Electrical Current Generation Using SI Engine Waste Exhaust Heat in a Thermoelectric Generator

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Abstract

An experimental study was conducted to generate electrical power from the waste heat of a four-stroke single-cylinder, air cooled SI engine. This study was accomplished by installing a single module thermoelectric generator (TEG) between the hot surface of the engine muffler and a heat sink.

The experimental results showed that the maximum voltage generated was 5 volts at an engine speed of 2,500 rpm with a 121 °C difference in temperature between the two sides (hot and cold) of the TEG. The engine fuel consumption was 0.7 L/hr, with a maximum temperature on the hot side of 195 °C.

Key Words: Waste Heat, SI Engine, Thermoelectric Generator.

1 – Introduction:

In general, only one-third of the energy generated due to combustion in an internal combustion engine is converted to mechanical work, even in highly efficient engine, while the largest amount of energy must be removed from the engine as a waste heat. The waste heat is dissipated from the engine in cooling, exhaust, and lubrication systems, as revealed in the figure (1) [1]. Engine researchers and manufacturers have thus made strenuous efforts to recover engine waste heat in various ways to increase engine thermal efficiency and reduce fuel consumption. One of the more practical methods to convert the heat lost in the exhaust system to electrical energy is by using a thermoelectric generator (TEG).

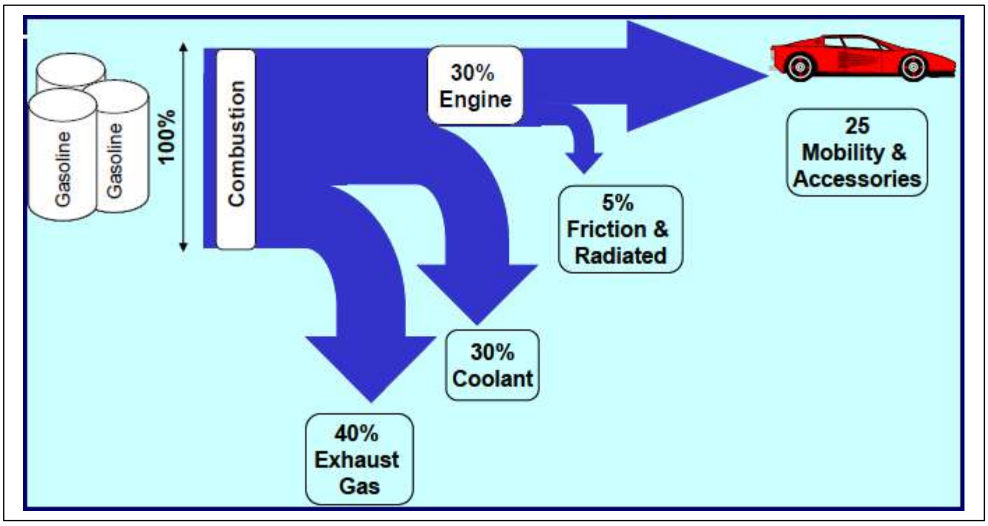

Figure (1): Distribution of fuel energy in passenger vehicles.

The generated voltage can then be used to feed engine components rather than using the alternator; in this situation, the practical load will thus be reduced. Jadhav et al. (2017) [1] did an experimental study on a four-stroke air-cooled SI engine where the voltage generated at different engine speeds and the hot and cold side temperatures were measured with respect to the operation time. Gaurav et al. (2016) [2] achieved an experimental study on heat recovery in common rail diesel engines. The TEG was cooled by air on the upper face of the heat sink. Ming et. al. (2016) [3] studied the performance, design, manufacture, and testing of a TEG system to recover the heat lost in the exhaust system. Their study focused on the effects of cooling air velocity on the rate of exhaust gases mass flow and temperature. The experimental work results explained the relationship between engine load and output voltage generation on the TEG as well as deriving the mathematical relationship between the output voltage from the TEC and the temperature difference between the cold and hot sides.

