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# Review of Solar Panels & Thermoelectric Generator for Waste Heat Recovery from Automobile Exhaust

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**Abstract:** *This Project involves the thermoelectric generation from the thermoelectric generator module whose principal is Seebeck effect. These modules are connected in series and parallel manner which is attached at the hot junction created by the hot water coming out of the heat engine and the exhaust gasses coming out of the engine. The cold side is created by the fins connected to that module. Both of the heat is large in amount and are wasted if not used. Produced energy from the thermoelectric generator module is transferred to the battery. This battery supplies the energy to the Peltier module which is used to create the colder side as well as hotter side. Again, this module is connected to the solar panels to produce the energy from the sun during the day time which ultimately reduces the load on the AC. So, in this invention the combination of the solar panels and thermoelectric generation module reduces the load on the AC.*

**Keywords:** Thermoelectricity, Electricity Generation, Heat Utilization, Peltier Effect, See Back Effect, Solar Energy, etc.

## I. INTRODUCTION

Efficiency of the diesel engine is 45%. Whereas the efficiency of the petrol engine is 30 %. Thus rest all the energy is get converted into heat. Until recently, the operating temperatures of a car engine have typically been between 180F and 200F which is nearly 78 c to 100c. This is the temperature at which the thermostat opens allowing coolant to travel to the radiator. Coolant temperatures at the cylinder heads, particularly the exhaust valve area, are much higher and temps at the output end of the radiator will be lower. Whereas the ambient temperature is approximately 30 c. Thus, let us consider the diesel engine about 55 % of heat energy is wasted to utilize this energy we are bringing this experiment. According to the data available by conducting the experiment temperature available at the exit of the hot exhaust gases is 530 c thus we can say that the major heat source of escaping the heat is exhaust and the water jacket. Thus, instead of leaving the heating we can utilized the heat by using the thermoelectric generator this thermos electric generator is been fixed at the exhaust and as well as near the cooling jacket.

Previously this heat is been travelled through the radiator and thus this heat is escaped to the atmosphere whereas the exhaust gasses are escaped without any utilization of heat. One of the parts of the cooling water is been used by the recent ac system by using the simple VAS system. This VAS system is been working at a higher temperature. Apart from this system no other system uses this energy for any other energy generation. The exhaust gases are passes through the silencer which contains the analyser to reduce the pollution and then passes through muffler to reduce the noise no processes is been used to utilize this heat. Whereas this exhaust gas temperature is still very high and can be usable. Earth is close to the sun so earth is provided with the abundant sunlight this sunlight is been used to generate the electric energy. This energy is pollution free and are available most of the day time. The ACs are been operated during the summer because, at that time only the rider is feeling hot.

Whenever the vehicle is been parked under the sunlight during the summer the temperature inside the vehicle is high so when we operate the AC system, we required the power for its operation to be taken in to place. This power we get it from the battery if the vehicle is in steady condition i.e., the vehicle's engine is not ON, which leads to the battery drains. Another thing is some people start the vehicle's engine to start the AC of the vehicle thus this Leeds to wastage of the fuel and also leads to wastage of money and environment also get polluted due to the exhaust gasses. This problem can be solved by the Peltier module which sinks the one side's temperature and drains it to another side by Appling the power to this Peltier module. Thus, by using this invention we can operate the vehicle's AC system during the ON as well as in the OFF state.

During the ON state we use the engines heat and during the OFF state we use the solar panels for power generation. This leads to the individual power producing system. Thus, in this project our main aim is to reduce the power consumption of the engine and battery or rather to utilize around 90% of the waste heat since as we know that the one energy cannot be completely converted into the other form of energy without any wastage. Whereas apart from this the alternator a mechanical to electrical energy generator is used to generate the electricity for charging of battery. Thus, after installing these 3 systems the battery gets charged. Also, apart from the AC used the power is also used to operate the other instrument inside the vehicle such as the lights and all.

## II. LITERATURE

Q. Cao et.al. had performed an experiment using heat pipes assisted thermoelectric generator for automobile waste heat recovery. Because of the low thermal resistance of the heat pipe, it is widely applied to exhaust waste heat. Heat pipes will make the TEM surface temperature be closer to the exhaust temperature when fins are employed in the gas flow channel. A thermoelectric generator including 36 TEMs for automobile exhaust waste heat recovery is proposed. Several factors of the heat pipe application were tested before it was put into application on the HP-TEG system construction. Comparative study of the TEG with or without heat pipes was analyzed. This improvement of power generation efficiency with the rising of exhaust temperature was found out.

