Study the Effect of using Exhaust Heat in Electric Power Generation and its Impact on Engine Performance

Rady Mahfouz[1], Essam Allam[2], Sabry Allam[3] and Ibrahim Ahmed[4]

[1]Researcher at Department of Automotive Technology, Helwan University, Cairo, Egypt
[2]Professor at Automotive Engineering Department, Faculty of Engineering, Helwan University, Cairo, Egypt
[3]Professor at Automotive and Tractors Technology Department, Helwan University, Cairo, Egypt
[4]Professor at Automotive and Tractors Technology Department, Helwan University, Cairo, Egypt

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Abstract – *This paper discusses how to achieve electrical energy using the amount of waste heat from the exhaust using TEG, as the use of electricity in cars is one of the most important problems in cars. this research has used a two-stroke engine and has also used a cooling circuit (Tetrafluoroethene R 134A) to cause temperature differences for the TEG, also used a cooling fan, water pump, a set of electrical connections and an Arduino circuit to read the results on a statement screen, and all components have been installed on a metal structure installed in a hurry for ease of movement. The paper was directed towards achieving the use of TEG in the application of automotive, in this paper we will discuss designing a strategy to generate electricity by comparing experimentally that were conducted on the model and the theoretical in which a program is used ANSYS. Heat capacity and heat transfer are major factors that influence the thermal performance of TEG. To achieve a uniform distribution of temperatures, two types of exhaust muffler were studied by using ANSYS (Thermal-Fluent), and SolidWorks to design model. The first type using the fins and the maximum temperature was 259.711, and by not using the fins the maximum temperature was 263.049, and the heat distribution in the second case was better than in the first case. At the maximum temperature, the highest voltage and current was obtained at 30 Volts and 4.1 Amps. The experimental and theoretical results after the comparison showed that the congruence is positive and this system can be developed and used in the automotive field on a large scale.*

Key Words: Solid Works, ANSYS Fluent; CFD, Thermoelectric generator; Waste heat recovery; Internal combustion engine.

1.INTRODUCTION

During the last decade, it has become increasingly clear that climate changes together with a shortage of fossil fuel are two of the main threats to the environment and our society today. The transport sector represents about one third of the overall energy consumption in the world and the source of energy in the sector is completely dominated by fossil fuels [1], and also Vehicle manufacturers are constantly striving to lower fuel consumption.

Thermoelectric generation (TEG) is one such technique that allows direct conversion of heat into electricity. It is rising in popularity for heat recuperation applications mainly because of its compactness and robustness without moving parts. Different fields of implementation of TEGs have been reported in the literature including biomass [2-3], solar energy [4], geothermal, nuclear, and even industrial power plants. Several researchers have studied thermoelectric recuperation for automotive applications. Due to the broad interest in developing technical applications, effort has also been put into developing simulation tools that range from first principle simulations of small systems, to full-scale TEG system simulations using simplified models, and also coupled system simulations that combine fluid dynamics simulations with thermoelectric models [5].

Thermoelectric is the science and technology associated with the direct conversion between heat flow and electric current. Thermoelectric can be used either to create a current from an existing temperature gradient or to create a temperature difference by applying an electric current. Both of these applications have been known since the early 19th century [6]. The technique has the advantage of being robust without any moving parts and having a long lifetime. The disadvantage of the technique is its low efficiency. Since the discovery of the thermoelectric effect, a lot of research has been conducted in the field, but, nevertheless, the typical efficiency of commercial modules is not more than around 5% [7]. However; The thermoelectric generation system and their application is a system that can be used to generate electrical energy from the amount of waste heat from the exhaust, as well as improving the efficiency of internal combustion engines. There are many heat generation systems that can be controlled (classic or modern) to achieve electrical energy from thermal energy generation to be used for any engineering or industrial applications.

The system consists of an internal combustion engine and a heating system. It is represented in the exhaust system, and a cooling circuit of the TEC system in addition to 10 pieces of TEC and the measurement system, which are fixed and installed on an iron chassis. The engine turns without load for 10 minutes until the highest temperature is reached. Then operating the cooling circuit based on the temperatures notified by theoretical study using ANSYS (Thermal-Fluent). Issues a problem with controlling the specific system in maintaining temperature constant. To complement temperatures, voltage, current, and power values a sensor will be used to record readers and clarify them on the data screen to compare the results with the theoretical results required to reduce the error between practical and target theoretical.

The exhaust gases were studied using (CFD) to check the surface temperature, heat transfer rate and pressure drop in three different driving cycles. An electric thermal unit was used to convert heat into electricity. This research work focuses on improving the design of the exhaust heat exchanger by removing the internal fins and changing the cross-sectional area of the heat exchanger to reduce the problem of pressure drop. Computational Fluid Dynamics (CFD) is used to simulate the exhaust gases flowing into the heat exchanger. The researchers used a car equipped with a 1.2-liter petrol engine. A rectangular heat exchanger is used in the manifold of the internal combustion engine (ICE) numerical style to recover heat lost from the engine exhaust. It was found that a rectangular heat exchanger with a gradual increase in the cross-section area, which reduces pressure drop and gives a better temperature on the surface and increases the heat transfer rate [11]. However; the effectiveness of heat exchanger for thermo-electric power generation using exhaust heat energy from IC engine was designed and analyzed. The heat exchangers were assembled in sandwich arrangement with TEGs between them. Thermal grease was spread on the surfaces where TEG modules were attached to increase the heat transfer. It was found that double stacked type heat exchanger gave better temperature gradient across the TEG. Counter flow type arrangement enhances the effective heat transfer [8].

