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ENERGY RECOVERY FROM ICE WASTE HEAT USING THERMOELECTRIC GENERATORS

BY

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Abstract. In recent times, people pay more attention to global warming because they realise its impact on the environment and human life. The main factor that influences it are the emissions produced by the transportation industry. Automobiles are one of the biggest source CO2 emissions. Because the engine efficiency is low, most of the energy produced is lost as heat. If the lost heat is recovered and transformed to electrical energy it could power some of the automobile systems, thus reducing the fuel consumption and CO2 emissions. Among the researched power generation technologies, one of the most advantageous in this situation is the thermoelectric generator (TEG). TEGs take advantage of Seebeck effect to convert low temperature heat into electricity using materials similar to thermocouples. The purpose of this paper is to provide a comprehensive overview of the TEG, including its operational principle, the experiments conducted to test it, the materials used in its construction, and the methods employed to improve its performance.

Keywords: Thermoelectric generator, Seebeck effect, waste heat, Automobiles, Exhaust.

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1. Introduction

According to the United States Environmental Protection Agency (EPA) the largest source of green gas emissions in USA comes from transportation. Carbon dioxide (CO2) accounts for most greenhouse gas emissions generated by transportation. In 2021, the transportation area was responsible for approximately 28% of the emissions. Out of these 28%, 81% comes from the automotive area (EPA, 2023).

An internal combustion engine (ICE) efficiency is very low being able to use only 35 to 40% of the energy it generates. The rest 65 to 70% is lost as heat (Burnete *et al*., 2022). Utilizing wasted heat for electricity generation would enhance engine efficiency and lead to a reduction in greenhouse gas emissions.

Some of the most common waste heat recovery (WHR) technologies are based on the organic Rankine or Kalina cycle and heat pumps, all three known for their relatively high efficiency. However, these technologies require the use of working fluids to generate electricity, which results in complex construction and substantial space requirements (Ochieng *et al*., 2022). Implementing these technologies may increase engine complexity and weight, which can potentially lead to higher fuel consumption and introduce additional failure points in the internal combustion engine.

There are also devices that are capable to convert the heat directly in energy like thermoelectric, thermionic and piezoelectric generators (Ochieng *et al*., 2022).

Thermoelectric generators (Fig. 1) are composed of thermoelectric (TE) modules, a heat source and a heat sink. Each thermoelectric module consists of multiple pairs of TE couples, ranging from several tens to hundreds, which are electrically connected in series and thermally connected in parallel (Champier, 2017).

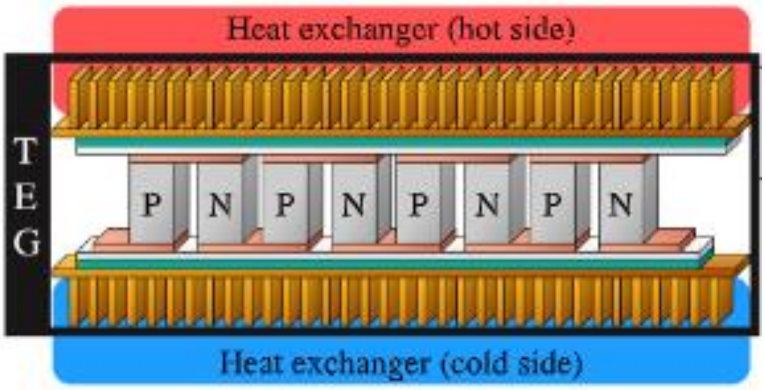

Fig. 1 – Thermoelectric generator (Burnete *et al*., 2022).

Thermoelectric generators (TEGs) advantages are the following: compact size, lightweight nature, absence of moving parts or working fluids, and environmentally friendly operation with no pollution or noise generation (Sun *et al.*, 2014; Champier, 2017).

Considering their advantages, thermoelectric generators are more suitable to be used on automobiles because they can be easily integrated into the engine without major changes. Their absence of moving parts eliminates the risk of introducing potential points of failure to the engine, ensuring high reliability. Moreover, TEGs show a longer lifespan and demand minimal maintenance compared to other generator types.

The main disadvantage of TEGs is the low efficiency. According to Ochieng TEG's efficiency is between 5 to 10% (Ochieng *et al.*, 2022). In his paper, Shen Zu-Guo *et al.* made a study that talks about some of the TEG experiments that were conducted all over the world. In most of the presented cases the TEG efficiency is lower than 5% (Shen Z.-G. *et al.*, 2019).

Ikoma K. conducted an experiment which revealed that the temperature along the thermoelectric generator is not constant. The outlet temperature was found to be lower than the inlet temperature (Ikoma *et al.*, 1998). Based on the data depicted in Fig. 2, it can be concluded that the energy produced by the TEG is greater when the exhaust gas temperature is higher. Additionally, the non-uniform temperature distribution along the TEG represents a disadvantage.

