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ADD-ON ENERGY HARVESTING OF DIESEL EXHAUST MUFFLER USING THERMOELECTRIC GENERATOR

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ABSTRACT

Trends Light fossil fuel vehicles are now turning to electricity. The electric vehicle transition begins with a hybrid car. The Hybrid vehicle uses an internal combustion engine as a generator. Controller systems, driving safety and entertain light vehicles are growing so that they consume a lot of electricity, Safe devices and driving lifestyle support. An additional battery charging system for a hybrid car now is being developed by the automotive manufacturer at least the system can increase the fulfilment of electricity consumption needs.

The charging system can utilize waste energy vehicle itself or even from outside the vehicle system. In this research, the author wants to explore the thermal energy harvesting system in the remaining exhaust gases. The concept of this research is to develop a Thermoelectric Generator (TEG) as a power producer. The heat source uses a 140kW diesel engine with a heat potential of 523K at stationary conditions, and an exhaust velocity of 1407.05 m / s. This study demonstrates the potential prototype TEG then compared Ansys simulation and manual calculations as the first step for further research. The results obtained, the Exhaust TEG can produce a voltage of 2.1 Volt at 30 seconds of data collection. The cooling system on the TEG exhaust from the HVAC cooler with a temperature of 289K and a Velocity of 0.8 can produce a significant temperature difference.

Keywords: Diesel Engine; Thermoelectric; Exhaust TEG system; Electricity
Paper type Research paper

INTRODUCTION

Thi The vehicle of car technology has approached electric vehicle technology. Vehicles are now like walking gadgets that can help and pamper humans in their activities. The need for electric power in a car is currently very high, followed by pampering facilities for humans such as audio devices, visual systems, cooling, and even massage chair systems. Vehicle technology is undergoing a transition to electric-powered vehicles. A transition technology cannot be carried out quickly, depending on the infrastructure in a country. Vehicle technology that is still acceptable in developing countries is Hybrid vehicles. Most hybrids dominated car's by a piston motor system as a motion input generator.[1]

Diesel engines promise a high level of efficiency. However, the diesel engine also produces secondary energies that can be harvestings, such as vibration, noise, thermal and high exhaust gas pressure due to the large compression ratio. The potential vibration diesel engine ranges 900 watts at 50-200 Hz in every single Engine mount. [2,3] Meanwhile, the heat generated by the piston engine exhaust gas has a heat potential of 500–700 ° C (773–973K) with a load and no-load 200–300 ° C (473–573K).[4]

Additional energy harvesting systems on vehicles can lighten the engine or even cover the vehicle's electricity supply. The application energy harvesting system in a hybrid vehicle's can lighten the piston engine performance and capable backup electrical power to the entertainment system. Around the car, there are many things that can be harvested, such as diesel, engine vibration, electromagnetism, the wind caused by nature and vehicle motion, heat in engines, or even radio frequency as the simple scheme is shown in Figure 1 This harvesting system has the potential to be developed in the future. front for electric vehicles with a battery storage system [6-9].

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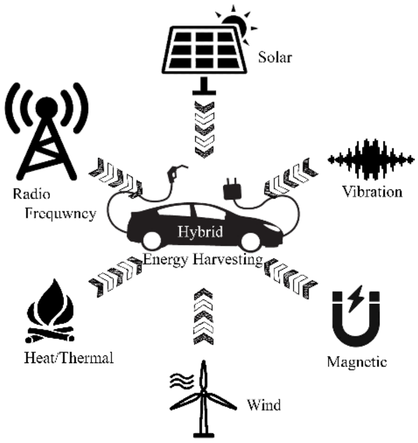

Figure 1. A potential additional power source apart from engine motion. Solar power, vibration, magnetism, wind, thermal, and radiofrequency have the potential to be harvested to meet the needs of the electrical system in Hybrid vehicles.

