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Experimental Study on Effect of Reflector Bed Designs Heated by Direct Solar Radiation for Hot Water Storage System

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Abstract* – The aim of this research is to investigate the performance of different reflector bed design heated by direct solar radiation for a water storage system that can be used in accordance with the climate of Malaysia country. In general, this research is related to thermal efficient water heating system, specifically to improve the water heating system that exists nowadays. The focus is to improve the thermal efficiency by adding different absorber bed designs. Based on experimental results shown the temperature of the water increases more efficient and faster by using the curve reflector bed.

Keywords – Reflector bed designs, direct solar radiation, water storage, thermal efficient.

I. INTRODUCTION

The basic unit in a solar hot water system is solar thermal collector or also known as reflector bed. Solar energy can be trapped more efficiently dependent upon the type of solar collectors used. Each type of solar thermal collector is designed to absorb the shorter wavelengths of light which are received from the sun (0.3-2µm in length) but prevent heat wavelengths (2-10µm in length) from escaping by utilizing the greenhouse effect then delivers radiant energy either directly or indirectly to a hot water storage tank. There are many inventors that came up with their design to improve the efficiency of the thermal water heater [1-3]. This is because the opportunities of this technology to grow are wide open. The source for this technology is the sun, which is a utopian fuel, limitless, ubiquitous and clean. These are the main causes that attracted many researchers to investigate and develop this technology wider. There are many researchers tried to optimize the usage of solar energy such as Lindblad et al., [4], Hammer et al., [5], Reim et al., [6] and Trillat-Berdal et al., [7].

Flat plate collectors have been extensively studied by Hottel and Woertz [8], Bliss [9], Nahar and Garg [10], Francken [11]. Flat plate collectors are either corrugated Mathur et al., [12], bond duct, Patil [13] or tube-in-plate type [14] with different clamping arrangements Yellot and Sobotka [15], Gupta and Garg [16], Bliss [9]. The performance of the flat plate collector depends upon various design parameters, such as the number of covers, type and thickness of glazing Whillier [17], the type of coating on the collector plate Nahar and Garg [18], spacing between the collector and the inner glass Nahar and Garg [10], antireflecting coating on cover glass Hsieh and Coldeway [19].

Besides, other various design such as heat mirror coating on the inner glass Winegarner [20], an evacuated space between the collector and the inner glass Simon [21], the arresting of convective movement between the collector plate and the inner glass by using transparent insulation material Hollands [22], Nahar et al., [23] and the type of insulation used Whillier and Saluja [24], all of which are responsible for the performance of a flat plate collector. There are several other operational parameters, such as the mass flow rate of fluid, solar radiation, inlet temperature, ambient temperature, wind speed, sky conditions, dust deposition on glass cover Nahar and Gupta [25], which also affect the collector performance

The evacuated-tube collectors is referred to the absorber strip is located in an evacuated and pressure proof glass tube. The heat transfer fluid flows through the absorber directly in a U-tube or in countercurrent in a tube-in-tube system. Several single tubes, serially interconnected, or tubes connected to each other via manifold, make up the solar collector. A heat pipe collector incorporates a special fluid which begins to vaporize even at low temperatures. The steam rises in the individual heat pipes and warms up the carrier fluid in the main pipe by means of a heat exchanger. The condensed liquid then flows back into the base of the heat pipe [26]. The pipes must be angled at a specific degree above horizontal so that the process of vaporizing and condensing functions. There are two types of collector connection to the solar circulation system. Either the heat exchanger extends directly into the manifold in wet connection or it is connected to the manifold by a heat-conducting material at dry connection. A dry connection allows to exchange individual tubes without emptying the entire system of its fluid. Evacuated tubes offer the advantage that they work efficiently with high absorber temperatures and with low radiation [27]. Higher temperatures also may be obtained for applications such as hot water heating, steam production, and air conditioning.

The concentrators collector This article is not included in your organization's subscription. However, you may be able to access this article under your organization's agreement with Elsevi is a new principle for collecting and concentrating solar energy, the ideal cylindrical light collector, has been invented. This development has its origins in detecting Cherenkov radiation in high energy physics experiments [28]. In its present form, the collector is a trough like reflecting wall light channel of a specific shape which concentrates radiant energy by the maximum amount allowed by phase space conservation as mentioned by Winston [29].

The principle behind heat pipe's operation is actually very simple. The heat pipe is hollow with the space inside evacuated, much the same as the solar tube. In this case insulation is not the goal, but rather to alter the state of the liquid inside. Inside the heat pipe is a small quantity of purified water and some special additives. At sea level water boils at 100 oC, but if you climb to the top of a mountain the boiling temperature will be less that 100oC. This is due to the difference in air pressure.

