Flat Plate Solar Collector Characteristic with Shutter Glass Distance Variation and Collector Inclination Angle

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Abstract. It has been done a research to determine the solar thermal collector efficiency of the flat plate collector. The testing of the collector was conducted on 30th November 2005, 1st, 3rd, 5th, 6th, 7th December 2005 with the variation of distance between one glass covers were varied from 3 cm, 6 cm, and 9 cm; and with inclination angle variation of collector from 10°, 20°, 30°, and 40°. Solar thermal collectors absorb the radiant energy from the sun and convert it to heat between the bottom glass cover and absorbing plates in the collector. Parameters which influence on the collector performance include distance between plate collector with glass covers and the inclination angle. It was found that the difference between output- input temperatures is the highest on a distance of 3 cm and inclination angle of 10°. This is influenced that inclination angle 10° more close to zenith angle. The solar thermal collector efficiency is not a constant; The solar collector efficiency depends on solar radiation intensity, input-output temperature difference and air flow. The smaller the inclination angle of solar collector, the higher the absorption radiation. If inclination angle of collector same with zenith angle, so the absorption radiation will maximum.

1. Introduction
Indonesia has a tropical climate which is relatively high ambient temperature, relative humidity, and in some places have high rainfall as well. Indonesia is also known as an agricultural country that produces in addition to staple foods also produce other agricultural products such as cocoa, coffee, copra, nutmeg and others [1]. Commodities were mostly should be dried immediately after harvest, because if too late there will be a process of decay so very detrimental.

To dry it takes enormous energy. Farmers mostly do the drying in the hot sun. Ambient temperature is about 33 °C, while the drying temperature for late-many agricultural commodities ranging from 60-70 °C. If we use the air heater temperature environment or lower than the drying temperature, it will take longer. Raising the temperature of the environment can be done by collecting the air in a solar collector and exhale into commodities [2].

Fossil energy, especially petroleum, is the main energy source and limited in number. The limited resources of fossil energy cause the need for renewable energy development. Renewable energy is a non-fossil fuels derived from natural and renewable [3]. When properly managed, these resources will not be exhausted.

Indonesia, on the one hand is an archipelago so that the transportation of commercial energy will remain an obstacle to the provision of cheap energy in remote places mentioned above. On the other
hand, Indonesia has the potential of renewable energy sources is large enough [4]. In the future, the potential for developing renewable energy sources and has a great chance given the strategic nature of renewable energy sources is a source of clean energy, environmentally friendly and sustainable.

1.1 Solar energy and utilization

As the nearest star on the blue planet Earth, which is only about 150 million km, it is natural that only radiant solar energy that affect the dynamics of the atmosphere and life on Earth. The energy that comes to Earth is largely the sun’s radiation. This energy is then transformed into various forms of energy, for example warming the Earth’s surface, the motion and the warming of the atmosphere, ocean waves, photosynthesis of plants and other photochemical reactions [5].

Spreading sunshine each year varies hemisphere. Indonesia receives an average of eight hours a day of sunlight and the intensity of sunlight entering the specified position of the sun against the collector.

1.2 Review of heat transfer

1.2.1 Conduction

Heat flows by conduction from high temperature areas to temperate areas. Conduction heat transfer rate can be expressed by the Fourier law as follows [6]:

\[ q = -kA \frac{dT}{dx} \]  

where \( q \) is the rate of heat transfer, W; \( k \) is the thermal conductivity, W/(m.K); \( A \) is the cross-sectional area perpendicular to the flow of hot m² and \( dT/dx \) is the temperature gradient in the direction of heat flow, -K/m.

1.2.2 Convection

The air flowing over a metal surface on a solar air heater was heated by convection. There are two types of convection process that forced convection and natural convection. The heat transfer rate can be expressed by the following equation [6]:

\[ q = hA(T_w - T_f) \]  

where \( q \) is the rate of heat transfer, W; \( h \) is the convection coefficient, W/(m².K); \( A \) is the surface area, m²; \( T_w \) is the temperature of the walls; and \( T_f \) is the temperature of the fluid, K.

