Experimental Study of Collector Performance Solar Air Heater with Dimple Staggered Arrangement On A V-Corrugated Absorber Plate

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Abstract. The energy crisis is currently the world's major issue in recent decades. The use of energy is almost in all aspects and all human activity depends on energy. For now, the world's energy consumption is still in dominance by fossil energy (petroleum, gas, and coal). Given the limited supply of energy sources, the energy alternative that can be utilized is solar energy. Solar energy utilization technology can be distinguished into two namely the conversion of solar energy into electricity through solar cells, and the utilization of solar heat using solar collectors for drying. This study discusses the influence of the Absorber plate of V-Corrugated dimple form with a staggered arrangement against the performance of solar collectors. The diameter of a dimple on the absorber plate measuring 5, 7, 9 mm. Experiments using halogen lamps with radiation intensity varying from 431; 575; 718 W/m$^2$ and varying mass flow rate of 0.001; 0.002; 0.004; 0.006 kg/s. The results obtained are the magnitude of useful energy that is absorbed by the working fluid of solar collectors directly proportional to the increase in mass flow rate and radiation intensity. For the V- Corrugated absorber plate with a diameter of a 9 mm dimple, the highest Qusefull is achieved at a mass flow rate of 0.006 kg/s with a radiation intensity of 718 W/m$^2$ of 65.9 W and the highest efficiency of 65.7 % achieved at a mass flow rate of 0.006 kg/s with radiation intensity of 718 W/m$^2$.

Keywords: Solar collectors, Absorber V-Corrugated, Dimple, Staggered, The Collectors Efficiency.

1. Introduction

Today's energy crisis has been the main issue of the world in recent decades, the world's energy consumption is still dominated by fossil energy (petroleum, gas, and coal), given the limited supply of energy sources, the energy alternative that can be utilized is solar energy. As a country under the equator, Indonesia has the potential of solar energy resources that can be utilized and applied to a variety of sources, one of them as a source of solar energy for the drying process. Based on data (Indonesia Energy Outlook 2017), said that solar energy that can be utilized in Indonesia is 4.80 kWh/m$^2$/day. [1]. The availability of solar energy is very abundant and easy to obtain because it is very important to be developed with solar collector technology that functions to collect solar energy that is converted into thermal energy and forward the energy to the fluid. The working principle of this solar collector is solar radiation that falls on the collector's surface, then is transmitted through a transparent cover glass and converted into heat energy by an absorbent plate. Then there will be heat transfer from the absorber plate to the fluid flowing through the collector. There are many different types of solar
collectors such as flat plates, wave plates, rack types, and many other collectors, and it all depends on the design and shape of the absorber.

The study was created based on data from previous research related to the use of the V-Corrugated plates as an absorber in solar collectors with experimental studies to obtain data, according to El-Sebaii et al [2]. To improve the performance of solar collectors is using an absorbent plate which is painted using black color. Bashria et al [3], Researching the performance analysis of solar collector V corrugated. The study showed that the channel in the V wave absorber using absorbent media and the variation of flow that passes through the dual-channel (top and bottom) of the absorber plate decreases pressure. This is due to the flow of air passing through V-groove experiencing increased efficiency by reaching 4-5% and airflow using an absorbent media efficiency reaches 7% while the efficiency resulting from solar collectors without the use of media Absorbent only increased by 2-3%. M. D Azharul Karim et al [4], Conducting experiments using three types of solar collectors, namely the Flat-Plate, Finned and V-Corrugated type, results showed that significant efficiency gains were obtained using the V- Corrugated type, solar collector efficiency with V-Groove Absorber has a value of 10-15% higher than solar collector efficiency with flat plate absorber. Tao Liu et al [5], Perform research on solar collector V- Grove Absorber Solar water heater and flat plate absorber solar water heater. The results of the research are known that the V-corrugated solar collector delivers better performance compared to flat plate collectors. Nat Varayos et al [6], conducted experiments by analyzing heat transfer, whereby the plates formed dimple arranged in Staggered as many as 14 dimples and studied, then the research results compared with flat plate surfaces. Where the number of Nusselt for dimple with Staggered arrangement 26% better than the flat plate surface. And for the absorber plate with a surface dimple arrangement inline composition of the result shows the amount of Nusselt 25% better than the flat surface plate.

