Effect of a Pipe Number on The Heat Transfer Rate
For a Granit Stone Absorber Solar Collector

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Abstract

As the fossil energy has been getting depletion, it is important to utilize alternative energies such as solar energy. An equipment that can be used for capturing and converting solar energy is solar collector. Two identical collectors used in this study were placed facing to the North with an inclination angle of 15°. The collector dimension was 0.8 m x 1 m x 0.05 m. One collector contained 5 parallel pipes and the other contained 7 parallel pipes. The water used in the test was flowed naturally due to the gravity force from a higher tank and was adjusted using a valve fitted at the end of the collector. The water flow rates employed were 200, 250 and 300 cc/minutes and measured using a volume meter and a stop watch. The results showed that the energy coming into the collector, energy absorbed by the absorber and water, increased with an increase in the observation time and reached the peak value at about 2.30 pm. After that, they decreased. The effect of the pipe number is significant and the performance of the collector containing 7 pipes is better than that containing 5 pipes.

Keywords: solar collector, stone granite absorber, collector performance.

INTRODUCTION

Energy is something that is always needed for human survival . In all conditions human requires or uses energy . However, most human life still depends on fossil energy. Fossil energy such as petroleum and coal is an energy source that cannot be renewed. Therefore, efforts to conserve energy and utilize alternative energy are required. One of the alternative energies is solar energy.

Solar energy is one of the renewable energies that is cheap and free and it has high potencies to be used. The use of solar energy in Indonesia is really suitable because Indonesia is a region that locates under the equator and between 6° NL and 11° SL. In this position, Indonesia has a tropical weather and sun rays along the day spread uniformly. Therefore, Indonesia has solar energy with a radiation intensity of about 1000 W/m² or almost 4.8 kWh/m² a day, Rahardjo and Fitrianan [1].

To increase the effectiveness of solar energy use, a device called solar collector can be utilized. This device can be used for converting solar energy to be useful energy. One type of this device is flat plate solar collector. In general, from the view point of capturing the solar energy, collectors are grouped into two types: (i) concentrating collector and (ii) non-concentrating collector. For the non-concentrating collector, the absorber area is the same as the aperture, Lunde [2].

The collectors used in this study are non-concentrating collectors, they are flat plate collectors with granite stone absorbers. Generally, solar collectors use metallic absorbers to absorb the solar heat. However, in this paper, the authors wanted to know if the granite stone could be used as an absorber. So the main objective of this study is not to compare the performance of the metallic absorber to the granite stone absorber, but just to know the performance of the granite stone as an absorber of a flat plate solar collector. The previous study conducted by Jatmiko [3] reported that granite stone absorber gave better performances than sand absorber. The differences between the current study and the study of Jatmiko [3] are bigger dimension of the collector and the number of the pipe, while in Jatmiko [3], they used pipes arranged in a serpentine form.

When the sun rays falls down on the absorber of a collector, part of the sun energy is reflected to the ambient and other part absorbed by the absorber and converted into useful energy.

Heat energy absorbed by the absorber is transferred to the fluid flowing inside the pipes mounted in the absorber. Finally, the heat can be used for other purposes, Permana and Nasbey [4].

The main components of the flat plate collector as also mentioned in Permana dan Nasbey [4] are:
1. Cover. This component is functioned to reduce the heat lost from the top of the absorber in convection ways.
2. Absorber. This component is used for absorbing the solar heat from the solar radiation.
3. Pipe. This is to transfer the heat from the absorber to the working fluid.
4. Isolator (insulation). This component is employed to minimize the heat loss though the walls in conduction manners.

FACILITY AND EXPERIMENTAL SETUP

This study uses two prototypes of the flat plate collector with absorbers made of granite stone. All variables were recorded directly unless some calculated variables.

