Performance test of greenhouse effect (GHE) vent dryer with the addition of paraffin as a heat storage medium

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Abstract. Green House Effect (GHE) vent dryer is a kind of dryer design by utilizing solar energy as a drying energy source. Adding paraffin as a heat storage medium is one solution so that the GHE vent dryer can operate when the solar energy has dimmed. The purpose of this study was to test the performance of heat storage media using paraffin as a heat storage medium. 9 kg of paraffin was prepared, put into 9 copper pipes and placed in the absorber chamber. The data measured were the temperature in the drying room (T1=room 1, T2=room 2 and T3=room 3), the temperature of the absorber room, the temperature of the outlet, ambient temperature, air velocity and solar radiation. The results showed that the average ambient temperature ranged from 30°C to 40°C. Meanwhile, the average temperature in the GHE vent dryer ranges from 69°C to 71°C. The drying air flow velocity in the environment reaches 1.3 m/s and on the ventilator 1.1 m/s. During the study, data on solar radiation was also obtained on average reaching 6.6 W/m². The final conclusion of this study shows that the use of paraffin as a heat storage medium in the GHE vent dryer is able to maintain the temperature in the drying chamber for 4 to 5 hours when solar radiation is not present.

1. Introduction
Drying is a process of reducing water content contained in a material to be safe for further use. According to [1], drying process can be done by using natural methods (in sun or shade) or artificial drying methods. Natural drying method is a very easy and a cost-less method, but this method has some disadvantages such as the need of a large land and easily contaminated by unwanted materials. Drying machine GHE vent dryer uses solar power as energy resource, but the limit time of solar radiation become a problem in the use of GHE vent dryer, the use of heat storage media on GHE vent dryer absorber becoming the best solution. Candle is one of the materials that can be used as a heat storage medium. Paraffines are saturated hydrocarbons with open chains and are alkanes. Paraffin is a mixture of alkanes (long chains of carbon and hydrogen atoms), contained in petroleum. Paraffin will melt at 40 to 50 ºC. Paraffin is a mixture of hydrocarbons that filled with high molecular mass, produced during the petroleum distillation process. The current paraffin mad from petroleum, has the highest commercial value [2].

Additional energy sources that are widely integrated in solar dryers are biomass energy from solar furnaces and collectors. A solar collector is a device collected incoming solar energy and convert it into thermal energy and transmit that energy to the fluid [3]. Flat plate collectors are generally used to
produce low working fluid temperatures, and have been mass-produced for household needs [4]. If the paraffin is heated, there will be real changes at two temperature points. Paraffines are easy to shaped when the solid form of it melted, and will returned solid after left at room temperature. Paraffin will melt when heated. Because paraffin is a mixture of triglycerides, it has no clear melting point but will melt over a certain temperatures range. The temperature at which the paraffin is seen to melt is called the slip melting point. Most of the paraffines will melt between approximately 30°C and 40°C [4] [5]. The melting point of paraffin is below normal air temperature. The value of the thermal conductivity of a material can be seen in Table 1.

| Material | K (W/m.K) | Material | K (W/m.K) |
|----------|-----------|----------|-----------|
| Metal    |           | Others   |           |
| Aluminum | 205,0     | Brick    | 0,6       |
| Brass    | 109,0     | Insulation | 0,15      |
| Copper   | 385,0     | Brick    | 0,8       |
| Lead     | 34,7      | Concrete | 0,04      |
| Silver   | 406,0     | Cork     | 0,8       |
| Steel    | 50,2      | Glass    | 0,04      |
| Mercury  | 8,3       | Stone    | 0,8       |
| Iron     | 73        | Paraffin | 0,4       |
| Gas      |           | Styrofoam | 0,02      |
| Air      | 0,024     |          | 0,01      |
| Argon    | 0,016     |          |           |
| Helium   | 0,14      |          |           |
| Hydrogen | 0,14      |          |           |
| Oxygen   | 0,023     |          |           |

