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Thermal Analysis of Inlet/Outlet Temperature for Heat Exchanger in Micro Gas Turbine by Numerical Method

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Abstract: Recuperator is one type of heat exchanger that frequently used in a gas turbine to enhance the effectiveness of the system by two-way method of heat transfer, cooling, and heating. The heat exchanger is a heat transfer system used to transfer thermal energy between two or more fluids available at different temperatures. There is a lack of improvement research for the recuperator that can achieve slight thermal equilibrium for the heat distribution for maximum efficiency of the system. By using ANSYS-FLUENT software with steady-state thermal conduction, most efficient plate fin geometrical design and material used for fabrications will be evaluated to enhance thermal distribution of the heat exchanger, and three inlet temperatures will constantly be supplied by waste heat which are 200°C, 350°C and 500°C. A distinct boundary condition and mesh sizing need to be emphasized to attain good mesh node value and accurate outcomes. The specific turbulence model, *K*-Omega SST is chosen for the similarity of its characteristics to be selected with this study criteria. The simulation on steady state condition found the copper is better in thermal or heat conductor than aluminum due to high value of thermal conductivity, *k*. In terms of design, triangular type heat exchanger recorded the highest net temperature between the inlet and outlet temperature compared to rectangular type heat exchanger. As a conclusion, the combination between triangular type design and copper material will produce the best heat exchanger that will be used in experimental test of recuperator system.

Keywords: Droplets, mask, flow characteristic, cough, dispersion, velocities

1. Introduction

Gas turbines are energy systems (based on thermodynamic transformations) that used to converts the chemical energy in the fuel into mechanical energy, such as natural gas or similar fuel. The mechanical energy generated by the exit shaft of the turbine is then transferred to the generator shaft through the gearbox. Afterwards, the generator will produce electrical energy, where the form of energy would usually have a low or medium voltage level and, to better control the power loss in the transmission line, the voltage would be increased by the step-up transformer. Such a transformer generates enough voltage for the electrical energy to be transmitted through the transmission lines and distributed to the grid.

The common industries sector that used gas turbine power plant such as energy production, oil & gas processing plants, and small industries. The simple cycle turbine called Brayton gas cycle is mounted by a compressor, combustion chamber and a gas turbine on a single axis [1]. Open-cycle and closed-cycle are the existing types of gas turbine. To improve the gas turbine efficiency and reduce air pollution due to gas turbine emission, researchers has been strived to study and develop [2]. One of approaches are focusing on raising turbine temperatures of input and output, and the compression ratio. Both are restrained by material resistance, but also by the chance that turbine temperatures may degrade. This study will be analyzed on the aspects of design geometry and best material selection to examine the heat distribution at the inlet and outlet location.

The efficiency of the latest design of the micro-gas turbine cogeneration and trigeneration systems with the steam ejector cooling system and the Heat Recovery Steam Generator (HRSG) is currently being studied in numerous recent modern research [3-5]. An industrial micro gas turbine cycle can generate from 30 - 500 kW of power, and it would be huge loss for the exhaust gases to be released to surrounding without reusing it to pre-heat the cold intake air.

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For micro gas turbine, they generally used in the light industry as they are small-scale (up to 500kW), rather that Combined Heat and Power production where there usually belong in the major market [6]. Even though it not widespread in the heavy industry micro gas turbine have also a relatively high specific investment cost, so any breakdown of the operation where there is no need for heat has a negative impact on economic growth. To counter the obstacle for the micro gas turbine to improve significantly, hence increasing the economic performance and the electrical efficiency, research suggests to introduced water in micro gas turbine cycle during periods with low heat demand. In this study, we will confront on what type of recuperator heat exchanger design specification that are most efficient.

1.1 Heat Exchanger

A heat exchanger is a heat transfer system that transfers thermal energy between two or more fluids that are at different temperatures. It is commonly utilized in practically all process and power facilities to generate steam for the primary purpose of generating energy via steam turbines [7]. In most heat exchangers, the fluids are separated by a heat transfer surface and are preferably not mixed or in close contact with each other. Popular examples of real-life use heat exchangers are automotive radiators, condensers, evaporators, air preheaters, and oil coolers. Frequently used heat exchangers are shell and tube, finned tube, plate fin and cooled air.