The maximum power generation efficiency of 2.58% was reached with exhaust temperature of 3000C and mass flow rate of 80 Kg/h. For the pressure drop was relatively lower than the allowable pressure drops of engine exhaust, indicated the acceptability of HP-TEG be used in automobile without affecting the normal operation of the engine. With reference to this research paper, the design considerations are taken into account. Estimated number of modules has also been taken for available space constraint from this paper. Insulation parameters regarding the concentration of heat at a single space is also found. The temperature gradient should be high enough so that maximum voltage could be produced and this is possible by the use of fins which will improve the heat transfer rate.

D. Patilet.al Attempted to review the materials which are efficient for the thermoelectric generation and heat exchangers with internal structures. Highly doped semiconductors showed good thermal resistance which are important characteristic for the TEG. The thermoelectric material which are based on bismuth telluride, lead telluride and silicon germaniums are used in the TEG's according to their temperature capability. The output power of the TEG's is built upon the type of economic TEM's, temperature difference between the heat sink and the heat source and the physical properties of the working fluid.

The temperature dissemination of the exhaust heat exchanger is very crucial for thermoelectric generator as the heat exchanger provides primary heat to the TEG's and their conversion efficiency and capacity depends on shape, material and type of heat exchanger. Irregular thermal stresses make the contact between the TEM and the heat dissipating surface rough and can lead to the permanent damage to the TEM's. With reference to this research paper, material that could work under the specified temperature limit of below 2500C is bismuth telluride and is readily available in commercial module form. The lower temperature kept for bismuth telluride -500C thus, the working temperature should be maintained between these limits of temperature.

A. Hlghoolet.al stated a brief background on the principles and theories of TEGs, with their significance and applications on waste heat energy. The materials used in the TEG device and their impact on the conversion efficiency are also elaborated. Towards the end, the paper focuses more on the classification of the heat sinks and their application with TEG. Two inter-dependent factors on the development of thermoelectric efficiency are expected to enhance future performance of TEG, firstly by enhancements in thermoelectric materials through increasing the Figure-of- merit (ZT) by using thermo-electric materials and secondly, by further improvement of thermal design of heat exchangers through enhancement of heat dissipation using heat sinks. Increase in TEG efficiency is dependent on good selection and careful designing of heat sinks. The following considerations are important when choosing existing heat sinks options or designing new ones.

Firstly, the heat sinks applied to the TEG are dependent upon applications of power density. Secondly, passive heat sinks are most appropriate because of the inherent efficiency of TEG since they lack auxiliary power consumption. Thirdly, other than not having auxiliary power consumption another efficient approach is to use phase change and liquid cold heat sinks. Fourthly, when heat pipe heat sinks (HPHS) are incorporated as heat exchangers, medium temperature range below 3000C is found to be most suitable. Fifthly, although micro-channel heat sinks can significantly improve the heat flow thus further enhancing the electricity generation, in view of the high cost connected with specific creation methods required to fabricate the micro-channels, they are not yet able to supplant the traditional channels. Last but not least, it is helpful to take advantage of the exhaust heat or cooling sources in the industry, or even in domestic applications in order to cool the TEG without extra energy consumption for cooling which reduces its conversion efficiency.

With reference to this paper, TEG is suitable for only medium and high temperature sources of waste heat. Voltage produced in every difference of temperature in good conducting material and electrical conductivity is inversely proportional which does not increase the Figure-of-merit (ZT) and the thermal power and electrical conductivity are constant. Thus, the only variable parameter is electrical properties of conductor. Hence, the Figure-of-merit (ZT) can be maximized by increasing electrical conductivity. Generally, for good thermoelectric power generator Figure-of-merit (ZT) should be more than 4.

## III. THERMO ELECTRIC COOLING

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials. A Peltier cooler, heater, or thermoelectric heat pump is a solid-state active heat pump which transfers heat from one side of the device to the other, with consumption of electrical energy, depending on the direction of the current. Such an instrument is also called a Peltier device, Pettier heat pump, solid state refrigerator, or thermoelectric cooler (TEC). It can be used either for heating or for cooling, although in practice the main application is cooling. It can also be used as a temperature controller that either heats or cools.