For solar heaters that work in the area of Reynolds number between 2000 and 10000, and the value of Nusselt number [5]:

\[ N_u = 0.00269 \times Re \]  

\( Re \) is the Reynolds number that usually ranges from 2000 to 10000 for turbulent flow, and below 2000 for laminar flow. Reynolds number can be formulated [6]:

\[ Re = \frac{\nu d_p \rho}{\mu} \]  

where \( Re \) is the Reynolds number, \( \nu \) is velocity - average of the fluid (m/s), \( d_p \) is the diameter of the pipe (m), \( \rho \) is the density (kg/m³), \( \mu \) is the dynamic viscosity (kg/m.s).
1.2.3 Radiation
Total radiation heat transfer from a perfect black body is proportional to the fourth power of the temperature of the object. This is the Stefan-Boltzmann law so that it can be written as follows \[7\]:

\[ E = \sigma A T^4 \]  

(5)

where \( \sigma \) is the Stefan-Boltzmann constant magnitude \( 5.67 \times 10^{-8} \text{W/m}^2\text{K}^4 \), \( A \) is the cross-sectional area of the object (m\(^2\)), \( T \) is the absolute temperature of the object (K).

1.3 Overview fluid mechanics
Viscosity is a trait that determines the characteristics of the fluid which is a measure of the shear fluid prisoners. Dynamic viscosity is defined as the ratio between shear stress and shear strain rate.

1.4 Position of the sun

1.4.1 Equation for Angle Zenit
The zenith angle is shown as the angle between the zenith \( z \), or a straight line above the head, and the line of sight to the sun. The equation for the zenith angle can be formulated [6]:

\[
\cos \theta_z = \sin \delta \sin \phi + \cos \delta \cos \phi \cos \omega
\]

(6)

where \( Y_z \) is the zenith angle, \( \delta \) is declination, \( \phi \) is the latitude angle, and \( \omega \) is the hour angle (15° per hour). Declination \( \delta \), is the angle formed by the sun in the equatorial plane, it changed as a result of the tilt of the earth, of +23.45° in summer (June 21) and -23.45° in winter (December 21). Declination at any time can be estimated from the following equation [6]:

\[
\delta = 23.45 \sin \left(360 \times \frac{284 - n}{365}\right)
\]

(7)

where \( n \) is the day of the year.

1.4.2 Intensity radiation on the inclined plane
Component of radiation on a tilted surface, which spotlight \( I_{BT} \) component is obtained by converting the radiation beam on the horizontal surface into a normal entry by using the zenith angle, and then get the component on an inclined surface by using a corner entrance.

\[
I_{BT} = I \frac{\sin \delta \sin(\phi - \beta) + \cos \delta \cos(\phi - \beta) \cos \omega}{\sin \delta \sin \phi + \cos \delta \cos \phi \cos \omega}
\]

(8)

1.5 Variety solar thermal collectors
1. Flat plate solar collectors
2. Collectors concentrated
3. Tube collector
4. Passive collectors

1.6 Analysis of the working solar thermal collectors flat type

1.6.1 Energy equation equilibrium
Equilibrium equations rate of heat energy in thermal collectors can be expressed by the equation:

\[ q_u = q_i - q_l \]  

(9)
Where \( q_u \) is the energy used (J/s), \( q_i \) is the incoming energy (J/s) and \( q_L \) is the lost energy (J/s).

a. The rate heat energy entering

The rate of heat energy entering the thermal collector solar energy (J/s) affected by the \( I_{bT} \) amount of the intensity of solar radiation on an inclined surface (watt/m²), \( A_p \) wide plate absorber thermal collector (m²), and the product of transmissivity glass cover-absorptivity plate absorber \( (\tau, \alpha) \), expressed by the equation:

\[
q_i = A_p I_{bT} (\tau, \alpha)
\]  
(10)

b. The rate heat energy used

The rate of heat energy out of the solar thermal collectors can be expressed in the equation:

\[
q_u = m C_p (T_0 - T_i)
\]  
(11)

c. The rate heat energy missing

Not all of the incoming heat energy can be used entirely because there are heat loss factors on thermal collectors. The heat losses occur at the top of the solar thermal collector called heat losses at the top and bottom of the solar thermal collector called the lower heat losses. Whereas, the amount of heat loss is the total heat loss.

