Performance Evaluation of Absorber Rod Type Solar Air Collector

Zainab Saberi, Ahmad Fudholi, Zahari Ibarahim and Kamaruzzaman Sopian
Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia
E-mail: zai9520@gmail.com, a.fudholi@ukm.edu.my, zbi@ukm.edu.my, ksopian@eng.ukm.my

Abstract. Solar air collector is a device that collects heat energy from the sun where the solar energy is converted to heat energy. A good solar air collector is when it can absorb maximum heat and can reduce as minimum as heat loss possible. In this study, a solar air collector device has been designed and constructed by attaching aluminium rod of 210 pieces with height 2 cm on the absorber plate to increase the heat transfer surface area. Apart from that, fin also built in airway to increase transfer of heat from plate absorber to air flow. There are 4 parameter of intensities value and mass flow rate is changed in this experiment which are 101.5 W/m$^2$, 302.4 W/m$^2$, 530.6 W/m$^2$ and 720.0 W/m$^2$ while for the mass flow rate is 0.0236 kg/s, 0.0340 kg/s, 0.0452 kg/s and 0.0584 kg/s. The aim of this study was to investigate the effect of mass flow rate and the solar intensity in improving the efficiency of thermal solar collectors. The results showed that the efficiency is between 57.2% to 77.4%. Maximum thermal efficiency mass flow rate recorded at 0.0584 kg/s with radiation intensity of 530.6 W/m$^2$. Changes in temperature, $\Delta T$ are decreased when mass flow rate is increased which 19.0°C to 1.2°C depending on the solar radiation intensity.

Keywords: solar air collector; aluminium rod; absorber plate; intensity; mass flow rate; efficiency.

1. Introduction
Energy is a basic necessity of creature on earth. All living things need an energy. The more developed a country, the more energy it uses. Thus, if a country plans to develop its country, sufficient energy generation should be given due attention [1]. There are two types of energy sources, namely common energy and renewable energy.

The common source of energy is the energy that will be finished when used where it is obtained from the earth’s crust such as petroleum, natural gas and coal. The source of renewable energy is the continuous energy sources such as solar, wind, hydro, biomass and biogas. The source of renewable energy has several advantages such as reducing dependence on fossil fuel sources and reducing carbon emissions on air [2].

The current shortage of existing common sources of energy raises concerns. Hence, efforts to find alternative energy sources need to be made in an environment that does not affect the development of the country, especially developing countries [1]. The use of solar energy is a substitute energy source...
that saves, even did not pollute the environment and safe to be used. Solar energy is the cheapest and
cleanest source of energy and available on earth [3].

The simplest and most efficient way to use solar energy is by converting solar energy to thermal
energy (thermal system). Solar collectors are an alternative that can be used to collect energy where it
can be used for specific purposes such as water heating, drying clothes, agricultural products such as
paddy, cocoa, anchovies and so on.

There are various types of solar collectors that have been built such as non-convex collector, flat
plate collector, evacuated tubular collector, inline-focused collector and point-focused collector. The
build and structure vary depending on the temperature range to be achieved [1].

| Nomenclature               |
|----------------------------|
| V  | volume of air through the collector (m³/s) |
| ρ  | density of air (kg/m³)                     |
| ΔT | gradient air temperature (°C)              |
| Cₚ | specific heat of the air (J/kg°C)          |
| Aₐ | area of collector that exposed to solar radiation (m²) |
| I  | Intensity of solar radiation that override the surface of solar collector (W/m²) |

2. Experiment Preparation and Measurement Procedure

2.1 Model Building
In this study, the aluminum rod-type absorber plate has been painted black dull. The aluminum rod
height is 2 cm and a total of 210 aluminum rods are arranged on the absorber plate as shown in
Figure 1 and Figure 2.

![Figure 1. Sketch of the solar collector system used.](image)

![Figure 2. Modified absorber plate.](image)
2.2 Acquisition Temperature Data
The location of the thermocouples, the number of points and symbols used during the study is shown in Table 1 while Figure 3 shows the location where the thermocouples are placed on the top of the surface of the solar collector.