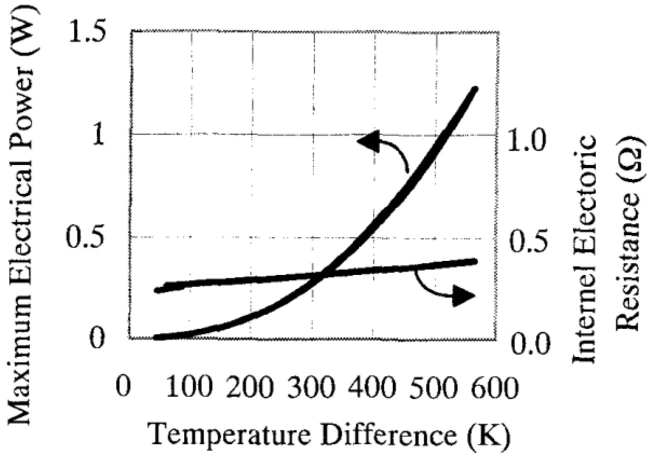

Fig. 2 – The maximum electric power and the internal electric resistance as a function of the temperature difference (Ikoma *et al.*, 1998).

2. The thermoelectric conversion

In order to produce electrical energy, thermoelectric generators are using the Seebeck effect (Jaziri *et al*., 2020).

The Seebeck effect is a thermoelectric phenomenon that produces a voltage difference when two different materials (such as conductors or semiconductors) are connected at junctions and exposed to different temperatures, thus creating a temperature gradient (Ochieng *et al*., 2022).

TEG uses P- and N- type conductors or semiconductors to form a PN junction, which is connected on the high-temperature side and disconnected at the low-temperature location. Due to thermal excitation, the concentration of holes (P-type material) and electrons (N-type material) is higher on the high-temperature side compared to the low-temperature side. Once the temperature rises, the holes and electrons migrate towards the lower temperature region, resulting in the generation of a potential difference, as shown in Fig. 3. Thermoelectric modules are composed of connected pairs of semiconductor elements (Yuan *et al*., 2023).

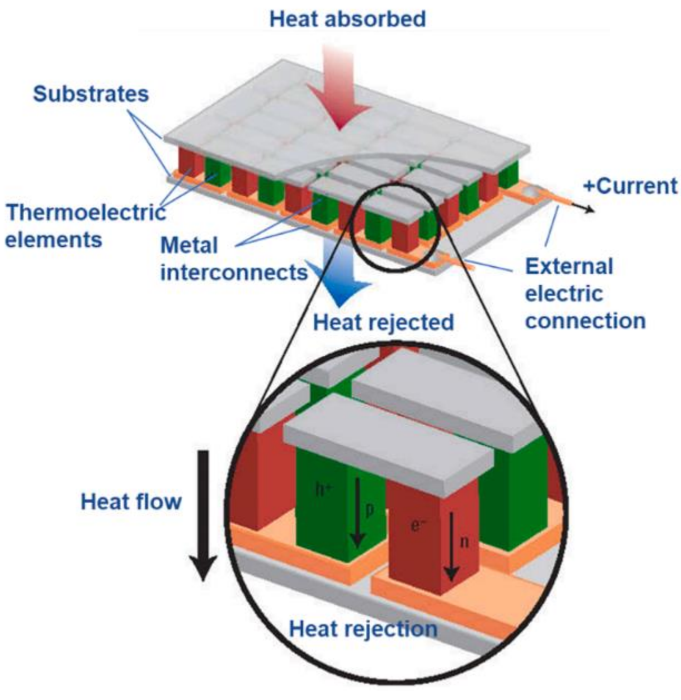

Fig. 3 – Principle of thermoelectric technology (Yuan *et al*., 2023).

According to Seebeck, the electrical potential difference created in a conductor material is directly proportional to the temperature gradient applied across its surfaces. This principle is predominantly employed to demonstrate that the electricity produced, and consequently the conversion efficiency, by a basic TEG relies on the temperature difference existing between both sides of the device (Ochieng *et al*., 2022).

3. Efficiency

The efficiency of a thermoelectric module (η) that is used as a generator is equal to the ratio of the electrical energy produced (W_{elec}) to the thermal energy entering the hot face (Q_H) and it can be written as follows (Champier, 2017):

$$\eta = \frac{W_{elec}}{Q_H} = \frac{\Delta T}{T_H} \cdot \frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+\frac{T_C}{T_H}} \quad (1)$$

where ΔT is the difference between the temperature of the hot side of the module (T_H) and the temperature of the cold side of the module (T_C) ($\Delta T = T_H - T_C$) and ZT represents the device and material figure of merit, Z being the main parameter to describe the potential of the thermoelements.

$$Z = \frac{(\alpha_p - \alpha_n)^2}{\left(\sqrt{\kappa_p \cdot \rho_p} + \sqrt{\kappa_n \cdot \rho_n}\right)^2} \quad (2)$$

where κ represents the thermal conductivity, α is the Seebeck coefficient and ρ is the electrical resistivity. The p and n subscripts are used to identify the materials of the thermocouple (p- and n- type) (Burnete *et al*., 2022; Champier, 2017).

$$Z\overline{T} = \frac{\alpha^2 \sigma}{\kappa}\overline{T} = \frac{\alpha^2}{\rho\kappa}\overline{T} \quad (3)$$

where σ represents the electrical conductivity.