A circular heat exchanger with fins attached with the TEGs for recovering waste heat from an automobile exhaust pipe was analyzed by performing CFD analysis. As the temperature increased voltage produced also increased as voltage was proportional to the temperature difference. It is analyzed that the heat exchanger attached between muffler and catalytic converter gave more uniform flow distribution, lower back pressure, and higher surface temperature [12]. However; TEG was fabricated for a two-wheeler silencer. The performance of the engine will not be affected because only the surface heat of the silencer was drawn out. The main aim of this research is to transfer the surface exhaust heat to avoid the accidents (Burn-outs) caused by the overheated silencers, and to transfer the recovered heat to useful electric energy. The output could be increased by connecting TEGs in series. So that the voltage gets added up leading to increase power. The energy produced from this system is utilized in powering any auxiliary devices in a vehicle directly or it could be stored in a battery and then used later [13].

Another piece of work focused on different working condition i.e. rate of mass flow, fluid temperatures and correct place of thermoelectric module. The electric power produced from TEG is observed to be a strong function of mass flow rate and inlet exhaust temperature. The heat exchanger should be highly efficient which is necessary to enhance the amount of heat energy extracted from exhaust gas. It is observed that exhaust gas parameters and heat exchanger structure have a significant effect on the power output and the pressure drop. It is also identified that the potentials of the technologies when incorporated with other devices to maximize the performance of the vehicles [9]. A transient 3D CFD model for simulation of exhaust gas flow, rate of heat transfers and power output is developed. The model works under critical design parameters for TEG- EGR to be verified and design criteria for the TEG. Besides the theory of Seebeck effects, the thermal simulations of model give detailed analysis of the temperature gradients in the gas phase and inside the TEGs. CFD model is a valuable tool to identify bottlenecks, improve design and select optimal TE materials and operating conditions. CFD analysis shows that the greatest heat transfer resistance is in the gaseous phase and it is not possible to change this to get a larger temperature gradient over the thermo-electric elements without effecting on the maximum allowable pressure drop in the system. [10].

2. ACTUATION EXPERIMENTALLY MECHANISM

A. EXPERIMENTAL TESTS

The parts with the arrangement of TEG modules are assembled as shown in **figures 1 and 2**. The motor is started and the acceleration is to be given, so that the amount of heat leaving the exhaust will be increased. Due to this heat, the surface of the exhaust pipe and the silencer will be heated to very high temperatures. These hot surfaces will try to liberate the heat to the atmosphere, which acts as a Heat Sink. Since the atmospheric temperature is less than that of the silencer surface, a temperature difference is created and hence the surface tries to attain the equilibrium state through the heat transformation process. But this will take much longer time. Hence in order to increase the rate of heat transfer the Thermal Grease is used to enhance the heat transfer. The Thermal Grease is coated on the hot surface of the silencers and also in the inner surface.

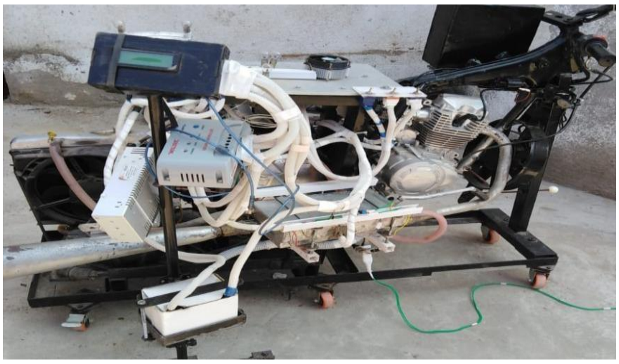

Fig – 1: Experimental Setup.

As the surface of the silencer gets more and more heated, the heat transfer rate will increase due to the increase in the temperature difference. The Peltier module is placed between the Heat Source (Hot Silencer Surface) and the Heat Sink. The module is made of semiconducting materials. Hence by the principle of Seebeck Effect, the temperature difference can be directly converted into voltage by using some thermoelectric materials. Based on this effect, when the surface heat of the silencer is passed on to the atmosphere, the electrons and holes of the thermo electric semiconductors will try to move towards the junction and make the flow of electric current to be possible. The voltage developed due to this effect can be increased by using some Booster circuit and Arduino system as DC-DC Converter. This will step up the voltage generated to some nominal value, so that it can get the sufficient amount of voltage. For this converter the general formula used to measure the approximate voltage for the given temperature is T=V/10mV. Hence this voltage can be connected to some battery and stored, or else it can be given directly to some electric appliances which uses DC. If there is a need for AC voltage, it can be converted using the rectifier. The voltage generated can be increased by placing a greater number of modules and connecting them with one another to meet the demand of the required voltage. This voltage can then be supplied to the suitable electrical appliances.

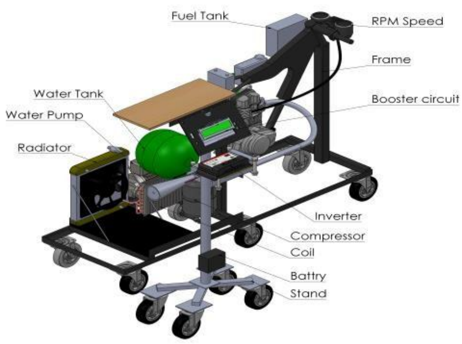

Fig – 2: CAD model

Table-1: Parameters of experimental setup of a TEG system.

