

An Investigative Study on Heat Energy Recovery Using a TEG in a Hybrid Vehicle

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ABSTRACT: Energy recovery in automobile sector is an area which is gaining attention in the current scenario and various research works are in progress towards the same. About 60-70% of the heat energy produced during the process of combustion in an IC engine cannot be utilized and a major portion of this is wasted through exhaust gas. This paper deals with a study about harvesting heat energy from exhaust gas using a Thermo Electric Generator (TEG), storing the same in a battery and utilizing the same as an alternative source of energy in a hybrid vehicle. A TEG works on seebeck effect, according to which when two dissimilar metals are joined together and kept at different temperature and e.m.f will be generated at their junction of joining. As the exhaust leaving an IC engine have a temperature around 450 – 600°C, this idea can be effectively used for harvesting heat energy. The e.m.f generated can be stored in a metal hydride battery and coupled with a electric motor to drive a hybrid vehicle in its operating conditions. Even though there are various systems currently being used to extract heat energy, the study shows that this system is par more effective and compactable with hybrid technology as the charging time can be cut down and efficiency can be improved. Using of hybrid vehicles in this format also helps to keep up with various pollution standards and to tackle the issue of depleting Petroleum fuels.

KEYWORDS: Energy recovery in automobiles, TEG, Hybrid vehicles

I. INTRODUCTION

Automotive field is in an era of drastic change as pollution regulations are becoming narrower. Various agencies had put up strict regulations over the rate of pollution which indirectly point towards in search of new sources of energy rather than conventional ones. One of the major reasons for the domination of IC engines over the other resources of energy was that the lack of technology to extract the power to propel the vehicle at all conditions. Initial cost when compared with the rate of extraction is also an important factor. Apart from using new sources of energy, the complete utilization and minimizing the wastage of energy is one of the latest trend in energy utilization. While Investigating the working of IC engine, it is found that around only 30- 35% of total energy produced is converted in to useful work even in the most modern engine. The rest of the energy produced is wasted through sources like exhaust, cooling water, lubrication oil and so on. Among these exhaust gases accounts for a major energy loss. The main conventional methods of extracting energy from exhaust gases are Turbochargers, superchargers, Exhaust Gas Recirculation. One of the main drawbacks of these systems are due to its complexity, Initial cost and rate of extraction.

Hybrid vehicle is a vehicle which uses an alternative source of energy like fuel cells, dc powered motor and so on in such a way that, the conventional source of fuel is used to give the drive in the conditions that vehicle requires maximum torque or power and deploy alternative sources during low power mode conditions. Hybrid technology was introduced in to automotive sector in 1950's, which uses another source of power apart from the conventional fuel. It was commercially introduced by Toyota in their model 'prius' in 2002. Even though several models came after that by various manufacturers, they still lack popularity as of the drawbacks like *low performance when compared with conventional fuel*, high initial cost, charging time, less power extraction.

II. RELATED WORKS

Thermo Electric Generators (TEG)

Thermo electric generators are solid state devices used for converting heat energy into electrical energy directly and it is worked on the basis of seebeck effect .This effect was discovered by Thomas seebeck in 1821. One of the key features of the device is that as it doesn't have any moving part , no mechanical work is done so less complexity , noise and pollution compared to other power generators . This makes them adaptable to any extreme conditions and in confined spaces .

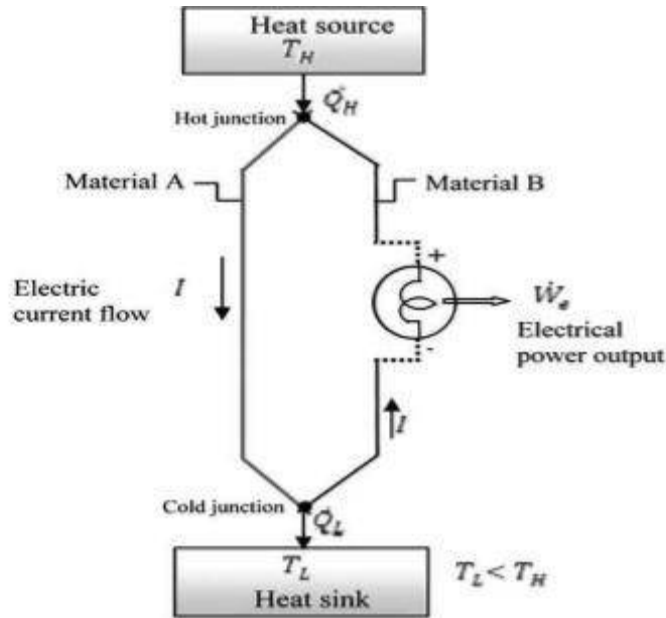


Fig 1: Thermo-electric generator principle

Seebeck effect

It states that- “The **Seebeck effect** is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances”

