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

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ABSTRACT

A major part of the heat supplied in an internal combustion engine is not realized as work output, 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 improved.The percentage of energy rejected to the environment through exhaust gas which can be potentially recovered is approximately 30-40% of the energy supplied by the fuel depending on engine load. Thermoelectric modules which are used as thermoelectric generators are solid state devices that are used to convert thermal energy from a temperature gradient to electrical energy and it works on basic principle of Seebeck effect.This paper demonstrates the potential of thermoelectric generation. The use and evolution of different kinds of thermoelectric materials will be presented. Also, several main characteristics of the different structures proposed for the thermoelectric generators (TEGs) will be compared. In the review included in this paper, it would be useful to update the potential of thermoelectric generation in the automobile industry nowadays. The results presented can be considered as references of the minimum goals to be reached.

*Keywords:***I.C. engine, waste heat energy, Thermoelevtric, Seebeck effect.**

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I. INTRODUCTION

Heat engines are predominantly designed to produce useful work only. Waste energy in the form of heat is normally a byproduct resulting from the irreversibility of the processes involved in the conversion of primary energy to mechanical or electrical energy. The efficiency of a modern internal combustion engine is about 37% in a normal passenger car spark ignition Engine whereas 50% in low speed marine diesel engine. The energy dissipated is lost by transmission to the environment through exhaust gas, cooling water, lubrication oil and radiation. The electric power used in automobile is generated by taking part of useful mechanical energy. Due to improvements of comfort, driving performance and power transmission the electric load of a vehicle is increasing day by day. Due to this tendency, the alternator sizes, load of engine power and engine weight are becoming larger. However, the engine room is becoming smaller in order to expand the passenger room. For this reason, the space for the alternator cannot be freely increased. With the help of TEG fuel consumption can be reduced by 10% by converting only 6% of waste heat into electrical power. In this way the overall efficiency of the internal combustion engine can be increased.

I. ELEMENTS OF THERMOELECTRIC GENERATOR

Thermoelectric generator basically consists of three elements these are thermoelectric module, support structure and sink.

a. Thermoelectric module – Depending upon the range of temperature different thermoelectric modules are selected like Silicon Germanium, Bismuth Telluride, Lead Telluride also many new material like Zinc Antimonides, Thermoelectric oxide material NaxCo2O4, Thin Films Materials etc.

b. Support structure – It is the very important part of the TEG, where the thermoelectric modules are mounted. The internal part of this structure normally is modified in order to absorb the most part of the heat accumulated in the exhaust gases.

c. Sink – It is nothing but the heat dissipation system which favors the heat transmission through thermoelectric module.

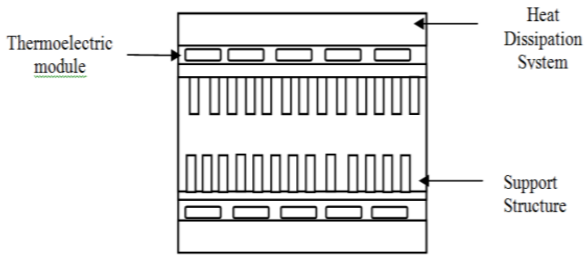

Fig. 1Schematic of generic thermoelectric generator

II. THERMOELECTRIC MODULE

The Thermoelectric module used in a typical TEG can be classified on the basis of material used, shape and size and configuration of their thermoelectric pair. . The semiconductor material used in fabrication of TEG is dependent on maximum temperature obtained and hence location of TEG mounting on the exhaust pipe. There are three positions for TEG mounting.

1) Just behind the exhaust manifold- The temperature range of the exhaust gases obtained is in between 10000 c and 7500 c. The thermo elements were fabricated on the basis of β-FeSi2**,** with co-doping for N type and Aluminium doping for P type. Si-Ge alloys are also used.

*2) Between the exhaust manifold and the catalytic convertor***-** In this region the temperature range ofexhaust gases is in between 7500 c and 4000c.Thelead telluride material is generally used for thistemperature range.

3) Just behind the catalyst convertor- The temperature range obtained in this region is in between 4000 c and 2000c.All the TEGs designed to this temperature range are based on Bismuth Telluride alloys.

IV. DESIGN OF THE THERMOELECTRIC GENERATOR

Researchers [1] have been worked on Experimental study on waste heat recovery from an internal combustion engine using thermoelectric technology.Two designs of the heat exchangers, rectangular and hexagonal shape have been proposed by [2]. Moreover, researchers [3] have used hexagonal shaped TEG but only few worked on rectangular TEG [4].The TEG consists of an exhaust gas heat exchanger, counter flow coolant cooling chamber and 18 TEM connected in series. The amount of heat transferred from the exhaust gas to the TEM depends on the design of the TEG and the critical parameter is the heat flux which crosses the TEM. In order to achieve this, the TEM should work close to its best conditions of power, and it is also necessary to reduce the thermal resistance which includes thermal resistance from the exhaust gases to the inner wall of heat exchanger, and the thermal resistance from the inner wall of the heat exchanger to the hot surface of the module. The heat transmission from the inner wall to the hot surface of the TEM is basically a heat conduction problem. Thermal resistance exists between the surfaces of the hot plate and TEM because of the surface roughness. Hence, care was taken to ensure high degree of smoothness between the surfaces by polishing it. The most common materials used in the construction of the support structure of the TEG are steel, stainless steel, and in one case haste alloy, and aluminum [1]. The best material to be used for the contact of the TEG with the exhaust pipe is copper because it is 6 times and 25 times better as a thermal conductor than carbon steel and stainless steel, respectively, while the maximum gain in weight compared to the lightest steel is only 14.3%.The coolant used in engine cooling system is circulated into the TEG by using a small split joint. Figure.2. shows the schematic of the TEM Sandwiched between hot and cold plate and the flow direction of the hot and cold fluids. This avoids the requirement of a separate cooling system for modules. The power required to pump the coolant to the TEG is one of the losses as compared to the power produced by the TEG. As the coolant chamber has to be designed to accommodate maximum flow of coolant at higher speeds and loads, the maximum flow of coolant was estimated by taking exhaust gas properties at higher speeds and loads. The specific heat capacity of the exhaust gas was calculated using an exhaust gas calorimeter.