Tang et al. (2015) [4] experimentally studied the effects of temperature difference across the two sides of the thermoelectric generator. The experimental results showed that suitable mechanical pressure exerted across the thermoelectric generator improved electrical current generation. The results also showed that the power losses were reduced by 11% when the thermoelectric generator was placed in series at the outer surface of the engine muffler. Jadhao et al. (2013) [5] investigated the possibility of heat recovery from exhaust systems using thermionic generation, Piezoelectric generation, and thermoelectric generation. The experimental results showed that the thermoelectric generation process was more efficient than Piezoelectric generation. Ramade et al. (2014) [6] modified the design of an automobile exhaust thermoelectric system (AETEG) to develop lost heat in exhaust system retrieval in an automobile engine. The automobile exhaust thermoelectric system was installed on the exhaust muffler of a four-cylinder, four-stroke Maruti 800cc SI engine. The double cold side heat sink gave a significant temperature difference across the two sides of the TEG, and the counter flow type arrangement enhanced the effective heat transfer. The experimental results illustrated the increased efficiency of this system.

Prakash et al. (2015) [7] studied the effect of lost heat retrieval system design on temperature differences across the two sides of a thermoelectric heat generator. Three types of heat recovery system were designed using Flaunt software. The theoretical results showed that a rectangular shaped heat recovery system was more efficient than the other types of heat recovery system. Mohamed Shameer and Christopher (2013) [8] investigated the influence of exhaust gas heat recovery power generator design on generated voltage. The experimental work was done by placing a Peltier device on the muffler of a motor cycle engine and using a special electronic circuit to increase the output voltage. Adavbiele (2013) [9] performed experimental work on heat recovery on a spark ignition engine by installing a thermoelectric generator on the outer surface of an engine muffler and at the end of the water cooling pipe. The experimental work was accomplished under both with and without load conditions. The maximum voltage generation was 4.6 volts. Kumar et al. (2011) [10] demonstrated the potential of thermoelectric generation: experimental work was implemented to study the performance of TEG under various engine operating conditions. The study explained that waste energy can be recovered from the engine exhaust system and that, in the near future, thermoelectric generators should be able to reduce the size of alternators or eliminate them in automobiles entirely.

In this paper, the design of a heat recovery power unit to be placed at the outer surface of an insulated engine muffler with a square section was undertaken. The operating conditions in which the practical work was accomplished were at lab room temperature of 43 °C, where the maximum temperature difference across the TEG hot and cold sides reached 121 °C and the maximum temperature at the hot side of TEG reached 195 °C.

2. Principles of Thermoelectric Modules

A thermoelectric generator (TEG) is a device used to convert heat into electrical energy. Thermoelectric generators have attracted a great deal of attention from engine manufacturers, designers, and researchers due to their recovery of waste heat. The outer surface temperature of an engine muffler may be as high as 750° C in some internal combustion engines, while the maximum ambient temperature may reach 58 °C in Iraq, for example, introducing a greater temperature difference between ambient and muffler temperature and allowing electricity to be generate by means of a TEG.

The TEG in this study was comprised of a couple of n- and p-type semiconductors, called a thermocouple, which form the basic thermoelectric unit. The working principles of TEG are that an electron gains heat from the hot side, then flows to the cold using the n-type semiconductor, while the electron hole flows from hot to cold in the p-type. Thus, these electrons are combined electrically in series [11,12,13]. When the electron is freed, it leaves an empty spot with a positive charge in the crystal lattice, which is known as a hole.

This hole is not fixed to the lattice, but is free to move about. The free electron and hole both contribute to conduction within the crystal lattice. The electron remains free until it falls into a hole, a process called recombination. If an external electric field is applied to the semiconductor, the electrons and holes will conduct in opposite directions. Increasing the temperature will increase the number of electrons and holes, decreasing resistance. The TEG working principles are shown in figure (2).

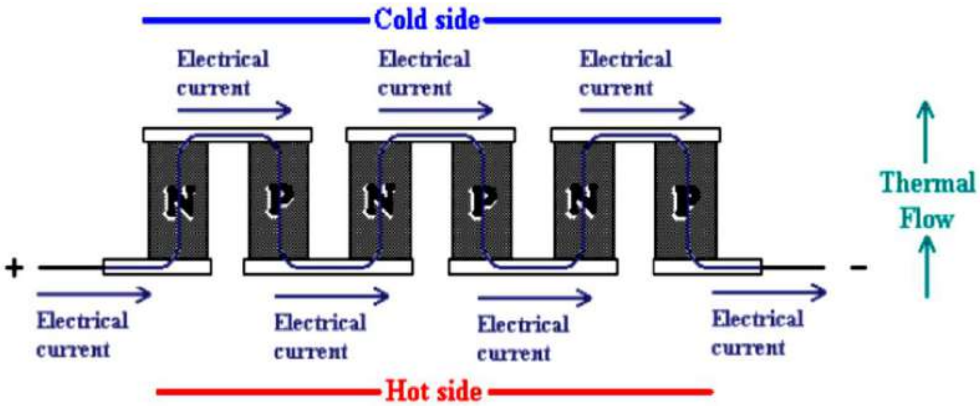

Figure (2) The principles behind a thermoelectric generator (TEG).