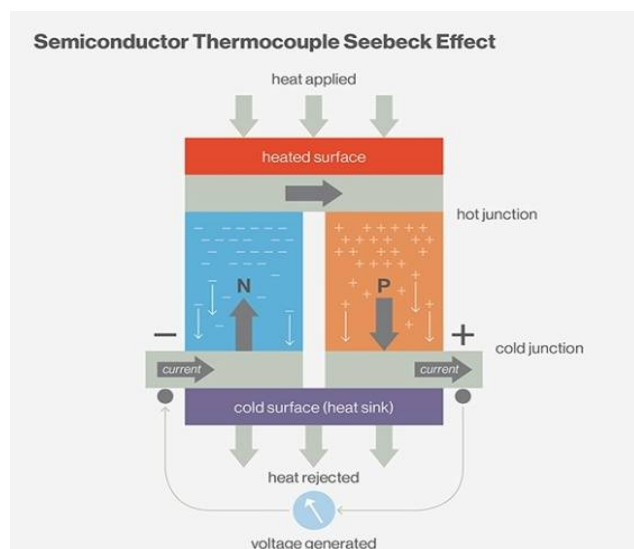


Fig 2: Seebeck effect

In the proposed work , the hot junction diode is kept at automobile exhaust and cold junction may be kept at atmospheric temperature or in any fluids depending up on the type of TEG used.

Construction of TEG

Thermoelectric generator is a device used for converting heat energy into electrical energy directly. The main component of TEG is a Thermo-electric module, which possess sandwiched like structure comprising of N- type and P- type semiconductors. A couple of semiconductors is known as pellets. The series arrangement of pellets produce the required emf for the charging of battery. Each pellets are inter connected with metal pieces for the flow of electron . An outer covering at the top and bottom is given by ceramic plates which will be acting as hot and cold junction. The schematic diagram is shown below . The upper ceramic plate will act as hot junction and lower one will act as cold junction.



Fig 3: Thermo-Electric Module

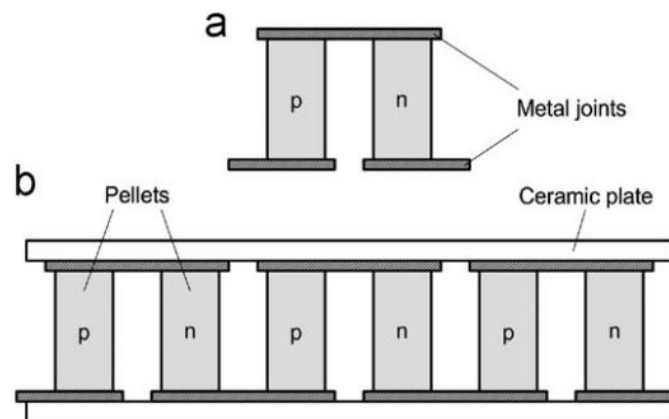


Fig 4: Construction and series arrangement of TEG

The N- type semiconductors are heavily doped to excess electron (majority carrier is electron) and the p- type semiconductors are heavily doped to excess holes (majority carrier is holes). In electrically they are connected in series but in thermally they are connected in parallel. Thus metals are sandwiched by two heat exchanger plates one of the heat exchanger plate is at high temperature is called hot junction and other end is at low temperature than hot junction is called cold junction so the electrons are flow from hot side to cold side so the energy is generated.

Since the exhaust temperature of a typical IC engine is about 500-600⁰C and average atmospheric temperature is about 30⁰C , bismuth-telluride (Bi2Te3) will be the better choice for optimum performance. These type of TEG mainly finds application in the fields of power generation , as topical insulators and as thermal coolers . The proposed semiconductor has excellent properties when used as TEG.