Parameter	Value
engine	Two stroke one piston
Bore/Stroke	50 X 50 mm
Compression Ratio	150 cc
Piston Displacement	6.6 : 1
Maximum Torque	0.98 kg-m at 3500RPM
Maximum Speed	6000 RPM
Dimension of TEG	62x62x4.0 mm
Max operating temperature of TEG	250 C
Dimension of cooling box	320x180x22 mm
Max power of pump	750 W (220 V AC)
Rated power of radiator	200 W (12 V DC)
Material cooling box	Aluminum
Material muffler box	Galvanize Steel

B. Experimentation

To the bend exhaust pipe of the IC engine specified above in **Table 1**, a galvanize steel plate 2 mm thick is welded to form the junction of the thermo electric generator. Eight thermoelectric generators connected in series, are placed on the hot galvanize steel plate acting hot junction, on the other side of the TEG, the cold sink of aluminum is connected as shown in figure 2. In between hot and cold junction TEG's are fitted by nuts and bolts shown in the figure. The hot and cold side temperature of TEG is continuously monitored using digital thermometers. The heat paste is applied at the junction to ensure proper contact between surfaces and conduction of heat. As the engine starts, the hot junction gets heated and the heat transfer rate increases across the thermoelectric generator, now with Seebeck effect it starts generating voltage. The voltage generated will be of very small magnitude hence the Joule Thief voltage booster, is used to boost up the voltage. Two digital multimeters are attached to continuously monitor the generated and boosted voltage. This boosted voltage is connected across the load and tests are done. One important thing which is worth mentioning is, if this system is attached to a vehicle, when the vehicle moves the air flowing over the fins of Aluminum sink will be fast creating more cooling of the sink, hence maintaining more temperature difference across the TEG and more voltage generation. Readings were taken by running the engine at different RPMs.

C. Electrical system description

The electrical system consists of some modules that integrate with each other to perform the task of regulating, charging controlling and monitoring the thermoelectric generation system (TEG) as clearly shown in **Figure 3**.

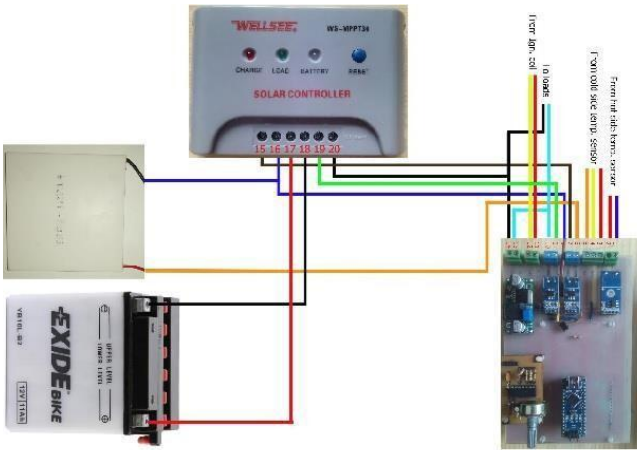

Fig – 3: Electrical system component

- The system is divided into two main parts:

First part is the charge controller ; its connected to the TEG plates , the battery and the load , it regulates the power generated from the TEG plates to a suitable level for charging the battery and operating the various loads , it also monitors the battery status tell it is fully charged and exclude it from the circuit if there is no need for consuming the stored power inside it , which will drive loads directly from the TEG plates and reserve the battery for other situations where TEG plates output is not sufficient to drive the loads , by that battery life time is extended by reducing its charge/discharge cycles over normal usage.

Second part is the monitoring system; it's based on an Arduino Nano as main processor integrated with various modules to keep track for temp, current, voltage and engine RPM, all the registered data are shown in real-time on an LCD screen, also data registered is sent via serial communication to pc for logging and representation.

- Detailed description for main controller board parts:

1- Arduino Nano: is an atmega328 based microcontroller used to register data from the various modules, perform any mathematical operations on it then display it on the LCD screen and send it via USB to the computer.
2- MAX 6675 temp transducer: it uses a K-type thermocouple sensor to sense the hot side temp and has a range of 0 - 700 °c and send data to Arduino through I2c communication protocol in the form of 12-bit resolution.
3- Terminal connection for the thermocouple to the MAX6675 module.
4- Terminal connection for LM35: the LM35 is temperature sensor that has sensing range varies from -55 to 150 °C and outputs an analog signal to the Arduino, this analog signal corresponds to10mV/°C linearly.
5- ACS712-30A-T current sensor: it's used to measure current supplied from the TEG plates to the charge controller and translates it into analog signal that is feed to the Arduino in form of 66 mV/A.
6- PC817 Opt-isolator: it's used to measure the voltage supplied from the TEG plates to the charge controller and translates it into analog signal that is feed to the Arduino in complete electrical isolation.
7- Terminal connection for the supply conductor of the TEG plates to allow supply voltage and current measurement.
8- ACS712-30A-T current sensor: it's used to measure output current from the charge controller to the load and translates it into analog signal that is feed to the Arduino in form of 66 mV/A.
9- Voltage divider: it's used to measure the output voltage from the charge controller to the load and translates it into analog signal that is feed to the Arduino in complete electrical isolation.
10- Terminal connection for the output conductor from the charge controller to the load to allow output voltage and current measurement.
11- Lm2907 module: it's a frequency to voltage converter used to count engine RPM and convert it into analog signal that is feed to the Arduino for further operations.
12- Terminal for the lm2907 module input, it connects the ignition coil control signal to the module as it represents the engine RPM.
13- DC-DC step-down converter: it's used to supply the whole board with fixed 5v for any input voltage up to 30 volts.
14- Terminal connection for the supply voltage to the dc-dc converter and is connected with the load terminals of the charge controller.
15- LCD display: for displaying real-time data registered by the system to keep track for its status.

D. Experimental result

A typical total waste heat recovering technology, using thermoelectric generators (TEGs), coupled with a gasoline engine was investigated in this study conducted at Helwan University, Cairo. According to the experimental analysis the temperature of pipe surface of exhaust gases flowing through exhaust gas pipe is high and it is around 70 °C to 270 °C, so a heat exchanger is made, which conducts heat from exhaust pipe to thermoelectric modules, one surface of these modules is in contact with the surface of hot side heat exchanger and other is in contact with the surface of cold side heat exchanger and thus potential difference is created and power is produced due to Seebeck effect.

Influence increasing heat on the electricity produce. The values at 2000 rpm of the measured parameters are summarized in table-2 and figure 24 shown the effect of the motor speed and time on temperature was studied at different speeds, and discard torque because didn't need it in the test. The motor speed was changed by hand. In addition, all measured results were performed at different speeds.

