APPLICATION OF WASTE HEAT RECOVERY TECHNIQUE USING THERMOELECTRIC GENERATOR- A PORTABLE TWO WHEELER REFRIGERATION UNIT

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Abstract: Energy plays a very vital role in the sustenance and development of life or as such any possible thing. With the enormous development of the mankind need of the energy is also increasing day by day but the resources which were conventionally used for that are limited and the renewable technology is still in the developmental stage. So it is the need of the hour to utilize the best from the resources which we have and conserve the energy. One such step would be utilizing the waste heat from the engine exhaust. In the I. C. engines, which dominate most of the transportation sector, about $2/3^{rd}$ of total energy of fuel is wasted as exhaust heat. The high exhaust gas temperature also leads to the problem of emissions and global warming so utilizing the waste heat would be beneficial in various ways. The Thermoelectric generator could be effectively used to recover the waste heat from the exhaust. As the TEG is in the developmental stage its efficiency is not that high so the power output is limited. So an effort is made to utilize that small quantity by using a thermoelectric cooler TEC as a portable automobile cooler. This will serve two purposes – recovery of waste heat and making the rides more comfortable with a portable cooler which runs independent of the engine load.

Key Words: Waste Heat Recovery, TEG, TEC

1. Introduction:

Energy is the basic requirement for sustaining life. Let there be no energy there would be no life. The need of our energy requirement is mostly fulfilled by the conventional sources of energy, due to low efficiency, uncertainty and high cost of the renewable sources of energy. But the problem with the conventional sources is that they are on the verge of extinction and are cause of harmful pollution. Both problems are very crucial at this hour. The transportation sector using conventional I.C. engines is making the problem worse because only $2/3^{rd}$ of energy of the fuel is converted into useful power rest of it is flushed out as waste heat in the form of exhaust gases. Further the high temperature exhaust leads to global warming and air pollution because of the emission content. Thus if we can trap the waste heat from the exhaust it can be a large step for the energy conservation and environment preservation.

This objective could be fulfilled at some level using a device named thermoelectric generator (TEG). This is a semiconductor device working on the Seebeck effect, which states that whenever a temperature difference is applied between two dissimilar conductors, an emf is induced between them. The magnitude of the emf induced depends on the material used, temperature difference between hot and cold side and effective heat exchanger design. With this a TEG becomes an ideal means for extracting waste heat from the hot exhaust gases, the hot gases could provide the high temperature on one side while atmospheric air or water could be used to provide cold side temperature. This temperature difference on hot and cold sides is converted into electrical power output which could be further used.

Now if the TEG is run in reverse fashion it could be used as a heater or cooler and is then known as thermoelectric cooler (TEC). **figure 1** shows the basic TEG and TEC thermocouple.

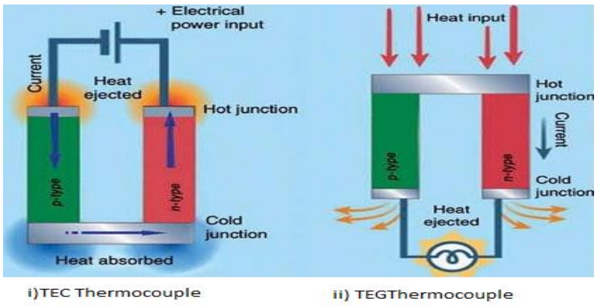

figure 1 basic principle of thermoelectric modules

A TEC works on the principle of Peltier effect, which states that whenever a voltage applied across two dissimilar conductors heat flows across them, the direction of which depends on the direction of current. Thus if a power input is provided to a TEC it could serve as heater on hot side and as a cooler on cold side. TEC is also a very useful and innovative device. It could be conveniently used to provide cooling effect without need of circulating any kind of refrigerant. It is less bulky and noise free than the conventional refrigeration system.

Thus seeing the advantages of these thermoelectric devices over conventional devices, an effort has been made in using both these devices together. A TEG module is used first for extracting the waste heat from the exhaust of the vehicle. Then the power output from the TEG is used to run a TEC module which could be used as a portable automobile cooler. Thus waste heat from the engine exhaust could be effectively utilized and the cooling system can be run independently from the engine load.

2. Literature Review:

2.1 Waste Heat Recovery Technology: The ever increasing fossil fuel price, growing demand and there by the competition among the automobile sector has led the manufacturers to utilize the power available to a maximum possible extent. A potential solution for this problem lies in utilizing the technologies to recover waste heat from the I. C. engines. **R. Saidur et al. [10]** in their work came up with technologies, which could be utilized to harness the waste heat from the engine exhaust, like thermoelectric generators, organic Rankine cycle, six stroke cycle I. C. engine , turbochargers. They discussed the potentials of energy saving through these techniques. By harnessing the waste heat there could be a considerable improvement in the exergy efficiency of the system along with the reduction in the emissions reducing the net green house effect. Amongst all these technologies, thermoelectric generators can be considered as the best possible option due to their simplicity, compact and easy design, no working fluid involved. It was also recognized that thermoelectric generator technology could be effectively incorporated with the other technologies such as PV, turbocharger or even the Rankine bottoming cycle to maximize the exergy efficiency.

