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The Study of Temperature Increment on Thermoelectric Generators in Internal Combustion Engines

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Abstract- In this paper, the effect of exhaust gases crossing over the thermoelectric generator has been studied. The calculations were carried out by using the thermodynamics, heat transfer, and thermoelectric equations in MATLAB software. The effects of exhaust gases temperature and ambient temperature increment on maximum efficiency, maximum power, and the initial cost of the thermoelectric generator were investigated. By comparing the results of different environmental conditions and system changes to enhance performance, increasing the exhaust gases temperature were led to efficiency elevation and decreasing the initial costs. The most ideal situation for using generator, is the place with the maximum exhaust gases temperature and minimum ambient temperature.

Keywords- *Thermoelectric Generator; Exhaust Gases; Ambient Temperature; Energy Optimization; Internal Combustion Engine.*

I. Introduction

Thermoelectric systems include pairs of P- and N-type semiconductors. These systems are connected in series and placed between two plates with maximum thermal conductivity and electrical insulation. Having fixed components, being almost silent, available in all sizes, and having high reliability are the advantages of thermoelectric generators [1,2].

Hicks and Dresselhaus [3] used quantum-well super lattices to obtain a high figure of merit from unusual semiconductors. This approach significantly increased the generators efficiency. They also used new Nano materials to enhance the efficiency of thermoelectric generators. Fleurial et al [4] designed a thermoelectric generator from new skutterudites and improved the empirical efficiency up to about 11%. Rowe and Gao [5,6] changed and optimized thermoelectric modules which provide maximum power by utilizing the maximum potentials of thermoelectric modules. Esarte [7] et al, presented a NTU numerical model based on thermodynamics relations using in the heat exchangers. They analyzed heat transfer between the heat source and heat sink in a thermoelectric module. They also examined the impact of flow rate, geometry of heat exchanger, and flow characteristics at the inlet temperature of thermoelectric generator.

Vazquez [8], studied thermoelectric generators for electricity generating from car exhaust gases. His analysis included a variety of materials for thermoelectric generators and their performance as well as the shape and elements sizes and their lineup. It also included thermoelectric modules optimization in the heat transfers, heat sink models, generator placement, and optimal assembling of generators elements. Gou et al [9] studied the effect of low temperatures on the output voltage and increased the power of thermoelectric generator. The results show that as far as the used semiconductors are able to withstand the temperature increment, voltage and output power will increase due to temperature increment. Also, increasing the number of modules were led to voltage and output power rise. In this paper, the effects of gases temperature and ambient temperature increment on the initial costs and maximum power of the thermoelectric generator were investigated.

II. SYSTEM MODELING

The calculations were carried out by using the thermodynamics, heat transfer and thermoelectric generators equations.

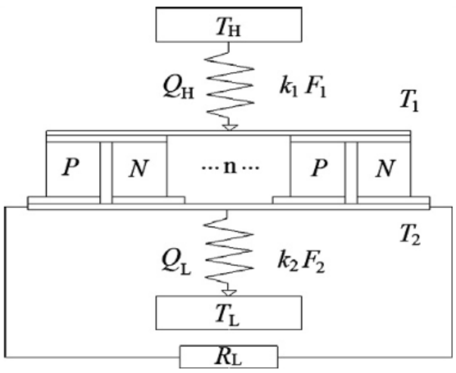

Figure 1. Schematic diagram of multi-element thermoelectric generator

A general thermoelectric generator composed of several thermoelectric elements (Fig. 1). Each element consists of P- and N-type semiconductor legs which work between high and low temperature heat sources whose temperature are T_H and T_L respectively.

The performance of a thermoelectric generator is measured by three main parameters, namely Seebeck coefficient, the electrical conductivity, and the thermal conductivity. The $S^2.\sigma$ and k are electrical and thermal factors respectively. Figure of merit and also semiconductors figure of merit can be expressed as follows:

$$Z = S^2 / \rho \cdot k \qquad (1a)$$

$$Z = (S_n + S_p)^2 / [(\rho_n \cdot k_n)^{1/2} + (\rho_p \cdot k_p)^{1/2}]^2 \qquad (1b)$$

The Q_H and Q_L in Figure 1 show the heat absorption from high temperature reservoir and the heat dissipation to low temperature reservoir per unit time.

