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Research paper

Harvesting Waste Heat Energy from Automobile Engine Exhaust Using Teg with Heat Pipes

Arun Seeralan Balakrishnan[1], Farrukh Nagi[2], Khairul Salleh[3] , Prem A/L Gunnasegaran[4]

[1]*University of Tenaga Nasional, (UNITEN) Kajang, Malaysia*
[1]*Asia Pacific University of Innovation and Technology, (APU) Bukit Jalil, Malaysia*
[2,3,4] *University of Tenaga Nasional, (UNITEN) Kajang, Malaysia*
**Corresponding author E-mail: aseeralan@gmail.com*

Abstract

This research investigates how the heat from car exhaust pipe line can be recovered as power using passive Thermo electric generator (TEG) using heat pipes. In this research the heat pipes are place on the cold side of TEG to remove the rising temperature and hot side of TEG is placed on the circumference of exhaust pipe line of car engine. The heat pipes with and without nano-fluids were placed on cold side of TEGs to investigate heat removal from increasing temperature and too maintain constant temperature on cold side. On the basis of results from 3D finite element simulations and experiments in the setup, the heat flow, voltage, and current were measured. The method presented in this paper gives detailed insight into how TEG modules perform in general, and also enables prediction of potential improvement in module performance by using different nano-fluids as coolants and Preliminary results were obtained. The results of Finite Element Analysis are analogous with the experimental results of TEG with water filled heat pipes with minimal possible errors. Therefore, the performance of nano-fluids in heat pipes are numerically evaluated and proposal are made for the enhancement of Module power outputs in Harnessing exhaust heat energy.

Keywords: *Thermo electric generator, heat pipes, waste heat energy, Nano fluids exhaust heat energy and green house effects.*

1. Introduction

Thermoelectric power generators have a wider scope and the current trend is to generate energy through waste heat that is available through the exhaust gases produced by automobiles [5]. The basic law applied is the Seebeck effect which converts the variation in temperature to electrical power. Thus, the exhaust gases available tends to act as the temperature source and thermoelectric devices are used to collate the difference in temperature between the hot gas and coolant. [1]

Thermo Electric Generator (TEG) efficiency is defined to be the ratio of output power to the input heat produced at the hot junction. This ratio indicates that an increase in the temperature difference between the hot and cold sides, increases the TEG efficiency [4]. IC engines has an efficiency of 37-50% while 40% is lost in the form of exhaust gases. Engine power is basically used to provide power to function the headlights, air conditioning system and so on, by running the alternators. However, efficiencies of these thermo electric materials [7-9] are typically low and are less than 10%, depending on temperature differences of the devices that are available. The generator's efficiency could be increased by 0.04 per degree rise in the temperature difference. Hence, it is necessary to design and develop a heat exchanging technique to make use of the available power fully. Further, the heat exchanging technique must be dynamically stable, efficient, and thermally capable. It must also allow the expansion of the TEG materials [2], which are due to the high temperatures involved. Moreover, there are many issues or challenges involved in the design of the heat exchanger. One such issue is to increase the surface area of the heat exchanger to increase the efficiency, but it cannot be increased due to limitation in the space available. Hence, any other heat transfer enhancement [6] based features could be added to overcome the space limitation, apart from the decision of the placement of the TEG.

Researcher validated TEG performance on vehicles in which two TEGs have been integrated such that they are installed parallel to the car engine with coolant to reduce the temperature, which was done with the help of an auxiliary water pump. The integrated system has been tested on Lincoln MKT and BMW X6, both under the transient and steady state conditions. The outcomes of the BMW X6 test results showed that the exhaust temperature and mass flow rate increases with increase in engine load. It was inferred that the TEG materials are always a leading factor in improving the efficiency. The issues further left over are basically to provide an excellent electrical isolation which is always challenging between the TE elements and heat exchangers. Another issue which is usually encountered at the TE engine, is the heat loss occurrence between the cold and hot sides and to the environment. The heat transfer rate is so low and possible by means of gas convection and TEG weight also contributes to transient operation issues. Hence, a system must overcome issues such as weight, voltage, engine's backpressure, volume and noise. [3]

Researchers proposed a novel TEG concept to improve the maximum output power generated by the TEG system, as it is difficult and challenging to recycle the waste heat produced by the TEGs, due to limited vehicle space. It was observed that the TEG system generates 1.8V of voltage due to transfer of heat through heat pipe. The closed loop made use of two fluids especially water and nanofluids at high and low heat flux of 90W and 30W. Thus, the heat pipe was able to transfer the heat to any identified location. But

the system could be further improved to improve the power output. [11]
According to different researchers there different system used where external power is required to remove the increasing temperature from the cold side of the TEG. It is required to maintain the temperature on the cold side of the TEG bcs the maximum difference in temperature between hot side and cold side helps the TEG system to generate the maximum power as the output. By using the heat pipes external power source is eliminated and from this research it has been proposed that heat pipes filled with nano fluids [10] provides an enhanced power without the usage of external power source.
Thus, in this paper, an investigation on the usage of heat pipe for harvesting heat energy to convert into power is studied with the help of new method of inserting the new pipe with nano fluids. It contributes the greenhouse effect by reducing the excess heat energy given to the atmosphere as waste. The waste heat energy given to the atmosphere is reused as a power to panel the dash board of the car.It increase the life of the battery bcs this system takes few loads given to the battery. It also contributes to the global warming as well.