2. Materials and methods
The Equipment used in this research are GHE vent dryer, anemometer (GM8901 BENETECH), solarimeter (DT830B MASDA) dan humidimeter (HTC-2) and other support material. Material used in this research is paraffin. Prepared paraffin and then weighed as much as 9 kg, after weighing, the paraffin is heated until it melts to be inserted into the 9 copper pipes with length of 100 cm and 1 kg paraffin volume that have been prepared. Then the test was carried out for 3 days starting from 08.00 am to 22.00 pm. Radiation checking using a solariometer which placed near the GHE vent dryer, temperature checking using thermometer on drying room temperature, ambient temperature, T absorber and T outlet (see in Figure 1), air flow checking using anemometer. The working mechanism of the paraffin is to absorb the heat generated by solar radiation and then store the heat when the solar radiation begins to dim, the paraffin will release the stored heat and keep the GHE vent dryer room above the ambient temperature.

The design concept of the GHE vent dryer uses the tunnel type drying concept. This GHE vent dryer is equipped with an absorber made of zinc plate and colored in black. This absorber used to absorb the solar heat and passed it into the drying chamber. This dryer is made of 5 mm transparent acrylic glass so that the GHE vent dryer concept occurs in the designed dryer. The savonius windmill is installed on one part of the roof which functions to suck water vapor in the drying chamber so that the drying process using a GHE vent dryer can run shorter than conventional drying. This dryer is 2,7 x 3,8 meter and has 6 shelves in the drying chamber [7].
Global radiation that measured based on the approach of instantaneous solar radiation periodically following the temperature measurements. Radiation measurements were carried out using a solarimeter. The total daily solar radiation ($I_h$) is calculated mathematically using the Simpson method. Simpson's Rule is a numerical method that approximates the value of a definite integral by using quadratic functions. Simpson's method is an alternative method of integral approach in addition to the trapezoidal and midpoint methods. By using the Simpson's method, although the width of the $h$ segment on the integration is considered wide enough, it is expected to obtain higher accuracy than the previous method. 

$$I_h = \frac{\Delta t}{3}[I_i + I_f + (4\sum I_{gl}) + (2\sum I_{gp})]$$

Thus:

- $I_h$ = Total daily solar radiation (Watt.h/m$^2$)
- $\Delta t$ = Measurement time interval (Hour)
- $I_i$ = Initial Radiation (Watt/m$^2$)
- $I_f$ = Final Radiation (Watt/m$^2$)
- $I_{gl}$ = Odd hours radiation (Watt/m$^2$)
- $I_{gp}$ = Even hours radiation (Watt/m$^2$)

3. Results and discussion

The solar collector is a device that functions to collect incoming solar energy and convert it into thermal energy and transmit the energy to the fluid. The solar collector has several components, namely: transmission, reflection and absorption. Transmission components can be obtained by using glass, reflection element component by using the mirror and absorber from aluminum or brass material coated with a black body surface [8]. Measurement of solar radiation in this study was measured using the Solarimeter, the measurement of the total radiation value was carried out using the Simpson method, where the total radiation value was taken from the radiation per day in each test. The intensity of solar radiation can be calculated using the Simpson method. Table 2 show the total daily solar radiation.
Table 2. Total daily solar radiation

| Day | ∆T (Hour) | Ii (W/m²) | If (W/m²) | ∑itgl (W/m²) | ∑itgp (W/m²) | Ih (Watt.Jam/m²) |
|-----|-----------|-----------|-----------|--------------|--------------|-----------------|
| 1   | 1         | 5,2       | 11,6      | 158,1        | 157,5        | 323,06          |
| 2   | 1         | 69,767    | 11,628    | 141,86       | 143,02       | 311,5           |
| 3   | 1         | 47,059    | 23,256    | 160,46       | 160,57       | 344,26          |

Measurement of temperature by using thermometers those are placed at several points, T absorber, T ambient, room 1, room 2, room 3 and T outlet. Measurements in this study were carried out in a favorable weather starting from 08.00 am to 22.00 pm. After the temperature measurement data is obtained, the results are recorded and converted into graphs. The graph can be seen in Figure 2 and 3. Figure 2 show the measurement result of GHE vent dryer without paraffin. While figure 3 show the result when GHE vent dryer with paraffin as heat storage medium.

