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Waste Heat Recovery Systems Utilizing Thermoelectric Generators and Heat Pipes

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***Abstract*: The persistent rising request for energy and the shortage of our conventional energy sources have succeed an urge towards searching new alternative renewable energy source. As the natural world, contamination and exhalation from automobile vehicle goes together, waste heat recuperation from automobile bodies should be the given last attention. A single path to do this is to boost the thermal efficiency of automobile engines. The efficiency of a conventional I.C Engine supplied fuel into heat is just about 37% whereas 50% in low speed Diesel engine, while the remaining heat is ejected to atmosphere through the engine cooling system. In addition, during this stage some uncountable losses has been occur. The electrical power worn in automobile is produced by assist of mechanical energy. The present paper illustrates the efficient ways to harvesting heat recovery system. Two technologies developed to work on exhaust heat recovery were Thermoelectric generators (TEG's) and Heat pipe. Its execution in automobile sector is carried out in various levels. TEG converts waste of heat directly into the electrical output. The implementation of this technology indirectly improves overall efficiency of system. Use of heat pipe minimizes thermal resistance and pressure losses in system along with maintaining the temperature of TEG.**

***Keywords*: Thermoelectric Generators (TEG), Heat pipe, Power generation, Environmental pollution, Waste heat recovery.**

1. Introduction

The vacillate internal combustion engine, worn in many of automobile, not able to transfigure all the fuel in the form of energy into mechanical work. Over a European standard cycle over a 38% of energy used is conveyed as heat to the exhaust gas [1] and this heat directly expelled to the atmosphere. Therefore, Waste Heat Recovery is a new concept to the common person. This system can withdraw some of this heat and use the same extracted heat to form electricity. This newly formed energy will be utilizing to charge the car battery that definitely lowers the load on alternator and prospectively reduce use of fuel. The heat emitted from exhaust equipment is hydrocarbon fuel and hydrocarbon fuel is equally proportional to the CO2 so the emission of CO_2 could potentially have lowered.

Some of the authoritative ways are being mention and that are thermoelectric generators (TEG) and Heat Pipe as seen in figure 1 and 2 respectively. TEG is just a metal chip without any moving parts and whenever there is temperature difference observed over a two sides of TEG, then voltage is created and which results in power generation. Heat pipes are acquiescent heat transfer gadget, which have thermal conductivity value much higher than copper.

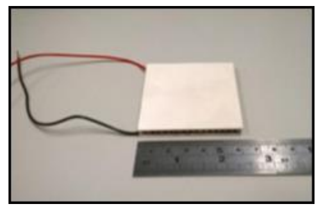


Fig. 1. Thermoelectric Generator (TEG)

Fig. 2. Cylindrical copper/water heat pipe

The leading automobile company's like BMW, Renault, TATA and Mercedes [4] has already showed their interest in recovering waste heat and planting a system, which use TEGs. The real time application has not used Heat pipe by the cars but engine coolant used as a cooling system by placing TEG on exhaust pipe. However, there are applications of both use of heat pipe and TEG in concurrent. Also the case of engine cooling heat recovery.

2. System Design

Fig. 3 is a schematic offered design of Waste Heat Recovery [5]. The main concept behind the setup is that as exhaust gases travelling the exhaust duct, some of his heat extracted by the fins placed on the walls of the duct. Then heat pipe transfers this heat to the one side of the TEG and this side is called hot side of TEG. Then according to the Seebeck effect, this small amount of heat is converted into electricity. Heat expelled by TEG is then passed through Heat pipes on the cold side of TEG to the fitted fins on the inner surface of cool air duct [3]. The ambient air, which is flowing inside the cooling duct, pull this air out to the atmosphere. A fan is placed at this position to control the airflow from a moving car. This setup used 8 TEGs placed in series combination

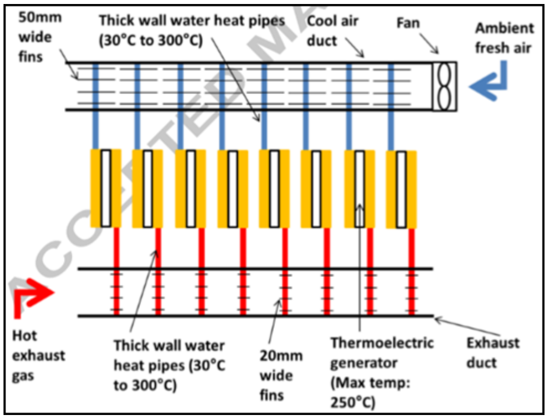


Fig. 3. Proposed car experimental setup

A. *Elements of Thermoelectric Generators*

Thermoelectric generators consist of three aspects Thermoelectric Module, Support structure and sink.

