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## Exhaust Waste Heat Recovery of I. C. Engine by Thermoelectric Generator

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### Abstract

A more part of heat added in IC engine is wasted, but dumped into the atmosphere as waste heat. If this waste heat energy is tapped and converted into usable energy, the overall efficiency of an engine can be increased. The maximum percentage of heat recovered during the exhaust approximately 30% -40 % added by the fuel depending on engine varying load. Thermoelectric modules which are used as thermoelectric generators are solid state devices that are used to convert thermal energy from a temperature difference to electrical energy and it works on basic principle of Seebeck effect. This paper demonstrates the potential of thermoelectric generation. Also, studied the performance factors of engine with and without thermoelectric generator. The conversion efficiency of thermoelectric generator is about 8%. Also, several main characteristics of the different structures proposed for the thermoelectric generators will be compared. In the review added in this paper, it would be useful to update the potential of thermoelectric power generation in the automobile and electric industry nowadays. The results presented can be considered as references of the minimum goals to be reached.

Keywords: Waste heat Recovery, seeback effect, thermoelectric modules devices, thermoelectric generator

### Introduction:

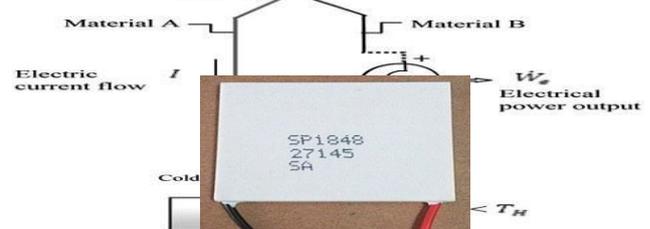
The thermoelectric power cycle, with charge carriers (electrons) serving as the working fluid, follows the fundamental laws of thermodynamics and intimately resembles the power cycle of a conventional heat engine. The major drawback of thermoelectric power generator is their relatively low conversion efficiency (typically ~8%).

The exhaust waste heat recovery of I. C. Engine by Thermoelectric generator in this project we studied source of waste heat i.e diesel engine. We have been checked the exhaust temperature range of available waste heat source. After checking the temperature range of waste heat source we studied different waste heat recovery systems. Then we selected thermoelectric generator system to recover the present heat source. Also we have studied effect of thermoelectric generator on engine performance. Basic concept of Thermoelectric generator –

The basic theory and operation of thermoelectric based systems have been developed for many years. Thomas Seebeck in 1821. i.e., Seebeck voltage. Extensively used for temperature measurements. Based on this Seebeck effect, thermoelectric devices can act as electrical power generators.

Heat is transferred at a rate of  $Q_H$  from a hightemperature and it is rejected at a rate of  $Q_L$  to a lowtemperature sink maintained at  $T_L$  from the cold junction. Using the first-law of thermodynamics (energy conservation principle) the difference between  $Q_H$  and  $Q_L$  is the electrical power output.

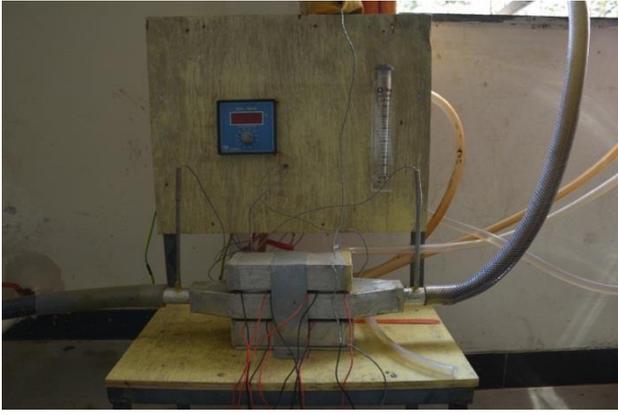
**Figure1. Basic concept of a simple thermoelectric power generator operating based on Seebeck effect.**



**Figure2. Theromelectric module**

Thermoelectric generator system –

Thermoelectric generator system is shown in following figure 3. Six TEG modules are fabricated in heat exchanger. The hot exhaust gas from engine is passed from one end and cold water is passed from other end, so temperature difference occurs and voltage is generated. Thermocouples and rotameter is provided to measure the temperature and cooling water flow rate. Cooling water is circulated by 0.5HP centrifugal pump.



