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An analysis of the efficiency of waste-derived heat recovery systems using thermoelectric mills and heat pipes

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Abstract: *Many individuals have been shocked by the inefficiency of the internal combustion engine. (ICE). An engine's exhaust pipe and cooling system must be used to disperse the majority of this energy. By focusing on immediate efficiency gains, engineers are no longer able to improve engines' performance. A potential technology for this purpose has been shown to be TEGs (thermoelectric mills) and heat pipes. Thermal energy generation and heat pipes may be used together. The machine's thermal conductivity may be reduced by the use of heat pipes. TEGs' temperature rule may be lowered in the same manner. TEGs aren't as successful as they may be because of their low performance and temperature limits. The technique has a few drawbacks, including as temperature limits and sudden temperature changes. This combination of methods may be used to recover all solid-state waste heat.*

INTRODUCTION

Pre-market testing is necessary to ensure that a new vehicle is in compliance with the most current emission regulations. People are having a harder time travelling across the globe unhindered. CO2 emissions and fuel use are strongly linked. Automobile makers must reduce their fuel consumption in order to meet the new regulations. According to the European Driving Cycle, ICE cars in Europe have been more fuel efficient during the previous four years (EDC). Coolant and exhaust gases will lose more than half of their heat potential. The alternator may be less stressed if heat produced by the alternator can be converted into power. TEGs and heat pipes may be used to reclaim heat that would otherwise be wasted. These gadgets make travelling more convenient due to their small size and solid-state construction. TEGs use the Seebeck effect to create power, as seen in Fig. 1. It is possible to create a TEG by thermally linking tiny N- and P-type semiconductor material components. Heating one side and then cooling the other generates voltage. For energy production, TEGs may be useful in regions that experience large temperature swings. This device can generate power under any condition. [2] When heated, the Carnot efficiency improves their performance. Approximately a 20% Carnot efficiency may be obtained when the temperature range is big enough to

produce heat (TEG). The thermoelectric figure of merit (ZT) may be used to compare different TEG efficiencies at the same temperature. As ZT rises, so does the TEG's efficiency. The availability of low-ZT gadgets is dwindling as the years go on. Allowing WHR systems to be extended indefinitely, TEGs are very small and quiet. Rust and wear are not a problem since there are no moving parts or chemical reactions to take place. Rankine cycle waste heat

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recovery systems [4] cost nothing more when compared to other solutions. The most extensively used thermoelectric material is Bismuth Telluride. Due to its low operating temperature, this material is unsuitable for generators. As a result of their widespread usage and vast production, thermoelectric materials are substantially less expensive than other materials.TEG power generation and efficiency have been greatly increased by using materials and technologies from a wide range of disciplines.

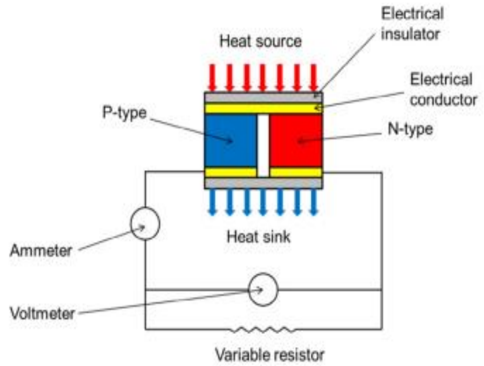


Fig. 1. Seebeck effect.

Exhaust heat recovery systems need the use of materials that can endure high temperatures. With a larger temperature difference, greater power and higher efficiency are possible. Because TEGs don't overheat, the design process may be streamlined. Since lead telluride and calcium manganese are capable of withstanding temperatures of exceeding 650 degrees Celsius, they have been used in TEGs Previously, segmented TEGs have been made. Lead telluride is utilised on the cold side, whereas temperature-dependent ZT is employed on the hot side (as is the case with other ZT materials) (i.e.: bismuth telluride). Copper has a lower heat conductivity. A heat pipe's principal purpose is to passively transfer heat. This system has no moving parts or fans. As an operational temperature medium, water is the most typical choice, although other fluids may be used. A condenser section is used to cool the system, an evaporator section is used to heat it, and an adiabatic section is used to transport heat. Because the pressure within the pipe is almost identical to that of a vacuum, when the temperature drops below freezing, the liquid turns into a gas. Inside, you'll only find saturated liquid and saturated vapour. Evaporation of a liquid into a gas in the evaporator part causes the gas to go to the condenser section. The cooler condenser section of the system removes heat by re-condensing the vapour back into liquid.

