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The performance and analysis of the thermoelectric generator system used in diesel engines

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ABSTRACT

Thermoelectric generator (TEG) has drawn significant for the waste heat recovery systems. In this study, a prototype has been developed for the working principle suitable to the thermoelectric generator systems. The exhaust system of diesel engine is used and benefited from the exhaust gas heat to heat the surface. In addition, thermoelectric cooling system is used for the cooling effect that is required under different temperatures. In experiments, internal combustion diesel engines are used in five different engine speeds and two different engine loads for each speed level. Electric connection of the 40-piece thermoelectric modules mounted on the octagon structure made from Aluminium 6061 material is made in series. Performance of TEG systems has been examined in terms of changing speed and engine load. The performance of TEG systems has been examined in terms of changing speed and load in the engine. In the system, with the assistance of fluent programme in the Ansys Workbench 12.0 and at the same time having the Calculating Fluid Dynamic (CFD) programme, the temperature and flow analysis is performed.

Contents

1. Introduction

Electric energy required by the vehicles is generated by alternators built on electromagnetic induction principle. Alternators provide this process by transferring the motion energy into electrical energy. It is noted that alternators work with a particular yield. Indeed, the value of this yield changes according to the speed, capacity and size of alternators. For this reason, the presence of TEG systems that can be alternative for alternators in the point of electrical energy production in the vehicles is important because the TEG systems only use residual heat energy of the engine. Thermoelectric is transformation of the thermal energy into electrical energy or electrical energy into thermal energy. Thermoelectric generators (TEGs) have found its potential in many

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applications, such as aerospace applications, thermal energy sensors, and textiles [1,2].