Figure 1. A potential additional power source apart from engine motion. Solar power, vibration, magnetism, wind, thermal, and radiofrequency have the potential to be harvested to meet the needs of the electrical system in Hybrid vehicles. In this research, the authors looked at the potential heat generated by a diesel piston engine. High thermal efficiency can be used as a heat source that heat can harvest into electrical energy. A simple concept using a Peltier or thermoelectric engine that is engineered can absorb and release heat according to the characteristics of a generator. Thermoelectric Generator (TEG) can convert heat into electricity in a vehicle.[10] The heat generated by engine exhaust can be harvested using TEG.

TEG uses the concept behind thermoelectric as a generator of electricity. Peltier can generate electric power when the hot side is given a low temperature, while the cold side is given a high temperature. If the heat dissipation system cannot provide a significant temperature difference, the TEG will not be able to convert electricity to the maximal or even fail to work [11]. This research will be proven by simulating the potential for thermal propagation with Ansys and Velocity produced at TEG. Data retrieval was carried out on a 2KD-FTV diesel engine cold start at stationary to dynamic engine temperature (stationary in time). The heating rate will compare the result of thermal heating rate between simulation and manual calculation. The simulation of heat propagation at the TEG exhaust between using coolers and without cooling becomes the benchmark for the TEG system to convert heat into electricity optimally. Voltage measurements on the TEG system were carried out and validated by Polynomial and Linear Regression.

METHOD

Peltier is a cooling or heating device consisting of a semiconductor that is electrified. Peltier has a hot side and a cold side with a ceramic coating as a semiconductor protector. There are two types of semiconductors in Peltier: "N" type and "P" type.[12] Figure 2 shows the thermoelectric specifications used in this project. important to display real time video on ground so that the user can make decision immediately in case an emergency or an accident occurs on the road. Therefore, the authorities can make action faster in order to prevent more danger to road users.

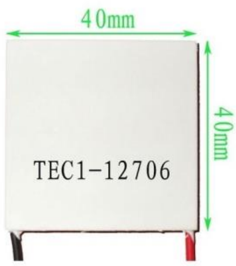

Figure 2. Peltier or Thermoelectric heat and cool side on TEG Project.

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An electric current passing through the semiconductor will result in a decrease in temperature on the cold side peltier, being on the hot side, will result in increased thermal. System cooling is proportional to the release of heat in the heat.[13] However, Peltier can generate electricity by giving thermal energy to the hot and cold side schematically. Seen in Figure 3 describes in detail the thermoelectric scheme.

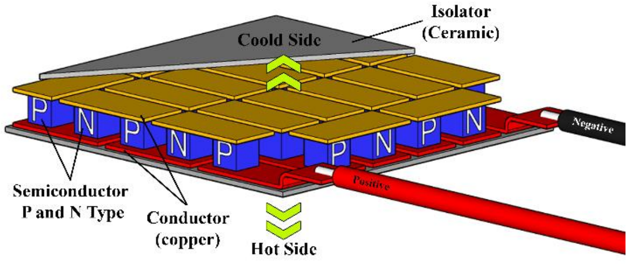

Figure 3. Thermoelectric illustration, there is a hot side and a cold side that functions as a heat release and heat absorbent. in thermoelectric there are semiconductor P and N type.

Semiconductor "P" and "N" Type is associated with the conductor made of copper isolators with ceramic material wrapping semiconductors and conductors at the hot and cold side.[15] Figure 4 presents a scheme of two-dimensional systems of electricity producers, which consists of a hot side and a cool side.