B. *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 Antimonies, Thermoelectric oxide material NaxCo2O4, Thin Films Materials etc.

C. *Support structure*

It is a crucial part of TEG where the thermoelectric modules are mounted. The internal part of structure is well designed that it can absorb all the accumulated heat in the exhaust gases.

D. *Sink*

It is nothing but heat appellation system that favors heat transmission through thermoelectric module.

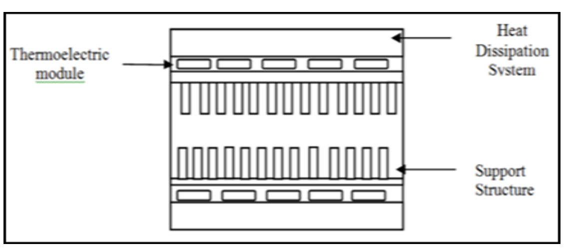


Fig. 4. Schematics of generic thermoelectric generator

3. Literature Review

Thermoelectric generators works on Seebeck effect [5]. The Seebeck effect is conversion into the electricity. This name has given from Baltic German physicist Thomas Johann Seebeck. Seebeck, in 1821. He discovered that, compass needle is deflecting when takes close to loop formed by two different metals joined in two places. This is because the electron energy levels in each metal transformed differently and this result in formation of electrical current and voltage difference between the two junctions. However, initially Seebeck was not able to recognize there was an electric current involved, so he named the phenomenon as thermomagnetic effect. Danish physicist Hans Christian Ørsted does rectification on this and then invented the term "thermoelectricity".

The Seebeck coefficients is proportional to the function of temperature, and based on the composition of the conductor. For ordinary materials at room temperature, the Seebeck coefficient may range in value from −100 μV/K to +1,000 μV/K (see Seebeck coefficient article for more information).

If the system reaches a steady state where $\mathbf{J} = 0$, then the voltage gradient is given simply by the emf: $-\nabla V = S\nabla T$. This connectivity, which does not depend on conductivity, is used in the thermocouple in order to measure a temperature difference; an absolute temperature may be examine by measuring the voltage at standard reference temperature. A metal of unknown composition can be able to classify by its thermoelectric effect but if we place metallic probe of known composition at a constant temperature that is locally heated to the probe temperature and the intention behind this is to identify the metal alloys.

The peltier effect is nothing but the heating or cooling at junction where electricity formation occur and is named after French physicist Jean Charles Athanase Peltier, who discovered it in 1834. But when current is allow to flow through the junction between the two conductors A and B there is a possibility of heat formation or removal The Peltier heat generated at the junction per unit time, $\dot{Q}$, is equal to

$$\dot{Q} = (\Pi_A - \Pi_B) I$$

Π_A (Π_B) is the Peltier coefficient of conductor A and B whereas, I is the electric current (from A to B). The peltier is not capable to determine total heat generation as Joule heating may also influence it and thermal gradient effect also.

The peltier coefficient [5] is the mathematical expression that shows how much heat is conveyed per unit charge. Although charge current should be forming continuously across the junction, the associated heat flow will develop a discontinuity if Π_A and Π_B are different. The simple difference in Seebeck and peltier is, when simple thermoelectric circuit is closed then current is formed in Seebeck whereas in Peltier, heat transfer takes place from hot to cold junction. The close relationship between Peltier and Seebeck effects can be seen in the direct connection between their coefficients: $\Pi = TS$ (see below).

A typical Peltier heat pump device involves multiple junctions in series, through which a current is driven. Some of the junctions lose heat due to the Peltier effect, while others gain heat. The same phenomenon utilized by heat pumps,

4. Experimental Setup

As can clearly be seen from fig.5, thermoelectric generator setup is used as a supply to exhaust gas [2]. The engine in the car was 3.0L fuel injected V6. Test setup is connected to exhaust system by a flexible metal pipe. And extractor was attached to the outlet of exhaust duct to expel out exhaust gases outside the experiment lab. A black plastic hose connected from the fan outlet to the cool air duct inlet on the system. A large cooling fan also placed in front side of the car to avoid overheating.

Fig. 5. Lab setup of heat recovery system

The Exhaust Waste Heat Recovery system is most important aspect today. Because of this reason, it has recent hotspot today. Now if we see Doyle and Patel's design which is based on Rankine Cycle on a truck engine. And by using same setup for 450kilometers result showed that devise was able to fuel consumption by 12.4%. James C. Conklin and James P. Szybist have proposed a design of a six-stroke internal combustion engine cycle with water injection for in-cylinder exhaust heat recovery and this has potential to ameliorate engine efficiency and fuel economy.