4. Materials

As mentioned before, ZT represents the material figure of merit. According to M. Rull-Bravo, in order to obtain a conversion efficiency that is close to the one of mechanical power generators, a theoretical Figure of merit that is close to ~3 would be necessary. During experimentation, it is observed that the value of ZT is relatively low, primarily due to its temperature dependence. (Rull-Bravo *et al*., 2015). Currently, the most common ZT values are close to 1, with

Bismuth Telluride (Bi2Te3) being the only material employed in industrial thermoelectric (TE) modules.

In order to improve the value of ZT, it is desirable to have a high Seebeck coefficient and electrical conductivity, along with low thermal conductivity (Chen and Ren, 2013).

Thermoelectric materials have different operating temperatures. Materials that are based on Bismuth Tellurium are more suitable for lower temperatures (up to 200ºC). Medium temperature materials are half-Heuslers, skutterutites or materials based on lead combined with chalcogen elements (PbTe and PbSe) (500-800ºC) and materials that operate at high temperatures are silicon-germanium (>800ºC) (Chen and Ren, 2013). Figure 4 and Table 1 present some materials, their costs and their ZT based on the operating temperature.

Skutterudites are a class of intermetallic compounds that belong to the broader family of minerals known as skutterudite minerals. These compounds have a specific crystal structure characterized by a cubic framework formed by transition metal atoms surrounded by main-group elements. The most common skutterudites have a general formula that is MT_4X_{12} (where M represents an alkaline metal, an alkaline-earth a rare earth or an actinide, T is a metal from the VIIIth subgroup and X is an atom from the Vth group) (Rogl *et al.*, 2014).

Half-Heusler compounds are composed of XYZ as their primary chemical composition. Here, X can represent a transition metal, noble metal, or rare-earth element, while Y can be a transition metal or noble metal, and Z is a main group element (Chen and Ren, 2013).

In recent years, research and development efforts have been made in order to obtain materials with higher ZT values. Although some results have been obtained it is very difficult to commercialize those materials that are obtained in laboratories. This difficulty arises from the complexities involved in material research, practicality in material fabrication, and the construction of thermoelectric devices (Zheng *et al.*, 2014).

Table 1

ZT and Temperature based on TE material (Chen and Ren, 2013)

Composition	ZT value	Temperature (ºC)
$Cu_{0.01}Bi_2Te_{2.7}Se_{0.35}$[4]	~1.1	100
$Bi_xSb_{2-x}Te_3$ [5]	~1.4	100
$PbTe_{0.9988}I_{0.0012}$[8]	~1.4	527
$K_{0.02}Pb_{0.98}Te_{0.15}Se_{0.85}$[9]	~1.7	600
$Ba_{0.08}La_{0.05}Yb_{0.04}Co_4Sb_{12}$[10]	~1.7	577
$Ce_{0.45}Nd_{0.45}Fe_{3.5}Co_{0.5}Sb_{12}$[11]	~1.1	527
$Hf_{0.25}Zr_{0.75}NiSn_{0.99}Sb_{0.01}$[17]	~1.0	500-800
$Hf_{0.44}Zr_{0.44}Ti_{0.12}CoSn_{0.8}Sb_{0.2}$[18]	~1.0	500-800
$(Si_{95}Ge_5)_{0.65}(Si_{70}Ge_{30}P_{30})_{0.3}$[6]	~1.6	800-1000
$(Si_{80}Ge_{20})_{0.8}(Si_{100}P_3)_{0.2}$[7]	~0.9	800-1000

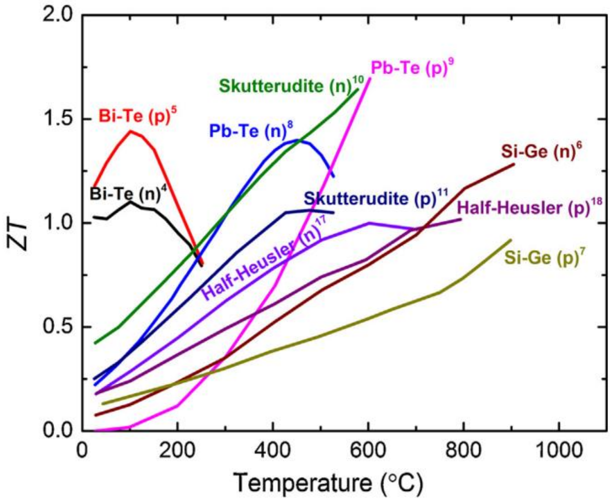

Fig. 4 – Thermoelements ZT value based on different temperatures (Chen and Ren, 2013).