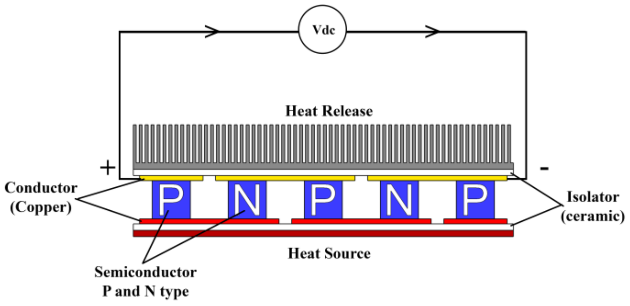

Figure 4. Illustration of electric current to the thermoelectric thermoelectric

The hot side will absorb heat from the heat source, which will flow to the ceramic insulator. On the reverse side, there is a cooling system to release heat, called heat realization.[14] Absorption and release of heat will result in a temperature difference ΔT, which results in electrons' movement in the semiconductor. In this project, power electricity can find the power generated by Thermoelectric using the formula below.

Electrical current (I) is determined by:

$$I = \frac{U_0}{R_L + R_g}, \tag{1}$$

$$U_0 = \int_{T_c}^{T_h} \alpha(T)\, dt, \tag{2}$$

Where: U0 is the voltage of thermocouple, Rg is the electrical resistance of TEG cell, which contains resistance and contact resistance, and α(T) = αp(T) − αn(T)

$$P_{out} = q_h - q_h = I^2 R_L, \tag{3}$$

Where: Heat flow qh passes from heat source to hot side of thermocouple and the counterpart qc outflows from cold side of air cooling heat sink.

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$$\Delta T_g = \frac{\Delta T}{1+R_{th,c}K_g+R_{th,h}K_g+\alpha^2\frac{(R_{th,c}T_1+R_{th,h}T_0)}{R_g+R_L}}, \qquad (4)$$

It can be seen, that ΔTg is influenced not only by thermal resistances Rth,c and Rth,h, but also by Peltier effect, which is presented in the last term of the denominator and functions to decrease ΔTg. Because it is tantamount to accelerate heat conduction in thermocouple, Peltier heat flows in and out on two sides of thermocouple. By combing Eqs. (4) and (1), (2), (3), the output power Pout is:

$$P_{out} = \frac{\alpha^2 \Delta T_g^2 R_L}{(R_g+R_L)^2}, \qquad (5)$$

$$P_{out} = \frac{\alpha^2 \Delta T^2 R_L}{(1+R_{th,c}K_g+R_{th,h}K_g)^2\left[R_g+R_L+\frac{\alpha^2(R_{th,c}T_1+R_{th,h}T_0)}{1+R_{th,c}K_g+R_{th,h}K_g}\right]^2} \qquad (6)$$

Simply concept of exhaust TEG system

The concept of energy harvesting in the exhaust gases by collecting heat energy from diesel piston engine combustion. The hot side will absorb heat, and the cold side will be a continuously flowing coolant. Cooling the TEG system uses liquid cooling and cold air. Figure 5 presents a side view scheme TEG.

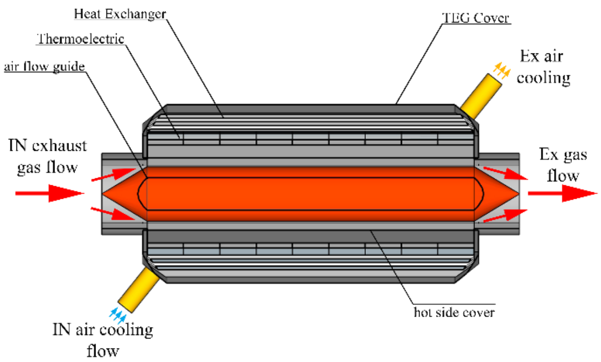

Figure 5. Prototype scheme thermoelectric generator in the research project.

Intake of hot air into the TEG system, which then gets routed reactor wall with Air Flow-Flow Guide to Exhaust gas generator. The hot side will absorb the heat is forwarded to the thermoelectric cover on each side. The cold side serves as a heat release, a Heat shrink as a medium for heat release. Heat shrink-wrapped by TEG impermeable outer cover pressure and then fed by cold air a continuously low pressure.

