Study of Thermoelectric Generator for Harnessing of the heat energy wasted from automobiles and Thermal Power Plant

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Abstract—The ever growing huge demand for electricity needs is to be fulfilled with taking in consideration the environment factor. Thus, recycling of energy must be done as effectively as possible. Harnessing of the heat energy wasted from automobiles, industries, domestic appliances etc. all of which can generate power is proposed in this paper. Industries and automobile sector is the main source for the supply of waste heat which can generate power that can be further used for powering various accessories thus increasing the overall efficiency of the system itself. Technology under study in this paper for waste heat recovery is called TEG which stands for Thermo Electric Generators based on the See beck effect. TEG is a device which makes use of the temperature gradient across it to generate an electromotive force (EMF). TEGs are most suitable for waste heat recovery applications due to lack of mechanical parts, low maintenance and high durability and are proved in space missions over the past decades. The focus of this paper is to study characteristics of TEG and factors affecting its performance in turn reducing the environmental impact. Power generation from automobile and thermal power plant and accordingly future scope can be defined.

Keywords—*waste heat recovery; TEG;green technology.*

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I. Introduction

A. Automobile:

About 70% of the available energy in the fuel is rejected as heat in the exhaust and coolant. The remainder of energy is transformed into mechanical energy to propel the vehicle or into work. Some of the work generated by the engine is used to overcome frictional losses that occur in the transmission and some other parts of the drive train. Moreover it is also utilized to operate the vehicle accessories such as alternator, coolant pump, fuel pump etc. As a result only about 20 to 25% of the original energy contained in the fuel is actually used to propel the vehicle. This propulsion energy overcomes:

(1) The inertia when accelerating or climbing hills,
(2) The aerodynamic drag, and
(3) The rolling resistance offered by the tires on the road surface.

Consequently to reduce vehicle fuel consumption generally there is two ways:

(1) Increase the overall efficiency of the power train i.e. engine, transmission, final drive in order to deliver more work output from the fuel consumed and
(2) Reduce the required work (weight, aerodynamics, rolling resistance and accessory load) to propel the vehicle.

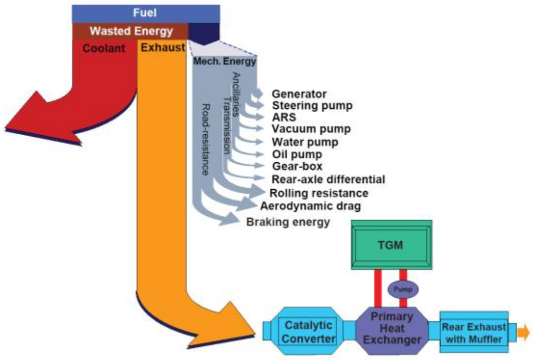

Fig. 1 ***Waste Heat from Internal Combustion Engine***

B. Thermal Power Plant:

Generally thermal power plants basically consist of steam-powered generators. These power plants are provided with once-through cooling systems used for cooling significant volume of water and to condense the steam for recirculation to the boiler. The heated water after the processing normally is to be discharged back to the source water such as, river, lake, or the ocean; or any of the nearest surface water body. In general, thermal discharge should be designed such that the discharge water temperature does not exceed the relevant ambient water quality temperature standards beyond a regulations specified scientifically established mixing zone. The mixing zone can be thus defined as the zone where initial dilution of a discharge water would takes place within which relevant water quality temperature standards are allowed to exceed within limit and it also takes into account cumulative impact of ambient water quality, receiving water use, seasonal variations, assimilative capacity and potential receptors among other considerations.