5. Thermoelement design

Based on the heat flow direction and thermocouples (TC) arrangement, there are three types of TEG designs which are presented in Fig. 5: (a) lateral heat flow and lateral TCs arrangement, (b) vertical heat flow and lateral TCs arrangement and (c) vertical heat flow and vertical TCs arrangement (Glatz *et al*., 2009).

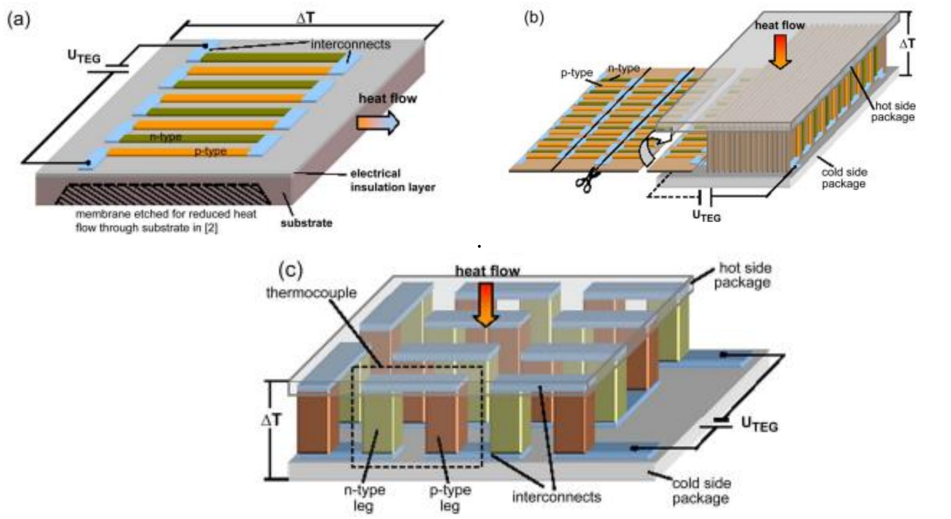

Fig. 5 – TEG designs (a) Lateral/lateral-type. (b) Vertical/lateral-type. (c) Vertical/vertical-type (Glatz *et al*., 2009).

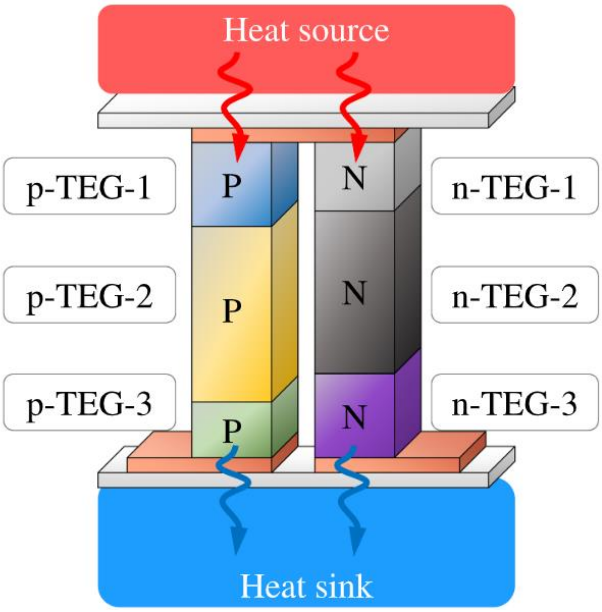

Fig. 6 – Segmented thermoelectric generator (Burnete *et al*., 2022).

Normally the single-stage TEG is not efficient because of the TE material properties. The temperature of exhaust gases can vary based on the load of the engine. Higher engine loads generally result in higher exhaust gas temperatures, while lower loads lead to lower exhaust gas temperatures. Because different TE materials have different operating temperatures, by connecting thermoelectric modules with distinct properties, it is possible to create a stacked thermoelectric generator system. This approach not only allows for a higher utilization rate of the heat source but also results in a greater power output (Shen R. *et al*., 2017). In this situation the impact of compatibility mismatch on the optimal power output when efficiency for different element segments occurs at significantly different current densities must be taken into consideration. To manage these effects, each material segment and layer have different thicknesses (LaGrandeur *et al*., 2006). A design example can be seen in Fig. 6.

A study conducted in Japan by HondaR&DCo., Ltd revealed that a TEG consisting of two different types of materials within one leg exhibited the capability to generate over 30% more power compared to a single type high-temperature material (Shen Z.-G. *et al*., 2019).

Using stacked TE elements can also lead to the following challenges: contacts failure due to thermomechanical stresses, failures from shear stresses could appear due to high temperature differences between the hot and cold side (Atassi *et al*., 2013).