2. Proposed Method

In this section, the constructional details and working principle are explained. Figure 1 shows the proposed TEG system using heat pipes, in which the TEG is placed in between the exhaust pipeline of the automobile engine and heat pipes. The placement of LCD, temperature sensor LM35, aluminium foil and electronic circuit are also shown in Figure 1 that converts the analog signal into digital signal.

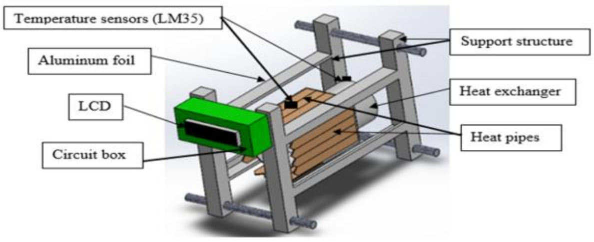

Fig.1: Proposed TEG system using heat pipes

2.1. Constructional Details

The mechanical construction for the implemented TEG device consists of a sandwich design in order to maintain the volume of the thermoelectric generator to a small standard and compact design. A cage structure is implemented to provide the necessary support required especially when moving it from place to place as illustrated in Figure 2.

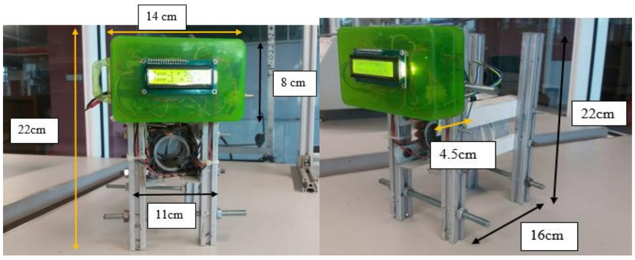

Fig.2: Front and Side view of the implemented TEG system using heat pipes

The TEG constructed measured 40mm by 40mm by 3.4mm and is mounted on the flat surface of the rectangular shaped Aluminum thermoelectric harvesting mechanism. The cooling of the TEG modules is achieved by using heat sinks along the top surface (cold end) of the modules, thereby creating a see-beck effect (temperature difference). A car exhaust pipe of diameter 15cm is used to direct the heat generated by the exhaust fumes coming from the car engine into the TEG harvesting mechanism. Coated Aluminum alloy material was used for the construction of the exhaust pipe. Four housing heat pipes made up of stainless steel with copper alloy coating are used to help in the circulation of the cooling fluid are attached on the top panel (cold side) of the modules as shown in Figure 3.

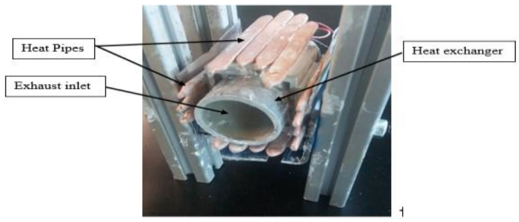

Fig.3: Cooling system using heat pipes

The electrical construction of the thermoelectric generator basically consisted of the signal conditioning circuit which is mainly implemented to analyse and stabilize the initial output of the 4 TEG modules.

2.2. Working Principle

The implemented Thermoelectric Generator operates based on the "See-beck effect" principle as illustrated in Figure 4. Flow chart for the TEG system**.** The operation of the thermoelectric generator relies on the heat produced by a combustion engine with a maximum capacity of 4,600 revolutions per minute. The output of the system in terms of voltage, current and temperatures produced is monitored with the help of an Arduino microcontroller.
The first step in the operation of the generator starts with the running of the car engine from where the Arduino based monitoring system is switched ON as illustrated in the flow chart in Figure 4. The combustion of the fuel in the car engine produces exhaust gases which largely consists of hot gases. The gases are directed towards the heat exchanger by means of an exhaust pipe from where the heat is extracted. The TEG modules harvest the heat energy on the "Hot side". A series of four heat pipes are connected on "Cold side" with the aim of creating a cooling effect. The temperature difference created on the Hot and Cold sides of the TEG modules leads to the generation of power by obeying the "See-beck effect." The voltage generated is read and displayed by use of the Arduino microcontroller and LCD display respectively.