Brij Brushan [7], conducted research on Nusselt number and friction factor for air heater pipe owned by absorbent plate, from the results of its experimental research on the plate absorber form of dimple producing Heat transfer, is higher compared to the flat plate. Ekadewi A. Handoyo et al [8], Conduct testing on solar collectors air heaters with a V-corrugated type absorber plate that is given obstacle at the base of the airways. Experiments were performed for streams without obstacle and flow by using bent obstacle with all different angles, ranging from 0° (straight, not bent),10°, 20°, 30°, 40°, 50°, 60°, 70°, and 80°. The highest efficiency of the collector is 0.85 achieved when the radiation intensity is 430 \text{ W/m}^2, the airflow speed in the channel is 6.5 \text{ m/s} (Reynolds number 10,000), and the given obstacle straight. From the results obtained, the obstacle with optimal performance is when bent with an angle of 30°. Hakam et al [9], Conducting experimental research on solar collector air heaters with V-corrugated absorbent obstacle half-shaped with a bend angle of 30°. The best efficiency is 0.92 % gained when the mass flow rate is 0.008 \text{ kg/s} and the solar radiation intensity is 431 \text{ W/m}^2. From some of the research, some problems will be further researched regarding solar collector's V-corrugated absorber air heater with the addition of dimple on the Absorber plate with a staggered arrangement so that the authors focus the research On the V- Corrugated solar collector absorber dimple that in stacking is staggered.

2. Experimental Setup and procedure
This study used a solar collector type V-Corrugated absorber plate formed dimple. On the surface of the plate dimple arranged in staggered left and right sides. Where in conducting this research conducted experimentally, this study 3 solar collectors varied diameter dimple with a size of 5, 7, 9 mm. Experimental study has been done in a laboratory of Mechanical Engineering Department of Institute of Teknologi Sepuluh Nopember, Surabaya, Indonesia. Specification solar collector, size 900 mm (long) x 60 mm (width) x 125 mm (height), use glass tempered glass cover, thickness = 5 mm, absorbent plate (Absorber), plate made of aluminum with 2 mm thickness, and painted black color V-Corrugated shaped, size 900 mm (length) x 30 mm (width) x 86 mm (height), number of routes, 1 route.
Fig. 1. The dimension of the solar collector plate v-corrugated absorber with dimple staggered

Fig. 2. Work Scheme and equipment used in solar collectors

Description:

1. Halogen Lamp
2. Cover Glass
3. Absorber Plate Dimple
4. Honeycomp
5. Blower
6. Thermocouple display
7. Air Flow
8. Isolator

The working principle of this solar collector is the solar radiation will be directly emitted on the collector and about the glass cover solar collector. The heat of radiation is absorbed by the absorber plate to heat the working fluid. The fluid that is sucked by a blower with a certain speed to its next duct about the absorber plate formed dimple with a staggered arrangement. The temperature increase is expected to occur when the fluid exits the duct.
3. Experimental Study

The research equipment used is a Pyranometer, which serves to measure solar radiation from the field of hemispherical view on a flat surface. The SI Irradiansi Unit is a watt per square meter (W/m²), Anemometer, used to measure wind velocity thermometer, Arduino Thermocouple Multiplexer Shield, used to read temperature, type: KTA-259K, Thermocouple type K, artificial Ocean Control Australia, temperature range : -200 ± 1350 °C, accuracy : 2 °C, Magnetic Differential Pressure Gage, used for reading pressure, type: 2300-120 Pa, Zero Range Center, artificial: Dwyer Range :-60 to 60 Pa, accuracy: ± 2%, Halogen lamp, for lighting on solar Collectors as a sun repellent in conducting research, Voltage Regulator, used to adjust the velocity of the inlet air, Blower, used for air supply into the solar collector, Power supplay : 260 watts. Voltage : 220 Volt, Speed Blower : 3600 rpm. Discharge Diameter : 2.5 Inch.

During the testing process in the solar collector, some parameters will be measured, the working fluid temperature into the channel ducting (T_{fluid in}), the temperature of fluid working out ducting channel (T_{fluid out}), ambient air temperature (T_{amb}), Absorber plate temperature (T_{abs}), temperature cover glass (T_{cg}), base temperature (T_{base}), temperature insulation (T_{iso}), intensity of radiation extraterrestrial (I_t), speed fluid work (V_f), Δ Pressure (Pa).

