Design And Experimental Investigation of Heat Recovery System for I.C. Engine using TEG

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Abstract- *This paper explains design and analysis of Heat Recovery System for I.C. Engine using Thermo electric generators. The motivation behind doing this work is that the internal combustion engines are the major consumer of fossil fuel around the globe. Recent trend about the best ways of using the deployable sources of energy in to useful work in order to reduce the rate of consumption of fossil fuel as well as pollution. Out of the total heat supplied to the engine in the form of fuel, approximately, 30 to 40% is converted into useful mechanical work. The remaining heat is expelled to the environment through exhaust gases and engine cooling systems, resulting in to entropy rise and serious environmental pollution, so it is required to utilized waste heat into useful work. The recovery and utilization of waste heat not only conserves fuel, usually fossil fuel but also reduces the amount of waste heat and greenhouse gases damped to environment. The paper include design of every component used to form thermoelectric generation system. After design of system we have carried experimentation of system to find out the effect of various system parameters such as load, temperature difference etc. In result and discussion section effect of these parameters on estimated parameters such as Amount of voltage generated, Amount of fuel saved, Reduction in pollutants are discussed with the help of graph.*

Keywords- Waste heat recovery, thermoelectric generators, IC engines.

I. INTRODUCTION

The IC engines are prime source of mechanical energy in number of applications like automobiles, machines, ships etc. Even though IC engines are use in number of applications on tremendous scale, the efficiency and emissions of IC engines are arising as a concern to different researchers in the world. The efficiency of IC engine is very low as large part of supplied energy is lost into the mechanical thermal losses. IC engine uses chemical energy of fuel and converts it into heat and pressure by combustion due to which large amount of heat is produced inside combustion chamber, most of this heat is lost to the engine body which then requires cooling arrangement and other heat leaves through exhaust gases. Only a small portion of the chemical energy can be converted as output for useful work. This loss of energy cannot be avoided completely but it can be reduced by improving design of IC engines which provides preventive action to the heat loss. Even though this method has its own limitations. Hence there is another corrective action present for the heat loss known as Waste heat recovery. Waste heat recovery uses heat from the exhaust gases of IC engines which can be used for any useful applications like battery recharging, cooling, heating air, electricity source etc. But applying waste heat recovery systems in automobiles is not easy task due to weight, space and other design considerations. Recovering waste heat from exhaust gases is very crucial task which requires thorough study and feasible setup. There are number of ways to recover heat from exhaust gases of IC engines. But thermoelectric generation is a very reliable method for recovering waste heat from automobile exhaust. Recovering heat using thermoelectric generators provides good fuel efficiency as it is observed that more than one third of energy can be converted into useful work. Waste heat recovery leads to energy conservation and It is also best solution for reducing emissions and increasing fuel efficiency of the engine.

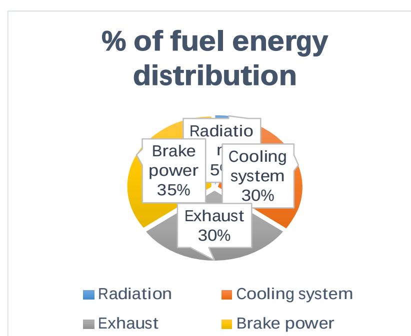

Figure 1. Percentage of fuel energy distribution in an I C engine

II. WORKING PRINCIPLE OF THERMOELECTRIC GENERATOR

1. Seebeck Effect

The Seebeck Effect is the conversion of temperature differences directly into electricity. It is a classic example of an electromotive force (emf) and leads to measurable currents or voltages in the same way as any other emf. Electromotive forces modify Ohm's law by generating currents even in the absence of voltage differences (or vice versa); the local current density is given by,

$$\mathbf{J = \sigma\,(-\Delta V + E_{emf})}$$

Where, V the local voltage and σ is is the local conductivity. In general the Seebeck effect is described locally by the creation of an electromotive field.

$$\mathbf{E_{emf} = -S\,\Delta T}$$

Where S is the Seebeck coefficient (also known as thermo-power), a property of the local material, and ΔT is the gradient in temperature T.