**Figure3. Thermoelectric generator system**

In shell and tube heat exchangers classified widely used in a TEMA standards.(Tubular Exchanger Manufacturers association),the range of tube sizes and pitches, baffle space and plates, tube sheet thickness formula, pressure classification and so on. widely used in industries because operating condition such as from high vacuum to ultra high pressure(100Mpa).It can be designed for special operating conditions :erosion, corrosion, toxicity, vibration, highly viscous fluid, multi component mixtures, density of fluid, flow of fluid.

#### Literature Review:

**Crane D. et al. [1]** described a design concept that maximizes the performance for thermoelectric power generation systems in which the thermal power to be recovered is from a fluid stream (e.g., exhaust gas) subject to varying temperatures and a broad range of exhaust flow rates. The device is constructed in several parts, with each part optimized for a specific range of operating conditions. The thermoelectric system characteristics, inlet mass flow rates and fluid temperatures, and load and internal electrical resistances are monitored and generator operation is controlled to maximize performance. With this design, the system operates near optimal efficiency for a much wider range of operating conditions. Application of the design concept to an automobile is used to show the benefits to overall system performance.

**Basel I. I. et al. [2]:** he works on “Thermoelectric power generation using waste-heat energy as an alternative green technology,” Engine exhaust has tremendous amount of energy which can be recovered by waste heat recovery systems.. In recent years, an increasing concern of environmental issues of emissions, in particular global warming and the limitations of energy resources has resulted in extensive research into novel technologies of generating electrical power. Thermoelectric power generators have emerged as a promising alternative green technology due to their distinct advantages. application in the direct conversion of waste-heat energy into electrical power where it is

unnecessary to consider the cost of the thermal energy input. The application of this alternative green technology in converting waste-heat energy directly into electrical power can also improve the overall efficiencies of energy conversion systems.

**Liang G. et al. [3]** studied the performances of parallel thermoelectric generator (TEG) by theoretical analysis and experimental test. An analytical model of parallel TEG was developed by theoretical analysis and calculation, based on thermodynamics theory, semiconductor thermoelectric theory and law of conservation of energy. Approximate expressions of output power and current of parallel TEG were deduced by the analytical model. An experimental system was built to verify the model. cerathe parallel properties of the TEG are the same as that of common DC power. The existence of contact resistance is just like the increase of the TE module’s internal resistance, which leads to the deceases of output power. The thermal contact resistance reduces the output power by reducing the temperature difference between the two sides of the thermocouples. The results derived from the model are basically consistent with the experimental results