- The curves shown in figure 4, voltage current and output power characteristics of a TEG, simulated by Arduino circuit and output data created by Matlab/Simulink are given as depending on the temperature differences between the surfaces of TEG at the temperature difference.
- The experimental measured values of hot side and Time at 2000 rpm, and shown increase temperature related by time. In figure 5, shown power in the first-time values are constant, and increasing power start from 40 °C. In figure 6, shown current values in the first time are constant also, and take a time to increasing. In figure 7, shown voltage also the stability at first time and increasing at 40 °C.

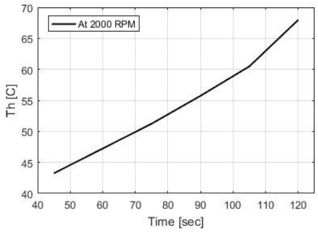

Fig. 4 The experimental measured values of Hot side and Time.

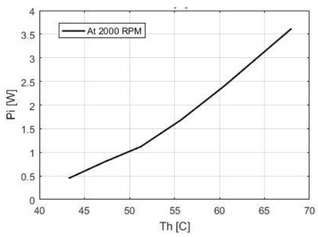

Fig. 5 Power curve at the various temperature.

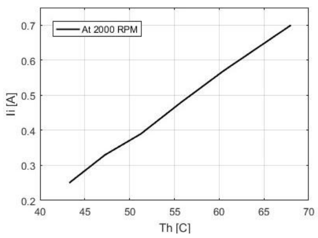

Fig. 6 Current curve at the various temperature.

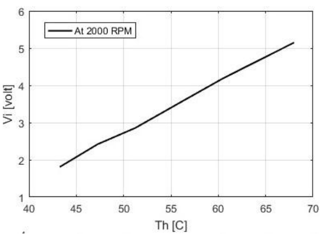

Fig. 7 Voltage curve at the various temperature.

In the figure 8-11, at 3000 rpm shown the curves, voltage current and output power characteristics of an TEG. As in indicated in table-2 and figure 25. In figure 8. The experimental measured values of Hot side and Time at 3000 rpm, and shown increase temperature related by time. In figure 9 shown increasing voltage related by time and hot temperature. In figure 10 shown current values. However; in figure 11 shown power the values are increasing.

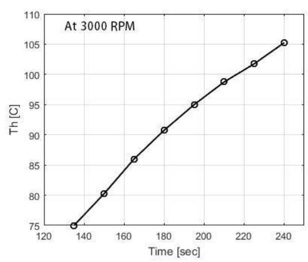

Fig. 8 The experimental measured values of Hot side and Time.

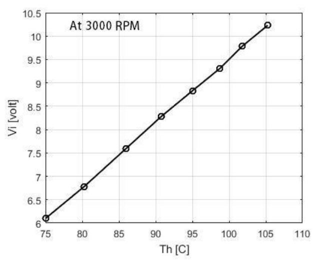

Fig. 9 Voltage curve at the various temperature.

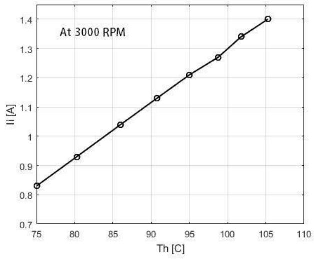

Fig. 10 Current curve at the various temperature.

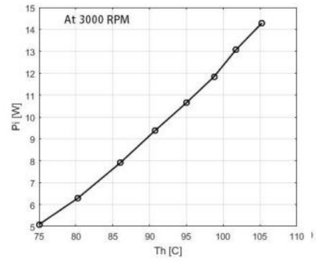

Fig. 11 Power curve at the various temperature.

At 4000 rpm the values of the measured parameters. The curves shown, voltage current and output power characteristics of an TEG as indicated in table (2) and figure 26. In figure 12 the experimental measured values of Hot side and Time at 4000 rpm, and shown increase temperature related by time. And in figure 13 shown increasing voltage related by time and hot temperature. In figure 14 shown current values. However; in figure 15 shown power the values are increasing.

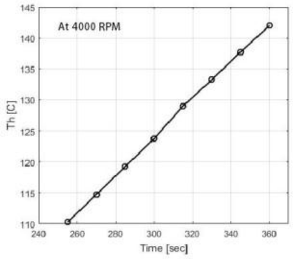

Fig. 12 The experimental measured values of Hot side and Time.

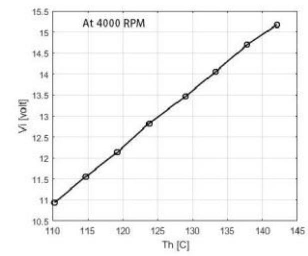

Fig.13 Voltage curve at the various temperature.`

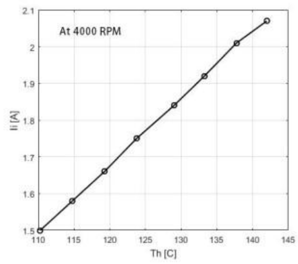

Fig.14 Current curve at the various temperature.

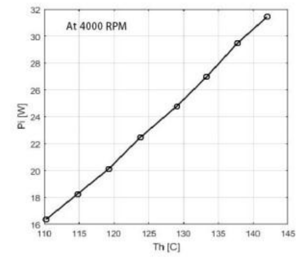

Fig. 15 Power curve at the various temperature.

At 5000 rpm the values of the measured parameters. The curves shown, voltage current and output power characteristics of an TEG. As in indicated in table-2 and figure 27. In figure 16, the experimental measured values of Hot side and Time at 5000 rpm, and shown increase temperature related by time. In figure 17 shown increasing voltage related by time and hot temperature. In figure 18 shown current values. However; in figure 19 shown power the values are increasing.