Figure 2 shows the difference in temperature between the temperature of the drying room and the ambient temperature where the temperature of the drying chamber tends to be higher than the ambient temperature. The drying room temperature has the highest temperature at 11.00 am, namely in room 1 is 61 ºC, in room 2 is 62 ºC and in room 3 is 61 ºC with the temperature in the absorber chamber reaching 69 ºC and irradiation reaching 6.3 W/m². Then the temperature of the drying room began to decrease at 17.00 pm, the temperature of room 1 was 36 ºC, the temperature of room 2 was 30 ºC and in room 3 was 37 ºC with an absorber temperature of 31 ºC. At 18.00 pm to 22.00 pm the absorber temperature began to decrease slowly so that the temperature inside the dryer matched the temperature outside the dryer. At 22.00 pm, the temperature in room 1 is 25 ºC, in room 2 it is 25 ºC, in room 3 it is 26 ºC, the absorber temperature is 26 ºC and the ambient temperature has matched the temperature in the dryer so that at 22.00 pm the temperature is said to be constant.

The temperature difference in the drying room fluctuates every day but it does not affect the temperature in the drying room because the temperature in the drying room is higher than the ambient temperature. In addition, the increase in temperature in the drying chamber is also caused by the presence of an absorber plate with a transparent cover as an absorber of sunlight so that heat is trapped in the drying chamber[9] [10]. The temperature in the drying chamber fluctuates due to the influence of solar radiation entering through the glass. The temperature in the absorber chamber using paraffin media has a temperature of 40 ºC with an irradiation value of 0.8 W/m² with a temperature spread in the drying
chamber of room 1 is 39 °C, in room 2 is 47 °C and in room 3 is 46 °C then the temperature of the absorber continued to increase until the highest temperature occurred at 12.00 PM, where the highest temperature obtained reached 71°C, with irradiation reaching 6.7 W/m², the temperature of the drying room in room 1 was 75°C, room temperature 2 was 70 °C and room temperature 3 is 66°C.

Figure 3. GHE vent dryer temperature distribution with paraffin

Air humidity is influenced the drying process, because air humidity indicates the water content in the air. High air content will affect the drying process so that drying will last longer and vice versa, if the air humidity is low it will speed up the drying process. Measurement of drying room temperature was carried out at 6 points, relative humidity (RH) measurement using a humidity meter with sensors placed inside the drying room and sensors outside the dryer for RH ambient measurements. Then the measurement of the drying room temperature will be measured using a thermometer which is placed at several points as shown in Figure 4.

Figure 4. RH vs temperature of GHE vent dryer day 1

Figure 4 shows the comparison between the ambient temperature and the temperature in the drying chamber that the hotter the radiation, the lower the humidity produced in the drying chamber and the environment. The lowest RH value was at 15.00 pm, which is RH value reached 25%. Based on the graph, we can see that the drying temperature began to increase around 10.00 am to 17.00 pm, at 18.00 pm the temperature began to decrease, this was influenced by the decreasing value of solar irradiation.
The amount of pressure is directly proportional to the humidity of the air inside the tool, the smaller the pressure inside the tool, the lower the humidity [11].

The temperature of the drying chamber during drying has a relatively uniform pattern with respect to time in each hour. In the first test at 08.00 am the absorber temperature was 31 °C with an ambient temperature of 27 °C then at 09.00 am was 40 °C with an ambient temperature of 29 °C. The difference between the temperature of the drying chamber and the ambient temperature indicates that the temperature of the drying air in the drying chamber has absorbed heat from solar radiation. The lowest RH value was at 15.00 pm, which was the RH value reached 25%. Based on the graph, we can see that the drying temperature began to rise around 10.00 am to 17.00 pm. While at 18.00 pm the temperature began to decrease this was influenced by the decreasing value of solar irradiation [12].