3. Experimental setup and procedures

The internal combustion engine test rig, as shown in the figure (3), was a single- cylinder, four-stroke, air cooled (SI) engine with capacity of 175 cm^3, coupled with an electric dynamometer. The engine specification is detailed in table (1). The dynamometer was connected to a variable electric load. The current and voltage delivered to the load was measured using a digital voltmeter and ammeter to evaluate electric power, which represents the brake power. The test rig was provided with a fuel measuring system comprised of a stop watch and a graduated glass tube. The engine speed and engine emissions were calculated using as gas analyser. The gas analyser included a speed sensor which was installed at the spark plug wire to convert the magnetic field generated due to electrical signal transfer into electrical pulses which were then measured by the electronic circuit. The combustion system was provided with a heat recovery system by installing a thermoelectric generator type 12706 at the outer surface of the engine square muffler with dimensions of 8 × 8 × 30 cm. An aluminium heat sink with dimensions 6 × 9 × 5 cm was installed at the outer surface of the thermoelectric generator to reduce the temperature of the cold side.

The thermoelectric generator with dimensions of 50×50×10 mm was inserted between the upper and lower aluminium small blocks and featured a hole to insert a thermocouple. The temperature of both sides of the thermoelectric generator were measured using a type K thermocouple and digital reader. The generated voltage was measured using a digital voltmeter. The contact surfaces between the engine muffler, thermoelectric heat generator, heat sink, and aluminium blocks were coated with thermal paste to decrease thermal contact resistance between the contact surfaces. This heat recovery system is shown schematically in figure (4.A) and photographically in figure (4.B).

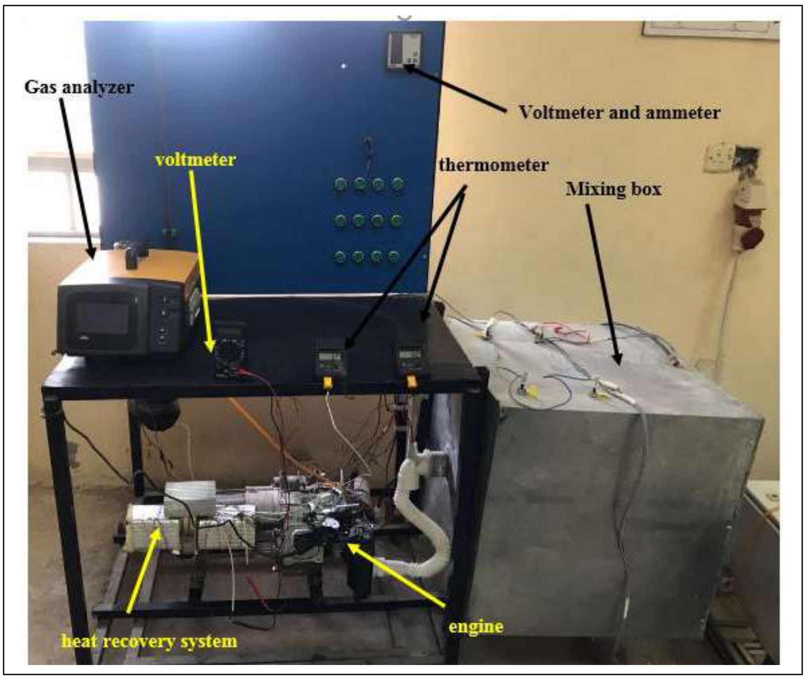

Figure (3) The internal combustion engine test rig.

