Numerical and experimental study on Solar Updraft Power Generator (SUPG)

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Abstract. The need for energy is fundamental to drive the economy and social from the community. Clean, renewable, and sustainable energy is the one desired by the community today. Solar Updraft Power Generator (SUPG) is one power generation system that utilizes heat from solar radiation to produce artificial wind that will drive the wind turbine. This study consists of numerical and experimental analysis. The numerical analysis uses ANSYS 17.2 and SOLIDWORKS 2016. SOLIDWORKS 2016 is the software used in designing SUPG geometry. ANSYS 17 is the software used to analyse SUPG velocity and temperature contour. Then the numerical analysis would be compared with the experimental analysis. The study took place on a SUPG the laboratory conversion energy of the Muhammadiyah University of Riau. From the numerical analysis we can conclude that the higher ∆T ground-ambient would resulting a higher air velocity. Compared numerical to experimental analysis showed a difference. For numerical analysis from ∆T ground-ambient 5℃ resulting maximum velocity 1.6 m/s, while for experimental analysis from average ∆T ground-ambient 3.6℃ resulting maximum velocity 4.1 m/s. This happened because there still much external force (such as wind) that increase the velocity that generated inside the Solar Updraft Power Generator beside the buoyance force.

1. Introduction

In 2011, the international energy agency stated that "the development of affordable, non-depleted and clean solar energy technology will provide a large long-term profit. This development will improve the energy security of countries through the use of existing energy sources, not exhausted, and not dependent on imports, improve sustainability, reduce pollution, reduce the cost of mitigating climate change, and keep the price of fossil fuels low than before.

Solar Chimney is a system used to convert heat radiation into air. Solar thermal power plants are grouped into two main categories: high and low power plants. This depends on their temperature level. High temperature power plants collect direct solar radiation and use thermodynamic processes with closed cycles. Plants have very high efficiency, but behind it all the operational costs and capital are very high. Chimney solar power plants are classified as power plants with low temperatures because the working fluid is still maintained, especially in the free atmosphere. This process showed at fig 1 below.
Figure 1. Solar Updraft Power Generator Process

In this context, the work of this research aims compared numerical analysis used fluent and experimental data on Solar Updraft Power Generator. The experimental data used a Solar Updraft Power Generator Device in the laboratory conversion energy of the Muhammadiyah University of Riau. This device showed at fig 2 below.

Figure 2. Solar Updraft Power Generator Device

Where:
1) Chimney
2) Bell mouth
3) Acrylic collector
4) Acrylic support

2. Literature Review
Shiv L, S.C. Kaushik and Ranjana Hans [1] 2016. Experimental investigation and CFD simulation studies of a laboratory scale solar chimney for power generation. Hermann F. Fasel, Fanlong Meng, Ehsan Shams and Andreas Gross [2] 2013. CFD analysis for solar chimney power plants. Aakash Hassan, Majid Ali, and Adeel Waqas [3] 2018. Numerical investigation on performance of solar chimney power plant by varying collector slope and chimney diverging angle. Yangyang Xua and Xinping Zhou [4] 2018. Performance of divergent-chimney solar power plants. Rayan Rabehi, Abla Chaker, Tingzhen Ming & Tigrui Gong [5] 2018. Numerical simulation of solar chimney power plant adopting the fan model. Ridwan Abdurrahman, Ari D. Pasek and Pandji Prawisudha [6] 2017. Numerical and Experimental Study On Rocket Stove Combustion Process for Heating Stirling Engine.

2.1 Computational Fluid Dynamic
In this study, ANSYS workbench (17.2) software was used in the computational fluid dynamic analysis on Solar Updraft Power Generator. An 3D model Solar Updraft Power Generator was made using Solidwork 2016 & export to ANSYS workbench as shown in fig 3. Tetrahedral and triangular elements were used to mesh of Solar Updraft Power Generator design. The design was modeled with 10249 nodes and 42766 elements.