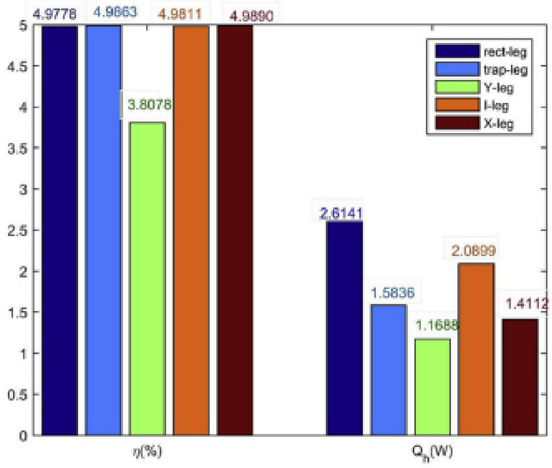

Fig.7 – Model efficiencies and absorbed heat at hot junction (Ibeagwu, 2019).

The study of leg geometry in thermoelectric generators (TEGs) focuses on understanding and optimizing the shape and design of the individual legs that make up the TEG module. The leg geometry plays an important role in determining the overall performance and efficiency of the TEG system. By studying leg geometry, researchers aim to identify optimal configurations that maximize the conversion efficiency of thermal energy into electrical energy. This involves finding a balance between minimizing heat loss, maximizing electrical power output, and ensuring mechanical stability.

Ibeagwu O.I. and ALkhadher Khalil *et al.* conducted a study in which different leg geometries are compared. In both studies the geometries compared are: rectangular, I, X, trapezoidal and Y. The study conducted by Ibeagwu the material used was $Sn_{95}Ag_5$, the leg height was 6mm leg volume was different and the temperatures were held at 423K and 295K for all elements. After the numerical computation, it was proven that X-leg has the highest efficiency while the Y-leg has the smallest efficiency (Ibeagwu, 2019). The efficiency is also presented in Fig. 7.

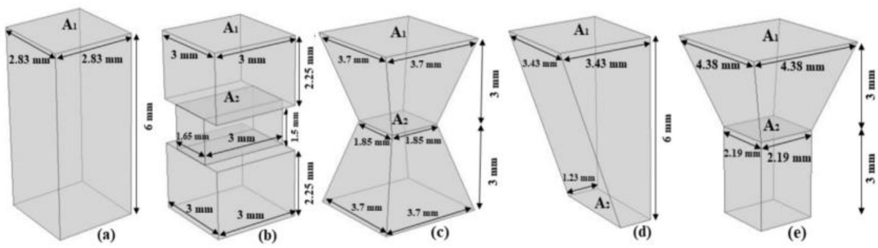

Fig. 8 – Geometric design of the legs. (a) Rectangular leg, (b) I-leg, (c) X-leg, (d) Trapezoidal leg, (e) Y-leg (Khalil *et al.*, 2023).

Table 2
Efficiency and power for different element geometry (Khalil et al., 2023)

Model	Power (W)	Efficiency (%)
Rectangular - leg	0.041	5.482
I – leg	0.036	5.091
X – leg	0.034	4.955
Trapezoidal – leg	0.037	5.277
Y – leg	0.032	5.222

On the other hand, in the study conducted by Khalil A. *et al.* the material used was Bi_2Te_3, the height was also 6mm, the volume was the equal for all leg shapes and the temperature was also 423K and 295K for all elements. The result of this study was that the rectangular geometry had the highest efficiency (Khalil *et al.*, 2023). The shape of the legs can be seen in Fig. 8 and the efficiency of each leg can be seen in Table 2.

The findings from these two studies indicate that the efficiency and power output of the element are influenced by both the shape and material properties, as well as the volume of the element.

6. Thermoelectric generator design

When designing the thermoelectric generator, it is important to consider various factors that contribute to its overall performance and efficiency. The design of a TEG involves careful consideration of the materials used, the arrangement of thermoelectric elements the heat transfer mechanisms. A good method to test and improve the performance of TEG in the early design stages is using a computational fluid dynamic program. This way the temperature difference, pressure drop and temperature uniformity can be obtained without creating the physical generator (Wang Y. *et al*., 2018). The primary materials used in the manufacturing of most automotive heat exchangers are stainless steel, aluminum, and, in certain instances, brass. These materials are utilized in the construction of direct or contact type heat exchangers (Ochieng *et al*., 2022).

Wang Y. along with the team he is part of, conducted a study on different patterns inside a thermoelectrical generator that is plate shaped and uses liquid coolant (Fig. 9) (Liu *et al*., 2014; Wang Y. *et al*., 2018).