There was previous attempt to refine the configuration of the air-fuel heat exchanger design on investigating individual air and fuel side heat transfer systems. Numerous heat exchanger designs use the fluid flow to regulate the heat distribution on the system, which means raising the effectiveness of system by heating/cooling the fluid. The exhaust gas is reused to heat the cold air. A study used metal foam to facilitate airborne heat transfer [8-10]. Their tests have shown that foam is too heavy for turbine engines and have suggested that other designs with better heat-to-weight ratios be produced. In the preliminary analysis of this study, we will select aluminum and copper as the material used for the heat exchanger for lower production cost, and high thermal conductivity, *k*.

2. Problem Background

Regardless of all advances in the gas turbine industry, there are still many problems that need to be explored to improve the estimation of the performance and efficiency of the gas turbine. There is a lack of overall research into heat exchangers and, as a result, the heat exchanger in the gas turbine does not have a proven conceptual design. Heat exchangers in gas turbines are critical for engines to be used in the best optimal performance. It is necessary to make the thermal distribution process in heat exchangers to strive for thermal equilibrium to boost the overall performance of the gas turbine or device [11-13].

Analysis of the geometry of the plate design requires a high cost and time-consuming due to many parameters involved in the study. The cost and time would be minimized by the simulation process. In this analysis, the geometrical design type of heat exchanger, materials use for manufactured, and different hot inlet temperature will be examined [14,15]. From this analysis, the most efficient plate fin geometry and material used will be evaluated to enhance heat distribution in the system. Hence, the objective of this study is to determine the most optimum geometrical design and materials used for the plate-fin heat exchanger to regulate fluid temperature distribution using simulation of ANSYS FLUENT software.

3. Methodology

Nowadays, the usage of computational fluid dynamic (CFD) Ansys Fluent are recommended compared to the traditional experiment approach to complete this research. It is because the Ansys Fluent provide the low costing to run the experiment throughout simulation analysis. Analysis of the geometry of the plate design requires a high cost and time-consuming design due to many parameters involved in the study.

3.1 Conceptual Design

The conceptual design of heat exchanger for this project is generated based on turboshaft gas turbine aeroengine design by Combustion Research Group (CRG), FKMP, UTHM. The concept geometrical design of cooling/heating recuperator of the micro gas turbine was a basic idea of conceptual idea and shows in Figure 1.

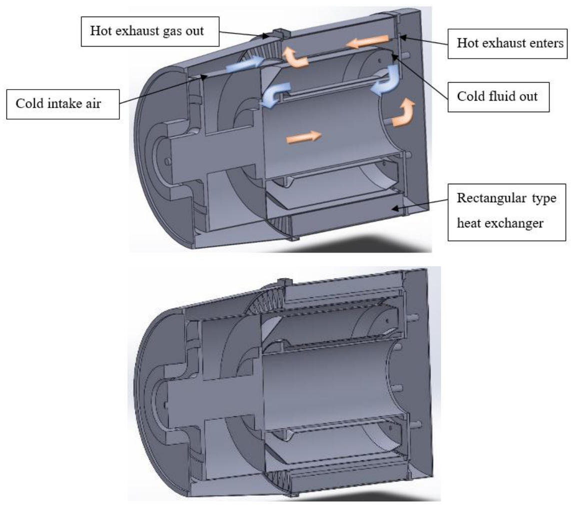
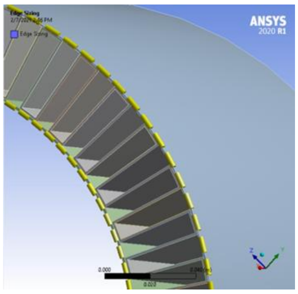
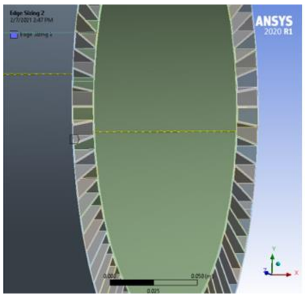


Fig. 1 – Turboshaft gas turbine aeroengine with rectangular type of plate fin heat exchanger (above), with triangular type of plate fin heat exchanger (below).

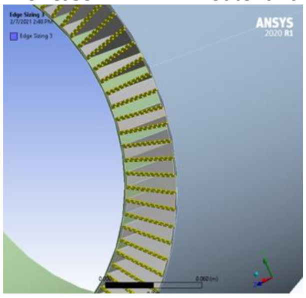
For design process, SolidWorks software was used to produce detail CAD drawing of heat exchangers. The design was exported to ANSYS Fluent for simulation process. The design that imported from SolidWorks then be meshing using meshing tool in ANSYS. Figure 2 shows the meshing process that implement for the design.