## IV. THERMO ELECTRIC GENERATOR

A thermoelectric generator (TEG), also called a Seebeck generator, is a solid-state device that converts heat flux (temperature differences) directly into electrical energy through a phenomenon called the Seebeck effect (a form of thermoelectric effect). Thermoelectric generators function like heat engines, but are less bulky and have no moving parts.

## V. PRINCIPAL OF OPERATION OF PELTIER MODULEAND THERMO ELECTRIC GENERATOR MODULE AND SOLAR PANELS.

PELTIER MODULE OPERATING PRINCIPAL.

Thermoelectric coolers operate by the Peltier effect (which also goes by the more general name thermoelectric effect). The device has two sides, and when a DC electric current flows through the device, it brings heat from one side to the other, so that one side gets cooler while the other gets hotter. The "hot" side is attached to a heat sink so that it remains at ambient temperature, while the cool side goes below room temperature. In some

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applications, multiple coolers can be cascaded together for lower temperature.

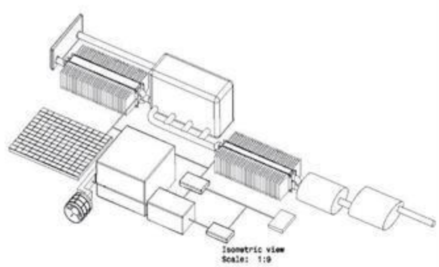
WORKING PRINCIPAL THERMOELECTRIC MODULE

A thermoelectric module is a circuit containing thermoelectric materials which generates electricity from heat directly. A thermoelectric module consists of two dissimilar thermoelectric materials joined at their ends: an n-type (negatively charged), and a p-type (positively charged) semiconductor. A direct electric current will flow in the circuit when there is a temperature difference between the ends of the materials. Generally, the current magnitude is directly proportional to the temperature difference.

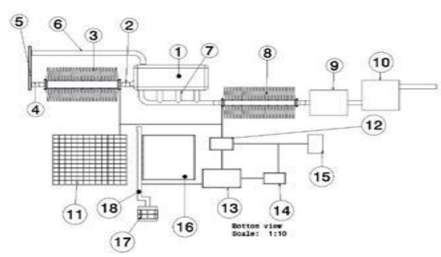
THE WORKING PRINCIPLE OF SOLAR CELLS AND SOLAR PANELS

When the photovoltaic cells absorb solar radiation, photovoltaic effect leads to the production of the electromotive force at the ends of the cells. Thus, the solar cells become a source of electricity. Every solar cell is composed of a plurality of diodes. The cells can be connected together in series and in parallel to produce the corresponding voltage. Thirty-six cells connected in series can provide voltage of 12 volts. In this way we obtain a solar cell module in which the cells are fixed and protected from adverse weather conditions.

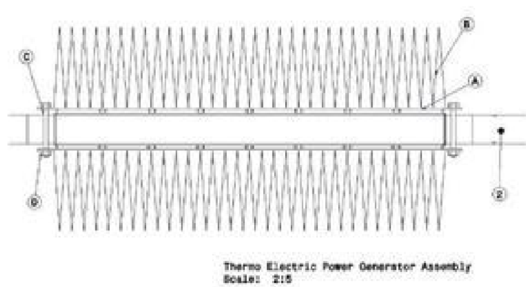
CAD MODELING: SOLAR PANELS & THERMOELECTRIC GENERATOR



Isometric view




Top view




Thermoelectric Power Generator Assembly

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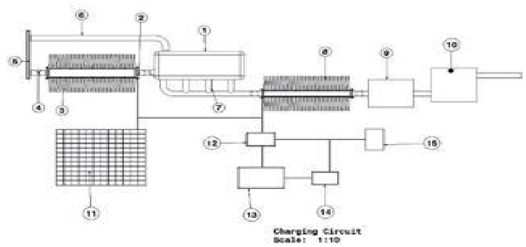
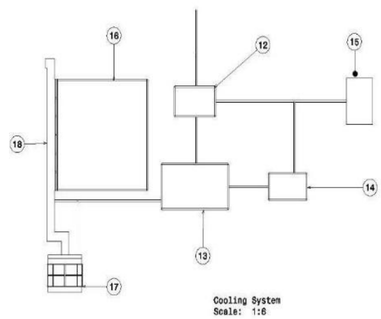
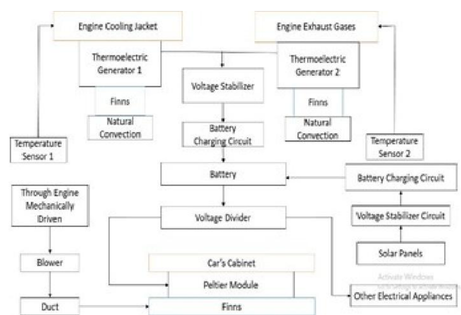