Design of diesel exhaust TEG

Flow of diagram

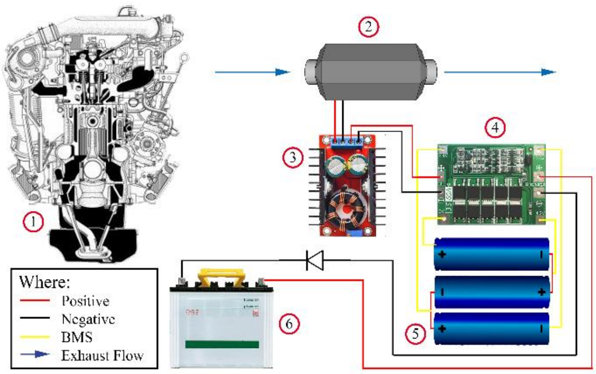

Figure 6. Flow diagram TEG harvesting system

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1) Engine heat Sourch
2) TEG
3) BMS
4) Battery Pack
5) Accu vehicle's

In the picture above, the TEG system described the groove on this project. The 2KD-FTV engine became a heat source in this research project. The engine produces exhaust gas that will be blown into the exhaust manifold, leading to the TEG system. TEG containing thermoelectric will absorb heat and release heat engineered in the design and structure. Furthermore, it produces an electric voltage supplied to the step-up booster with optimal charging voltage conditions.[15] Before going to the power pack, BMS will stabilize the lithium battery charging voltage. The power is stored in the power pack before distribution; the voltage and current will pass through BMS on discharge conditions. Power electricity would then channel to the vehicle's electrical system.

Potential Power heat source

In this case, using 2500cc diesel 2DK-FTV with output power 140kW. The Engine efficiency factor usually 46% for a modern diesel engine.

TABLE I. HEAT ENGINE POWER SOURCE

Layout	
Configuration	Straight-4
Displacement	2.5L (2,494 cc)
Valvetrain	DOHC 4 valves x cyl.
Compression ratio	17.4:1
Combustion	
Fuel system	Common rail Direct injection
Fuel type	Diesel
Output	
Power output	140 kW (188 hp, 102 PS)
Torque output	200 N·m (148 lb·ft)@1.400 – 3.400

*estimate exhaust flow velocity:
the fuel consumption F at this operating condition

$$F = \frac{P}{\left(\frac{LHV}{3600}\right) x \left(\frac{E}{100}\right)} (kg/h) \tag{7}$$

Find the air flow and exhaust gas flow:
The air flow is Fa = F* (AFR). AFR = 18 - 85 for diesel engines. Assume AFR = 23 if this operating point sits in the middle of the engine map, if you don't have any data available.

$$F_a = F\ x\ (AFR)(kg/h) \tag{8}$$

For find The total exhaust gas flow:

$$F_{eg} = F + F_a\ (kg/h) \tag{9}$$

EG volume flow:

The molecular weight of exhaust gas MWeg is approximately 28.75 (g/mol).

$$V_{eg} = \frac{\left(\frac{F_{eg}}{MW_{eg}}\right) x\ 22.414\ x\ \frac{(T+273)}{273}\ x\ 1.013}{P}\ (m^3/h) \tag{10}$$

know the diameter of the EG pipe and the cross sectional area, the E flow velocity can be calculated from

$$U = \frac{(V_{eg}/3600)}{A}\ (\mathrm{m/s}) \tag{11}$$

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The diesel engine with the 2KD-FTV type is a source of research heat. Diesel engines have good thermal efficiency. However, the thermal potential of the diesel engine is researched to obtain a suitable power supply.

TABLE II. EXHAUST GAS PROPERTIES AT STATIONER WITH THEMP 523K

Fuel Consumption (f)	2,36	kg/h
Air Flow ($F_{a)}$)	54,19	kg/h
Total Exhaust Gas Flow ($F_{eg)}$)	2410,43	kg/h
Volume Flow ($V_{eg)}$)	25732099,38	m^3/h
Flow Velocity	1407,05	m/s

The diesel engine in this study has the characteristics shown in Table II. The fuel consumption when diesel took the measurement was 2.36 kg per hour. The total gas flow is 2410 kg/h with a 25.732.999 m^3/h volume and a flow rate of 1.407 m/s.