(a) Mesh sizes at the front of outer and inner case



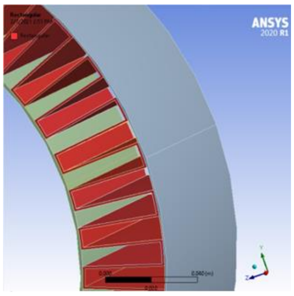
(b) Mesh sixes at the middle outer and inner case



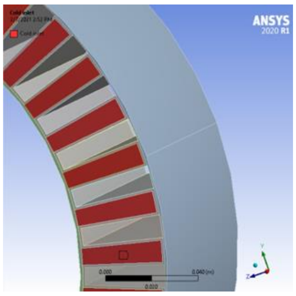
(c) Mesh sizes at the front rectangular/triangular heat exchanger

Fig. 2 – Meshing sizes location that generated

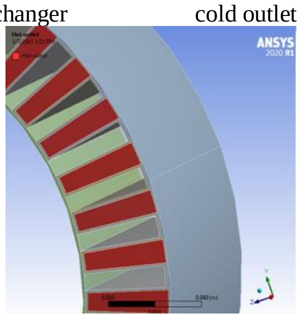
The next step in ANSYS setup was specify the boundary conditions. The boundary condition was named for the inlet and outlet position for both hot and cold fluid, the rectangular/triangular type plate fin heat exchanger, and the inner and outer case body of the heat exchanger. The named boundary condition selected are shown in Figure 3.



(a) BC for rectangular type heat exchanger



(b) BC for cold inlet (front), cold outlet fluid (back)



(c) BC for hot inlet fluid (front), hot outlet fluid (back)

Fig. 3 – Location for boundary condition setting

The other important parameter that was set for simulation was the value of boundary conditions itself. Table 1 are summarized of the properties for aluminum and copper that used for simulation.

Table 1 – Parameter of boundary condition

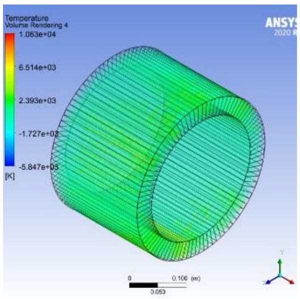
Properties/Materials	Aluminum	Copper
Density	2702.0 kg/m^3	8933.0 kg/m^3
Specific heat	903.0 $J/kg.K$	385.0 $J/kg.K$
Thermal conductivity	237.0 $W/m.k$	401.0 $W/m.k$

4. Results and Discussion

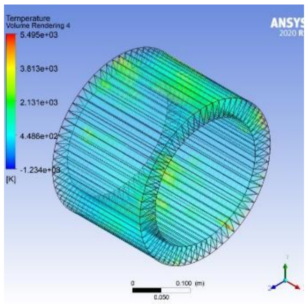
4.1 Steady State Thermal Analysis

Steady-state thermal analysis calculates the effect of steady thermal loads on a system or component. Engineer often performs a steady-state analysis before doing a transient thermal analysis, to help establish initial conditions. A steady-state analysis also can be the last step of a transient thermal analysis; performed after all transient effects have diminished. A steady-state thermal analysis may be either linear, with constant material properties; or nonlinear, with material properties that depend on temperature. The thermal properties of most material do vary with temperature, so the analysis usually is nonlinear. Including radiation effects also makes the analysis nonlinear.

Control parameter used in the simulation were 3 different inlet temperature: $200°C$, $350°C$ and $500°C$. Figure 4 showed that temperature profile in Condition 1; Copper in Steady-State Thermal with $200°C$ Inlet Temperature where different colours on the profile showed the temperature distribution on the exchangers. For rectangular type heat exchanger, Figure 4(a) showed uniform temperature distribution where the hot fluid outlet emits higher temperature reading rather than cold fluid outlet. However, the temperature is evenly distributed throughout the system even though the temperature desired for hot fluid outlet location tend to be much higher that the hot fluid inlet location, $200°C$. In contrast, for Triangular type Heat Exchanger, the temperature that was sought-after was achieved as showed in Figure 4(b).