This may be done by employing heat pipes to increase the fins' efficiency in the gas stream, reducing thermal resistance. This means the TEG's surface will be closer to the gas's temperature as a consequence of this change. In certain cases, pressure loss reduction may be more important than other considerations. Pressure losses are decreased because less fin surface area is needed to maintain the same fin efficiency. Heat pipes may be used to adjust the temperature of TEGs.

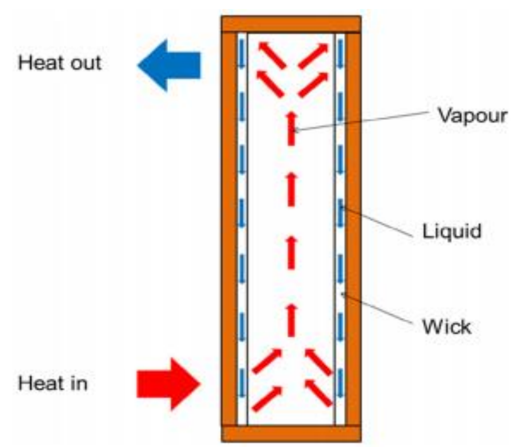


Fig. 2. How a heat pipe works.

Variable conductance heat pipes may be used to extend or shorten both the evaporator and the condenser depending on the system's needs. Thermal energy transfer (TEG) devices are confined to the exhaust pipe in the absence of heat pipes. In addition to the fact that heat pipes can only carry heat at a specific pace, there are numerous more limitations to using heat pipes. The needed number and size of heat pipes may not be able to be used because of the high heat transfer rate. Heat pipes' operational temperature range is also a limitation. Thick-walled heat pipes are required to increase the typical operating temperature range of water heat pipes from 100°C to 300°C [6]. It is necessary to change the working fluids if the temperature rises over this limit. With liquid metals like potassium and sodium, naphthalene's working temperature range surpasses 250°C to 450°C. Other working fluids are more costly, but water-based heat pipes are less expensive than heat pipes based on other working fluids.equipment for thermally powered automobiles

Exhaust heat recovery is something that both Ford and Renault are clearly interested in pursuing. It's almost impossible to tell the difference between two designs. To keep the exhaust pipes cold, TEGs are used to cover the engine coolant pipes (rectangular, hexagonal, or other form). [12] Figures 3 and 4 depict rectangular and hexagonal heat exchangers, respectively. This technology, which is merely a hypothesis at this point, does not exist in any contemporary autos. The heat exchangers in this system are shell-and-and-and-tube. One 20 W TEG may generate up to 750 W with this high-temperature TEG technology. The Ford system heat exchanger receives exhaust gases through a series of parallel thermoelectric tubes. Liquid cooling is used in this instance. There is 4.6 kg worth of thermoelectric material in this gadget, and it can generate 400 watts of electricity. A diesel truck's engine will produce less pollution if it is fitted with Renault technology. In all, it is 10 cm x 50 cm x 31 centimetres. Liquid is used to cool counter-flow heat exchangers. TEGs of different temperatures may be combined.

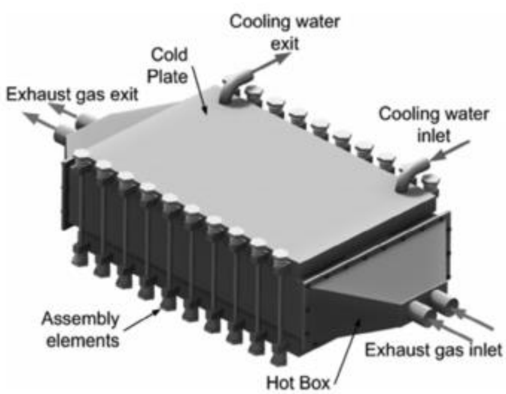


Fig. 3. Rectangular exhaust heat exchanger.

The TEG was employed at a low temperature. The computer simulation predicts that one kW of power will be produced. Using the Honda configuration, the top and bottom of a TEG-filled rectangular box were inserted. Liquid cooling was used in this design. TEGs, which were employed in the system to generate electricity, were 32 in length and 30 in diameter. There was a 3% drop in gasoline use, according to the data. Images of Honda's future concept car are seen in Figure 5. [13] For the examination of heat exchanger design alternatives,

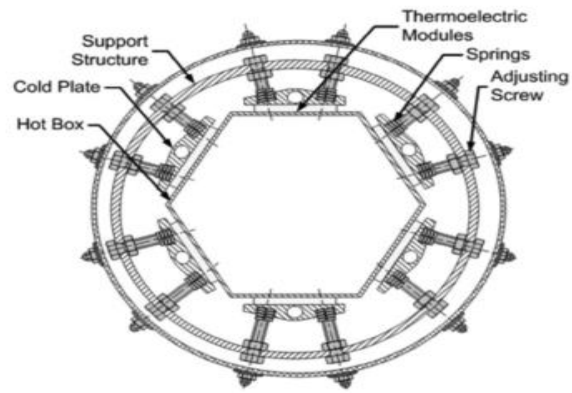


Fig. 4. Hexagonal exhaust heat exchanger.

