Study of Performance of Coaxial Vacuum Tube Solar Collector on Ethanol Distillation Process

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Abstract. Coaxial vacuum tube solar collectors can generate heat up to 80°C is possibly used for ethanol distillation process that required temperature 79°C only. This study reviews the performance of coaxial collector vacuum tube used for ethanol distillation process. This experimental research was conducted in a closed space using a halogen lamp as a solar radiation simulator. We had done on three different of the radiation values, i.e. 998 W/m², 878 W/m² and 782 W/m². The pressure levels of vacuum tube collector cavity in the research were 1; 0.5; 0.31; 0.179; and 0.043 atmospheres. The Research upgraded the 30% of ethanol to produce the concentration of 77% after distillation. The result shows that the performance of coaxial collector vacuum tube used for ethanol distillation process has the negative correlation to the level of the collector tube cavity pressure. The productivity will increase while the collector tube cavity pressure decreased. Therefore, the collector efficiency has the negative correlation also to the level of collector tube cavity pressure. The best performance achieved when it operated at a pressure of 0.043 atmosphere with radiation intensity 878 W/m², and the value of efficiency is 57.8%.

1. Introduction
Human life on the earth always needs energy. It has an implication that human population growth will affect the amount of energy required. According to the International Energy Agency-IEA, world energy demand will increase steadily. It predicted, the average up to 2030 is 1.6% per year. The whole nation in the world will continue facing energy supply problems. In another hand, especially the dwindling amount of fossil energy, while eighty percent of the energy supply in the world using fossil fuels. We know that burning fossil fuels release harmful emissions, such as carbon dioxide, nitrogen oxides, aerosols, etc. that can pollute the environment. We need to have a framework to develop energy sources that do not pollute the environment. The alternative solution is to use environmentally friendly renewable energy as an energy source.

The most abundant of the renewable energy sources is the solar radiation, especially in the area around the equator. Solar radiation is the main source of the energy system that can affect the Earth's natural cycles as well as support all life on the earth [1]. The technology applied to use the energy of
solar radiation is classified into two types. It was namely photovoltaic technology and solar thermal technology [2].

Ethanol as a renewable energy source is very potential to be also developed because it can be produced from carbohydrates contained in the plant, (cassava, maize, sorghum, etc.) or molasses (sugar production waste). Ethanol can improve combustion efficiency, especially in motor Otto. It because of ethanol contains approximately 35% oxygen. It has a higher octane number (112) also if it’s compared to gasoline that has the octane value less than 90 only [3]. The low-level ethanol (10%-20%) can be produced in several ways, one of which is a biological process of fermentation. Increasing the level of ethanol can be done by separating the water contained therein. Distillation is the process of components separation based on their boiling points. Pure ethanol boiling point is 79°C and water boiling point at a standard condition is100°C [4].

Therefore, this research is vital because the aim of this study regarding the performance of coaxial vacuum tube collector used for ethanol distillation process. None of the researchers applied the coaxial vacuum tube collector for ethanol distillation process that required a temperature of 79°C only. As we have already known that the vacuum tube collectors generate heat up to 80°C. This distillation technique based on the differences in boiling point or melting point is very useful to upgrade the 30% of ethanol to the concentration of 77% [5].

The previous researches related to this study as the comparison of ours are [6-14]. They had talked about solar collector or water heater efficiency.

This paper organizational structure is as the following: Chapter 1 talks about the introduction, chapter 2 for analysis and efficiency of evacuated tube collectors, methods in chapter 3, result and discussion in chapter 4, and chapter 5 for the conclusion.

2. Experimental

2.1. Analysis and efficiency Evacuated Tube Collectors (ETC)

The Solar thermal collector is a heat exchanger system that utilizes radiation as a primary energy source. It collects the heat and transfers to the circulating fluid in it (fluid can be air, water, or oil). Basically, the solar thermal collectors are classified into two types i.e. non-concentrating or stationary and concentrating. The stationary solar thermal collector system was classified into three categories, i.e., 1. Flat-Plate Collectors (FPC), this type uses the absorber, 2. Compound Parabolic Collectors (CPC). It uses a concentrator component that made of the high transmissivity material. This concentrator capable is focusing the energy of solar radiation on a receiver. 3. Evacuated Tube Collectors (ETC) [17].

Principally, the Evacuated Tube Collectors (ETC) put the absorber in the vacuum glass tube. The advantages of this collector due to the high heat transfer efficiency. It because the heat loss factor is relatively low. It due to the air trapped between the absorber and the glass tube conditioned in a vacuum space.

The Evacuated Tube Collectors can produce fluid temperature 50°C-200°C. We improve the effectiveness of the absorption of radiation absorber using the metal having high conductivity (copper) that painted black.

There are several types of absorber employed in the evacuated tube collectors, one of which is Coaxial Evacuated Tube Collectors. This collector has the advantage absorber cylindrical shape. The total amount of radiation of incident ray which is perpendicular to the absorber unchanged. It has implications on the total effective area of heat absorption is always equal.