With the semi conductors with different temperatures at the same time, a variety of effects including Seebeck, Peltier, Thompson, Joule and Fourier occur. The physical principles date the foundation of thermoelectric back to the 1800s. Scientists that have worked in this field so far have insisted on the maximum material factor value (ZT). This factor consists of the consideration of materials' conductibility of electric and temperature while generating electricity from heat. The Seebeck effect is described as the transformation of heat into electricity. Electrons in the n type materials that have the ability to move in semi conductors and metals, endure as the holler of the p type materials load carrier [3]. As we know, a certain percentage of the energy obtained by using fuel-air mixture in internal combustion engines becomes useful work. A portion of the thermal energy resulting from the combustion is thrown into the environment by cooling water, exhaust gas and radiation. Thus, a large percentage of the energy generated in the engine is not used [4]. Combustion in the internal combustion engines is a physicochemical process formed in the gas phase in a very short time. Exhaust process starts with the opening of a specific advance of exhaust valve at the end of the combustion process and it ends with the closing of exhaust valve. The thermal energy of gases that leave the cylinders in a certain speed and temperature is an important potential. For this reason, the studies in the field of recovery of waste energy are becoming more important because the comfort in the vehicles is improving everyday depending on the demands from customers and progress of the technology. Energy consumption in the vehicles is increasing in parallel with the increased comfort. This increase provides vehicle alternators to increase the power generation capacity. For this reason, alternative power generation production should have adequate quality to meet this increase [5]. Waste heat from internal combustion engine is considerable as well. About 40% of the fuel energy is discharged from the exhaust pipe and about 30% is lost into the coolant. Electric energy capacity that will be generated by the thermoelectric generator system designed for internal combustion engines is dependent on the exhaust gas temperature and flow and its specific heat namely related to heat capacity of the exhaust gas, the temperature values of the combustor is important [6]. In the recent studies, system and equipments on transferring the waste thermal energy have been discussed. The method of using the waste heat is an alternative solution in order to meet the need of electricity. In the case of installing a system based on exhaust system, continuity of the energy will be provided and emissions of greenhouse gases in the environmental dimension will be reduced. In many studies, it has been discussed that the electrical energy produced by thermoelectric generators may have an important effect to meet a part of the energy produced by alternators [7]. In the study conducted on this basis, 18 TEG modules have been placed on the system that has rectangular structure. Three bulbs of 25 W and one bulb of 15 W have been connected to the system.The vane hasn't been used for exploitation of energy of exhaust gases in the system. It is considered that the using of vane increases the back-pressure of exhaust gas and it affects the engine negatively [8]. In many studies, effect of the heat on pressure decrease of gas flows has been emphasised being a negligible level. Therefore, there are no serious pressure changes when the pressure values of exhaust gases in the engine with TEG system is examined [9–11]. Significant improvements in the recycling of exhaust gases and thermoelectric systems produced for vehicle applications have been obtained. The system where the temperature of exhaust gas is 600 °C and output power is 125 W has been adapted to single-cylinder engine [12]. Thermoelectric systems expressed by academic studies have caused the firms commercial competitiveness. It is possible to meet a great number of modules in different models and brands across the market for sale. In another study, it has been obtained that TEM that has got TEP1-1264-1.5 model has produced a maximum of 3 V voltage, 0.637 A current and 1.91 W power in 200 °C and the module with TMG-450-0.8-1.0 has produced a maximum of 8.97 V voltage, 0.41 A current and 3.742 W power in of 200 °C. In addition, it has been observed that the different electrical loads have been applied to the modules and different output power has been formed [13]. In another study, the losses generated by thermoelectric generator system that will be used in internal combustion engines have been discussed. Fan and pumps used for additional cooling system are considered as lost in thermoelectric systems. An internal combustion engine used with TEG system that provides energy recycling has been developed by Modelica Library-based model. In this model, useful power values have been determined for two different thermoelectric modules for commercial use. Electrical power values created by Bi_2Te_3 and PeTe based thermoelectric modules have been found as 180 W and 310 W [14]. When the combustion value decreases, the engine power is decreased along with it and the fuel consumption value is obtained. Therefore, the exhaust system should be designed so that the hydrodynamic pressure loss is minimised and the component of the exhaust gas flow inertial is not decreased. In this case the amount of the exhaust gas from the previous speed will be at minimum [15]. Temperature of the exhaust system pieces shows variations, when the temperature is distributed depending on the engine's working conditions. The exhaust gas temperature variations of the engines working conditions should be known and detected. For the designed TEG systems, the area where the generator is connected to the vehicle is important and the most suitable working temperature distance should be determined [16]. Lately studies on the thermodynamic modules being modelled have increased as generators. With Matlab/Simulink similarity programme, the thermoelectric model is made similar to the mathematical model and the similarity experiments show the results of two different temperatures have been confirmed. With the Matlab/Simulink similarity programme, the thermoelectric model is made similar to the mathematical model and the similarity experiments show the results of the various two temperatures have been confirmed. SCADA programme has been developed so that the current, stress, force, hot surface and cold surface temperatures, observation and recording of the different values of to the module [17]. In another study where the waste thermal energy used in the engine, with an internal combustion engine having a single cylinder with the temperature of the exhaust gas is 600 °C, with the help of the TEG system, the electric output energy obtained from the electric energy is 125 W [12]. In a different study, it is emphasized in the design that allows beneficial usage of the exhaust gas energy between 0.6 and 5 kW. According to the load values changing between 20–120 Nm, when the engine is at a 3300 speed, for a 1.4–5 kW, 2300 min^{-1} engine speed a 0.6–3 kW energy is obtained. Changes made exclusively to the design, explain that more exhaust gas temperature energy can be obtained and 750 W of electrical energy can be produced [18]. Waste heat from internal combustion engines is considerable as well [19]. Liu et al. investigated a thermoelectric energy generation system which the maximum electrical power output is 183.24 W [20]. Some car companies [21] have proved their interest in exhaust heat recovery, developing systems that make use of TEGs. Kim et al. has designed an exhaust heat recovery using both TEGs and heat pipes In This study generated a maximum of 350 W using 112 TEGs [22]. It is possible to analyse the thermoelectric modules and systems with the help of different programmes such as Matlap, Ansys, Comsol. In the study, TEM structure that consists of Comsol V 4.2 software and p and n couples has been examined by using the heat in the surfaces and voltage distributions [23,24].