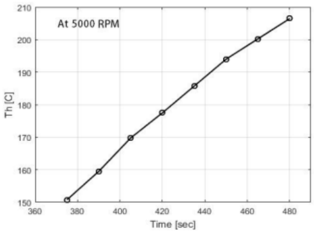

Fig.16 The experimental measured values of Hot side and Time.

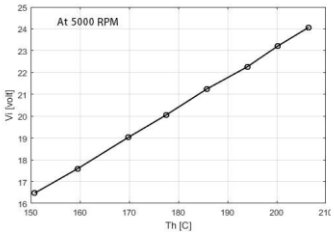

Fig.17 Voltage curve at the various temperature.

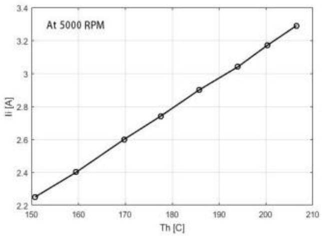

Fig.18 Current curve at the various temperature.

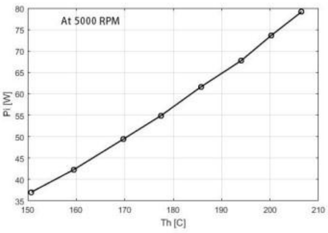

Fig.19 Power curve at the various temperature.

At 6000 rpm the values of the measured parameters. The curves shown, voltage current and output power characteristics of an TEG. As in indicated in table-2 and figure 28. In figure 20, the experimental measured values of Hot side and Time at 6000 rpm, and shown increase temperature related by time. In figure 21 shown increasing voltage related by time and hot temperature. In figure 22 shown current values. However; in figure 23 shown power the values are increasing.

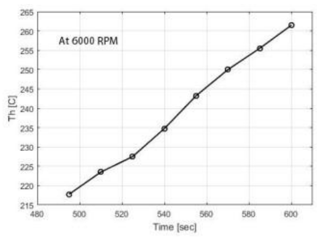

Fig.20 The experimental measured values of Hot side and Time.

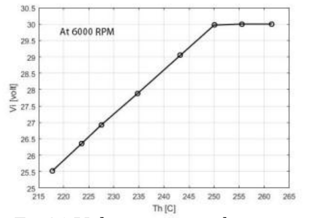

Fig.21 Voltage curve at the various temperature.

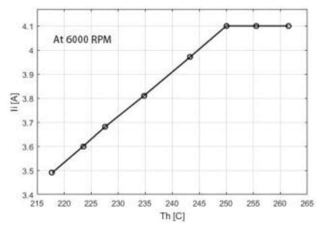

Fig.22 Current curve at the various temperature.

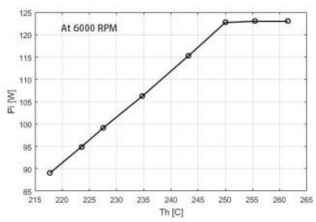

Fig.23 Power curve at the various temperature.

Table- 2: Experimental Result Table

RPM	T (sec)	Th	Tc	Vi	Ii	Pi	Vo	Io	Po
2000	120	68	11	5.15	0.7	3.62	10.68	5.71	60.9828
3000	240	105.25	18	10.23	1.4	14.29	11.92	5.71	68.07
4000	360	142	25	15.17	2.07	31.45	11.78	5.5	64.81
5000	480	206.5	32	24.07	3.29	79.17	11.55	5.59	64.58
6000	600	261.5	38.3	30	4.1	123	13.34	5.56	74.1704

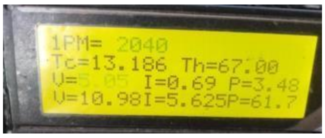

Fig. 24 Measure Experimental at 2000 rpm

Fig. 25 Measure Experimental at 3000 rpm

Fig. 26 Measure Experimental at 4000 rpm

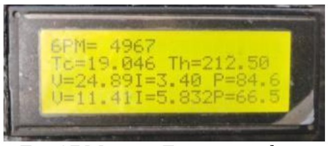

Fig. 27 Measure Experimental at 5000 rpm

Fig. 28 Measure Experimental at 6000 rpm

Finally, the effect of temperature was studied at different speeds, and volt, current and power depended on temperature in the test. In addition, all measured results were performed at different temperature hot and cold at time and rpm. The maximum values of the measuring parameters are summarized in the table 2 and in figures 29, 30, 31 and 32.

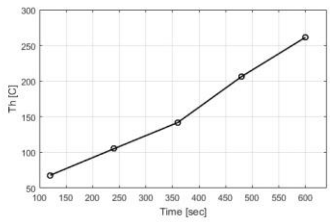

Fig.29 The experimental measured maximum values of Hot side.

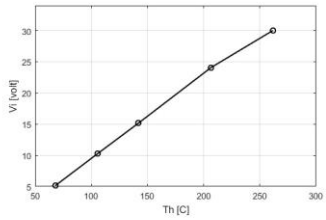

Fig.30 Maximum Voltage curve at the various temperature.

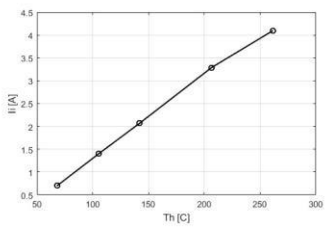

Fig.31 Maximum Current curve at the various temperature.

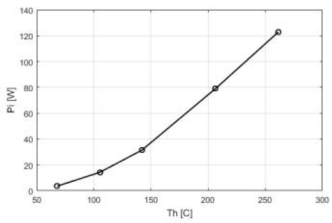

Fig.32 Maximum Power curve at the various temperature.

3. ACTUATION THEORETICAL MECHANISM

Dimensions for the muffler, coolant and TEG were taken directly from the SolidWorks drawings provided by the two models, with fins and without fins. Within the SolidWorks software, there is a tool which allows the user to specify two points of a model and find the corresponding length between them. In this manner, the various distances making up the components of the muffler, coolant and TEG were collected and solid models were then created in ANSYS using these values. The converted SolidWorks model in ANSYS is shown in figure 33 (a, b).