2. Thermoelectric Principle of Operation

Thermoelectricity means the direct conversion of heat into electric energy, or vice versa. According to Joule's law, a conductor carrying a current generates heat at a rate proportional to the product of the resistance (R) of the conductor and the square of the current (I). A circuit of this type is called a thermocouple; a number of thermocouples connected in series are called a thermopile.

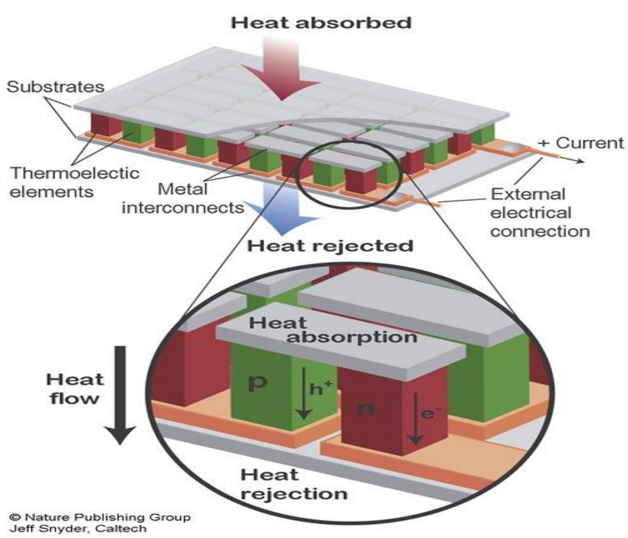

Figure 2. Thermoelectric Principle of Operation

III. DESIGN OF HEAT RECOVERY SYSTEM FOR THERMOELECTRIC GENERATION

The exhaust pipe contains a blocks with thermo electric materials that generates a direct current, thus providing some of the electric power requirements. Thermo Electric Generator is used to convert thermal energy from different temperature gradients existing between hot and cold ends of a semiconductor into electric energy.

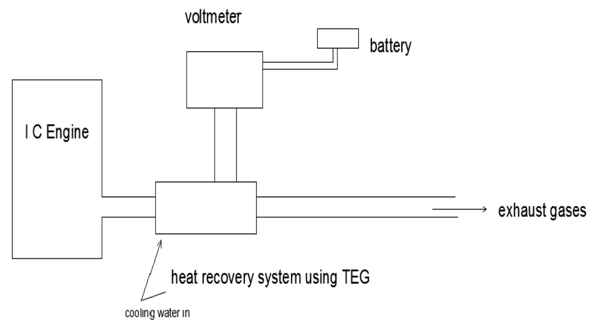

Figure 3. Thermoelectric generator and its components

The exhaust pipe is designed so that TEG modules can be easily mounted on it, eight such modules are mounted on the surface of the exhaust pipe. On upper surface of TEG modules a water jacket is made so that one surface of TEG modules gets easily cooled. Therefore one surface of TEG is heated because of temperature from exhaust gases and other surface is cooled by circulating water from water jacket. When required temperature difference is reached these modules start generating electricity. The TEG modules are arranged such that we can connect them in series to check their performance.

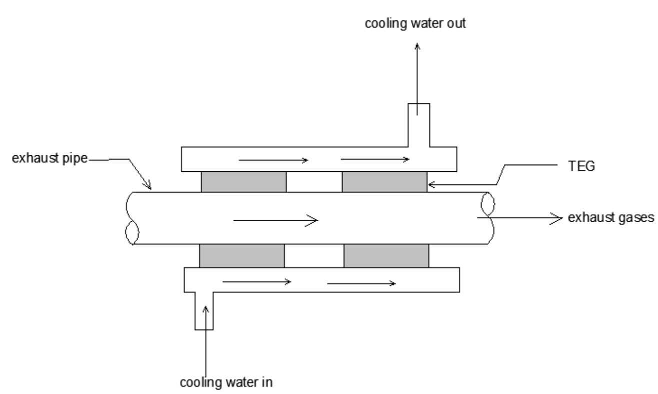

Figure 4. Designed exhaust pipe with TEG and cooling water jacket

Figure 5. working of heat recovery system using TEG in I C engine

IV. EXPERIMENTAL SETUP

Table1 Specification of present experimental setup are given in the following table

Table 1.