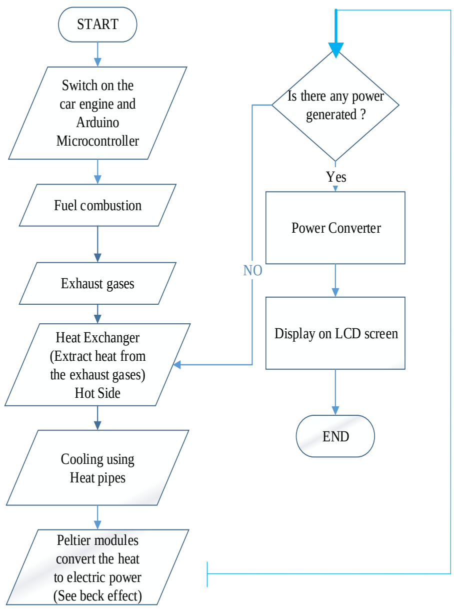

Fig.4: Flow chart of working principle

3. Experimental Analysis

Initially water is used as the heat transferring medium inside the heat pipes and the experiment analysis is based on this. Experimental data collected are actually tabulated and corresponding graphs are drawn for analysis and inference purpose using four different modules. Water-cooled heat pipes were used to remove the excess heat from the cold side of TEG and it acts as a heat sink. Because the water was heated on its way through the system, the water channels in the blocks were connected in series, from one block to the other and back again, so the temperature distribution was as uniform as possible. The mass flow rate of water affected the temperature difference between the hot side and the cold side. The four modules studied here were commercial bismuth telluride module. The thermoelectric module was connected in series with an electronic load approximately 3 ohm. The resistance was slightly varied at each load point to achieve a voltage over the module that was 50% of the voltage when it was measured at open circuit at the same temperature. This was done to maximize the power delivered by the modules. The hot-side temperature was incremented in six steps and all the measurements were taken when steady state conditions were achieved.

The mass flow rate of water affected the temperature difference between the two cold blocks, i.e. the higher the mass flow rate of water, the lower the temperature difference between the blocks. The experiment is carried out with the Toyoto Engine of exhaust internal Diameter 40 mm. The Thermo Electric modules are placed tangentially around the curved surface of the Exhaust pipe as shown in the Figure 1.

The Experimental study is carried out in three cases of different heat dissipation at the cold side.

1. TEG system without additional heat dissipation arrangements.
2. TEG system with additional heat dissipation using fins and fans.
3. TEG system with heat pipes on cold side using water as a circulating medium.

Case 1: TEG System without Additional Heat Dissipation Arrangements

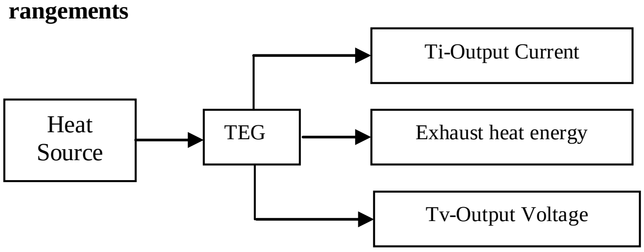

Fig.5: Block Diagram of TEG system without additional heat dissipation arrangements

Table 1: Analysis of TEG system without additional heat dissipation arrangements

Engine Speed (rpm)	Max(°C)	Min (°C)	Temp Difference (°C)	Experimental Results		
				Exp. Voltage (V)	Exp. Current (A)	Exp. Power (W)
1000	55	39.8	15.2	2.9	0.13	0.377
1500	68	51.3	16.7	4.3	0.18	0.774
2000	76	58.4	17.6	6.1	0.21	1.281
2500	87	68.1	18.9	7.6	0.27	2.052
3000	92	72.6	19.4	8.2	0.36	2.952
3500	113	74.6	20.6	9.2	0.39	3.588

The analysis of TEG system is done by varying the speed of the automobile engine. The raise in temperature is directly proportional to speed of the engine. The temperature on the cold side and hot side of the TEG is measured and the difference in temperatures are tabulated as shown in Table 1. Due to the temperature difference focused on the TEG surface, output voltage and current are generated by the TEG component. The output voltage, current are measured and tabulated as shown in the Table 1. The inference from Table 1 indicates that a continuous focus of heat energy on the surface of TEGs conducts partial heat energy to the cold side as per the law of thermodynamics. To enhance the TEG system, different cooling system are used on the cold side of TEG that could remove the rising temperature and maintain the temperature difference at an appropriate level. Due to the temperature difference focused on the hot side and cold side, the output voltage and current indicates a gradual rise as shown in Table 1.

Case 2: TEG System with Additional Heat Dissipation Using Fins and Fans

Figure 6 shows the block diagram of the TEG system with additional heat dissipation using fins and fans. Fins are surfaces that extend from an object to increase the rate of heat transfer to or from the environment by increasing convection. The amount of conduction, convection, or radiation of an object determines the amount of heat it transfers. Increasing the temperature gradient between the object and the environment, increasing the convection heat transfer coefficient, or increasing the surface area of the object increases the heat transfer. Sometimes it is not feasible or economical to change the first two options. Thus, adding a fin to an object increases the surface area and can sometimes be an economical solution to heat transfer problems.

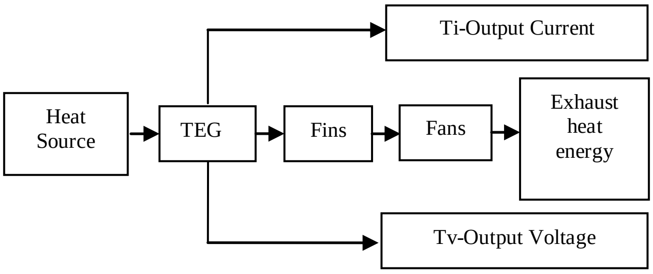

Fig.6: Block Diagram of TEG system with additional heat dissipation using fins and fans

The thermoelectric modules close to the inlet generates higher electrical output power per unit area. By optimizing the fin spacing and thickness, the heat transfer rate can be enhanced considerably.