Tools and Materials

Tools or instruments used were:

1. Thermocouple. Thermocouples used were K type with measuring ranges ranging from -200˚ to +1200˚C. These thermocouples were used to know the temperatures of the glass cover, absorber, collector walls, ambient, inlet and outlet of the water.
2. Glass volume meter and stopwatch. These tools were utilized for measuring the volumetric rate of the water.
3. Compass. A compass was used to determine the North-South direction. This was to know the position of the sun so that the collectors could be placed correctly.
4. Pump. The pump was used for raising the water from the well to the top reservoir.
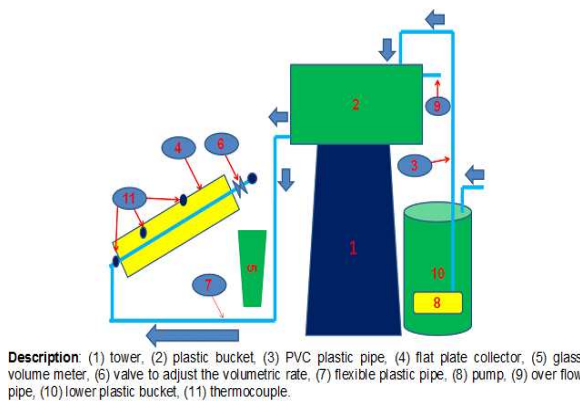

Description: (1) tower, (2) plastic bucket, (3) PVC plastic pipe, (4) flat plate collector, (5) glass volume meter, (6) valve to adjust the volumetric rate, (7) flexible plastic pipe, (8) pump, (9) over flow pipe, (10) lower plastic bucket, (11) thermocouple.

Figure 1. Schematic diagram of the research apparatus

Materials employed in this study were granite stone, water, sterofoam, collector frame, plastic buckets, copper pipes, flexible plastic pipes.

The schematic diagram of the research is shown in figure 1 comprising a tower, plastic buckets, a flexible plastic pipe, flat plate collectors, a glass volume meter, valves, a pump, an over flow pipe and thermocouples. The water flowed from the upper plastic bucket (2) through the flexible plastic pipe (7). At the collector entrance and exit, the temperature of water was measured. The water received the heat from the absorber/pipe. Measuring the volumetric rate of the water was performed at the outlet of the collector using the glass volume meter and the stopwatch. Meanwhile, the test section construction is presented in figure 2.

All temperatures were measured using calibrated type K thermocouples with an uncertainty of ± 0,5°C. The volumetric rates used were 200, 250 and 300 cc/minute measured using the glass volume meter and stopwatch.

Description:
1. Wood wall.
2. Copper pipes.
3. Granite stone absorber.
4. Glass cover.
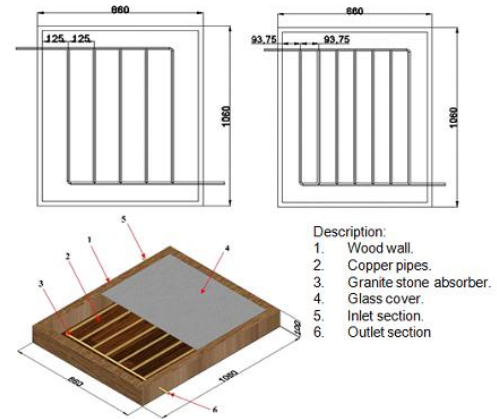5. Inlet section.
6. Outlet section

Figure 2. Flat plate solar collector construction

Data Reduction

Equations used to process the data consist of conduction, convection, radiation equations and Newton Law of cooling which can be obtained in Holman [5]:

$$q_{use} = \dot{m} c_p \left(T_o - T_i \right) \qquad (1)$$

Where q_{use} is the useful energy, c_p is the specific heat which can be attained in the fluid property table based on the bulk temperature $\left(T_i + T_o \right)/2$, $\dot{m}$ represents the mass flow rate of the working fluid which can be predicted using equation (2).

$$\dot{m} = \rho A V \qquad (2)$$

Where ρ is the fluid density, A is the cross sectional area, V is the mean fluid velocity inside the duct.

