A Study of Exhaust Waste Heat Recovery in Internal Combustion Engines

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Abstract. This research presents an investigation of an energy recovery solution from exhaust gases in internal combustion based on the heat exchange to distil fresh water from the sea water. Consequently, an optimization of the flow field design of the heat exchanger was performed using the commercial computational fluid dynamics (CFD) software. The result of this research showed that the energy recovery performance of the exchanger strictly depends on the engine load, which can reach a value of approximately 33% at the full load condition of the research engine. These results might forecast a future application of the optimized exchanger’s flow-field design in automotive waste heat recovery in order to improve the internal combustion engine efficiency.

1. Introduction

Recently, internal combustion engine has been considered as the major power sources for worldwide applications such as industry, transportation in over the world. However, the energy crisis and environmental pollution are highlighted to be one of the major global problems in the 21st century. As a result, finding the solution to enhance the internal combustion engine efficiency is the great challenge of scientists for sustainable development [1]. Many previous studies have been conducted to apply modern technologies and harvested some certain successes as mentioned in [2-4]. The use of cooling water and exhaust heat to improve the thermal efficiency of internal combustion engines is a potential solution to solve the above problems [5-9]. Especially, water distillation from the seawater using the exhaust gases energy has been performed in worldwide because it not only improves the internal combustion engine efficiency but also solve the problem pertaining to the freshwater scarcity in over the world [10].

However, due to the limitation of the technology, this solution has been only applied in the high-power ships. In the small ships, the efficiency of heat utilization is low because of the low energy from the exhaust gases, although the freshwater demand is still very high. This research aims to optimize the flow-field design of the exchanger applied in small ship engines in order to improve its efficiency. These results might forecast a future application of the optimized exchanger’s flow-field design in automotive waste heat recovery in order to improve the internal combustion engine efficiency.
2. The fundamental theory of the simulation software
The heat exchange process of the heat exchanger can be clarified into three stages as follows: The heat transfer process between the exhaust gas and heat exchanger wing, heat conduction in the wing and the heat transfer from the wing to the heating solvent. Meanwhile, it is so difficult to determine the heat transfer coefficients due to their variation according to their shapes, dimensions and gas ambulatory ability of the seawater inside the heat exchanger. However, ANSYS Fluent can solve these problems based on the Navier-Stokes to describe the energy exchange. The governing equations being used in this research are as follows: the continuity, momentum and energy equation.

3. Modelling of the simulation model
3.1. Proposed Model for Utilizing Exhaust Heat
The design of the heat exchanger is described in Fig. 2a. It includes 3 separate compartments. The exhaust gas normally comes into the center of tube and exchange heat with the wings inside the heat exchanger. Based on the parameters of the heat exchanger design, the 3D model was built in a CAD software and transferred to ANSYS Fluent for the numerical analysis.
3.2. Boundary conditions for the simulation
In this research, the D243 engine was selected for the exhaust gas energy calculation. Based on the parameters of this engine, the engine model was built in AVL-Boost to simulate its operation. Consequently, the exhaust gas flow was calculated and considered as the inlet boundary conditions for the heat exchanger as shown in Table 1.

Table 1. Exhaust gas parameters according to the load

| % load | Temperature (K) | Speed (m/s) | Flow (kg/s) |
|--------|----------------|-------------|-------------|
| 25     | 492            | 49          | 61.01       |
| 50     | 602            | 55          | 60.05       |
| 75     | 673            | 60          | 59.30       |
| 100    | 733            | 70          | 58.18       |

4. Result and discussion
4.1. The heat exchange analysis

Figure 3. Temperature distributions inside the heat exchanger at different reference locations (a, b, c, d, e, f), (A) 25% load, (B) 50% load, (C) 75% load, and (D) 100% load.
Fig. 3 shows the temperature distributions of the exchanger corresponding to a variety of the engine loads and reference locations. Consequently, at a reference location, the emission temperature is distributed symmetrically. However, it tends to decrease from the center of the tube to the wing. This trend can be observed more clearly at the rear cross sections or when increasing the engine load as shown in Fig. 3. Furthermore, the engine load increase also results in the increase of temperature; as a result, the peak temperature in case of 100% load reaches to 7500°C compared to 5000°C in case of 50% load.

4.2. Effect of engine load on the heat exchanger efficiency

Fig. 4 shows the temperature decrease of the exhaust gas and the heat of the sea water received from the heat exchange process with the exhaust gas as described in Fig. 4.

It is clearly observed that the decrease temperature level of the exhaust gas tends to reduce when increasing the engine load. Meanwhile, the received heat of the seawater is increased. These phenomena are caused by the temperature increase of the exhaust gas; as a result, the temperature difference between the exhaust gas and seawater is increased. In addition, the exhaust gas velocity is also increased when increasing the engine load, and thus the coefficient of heat transfer is also increased. Fig. 4b shows the effect of load on the engine load on the exhaust gas heat utilization. It is increased when increasing the engine load and can reach to a value of 33% at the full load condition of the engine. At the engine load of 50% to 75%, it is approximately 29% to 31%.

4. Conclusion

This research presents an investigation of an energy recovery solution from exhaust gases in internal combustion based on the heat exchange to distil fresh water from the sea water. The result clearly illustrates that the ability to utilize the exhaust gas heat strictly depends on the engine load and the exchanger design, which can reach a value of approximately 33% at the full load condition. These results are the foundation for applying the system design for Vietnam fishing boats.

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