Experimental and numerical simulation of two 20° angled solar collectors with trapezoidal groove plate

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Abstract
Experimental and numerical study of two 20° angled solar collectors. The solar collector is operated in the 4th floor of the Mechanical Engineering Masters Building, University of North Sumatra, with the working principle that the radiation entering the solar collector will heat the absorber plate further with the help of the natural convection optimum air temperature on the absorber plate will make the temperature the collector's room goes up. Data obtained from experimental measurements are then analyzed or validated using CFD software. The assumptions used in CFD simulations include: steady, incompressible conditions, k-epsilon flow, and models made in the form of 3-D, as well as giving boundary conditions to the object to be analyzed. The purpose of this numerical study is to analyze and study: temperature distribution and fluid flow numerically on the surface of the absorber plate. Based on the simulation results, conclusions are drawn both on temperature distribution and fluid flow according to the recording of results at the time of measurement.

1. Introduction
Solar energy has gone through rapid growth within the last decade due to global efforts to combating climate change where demand for renewable energy resources has increased immensely [1]. According to IEA SHC report [2] solar thermal plants has helped saving 40.3 million tons of oil and causing a CO2 emissions reduction by 130 million ton per year. The solar thermal collector market is expected to reach USD 41.96 billion by the year 2025 [3]. The trend of growing demand calls for more comprehensive solutions to raising the energy generation and reducing costs.

Solar thermal collectors are a major technology in solar energy, which is used to absorb the heat of the solar radiation. The classification of this technology could be made based on the state of system components, active or passive, or based on the type of collector, absorber, working fluid and flow arrangement [4]. Hence, various innovative designs and research work have been proposed to raise the thermal performance of air-based collectors. Trapezoidal groove designs have been introduced to enhance heat transfer rate between air and absorber by increasing the surface area of the heat transfer which is important to thermal performance enhancement of these collectors [5]. Laksahami [6] analyze the performance of trapezoidal corrugated solar air heater with sensible heat storage material. He finds out that, the maximum thermal efficiency in flat plate and trapezoidal corrugated absorber are 15.8% and 21.5% respectively. Gao et al [7] carried out analytical and experimental studies on two types of cross corrugated solar air heater and compared with the flat plate collector, they found that efficiencies of type 1 and type 2 absorber are about 58.9%, 60.3% where the flat plate has about 48.6% of efficiency. The efficiency of corrugated collectors are high and turbulence enhances the heat transfer as a result efficiency is more.
In this case we try trapezoidal groove plate in solar collector. The experimental and numerical studies about trapezoidal groove plate in solar collector. The solar collector is operated in the 4th floor of the Mechanical Engineering Masters Building, University of North Sumatera (3.33 ° N and 98.39 ° East).

2. Methods
In accordance with the limitations of the problem under experimental testing carried out at locations 3.33 ° N and 98.39 ° east. Experimental testing was carried out three days in a row. From the test, we take one data as a sample. The test data were taken on April 23, 2019 at 12:30.

| Experimental Test | \( T_{i_{\text{packs}}} \) | \( T_{o_{\text{packs}}} \) |
|-------------------|------------------|------------------|
| 23/04/19 - 12.30  | 66.73            | 82.76            |

2.1. Pre processing
This process is the initial modeling process in research to create a model that will be numerically computed. The model made is fluid domain that flows in the collector and this two pictures are collector and fluid domain.

![Design collector (a) Isometric view (b) Front view.](image1)

![The collector with trapezoidal grove.](image2)
The stages of pre-processing consist of several steps, namely geometry, meshing, and determination of boundary conditions and solar calculation. At this stage ANSYS Student Version 19.1 software is used.

**Table 2. Boundary condition.**

| Boundary condition | Information                                      |
|--------------------|--------------------------------------------------|
| Inlet              | Tipe: Velocity Inlet                             |
|                    | Temperature: 37.37°C (ambient Temperature)       |
|                    | Velocity: 1 m/s                                  |
| Outlet             | Tipe: Outflow                                    |
| Styrofoam          | Tipe: Wall                                       |
|                    | Material: Styrofoam                              |
|                    | Thickness: 0.03 m                                |
| Glass              | Tipe: Wall                                       |
|                    | Material: Glass                                  |
|                    | Thickness: 0.005 m                               |
| Absorber Plate     | Tipe: Wall                                       |
|                    | Material: Alumunium                              |
|                    | Thickness: 0.001 mm                              |

**Figure 3.** Fluid domain.

**Figure 4.** Meshing.
Radiation energy reaching the collector is calculated based on actual data obtained from the Hobo. Based on calculations, the value of energy reaches the collector within every minute of the test. The following graphs the intensity of solar radiation that occurs during testing.