This research has three phases, including the preparation phase, the data retrieval stage and the final stage. The explanation of each stage will be explained as follows: Preparation phase, Preparing and ensuring that all equipment used in the condition is calibrated: Pyranometer, thermocouple selector, blower, digital thermometer, magnetic differential pressure gage, and electrical circuits required. The data retrieval phase, Ensure that all equipment is properly arranged, Varying the velocity of air mass and the intensity of light. This variation is done to get a Useful Energy and efficiency. For each experiment process, the mass flow rate and radiation intensity are constant. Thus Q_{useful} and efficiency are gained from solar collectors. The energy in the

4. Result and Discussion

Solar collector air heaters used in this experiment were solar collectors with a Corrugated V-shaped absorber plate with a stout dimple arrangement on each side of the left and right along the route where the working fluid is streamed at the bottom of the plate Absorber. In this experiment carried out the calculation of 3 plates of absorber with a variation in the diameter dimple 5, 7, 9 mm. This experiment also performs variations in the velocity of air mass and the intensity of light. This variation is done to get a Useful Energy and efficiency. For each experiment process, the mass flow rate and radiation intensity are constant. Thus Q_{useful} and efficiency are gained from solar collectors. The energy in the
form of useful heat from the solar collector's flow type air heater under the V-Corrugated absorbent plate is outlined in the equation below:

\[ Q_{use, atual} = \dot{m} C_p \left( T_{fluida, out} - T_{fluida, in} \right) \]  

And

\[ Q_{use, desain} = A_C F_R \left( S - U L \left( T_{fluida, in} - T_{amb} \right) \right) \]  

Description: \( Q_\text{use} \) = Useful Energy (Watt), \( S \) = Absorbed solar radiation per unit area (W/m²), \( U_L \) = Collector Overall Heat Loss Coefficient (W/m² K), \( \dot{m} \) = mass flow rate (kg/s), \( C_p \) = Isobaric Specific Heat (J/kg °C), \( T_{fluida, in} \) = fluid temperature in ducting channel (K), \( T_{fluida, out} \) = fluid temperature out ducting channel (K), \( F_R \) = Collector Heat removal factor, \( T_{amb} \) = ambient temperature (K).

The efficiency of solar collector air heaters on a V-corrugated type absorbent plate is outlined in the equation below:

\[ \eta = \frac{Q_U}{A_C I_T} \times 100\% \]  

Description: \( \eta \) = Collector efficiency, \( Q_{use} \) = useful energy (Watt), \( A_C \) = Collector Area (m²), \( I_T \) = Solar radiation intensity (W/m²).

On the experiments done then obtained \( Q_{use} \) results and the efficiency of the solar collector with a diameter of dimple 5, 7, 9 mm. Calculation results can be seen in table 1.

4.1. Useful Energy Analysis on Solar Collectors

| \( I_T \)  (W/m²) | \( \dot{m} \)  (kg/s) | Temperatur Absorber (K) | \( Q_{use, aktual} \) (Watt) | \( \eta_{Atual} \) (100%) |
|-------------------|-----------------|----------------|------------------------|-----------------|
|                   |                 | Diameter Dimple | Diameter Dimple | Diameter Dimple | Diameter Dimple |
| 431.373           | 0.001           | 319.3          | 322.0                  | 326.1           | 11.8            | 13.4            | 17.1            | 17.3            | 19.3            | 23.9            |
| 431.373           | 0.002           | 317.9          | 320.1                  | 323.9           | 13.7            | 21.7            | 29.1            | 20.0            | 31.1            | 40.7            |
| 431.373           | 0.004           | 314.0          | 315.2                  | 317.1           | 22.1            | 35.1            | 45.0            | 32.4            | 50.3            | 63.0            |
| 431.373           | 0.006           | 313.1          | 314.9                  | 316.2           | 24.7            | 39.5            | 46.9            | 36.2            | 56.7            | 65.7            |
| 575.163           | 0.001           | 327.0          | 330.2                  | 332.2           | 16.0            | 19.2            | 23.7            | 17.5            | 20.7            | 24.9            |
| 575.163           | 0.002           | 323.2          | 327.4                  | 329.1           | 16.7            | 26.0            | 33.1            | 18.3            | 28.0            | 34.7            |
| 575.163           | 0.004           | 318.2          | 320.7                  | 321.8           | 30.2            | 42.0            | 53.8            | 33.1            | 45.1            | 56.5            |
| 575.163           | 0.006           | 315.6          | 317.3                  | 319.5           | 30.2            | 45.2            | 60.1            | 33.1            | 48.7            | 63.1            |
| 718.954           | 0.001           | 334.5          | 336.0                  | 338.9           | 17.9            | 24.0            | 28.5            | 15.7            | 20.7            | 23.9            |
| 718.954           | 0.002           | 327.7          | 331.3                  | 335.5           | 19.9            | 34.6            | 42.4            | 17.5            | 29.8            | 35.6            |
| 718.954           | 0.004           | 321.1          | 323.2                  | 327.5           | 35.4            | 48.1            | 61.8            | 31.1            | 41.4            | 51.9            |
| 718.954           | 0.006           | 318.1          | 322.5                  | 326.8           | 36.2            | 52.7            | 65.9            | 31.8            | 45.3            | 55.3            |

