cover are as shown in figure 2. The difference of these arrangements is in expressing the collector efficiency factor, F' .

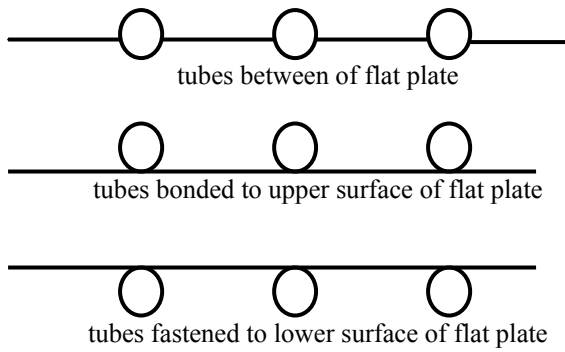


Figure 2. Tube arrangement and the plate absorber

The collector efficiency factors for each arrangement are:

$$F' = \frac{1}{\frac{WU_L}{\pi Dh_{f,i}} + \frac{W}{D + (W - D)F}} \quad \text{for figure 2.a}$$

$$F' = \frac{1}{\frac{WU_L}{\pi Dh_{f,i}} + \frac{1}{\frac{D}{W} + \frac{1}{\frac{WU_L}{C_{bond}} + \frac{W}{(W - D)F}}}} \quad \text{for figure 2.b}$$

$$F' = \frac{1}{\frac{WU_L}{\pi Dh_{f,i}} + \frac{WU_L}{C_{bond}} + \frac{W}{D + (W - D)F}} \quad \text{for figure 2.c}$$

where W is the tube spacing, U_L is overall loss coefficient, D is tube diameter, $h_{f,i}$ is heat transfer coefficient inside the tubes, C_{bond} is the bond conductance which depends on the bond thermal conductivity, and F is the fin efficiency.

When the bond conductance is very large, as usually assumed especially when copper are used for the tubes and plate, then the F' will have the same expression for the three arrangements. Thus, a research to find the effect of the arrangement is necessary.

The hypothesis for the research as followed: The tubes arranged above of the plate or between of the plate, as in figure 2.a and 2.b, will receive heat radiation directly from the sun. While the tube arranged below of the plate, as in figure 2.c get heat conduction transferred from the plate. The heat absorbed by the working fluid in tubes placed between of and above of the plate is much more than in tubes placed below of the plate. On the other hand, the tubes below of the plate emit less heat loss caused by convection to the surrounding. It is important and interesting to find out whether the larger absorbed area or the heat loss to surrounding that is more dominant for a flat-plate solar water heater.

Thus, the purpose of the research is to find out the effect of the tube arrangement to the temperature difference of the water flowing at the inlet and outlet of the collector and its flow rate as well. This result will be useful to improve a flat-plate solar water heater design.

Some previous works in Indonesia are adopted in this research. Kiem San [3] affirmed that the best result was when he used the 0.5-mm plate with 103-mm tube distance.

Purnawarman [4] declared that the best glass cover was 3-mm clear glass used with 2-cm space between the glass and the plate. The glass cover is used to shield the absorber plate and tubes from the surroundings and to trap the radiation reflected by the plate to create the greenhouse effect inside the collector.

The angle and orientation of the solar collector installed in certain location affect the collector performance. From his research, Mintorogo [5] said that in Surabaya which is located at 7°17'-21° South Latitude, the collector will receive the highest average solar radiation when the collector is installed with angels tilted 30 degrees and orientation to the north.

2. Research Methodology

The research was started with designing three model collectors for heating water using the previous works. The models are made of same material and dimension with three tube arrangements as shown in figure 2. The difference was only on the tube arrangement. Having three models, the experiment could be conducted simultaneously.

2.1 Design of the model collector

From the previous works, the model was designed as in figure 3 with following condition:

- The collector box is made of 2-cm wood.
- The insulation used in the bottom of collector is 4-mm Styrofoam and on the outside of the storage tank is 25-mm glass wool covered with aluminum foil.
- The glass cover on the top of the collector is made of 3-mm clear glass and placed 2 cm above the plate.
- The water to be heated is stored in a 1.5-litre plastic tank.
- The tubes are made of copper pipe which diameter is 0.5 inches.
- The absorber plate is made of 0.5-mm copper plate with tubes spacing is 103 mm.

The collector's plan of view is shown in figure 4.

Then, the three models were built as seen in figure 5.