![SOLAR_RADIATION](image)

**Figure 5.** The intensity of solar radiation.

In accordance with the experimental device testing carried out in terrain with coordinates 3.33° north latitude and 98.39° east longitude. This simulation is adjusted experimental test data to be compared. The data was taken on April 23, 2019 at 12:30

![Set-up solar calculator](image)

**Figure 6.** Set-up solar calculator.

After completing the solar calculator settings we can find out the solar radiation energy to the earth as for the results as follow

![Direct normal solar radiation](image)

**Figure 7.** Direct normal solar radiation.
2.2. Processing
This process is a continuation of processing where the geometry and set-up is ready to run at this stage, using the Fluent ANSYS Student Version 19.1 software.

2.3. Post processing
Numerical simulation is done then we will get temperature data on the flat absorber plate and angular absorber plate.

2.4. Overall heat loss coefficient
We can calculate overall heat loss coefficient based on question 1[8]:

\[ U_t = U_t + U_p + U_e \]  \hspace{1cm} (1)

Where is, \( U_t \) is the Overall Heat Loss Coefficient, \( U_p \) is the Top Heat Loss Coefficient, \( U_b \) is the Bottom Heat Loss Coefficient, and \( U_e \) is the Edge Heat Loss Coefficient.

Where by using the empirical equation S.A. Klein has been modified by Agarwal and Larson, so the upper heat loss can be searched using equation 2, which is:

\[ U_t = \left( \frac{N}{C \cdot \frac{1}{N} \cdot (N + f)} \right) + \frac{1}{h_w} \cdot \frac{\sigma (T_p + T_a) (T_p^2 + T_a^2)}{[\epsilon_p + 0.05 \cdot (1 - \epsilon_p)]^{-1} + \frac{2 + N + f}{\epsilon_c}} \]  \hspace{1cm} (2)

With :
\( h_w = 5.7 + 3.8v \) (W/m².K)
\( f = (1 - 0.04 \cdot h_w + 0.0005 \cdot h_w) \cdot (1 + 0.091 \cdot N) \)
\( C = 520 \cdot (1 - 0.000051 \cdot \beta^2) \)
\( \nu = \text{wind velocity (m/s)} \)
\( N = \text{Number of cover} \)
\( \epsilon_c = \text{emmissivity cover} \)
\( \epsilon_p = \text{emmissivity plat absorber} \)
\( \sigma = \text{Stefan-Boltzman constant} (5.67 \times 10^{-8} \text{ W/m}^2\text{.K}^4) \)
\( T_p = \text{Temperature of plate absorber (K)} \)
\( T_a = \text{Ambient temperature (K)} \)

The bottom value of the heat loss coefficient is approximated by the following this equation

\[ U_p = k \cdot L \]  \hspace{1cm} (3)

Where, \( k \) is bottom thermal conductivity of insulators, and \( L \) is Insulator’s thickness

The coefficient value of the side heat loss is also approximated by the following this equation[6]:

\[ U_e = \frac{\text{UA}_{\text{edge}}}{A_c} \]  \hspace{1cm} (4)

Where, \( UA \) is k/L x perimeter of collector x thickness and \( Ac \) is surface area of collector (m²)

2.5. Heat rate transfer from radiation
By knowing the dimensions of the collector and the intensity of solar radiation, the heat transfer rate received by the collector is obtained by this equation:

\[ q_{in} = U_d \cdot A \cdot \frac{q_{in} - q_{loss}}{q_{in}} \]  \hspace{1cm} (5)

where is, \( U_d \) is k/L x perimeter of collector x thickness and \( Ac \) is surface area of collector (m²)

2.6 Collector Efficiency
So we can calculate collector efficiency by this equation
3. Results and discussion
The experimental results and numerical simulation results that have been developed in accordance with the design and set-ups that have been prepared.

**Figure 8.** Numerical simulation results of temperature distribution on the dryer.

The temperature will be compared that gotten from experimental and temperature that we get from simulation.

| Table 3. Temperature comparison. |
|----------------------------------|
| Temperature plate Absorber 0° (°C) | Experimental | simulation |
| Temperature plate Absorber 20° (°C) | 82.76 | 82.44 |

**Figure 9.** Graphic experimental and simulation temperature comparison.

Next, we will calculate the rate of heat transfer that occurs in angular collectors. The calculation results are in tables

**Table 4.** Heat rate transfer effectivity comparison.

| Calculation Parameter | Heat rate transfer (W) | effectiveness |
|-----------------------|------------------------|---------------|
| $Q_{use,exp}$         | 1274.064               | 0.74          |
| $\varepsilon_{exp}$   |                        |               |
| $Q_{use, simulation}$  | 29646.81               | 0.90          |
| $\varepsilon_{simulation}$ |                    |               |
4. Conclusions
The simulation of the solar collectors has done. The heat transfer rate that occurs at the collector with experimental calculation is 1274.064 Watt, and simulation calculation is 1312.2 Watt. As we can see that efficiency of collector based on experimental calculation is 74% and simulation is 90%.

References
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