Specification of diesel engine	
No. of cylinders	1
No. of strokes	4
Rated speed	1500
Fuel	H.S. diesel
Rated power	5.2 kw
Cylinder diameter	87.5mm

The experimental setup is shown in fig.

Figure 6. Photographic image of single cylinder diesel engine

V. RESULTS AND DISCUSSION

1. Effect of variation of load on voltage developed by two TEG in series

To find the effect of increase in load on voltage developed by two TEG in series we have carried out trial on single cylinder diesel engine. While carrying test Two TEG are connected in series and mounted on exhaust pipe, load is varied from 0 kg to 8 kg, and for each load condition voltage generated by TEG and temperature difference of cooling water (used for removing heat from exhaust gas) is noted down.

We have plotted graphs of variation of Voltage developed by TEG with load and temperature difference variation.

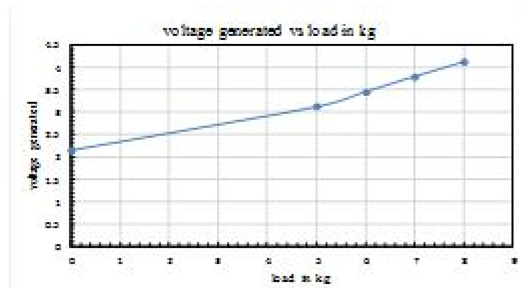

Figure 7. Effect of variation of load on voltage developed by 2 TEG in series

The graphs drawn are shown as follows.

Inferences derived from graph

As we increase the load on engine the voltage developed by TEG is increasing this is because as we increase load on engine we have to increase the fuel supply to maintain speed due increase in fuel supply the temperature of combustion chamber increases and so the temperature of exhaust and due to increase exhaust temperature the voltage developed in TEG is also increases.

The maximum voltage for two TEG in series is found to be 4.13 V at 8 kg load.

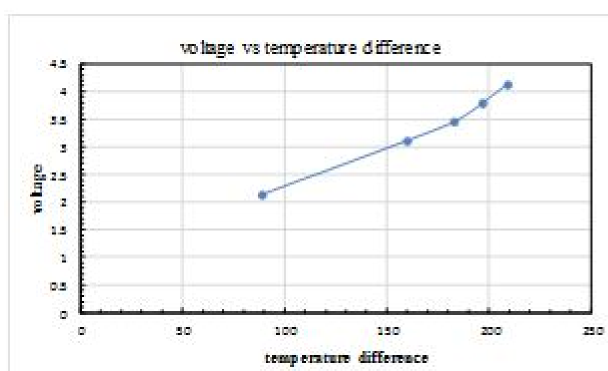

Figure 8. Effect of variation of temperature difference on voltage developed by 2 TEG in series

Inferences derived from graph

As the temperature difference between inlet and outlet of cooling water increases the voltage developed by TEG is increasing.

The maximum voltage for two TEG in series is found to be 4.13 V at 209 ^{0}C temperature difference.

2. Effect of variation of load on voltage developed by four TEG in series

To find the effect of increase in load on voltage developed by four TEG in series we have carried out trial on single cylinder diesel engine. While carrying test four TEG are connected in series and mounted on exhaust pipe, load is varied from 0 kg to 8 kg, and for each load condition voltage generated by TEG and temperature difference of cooling water (used for removing heat from exhaust gas) is noted down.

We have plotted graphs of variation of Voltage developed by TEG with load and temperature difference variation. The graphs drawn are shown as follows.

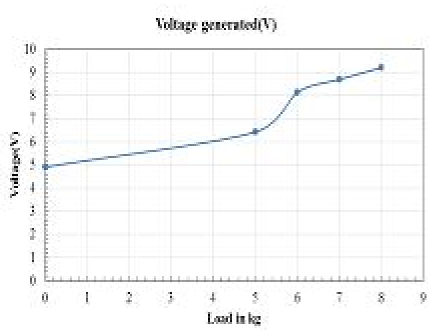

Figure 9. Effect of variation of load on voltage developed by four TEG

Inferences derived from graph

As we increase the load on engine the voltage developed by TEG is increasing .this is because as we increase load on engine we have to increase the fuel supply to maintain speed due increase in fuel supply the temperature of combustion chamber increases and so the temperature of exhaust and due to increase exhaust temperature the voltage developed in TEG is also increases.