Fig. 5. Honda prototype TEG exhaust heat recovery system.

Automotive waste heat recovery systems using TEGs and heat pipes

Radiators in cars have been replaced with waste heat recovery systems created by Kim et al and Baatar et al [1–15] in Korea and Mongolia, respectively. Figure 6 depicts this configuration. Repairing the radiator with no additional moving parts was the goal. This it was possible to transmit heat and create electricity without the need for any extra moving components. TEGs in the system were 40 millimetres by 40 millimetres, and there were 72 of them. More than 100 little heaters were used throughout the project. The hot and cold sides of the engine were about 90°C and 70°C, respectively, while the engine was idling. These settings yielded 28 watts of power. It was around a 90-degree travelling at an average speed of 80 kph. On this day, 75 W of power may be generated. TEGs and heat pipes were used to develop

Kim et al. [16]'s exhaust heat recovery system, shown in Fig. 7. A pipe with heat pipes extending from it serves as a conduit for exhaust gases. Some of the heat is absorbed by the aluminium block in which the heat pipes are encased, and the heat is then transferred to the aluminium block. The TEGs' hot side is attached to the aluminium block. Water-cooled heat sinks are positioned on the opposite side of the TEGs to dissipate the heat generated by the TEGs. At its peak output, the system used 112 40 mm x 40 mm TEGs. Heat pipe extraction from exhaust gases was utilised by researchers Goncalves, Brito and Martins [17–20], whilst Goncalves and colleagues [17–20] used water heat sinks for the same purpose. These measurements are made using a metric called thermal conductivity (VCHP).

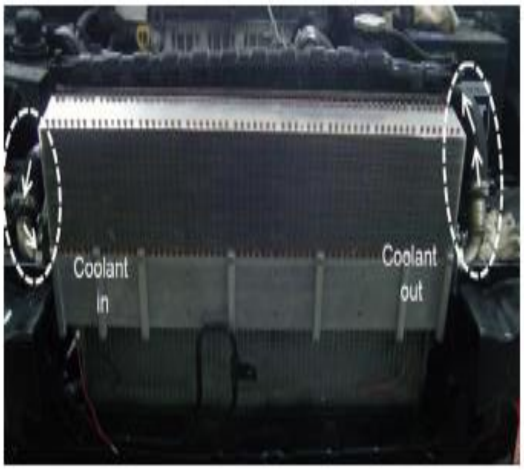
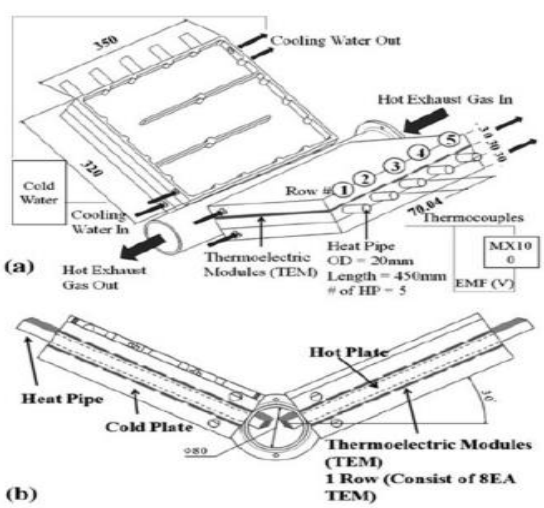


Fig. 6. Combined radiator and TEG waste heat recoverysystem.