II. THERMOELECTRIC POWER GENERATION MATERIALS

To make a good thermoelectric it is required that:

$$ZT = [\alpha^2 / \rho\lambda]*T$$

Where, α = see beck coefficient –large
ρ = Resistivity –small
λ = Thermal conductivity – small
ZT= Figure of Merit

There are number of materials known to date, but only few are identified as thermoelectric materials. Today's most widely used thermoelectric materials, such Pb-Te-based alloys and as Bismuth Telluride (Bi2Te3)-based alloys, at room temperature have a *ZT* value of around unity. However, thermoelectric power generators would become competitive with other power generation systems only when *ZT* is in range of 2-3. Requirement of properties for effective thermoelectric materials are:

1. It should have a low thermal conductivity
2. A high electrical conductivity
3. High ZT value
4. Large see beck coefficient.

A large amount of research has focused in thermoelectric materials on increasing the See beck coefficient and reducing the thermal conductivity. This is done especially by manipulating the nanostructure of the materials with thermoelectric properties. Different thermoelectric material combinations can be tried out depending upon temperature difference existing in between the hot side and cold side of the TEG module.

III. THERMOELECTRIC EFFECT IN POWER GENERATION

The thermoelectric effect defined as direct conversion of temperature differences between two junctions of dissimilar metals into electric voltage and vice versa. A thermoelectric device generates voltage across the circuit when there is a different temperature on each side of junction. Conversely, when a voltage is applied to these junctions, it creates a temperature difference. While studying at the atomic scale, it is observed that when the temperature gradient is applied, it causes charge carriers in the material to excite resulting to diffuse from the hot side to the cold side. This effect thus in turn can be used to measure temperature, generate electricity, or change the temperature of objects. As the direction of cooling and heating side of is determined by the polarity of the applied voltage to junctions, thermoelectric devices can be used as temperature controllers.

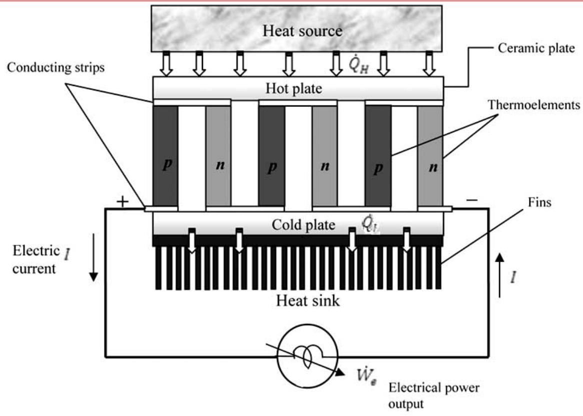

Fig 2- Thermoelectric effect

IV. THERMOELECTRIC POWER GENERATOR

The basic theory and operation of thermoelectric is based on a phenomenon called "See beck effect". It states that, when a temperature difference is generated between the two junctions i.e. cold and hot junctions of two dissimilar materials (semiconductors or metals) a voltage is generated, i.e., See beck voltage. In fact, this concept is generally applied to thermocouples that are extensively used for measurement of temperature. Thermoelectric devices can also act as electrical power generators, based on this See beck effect. A schematic diagram is shown below of a simple thermoelectric power generator operation based on principle of See beck effect. Heat is transferred at a rate of H from a high temperature heat source maintained at a temperature of T_H to the hot junction, and it is rejected to a low-temperature sink maintained at T_L i.e. the cold junction at a rate of Q. Based on the principle of See beck effect, when the heat is supplied at the hot junction, it causes an electric current to flow from hot junction to cold junction in the circuit and electrical power is produced.

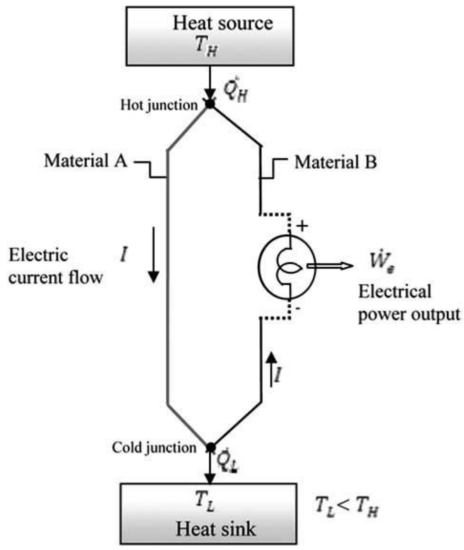

Fig. 3.Simple thermoelectric power generator operating based on Seebeck effect.