At steady state, the entire effective heat rate at the collector is equal to the rate of heat absorbed by the heat absorber plate minus the heat loss directly or indirectly discharged into the environment. According to [18], the Equation (1) defines the total effective heat rate of a collector.

\[ Q_e = A_e[\alpha - q] = mc_p[T_e - T_i] \]  

(1)
\( A_c = \text{area collectors}, \ T_i = \text{the fluid temperature of the inlet}, \ T_o = \text{the fluid temperature of the outlet}, \ \dot{m} = \text{the mass flow rate of the fluid}, \text{and} \ c_p = \text{specific heat of the fluid.} \)

The Equation (2) presents the efficiency of the collector.

\[
\eta = \frac{Q_a}{A_c I_i} = \frac{\text{Absorbed solar energy}}{\text{Incident solar energy}} - \frac{\text{Energy losses}}{\text{Incident solar energy}}
\]

\( Q_a = \text{total effective heat rate}, \ A_c = \text{absorber plate area}, \ I_i = \text{the intensity of radiation absorbed by the absorber plate}, \ \eta \text{ the efficiency of solar collectors.} [19]. \)

Equation (1) substituted into Equation (2), the collector efficiency becomes the Equation (3).

\[
\eta = \frac{\dot{m} C_p (T_o - T_i)}{A_c I_i}
\]

2.2. The distillation process

This experimental research was held in closed space using a halogen lamp as a solar radiation simulator. In this test, we used a coaxial vacuum tube solar collector consisting of transparent glass tubes with a diameter of 48 mm, the length 750 mm, and tube heat absorber made of copper with a diameter of 30 mm, the length of 710 mm. The tube heat absorber was painted black.

The definition of the vacuum is a space with a gaseous pressure than 1 atmospheric pressure. The meaning of the absolute vacuum is exactly zero gaseous pressure, but this is as a theoretical concept only. We simply call "vacuum" to use the term of the partial vacuum. The value of a partial vacuum refers to the proximity degree of an absolute vacuum [11], [12]. We created a vacuum using a pump to remove the gas from the tube. The implication was the gaseous pressure be reduced approaching the exactly zero gradually. We researched 4 different degrees of vacuum tube value that had the gaseous pressure less than 1 atmosphere.

During the experiment, we kept the level of 30% ethanol in the reservoir vessel in a permanent position. This was done ensure the inlet pressure of vacuum tube solar collector was always constant. Of course, this had implications for the precision outcome of the outlet flow volume. It can control the temperature not higher than 80°C also.
At the beginning step of the experiment was done at the pressure of tube collector 1 atmosphere and radiation intensity 998 W/m$^2$. The activated was done as data acquisition for one minute, and the real testing was for 90 minutes. The volume of distilled ethanol produced was measured after the absorber temperature reaches 35°C. We repeated from the beginning step for radiation intensity 878 W/m$^2$, and 782 W/m$^2$. The next step was repeated for all of the steps from the beginning using the pressure of tube collector 0.5, 0.315, 0.179, and 0.043 atmospheres.

The primary data obtained from the test include radiation intensity, pressure tube collectors, inlet volume flow of ethanol to the collector, glass tube temperature, absorber temperature, the inlet and outlet of ethanol temperature of the collector, environmental temperature, and volume ethanol distillation. We collected temperature data using sensor LM 35 and ARDUINO, roared model MECA 2560 R3. We have programmed the setting of the microcontroller for high precision data.

3. Result and Discussion
The Fig. 3 shows that evaporation temperature rise in ethanol outlet small relatively when associated with each level of the cavity pressure of tube collector declines. It occurred in all of the radiation intensity of the experiments. For increased radiation intensity and a decrease in the level of cavity pressure of the collector tube, distillation process affects the amount of ethanol produced. The total energy absorbed by the collector, on each of the radiation intensity 782 W/m$^2$, 878 W/m$^2$, and 998 W/m$^2$ are 21.25 Joule/second (J/s), 23.86 J/s, and 27.12 J/s, respectively.

![Figure 3. The overview of the evaporation temperature of the radiation intensity 782 W/m$^2$](image)

| Pressure of tube collector (Atmosphere) | Radiation intensity |
|----------------------------------------|---------------------|
|                                        | 782 W/m$^2$ | 878 W/m$^2$ | 998 W/m$^2$ |
| 1                                      | 13.839 %   | 15.417 %   | 16.666 %   |
| 0.5                                    | 14.013 %   | 15.596 %   | 16.919 %   |
| 0.315                                  | 14.342 %   | 15.934 %   | 17.255 %   |
| 0.179                                  | 14.376 %   | 16.121 %   | 17.621 %   |
| 0.043                                  | 14.988 %   | 16.987 %   | 18.856 %   |

Fig. 4. presents the total of energy collected to achieve the ethanol evaporation. The lower of the tube collectors cavity pressure has implications evaporation temperature is reached faster.
Fig. 5. shows that the cavity pressure inside the tube collector has a negative correlation with the rate of heat energy utilized in the distillation process. Reviewing of these conditions, we can conclude that the lower cavity pressure of the tube collector has implications to the smaller heat loss.

Total heat utilized in the process of ethanol distillation affected by the level of collector tube cavity pressure. The lower pressure in the cavity tube collector has implications to the amount of heat used for distillation process increases. This condition happens in all experiments of the radiation intensity i.e. 782 W/m², 878 W/m² dan 998 W/m². The research results also present that ethanol productivity affected by the level of tube collectors’ cavity pressure. Ethanol productivity increases if the value of the pressure tube collector is lowered. The lower level of the tube collectors cavity pressure increasing the efficiency. In other words, if we distillate ethanol by vacuum collector tube cavity, better we use low-pressure level of collector tube cavity. If carrying out this way, we can save energy, improve productivity and increase efficiency.

A vacuum cavity of the collector tube contributes as an insulator. The smaller vacuum level impacts to the greater thermal resistance values. The lowest number of the degree of vacuum cavity provides the best insulation for the propagation of heat out. The great amount of the heat more focused for boiling the ethanol.

4. Conclusion
Based on the result of this research, we conclude that the performance of coaxial vacuum tube collector used in this ethanol distillation process was influenced by the level of tube collectors’ cavity pressure. The lower of the pressure level of the collector tube collectors have implications for the better performance. The best performance achieved while it operated at a pressure rate of 0.043 Atmosphere with radiation intensity 878 W / m² and the efficiency value is 57.8%.
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