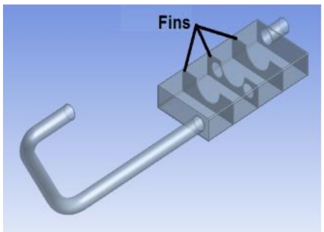

Fig. (33.a). Muffler with fins

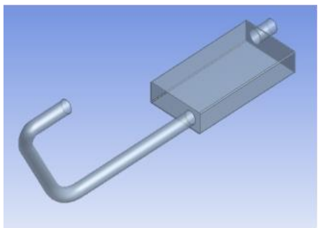

Fig. (33.b). Muffler without fins

A. Description of muffler and coolant box

For the purpose of comparison, structure were made with the same dimensions, with a shell of 320 mm×135 mm×33 mm and thickness 2 mm with the inlet and outlet of 27 mm in diameter, and coolant dimensions 330 mm×180 mm×22 mm and thickness 4 mm as shown in figures 34 and 35.

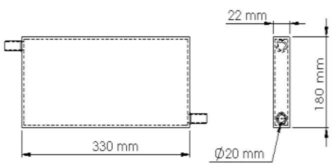

Fig. 34. Coolant box

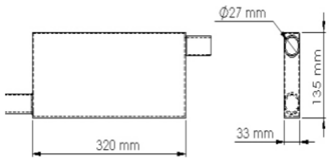

Fig. 35. Muffler

Calculations were made in 3D system in a steady state. Thermal of both exhaust, cooling and TEG was accepted as well as the following boundary conditions were from the experimental test.

B. Simulation model

Relation between hot and cold side shown in figure 36(a,b)

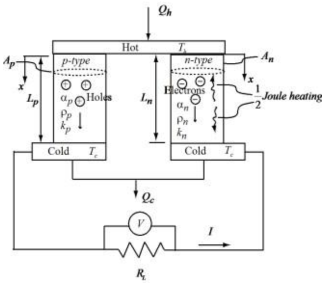

Fig. 36 (a) Cutaway of a thermoelectric generator module.

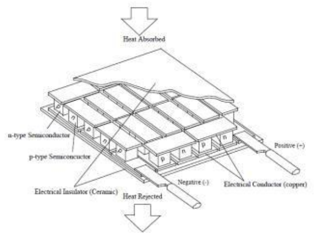

Fig. 36 (b) a p-type and n-type thermocouple.

$$\vec{\nabla} \cdot \vec{j} = 0 \quad (1)$$

$$\vec{E} = \rho\vec{j} + \alpha\vec{\nabla}T \quad (2)$$

The electric field $\vec{E}$ is affected by the current density j and the temperature gradient $\vec{\nabla}T$. The coefficients are known according to the Ohm's law and the Seebeck effect [5].

$$\vec{q} = \alpha T\vec{j} + k\vec{\nabla}T \quad (3)$$

The heat flux $\vec{q}$ is also affected by both the field $\vec{E}$ and the temperature gradient ∇T. The general heat diffusion equation is given by:

$$-\vec{\nabla} \cdot \vec{q} + \dot{q} = \rho C \frac{\partial T}{\partial t} \quad (4)$$

For steady state, we have.

$$-\vec{\nabla} \cdot \vec{q} + \dot{q} = 0 \quad (5)$$

Where $\dot{q}$ is expressed by [5].

$$\dot{q} = \vec{E}\cdot\vec{j} = \vec{j}^2\rho + \alpha\vec{j}\vec{\nabla}T \quad (6)$$

Substituting Equations (3) and (6) in Equation (5) yields.

$$\vec{\nabla}\cdot(k\vec{\nabla}T) + \vec{j}^2\rho - T\frac{d\alpha}{dT}\vec{j}\vec{\nabla}T = 0 \quad (7)$$

The electrical behavior is given by the thermal voltage V_{α} and the voltage drop V_{ρ} due to the material resistance R.

$$V = V_{\alpha} - V_{\rho} = \alpha\left(-\frac{\partial T}{\partial x}\right) - \rho j \quad (8)$$

The thermal behavior results from an energy balance:

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) - I T \frac{\partial \alpha}{\partial x} + I^2 \frac{r}{A} \quad 9$$

Where:

$$T\frac{\partial \alpha}{\partial x} = T\frac{\partial \alpha}{\partial T}\frac{\partial T}{\partial x} = \tau \frac{\partial T}{\partial x} \quad 10$$

The energy balance also includes an emitted electrical power P_{el}:

$$P_{el} = \dot{Q}_h - \dot{Q}_c = \alpha \left(-\frac{\partial T}{\partial x}\right) I - I^2 R = \dot{Q}_h - \dot{Q}_c \quad 11$$

With Seebeck coefficient α, thermal conductivity λ, electrical resistivity r, specific (isobaric) heat capacity c, mass density ρ, and Thomson coefficient τ. P_{el} is the electric power, $I^2 R$ is the Joule heat production.

C. Simulation results

- Model 1

The temperature contour diagram for the exhaust muffler model (Design 1) shown in Figure 37. From the figure, the temperature distribution across the muffler was observed. Comparing the temperature contour diagrams for the experimentally model and Design 1 model, it can be seen that the temperature that is built on the outlet side of the Design 1 muffler model was higher than that in the experimentally model.

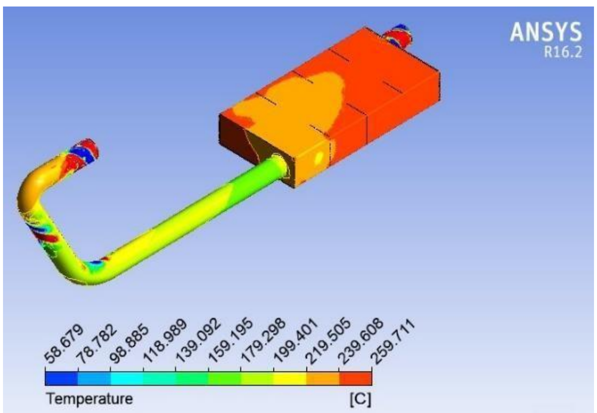

Fig -37: Temperature contour for model 1.