Table 1. Location of the thermocouples, number of points and symbols.

| Thermocouple location          | Number of points | Symbols                       |
|-------------------------------|------------------|-------------------------------|
| Ambient                       | 1                | $T_a$                         |
| Inlet temperature             | 1                | $T_{IN}$                      |
| Back plate temperature        | 3                | $T_B$                         |
| Glass cover temperature       | 5                | $T_G$                         |
| Absorber plat temperature     | 5                | $T_P$                         |
| Collector surface temperature | 15               | $T_{11}, T_{12}, T_{21}, T_{22}, T_{23}, T_{31}, T_{32}, T_{33}, T_{41}, T_{42}, T_{43}, T_{51}, T_{52}, T_{53}$ |
| Outgoing air route            | 1                | $T_{out}$                     |

Figure 3. Location where the thermocouples are placed on the top of the surface of the solar collector.

2.3 Procedure for taking temperature
There are several steps to take during this study. Among them are solar collector tools to be placed on parallel supporter under the solar simulator. The solar collector’s position is 76 cm from floor level and 125 cm from solar radiation.

After that, all K-type thermocouple should be connected to the logger data where the logger data connects to the laptop to record any temperature changes. Experiment initiated with the voltage regulator setting knob elevated to 118 V (0.0236 kg/s) and 50 V (101.5 W/m$^2$). To determine the voltage regulator, a multimeter is used to ensure that the readings are right and accurate.

Additionally, solar simulator and fan are fitted for one hour to produce a steady solar intensity and airflow. When the system is stable, the temperature is recorded following time that had set that is for 10 minutes. Data applications that have been downloaded in the computer are used to record data for 10 minutes and are presented in the excel sheet. The time interval taken is to ensure the data obtained from this system achieve steady state.

Subsequently, air speed readings were taken at 12 places by using the anemometer while solar intensity reading was taken at 9 places by using the pyranometer and the reading should be recorded.

Finally, repeat the following steps with a voltage regulator at 50 V, 81 V, 103 V and 119 V for intensity and 118 V, 148 V, 175 V and 199 V for air speed. The efficiency of each intensity and mass flow rate can be calculated by using the following formula:
\[ \eta_c = \frac{V \cdot \rho \cdot \Delta T \cdot C_p}{Ac \cdot I} \times 100 \]

3. Result and Discussions

Table 2 shows the thermal efficiency of solar air collectors studied at 4 mass flow rates and 4 different solar intensities.

| Mass flow rate, \( \dot{m} \) (kg/s) | Intensity of Radiation, \( I \) (W/m²) |
|-------------------------------------|---------------------------------------|
| 101.5 | 302.4 | 530.6 | 720.0 |
| 0.0236 | 57.2 | 60.3 | 63.9 | 65.4 |
| 0.0340 | 67.3 | 68.2 | 70.3 | 71.0 |
| 0.0452 | 72.1 | 73.7 | 74.3 | 74.8 |
| 0.0584 | 74.9 | 75.8 | 77.4 | 70.9 |

Figure 4 shows the efficiency graph against the mass flow rate at different intensities. The purpose of this study is to investigate the effects of mass flow rate and solar intensity in determining the thermal efficiency of the solar collector. The efficiency of a system will increase if the mass flow rate is also increased [4]. Based on Figure 4, the maximum efficiency of the solar collector is 77.4% on the intensity of the solar radiation 530.6 W/m² with a mass flow rate of 0.0584 kg/s. The results showed that the efficiency increased at 0.0236 kg/s, 0.0340 kg/s, 0.0452 kg/s and 0.0584 kg/s with solar intensity 101.5 W/m², 302.4 W/m² and 530.6 W/m². Nevertheless, the percentage of efficiency has decreased at the intensity value of solar radiation 720.0 W/m² with the efficiency of 70.9%.

The mass flow rate is very important in determining the efficiency of the solar collector as it allows the air that absorbs heat from the absorber plate to flow out well allowing the new air to absorb heat from the absorbing plate. The usage of fin structure in this experiment is very helpful in increasing the heat transfer from the absorption plate to fluid which is air.