Table 1: Various combinations of TEG

TYPES OF MATERIAL	HOT SIDE MATERIAL (700 K – 1000 K)	COLD SIDE MATERIAL (300 K – 400 K)	BTR (K) HOT SIDE MATERIAL	BTR(K) COLD SIDE MATERIAL
N – TYPE	CoSb3 PbTe SiGe	Bi2Te3	650-1100 600-850 >1000	<350
P – TYPE	Zn4Sb3 CeFe4Sb12 SiGe TAGS	Bi2Te3	>600 >850 900-1300 650-800	<450

Hybrid Vehicle Technology

Hybrid vehicles may be categorized under electrical vehicles equipped with multiple source of energy. These two source may simultaneously operate or separately works to propel the vehicle. It is a combination of an internal combustion engine and a electric motor. In normal driving conditions , where the power requirement is less, vehicle is propelled using electric power while in case high power requirement like starting, throttling IC engine powers the vehicle. The power drive train of the vehicle is coupled with both the power output of IC engine and electric motor , switching the appropriate source of power according to the drive condition. The system aims to improve fuel efficiency of the automobile with no compromise on performance.

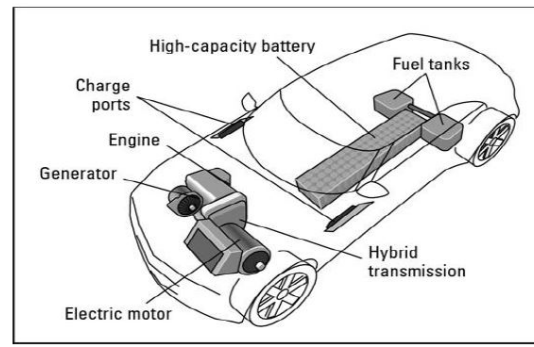


Fig 5: Basic parts of a hybrid car

Based on the arrangement of power train circuits, hybrid vehicles can be broadly classified as

Series Hybrid Configuration

This is a type of hybrid power train in which the power output from electric motor is used to propel the vehicle while the function of the IC engine is to charge the battery. This is a simple type of construction and in most of the cases IC engine is run with the help of fuel cell .Here the IC engine almost serves as the function of a generator as such. The main feature of this type is that , it will be comparatively large battery backup but cannot be used in large commercial application due to low rate of extracting power and high cost of the materials.

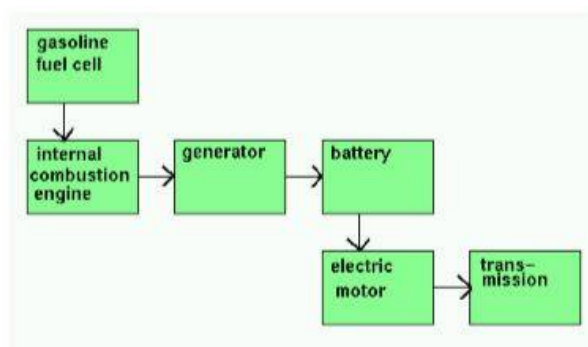


Fig 6: Series Hybrid power train

Parallel Hybrid configuration

This is used widely in application when compared with series configuration. Unlike from the series model , here both the electric motor and IC engine are in parallel connection and has a direct role in giving thrust power in the selected mode . Either the motor or the IC engine is coupled with the Power train of the vehicle at a time.

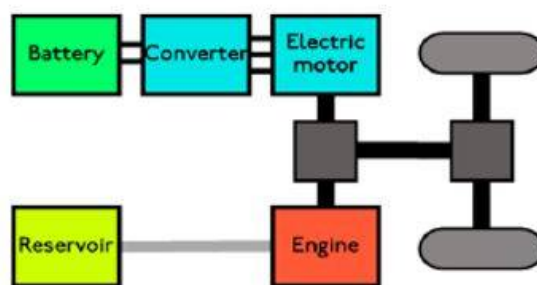


Fig 7: Parallel Hybrid power train

Series- Parallel Hybrid configuration

This type of configuration complies both the merits of parallel and series configurations. In this type IC engine has got provisions to power the wheels directly or to charge the battery through the generator.