As known, the source from the sun light is limitless and clean but in order to use this kind of source, there are many optimizations needed to be done on the system to make it more efficient. The theory on transferring the heat from the sun light is well known and is usually a famous topic to be discussed about. This is clearly proven when researchers such as Velraj et al., [30], Mettawee and Assassa [31] and Jaisankar et al., [32] attempted to improve the efficiency of the solar water heating system. The less energy usage for the water heater becomes the main reason for many researchers to keep improving the system in order to replace conventional water heater [33-35]. This is because the energy that is required to heat the water is higher than cooling the water. Therefore, by using solar as an energy source for heating the water, the use of electricity for the heating process can be replaced.

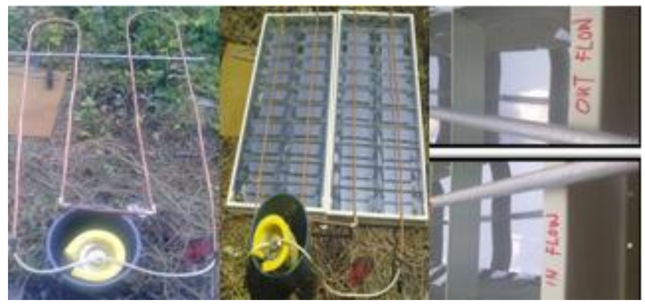
Thus, the thermal collector bed for hot water system needs to be redesigned in order to improve the efficiency of the thermal conductivity. In this research, an appropriate thermal collector bed is proposed to improve the thermal efficiency of heating pipe by considering Malaysia weather conditions.

II. MATERIALS, METHOD & PROCEDURES

The experiments conducted using three different methods of design in the thermal collector bed for water storage system. Those three methods will be name it as method I, II and III.

The first method is set up by using a copper heating pipe without the reflector bed as shown in Figure 1 (a). The second method is using copper heating pipe with the flat reflector bed on heating pipe as depicted in Figure 1 (b). The Figure 1 (c) shows the third method is using copper heating pipe with the curve reflector.

The experimental setup consists of two dimensionally similar solar collectors set same location and can be tilted to a predetermined angle through a mechanical system. It consists of two modules, the collector module and the control system module. The collector module consists of the absorber, glazing reflector, insulation, back and front casing and copper water heating pipe to assemble these components. The control system module consists of a water pump, of maximum up to 450 L/h, 6.5 watt, control system, heat sensor and two temperature views (Environment & water tank thermometer).



(a) (b) (c)

Fig. 1. Schematic experiment setup for methods (a) I, (b) II, (c) III.

The measured variables in this experiment include the inlet and outlet air temperature, ambient temperature and total energy transfer into water tank. The collectors are instrumented with two unit thermometer sensor for measuring the inlet and outlet temperatures of the collector exit point. The ambient temperature is measured using an infrared thermometer around the absorbed bed from direct sunlight. The same facility design of water flow and size heating pipe calibrated to assure accurate comparison. The thermometer sensor is amplified the final result of the total heat in water.

All the copper pattern collector has diameter 12 mm of flow pipe and total length of the flow design leading to a flow passage area is 700 cm. Normal mirror is used as the reflector for both methods of collectors (flat and curve). But in this case study, the reflector of absorber rests on a stainless steel flat plate (high reflection surface) of the collector, whereas the stainless steel flat plate is lifted above the casing supports to create and fix the flow design of water. Heat insulation is provided to prevent heat loss of the water temperature as well as into the tank. Closed loop water inlets and outlets are used to distribute the flowing water uniformly throughout the collector and keep warm in the tank. Design data for the three methods of absorber bed are shown in Table 1.

The experiments are conducted between one hour before and two hours after the solar noon (12.00 pm). Each 15 minutes will read and record the temperature at inlet, outlet and tank. The effect of incident angle on the thermal performance is negligible since data are recorded in near normal incident. The procedures stated in the ASHRAE standard are followed to obtain a steady state condition of the collector [36].

Table 1. Design data for three methods.

Details	Method I	Method II	Method III
Heating pipe material	Copper	Copper	Copper
Diameter of heating pipe	12 mm	12 mm	14 mm
Thickness of heating pipe	0.5 mm	0.5 mm	1.0 mm
Total length of water flow	690 cm ≤ 700 cm	690 cm ≤ 700 cm	690 cm ≤ 700 cm
Reflector Base	No	Yes	Yes
Collector tilt	≠10°	≠10°	≠10°
Tank capacity	2 Liter	2 Liter	2 Liter
Tank insulation	Foam rubber	Foam rubber	Foam rubber
Qmax of water pump	450 l/h	450 l/h	450 l/h

The collectors are warmed up and run at least 30 minuts before tests are conducted. The collector slope is adjusted to ≠10 degree, which is considered suitable for the geographical location of Malaysia. Before starting the performance tests, the collectors with their respective settings are tested for leaks under the operating pressure. Figure 2 shows the complete system design, which is changer only at plate refector for all the testing methods.