Table 2: Analysis results of TEG system with additional fins and fans on cold side

Engine Speed (rpm)	Max (°C)	Min (°C)	Temp Difference (°C)	Experimental Results		
				Exp. Voltage (V)	Exp. Current (A)	Exp. Power (W)
1000	55	33.3	21.67	3.012	0.1568	0.47
1500	68	44.1	23.9	4.368	0.2	0.87
2000	76	51.3	24.7	6.2	0.2492	1.54
2500	87	60.2	26.8	7.96	0.2852	2.27
3000	92	64.4	27.6	8.32	0.44	3.66
3500	113	83.8	29.2	9.52	0.56	5.33

The inference from Table 2 indicates that as the difference in temperature on the TEG increases, the experimental power produced is increased, as compared with the previous method of natural air cooling system on the cold side.

Case 3: TEG System Using Heat Pipes on the Cold Side using Water as the Circulating Medium

Heat pipe is a heat-transfer device that combines the principles of both thermal conductivity and phase transition to effectively transfer heat between two solid interfaces. At the hot interface of a heat pipe, a liquid in contact with a thermally conductive solid surface turns into a vapor by absorbing heat from that surface. The vapor then travels along the heat pipe to the cold interface and condenses back into a liquid – releasing latent heat. The effective thermal conductivity varies with heat pipe length, and can approach 100 kW/(m-K) for long heat pipes, in comparison with approximately 0.4 kW/(m-K) for copper. Most heat pipes use a wick to return the liquid from the condenser to the evaporator, allowing the heat pipe to operate in any orientation.

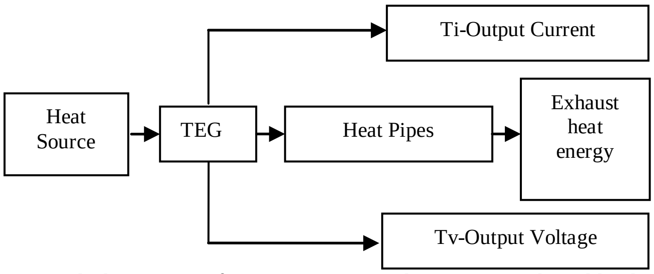

Fig.7: Block Diagram of TEG system using heat pipes on the cold side using water as the circulating medium

The inference from Table 3 indicates that as the difference in temperature on the TEG increases, the experimental power produced is increased, and the increase is drastic as compared with the previous above method.

Table 3: Analysis results of TEG system using heat pipes on the cold side using water as the circulating medium

Engine Speed (rpm)	Max(°C)	Min (°C)	Temp Difference (°C)	Experimental Results		
				Exp. Voltage (V)	Exp. Current (A)	Exp. Power (W)
1000	55	33.3	22.2	5.6	0.29	1.63
1500	68	41.5	26.3	6.5	0.27	1.75
2000	76	50.1	27.1	8.8	0.30	2.72
2500	87	57.7	29.7	9.2	0.40	3.68
3000	92	73.2	33.1	9.8	0.46	4.50
3500	113	86.3	34.6	11.8	0.48	5.66

To evaluate the performance of TEG, nine cases of analysis has been carried out for optimized results through simulation as listed below:

1. Simulation of TEG System without heat dissipation arrangements on the cold side.
2. Simulation of TEG System with heat dissipation using fins and fans on the cold side.
3. Simulation of TEG System using heat pipes on the cold side.
4. Simulation of TEG System using Silver oxide nano fluid in heat pipes as cooling medium.
5. Simulation of TEG System using Aluminum oxide nano fluid in heat pipes as cooling medium.
6. Simulation of TEG System using Copper oxide nano fluid in heat pipes as cooling medium.
7. Simulation of TEG System using Diamond nano fluid in heat pipes as a cooling medium.
8. Simulation of TEG System using Silicon dioxide nano fluid in heat pipes as cooling medium.
9. Simulation of TEG System using Titanium oxide nano fluid in heat pipes as a cooling medium.

Simulation is carried using ANSYS R16.2 software. The following explains the simulation setup on ANSYS:

a. Design of exhaust pipe in Solid-works software.
b. Design of TEG in solidworks software.
c. Design of heat pipes in solidworks software.
d. In the Assembly window import the exhaust pipe and fix as a default component.
e. Import the TEG system and place it on the circumference of the exhaust pipe so that heat can be transferred through conduction process.
f. Now import the heat pipes to the assembly window and assemble it on the cold side of the TEG opposite to the exhaust pipe. Assembly should be made in such a way that all the three components must be attached to together.
g. After assembly, import the file to the Ansys software and define the properties of the different components.
h. The inlet temperature through the exhaust pipe line is defined and the external boundary to be the atmospheric condition.
i. The meshing process is carried out equally for the totally assembly of exhaust pipe, TEG and heat pipes.
j. For the first case water properties are defined as it is filled in the heat pipes.
k. After defining the properties of different components, simulation process starts and final result was obtained.
l. The graph is plotted according to the results obtained from experimental setup and simulation results.
m. Each simulation is carried out by varying the properties of the liquid present inside heat pipes by providing the properties of nano fluids and the simulation process carried. Results are obtained after the simulation process.