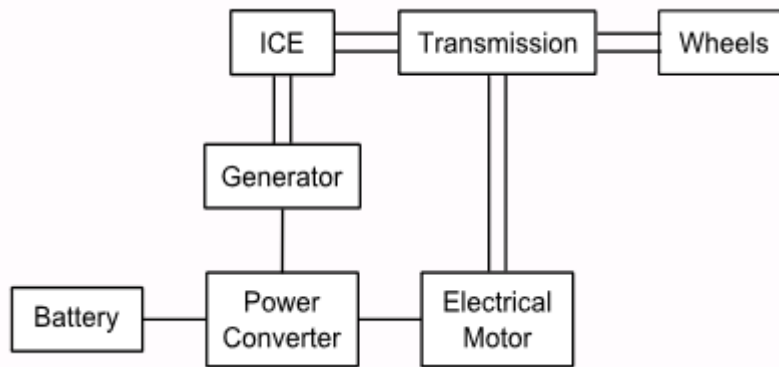


Fig 8: Series – Parallel hybrid configuration

Technologies used in hybrid

Charging System

The Battery used in the system is either charged through a AC power supply or systems like regenerative braking system, KERS etc.

Electric battery

Electric batteries are one of the major component of a hybrid vehicle and the one of the parameter determining the performance of the vehicle. DC batteries are commonly used for this purpose. Charging time and power delivery at required intervals are the common characteristics of these type of batteries. The output from the battery is used to drive the dc motor coupled with it . The average power requirement of an automobile while it is working in hybrid conditions varies from 60- 90 KW. Commonly used batteries are different types of metal hydrides (combination of ‘n’ number of cells). The selection may vary from different manufacturer, Engine design, Pay load of the vehicle , space available , power to weight ratio and stability of the vehicle . A typical example of a hybrid battery is Lithium –Ion and it is discussed below

In this project we use lithium ion cell as battery because it is a rechargeable battery. The main functional components of a lithium ion battery are positive and negative electrode. The negative electrode of the cells is made up of carbon and the positive electrodes are made up of metal oxide. The battery arrangement consisting of a anode, cathode, and a electrolyte. Graphite act as anode and lithium cobalt act as cathode. And thus anode and cathode is separated by a electrolyte, and the ionic components of chemical reactions are transferred to this electrolyte

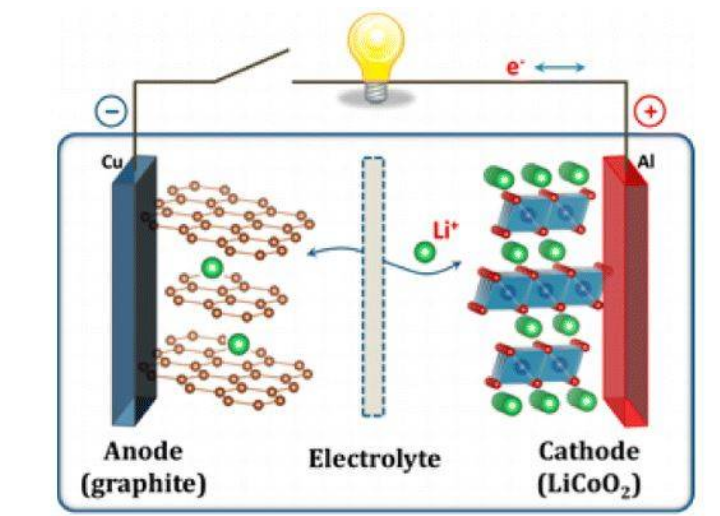


Fig 9: Li-Ion battery

Table 2: Battery module specifications

Number of cells	4
Construction	2 in-series pairs in parallel
Length	11.9291" (303 mm)
Width	8.7795" (223 mm)
Thickness	1.3779" (35 mm)
Weight	8.3775 lbs (3.8 kgs)
Output terminal	M6 nut
Voltage sensing terminal	M4 nut
Module fixing hole diameter	0.3582" (9.1 mm)