Steep Up Voltage Booster

The TEG output voltage needs to be increased to be able to charge the storage battery. The use of a steep voltage booster is used as a voltage stabilizer when setting. It aims for optimal charging when the TEG output voltage is low or when the voltage is exceeded.

BMS (Battery Management System)

Lithium power packs always use a Battery Management System (BMS). In this project, BMS is used so that the battery pack voltage circuit gets a uniform charging voltage distribution. The BMS functions as a discharge voltage stabilizer, which can then be transferred to the vehicle's electrical system.

Cooling

The Heating Ventilation and Air Conditioning (HVAC) vehicle's system has a standard speed of 0.8 m / s. airspeed restrictions aim for the convenience and equal distribution of temperature exchange systems.[16] HVAC in the test vehicle cooling system has a temperature and blowing speed, as shown in Table III below.

TABLE III. PROPERTIES OF HVAC ON VEHICLE PROJECTS

Temperature	289K
Velocity	0,8 m/s

TEG project used coolant in the cooling air from the air conditioner. The Air Conditioner vehicle's has a temperature of 16 ° C, equal to maximal 289K with a Velocity of 0.8 m / s. cooling without the use of additional pressure, just do a bifurcation in the cooling system. System safety valve branching gave the same direction to avoid the hot air behind.

Efficiency

Thermoelectric devices can be used to generate direct current (DC) electrical energy when there is a temperature difference. However, currently available thermoelectric materials have ZT < 1 and the efficiency of devices in generating electrical energy rarely exceeds 5%. This performance limits thermoelectric generators to applications where their requirements for remote operation, robustness, no moving parts, and silence have outweighed the worse aspects of high cost and low conversion efficiency. The maximum efficiency of a thermoelectric device in a power plant is determined by the following relationship:

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$$\eta = \frac{T_h - T_c}{T_h} \frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+\frac{T_h}{T_c}} \quad (12)$$

Where:

ZT	= Figure of Merit
TH dan TC	= Hot Temperature and Cold Temperature
Tm = (T_H +T_C)/2	= Average Temperature

Figure of Merit (ZT)

Thermoelectric efficiency refers to the ability of a thermoelectric device to convert heat energy into electrical energy or vice versa. It is commonly expressed as the ratio of the electrical power output to the heat power input, or vice versa. The efficiency of a thermoelectric device is typically denoted by the symbol "η" (eta) and is given as a percentage.

The efficiency of a thermoelectric device depends on several factors, including the materials used, the temperature gradient across the device, and the operating conditions. The efficiency is determined by the figure of merit (ZT) of the materials employed in the device. The figure of merit, ZT, is a dimensionless value that quantifies the performance of a thermoelectric material. It is given by the equation:

$$ZT = (S^2 * \sigma * T) / \kappa \quad (13)$$

Where:
S is the Seebeck coefficient (also known as the thermopower) that represents the voltage generated per unit temperature difference,
σ is the electrical conductivity of the material,
T is the absolute temperature, and
κ is the thermal conductivity of the material.

The higher the ZT value, the better the thermoelectric performance of the material. Generally, higher electrical conductivity, higher Seebeck coefficient, and lower thermal conductivity lead to higher ZT values and, consequently, better thermoelectric efficiency. In recent years, there have been significant advancements in thermoelectric materials, leading to improved efficiency. However, even the most efficient thermoelectric materials currently available have relatively low efficiencies compared to other energy conversion technologies, such as combustion engines or solar cells. Therefore, thermoelectric devices are typically used in niche applications where their unique properties, such as solid-state operation and compactness, outweigh their lower efficiency.