As seen from above literature, thermoelectric generators are a potential source for waste heat recovery. **Daniel Champeir [4]** in his paper studied the further advances in thermoelectric materials and its scope and applications. Even with a several advantages the TEG has limited acceptance due to problems like low efficiency and high cost. Efficiency of the module depends upon a material property known as figure of merit(ZT). The thermoelectric material which is currently used has a ZT of about 1. However, the recently developed materials like Half Heusler, Skutteudites, phonon based materials are claimed to be having a ZT up to 4. Alongside the advanced materials, efficiency could also be increased by using proper heat exchanger designs to amplify heat transfer between the module and the heat sources and electrical converters to transform electrical power to a suitable voltage to level corresponding to the end users needs. With these advancements TEG has found its application in various sectors. It could be effectively used for electricity generation in extreme environments such as space exploration. Waste heat recovery in automobile sector is also possible with the TEG technology. It could also be used in combination with the PV cells i.e. solar TEG and again for micro-generation for sensors, microelectronics, etc.

2.2 Advancements in Thermoelectric Modules: In order to harness the maximum output from a TEG module, various researches have been carried out in order to improve the material quality and heat extraction with a suitable design of the heat exchangers. Among those is the review by **Dipak Patil et al.[2]**, in which they showed that the power output of TEG depends upon the type of TEG material used, temperature difference between heat source and heat sink and heat exchangers design. Heavily dopped semiconductors with a high Seebeck coefficient, low thermal conductivity and a high electrical conductivity are supposed to increase the overall conversion efficiency of a TEG. The heat exchangers with different internal structures are claimed to enhance the rate of heat transfer and thermal uniformity, which cause the power generation by the TEG to increase. Most of the researchers recommend a plate type heat exchanger. Also with different inserts and fins their thermal uniformity and the heat transfer rate could be further increased. When exhaust gas flows through the heat exchangers, along with heat transfer some pressure drop is bound to occur. Hence it is of great necessity to test pressure drop for different structures with wide range of operating conditions. An ideal heat exchanger design can recover maximum amount of heat from the exhaust with minimum amount of pressure drop and a high thermal uniformity.

Based on the same grounds, **Murat Demir et al.[6]** in their research paper proposed a novel system that recovers waste heat from the exhaust of a passenger car. A heat exchanger was placed after the exhaust manifold of the vehicle. TEGs were installed on pipes of the heat exchanger to generate electricity by temperature difference between hot and cold sides of the TEG. The heat transfer of the TEG was numerically analyzed. Two different configurations of TEG units were investigated for various exhaust flow rates and temperatures. The overall heat transfer rates of the exhaust gas to the TEG, the power capacity of the system and the overall heat transfer coefficients of the system were calculated. It was observed that the power capacity of the system was directly related to the inlet temperature and mass flow rate of the exhaust gas entering the system. The power generated by the system could be improved by 90% with an increase of the mass flow rate and temperature of the exhaust gases. Also increasing the size of the TEG system by 66.7 % raises the overall heat transfer rate of the system by 33.8%. It has been seen that, despite of low efficiencies, TEGs are still useful for recovering heat in various applications. The exhaust gasses of vehicles are a unavoidable loss. Due to the lack of space in vehicles, using exhaust heat of the vehicle in another cycle becomes tedious. With such scenario TEGs become a more suitable choice.

Andrew Royale et al. [5] in their paper conducted investigation, measurements and simulations on the engine heat sink thermal energy recovery system. They had a new TEG unit subsystem mounted to the heat sink. The experimentation showed that a strategically positioned TEG unit could extract the direct heat transfer from the combustion chamber of the engine and the convert it to electrical power. The results also indicated that it might be possible to extract and recover energy from the high temperature source ranging from 500 –800^{0}C in conventional motor vehicle engines and converting it to electrical power for hybrid vehicle systems. They also proposed to build a new cylindrical TEG unit system that matched with engine geometry which was supported by the design and simulation presented in the paper. Their work focused on a prototype design for a small scale model, but it is expected that new development would expand to full scale combustion engines.