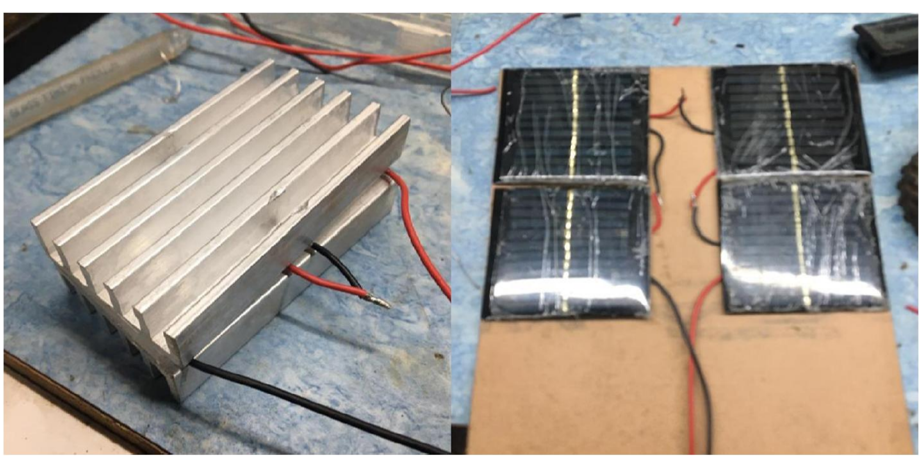

Charging Circuit Flow




Peltier Module Cooling System & Power Usages




Flow Chart solar panels & thermoelectric generator



## VI. PART DESCRIPTION

Part 1 Engine: The SI or CI engine consist of number of cylinders on which fuel burns and produce heat energy. Engine is surrounded by water jacket. The water jacket has inside hydraulic fluid which decreases temperature of engine cylinder in order to avoid over heating or melting of mechanical parts. The heat energy from engine is transfer by means of conduction to the water jacket. The engine is connected by part 2 and 6. Part 2 carries heated water from water jacket and ample of thermo electric generators are mounted on it while part 6 is the inlet of water jacket.

Part 2 Inlet Y shaped pipe: It is a 2-way pipe, connected by engine via inlet water jacket. The extended Y shaped pipe carries heated Fluid from water jacket. On this pipe, ample of Thermo electric generator module are mounted which contain one hot and one cold side. The entrance of Y shaped pipe provides a turbulence for a fluid. Turbulence of fluid increases the temperature and hence amount of heat absorbed by module is more in one side while keeps other side cooler and hence electricity generation takes place.

Part 3 Fins: Fins are mounted on the covering pipe of modules which helps to maintain cold side of module by taking away heat to the surroundings.

Part 4 Outlet Y shaped pipe: The water from inlet Y shaped is carried away by outlet Y shaped pipe. It also creates turbulence inside to achieve high temperature. The water is forwarded towards the Heater.

Part 5 Heater: It is a heating element used to form heated air in order to achieve user comfort. It also supply water/fluid back to the engine cylinder.

Part 6 Pipe: It carries water from heater back to the engine.

Part 7 Exhaust manifold: The exhaust gases from cylinder are transferred to the exhaust manifolds

Part 8 Extended pipe from manifold: The extended portion of manifold contains number of modules mounted on it. The modules extract some heat from that waste and generates electricity. The modules are covered with thin covering, on which fins are mounted which maintain cold side of module.

Part 9 Analyzer: It is a device which controls pollutant emissions by absorbing hazardous contain in exhaust like oxides of nitrogen & sulphur.

Part 10 Muffler: It is a sound and shock absorbing device which is connected after Analyzer. It delivers exhaust to the surroundings.