Heat received by the collector, q_i, can be estimated as:

$$q_i = I_T A_c \qquad (3)$$

Where I_T is the energy intensity of the solar radiation which can be detected using a pyranometer and A_c is the area of the collector absorber or aperture, see Holman [5]. The heat loss to the ambient, q_{loss}, is determined as:

$$q_{loss} = q_i - q_{use} \qquad (4)$$

One indicator representing the performance of the collector is a collector efficiency which is defined as a comparison between the useful energy and the heat coming and given by:

$$\eta = \frac{q_{use}}{q_{in}} \qquad (5)$$

lines indicating the useful energy are touching each other for both collectors (5 pipes and 7 pipes). This phenomenon occurs at all the tested volumetric rates. If they are calculated using a percentage of the useful energy deviation, their difference is still very small. For example, at the volumetric flow rate of 200 cc/minute, their deviation is only 5,87%, at the
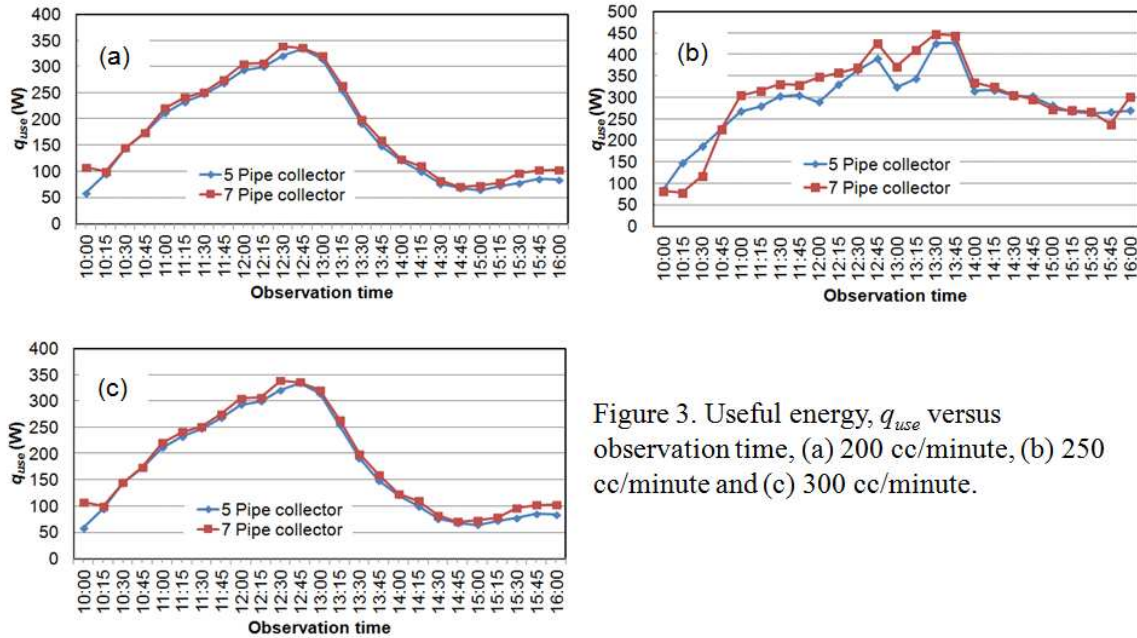

Figure 3. Useful energy, q_{use} versus observation time, (a) 200 cc/minute, (b) 250 cc/minute and (c) 300 cc/minute.

RESULTS AND DISCUSSIONS

Using equation (1) results in calculated useful energy data, q_{use}, which are presented in figure 3. The data were obtained from the experiments at the volumetric rates of 200, 250 and 300 cc/minute. In figure 3, it is clear that effect of the pipe number on