Table 1 shows that various engines and their power ranges. So according to the given data, diesel 35% efficiency so the remaining heat is directly dissipated. Whereas, in water cooled engine about 30-40% of input energy is wasted in coolant and exhaust gases respectively. Therefore, according to given data almost 75% of input heat directly wasted. We can use it as a heat by using it as additional source of power we will able to increase efficiency of engine.

Table 1
Types of engines and their applications

S. No.	Engine Type	Power Output (KW)	Waste Heat
1.	Small air cooled diesel engine	35	30-40% Of Energy wastage in I.C engine
2.	Small agricultural tractors and Construction equipment	150	
3.	Water air cooled engine	35-150	

5. Experimental Testing

The main intention behind testing the system is to examine its peak power output. The number of required changes has been made to get appropriate results. These results can be seen in table no.2. For the very first test engine was run at 2600 RPM under no load. In this case, the exhaust duct temperature was 220 °C and the mass flow rate was 0.0159 kg/s. The cool air duct temperature was 31 °C and mass flow rate was 0.023 kg/s. This test was conducted in a horizontal orientation. When tested under these conditions, the system produced 16.23 W.

To get better results first change has made by increasing the exhaust gas temperature and gas flow rate. The engine produced 10 kW of mechanical power during 3ed gear, which results in increase in power output to 20.01 W. Although, increase in exhaust gas temperature, TEGs well still not operating at its peak temperature range of 250^{0C} it was decided again to rise exhaust gas temperature and flow rate. During this stage power, output observed was 28.70 W at 4000RPM and TEGs temperature was just below its maximum temperature range.

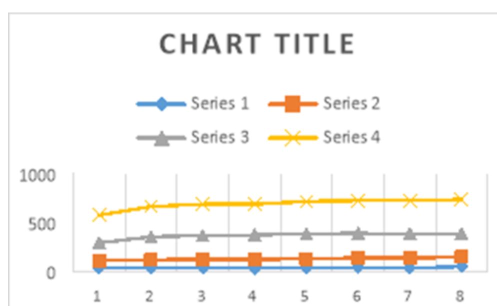
Table 2
Applicable changes, made to improve power output

Power produced (W)	Rate of Heat Transfer (W)	TEGs Efficiency	Cumulative Changes Made
16.23	890	1.50%	None
20.01	960	2.10%	Increased mass flow rate to 0.01 kg/s and temperature to 2200C
28.70	1155	2.46%	Again mass flow rate increased to 0.023kg/s and temperature to 3250C
37	1541	2.46%	Increased cool air duct mass flow rate to 0.0420 kg/s.

During 4000RPM cool air temperature observed 860C at the outlet which result as lower positioned TEGs being cooled by hot air but this is not acceptable because it lowers the temperature difference in down side TEGs.

To overcome this issue cooling duct temperature lowered by placing more powerful fan in front of the car then outlet temperature reduced to 52^0 C. During this stages maximum output was recorded 37 W.

The profile of Duct and TEGs temperature at maximum power can be seen in graph no.1. Ideally, the exhaust temperature and TEG hot side temperature should be as close to each other as possible. Same case is for cool air temperature and TEG cold side temperature. This can only be achieved by reducing the heat exchanger thermal resistance. Unfortunately, this system has limitation so practically it is impossible.



Graph No. 1: Experimental duct and TEG surface temperatures for the maximum power case

Where,
Series 1: Cool Air Temperature
Series 2: Exhaust Temperature
Series 3: TEG Hot Side Temperature
Series 4: TEG Cold Side Temperature
Retesting of the procedure is not possible as it is impossible

to maintain constant RPM rate under no load. As it simplifies the procedure by allowing the tester to put accelerator pedal on ground so that constant RPM of 4000 easily maintained. After that repeat test was performed in order to check repeatable results and it was 0bserved that results are repeatable and constant through the test.

6. Conclusion

Actual intension behind implanting was to reduce CO2 emission, fuel consumption and load on alternator. It has been observed that large unit of fuel saved due to the Waste Heat reuse system. This concoct design is completely solid state. And the biggest advantage of this design is the use of Heat Pipes. Because use of heat pipes makes design more flexible. The reason behind this, TEGs location is not limited to exhaust pipe surface. In all test that conducted during the experiment results in net power output increased. The maximum power generated was 37W and the rate of heat transfer was 1541w. So according to present scenario, if this technique were applied by automotive companies then it will result in efficient engine performance and low emission. This technology has been successfully demonstrated on a laboratory scale and in prototype commercial systems. Definitely, in future Thermoelectric Generator will be more practical way to reduce emission by using heat recovery system.

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