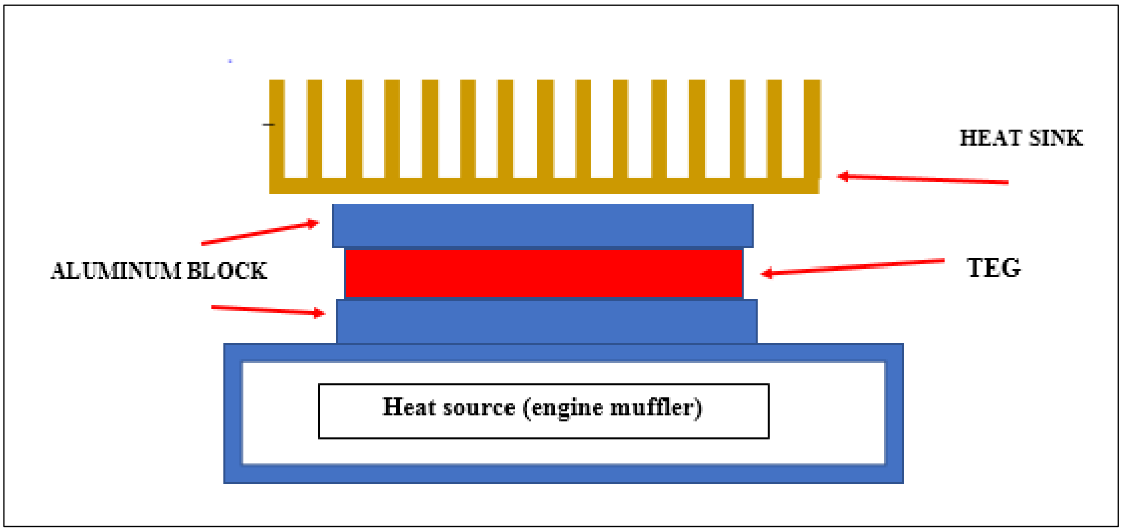

Figure (4.A) Schematic diagram of waste heat retrieval

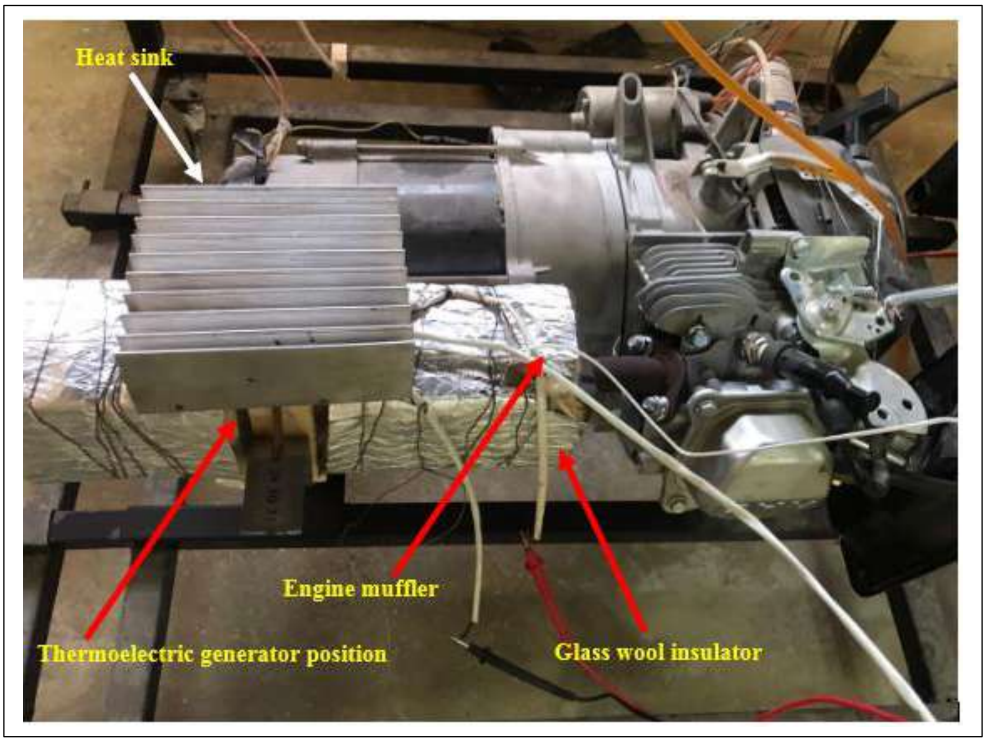

Figure (4.B) Waste heat retrieval system.

Table (1) Main technical specifications of spark ignition engine.