250 cc/minute, it is 4,1% and at the 300 cc/minute the deviation is about 2,5%, see figure 4. Based on the acceptable error theory written by Adebayo and Osmond [6], Sommer and Kochsiek [7], the deviations here are less than 10%, therefore, the deviations can be negligible. In another word, the
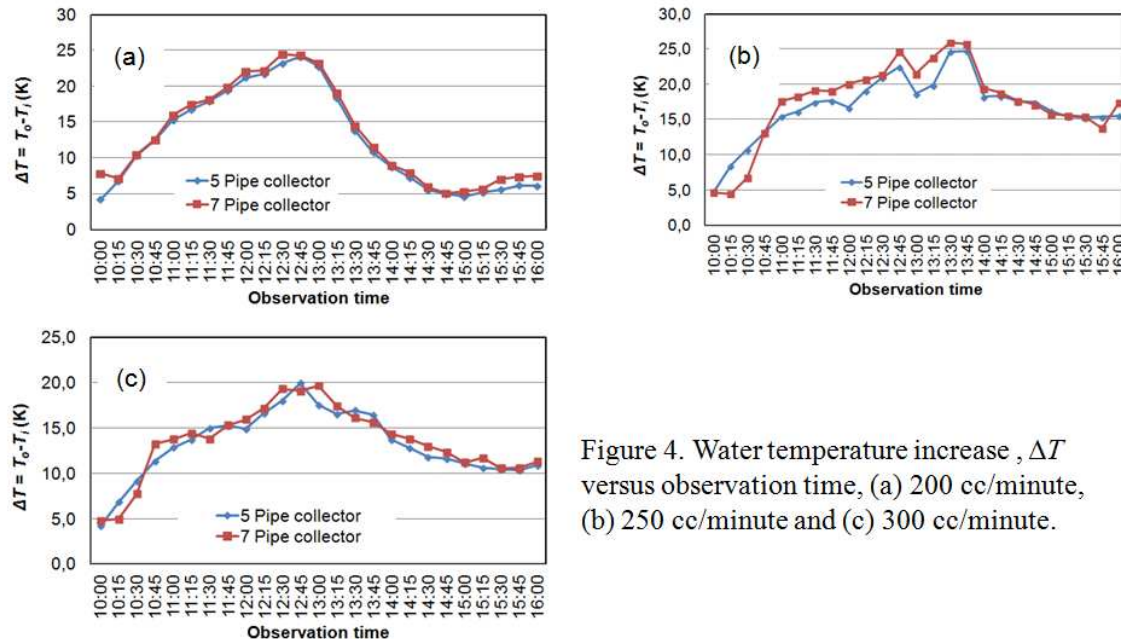

Figure 4. Water temperature increase, ΔT versus observation time, (a) 200 cc/minute, (b) 250 cc/minute and (c) 300 cc/minute.

the heat transfer rate is insignificant because the

deviations do not represent the effect of the pipe number on the heat transfer rate. One of the causes of this phenomenon is due to the same collector area, so that the energy received by the absorber is the same, consequently energy absorbed the water is also the same. Of course, there is a difference of the pipe heat transfer area for 5 pipe and 7 pipe collectors, however, the pipe heat transfer is to small compared to the heat transfer area of the collector, hence, the difference of the pipe heat transfer area is not enough to make significantly deviations. Therefore, the effect of the pipe number on the heat transfer rate is insignificant. Similarly, from the view point of the useful energy, see figure 4, the number of the pipe does not show different useful energy. Nevertheless, in figure 3, It seems that the useful energy for both 5 pipe and 7 pipe collectors is higher at the volumetric rate of 250 cc/minute. This was due to the different solar radiation energy received by the collectors. The three different volumetric rates were tested on the different days, when the 250 cc/minute was being tested the solar radiation energy was higher, consequently at the 250 cc/minute the useful energy is higher than those at the other two volumetric rates.

Another result relating to the useful energy is the water temperature increase. The increase of the water temperature is presented in figure 4. From the figure, it can be seen that the increase of the water temperature for the two solar collectors at the same volumetric rate is not significant. This is one of the factors that causes no different useful energy for both collector. The useful energy is only a function of the water temperature if the specific heat and the mass flow rate is the same. Therefore, the graph of the useful energy trend (figure 3) is almost the same as the graph of the water temperature increase (figure 4).