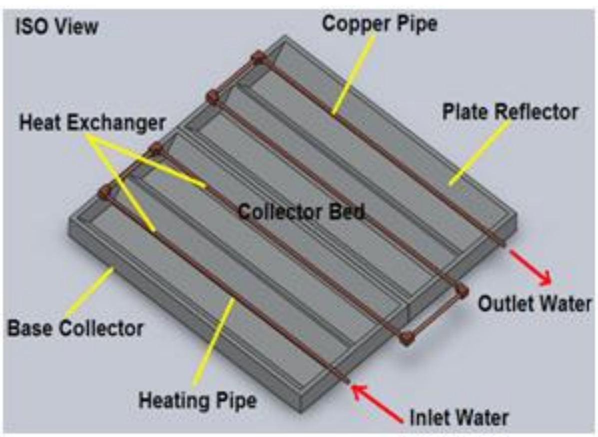


Fig. 2. The complete system design of the experimental.

III. RESULTS & DISCUSSION

In Method I, only one independent set of experiments is conducted to investigate the performance totalheatof both inlet and outlet point of collectors. Result from the data shown that temperature of inflow water always higher then outflow temperature.

Figure 3 shows the inflow and outflow temperature based on time for Method I. The temperature of outflow always lower than inflow water is because the effect of the ambient temperature during the experimentation. In this experiment, the average of ambient temperature is ±29°C. The temperatures between the heating pipe and ambient temperature are driving forces for heat transfer. The larger amount of temperature difference, the higher is the rate of heat transfer. Besides that,another issue of outflow temperature always lower than inflow temperature because the heat loss at copper heating pipe. Without the reflector at absorber bed, the heat loss from copper heat pipe is higher. The result of experiment clearly shows that the experiment undergone without a reflector it is less efficient for the heat to transfer into the water.

The second experiment method is using copper heating pipe with the flat reflector on heating pipe. Figure 4 shows the inflow and outflow of temperature based on time for method II. The temperatures of inflow and outflow show similarities rate to certain extend. The performance of the absorber bed is higher when the average ambient temperature is same with Method I (±29°C). It shows that the reflector of absorber bed can minimized the heat loss between the heating pipe and ambient temperature. The concept of concentrating solar energy is provenworking in this experimentation. The reflector can maintain the inlet and outlet temperature constant very well if compare with Method I.