Fig. 2 TEG with the stand

Now by heat balance equation,

$Q_{lost} = Q_{gained}$

$Q_{lost} = m_{ex}\, c_{pg}\, (T_{g1} - T_{g2})$

$Q_{gained} = m_w\, c_{pw}\, (T_{wo} - T_{wi})$

where,

m_{ex}: mass rate of exhaust gas in kg/s.

c_{pg}: specific heat of exhaust gases in J/kg.k

T_{g1}: Inlet temperature exhaust gases in K.

T_{g2}: Outlet temperature exhaust gases in K.

m_w: mass rate of water in kg/s.

c_{pw}: specific heat of water in J/kg.k

T_{wo}: Outlet temperature of water in K.

T_{wi}: Inlet temperature of water in K.

Mass flow rate of water is calculated by

$Q = m_w c_{pw}(T_{c2} - T_{c1})$.

V. EXPERIMENTAL SET UP

The test was carried out on an engine dynamometer. No modifications were made on the engine. The exhaust pipe was insulated on the upstream side of the exhaust chamber up to the catalytic converter to minimize heat loss. 0-1200 °C K-type thermocouples with digital measuring unit were used to measure exhaust gas temperature, hot and cold side temperatures of TEM next to catalytic converter. The only concern is that the generator, if located upstream of the catalytic converter, would decrease the efficiency and increase the warming time of the catalytic converters. Schematic diagram of the experimental setup is shown in fig.3.

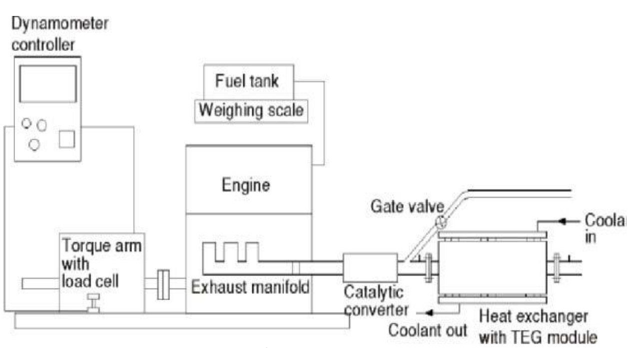

Fig. 3 Schematic diagram of the experimental setup with TEG module

VI. RESULTS AND DISCUSSION

In order to observe the differential change in exhaust back pressure and exhaust emissions due to the addition of TEG to the exhaust system, experiments were conducted on the test engine with and without TEG and results were compared.

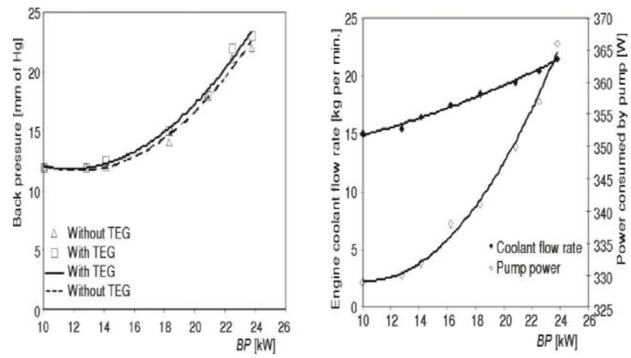

Fig.4. Variation of back pressure with brake power

It is found that back pressure is increases as the break power increases with TEG as compare to without TEG. Also engine coolant flow rate and power consumed by pump is increases as the break power increases with TEG as compare to without TEG.

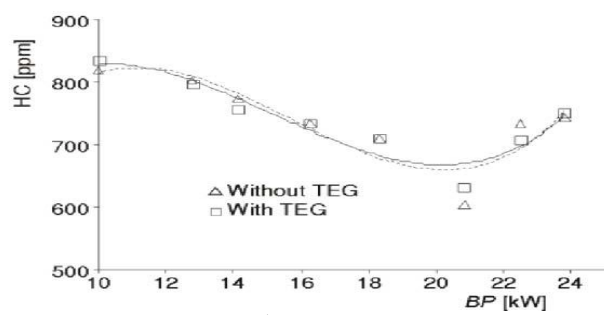

Fig.5. Variation of HC with brake power

VII. CONCLUSION

1. By the utilization of the waste heat the performance of the internal combustion engine is considerably increased.

2. The performance of TEG is mainly depend upon heat transfer from the exhaust gas to TE module, material of TE module, location of TEG.

3. It is found that back pressure is increases as the break power increases with TEG as compare to without TEG. Also engine coolant flow rate and power consumed by pump is increases as the break power increases with TEG as compare to without TEG.

4. It is found that the HC emission is reducing as brake power increases with TEG as compare without TEG.

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