V. WASTE HEAT RECOVERY

Thermal power plants

In present situation, energy from thermal power plant are harnessed by the use of other technology such as binary Rankine cycle. But it suffers from some of the serious drawbacks, one of them being high maintenance and minimum temperature above 450K. Whereas, thermoelectric generators coupled with heat exchangers can produce electricity even at low temperature of around 350K with low maintenance. There are two types of thermoelectric modules, one used for high power application which is also known as large bulk TEM and other for module for low power production known as thin film TEM or micro TEM. At high temperature TEM are used and they also help in low weight of heat exchanger. Some of the limitations in the application of TE devices for geothermal energy are:

1. Difficulty in designing of heat exchanger, since the surface temperature of hot and cold surface of TE device would be unlike working fluid.
2. Fouling in heat exchanger may lead to reduction in conversion efficiency of TE module. If hot water is used as a heat source on hot side fluid it may lead to excessive increase of fouling resistance.
3. For doubling the power production capacity of the plant, high surface area for heat exchanger, thus, size of heat exchanger must also be doubled which subsequently leads to the increase in investment cost.

By using better and optimized heat exchange mechanism, some of these limitations can be avoided. Periodic water treatment and regular maintenance of heat exchanger can reduce fouling in heat exchanger. Also; surface temperature of conversion devices TE can be kept as close as possible to that of working fluid.

Automobile

In internal combustion engine of automobiles out of the total heat supplied to an I.C engine of an automobile, about 30% to 35% of the heat is rejected to the environment in the exhaust. The current two methods employed to increase fuel efficiency and powers of the engines are Turbo charging and supercharging. The further heat recovery of useful exhaust heat from the exhaust gas is difficult or infeasible but with the recent advancement in thermoelectric materials, thermoelectric power generation is now possible under reasonable costs. The basic preliminary model of automotive TEG uses exhaust gas of engine as heat source while coolant through radiator acts as heat sink. Performance of this TEG greatly depends upon:

1. the exhaust mass flow rate,
2. the exhaust temperature, and
3. the design of heat exchanger used along with control system and the type of thermoelectric material used.

Some of the problems that would be encountered during its operation would be:

1. Due to the presence of extra heat exchanger of TEG increases the weight of the vehicle.
2. The heat exchanger used should be of compact heat exchanger taking in account the space constrains. Thus, types of heat exchanger preferred are such as the cross counter flow and two stream heat exchanger.
3. Another possibility is the direct installment of TE modules to the exhaust which is very less in weight but suffers from reduced convective heat transfer coefficient.

VI. CONCLUSION

TEG technology has broad application prospects, but due to the relatively low thermal conversion efficiency, without large-scale practical applications it is still only at the stage of theoretical experimental demonstration and research. The conversion efficiency of TEG can be improved from the following two aspects: increasing the thermoelectric material optimal value of ZT, and increasing the temperature difference between the hot and the cold sides of thermoelectric module (TEM). On the one hand, an inherent property of thermoelectric material is depended on the optimal value of ZT, thus, improving the structure of thermoelectric material itself as much as possible can raise ZT value. But ZT values of large-scale commercial thermoelectric materials are generally less, for example, the value of Bi2Te3 is only about 1. On the other hand, if it is feasible, efforts can be made in the direction of optimization of TEG heat exchanger structure such as, making the contact surface as flat as possible to reduce the thermal contact resistance, improving the thermal environment to reduce heat loss, reducing the impact of intermediate links, etc. Moreover, increasing the temperature difference across TEMs can also improve the conversion efficiency of TEG.

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