RESULTS AND DISCUSSION

Figure 7 shows the Velocity Exhaust TEG simulation results at the initial stationary engine condition with a temperature of 473 K. The TEG system is lowered in temperature with a unique forked cabin cooling air to cool the TEG 273 K cold air flows from the small pipe above, flowing throughout the heat exchanger body and then discharged into the cooling exhaust pipe.

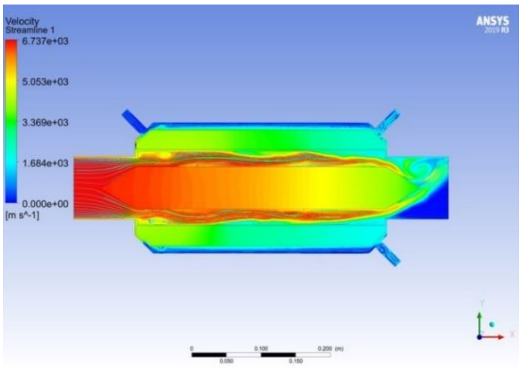

Figure 7. Velocity Exhaust TEG with Cooling at first run engine (473K)

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The cooling phenomenon can affect the system between the cold side and the hot side. Fig. 8 describes the simulation of heat absorption and dissipation in Exhaust TEG working correctly. [17-19] The simulation is taken a few minutes after the diesel engine stationary condition takes place. The heat generated under steady conditions is 573 K. The cooling air remains constant at 289 K.

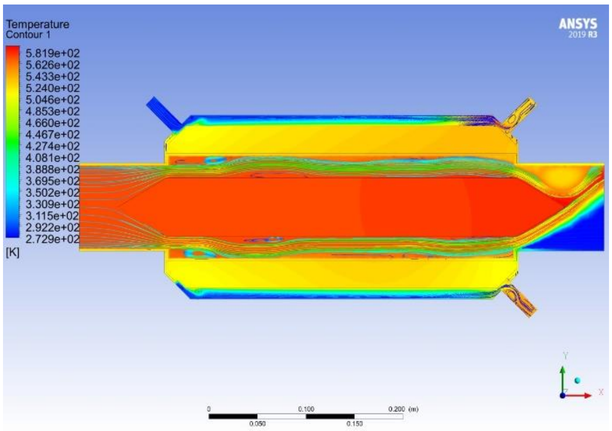

Figure 8. Exhaust TEG at 573 K temp, In a couple time of operation conduction engine.

In this condition, the heat dissipation in the cooling system works well. The hot side of TEG seems to absorb the heat generated by the exhaust gas continually.[20] Heat absorption on the hot side is seen at approximately 543 K evenly at the top and bottom. On the cooling side, the plot can see that the cooling performance with cooling temperature properties of 289 K can reduce the temperature by 69 points in kelvins units. The coolant's climate in the exhaust is at 490 K. This means that the cooler's heat sink is working correctly. The heating rate of the TEG Exhaust system is compared between manual calculation and simulation. The heating rate is affected by heating time and temperature. Figure 9 explains the comparison between manual calculation and Ansys simulation.

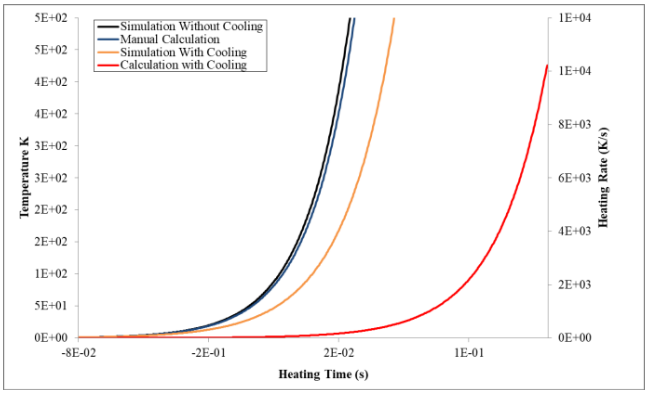

Figure 9. The Comparison of Heating Rate between manual calculations and Ansys simulation on Exhaust TEG

The graph above shows that the black and blue lines represent the heating rate trend between simulation and manual calculation. The predicted value and the simulated value are almost close together. This differs significantly from manual calculations with a cooling system. With the cooling system represented in red, the heating rate is slower than manual accounting. This is due to manual measures where many factors are ignored. It is incomplete if we do not compare the two simulation data between cooled and uncooled. Trends in heat absorption and release are very significant. Ansys simulation data between using cooling and without using cooling can see in Figure 10.