It is likely that the efficiency decreases as the intensity and mass flow rate are too high. This is because when the intensity is too high, it causes the air through the air duct could not absorb the heat from the collector plate well because they are saturated and causes the collector plate to be dense with heat, thus unable to absorb the heat well. Therefore, the optimum intensity of the solar collector system is at the intensity of 530.6 W/m² where it has a high efficiency of 77.4%. On the intensity of 720.0 W/m², the optimum efficiency is achieved at a mass flow rate of 0.0452 kg/s of 74.8% but when the mass flow rate increases to 0.0584 kg/s, the efficiency decreases to 70.9%. It shows that the system is no longer efficient in generating useful heat.
Based on Figure 4, at the lowest mass flow rate of 0.0236 kg/s, the lowest efficiency value is recorded at about 57.2% - 65.4%. This is because when the airflow passing through the airway is quite slow, the amount of heat transferred from the absorber plate to the fluid is small.

Mass flow rate affects the air temperature through solar collectors. Therefore, Figure 5 shows the temperature difference increasingly descend with increasing mass flow rate at different intensities. This is because the mass flow rate helps in flowing air by turbulence. Therefore, lower heat losses occur and affect the efficiency of the system. At intensity 101.5 W/m², at mass flow rate of 0.0236 kg/s (ΔT = 2.2 °C), efficiency is 57.2% while mass flow rate is 0.0584 kg/s (ΔT = 1.2 °C) which is 74.9%. The results of these experiments are summarized in Table 3.

**Table 3.** Value of the difference in out and inlet temperature, ΔT (T in - T out) based on the mass flow rate, ṁ and solar intensity, I specified.

| Mass flow rate, ṁ (kg/s) | Intensity of radiation, I (W/m²) | 101.5 | 302.4 | 530.6 | 720.0 |
|-------------------------|---------------------------------|-------|-------|-------|-------|
| 0.0236                  | 2.2                             | 7.0   | 13.1  | 18.1  |
| 0.0340                  | 1.8                             | 5.5   | 10.0  | 13.7  |
| 0.0452                  | 1.5                             | 4.5   | 7.9   | 10.8  |
| 0.0584                  | 1.2                             | 3.6   | 6.4   | 8.0   |

**Figure 5.** Graph the difference in temperature out and the inlet temperature against the mass flow rate.

**Table 4.** Difference in temperature out and the inlet temperature / I, (ΔT / I) based on the mass flow rate, ṁ and solar intensity, I specified.

| Mass flow rate, ṁ (kg/s) | Intensity of radiation, I (W/m²) | 101.5 | 302.4 | 530.6 | 720.0 |
|-------------------------|---------------------------------|-------|-------|-------|-------|
| 0.0236                  | 0.0221                          | 0.0232| 0.0246| 0.0252|
| 0.0340                  | 0.0180                          | 0.0183| 0.0188| 0.0190|
| 0.0452                  | 0.0145                          | 0.0148| 0.0150| 0.0151|
| 0.0584                  | 0.0117                          | 0.0118| 0.0121| 0.0110|
Figure 6 shows the constant mass flow rate, the value (ΔT/I) increases as the intensity and efficiency increase, η. The difference in out and in temperature of the highest intensity is 0.0252 °Cm²/W recorded at mass flow rate of 0.0236 kg/s and intensity of 720.0 W/m². The efficiency value is also lowest at this mass flow rate. Summary of experimental is results summarized in Table 4.

This is due to the temperature rise through the collectors is high. This leads to higher heat loss. According to the concept of heat transfer through convection to achieve a temperature equilibrium, the heat from the heat collector plate frees much into the air cooler environment. When the absorber plate has a higher temperature than the ambient temperature, then heat transfer occurs quickly and affects the efficiency value. Therefore, high system efficiency can be achieved if the difference in and out temperature of the intensity is small.

4. Conclusion
The relationship between system efficiency and other parameters such as mass flow rate, intensity, temperature difference of the glass cover with the ambient temperature and the difference in outgoing temperature and inlet temperature on the four different intensity can be seen and studied. Based on the data obtained and analyzed, at the highest mass flow rate of 0.0584 kg/s, it has the highest efficiency of 77.4% where the difference in temperature and inlet temperature is 6.4 °C at 530.6 W/m² intensity. It clearly shows that the efficiency of a system increases when the value of the difference in temperature of the out and inlet is smaller. Additionally, the usage of the fins and the surface of the absorber plate attached to the aluminium rod in the experiment is helpful in enhancing heat transfer from absorber plate to fluid which is air and increase absorber surface area exposed to the intensity of the solar simulator. Additionally, when high intensity is used, it will supply more heat through the radiation by solar simulates where this heat will flow well due to the high mass flow rate.

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