#### Experimental set-up:

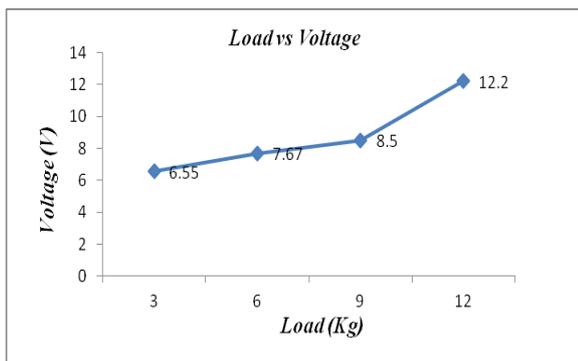




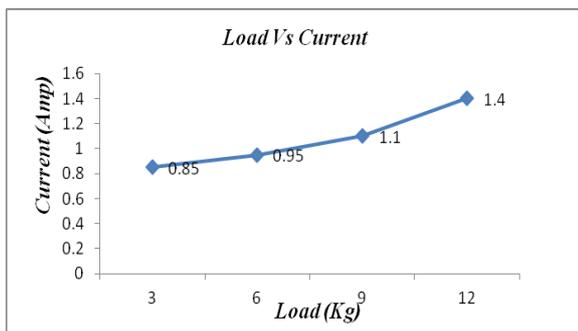
**Experiment and Result**

The heat exchangers are assembled with the sandwich arrangement of thermoelectric modules between them. Before assembly the thermal grease is applied on both the surfaces of TEG modules to enhance the heat transfer. Thermocouples (K-Type) are connected along with the display for temperature measurement. After successful assembly of heat exchangers, TEG System is attached on a 1 cylinder, 4 stroke, and Diesel Engine test rig. Experimental Setup is ready to take sets of trials at different engine speed. As a load on system, LED load bank is used. Using the thermocouples; temperatures at 5 sections are measured on Digital temperature indicator. Then voltage & current at various engine speeds are measured on Digital

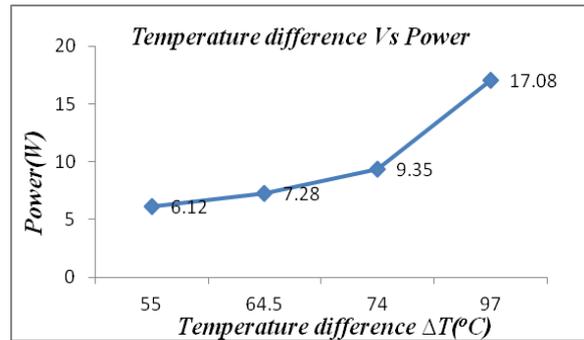
**Figure 5. (a) Load Vs Power**



**Figure 5. (b) Load Vs Voltage**

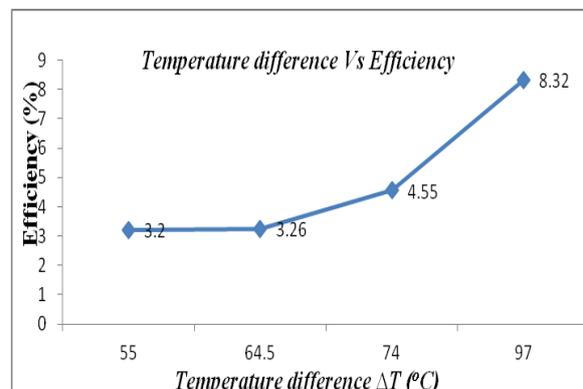


**Figure 5. (c) Load Vs Current**

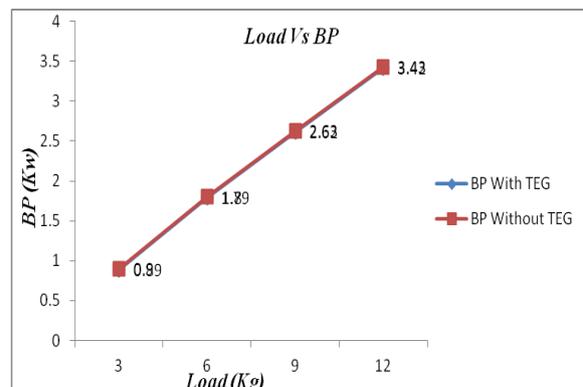


**Figure 5. (d) Temperature difference Vs Power**

The above graphs shows that if the load increases then thermoelectric power, voltage and current is also increases as shown in figure 5. Hence the power, voltage and current are proportional to load on the engine. Also if temperature difference between hot and cold side of the thermoelectric generator is increases then power also increases as shown in figure 5