The maximum voltage for four TEG in series is found to be 9.2 V at 8 kg load.

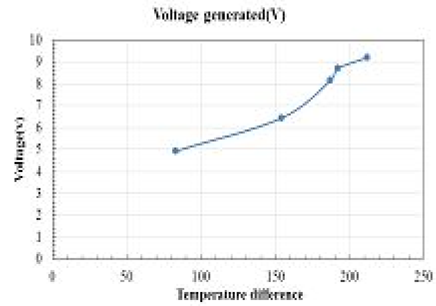

Figure 10. Effect of variation of temperature difference on voltage developed by 4 TEG in series

Inferences derived from graph

As the temperature difference between inlet and outlet of cooling water increases the voltage developed by TEG is increasing.
The maximum voltage for four TEG in series is found to be 9.2 V at 192 ^{0}C.

3. Effect of variation of load on voltage developed by six TEG in series

To find the effect of increase in load on voltage developed by six TEG in series we have carried out trial on single cylinder diesel engine. While carrying test six TEG are connected in series and mounted on exhaust pipe, load is varied from 0 kg to 8 kg, and for each load condition voltage generated by TEG and temperature difference of cooling water (used for removing heat from exhaust gas) is noted down.

We have plotted graphs of variation of Voltage developed by TEG with load and temperature difference variation. The graphs drawn are shown as follows.

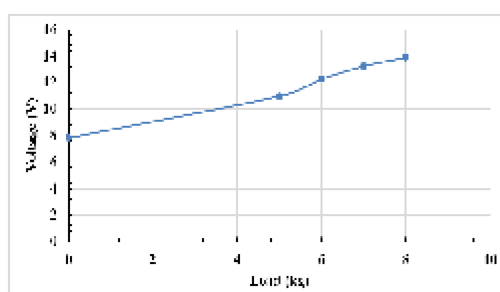

Figure 11. Effect of variation of load on voltage developed by 6 TEG in series

Inferences derived from graph

As we increase the load on engine the voltage developed by TEG is increasing .this is because as we increase load on engine we have to increase the fuel supply to maintain speed due increase in fuel supply the temperature of combustion chamber increases and so the temperature of exhaust and due to increase exhaust temperature the voltage developed in TEG is also increases.

The maximum voltage for six TEG in series is found to be 13.89 V at 8 kg load

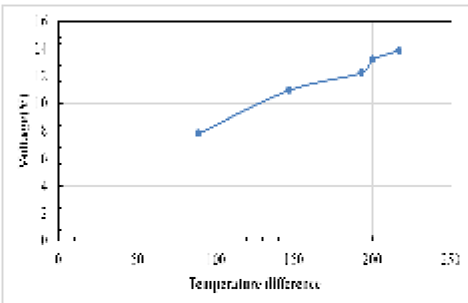

Figure 12. Effect of variation of temperature difference on voltage developed by 6 TEG in series

Inferences derived from graph

As the temperature difference between inlet and outlet of cooling water increases the voltage developed by TEG is increasing.

The maximum voltage for six TEG in series is found to be 13.89 V at 217^{0}C temperature difference.

VI. CONCLUSION

1. Waste heat from internal combustion engine is captured and reused for generating electrical work
2. As the temperature difference increases voltage generated also increases.
3. As we connect thermoelectric modules in series then amount of voltage generation increases.
4. The maximum voltage for two TEG in series is found to be 4.13 V at 209 ^{0}C temperature difference and at 8 kg load.
5. The maximum voltage for four TEG in series is found to be 9.2 V at 192 ^{0}C temperature difference.
6. The maximum voltage for six TEG in series is found to be 13.89 V at 8 kg load. At this load temperature difference was 217^{0}C.
7. Thermoelectric generators are solid state, passive, silent, scalable and durable.

VII. ACKNOWLEDGMENT

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