Absorber temperatures are important thing in the solar water heater. They relate the heat loss to the ambient. The higher absorber temperature results in the higher heat loss and the lower useful energy. The absorber temperatures obtained from the experiments are presented in figure 5.
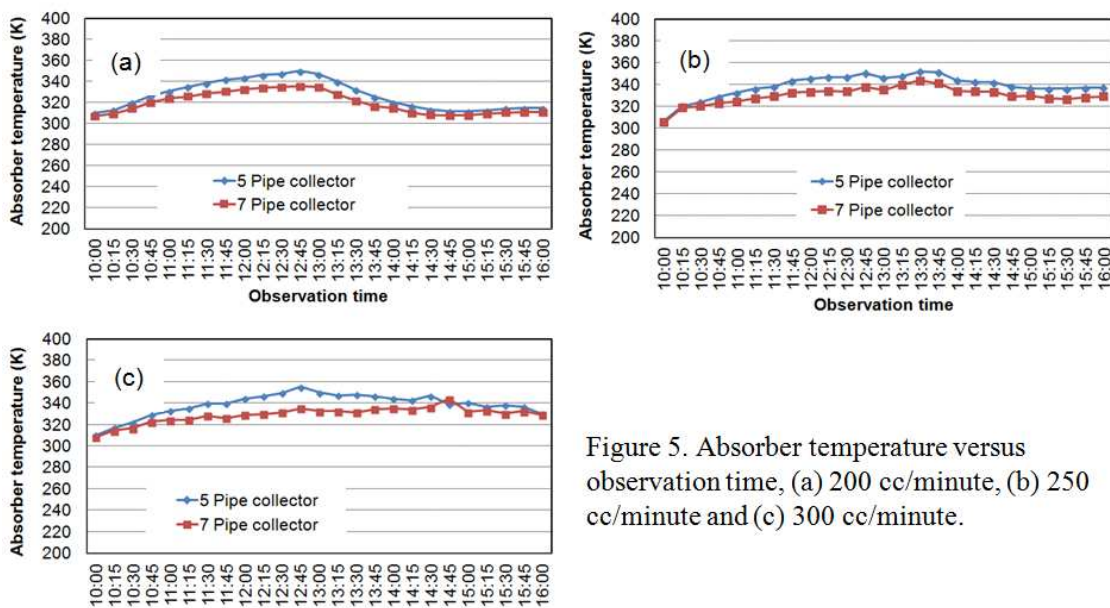

Figure 5. Absorber temperature versus observation time, (a) 200 cc/minute, (b) 250 cc/minute and (c) 300 cc/minute.
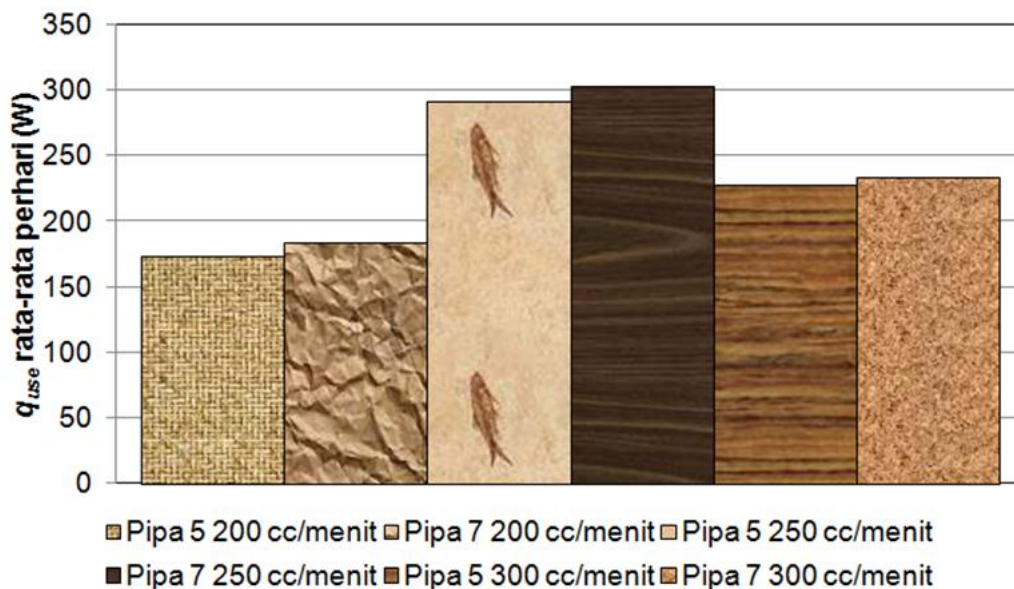