![Mashing of model](image)

Figure 3. Mashing of model

Computational fluid dynamic of Solar Updraft Power Generator by ANSYS software for gaining the temperature and velocity inside the Solar Updraft Power Generator with variation of temperature outside, and surface of Solar Updraft Power Generator. Condition parameters for this research are listed in Table 1.
Table 1. Condition Parameters

| Condition | T ambient (celcius) | T ground (celcius) |
|-----------|---------------------|-------------------|
| 1         | 30                  | 35                |
| 2         | 30                  | 40                |
| 3         | 30                  | 50                |
| experimental | 31.7                | 35.3              |

The properties of component of Solar Updraft Power Generator

Table 2. Properties of materials

| Properties                          | Peat (Absorber Plate) | Aluminium (Chimney) | Acrylic (Collector Roof) | Air |
|-------------------------------------|------------------------|----------------------|--------------------------|-----|
| Density (kg/m³)                     | 400                    | 2700                 | 1180                     | 1,125 |
| Thermal Conductivity (W/mK)         | 1880                   | 910                  | 1460                     | 1006,4 |
| Specific Heat Capacity (J/kgK)      | 0.11                   | 237                  | 0.17                     | 0.0242 |

2.2 Stack Effect

The stack effect happens because the temperature inside the chimney is higher than outside the chimney, this condition makes the density of air become smaller and lighter. The lighter air would move up and cause a vacuum inside the chimney. This vacancy will be filled with new air from outside the chimney. Stack effect on solar updraft could be seen in fig 4.

Stack effect equation,

\[ \Delta Ps - 0 = \left( \frac{1}{T_o} - \frac{1}{T_s} \right) g \cdot h \cdot P \]

where
\( \Delta Ps - 0 \) = pressure difference (Pa)
\( T_o \) = T ambient (K)
\( T_s \) = T ground (K)
g = gravity (m/s)
h = chimney height (m)
p = atmospheric pressure (Pa)
R = ideal gas coefficient (J/kg.K)

2.3 Boundary Condition
The boundary condition of this simulation showed on fig 5 below.

A semi-transparent wall with heat transfer coefficient 10 W/m2K is applied to wall akrilik (i.e. at position “A” marked on fig 5). An opaque wall with adiabatic condition is applied to wall cerobong (i.e. at position “B” marked on fig 5). An atmosphere pressure is applied to pressure outlet (i.e. at position “C” marked on fig 5). A pressure based on stack effect equation is applied to pressure inlet (i.e. at position “D” marked on fig 5). An opaque wall with temperature based on surface temperature is applied to wall base (i.e. at position “E” marked on fig 5). An opaque wall with adiabatic condition is applied to wall rangka (i.e. at position “F” marked on fig 5).

3. Result and Discussion

3.1 Velocity
The maximum velocity happened on bell mouth area. maximum velocity on condition 1 was 1.6 m/s shown on fig 6. This value gradually drops around inlet at 0 m/s. velocity for other condition were shown on fig 7.
The influence of temperature showed that higher $\Delta T$ ground-ambient, the higher velocity that generated by solar updraft. By comparing the velocity that generated between simulation and experiment, we notice there are differences. For numerical analysis from $\Delta T$ ground-ambient $5^\circ$C resulting maximum velocity $1.6$ m/s, while for experimental analysis from average $\Delta T$ ground ambient $3.6^\circ$C resulting maximum velocity $4.1$ m/s. This happened because there still much external force (such as wind) that increase the velocity that generated inside the Solar Updraft Power Generator beside the buoyance force.

3.2 Film Temperature
The influence of temperature showed that higher $\Delta T_{\text{ground-ambient}}$, the higher $T$ film that happened on solar updraft.

By comparing the velocity that generated between simulation and experiment, we notice there are difference. For numerical analysis from $\Delta T$ ground-ambient 5°C resulting $T$ film 39.5°C, while for experimental analysis from average $\Delta T$ ground-ambient 3.6°C resulting $T$ film 33.7°C.

4. Conclusion
The result shows that
1) The influence of temperature showed that higher $\Delta T$ ground-ambient;
   a) the higher velocity that generated by solar updraft
   b) the higher $T$ film that happened on solar updraft
2) The difference velocity between simulation and experimental happened because there still much external force (such as wind) that increase the velocity that generated inside the Solar Updraft Power Generator beside the buoyance force.

References
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