Table 3: Battery Specifications

Type	Laminated lithium-ion battery
Voltage	403.2V
Nominal voltage	360V
Total capacity	24 kWh
Power output	Over 90 kW
Energy density	140 Wh/kg
Power density	2.5 kW/kg
Dimensions	61.8 x 46.8 x 10.4 in. (1570.5 x 1188 x 264.9 mm)
Weight	648 lbs
Number of modules	48, each with four cells (total 192 cells)
Battery pack contents:	<ul style="list-style-type: none"> • Positive electrodes: lithium manganate • Negative electrodes: carbon • Cells • Modules • Assembly parts
Charging times:	<ul style="list-style-type: none"> • Quick charger DC50kW (0 to 80%): approx. 30 min (Level 3 charging) • Home-use AC240V charging dock (0-100%): 8 hrs (Level 2 charging) • Regular 110/120V 15-amp outlet: 22 hours (Level 1 charging)
Battery layout	Under seat & floor

Table 4: Li -Ion Cell specification

Cell type	Laminate type
Cathode material	LiMn ₂ O ₄ with LiNiO ₂
Anode material	Graphite
Rated capacity (0.3C)	33.1 Ah
Average voltage	3.8 V
Length	11.417" (290 mm)
Width	8.504" (216 mm)
Thickness	0.2795" (7.1mm)
Weight	1.7624 lbs (799 g)

Electric Motor drive

Electric motor supplies power to the power train circuit of the vehicle in the specific operating conditions. Similar to the hybrid configuration, a number of motor arrangement is possible according to the design of transmission system. The main types are

- 1) A central master motor providing output to the drive
- 2) Separate master motor to front wheel and rear wheel drive
- 3) Hub motors on each wheels

The later ones are the recent advancements in technology providing high torque ratio with better fuel efficiency. "BMW i8" has used this technology having 357 HP and fuel efficiency of 42 km/litre.