P. Mohamed Shameer et al. [7], in their paper used TEGs to extract power from a two wheeler petrol engine with a goal to implement a thermoelectric waste heat energy recovery system for internal combustion engine automobiles, including gasoline vehicles and hybrid electric vehicles. They showed that TEG is the key to directly convert the surface heat energy from automotive waste heat to electrical energy. This energy could be then regulated by a DC–DC Cuk converter to charge a battery using maximum power point tracking. Thus, the electrical power stored in the battery can be maximized in this way. The experimental results demonstrated that the proposed system can work well under different working conditions, and is promising technology for the automotive industry.

2.3 Thermoelectric Cooling: Same as TEG, a lot of research has also been done on the TEC. **D. Zhao et al. [9]**, in their paper reviewed the development of thermoelectric cooling in the recent decade from aspects of advances in materials, modeling approaches, and applications. Thermoelectric cooling systems have several advantages over conventional cooling devices, including compactness in size, light in weight, high reliability, no mechanical moving parts, no working fluid used, being powered by direct current, and easy switching between cooling and heating modes. To improve thermoelectric cooling system’s performance, the modeling techniques have been described for both the thermo-element modeling and TEC modeling including standard simplified energy equilibrium model, one-dimensional and three-dimensional models, and numerical compact model. Also the thermoelectric cooling applications such as domestic refrigeration, electronic cooling, scientific application, and automobile air conditioning and seat temperature control are mentioned with summaries for the commercially available thermoelectric modules and thermoelectric refrigerators.

Further, **Wei He et al. [8]** in their paper discussed the existing work on thermoelectric potential theory, material, model, energy resources, construction and applications in electricity generation and cooling. In order to be comparative with the conventional devices, the ZT i.e. figure of merit of the TEG should be higher. It is urgent to find the high efficiency TE materials. Further, they emphasized on the importance of enhancing the TE devices by improving and optimizing the heat-exchanger structure, geometry design and the operating parameters, because those aspects significantly affect the efficiency of the whole system. The application areas for TEG and TEC are both in niche fields. A traditional area for TEG is space, especially where solar energy is insufficient. The novel areas for thermoelectric technology in recent decades are automobile, the self-cooling of electric devices, building, etc. The development of new TE material with large ZT and cheap price could make a big breakthrough for all the application areas. The material research is still important in order to gain the high ZT and better properties.

2.4 Combined TEG – TEC systems: The studies have revealed that the thermoelectric devices are environmentally friendly for power generation and also cooling purposes, therefore **Khaled teffah et al.[3]** in their paper, investigated a combined TEC-TEG module via simulation and experiment. The module consisted of TEC, TEG and total copper heat sink attached thermally in series. The cooling behavior of TEC and TEG's electric power generation were examined. When direct electric current was passed through TEC, it transferred an amount of heat from the cold side to the hot side of the module. The electrical potential generation of TEG increased with increasing the voltage input of TEC. Moreover, results in their study showed the influence of the TEC's input voltage on the temperature difference between the hot and cold side of the TEG which is important to maximize the electric potential generated by the TEG. The temperature difference between TEG's sides was found to be directly proportional to the TEC's input voltages. Design and results of their work showed the significance of using thermoelectric generators as partial heat sink and remedy device for thermoelectric coolers, even without an additional external thermal load. Their study paved the way for new thermoelectric modules that can be directed to manufacturing for both cooling and electric power generation.

Based on the similar combination of using TEG and TEC system together, **Simon Chinguwa et al.[1]** came up with an idea of using a TEC as a portable refrigeration system for the automobile with the TEC being powered by a TEG. They designed TEG waste heat recovery system to meet all TEC refrigeration systems power requirement. The TEG module converts thermal energy of exhaust directly into electrical energy for TEC consumption as well as further storage. Thus this design enabled the percentage of waste heat that could have been rejected otherwise to be used in generation of DC power to meet the TEC electrical power requirements making the system independent altogether thereby reducing the number of loads on vehicle itself.

3. Conclusion:

It is seen that TE system has a potential to be used as waste heat recovery technology from the exhaust of the I.C. engine. A lot of research has been done on improving the conversion efficiency from the system by developing new materials with a high figure of merit and by doing improvement in the heat extraction by means of proper heat exchanger layout with different inserts to get maximum heat transfer and a good thermal uniformity.

Same as the TEG, TEC module is also having advantage over the conventional refrigeration system because of its features such as high reliability, no mechanical moving parts, compact in size and light in weight, and no working fluid i.e. no CFCs used. In addition, it possesses advantage that it can be powered by direct current (DC) electric sources such as TEG itself. So, in this paper it is proposed to utilize waste heat from a two wheeler engine to power a TEG which is further utilized to power a portable refrigeration unit based on TEC. By doing so two goals could be achieved, first is utilizing the heat from exhaust which was previously been lost and second is increasing the comfort of the user without any additional load on the system.

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