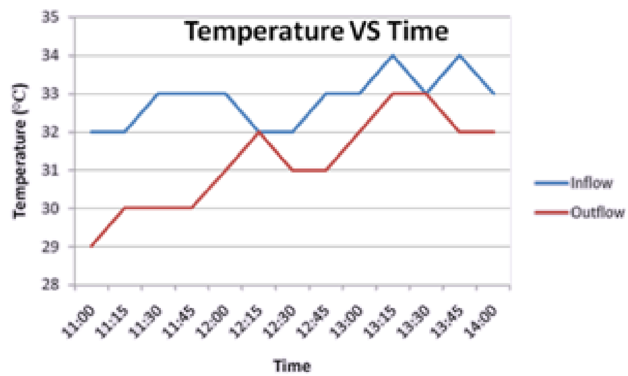


Fig. 3. Result for method I

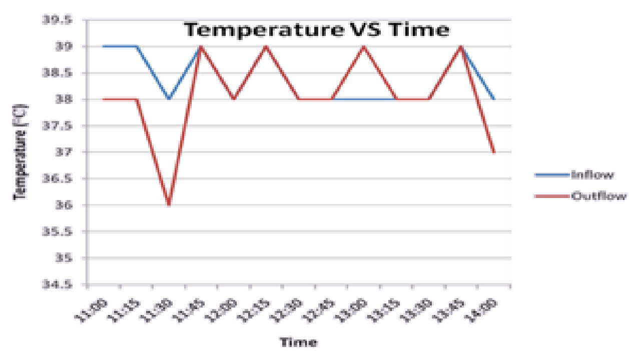


Fig. 4. Result for method II

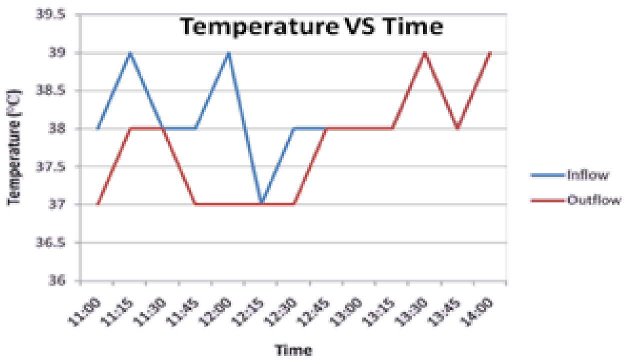


Fig. 5. Result for method III

Figure 5 shows the inflow and outflow temperature based on time for Method III. Generally, thetemperature of inflow and outflow in Method III is similar with Method II. The result of Method III is showing thesame performance with Method II when the average of ambient temperature same with Method I (±29°C). In theoretical, the thermal conductivity of copper heating pipe is 401W/m°C

From experiment of method I, II and III, the results have shown thedifferencesin temperature in the storage tank. Figure 6 shows that the thermal efficiency increasedgraduallyin storage tank in three hours. In Method I, the increase of the temperature of water in storage tank increase to its maximum point which is about 36°C. At the same time, the temperature of Method II and III reached about 46°C. The existence of the reflector significantly influenced the heat level in the storage tank, because it even though the heat is dissipated from the heating pipe, but the reflector regenerate heat for the heating pipe by focusing the ray of sun onto the pipe thus reheating it to the maximum temperature yet sustaining the temperature of water in the pipe [38].

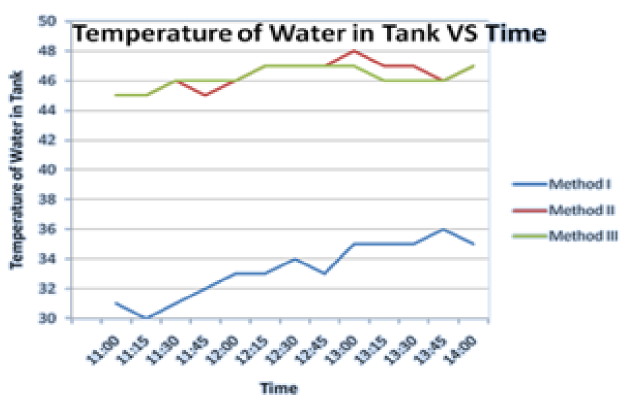


Fig. 6. Average water temperature in storage tank for three methods.

Three different methods with independent sets of experiments are conducted to investigate the performance of the total heat transfer into water. The first experiment of method I is set up by using copper heating pipe without the reflector. The second experiment of method II is by using copper heating pipe with the flat reflector on heating pipe. The third experiment method is using copper heating pipe with reflector.

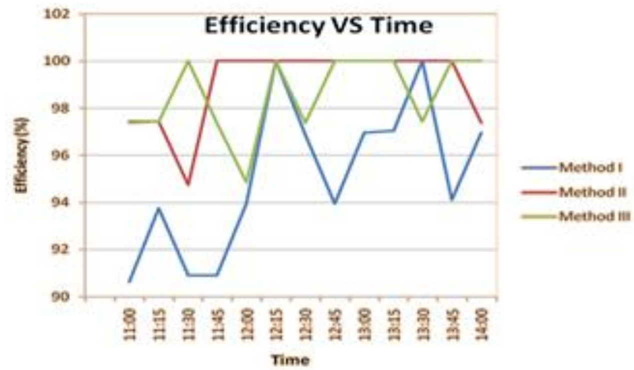


Fig. 7. Efficiency method for three methods.

Figure 7 shows the efficiency of the inlet and outlet temperature as well as the efficiency of the performance for each method of collector. The graph clearly shows that with the reflector it is more efficient than without the reflection plate over the entire range of mass flow rate considered [37]. This is because the efficiency of Method II and III is very high, average of efficiency performance is 99% and 98.60%. The lowest range of efficiency among the three methods is the Method I. The average efficiency of Method I only achieved 95.08%.

IV. SUMMARY

The purpose of the experiment undergone is to test and verify the performance of the absorber bed with the different method, which is method I, II and III. By instilling the principle of concentrators collector and evacuated-tube in the heating pipe application, it is shown successive thus allowing this novel design to apply for a patent of solar collector.

Experimental results have shown that this new concept have 4 % improvement in the thermal efficiency and an increase of about ±10°C temperature in the storage tank. Generally, the Method III absorber has a lower overall loss coefficient compared to the other considered types. This novel design of the copper collector lends itself as an economical and efficient alternative for known solar collectors.

The important of this research is not only cost saving, but also a part of green project to save mother earth by focusing on the environmental issue, due to the inclination of catastrophic occurrence.

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