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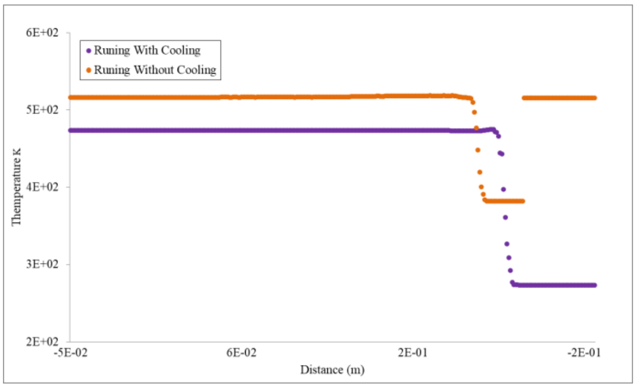

Figure 10. The temperature simulation data when running the system between using cooling and without cooling.

The graph above explains the temperature differences in the TEG system. Running without cooling is represented by an orange line, and cooling is represented by a purple line. The optimal temperature drop in the TEG system occurs in systems that use cooling flow. In non-cooling systems, there is an increase in temperature after the TEG system absorbs heat from the exhaust gas system. The temperature had dropped due to time delay, distance, and heat absorption area. But the temperature at TEG will rise again when all the material has reached its maximum exhaust gas temperature.[21]

Whereas in a system that uses cooling, there is a constant decrease in temperature after getting cold air blows. In this condition, ΔT is formed, so it is very suitable for the conversion of heat energy into electrical energy.[22] The electric voltage measurement is carried out at one of the Thermoelectrics in the TEG Exhaust system. The heat energy that is converted into Voltage can be the initial achievement of this research. Potential Voltage between the generator with coolant and without cooling is measured to determine the potential generated at TEG. Figure 11 shows a graph of the Voltage and polynomial lines to see the trends that occur in the TEG system.

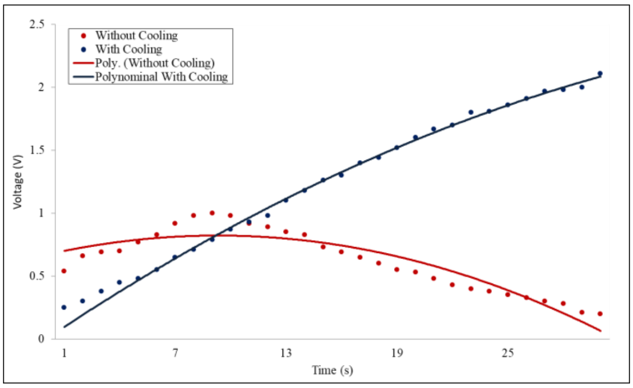

Figure 11. Voltage data on a sample of one peltier on Exhaust TEG. Trends shown by polynominal line between the coolant and without coolant.

The graph above shows that the peak voltage generated by the system without cooling is 1.2V at 8s.[24-28] The decrease occurred up to 30 seconds of data collection. The equation generated by the line is obtained y = -0.0042x2 + 0.1206x with a value of R^2 = 0.109. A cooling system produces a peak voltage at 30 seconds and can be predicted to increase again. The peak value of the voltage voltage in a cooled system is 2.1 volts at 29-30 second with the equation y = -0.001x2 + 0.0983x and the value of R^2 = 0.9937.