**Figure 6. (a) Temperature difference Vs Efficiency**



**Figure 6. (b) Load Vs Break power**

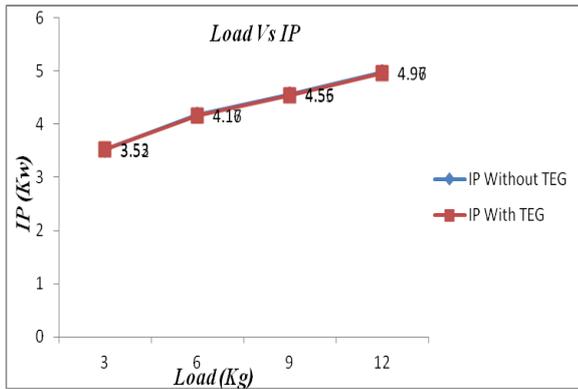


Figure 6. (c) Load Vs Indicated power

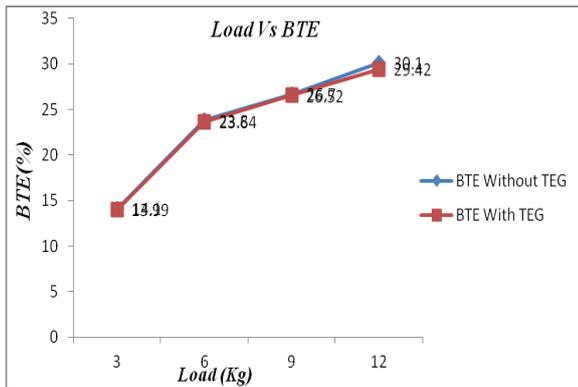


Figure 6. (d) Load Vs Break thermal efficiency

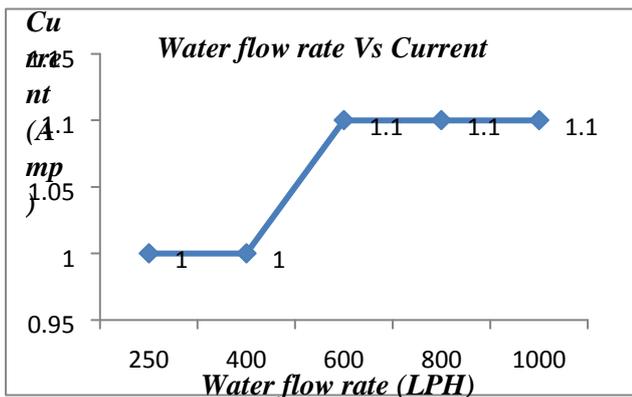


Fig.6.(e) Water Flow Rate Vs Current

If the temperature difference between hot side and cold side of thermoelectric generator is increases then efficiency of thermoelectric generator is also increases as shown in figure 6. The performance factors of engine break power, indicated power and break thermal efficiency are slightly decreased with thermoelectric generator as shown in figure 6.

Table -1 Experiment Result

Sr. No.	Temperature difference between hot and cold side $\Delta T$ ( $^{\circ}C$ )	Power output P (W)	Efficiency $\eta$ (%)
1.	55	6.12	3.2
2.	64.5	7.28	3.26
3.	74	9.35	4.55
4.	97	17.08	8.32

Table -2 Experiment Result

Load (Kg)	Without TEG			With TEG		
	BP (Kw)	IP (Kw)	BTE	BP (Kw)	IP (Kw)	BTE
3	0.90	3.53	14.1	0.89	3.52	13.99
6	1.18	4.17	23.8	1.79	4.16	23.64
9	2.63	4.56	26.7	2.62	4.55	26.52
12	3.43	4.97	30.1	3.42	4.96	29.42

Table 1 show the temperature difference between hot side and cold side of thermoelectric generator, power output and efficiency of thermoelectric generator. Table 2 shows the performance factors of engine break power, indicated power and break thermal efficiency with and without thermoelectric generator.

#### CONCLUSION

1. Results show that voltage, current, power developed and efficiency of the system increase with the increase in Engine load, exhaust temperature & flow rate of cooling water.
2. With variation in load it is observed that if load increases the power, voltage, current and efficiency of thermoelectric generator is increased.
3. With variation in load we got maximum power of 17.08W, voltage 12.2V, current 1.4A and efficiency 8.32% at load 12 Kg.
4. If temperature difference between hot side and cold side of thermoelectric generator is increased then efficiency is also in increased.
5. The performance factors of engine break power, indicated power and break thermal efficiency are slightly decreased with thermoelectric generator.

## References:

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