![Figure 5. RH vs temperature of GHE vent dryer day 2](image)

The drying temperature at each initial time tends to increase and exceeds 5 °C from the ambient temperature, at 14.00 pm the radiation value begins to decrease due to the cloudy weather, then at 16.00 pm the weather gets worse with rain, but with reduced radiation, it does not affect the absorber temperature, it can be seen at 18.00 pm the radiation value obtained at that time was 0.4 W/m², the ambient temperature reached 30 °C, while the absorber temperature was 49 °C. From this result, it can be seen that paraffin media is good for storing heat [13].

![Figure 6. RH vs temperature of GHE vent dryer day 3](image)
The values of humidity and temperature on days 1, 2 and 3 showed varied results. The temperature on day 2 tends to be higher rather than day 1 and 3 with an average temperature of 65 °C, this is caused by the high value of radiation on day 2 with an average temperature of 70 °C, thus making the storage temperature on that day higher because the initial temperature was high.

The highest air flow velocity measured using an anemometer is found in the outside air, at 08.00 am there is an external air flow velocity (outlet) of 1.2 m/s while the air flow velocity near the ventilator fan is 0.3 m/s. The highest air flow velocity is at night, the air speed was at 22.00 pm, the outside air speed is 1.8 m/s, the air speed near the ventilator (inlet) is 1.5 m/s. High air flow velocity can shorten drying time. An increase of airflow velocity resulted in increase of moisture removal rate [14].

![Airflow velocity diagram](image)

**Figure 7.** Air flow speed day 1

The speed of air flow in the drying process functions as a driving force for the Savanius wheel as a distribution of hot air which is used to evaporate the water content in the material being dried, and at the same time to remove water vapor so that condensation does not occur when drying is in progress [15].

The speed of air flow greatly affects the rate of drying, the faster the wind speed, the faster the rotation of the savanious wheel will be to suck the water vapor of the material in the drying chamber so that drying can take place more quickly. The speed of the outside air greatly determines the rotational speed of the savanious wheel [7]. For the speed of outside air flow using heat storage media can be seen in Figure 7, where the outside air flow rate at 08.00 am to 12.00 pm has increased between 0.2 to 0.5 m/s this is caused by large vehicles passing through the dryer. Figure 8 shows the velocity of the air flow during the drying process. In Figure 8, the air flow velocity for drying day 2 is not much different from the test on day 1. Figure 9 explains that the speed of air flow for drying on day 3 is not much different from the test on day 1 and day 2. Environment and climatic factors also affect the speed of air flow as [16] said. In the drying process, there are many processes that need to be considered, such as climate and raw materials that affect drying time.
The drying chamber temperature is always higher than the ambient temperature. The drying chamber temperature reaches 60°C to 70°C while the ambient temperature is 30°C to 40°C with radiation reaching 1578.0 to 1424.4 (W.hour/m²). The air flow speed is 1.1 to 1.3 m/s, the air flow speed aims to move the ventilator so that the air circulation in the drying room does not evaporated so that it can speed up the drying process. The addition of paraffin heat storage media can increase the temperature in the drying chamber when solar radiation is high and can maintain heat when solar radiation begins to dim.

4. Conclusions
Total radiation at the time of testing without using heat storage media was 1622 W/m². The average total radiation produced when using heat storage media is 1543.6 W/m². The temperature of the absorber plate, absorber chamber, heat storage medium, cover glass and drying chamber is strongly influenced by solar radiation and ambient temperature, where the temperature can change every second due to the influence of solar radiation and the ambient temperature. While, the speed of air flow greatly affects the process of driving the ventilator to remove moisture from the GHE vent dryer so that the drying process
becomes faster. The air velocity in the research area ranges from 2 to 5 m/s. This research concluded that the use of paraffin as a heat storage medium in the GHE vent dryer is able to maintain the temperature in the drying chamber for 4 to 5 hours. It is necessary to add paraffin to retain heat in the drying chamber for a longer time.

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