- Model 2

The temperature contour diagram for the exhaust muffler model (Design 2) shown in Figure 38. From the figure, the temperature distribution across the muffler was observed. Comparing the temperature contour diagrams for the exhaust muffler model (Design 1) and exhaust muffler model (Design 2) and the experimentally, it can be seen that the temperature that is built on the outlet side of the Design 2 muffler model was higher than that in the two models. However, it is expected that there occurs cross increase to temperature at locations of chamber.

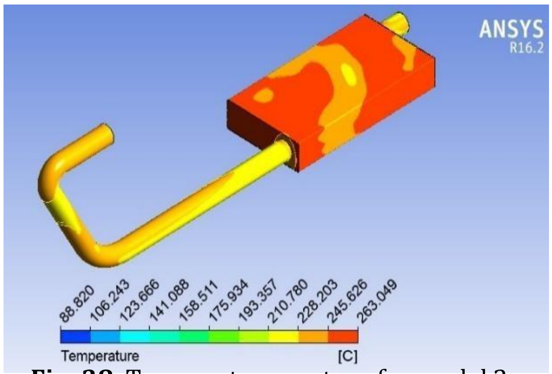

Fig -38: Temperature contour for model 2.

Finally in the figure 39 (a, b), shown different between two models curves, at maximum and minimum temperature.

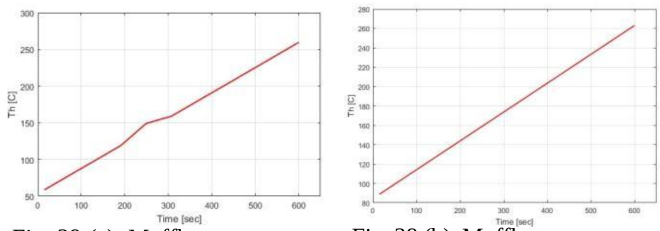

Fig. 39 (a). Muffler temperature with fins.

Fig. 39 (b). Muffler temperature with fins.

In the figure (40) shown between two surfaces hot and cold, and temperature distributions.

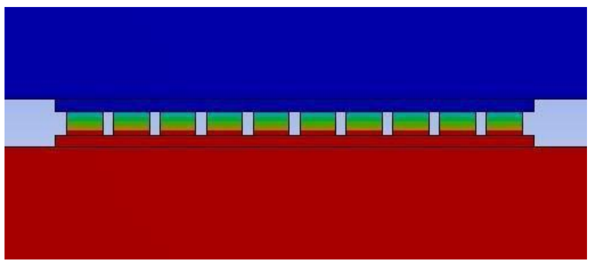

Fig -40: View details of temperature.

In the table (3) the values of theoretical of simulation study and results are summarized in table shown the effect of temperature and time was studied at different temperature, the temperature based on simulation factors.

Table- 3: Theoretical Result Table

RPM	T (sec)	Th	Tc	Vi	Ii	Pi
2000	120	72.0000	11	4.8800	0.9340	4.5578
				10.1200	1.4086	14.2552
				14.9864	2.0211	30.5195
				23.8073	3.2822	77.2554
				30.7637	4.1932	128.9989

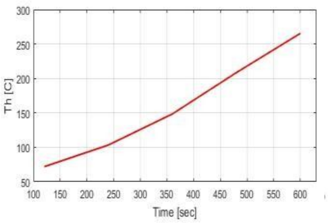

Fig. 41 The effect of heating the TEG

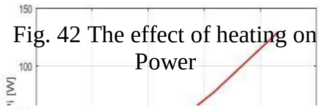

Fig. 42 The effect of heating on Power

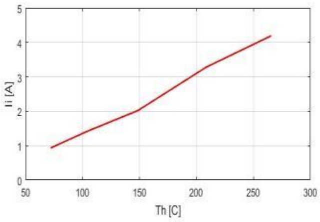

Fig. 43 The effect of heating on Current

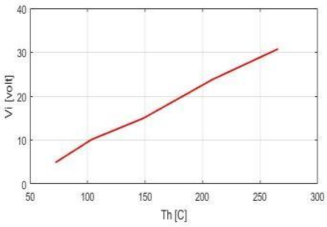

Fig. 44 The effect of heating on Voltage

4. Validation of work

To make sure that the work done is accurate we make validation with a research of the same conditions. In order to confirm the validity of research, additional comparison between experimental data and theoretical data, for recent research are discussed. It was found that Predicted responses show good agreement with actual results.

After comparing the theoretical and the experimental data at each speed we can find use the theoretical data to find the experimental data by assuming the error relation between them and for simplicity we assume that the error will be fixed or follow an 1st order equation.

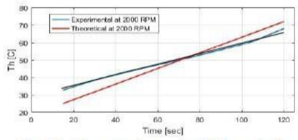

Fig. 7.1. The experimental and theoretical measured values of Hot side and Time.

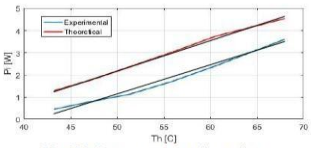

Fig. 7.2. Power curve at the various temperature.

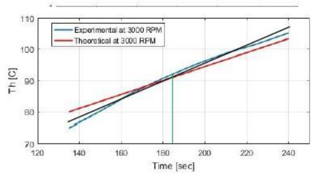

Fig. 7.5. The experimental and theoretical measured values of Hot side and Time.

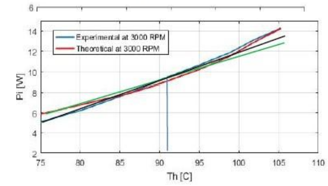

Fig. 7.6. Power curve at the various temperature.