Spark ignition engine	
Engine type	Single cylinder, four- stroke
Engine model	95310
Ignition timing	20^0 BTDC
Displacement	175 cm^3
Valve per cylinder	two
Bore	60 mm
Stroke	42 mm
Compression ratio	7.5
Engine cooling type	forced air cooled
Lubrication	Forced lubrication
Engine oil capacity	0.6 L
engine rotation direction	counter clock wise (view from output shaft)

The engine test rig and instrumentation were set to stand-by mode and the two thermocouples were inserted inside the two aluminium blocks. The speed of the engine, brake torque, and time for fuel consumption for a volume of 100 ml were measured. The voltage across the TEG and the temperatures on the hot and cold sides of the TEG were also recorded. The experimental work was accomplished at ambient conditions of 43 °C and 55% relative humidity.

4-Results and Discussion:

The results obtained from the experimental work are presented to demonstrate the use of this method of waste heat recovery from a spark ignition engine via an integrated TEG.

The experimental results demonstrated that TEG voltage generation increased with increases in the hot side temperature. These improvements showed that voltage generation can be as much 5 volts at hot side temperatures of 195 °C, as presented in Fig. 5.

Figure (6) shows that the hot side temperature increased with time; this was mainly due to heat accumulating from the engine over time. Accordingly, the generated voltage from the TEG also increased with time, as shown in figure (7).

In terms of temperature difference, the 5-volt generation was obtained when the temperature difference reached a value of 121 °C, as shown in Fig. 8. This occurred after a time period of 21.16 minutes, as shown in Fig. 9

The increase in the generated voltage with increasing temperature difference between the hot and cold side of the TEG can be attributed to the larger temperature difference causing the electrons to become more activate in terms of flowing to the cold side using the n-type thermocouple while the electron holes flowed from hot to cold in the p-type thermocouple, causing the electrons to combine electrically in series.

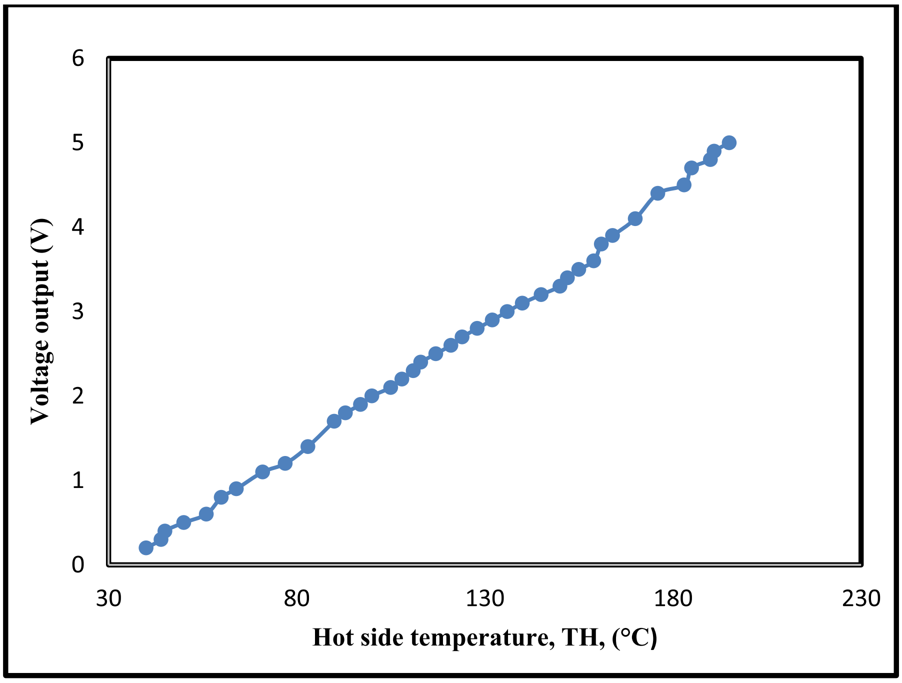

Figure (5) Voltage output from thermoelectric generator as a function of hot side temperature.