- The rate of heat energy losses Section differences (top loss) \( q_{tl} \)
- The rate of heat energy losses Bottom (bottom loss) \( q_{bl} \)

1.6.2 Efficiency solar collector

The definition of the efficiency of the solar collector is the ratio between the energy used by the amount of solar energy received at a particular time by the solar collectors.

\[
\eta = \frac{m C_p (T_0 - T_i)}{A_p (\tau\alpha) I_{bT}}
\]  
(12)

air mass flow rate is the amount of air mass that flows per unit time and can be expressed as follows:

\[
m = \frac{m}{t_u} = \frac{V \rho}{t_u}
\]  
(13)

2. Experimental

2.1 Place and time collection

This study was conducted in a central laboratory backyard UNS Surakarta on November 30 to December 7, at 10:00 to 14:00.

2.2 Tools

All tool were used are thermocouples, anemometer testo, digital thermometers, light Meter Model Li-250 No Sri LMA – 2706, and sensor pyranometer No seri PY – 46415.
2.3 Research procedure

3. Results and Discussion

3.1 Intensity of solar radiation

3.1.1 Temperature variation of the distance collector on glass cover

The results of temperature measurement input and output temperature on the research conducted on December 1, at a distance of 3 cm and 9 cm can be seen in Figure 1 and Figure 2.

In Figure 1 and Figure 2 we can see that a large output temperature greater than the temperature input. At a distance of 3 cm difference plate temperature value, input and output reached 23.1 °C and 9.9 °C little difference. Temperatures highest output reached 63.8 °C at 11:45 and the intake temperature reached 41.7 °C at 12:45. At a distance of 9 cm difference plate input and output value reached 13 °C largest and the smallest difference of 0.4 °C. Temperatures highest output reached 51.2 °C at 11:45 and the intake temperature reached 42.6 °C at 11:45.
Results temperature solar collectors can be seen in the chart entry of the temperature difference ($T_{in}$) and the discharge temperature ($T_{out}$) of the hours of observation:

**Figure 1.** Graph of temperature with hours of observation at a distance of 3 cm

**Figure 2.** Graph of temperature with hours of observation at a distance of 9 cm

**Figure 3.** Chart input-output temperature difference at a distance of 3 cm and 6 cm
In Figure 3, Figure 4 and Figure 5, we can see that on November 30, 2005 the difference in temperature at a distance of 3 cm glass the result is higher than the glass 6 cm distance. But there are two data results are the opposite, this is because any change in the flow that moves around the collector. On December 1, 2005, the difference in temperature at a distance of 3 cm glass the result is higher than the glass 9 cm distance. This is because at a distance of 9 cm glass heat is lost to the greater environment. So that heat absorption on the plate is reduced. But on December 3, the difference in temperature at a distance of 6 cm glass results is mostly higher than the glass 9 cm distance. At a distance of 9 cm glass much heat is lost to the environment. But there are some circumstances where the amount of the opposite, this is due to differences in the airflow moving around collector. Base on the measurement results can be concluded that the variation within the glass effect on the temperature difference between the collector. The temperature difference will be maximum at a distance of a little glass, because little heat energy is lost to the environment.

3.1.2 Temperature collector on variation of the angle of the collector
The results of the temperature in the solar collectors can be seen in the chart entry of the temperature difference ($T_{in}$) and the discharge temperature ($T_{out}$) of the hours of observation. In Figure 6, Figure 7 and Figure 8 we can see that on December 5, there is a large difference in temperature at a 10° angle no greater than the temperature difference at an angle of 20°, but there is the opposite. This is because the temperature difference would be maximized if the slope of the collector in accordance with the zenith angle. In this study, the zenith angle of collector surface of 14.8°. On December 6, 2005 a large temperature difference at an angle 20° is greater than the angle 30°. This is because the angle of 20° approaching the zenith angle than angle 30°. On December 7, a large temperature difference at an
angle of 20° mostly the result is higher than the temperature difference 40°, this is because the angle zenith angles approaching 20° more than 40°. But at the corner of the graph shows the presence of some value at an angle of 20° that the result is smaller than the angle of 40°, this is due to return air stream. It also can lead basar intake temperature becomes greater than the output temperature.