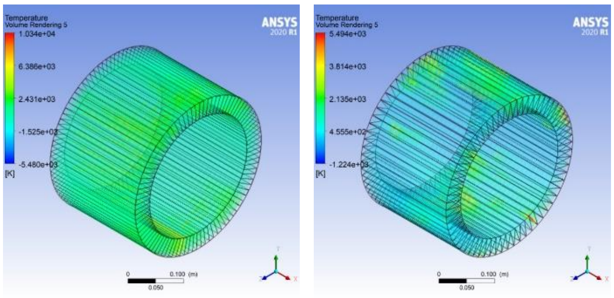
(a) Rectangular type HE



(b) Triangular type HE

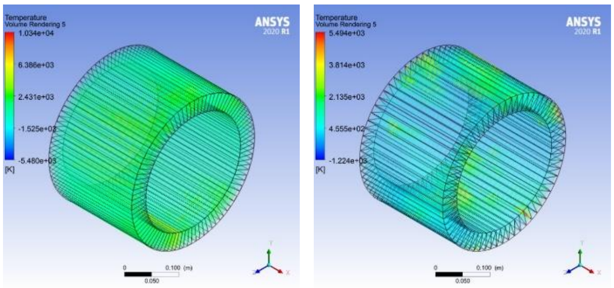
Fig. 4 – Condition 1: Copper in Steady-State Thermal with $200°C$ Hot Inlet Temperature

Based on the observations made for the next inlet temperature of $350°C$ and $500°C$, there are similarities in the patterns in temperature distribution even at different inlet temperature. The results for condition 2 and 3 were shown in Figure 5 and 6 respectively. Where the result may vary from one other, which rectangular type of heat exchanger may give higher difference between inlet and outlet output, and some results also showed triangular type heat exchanger gave higher difference.



(a) Rectangular type HE (b) Triangular type HE

Fig. 5 – Condition 2: Copper in Steady-State Thermal with $350°C$ Hot Inlet Temperature



(a) Rectangular type HE (b) Triangular type HE

Fig. 6 – Condition 3: Copper in Steady-State Thermal with $500°C$ Hot Inlet Temperature

Table 2 and 3 shows the outcome for the hot fluid outlet, the desired data needed was achieved but with a small margin rather result from the table where it has higher temperature difference.

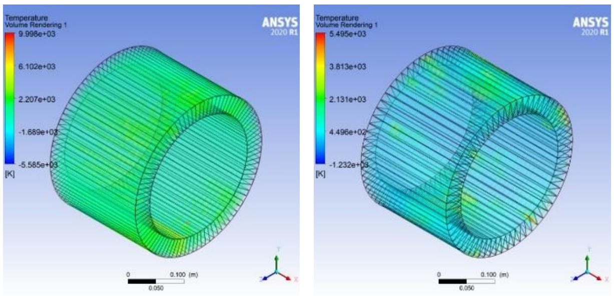
Table 2 – Rectangular HE Static Temperature for Copper

Fluid Type	Analysis Location	Average of Facet Value Static Temperature, *K*
Cold	Inlet	300.000
	Outlet	357.691
Hot	Inlet	473.000
	Outlet	468.009
Net Value		399.675

Table 3 – Triangular HE Static Temperature for Copper

Fluid Type	Analysis Location	Average of Facet Value Static Temperature, K
Cold	Inlet	300.000
	Outlet	417.359
Hot	Inlet	473.000
	Outlet	454.462
Net Value		411.205

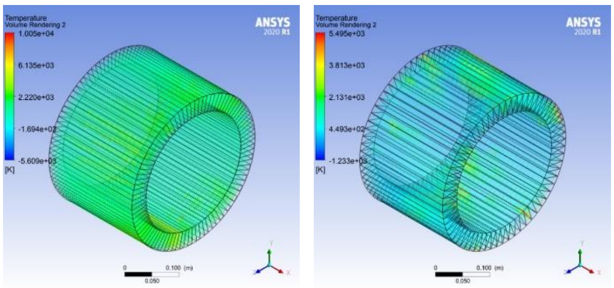
Figure 7 showed that temperature profile in Condition 1; Aluminum in Steady-State Thermal with $200°C$ Inlet Temperature where different colours on the profile showed the temperature distribution on the exchangers.