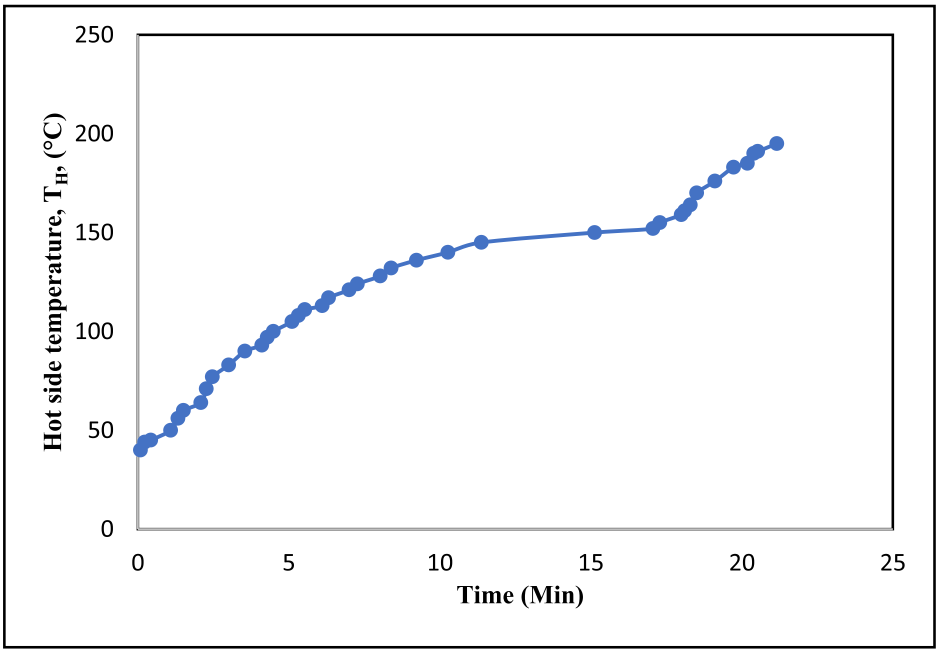

Figure (6) Relationship between hot side temperature and time.

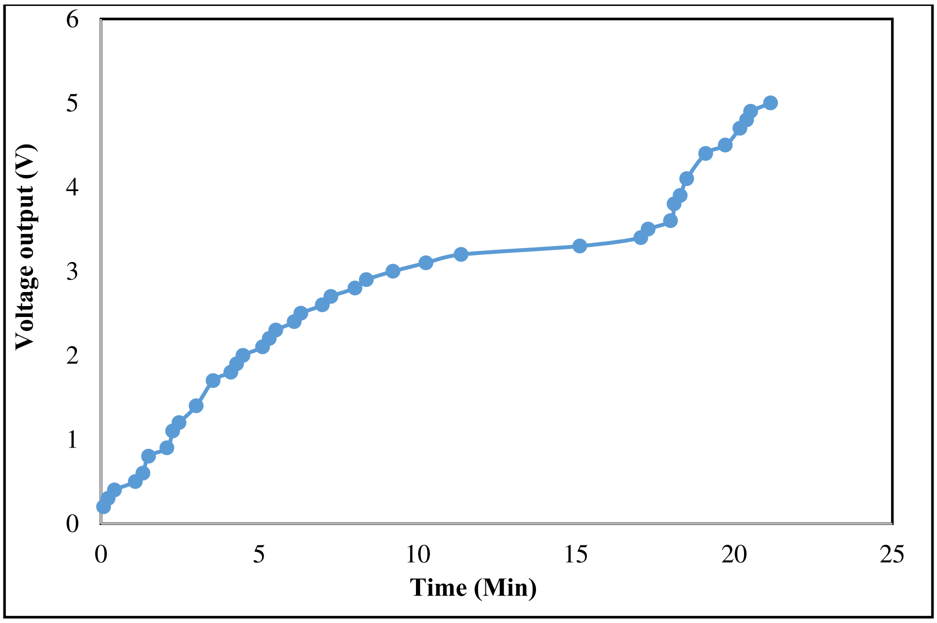

Figure (7) Voltage output as a function of time.