![Figure 6](image-url)  
**Figure 6.** Chart input-output temperature difference at the corner of 10° and 20°

![Figure 7](image-url)  
**Figure 7.** Chart input-output temperature difference at the corner of 20° and 30°

![Figure 8](image-url)  
**Figure 8.** Chart input-output temperature difference at the corner of 20° and 40°

From the above results it can be concluded that the variation of the angle effect on the temperature difference collector. Where in the temperature difference will be maximum if the collector surface perpendicular to the sun's position [8].

3.1.3 *Efficiency of solar collection on variations within the glass*
The results of the efficiency of the solar collector can be seen in the graph efficiency solar collector to the temperature difference between the entry \((T_{in})\) and the discharge temperature \((T_{out})\), which is in Figure 9, Figure 10, and Figure 11.

**Figure 9.** Graph thermal efficiency with a distance of absorbent glass cover plate with 3 cm and 6 cm

**Figure 10.** Graph thermal efficiency with a distance of absorbent glass cover plate with 3 cm and 9 cm

**Figure 11.** Graph thermal efficiency with a distance of absorbent glass cover plate with 6 cm and 9 cm

In Figure 11, Figure 12, and Figure 13 we can see that on November 30, the highest thermal efficiency of the glass at a distance of 3 cm reached 72.82% and the lowest was 33.05%. Meanwhile, at a distance of 6 cm glass highest thermal efficiency reached 97.59% and the lowest was 23.65%.

On 1 December, the highest thermal efficiency at a distance of 3 cm glass reached 81.58% and the lowest was 29.22%. Meanwhile, at a distance of 9 cm glass highest thermal efficiency reached 98.59% and the lowest was 11.2%.

On December 3, the highest thermal efficiency of the glass at a distance of 6 cm reached 82.48% and the lowest was 28.47%. Meanwhile, at a distance of 9 cm glass highest thermal efficiency reached 81.51% and the lowest was 23.6%.

So it can be said that the results of the calculation of the thermal efficiency of the solar collector in this study is not a constant but a variable characteristic that depends on the intensity of the sun, the temperature of the input, output temperature and airflow. Where the sun intensity received collector
does not fluctuate, laminar air flow, and the temperature difference between the input and maximum output. The temperature difference will be maximum at a distance of a small glass.

3.1.4 Efficiency solar collector on the variation of the angle of the collector

The results of the efficiency of the solar collector can be seen in the graph efficiency solar collector to the temperature difference between the entry \( T_{in} \) and the discharge temperature \( T_{out} \), that in Figure 12, Figure 13, and Figure 14.

![Figure 12. Graph thermal efficiency with an angle of 10° and 20°](image1)

![Figure 13. Graph thermal efficiency with an angle of 20° and 30°](image2)

![Figure 14. Graph thermal efficiency with an angle of 20° and 40°](image3)

In Figure 14, Figure 15, and Figure 16 we can see that on 5 December, the highest thermal efficiency at an angle of 100 reached 94.46% and the lowest was 31.26%. While in the corner of the 200 highest thermal efficiency reached 93.04% and the lowest was 35.23%.

On 6 December, the highest thermal efficiency at an angle of 200 reached 99.23% and the lowest was 20.92%. While in the corner of the 300 highest thermal efficiency reached 97.53% and the lowest was 22.64%.
On 7 December, the highest thermal efficiency at an angle of 200 reached 96.29% and the lowest was 18.10%. While in the corner of the 400 highest thermal efficiency reached 96.43% and the lowest was 28.5%.

So it can be said that the results of the calculation of the thermal efficiency of the solar collector in this study is not a constant but a variable characteristic that depends on the intensity of the sun, the temperature of the input, output temperature and airflow. Where the sun intensity received collector does not fluctuate and collector surface perpendicular to the sun's position, laminar air flow, and the temperature difference between the input and maximum output. The maximum temperature difference would be if the collector surface perpendicular to the sun's position.

4. Conclusion
In the third variation within absorber plate with a transparent glass, a score difference of input-output temperature at a distance of 3 cm highs and lows at a distance of 9 cm, and the absorber plate absorbs solar radiation optimally if the position of the plate perpendicular to the direction of the radiation coming sun. The slope of solar collector closer zenith angle of the input-output temperature difference increases. The thermal efficiency depends on the intensity of the sun, the temperature of the input, output temperature, thermal efficiency and airflow.

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