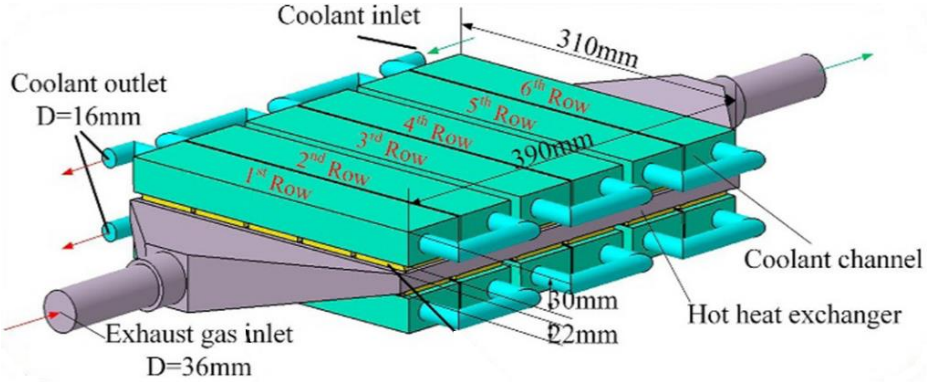

Fig. 9 – Thermoelectrical generator design (Wang Y. *et al*., 2018).

The model used a total of 60 pieces of TM placed on the front and back surface of the heat exchanger. The main parameters that were compared were the heat distribution and output power (W). The 3 patterns that were compared in are fishbone, inserted fins and dimpled surface. The first paper presents a comparison between the fishbone and the inserted fins pattern. In this case the heat distribution and the power output were higher for the inserted fins pattern. In the second paper the inserted fins and dimpled surface were compared, and the best heat distribution and power output were better for the dimpled surface. Out of the 2 comparisons the highest power output were close to 200 W and the best efficiency was 0.68% (Liu *et al*., 2014; Wang Y. *et al*., 2018). The patterns are also presented in Fig. 10.

In order to improve the heat distribution, Wang, Chenglong *et al.* proposed a thermoelectric design that uses heat pipes which are widely acknowledged as highly efficient passive technologies for transferring heat.

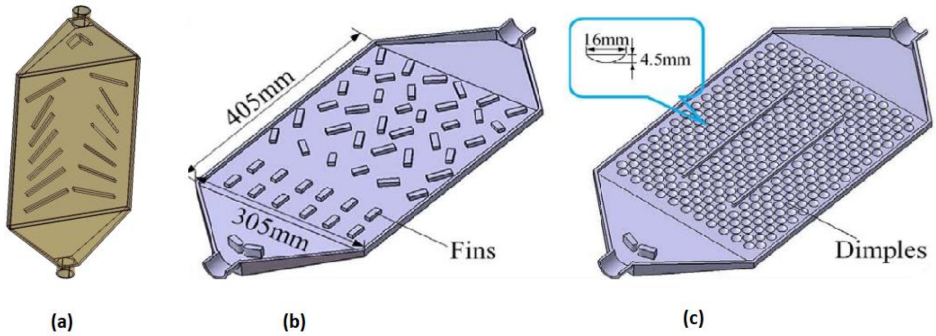

Fig. 10 – Inner structures of the hot heat exchanger. (a) Fishbone pattern, (b) Fin pattern, (c) Dimple pattern (Liu *et al*., 2014; Wang Y. *et al*., 2018).

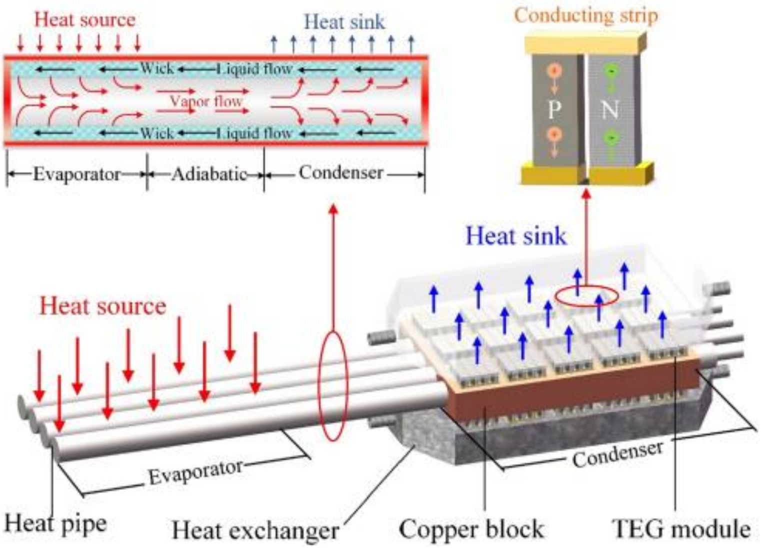

Fig. 11 – Heat pipes TEG schematic (Wang C. *et al*., 2020).