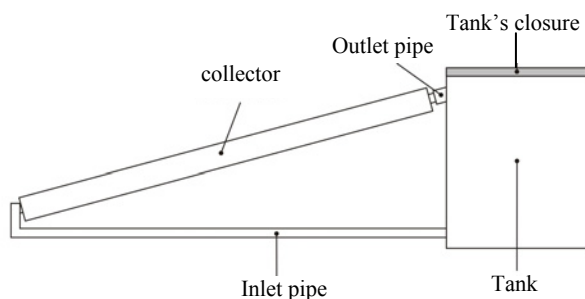


Figure 3. The model of collector

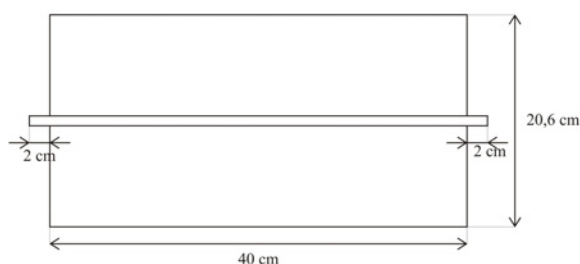


Figure 4. Plan of view the model collector

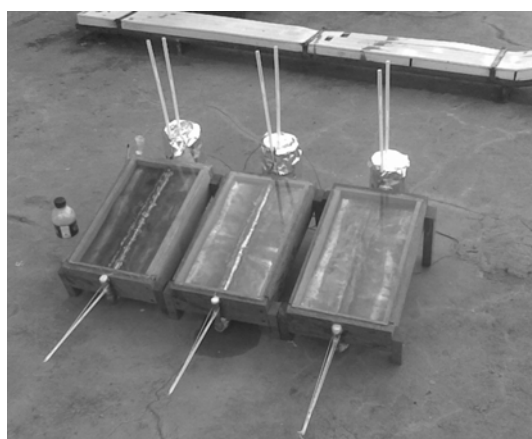


Figure 5. The photograph of three models.

2.2 The experiment

The experiments were conducted on 31 January, 25 February, 27 February, and 28 February, 2008 at Petra Christian University campus on Surabaya, Indonesia. For the three models as in figure 5, the data taken every 30 minutes were:

- The temperature of ambient air and its wind velocity,
- The temperature of the absorber plate,
- The temperature of water at the inlet and outlet pipes,
- The temperature of water in the storage tank.

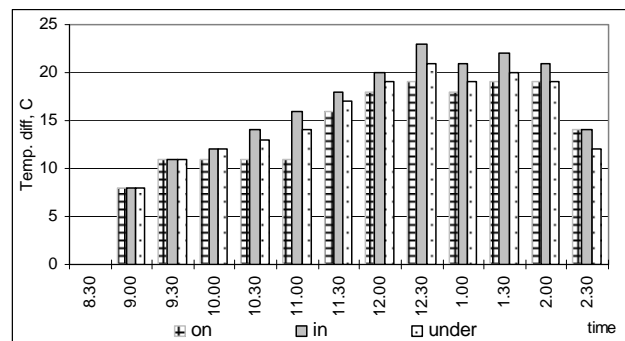
The data is written in the table. Actually, the table includes all three tube arrangements. Since the column in this paper is too narrow, the table 1 only shows for tube placed 'on' the flat plate.

Table 1
Data for tube placed 'on' above of flat plate

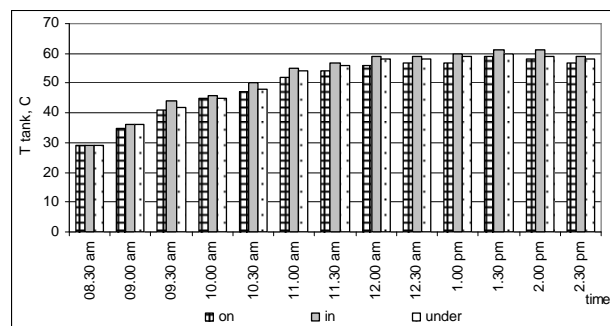
time	Tube 'on' plate ($^{\circ}\text{C}$)				T_{∞} $^{\circ}\text{C}$	Wind velocity (m/s)	Weather
	Tank	In	Out	Plate			
8.30							Clear/cloudy
9.00							
...							
14.30							

3. The result and analysis

The temperature difference of water at inlet and outlet of collector resulted from experiment done on 31 January 2008 is shown in figure 6.a and the temperature of water in the storage tank is shown in figure 6.b. The ambient temperature when the experiment was conducted was 29°C in the morning and changed to reach 34°C in 12.30 and decreased to 31°C at 2.30 pm. The wind's velocity was between 0.3 m/s – 2.1 m/s. On the day of the experiment, the wind blew harder in the morning.