Case 1: Simulation of TEG System without Heat Dissipation Arrangements on the Cold Side

Figure 8 shows the simulation results of the TEG system without heat dissipation arrangements on the cold side. Further, Figure 8 indicates that at the maximum running condition if the engine can generate a very high temperature and focused on, the TEG system can generate the power by the conventional technology and it is identified that the cold side temperature is 95.2°C, and the hot side the temperature is 113.0°C when the engine is running at 3500 rpm. Table 4 indicates the results obtained from the experiment setup and it clearly indicates that the hot side and cold side temperature are having the temperature during the engine running at 3500 rpm

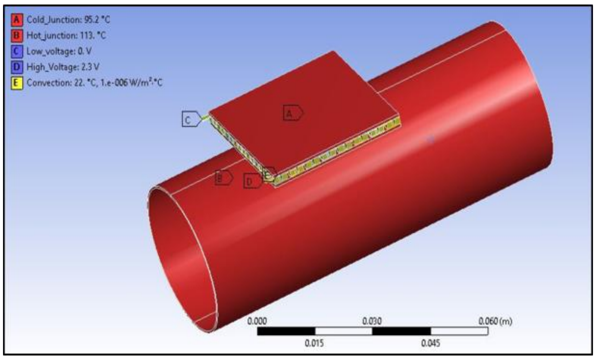

Fig.8: Simulation result of TEG system without heat dissipation arrangements on the cold side

Table 4: Analysis result of TEG system without heat dissipation arrangements on the cold side

Engine Speed (rpm)	Max (°C)	Min (°C)	Temp Difference (°C)	Simulation Results		
				Simulated Voltage (V)	Simulated Current (A)	Simulared Power (W)
1000	55	39.8	15.2	2.9	0.13	0.377
1500	68	51.3	16.7	4.3	0.18	0.77
2000	76	58.5	17.5	6.1	0.21	1.28
2500	87	68.8	18.2	7.6	0.27	2.05
3000	92	71.7	20.3	8.2	0.36	2.95
3500	113	89.6	23.4	9.2	0.39	3.58

Case 2: Simulation of TEG System with Heat Dissipation Using Fins on the Cold Side

Figure 9 shows the simulation results of the TEG system with heat dissipation using fins on the cold side.

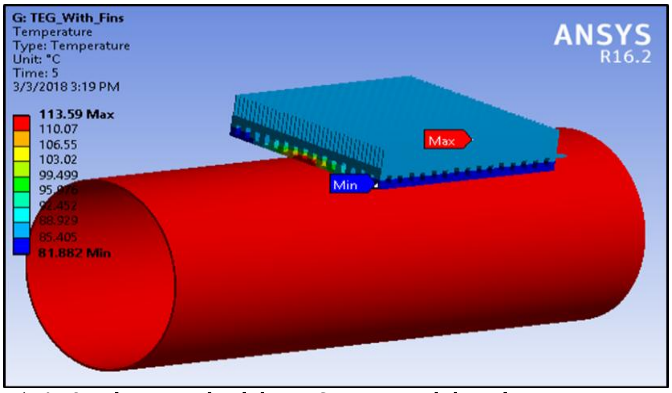

Fig.9: Simulation result of the TEG system with heat dissipation using fins on the cold side

The above simulation results show that the maximum temperature is 113°C on hot side and cold side temperature is 86.3°C at the engine running at constant speed of 3500 rpm. As the simulation results as tabulated in Table 5, are compared with the experimental results and it has been identified that the temperature on hot side and cold side during the engine running condition is same.

Table 5: Analysis results of TEG system with heat dissipation using fins and fans on the cold side

Engine Speed (rpm)	Max(°C)	Min (°C)	Temp Difference (°C)	Experimental Results		
				Exp. Voltage (V)	Exp. Current (A)	Exp. Power (W)
1000	55	33.3	22.2	5.6	0.27	1.512
1500	68	41.5	26.3	6.5	0.25	1.625
2000	76	50.1	27.1	8.8	0.297	2.613
2500	87	57.7	29.7	9.2	0.37	3.404
3000	92	73.2	33.1	9.8	0.43	4.214
3500	113	86.3	34.6	11.8	0.45	5.31

Case 3: Simulation of TEG System Using Heat Pipes on the Cold Side

The simulation results as tabulated in Table 6, are compared with the experimental results and it has been identified that the temperature on hot side and cold side during the engine running condition is same.

Table 6: Analysis results of TEG system using heat pipes on the cold side

Engine Speed (rpm)	Max (°C)	Min (°C)	Temp Difference (°C)	Simulation Results		
				simulated Voltage (V)	Simulated Current (A)	Simulated Power (W)
1000	55	32.5	22.5	5.9	0.19	1.13
1500	68	40.5	27.5	6.8	0.22	1.52
2000	76	49.3	26.7	9.2	0.23	2.15
2500	87	55.6	31.4	9.8	0.33	3.32
3000	106	71.5	34.1	10.3	0.35	3.64
3500	113	77.4	35.6	12.4	0.33	4.09

Case 4: Simulation of TEG System Using Silver Oxide Nano Fluid in Heat Pipes as Cooling Medium

In this case, the fluid used as coolant is Silver oxide Nano fluid which is used to transfer heat and is the medium filled inside the heat pipes. The simulation results obtained are tabulated in Table 7, and it is observed that the maximum power that can be generated is 4.61 watts when the engine speed reaches 3500 rpm.