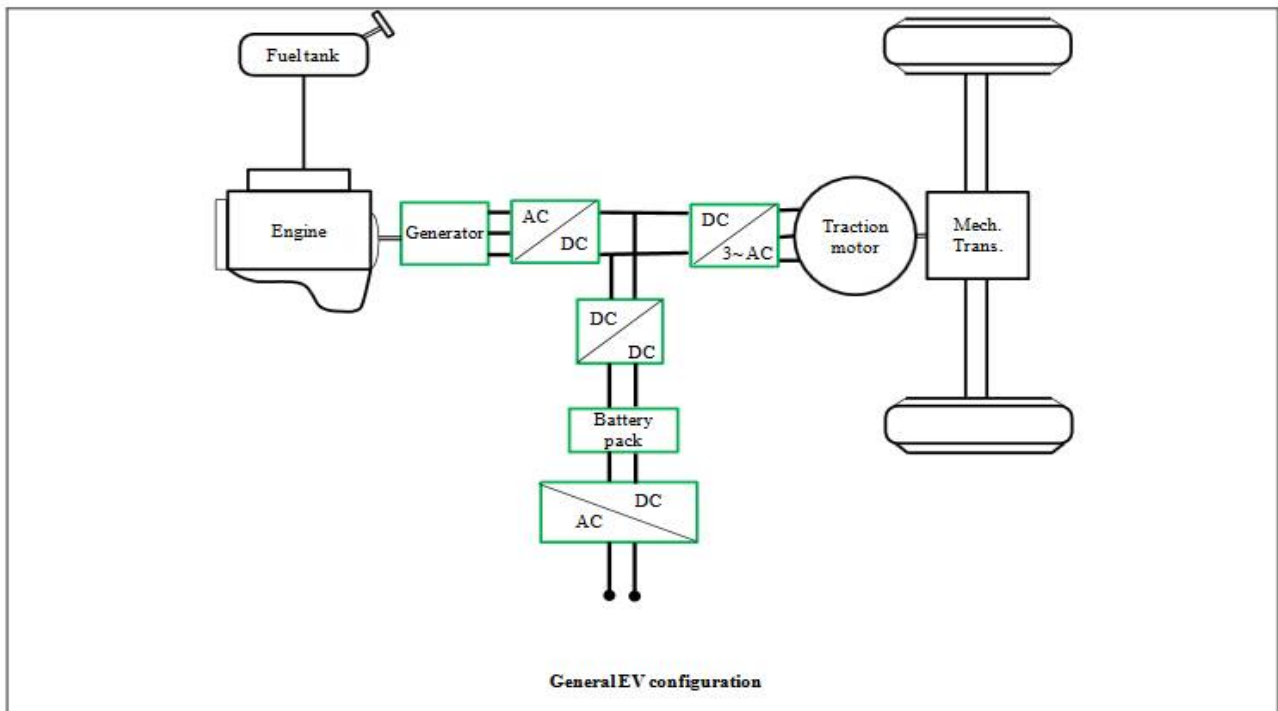


Fig 10: Single Master motor

Table 5: Technical Specifications of various hybrid models

Model	ICE	El. mot.	Battery	
	(HP) at (rpm)	(kW)	dc (V)	Ah
Chevy Silverado 2004	295 at 5200	14	36	70
Ford Escape 2005	133 at 6000	70	330	5.5
Honda Accord 2005	240 at 6250	12	144	6.0
Honda Civic 2006	110 at 6000	14.6	158.4	5.5
Lexus RX400h 2006	268 at 5600	123	288	6.5
Mazda Tribune 2008	133 at 6000	70	330	-
Nissan Altima 2007	158 at 5200	105	244.8	6.5
Saturn Vue 2007	170 at 6600	14.5	36	18.4
Toyota Camry 2007	147 at 6000	105	244.8	6.5
Toyota Highlander 2006	268 at 5600	123	288	6.5
Toyota Prius 2004	76 at 5000	50	201.6	6.5

Working of TEG in a Hybrid Vehicle

During the operation cycle of IC engine, a part of fuel energy is converted in to useful work, a major portion of leftover energy is carried by the exhaust gas which is at a temperature range of 500 – 600 Degree .TEG extracts the energy from this waste heat using Seebeck effect. In this temperature range bismuth telluride is the suitable material can be used as semi conductor for energy recovery. In the proposed system, the hot junction is kept in exhaust heat by drilling the exhaust pipe before the muffler and sealing it perfectly. The muffler is used to persist the sound variation due to the drilled hole. The cold side metal is kept in the atmospheric temperature, for getting a temperature gradient. Due to this temperature difference an emf is generated across this metal,. The generated emf Stored in battery. The motor coupled to the battery gives the drive according to the selected configuration.

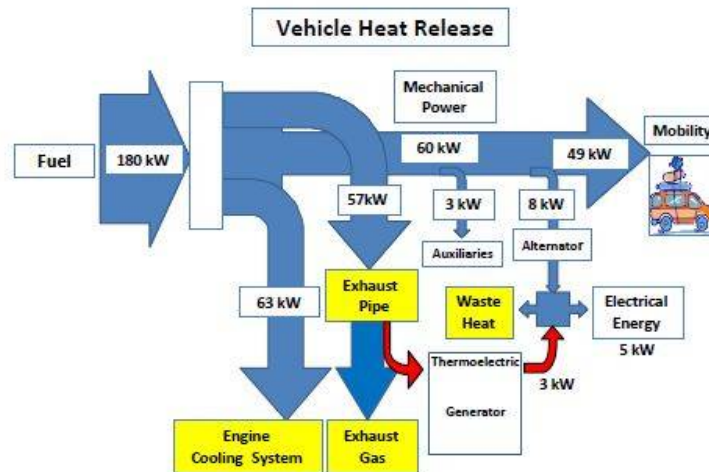


Fig 11: Working of TEG in Hybrid Vehicle

III. CONCLUSION

The Primary study conducted on IC engines revealed that even in most modern engines can only extract not more than 50 % of the total heat produced in to work .This creates a wide scope for the energy recovery technologies where TEG can play a big role .Even though hybrid technologies was introduced in early 19th Century, the technology failed to be in the mainstream of commercial manufacturing . As the pollution regulations becoming rigid and narrower and world is in search of alternate fuels , TEG applied in hybrid vehicles might be future technology. One of the setbacks that was understood in the course of study was the emf generated from TEG with the present systems is at an average of 600w,[8] so TEG alone cannot be applied to charge the battery for high power requirements. So it can coupled with present systems used in hybrid vehicles like regenerative braking system to charge the battery so as to enhance the performance. The area where more research has to be done is the rate of heat energy extraction and minimizing the cost of the system with no compromise on performance.

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