The temperature difference of water at inlet and outlet of collector



The temperature of water in the tank

Figure 6. The result of experiment done on 31 January 2008

The experiments done on the other dates showed the same phenomenon as happened on 31 January 2008. So, the result shown in figure 6 could represent the result on other days.

In a few words, the results are:

- The highest temperature difference of water flowing in and out of the collector is found in tubes placed between of the plate as shown in figure 2.a.
- The highest temperature of water in the storage tank is found in collector which tubes placed between of the plate as well.

From figure 6.a, it was found that the temperature difference of the water as it flows in and out of the collector at 8.30am was zero and it increased until reach a maximum value but then decreased. The experiment was stopped at 2.30 pm because the sky was getting to be cloudy. In Indonesia, January – February is wet season. The temperature difference at 12.30 pm could reach 23C° for collector with tubes placed ‘in’ (= between of) the plate while the other tube arrangements only reach 19C° and 21C° for ‘on’ (= above of) the plate and ‘under’ (= below of) the plate, respectively. Thus, tubes placed between of the plate gave a better temperature difference.

From figure 6.b, it was found that for all arrangements the temperature of water stored in the tank reached 50°C at 11am. Thus, the collector heated 1.5-litre water in 2.5 hours though it was cloudy. From the chart, it is obvious that the tubes placed ‘in’ the plate made water stored in the tank get higher temperature than the other tube’s arrangements.

Tubes placed between of the plate, as in figure 2.a, gave higher temperature difference of water flowing in it and higher temperature of water stored in the tank than the other arrangement. Why could this happen? The explanations are as followed.

Water flowing inside the tubes placed ‘under’ the plate, as shown in figure 2.c got heat transferred only by conduction from the plate which behaves as fin. Thus, the heat received by the water in this arrangement was less than the other arrangements. Yet, the tube below of the plate made water gives least heat loss to surrounding. This could be seen from chart in figure 6.a. The temperature difference of water flowing in tubes ‘under’ the plate was higher than tubes ‘on’ (= above of) the plate in the morning when the wind blew harder (means more heat loss to surrounding) and the sky was cloudy (means less solar radiant received). So, when solar radiation was low and the wind blows fast, tubes placed below of the plate gives better temperature difference than tubes placed above of the plate.

The water flowing inside the tubes placed ‘on’ and ‘in’ the plate receives heat more by conduction through the plate, by radiation from the sun, and by convection of the air trapped inside the collector. Thus, collectors which tubes placed above of and between of the plate get more heat. There is a temperature difference between the surrounding and the collector, including the water in the tube. This temperature difference drives heat loss from collector to the surrounding, even though glass cover is put on the top to restrict the heat loss. The tubes placed ‘on’ the plate are bare tubes compared to the ones ‘under’

the plate that are enclosed with insulation. So, when the surrounding is colder or cloudy and the wind blow harder, the tubes placed ‘on’ the plate gives the lowest temperature difference. Yet, the tubes placed ‘in’ the plate emit moderate heat loss and get more heat.

The temperature difference of water affects its circulation from the collector to the storage tank. Water flows from the tank to the collector by gravity and moves up to the tank by free convection. In free convection, fluid motion is due to buoyancy force which depends on the fluid density gradient. The higher the temperature difference, the higher the density gradient and the easier for water to move up back to the tank. Thus, it means the higher the flow rate. The flow rate of water flowing in the collector could not be measured in this experiment. Yet, the temperature of the water in the tank could be a parameter showing the flow rate of the water. When the temperature of the water in the tank rises faster and higher, it indicates that the water flow rate in collector is high.

4. Conclusion

From the experiments conducted on three flat plate solar water heater models, the conclusions are:

- Tubes placed below of the flat plate are suitable for a cloudy and windy surrounding.
- Tubes placed above of the flat plate are suitable for locations that are sunny and still air.
- Tubes placed between of the flat plate gives the best performance, i.e. the highest temperature of water stored in the tank (means highest flow rate) and the highest temperature difference of water flowing in and out of the collector. This arrangement is suitable for any weather.

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