Part 11 Solar Panels: Solar panels absorb energy from sunlight which produces electricity. By this energy we can operate AC of vehicle in OFF as well as in ON state of engine.

Part 12 Voltage stabilizer and charging module: Voltage stabilizer produces DC voltage by avoiding fluctuation in voltage.

Part 13 Battery: It is a storehouse of energy for energy acceptance from Voltage stabilizer and charging module.

Part 14 Voltage divider: It divides voltage as per requirement of different components in a vehicle.

Part 15 Operating component in vehicle: It takes energy from battery and perform specific task.

Part 16 Passengers area in vehicle/Cabinet area: It is area inside the vehicle in which inside heat generation takes place which is removed by Peltier Module.

Part 17 Blower: It is operated from engine power and used for providing cooling system as well as heating system inside the vehicle.an heating coil is placed inside the blower in order to achieve heating as well as cooling as per requirement.

Part 18 Peltier Module on channel: This module produces electricity by absorbing inside heat from cabinet.

## VII. METHODOLOGY

When the combustion of the engine starts tremendous amount of the heat is been carried away by the water jacket. This heat from water jacket is given to the part 2. This part 2 consists of inside valleys in order to create turbulence of the fluids (for increase on temperature). The extended portion of the part 2 contain no of thermos electric generator modules. The one side of the module absorbs the heat from part no 2 and the other side remains cooler by heat exchange from fins and hence electricity generation takes place by Seebeck effect.

This electricity is supplied to the part 12 and part 13 in order to stabilize and store the energy respectively. The fluid from the part 3 is supplied to the part 4, which also creates turbulence for the fluid to save the energy of part 5. The part 5 use as a heater for the conventional AC system. The fluid from part 5 is supplied to the part 6 and then to the engine jacket. The exhaust from the engine is supplied to the part 7 which contains inside valleys to create turbulence which increases temperature of exhaust gases. The extended portion of the part 7 contain no of thermo electric generator modules. Theone side of the module absorbs the heat from part no 7 and the other side remains cooler by heat exchange from fins and hence electricity generation takes place by Seebeck effect and this energy also stores inside the part 13. The rest of the exhaust gases of carried forwarded to analyzer to absorb the harmful gases and then to the muffler for noise absorption and then emitted these gases to the atmosphere.

Part 11 absorbs energy from solar radiations this energy is supplied to the part 13 for storage.

Part 16 contain inside heat in passenger area which is absorbed by the Peltier module. The Peltier modules are arranged on part 18 in such a way that heating and cooling inside the vehicle is conducted as per needed. This Peltier modules are arranged in alternate manner i.e.; some modules are used to cooling AND some are used as a heater as per weather conditions. Proper ventilation is been provided to control relative humidity and fresh atmosphere inside the passenger area. This can be done by providing a blower (part 17) used discharge the heat. When the user requires heating atmosphere then only Peltier modules which generate heat are only operated rest of the modules is in off state. Now if consider the modules get over heated the then the cooled air is come out from blower by stopping the heating coil to produce the heat and vice versa if user pressed the cooling button. This blower is operated on the engine power.

Part 12 is used to stabilize the fluctuating voltage coming from the part 3 and part 8. This stabilizer contains the battery level indicator to avoid the overcharging of the battery. This stabilize voltage is given to the battery for the charging purpose.

Part 14 contains the microcontroller and voltage regulator which divides and regulates the power as per need of the devices. As well as the control action is been carried away bythe microcontroller.

## VIII. THERMO ELECTRIC GENERATOR MODULESELECTION

The Four Classes of Thermoelectric Generator ModulesBi2Te3 (Bismuth Telluride) SERIES 1. Up To 320°C Pbte-bite (Lead Telluride/Bismuth Telluride) HYBRID SERIES 1 PB. Up to 360°C

(Bismuth Telluride cold side) calcium Manganese Oxide hot side CMO CASCADE. Up to 800°C Calcium Manganese Oxide hot side CMO Up to 900°C

There are other Thermoelectric TEG power materials using the SEEBECK EFFECT that hold promise in the thermoelectric generation field. These include but not limited to:

Mg2Si –N-typeMn2Si –P-type Skutterudites Znsb - N-type Znsb –P-type Half Heusler –N-Type