Table 7: Analysis results of TEG system with heat pipes on cold side using Silver oxide nano fluid in eat pipes as cooling medium

Engine Speed (rpm)	Max (°C)	Min (°C)	Temp Difference (°C)	Simulation Results		
				simulated Voltage (V)	Simulated Current (A)	Simulated Power (W)
1000	55	22.2	32.8	5.2	0.27	1.42
1500	68	26.3	41.7	6.5	0.25	1.64
2000	76	27.1	48.9	8.4	0.27	2.34
2500	87	29.7	57.3	9.2	0.38	3.51
3000	92	33.1	58.9	9.8	0.39	3.91
3500	113	34.6	78.4	11.2	0.41	4.61

Case 5: Simulation of TEG System Using Aluminum Oxide Nano Fluid in Heat Pipes as Cooling Medium

In this case, the fluid used as coolant is Aluminium oxide nano fluid which is used to transfer heat and is the medium filled inside the heat pipes. The simulation results obtained are tabulated in Table 8, and it is observed that the maximum power that can be generated is 4.56 watts when the engine speed reaches 3500 rpm.

Table 8: Analysis result of TEG system using Aluminium oxide nano fluid in heat pipes as cooling medium

Engine Speed (rpm)	Max (°C)	Min (°C)	Temp Difference (°C)	Simulation Results		
				simulated Voltage (V)	simulated current (A)	simulated Power (W)
1000	55	22.2	32.8	5.2	0.2624	1.36
1500	68	26.3	41.7	6.5	0.252	1.63
2000	76	27.1	48.9	8.4	0.266	2.23
2500	87	29.7	57.3	9.2	0.3784	3.48
3000	92	33.1	58.9	9.8	0.392	3.84
3500	113	34.6	78.4	11.2	0.408	4.56

Case 6: Simulation of TEG System Using Copper Oxide Nano Fluid in Heat Pipes as Cooling Medium

In this case, the fluid used as coolant is Copper oxide nano fluid which is used to transfer heat and is the medium filled inside the heat pipes. The simulation results obtained are tabulated in Table 9, and it is observed that the maximum power that can be generated is 5.05 watts when the engine speed reaches 3500 rpm.

Table 9: Analysis result of TEG system using Copper oxide nano fluid in heat pipes as cooling medium

Engine Speed (rpm)	Max (°C)	Min (°C)	Temp Difference (°C)	Simulation Results		
				simulated Voltage (V)	Simulated Current (A)	Simulated Power (W)
1000	55	33.33	21.67	3.2	0.14	0.46
1500	68	41.5	26.5	4.8	0.192	0.92
2000	76	48.1	27.9	6.08	0.24	1.45
2500	87	57.7	29.3	8.12	0.27	2.24
3000	92	61.4	30.6	8.24	0.40	3.32
3500	113	79.8	33.2	9.72	0.52	5.05

Case 7: Simulation of TEG System Using Diamond Oxide Nano Fluid in Heat Pipes as Cooling Medium

In this case, the fluid used as coolant is Diamond oxide nano fluid which is used to transfer heat and is the medium filled inside the heat pipes. The simulation results obtained are tabulated in Table 10, and it is observed that the maximum power that can be generated is 4.61 watts when the engine speed reaches 3500 rpm.

Table 10: Analysis result of TEG system using Diamond oxide nano fluid in heat pipes as cooling medium

Engine Speed (rpm)	Max(°C)	Min (°C)	Temp Difference (°C)	Simulation Results		
				simulated Voltage (V)	simulated current (A)	simulated Power (W)
1000	55	21.2	33.8	5.2	0.274	1.52
1500	68	24.2	43.8	6.5	0.252	1.69
2000	76	25.9	50.1	8.4	0.279	2.36
2500	87	27.8	59.2	9.2	0.382	3.59
3000	92	31.1	60.9	9.8	0.399	3.99
3500	113	33.4	79.6	11.2	0.412	4.78

Case 8: Simulation of TEG System Using Silicon Dioxide Nano Fluid in Heat Pipes as a Cooling Medium

In this case, the fluid used as coolant is Silicon dioxide nano fluid which is used to transfer heat and is the medium filled inside the heat pipes. The simulation results obtained are tabulated in Table 11, and it is observed that the maximum power that can be generated is 4.61 watts when the engine speed reaches 3500 rpm.

Table 11: Analysis result of TEG system using Silicon dioxide nano fluid in heat pipes as a cooling medium

Engine Speed (rpm)	Max(°C)	Min (°C)	Temp Difference (°C)	Simulation Results		
				simulated Voltage (V)	simulated Current (A)	simulated Power (W)
1000	55	23.1	31.9	5.2	0.252	1.31
1500	68	27.2	40.8	6.5	0.250	1.63
2000	76	28.7	47.3	8.4	0.260	2.18
2500	87	30.3	56.7	9.2	0.372	3.42
3000	92	34.3	57.7	9.8	0.386	3.78
3500	113	35.2	77.8	11.2	0.398	4.46

Case 9: Simulation of TEG System Using Titanium Dioxide Nano Fluids in Heat Pipes as a Cooling Medium

In this case, the fluid used as coolant is Titanium dioxide nano fluid which is used to transfer heat and is the medium filled inside the heat pipes. Figure 10 shows the simulation window of the TEG system with heat pipes having Titanium dioxide nano fluid as cooling medium. The simulation results obtained are tabulated in Table 12, and it is observed that the maximum power that can be generated is 5.19 watts when the engine speed reaches 3500 rpm.