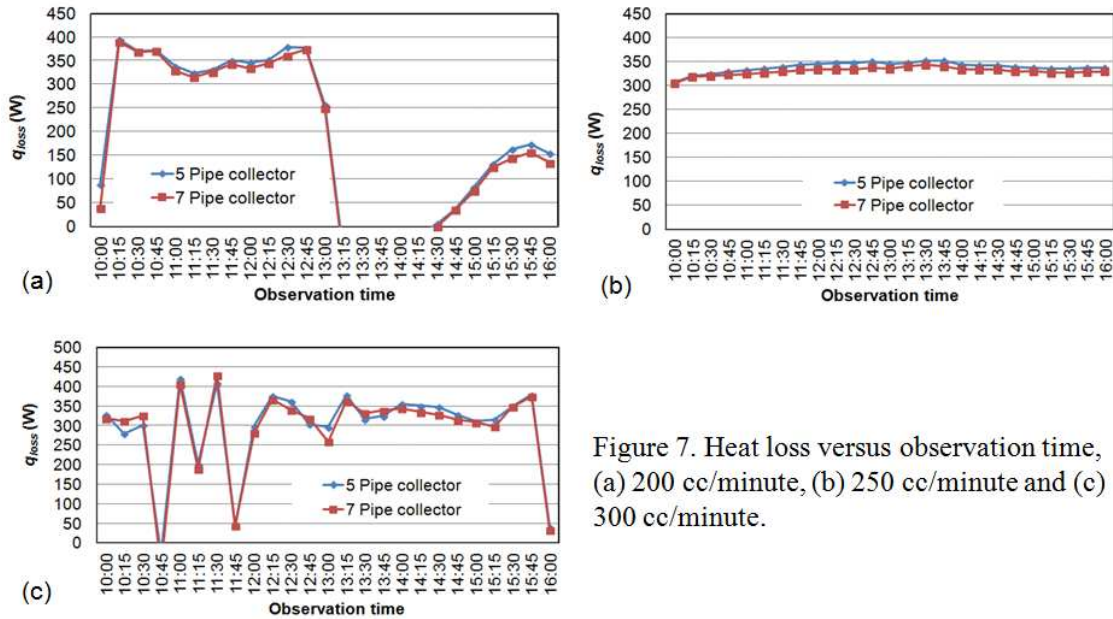Figure 6. Daily average useful energy

(a)

(b)

(c)

Figure 7. Heat loss versus observation time, (a) 200 cc/minute, (b) 250 cc/minute and (c) 300 cc/minute.

In figure 5 it seems that the absorber temperature for the 5 pipe collector is always higher than the absorber temperature for the 7 pipe collector. This was due to the lower energy absorbed by the water in the 5 pipe collector. Even so, the difference of the useful energy for both collectors is