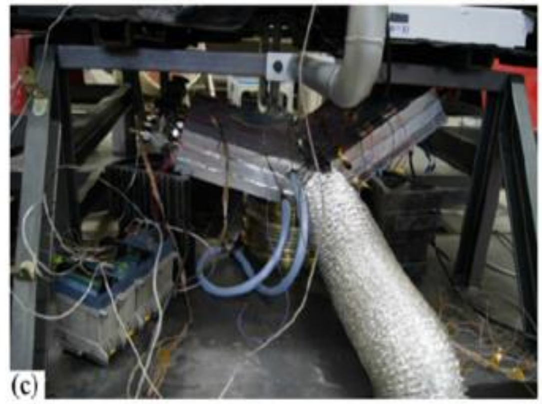


Figure 7 depicts a heat recovery system that makes use of both TEGs and heat pipes. Additional features include the ability to alter the operating temperature of ordinary heat pipes. There are gases in a VCHP that are not condensable. These gases are forced into the expansion tank by the heat pipe as the heat load increases. Parts that have been compressed have been made longer as a result of this. Since the length of the condenser increases, an increase in heat load has no effect on the temperature. TEG failure might occur if the temperature of the heat pipe is not maintained at a constant level. Figure 8 depicts a flowchart of the whole system. Figure 9 shows the exhaust heat recovery system built by Orr et al. Heat pipes on each side of the TEG carried heat to and from the device. Thermal resistance is projected to be low on both the hot and cold sides of the TEG with this configuration.

Thermal energy exchangers (TEGs) and heat pipes are shown in Figure 7. It is possible to heat a heat pipe to a different temperature using a standard heat pipe. In VCHPs, condensing gases is impossible. Because of this, when the heat load rises, these gases are pushed into an expansion tank. As a consequence, there are lengthier parts. Increasing the heat load has no impact on the temperature since the condenser has expanded in length. The heat pipe may fail due to thermal expansion and contraction (TEG). Overall, the system may be shown in Figure 8. Exhaust heat recovery system designed by Orr et al. is shown in Figure 9. There were two heat pipes on each side of the TEG that transported heat in and out. With this design, the TEG's hot and cold sides should experience negligible thermal resistance.

Fig. 9. An exhaust heat recovery system using heat pipes to transfer heat both to and from the TEGs.

When TEGs are heated, an exchanger made of Naphthalene prevents them from overheating.

Figure 9 depicts the system that Orr et al. [23,24] adjusted to handle greater exhaust temperatures. Figure 10 shows the most current iteration of the concept. An application of thick-wall copper water heat pipes was used in this instance to boost the heat pipe's temperature capacity Thermal paste and TEGs suited for greater temperatures were also employed. TEGs were used. For copper water heat pipes and TEGs, a naphthalene pre-heat exchanger was proposed. As long as the exhaust gas temperature is high enough, the naphthalene heat pipes are able to remove heat, even when the exhaust gas temperature is low. The temperature of the exhaust gas entering the car is adjusted by the naphthalene heat pipes. To generate 54 Watts of power using the system's architecture, 8 75 × 75 TEGs are required. Jang et al. [25] have developed an alternate exhaust heat recovery technique that incorporates the use of TEGs and heat pipes. Loop thermosiphons are used instead of standard heat pipes in this design. TEGs should be placed in the exhaust pipe sections of the loop thermosiphon's evaporator and condenser. TEGs should be cooled by air-cooled heat sinks with fins. In Fig. 11, this design is shown in full.

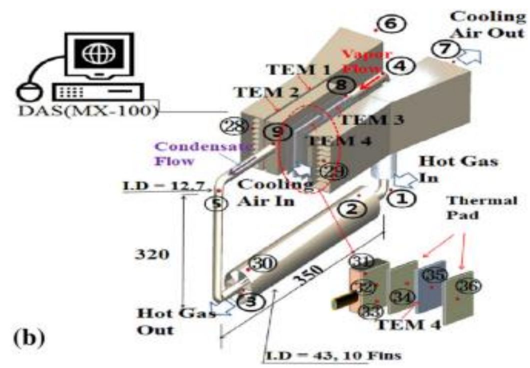


Fig. 11. An exhaust heat recovery system using a loop heat pipe to extract the heat.

Conclusion

Some of the heat that is lost during a car's operation may be useful in reducing its fuel consumption. For utilising waste heat, both of these systems have been considered. Heat pipes may be used to reduce thermal resistance. There are no moving parts and they are completely quiet and scalable.

- TEGs and heat pipes both have these characteristics.
- To reduce gas pressure loss, heat pipes may have a reduced fin surface area.
- Due to the use of heat pipes, TEG installation is not restricted to the surface of the exhaust pipe.
- Heat pipes may be used to maintain the temperature of TEGs.
- Poor efficiency and high maximum surface temperatures are among the downsides of TEGs.

While heat pipes may transport large amounts of energy, they are limited by their operating temperature ranges and their maximum heat transfer rates (MTTR). A passive exhaust heat recovery system may be developed using TEGs and heat pipes.

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