The graph below shows the results of the mass flow rate to the \( Q_{use, aktual} \) with radiation variations (\( I_T \)) 431; 575; 718 W/m², on a solar collector type absorber plate diameter of 5, 7, 9 mm dimple.
Fig. 4. (a), (b), (c): Graph of Mass Flow Rate Against Actual Quse with variations in radiation intensity on the solar collector Absorber Plate (Ø = 5, 7, 9 mm).

Fig. 4 a, b and c showing the trend of the Quse actual chart will increase with the increase in the mass flow rate, at every variation of radiation intensity 431, 575, 718 W/m². For the plate absorber diameter of a 5 mm dimple, the mass flow rate of 0.001 kg/s, Quse actual result is 11.8 Watt, on the mass flow rate of 0.002 kg/s, Quse actual result of 13.7 Watt, the mass flow rate of 0.004 kg/s, Quse actual results of 22.1 Watt and the mass flow rate of 0.006 kg/s, Quse actual result of 24.7 Watt. For diameter 7, 9 mm The actual Quse result can be seen in table 1. This is due to actual Quse calculations influenced by the magnitude of the mass flow rate (m) and the temperature difference generated during the testing process. Based on the calculation results, the greater the diameter of the dimple plate absorber, the Quse actual produced increases. The results of Quse actual calculations can be calculated thermodynamically with equations Quse actual = \( \dot{m} \times C_p \times (T_{\text{Out}} - T_{\text{In}}) \).

4.2. Efficiency of Solar Collectors

The graphic display below presents the radiation intensity graph of the actual \( \eta \) in the solar collector plate absorber v-corrugated dimple staggered arrangement, with dimensions of 5, 7, 9 mm dimple.
Based on the results of calculations that have been done the performance of solar collectors for actual efficiency can be seen in Table 1 and Fig. 5. (a), (b), (c), (d) by using variations in the mass flow rate. The graph shows the highest trendline in the figure (d), Solar Collector V-Corrugated type dimple staggered plate absorber diameter 9 mm dimple using mass flow rate 0.006 kg/s actual efficiency $\eta$ of 65.7 % at radiation intensity 431 W/m$^2$, and a change in efficiency $\eta$ actual 63.1 %, at radiation intensity 575 W/m$^2$ and the actual efficiency $\eta$ changed to 55.3 % with the intensity of 718 W/m$^2$. The same is also experienced by the solar collector of the absorber plate with a diameter dimple of 5, 7 mm dimple a change in efficiency can be seen in Table 1. It is in accordance with the equation

$$\eta_{\text{actual}} = \frac{Q_{\text{use, actual}}}{A_s I_t}$$

That large efficiency is directly proportional to the heat received by air and inversely proportional to the radiation intensity received the absorbent plate, therefore the trend of the chart increases with the rate of change of mass flow rate to Solar collectors.

5. Conclusions

From the analysis and discussion done, then there are several conclusions as follows: Based on experimental results and calculations on the solar collector the highest $Q_{\text{use, actual}}$ yield is a 9 mm dimple diameter absorber plate with a mass flow rate of 0.006 kg/s with radiation intensity of 718 W/m$^2$ of 65.9 Watt While $Q_{\text{use, design}}$ at a mass flow rate of 0.001 kg/s with radiation intensity of 431 W/m$^2$ of 17.09 W.
Based on the results of the experiment and calculation of solar collector V-Corrugated absorber plate type is staggered dimple, results of the highest efficiency is a plate absorber diameter 9 mm dimple, that is 65.7 % with a mass flow rate 0.006 kg/s. The radiation intensity of 431 W/m² and the lowest in the absorber plate with a diameter of 5 mm dimple, 17.0 % achieved at a mass flow rate of 0.001 kg/s with radiation intensity of 431 W/m².

Results of experiments and calculations on solar collectors, the larger the diameter of a dimple on the absorber plate then Q_{useful} and efficiency produced by the solar collector will be increasingly greater with the increase in the air time rate.

For the efficiency value, it is directly proportional to the mass flow rate. With the increasing rate of mass flow rate then the efficiency of the solar collector is getting bigger.

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