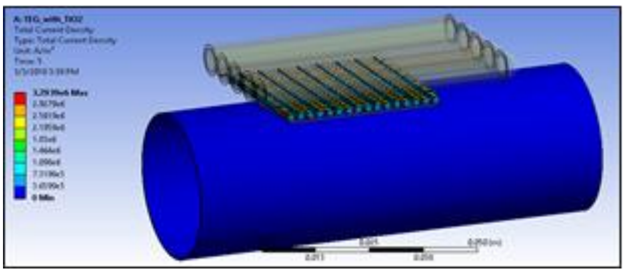

Fig.10: Simulation result of TEG system using Titanium dioxide nano fluid in heat pipes as a cooling medium

Table 12: Analysis result of TEG system using Titanium dioxide nano fluid in heat pipes as a cooling medium

Engine Speed (rpm)	Max(°C)	Min (°C)	Temp Difference (°C)	Simulation Results		
				simulated Voltage (V)	simulated Current (A)	simulated Power (W)
1000	55	18.3	36.7	7.19	0.321	2.31
1500	68	20.6	47.4	8.19	0.332	2.72
2000	76	24.2	51.8	9.29	0.342	3.18
2500	87	27.2	59.8	10.07	0.396	3.99
3000	92	30.2	61.8	10.91	0.478	5.22
3500	113	32.2	80.8	11.82	0.486	5.75

The results of the simulation results indicates that a large amount of heat energy has been converted into useful power. Furthermore, the results obtained from the simulation results indicate that Titanium dioxide has high capacity to absorb the excess temperature transferred from the hot side of the TEG. Table 13 shows the comparison table which provides a clear indication for the selection of the appropriate nano fluid to be filled in heat pipes.

Table 13: Analysis result of TEG system with different nano fluids in heat pipes on cold side

Simulation results obtained with different Nano fluids filled in Heat pipes with respect to power (watts)						
Sno:	Ag	Al_2O_3	CuO	DiO	SiO_2	TiO_2
1	1.42	1.36	0.46	1.52	1.31	2.31
2	1.64	1.63	0.92	1.69	1.63	2.72
3	2.34	2.23	1.45	2.36	2.18	3.18
4	3.51	3.48	2.24	3.59	3.42	3.99
5	3.91	3.84	3.32	3.99	3.78	5.22
6	4.61	4.56	5.05	4.78	4.46	5.75

The inference from Table 13 clearly indicates that the heat pipes filled with nano fluids using Titanium dioxide as liquid coolant conducts the heat energy efficiently when compared with the other nano fluids. The TEG system can generate maximum power by fixing the heat pipes on the cold side of TEG that is filled with Titanium dioxide. The Titanium dioxide effectively absorbs the excess temperature and maintains the temperature difference. The difference in temperature contributes the maximum power generation.

4. Results and Discussion

The TEG system used in the experiment is identical in nature. The TEG output is connected to an electronic load. Thermal energy is removed from the cold side through forced liquid flow. The Experimental results of using heat pipes with water having good enhancement in the harnessing of thermal energy. The same model is numerically analyzed and produced the same values with considerable percentage of errors.

