Simulate, evaluate the temperature performance of TEG when changing the height and angle of inclined plates

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Abstract. Thermoelectric generators (TEG) have attracted considerable attention for the recovery of waste heat of internal combustion engines. In this study, a three-dimensional digital model for engine-based emission generator (ETEG) was developed based on Ansys Fluent simulation platform. By considering the detailed shape of the thermoelectric generator (TEG) and the thermal zones, along with the change in height and angle of the inclined plate. From the various changes studied and the design, optimization proposal was made. It was found that the inclined plate size should be moderate to balance the heat transfer for the TEG modules and reduce the pressure along the inclined plates. Increasing the number of inclined plates can improve thermal efficiency. However, because more space and TEG modules are needed, system size and cost should also be considered. Although it is only possible to place the slant plates at the inlet of the slant plate, it is possible to increase the heat transfer coefficient for the entire TEG hot surface. To ensure efficient use of hot emissions, the angle of inclined plates should be large enough, especially for downstream locations. Since larger inclined angle angles significantly increase the pressure drop, it is suggested that the angle of inclined plates change, with the angle increasing along the flow direction, possibly as a middle lock to balance the heat transfer and pressure drop. A single TEG design may not be suitable for all engine operating conditions and adjusting the number of inclined plates and inclined corners according to different engine operating conditions can improve performance.

1. Introduction
In modern ship power plants (SPP), the main engine determines the overall composition, dimensions and layout of the SPP of any vessel. One of the most important criteria affecting the feasibility of operating DG (Diesel Generator) is its effectiveness in economic terms. One of the popular methods of increasing this productivity is the use of energy from the heat of exhaust gases (EG).

As it is known, in the DG, the SPP spends nowhere more than 48% of the heat of combustion of the fuel, while only the remaining 52% is converted into mechanical energy. One of the effective ways to efficiently use the SPP is exhaust gas utilization through the use of thermoelectric generators (TEG) [1]. They convert the exhaust heat energy directly into electrical energy. The advantages of these generators:

- No moving parts
- Significant lifespan
- Ecological cleanliness
- Silent operation
- Universality in the supply and recovery of heat and exhaust gas
Until recently, the lack of low efficiency (1-2%) was partially leveled (20-30%), which makes it advisable to use TEG in the SPP.

This study is devoted to the issues of increasing TEG productivity due to the intensification of heat exchange. The analysis of TEG structures and their use in power engineering, analysis of ways to increase TEG efficiency were carried out, TEG design was developed to provide heat exchange process intensification and increase of thermoelectric generator efficiency, experimental studies were carried out on a model installation, and experimental and theoretical studies were analyzed work TEG [2]. Despite a preliminary study on the use of TEG in combustion, installations on ships in which potential benefits were conceptually evaluated [3], the study evaluated the heat transfer ability in heat generators, increases the temperature difference between a hot surface and a cold surface, TEG will increase power and efficiency. The procedure of a thermoelectric generator when inserting an inclined plate inside a hot surface by changing the height and angle of the plate is presented in this article using the CFD modeling approach.

2. Methods and Materials.

To estimate the thermal transmittance of a TEG when inserting an inclined plate on a hot surface, we can follow the following scheme:

- **Building a database of TEG hot surface structures when installing inclined plates**
- The simulated surface design is heated by changing the height and angle of the plate
- Methods of summarizing the simulated data and the results of simulated studies
- **Generalized analytical dependences for calculating heat transfer and aerodynamic resistance in TEG with inclined plates**

**Figure 1.** Scheme of TEG heat transfer capability

2.1. **Building a database of TEG hot surface structures when installing inclined plates**

Figure 2 shows the specific size and design of the hot tilt surface when inserting the TEG plate [4]. The inclined plates are arranged in a parallel order, are symmetrical and deviate with a
horizontal surface at an angle \( \theta \), the height of the inclined plate \( h \). Exhaust gas flows to the hot surface of the inclined plates. In this case, heat transfer will affect the hot surface and airflow will affect inclined plates causing turbulent flow. The simulation of a hot surface with changes in the height and angle of the inclined plates to estimate the heat transfer of hot surfaces is confirmed by a change in the temperature field of the hot surface.

2.2. The simulated surface design is heated when changing the height and angle

Fluent-_ansys is a semi-experimental software. The accuracy of the task depends on the user. Particularly relevant are the problems of modelling and the inclusion of simulated constants [7].

The main boundary conditions of the simulation are as follows: the inlet gas temperature is 300 °C - 573 °K, the flow velocity is 5 m/s, the backpressure at the outlet is 1 bar. This requires users to understand the software, to understand the essence of the problem, to be able to analyse and evaluate the results of computational modelling calculated in accordance with the theory. Then outlines various options for improving accuracy. This step can be adjusted as necessary for the study of models.
The modelling process is described in Figure 3 with four specific steps:

1. **Real problem**
2. **Building a research problem model**
3. **Modeling, meshing and placing boundary conditions**
4. **Calculation of simulation values: Pressure, average temperature, etc.**
5. **Analysis of simulation results**

**Figure 3.** Flowcharts for computational simulations.

2.3. **Methods of summarizing the simulated data and the results of simulated studies**

The calculation procedure is similar to that specified in [5] \( F_g = \frac{a^2 \sqrt{3}}{2} \), with amendments taking into account the change in the surface of the heat exchanger. In particular, the calculation of the heat transfer coefficient of the gas was changed.