(a) Rectangular type HE (b) Triangular type HE

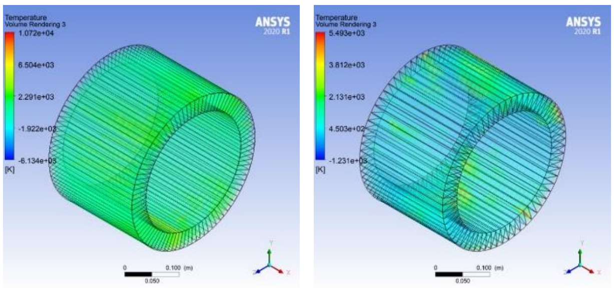
Fig. 7 – Condition 1: Aluminum in Steady-State Thermal with $200°C$ Hot Inlet Temperature

Based on the observations made for the next inlet temperature of $350°C$ and $500°C$, there are similarities in the patterns in temperature distribution even at different inlet temperature. The results for condition 2 and 3 were shown in Figure 8 and 9 respectively. In addition, the accumulated time iteration of convergence for a particular heat exchanger to reach inlet temperature same as condition 1 (inlet temperature $200°C$). This occurs due to the steady-state thermal conditions in which it should never change the time iteration of convergence factor. This shows the two types of heat exchanger design capable of conduct heat very well though copper has greater thermal conductivity than aluminum.



(a) Rectangular type HE (b) Triangular type HE

Fig. 8 – Condition 2: Aluminum in Steady-State Thermal with 350°C Hot Inlet Temperature



(a) Rectangular type HE (b) Triangular type HE

Fig. 9 – Condition 3: Aluminum in Steady-State Thermal with 500°C Hot Inlet Temperature

In steady-state thermal, there were no obvious difference in temperature difference throughout the systems in materials, copper, and aluminum. From this type of analysis known as steady state thermal condition, we can see the effectiveness each of the parameter used for the type of heat exchanger design. It can be seen in Table 4 and 5 the static temperature for aluminum at the same hot fluid inlet temperature, $200°C$.

Table 4 – Rectangular HE Static Temp. for Aluminum

Fluid Type	Analysis Location	Average of Facet Value Static Temperature, *K*
Cold	Inlet	300.000
	Outlet	334.691
Hot	Inlet	473.000
	Outlet	465.009
Net Value		393.176

Table 5 – Triangular HE Static Temp. for Aluminum

Fluid Type	Analysis Location	Average of Facet Value Static Temperature, *K*
Cold	Inlet	300.000
	Outlet	375.046
Hot	Inlet	473.000
	Outlet	464.462
Net Value		403.127

Table 6 sums up the time iteration of convergence recorded by the two-heat exchanger design with 2 different materials which clearly shows steady state thermal analysis has not varied over time iteration. The proper design of the heat exchangers was very important for the overall performance of the recuperator of micro gas turbine system. The cold fluid will be heated up from the inlet temperature, meanwhile the temperature for hot fluid will be cool down instead.

Table 6 – Time convergence comparison between Copper (*Cu*) and Aluminum (*Al*) in steady state thermal analysis

	Inlet Temperature					
	200°C		350°C		500°C	
Types of HE / Material	Cu	Al	Cu	Al	Cu	Al
Rectangular	55	55	55	55	55	55
Triangular	30	30	30	30	30	30

5. Conclusion

The following is a summary of conclusions from this study for the steady state of thermal analysis:

- Theoretical analysis of heat conduction for full body of heat exchanger showed that 5164.18 W of heat is flow through a copper body while aluminium body only flow 3509.13 W of heat.
- The ability to transfer more heat was a function of temperature distribution on the heat exchanger.
- Copper, as the heat exchanger material, provided faster temperature distribution inside heat exchanger itself compared to aluminium due to high value of thermal conductivity for copper ($401\ W/m.k$) and aluminium ($237\ W/m.k$) for steady state analysis.
- Triangular type heat exchanger shows the best design in term of the higher rate of heat transfer from inlet point to the plate fin's region due to more number fins and increase the rate of heat transfer throughout the system compared rectangular type heat exchanger design.

As a conclusion, there is one engagement between theoretical and numerical analysis which is triangular type is the best design for heat exchanger that will be fabricated with copper as the best material in conducting heat to setup experimental test rig of recuperator system.

For recommendation, instead of validation through grid independence test, one other step to do validation data for the mesh metric is by carrying out mesh quality test. Mesh metric are utilised to evaluate the mesh structure situations on multiple boundary surfaces. Mesh quality test also have different criteria to assess the qualities of solid mesh, which are aspect ratio, skewness, orthogonality and smoothness.

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