Figure 7 indicates the heat loss to the ambient for the 5 pipe collector is higher than that for the 7 pipe collector. This can be seen that the blue line is almost always above the red line. Figure 7 confirms the explanation given by the figure 5. Figure 7(a) shows a different phenomenon. That was due to the
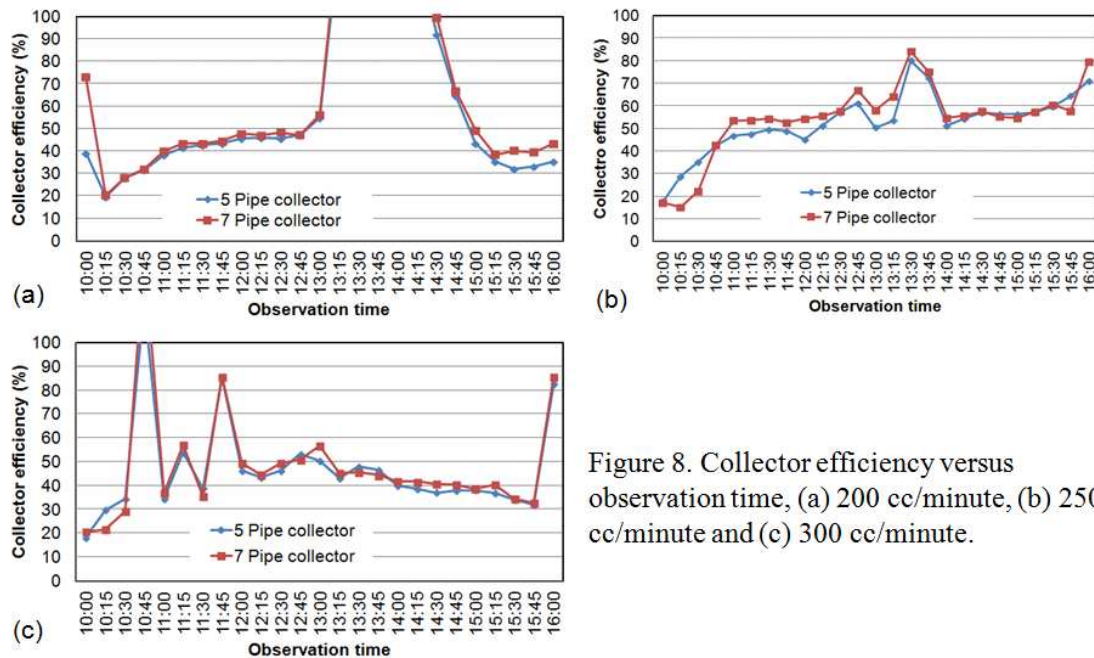

(a)

(b)

(c)

Figure 8. Collector efficiency versus observation time, (a) 200 cc/minute, (b) 250 cc/minute and (c) 300 cc/minute.

still below 10% or insignificant due to [6,7]. However, the average daily useful energy for the 7 pipe collector is higher than that for the 5 pipe collector, as seen in figure 6. Energy received by the collector is surely the same because the collector area is the same, nevertheless, the heat loss for the 5 pipe collector is higher than that of the 7 pipe collector. To know the heat loss to the ambient, figure 7 is presented.

condition of the sky. When the sky is cloudy, the sun energy coming into the collector is small, meanwhile the useful energy is still big because of the saved energy in the absorber than can be removed by the water. For that reason, applying equation (4) results in the lowest heat loss.

One important parameter in testing the solar collector is the collector efficiency. Theoretically, the efficiency of the collector can be predicted using

equation (5) and the results are shown in figure 8. The collector efficiency is affected by the useful energy and incoming energy, therefore, the efficiency of the collector when the sky is cloudy, is very high, see figure 8(a). This is due to the very low incoming energy when the sky is not clear, while the useful energy remains high, consequently, the efficiency is very high.

CONCLUSIONS

Base on the experimental results and discussion, several conclusions can be drawn as follows:
1. The effect of the pipe number on the heat transfer rate is insignificant.
2. The heat transfer rate is affected by the observation time.
3. The heat loss to the ambient is influenced by the absorber temperature.
4. The effect of the volumetric rate on the heat transfer rate is inconclusive.

ACKNOWLEDGEMENT

NOMENCLATURE

A : cross-sectional area (m²)
A_c : collector area (m²)
c_p : specific heat (kJ/kg K)
I_T : solar radiation heat flux (W/m²)
$\dot{m}$: mass flow rate (kg/s)
q_i : heat input (W)
q_{loss} : heat loss to the ambient (W)
q_{use} : useful energy (W)
T_i : water inlet temperature (°C)
T_o : water outlet temperature (°C)
V : average velocity (m/s)
ρ : density (kg/m³)
η : efficiency

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