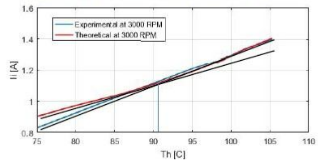

Fig. 7.7. Current curve at the various temperature.

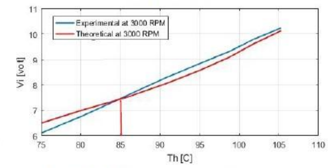

Fig. 7.8. Voltage curve at the various temperature.

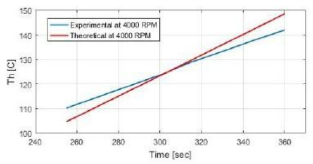

Fig. 7.9. The experimental and theoretical measured values of Hot side and Time.

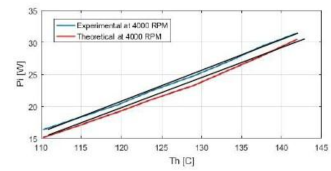

Fig. 7.10. Power curve at the various temperature.

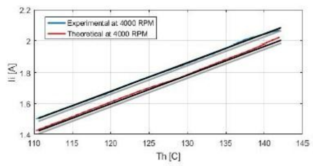

Fig. 7.11. Current curve at the various temperature.

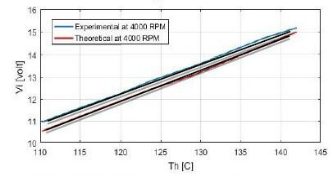

Fig. 7.12. Voltage curve at the various temperature.

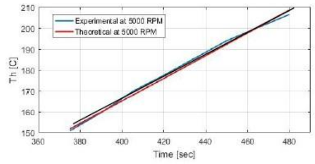

Fig. 7.13. The experimental and theoretical measured values of Hot side and Time.

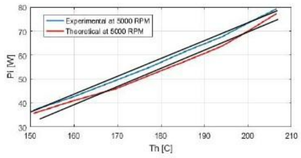

Fig. 7.14. Power curve at the various temperature.

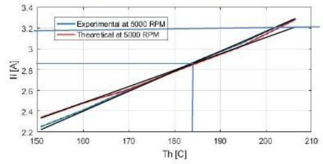

Fig. 7.15. Current curve at the various temperature.

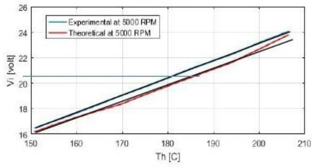

Fig. 7.16. Voltage curve at the various temperature.

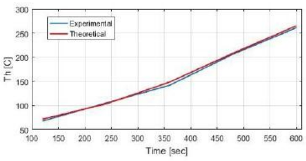

Fig. 7.17. The experimental and theoretical measured values of Hot side and Time.

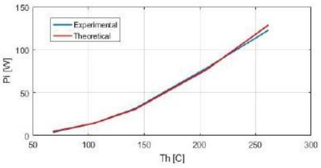

Fig. 7.18. Power curve at the various temperature.

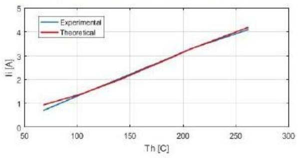

Fig. 7.19. Current curve at the various temperature.

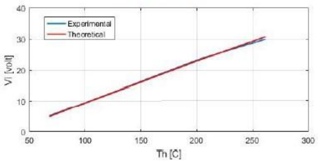

Fig. 7.20. Voltage curve at the various temperature.

5. CONCLUSIONS

From the results of the present study, the important conclusions are as follows:

Now we can find that the accuracy of the model increase by increase the engine speed this because the error between the theoretical and experimental data is reduce this men at high speeds we can use the model to find the actual data directly.

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BIOGRAPHIES

Rady Mahfouz is a researcher (M.Sc. student) at Helwan University. He obtained the B.Sc. in Industrial Education, Automotive and tractors Technology Department from Helwan University in 2008. He is currently working as a technical support at Manufacturing Commercial Vehicles (MCV) in Egypt. He was born in 1986 Elsharqia, Egypt.

Essam Allam, is a Professor of Vehicle Dynamic and control at Helwan University. He obtained the B.Sc., M.Sc. & PhD degrees in Automotive Engineering from Helwan University in 1995, 2001 & 2005 respectively. He has about 35 publications in the field of Vehicle Dynamic and control. In addition, his current research projects are focused on development of the vehicle noise and vibration from point of view of control and maintenance. Dr. Allam is a member of the Egyptian Society of Engineers.

Sabry Allam, is a Professor of Vehicle Dynamic and Control at the Faculty of Industrial Education, Helwan University in Egypt. He was a researcher at the Aeronautical and Vehicle Engineering Department, The Royal Institute of Technology, Stockholm, Sweden. He obtained his B.Sc. and M.Sc. of Automotive Engineering from Helwan University in Cairo, Egypt on 1989 and 1994 respectively. He obtained also the PhD from The Royal Institute of Technology, Stockholm, Sweden in 2005. He has many papers in the field of Vehicle Dynamics and also has many contributions in the field of Noise, Vibration and Harshness (NVH). Dr Allam is a member of Egyptian Engineering Syndicates, Egyptian Society of Automotive Engineers.

Ibrahim Ahmed, is a Professor of Vehicle Dynamic and Control at Helwan University in Egypt. He is currently the Head of Production Technology Department. He obtained his B.Sc. (1990) and M.Sc. (1995) of Automotive Engineering from Helwan Unversity in Cairo, Egypt followed by another M.Sc. from Eindhoven University 1997. He obtained also the PhD (2002) from Newcastle Upon Tyne, UK. He has about 50 papers in the field of Vehicle Dynamics and Tribology. He has many contributions in the field of Noise, Vibration and Harshness (NVH).