The exit temperature of water jacket is around 80 to 100 degrees Celsius. Hence the thermoelectric generator modules which we can uses from the catalog provided by the company are

TEP1-1263-3.4

Size: 30 mm x 30 mm

Open circuit voltage: 10.8 volts Matched load resistance: 5.4 ohms Matched load output voltage: 5.4 volts Matched load output current: 1.0 amperes Matched load output power: 5.4 watts

Heat flow through the module: about 96 watts Heat flux: about 10.7 watts/cm2 TEP1-12635-3.4

Size: 35 mm x 35 mm

Open circuit voltage: 10.8 volts Matched load resistance: 5.4 ohms Matched load output voltage: 5.4 volts Matched load output current: 1.0 amperes Matched load output power: 5.4 watts

Heat flow through the module: about 94.7 watts Heat flux: about 7.7 watts/cm2 TEP1-1264-3.4

Size: 40 mm x 40 mm

Open circuit voltage: 10.8 volts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Matched load output resistance: 5.4 ohms Matched load output voltage: 5.4 volts Matched load output current: 1.0 amperes Matched load output power: 5.4 watts.
Heat flow through the module: about 98.2 watts Heat flux: about 6.2 watts/cm2
As the heat flow through the module is minimum and generated is high hence, we select the TEP1-12635-3.4 module. Since as our system cannot completely works on the stated temperature, so in order to make our module workable below stated temperature we have selected this module.

The exit temperature of exhaust gases is around 500 to 560degree Celsius. Hence the thermoelectric generator modules which we can uses from the catalog provided by the company are
Size: 80 mm x 90 mm
Open circuit voltage: 13.3 volts
Matched load output resistance: 2.05 ohms Matched load output voltage: 6.65 volts Matched load output current: 3.27 amperes Matched load output power: 21.7 watts
Heat flow through the module: about 290 watts Heat flux: about 7.6 watts/cm2
The above module used is having maximum efficiency with lower temperature difference we have selected this module.

## IX. THERMO ELECTRIC COOLING MODULE SELECTION

The selection of the Peltier module depends on the require operational power and the generated cooling effect thus depend upon the above characteristics we have selected the following modules
TEC1-01708 TEC1-01708S
Size 15x15x3.7mm (w x d x h), weight 6g
IMAX 8.5A, Umax 2.0V, R = 0.21 ohm, 17 couples ΔT max. = 68°C, Qmax (ΔT =0) 9.5W TEC1-03108
Size 20x20x3.3mm (w x d x h), weight 8g
IMAX 8.5A, Umax 3.7V, R = 0.40 ohm, 31 couples ΔT max. = 68°C, Qmax (ΔT =0) 17.6W TEC1-07103 TEC1-07103HTS
Size 30x30x4.7mm (w x d x h), weight 14g
IMAX 3.3A, Umax 8.5V, R = 1.94 ohm, 71 couples ΔT max. = 68°C, Qmax (ΔT =0) 18.0W
Thus, after seeing its properties, we have selected the TEC1- 07103/TEC1-07103HTS module for use. Since it requires less ampere rating and gives high output.as we have to select the module for both heating and cooling effect this module is better in all condition.

## X. CALCULATION

Calculation For the Part 3 TEG
Temperature at the part 3 is around 70 to 100 degrees Celsius. Thus, taking the average of both the value we get the temperature as 85 degrees Celsius.
We consider the temperature of the atmosphere as ambient temperature, Equals to 30 degree Thus the DT = 85 – 30 = 55 degree Celsius.
As per the Catalog provided by the company of the moduleTEP1-12635-3.4 which we have selected, at no Load condition the voltage produce is equal to 10.8 V, Similarly the voltage is prepared at the Temperature difference of 270 degree.
With no load (RL not connected), the open circuit voltage as measured between points and b is: V = S x DT
Thus, from the Equation above we get the Seebeck Coefficient.
10.8 = S x 270
S = 0.04 volts/°C
Thus, for the Module TEP1-12635-3.4 the Seebeck Coefficient is 0.04.