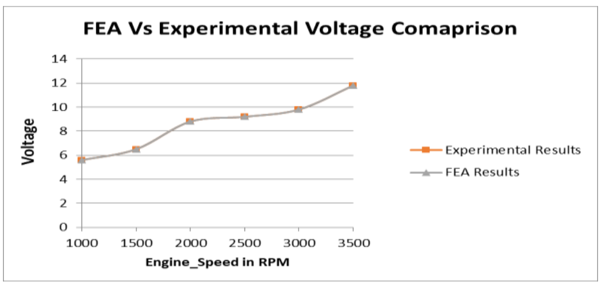

Fig.11: Engine speed vs output voltage

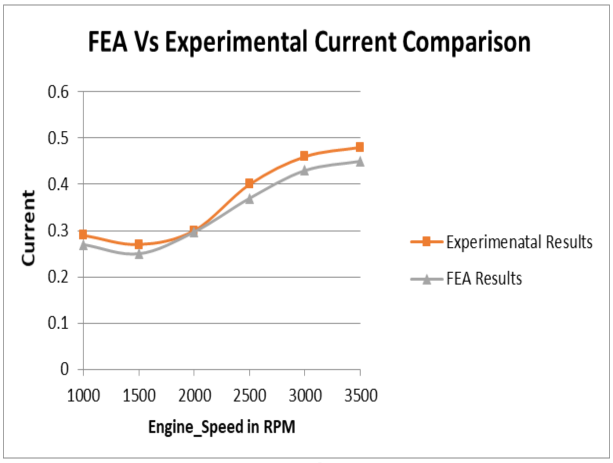

Fig.12: Engine speed vs output current

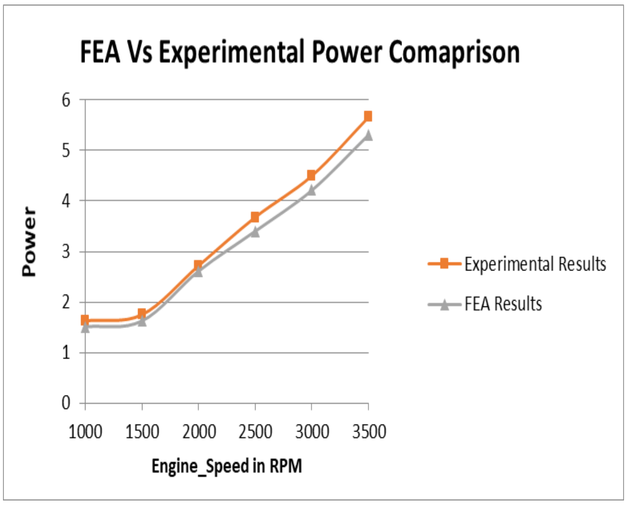

Fig.13: Engine speed vs output power

Figure 11 and 12 shows the graph plotted between the engine speed and the output voltage and current generated across the TEG, respectively. It is observed that the simulated results through the Finite Element Analysis (FEA) method and the experimental results, for the output voltage is same, while for the output current has an error deviation which is acceptable or is at the minimum. The minimum voltage measured is 7.19V at 1000 rpm and maximum voltage measured is 11.82V at 3500 rpm, while the minimum and maximum current measured are 0.332A and 0.486A, respectively. Further, it can be noted that the output voltage across the TEG increases as the engine speed is increased gradually and at the same time, it is inferred that the heat from the engine exhaust pipe is converted into useful output power, as shown in Figure 13.

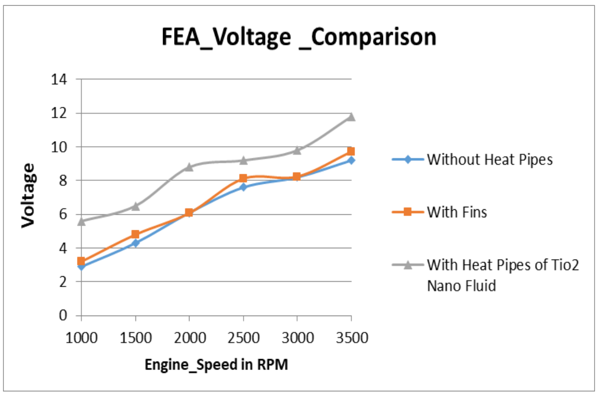

Fig.14: Comparison Graph between output voltage vs Engine speed with different setup as with fins, without heat pipes and with heat pipes of Titanium dioxide

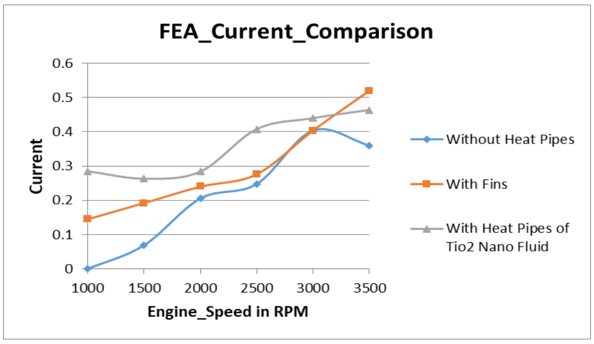

Fig.15: Comparison Graph between output current vs Engine speed with different setup as with fins, without heat pipes and with heat pipes of Titanium dioxide

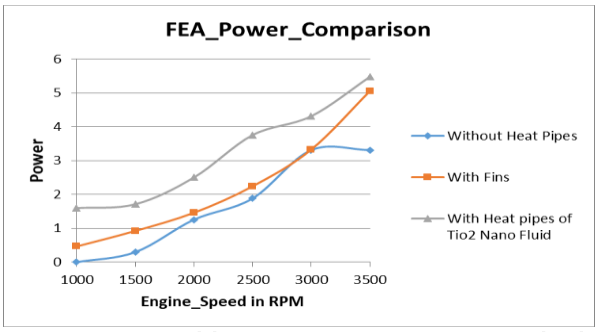

Fig.16: Comparison Graph between output power vs Engine speed with different setup as with fins, without heat pipes and with heat pipes of Titanium dioxide

Figure 14 and 15 shows the graph plotted between the engine speed and the output voltage and current generated across the TEG with different setup as with fins and fans, without heat pipes and with heat pipes of Titanium dioxide nano fluid, respectively. It is observed that the output voltage across the TEG is at its maximum at 3500 rpm, when the TEG is with heat pipes of Titanium dioxide nano fluid and the output current is at its maximum, when the TEG is with fins and fans. However, it is inferred that the heat from the engine exhaust pipe is converted into useful output power and is maximum when the TEG is with heat pipes of Tio_2 Nano fluid as shown in Figure 16.

5. Conclusion

This paper presents an innovative and powerful computer tool to accurately simulate real thermoelectric power generating systems even during transient conditions. The proposed simulation program, designed in Ansys Workbench, deals with all the most important thermoelectric effects and is able to cope with both thermal and electrical dynamics. Consequently it can greatly help the design phase of large-scale and/or complicated thermoelectric systems. A comparison of experimental and simulation results of using heat pipes shows the accuracy and capability of the model, showing that it can be employed to other Nano fluids with TEG systems.

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