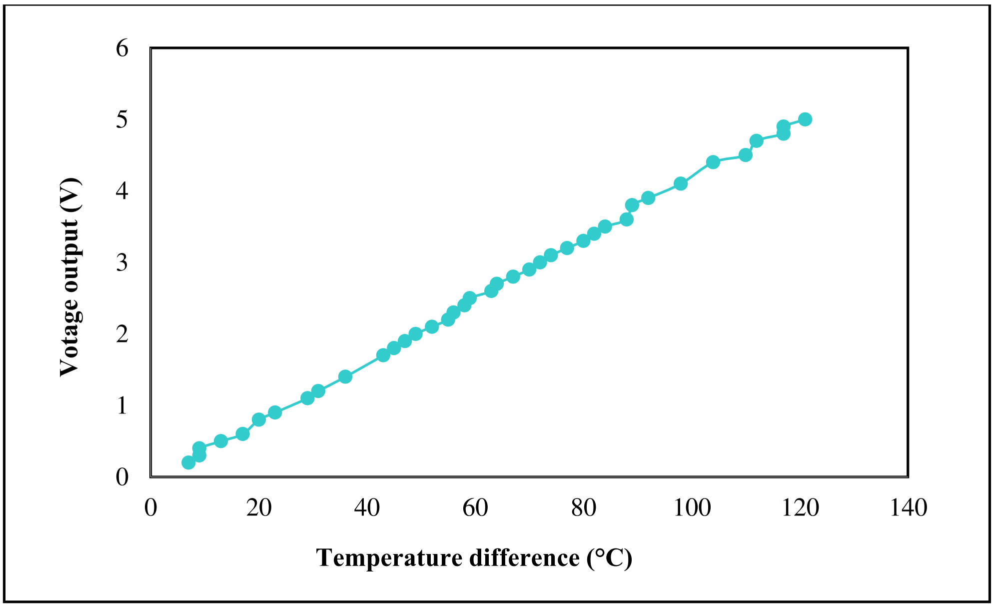

Figure (8) Relationship between voltage output and temperature difference.

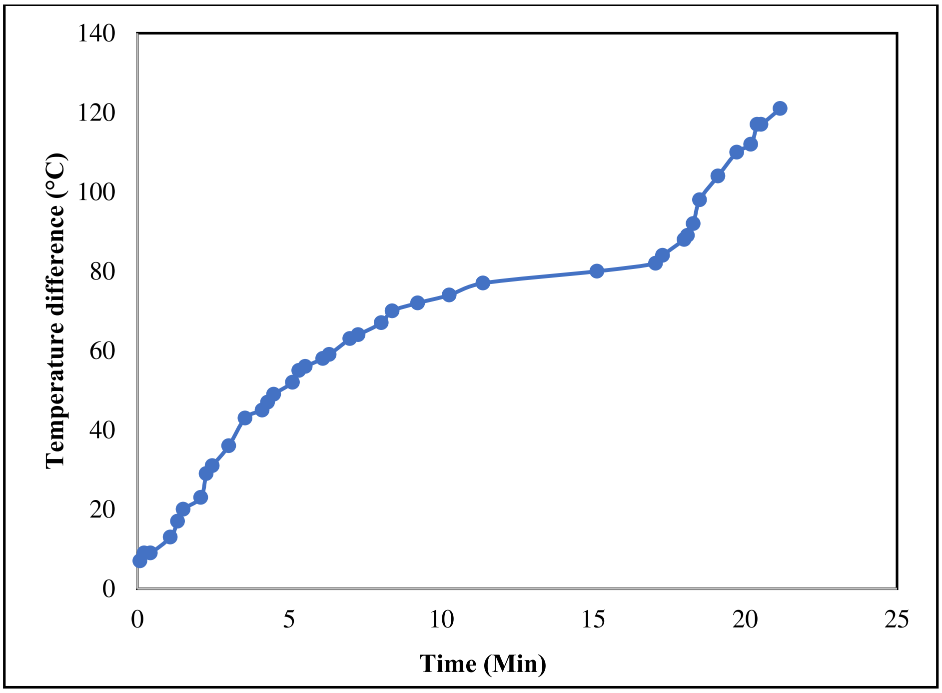

Figure (9) Relationship between voltage output and temperature difference.

5. Conclusions:

Waste heat recovery from an SI engine at a constant speed using a heat recovery system which includes a thermoelectric generator generates conclusions as follows:

The voltage generated from the thermoelectric generator increased with increases in the hot side temperature. The maximum voltage generated was 5 volts at a maximum hot surface temperature of 195 C°. The voltage generated by the thermoelectric generator increased when the temperature difference between the cold and hot sides of the thermoelectric heat generator was increased. The maximum voltage generated occurred at a maximum temperature difference of 121 ˚C. The hot side temperature, cold side temperature, and temperature difference all increased with respect to time. Future work should involve measuring the fuel saved due to electrical power generation from the application of TEG processes.

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