The cross-sectional area of the flue, \( m^2 \)

\[
F_g = \frac{a^2 \sqrt{3}}{2} + F_H
\]  

(1)

where \( a \) - size of the size of the face of the wall of the hot node, m;

\( F_h \) - cross-sectional area of inclined plates, \( m^2 \).

Cross-sectional area of inclined planes, \( m^2 \)

\[
F_H = 12h\delta \sin \theta
\]  

(2)

where \( h \) - height of the inclined plane, m;
\( \delta \) – element thickness, m;
\( \theta \) - inclination angle, °.

The clearance between inclined planes, m²

\[
\delta_b = \frac{L - \delta \cdot N_g}{N_g - 1}
\]  
(3)

where \( L \) - length of the heat exchanger, m;
\( N_g \) – number of inclined planes in TEG.

\[
\omega_g = \frac{G_g}{\delta_b \cdot h(N_g - 1)}
\]  
(4)

The gas velocity, (m/s)
where \( G_g \) - gas consumption, kg / s;

Heat exchange surface area, m²

\[
F = \frac{Q}{k \cdot \Delta t_{cp}} + F_s
\]  
(5)

where \( F_s \) – surface area of the plates

Nusselt number:

\[
Nu = 3.25 \cdot Re^{0.266} \left( \frac{h}{d} \right)^{0.072} \cdot \theta^{0.077}
\]  
(6)

Coefficient of convective heat transfer for gas with augmentation of heat transfer on the surface of a hot unit:

\[
\alpha_g = \frac{Nu \cdot h}{d}
\]  
(7)

where: \( d \) - the equivalent diameter of the gas flue, m.

Reynolds number for gas:
Re = \frac{\omega_d \cdot d}{v_g} \tag{8}

where: \(v_g\) – kinematic viscosity of gas, m / s.

\(\lambda_g\) – average thermal conductivity of air, W / (m-K), determined at \(t_g\) according to [6].

The process of modeling data processing is carried out in the form of building dependencies that are not limited between the equipment standard and parameters characteristic of the heat exchange process.

2.4. The results of simulated studies

For Task 1, which corresponds to a height of 5 cases TEG plate inclination are different, change the value of 2 mm ÷ 6 mm.

The calculation results obtained by simulation described in Figure 4 to 6, and it was observed that the temperature distribution is concentrated in a horizontal exhaust gas flow axis passing through the inclined plate TEG.

![Figure 4. Calculated results of simulation in the horizontal axis h = 2mm, 3mm](image)

![Figure 5. Calculated results of simulation in the horizontal axis h = 4mm, 5mm](image)
Figure 6. Calculated results of simulation in the horizontal axis h = 6mm

For task 2, which corresponds to 7 cases of the angle of inclination of the TEG plate is different, change the value from $10^\circ \div 60^\circ$.

The result of the simulation is shown in Figure 7 to 10, and it is noted that the horizontal temperature distribution of the axial flow of the exhaust gas passes through the TEG slope at an angle $\theta = 10^\circ, 30^\circ, 60^\circ$.

Figure 7. Calculated simulation results of horizontal temperature at $\theta = 10^\circ, 20^\circ$

Figure 8. Calculated simulation results of horizontal temperature at $\theta = 25^\circ, 30^\circ$
3. Results

Each case calculated by the Fluent-ANSYS software, corresponding to the height and angle of the various inclined plates, receives an average temperature value on the corresponding transition surface.

From the results obtained in the simulation according to the case of inclined angle and height of inclined plate change shown in figure 4-10, we go through the statistics of the program "Origin 9.0" and offer different temperature ranges, as in the height and angle of inclination of the plate changes and are shown in figure 11. From figure 11 we see that the average temperature of the hot surfaces of the TEG reaches the maximum value, when the angle of inclination of the plate is about (10-15 °) and the height of the inclination of the plate is 4 mm. However, the average temperature of hot surfaces will change in the direction of decreasing when we increase the angle and height of the inclined plate. Through statistical evaluations of us, focused on the design and development of an optimal TEG design serves for research and production.
Figure 11. The temperature field of the hot surface of the TEG when the angle changes, the height of the inclined plate

4. Conclusion

As a result of the research, the following results were obtained:
- Building a database of TEG hot surface structures when installing inclined plates;
- The simulated surface design is heated when changing the height and angle;
- Methods of summarizing the simulated data and the results of simulated studies;
- Simulation of the work process on the hot surface of the TEG to change the height and angle of the plate;
- Ensure the optimum range of height and angle of the plates with the highest temperature field.

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