The proof is continued with the calculation of Voltage Voltage (Predicted) with Actual Voltage Measurement. Linear regression can determine the trend of Predicted vs. Actual Voltage. Figure 12 presents a graph of Actual vs. Predicted.

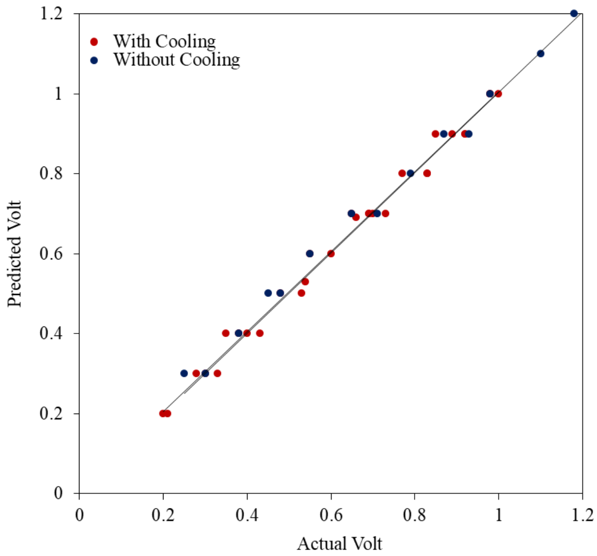

Figure 12. The Linear regression between voltage prediction manual calculation with TEG measurement at 30 seconds.

The picture above presents the Actual Stress versus Predicted Stress data with a linear regression line. The resulting plot data shows the relationship between the calculated stress and the measurement results. The voltage obtained from the serial events shown is not so far from manual measurement and calculation. The linear regression line obtained the values of y = 1.0051x and R^2 = 0.998 for manual calculations while y = 1.0069x and R^2 = 0.9888 for measurement.

Efficiency

Efficiency uses equation 13, which calculates the ZT value of thermoelectric type TEC1-12706. The value of thermal resistivity is according to [9] states that thermal conductivity for TEC1-12706 is k = 1.5 Wm-1K-1. The value of thermal resistivity according to data sheets of TEC-12706 is 1.98 Ω. For systems without cooling, T hot is 205 ºC and T cold is 135 ºC. As for the system with cooling, Thot is 202 ºC and Tcold is 120 ºC. Based on the study, ZT = 0.5711. Efficiency for thermoelectric systems without cooling obtained an efficiency of 4.56%. The amount of efficiency is influenced by the figure of merit, T hot and T cold.

$$N\ without\ cooling = 0.3436\left[\frac{\sqrt{1+0.5711}-1}{\sqrt{1+0.5711+\frac{135}{205}}}\right] = 4{,}56\%$$

Efficiency for thermoelectric systems with cooling obtained efficiency of 5.60%. The amount of efficiency is influenced by the figure of merit, T hot and T cold.

$$N\ with\ cooling = 0.407587\left[\frac{\sqrt{1+0.5711}-1}{\sqrt{1+0.5711+\frac{120}{202}}}\right] = 5{,}60\%$$

This efficiency is less than previous research that has been done by Harun [29] where the efficiency obtained is around 12%. This difference is due to the study of systems that are close to thermoelectric is not insulated so that the heat temperature spreads evenly so that the entire system becomes hot. The result of this spread causes fewer temperature differences and decreases the efficiency of the system.

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CONCLUSION

The TEG Exhaust System can produce an electric voltage that can be developed into a side charger. The Heat Dissipation Design at TEG can give a ΔT Value of 69k after 30 seconds of the heat absorption process. Thermoelectric will not produce optimum stress when heat dissipation is not perfect. Calculation of the prediction of heat release compared to the simulation there is a difference because the level of accuracy of the simulation is better in predicting heat flow and hot airflow. Data generated between manual prediction and actual voltage measurement show a similar difference. The efficiency of systems using cooling is higher than systems that do not use cooling.

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