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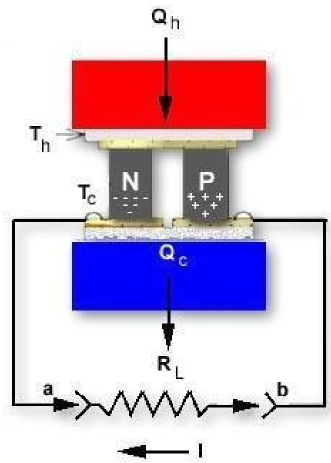
A thermoelectric module used for power generation has certain similarities to a conventional thermocouple. Let us look at a single thermoelectric couple with an applied temperature difference as shown in Figure



Electricity Generations with One Thermo Electric Power Module

Where:
V = the output voltage from the couple (generator) in volts
S = the average Seebeck coefficient in volts/°K DT = the temperature difference across the couple in K where DT = Th-Tc
When a load is connected to the thermoelectric couple the output voltage (V) drops as a result of internal generator resistance. The current through the load is 1 ampere given in the datasheet.
I=$\boldsymbol{S}$ $\boldsymbol{X}$ $\boldsymbol{DT}$/ $\boldsymbol{Rc}$ + $\boldsymbol{Rl}$
0.04 $X$ 270
1 =
$Rc + Rl$
Thus, we get the Rc + Rl = 10.8 Ω.
Where:
I = the generator output current in amperes
Rc = the average internal resistance of the thermoelectric couple in ohms
RL = the load resistance in ohms
When a load is connected to the thermoelectric couple the output voltage (V) drops as a result of internal generator resistance. Thus, we can find out the generated voltage at temperature difference of 55 degree.
V = S x DT V = 0.04 X 55 = 2.2 V
Thus, Voltage generated is 2.2 V.
Whereas at the same resistance the current we get is
I=S X DT / Rc X Rl I=0.04 X 55 /10.8
I=0.2037 ampere.
Thus, as per the value obtain above the one module produces is,
V=2.2 VI=0.2037 ampere
Temperature at the part 8 is around 500 to 560 degrees Celsius. Thus, taking the average of both the value we get the temperature as 530 degrees Celsius
We consider the temperature of the atmosphere as ambient temperature Equals to 30 degree Thus the DT = 530 – 30 = 500 degree Celsius.

As per the Catalog provided by the company of the module which we have selected, at no Load condition the voltage produce is equal to 13.3 V, Similarly the voltage is prepared at the Temperature difference of 570 degree. With no load (RL not connected), the open circuit voltage as measured between points a and b is: V = S x DT
Thus, from the Equation above we get the Seebeck Coefficient.
13.3 = S x 570
S = 0.0233 volts/°C
Thus, for the Module the Seebeck Coefficient is 0.0233. Where:
V = the output voltage from the couple (generator) in volts S = the average Seebeck coefficient in volts/°K DT = the temperature difference across the couple in K where DT = Th-Tc
When a load is connected to the thermoelectric couple the output voltage (V) drops as a result of internal generator resistance. The current through the load is 3.27 ampere given in the datasheet.
I= S X DT / Rc + Rl 3.27= 0.0233 X 570 / Rc X Rl
Thus, we get the Rc + Rl= 4.06146 Ω. Where: I= the generator output current in amperes
R= the average internal resistance of the thermoelectric couple R= the load resistance in ohms
When a load is connected to the thermoelectric couple the output voltage (V) drops as a result of internal generator resistance.
Thus, we can find out the generated voltage at temperature difference of 500 degree.
V = S x DT
V = 0.0233 X 500
= 11.65 V.
Whereas the same resistance the current we get is I= S X DT /Rc + RL
I=0.0233 X 500 / 4.06146
I= 2.868426 ampere Thus as per the values obtain above the one module produces is,
V = 11.65 V
I = 2.868426 ampere.

## XI. CONCLUSION

Thus, from above research we concluded that,

1. The power loss from engine can be converted into some useful energy by using the thermoelectric generator module, thermoelectric cooling module, solar panels.
2. Thus, we can operate any electric device from the power generated in the above experiment.
3. Thus, the bulky and power consuming AC can be replaced by the light weight and less power consuming thermo electric Peltier module.
4. Thus, the thermal efficiency of engine increase with decrease in power loss due to heat.
5. The costlier cooling system is also replaced by the cheaper system.
6. Thus, we can also operate our cooling devices during the off state of the engine without any fuel consumption as in conventional system.
7. In addition of the power generation through heat we are also using solar energy which is ecofriendly and easy to install.

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