Heat pipes are designed with very high thermal conductivity, facilitating the transportation of heat while ensuring a nearly uniform temperature throughout their heated and cooled sections. Heat pipes, in general, function as passive thermal transfer devices, capable of transporting substantial amounts of heat over considerable distances without the need for any moving parts. This is achieved through phase-change processes and vapor diffusion (Jouhara *et al*., 2017). The proposed model is composed of high-temperature heat pipes, a copper block, thermoelectric modules and two heat sinks (Fig. 11). High-temperature heat pipes are utilized to absorb waste heat from a heat source and transfer it over significant distances while maintaining high isothermality. The copper block is employed to connect the heat pipe condensers with the TEG modules and ensure a uniform thermal field for the modules. Giving the fact that the temperatures are around 500^{o}C, the thermoelements used are Skutterudites (Wang C. *et al*., 2020).

The placement of TEG modules between heat pipe condensers and heat sinks can restrict the heat transfer capability of the heat pipes due to the relatively low thermal conductivity of the TEG modules. However, this arrangement has the potential to enhance the isothermality of the heat pipe condensers. It is important to acknowledge that the temperature difference observed across the TE (thermoelectric) legs within the modules is lower than the measurement obtained by the thermocouples. This discrepancy arises due to the presence of thermal resistance in the interface materials and contact surfaces. Additionally, accurately measuring the actual temperature difference between the two sides of the TE legs presents challenges (Wang C. *et al*., 2020).

The simulation results using the material Seebeck coefficient directly lead to an overestimation of the TEG's thermoelectric performance, resulting in a significant simulation error. This error can be attributed to various factors, such as contact thermal resistance, thermal resistances of attached materials, and heat loss caused by bypass. Consequently, the effective Seebeck coefficient plays a crucial role as an important parameter in accurately aligning the TEG's thermoelectric performance with its practical applications (Wang C. *et al.*, 2020).

7. Conclusions

The paper presents a method of recovering energy from internal combustion engine waste heat. Thermoelectrical generators technology is not efficient enough for the moment and it needs further development, most of the practical experiments showing an efficiency that is lower than 5%.

The efficiency of TEGs can be improved through continuous research focused on thermoelement materials and their geometry. By exploring and improving thermoelectric materials with higher Seebeck coefficients and lower thermal conductivities, researchers can increase the conversion efficiency of TEGs. Additionally, investigating alternative materials or novel material combinations can lead to advancements in TEG performance.

Thermoelement materials have higher ZT values at different temperatures. By stacking materials with different temperature ranges, we can increase TEG power output. However, there are challenges such as finding compatible materials for the combination and calculating the right thickness for each element. These factors need to be carefully considered to ensure effective performance and get the most out of the thermoelectric configuration.

Heat transfer, heat distribution, the arrangement and the number of thermocouples are factors that need to be taken into consideration when designing a TEG.

Using a pattern inside the heat exchanger can improve the heat distribution along TEG.

Heat pipes might represent a good method of improving TEG efficiency, but for the moment further tests need to be made in order to obtain more accurate results.

Overall, thermoelectric generators have the potential to be a valuable solution for reducing greenhouse gas emissions and enhancing internal combustion efficiency. Therefore, it is crucial to prioritize further development in this field.

REFERENCES

Atassi Ibrahim, Ernst Bauer, Johann Nicolics, Bernhard Dangl, Lukas Spendlhofer, Dennis Knospe, Florian Faistauer, *Current thermoelectric materials and an evaluation of thermoelectric materials contacting approaches*, In 2012 35th International Spring Seminar on Electronics Technology, pp. 70-75, IEEE, 2012.

Burnete Nicolae Vlad, Florin Mariasiu, Christopher Depcik, Istvan Barabas, Dan Moldovanu, *On the review of thermoelectric generation for internal combustion engine waste heat recovery*, Progress in Energy and Combustion Science 91 (2022).

Champier Daniel, *On the Thermoelectric generators: A review of applications*, Energy Conversion and Management 140 (2017): 167-181.

Chen Shuo, Zhifeng Ren, *Recent progress of half-Heusler for moderate temperature thermoelectric applications*, Materials today 16, no. 10 (2013): 387-395.

Glatz Wulf, Etienne Schwyter, Lukas Durrer, Christofer Hierold, *Bi2Te3-Based Flexible Micro Thermoelectric Generator with Optimized Design*, Journal of Microelectromechanical Systems 18, no. 3 (2009): 763-772.

Ibeagwu Onyebuchi Isreal, *Modelling and comprehensive analysis of TEGs with diverse variable leg geometry*, Energy 180 (2019): 90-106.

Ikoma K., Munekiyo M., Furuya K., Kobayashi M.A.K.M., Izumi T.A.I.T., Shinohara K.A.S.K., *Thermoelectric module and generator for gasoline engine vehicles*, In Seventeenth International Conference on Thermoelectrics, Proceedings ICT98 (Cat. No. 98TH8365), pp. 464-467, IEEE, 1998.

Jaziri Nesrine, Ayda Boughamoura, Jens Müller, Brahim Mezghani, Fares Tounsi, Mohammed Ismail, *A comprehensive review of Thermoelectric Generators: Technologies and common applications*, Energy Reports 6 (2020): 264-287.

Jouhara Hussam, Amisha Chauhan, Theodora Nannou, Almahmoud S., Bertrand Delpech, Luiz C. Wrobel, *Heat pipe based systems-Advances and applications*, Energy 128 (2017): 729-754.

Khalil ALkhadher, Ahmed Elhassnaoui, Said Yadir, Obbadi Abdellatif, Youssef Errami, Smail Sahnoun, *Performance comparison of TEGs for diverse variable leg geometry with the same leg volume*, Energy 224 (2021): 119967.

LaGrandeur John, Crane D., Hung S., Mazar B., Eder A., *Automotive waste heat conversion to electric power using skutterudite, TAGS, PbTe and BiTe*, In 2006 25th International Conference on Thermoelectrics, pp. 343-348. IEEE, 2006.

Liu X., Deng Y. D., Zhang K., Xu M., Xu Y., Su C.Q., *Experiments and simulations on heat exchangers in thermoelectric generator for automotive application*, Applied Thermal Engineering 71, no. 1 (2014): 364-370.

Ochieng Alfred Oloo, Tamer F. Megahed, Shinichi Ookawara, Hamdy Hassan, *Comprehensive review in waste heat recovery in different thermal energy-consuming processes using thermoelectric generators for electrical power generation*, Process Safety and Environmental Protection 162 (2022): 134-154.

Rogl G., Grytsiv A., Rogl P., Bauer E., Hochenhofer M., Anbalagan R., Mallik R. C., Schafler E., *Nanostructuring of p-and n-type skutterudites reaching figures of merit of approximately 1.3 and 1.6, respectively*, Acta Materialia 76 (2014): 434-448.

Rull-Bravo Marta, Alberto Moure, Fernández J.F., Martín-González Marisol, *Skutterudites as thermoelectric materials: revisited*, Rsc Advances 5, no. 52 (2015): 41653-41667.

Shen Rong, Xiaolong Gou, Haoyu Xu, Kuanrong Qiu, *Dynamic performance analysis of a cascaded thermoelectric generator*, Applied Energy 203 (2017): 808-815.

Shen Zu-Guo, Lin-Li Tian, Xun Liu, *Automotive exhaust thermoelectric generators: Current status, challenges and future prospects*, Energy Conversion and Management 195 (2019): 1138-1173.

United States Environmental Protection Agency (EPA) 2023, *On the Sources of Greenhouse Gas Emissions*, accessed 8 May 2023, <https://www.epa.gov/>

Wang Chenglong, Simiao Tang, Xiao Liu, Su G.H., Wenxi Tian, Suizheng Qiu, *Experimental study on heat pipe thermoelectric generator for industrial high temperature waste heat recovery*, Applied Thermal Engineering 175 (2020): 115299.

Wang Yiping, Shuai Li, Xu Xie, Yadong Deng, Xun Liu, Chuqi Su, *Performance evaluation of an automotive thermoelectric generator with inserted fins or dimpled-surface hot heat exchanger*, Applied Energy 218 (2018): 391-401.

Yuan Dongdong, Wei Jiang, Aimin Sha, Jingjing Xiao, Wangjie Wu, Teng Wang, *Technology method and functional characteristics of road thermoelectric generator system based on Seebeck effect*, Applied Energy 331 (2023): 120459.

Zheng X.F., Liu C.X., Yan Y.Y., Wang Q., *A review of thermoelectrics research–Recent developments and potentials for sustainable and renewable energy applications*, Renewable and Sustainable Energy Reviews 32 (2014): 486-503.

RECUPERAREA ENERGIEI DIN CĂLDURA GAZELOR DE EVACUARE ALE M.A.I. UTILIZÂND GENERATOARELE TERMOELECTRICE

(Rezumat)

În ultima vreme, se acordă o atenție sporită încălzirii globale din cauza impactului negativ pe care îl are asupra mediului și calității vieții umane. Principalul factor care o influențează sunt emisiile provocate de industria transportului. Automobilele reprezintă una din cele mai mari surse de emisii de CO_2. Deoarece eficiența motorului cu ardere internă este scăzută, majoritatea căldurii produse se pierde sub formă de caldură. Prin transformarea căldurii pierdute în energie electrică, o parte din sistemele automobilelor ar putea fi alimentate de aceasta, scăzând consumul de combustibil și emisiile de CO_2. Generatorul termoelectric (TEG) reprezintă una din cele mai avantajoase tehnologii care ar putea fi folosită pentru producerea de energie. Acestea utilizează efectul Seebeck pentru a transforma o diferență de temperatură în energie electrică utilizând conductori sau semiconductori. Scopul acestui articol este de a prezenta potențialul generatorului thermoelectric, modul de funcționare, metodele de îmbunătățire a performanței și testele realizate asupra lui.