Carnot cycle thermal efficiency, Burner efficiency (ratio of heat transferred through the combustion chamber walls to the lower heating value of the fuel) and maximum conversion efficiency of thermoelectric generator read:

$$\eta_c = 1 - T_L / T_H \qquad (2)$$

$$\eta_b = 1 - 0.00045 T_S \qquad (3)$$

$$\eta_{mc} = \eta_c \frac{(1+M)^{1/2} - 1}{(1+M)^{1/2} + T_H / T_L} \qquad (4)$$

Total thermal efficiency of the thermoelectric generator defined as:

$$\eta_t = P / Q_H = \eta_b \cdot \eta_{mc} \qquad (5)$$

Where η_b and η_{mc} denotes the burner and conversion efficiencies. Due to the different semiconductors used in terminals, each of them separately can be calculated [2]. The output power of each element of the thermoelectric generator is determined accurately from:

$$P_{mpx} = S_x^2 \cdot A \cdot \Delta T^2 / 4 \cdot \rho_x \cdot L', \qquad x = p, n \qquad (6)$$

$$P_{mp} = P_{mpp} + P_{mpn} \qquad (7)$$

III. NUMERICAL RESULTS

Figures 2 and 3 show the numerical results of maximum exhaust gases and ambient temperatures increment on maximum efficiency of thermoelectric generator. Both figures illustrate the opposite behavior in which maximum exhaust gases temperature increment leads to an increase in maximum efficiency but increasing ambient temperature decreases the system efficiency.

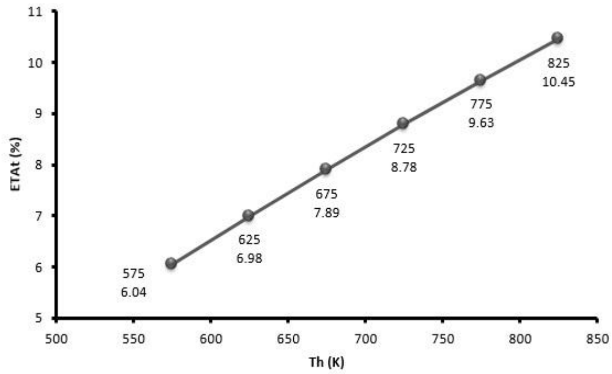

Figure 2. Effect of exhaust gases temperature increment on maximum efficiency

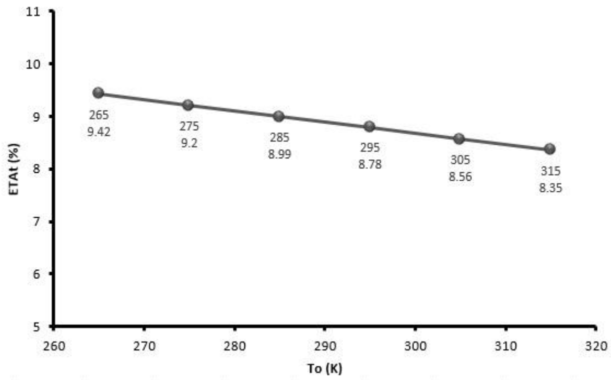

Figure 3. Effect of ambient temperature increment on maximum efficiency

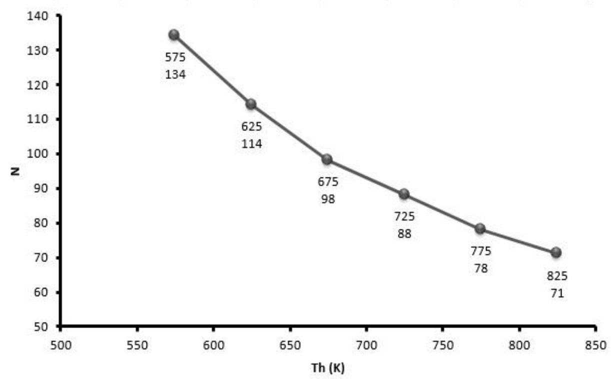

Figure. 4. Effect of exhaust gases temperature increment on number of modules

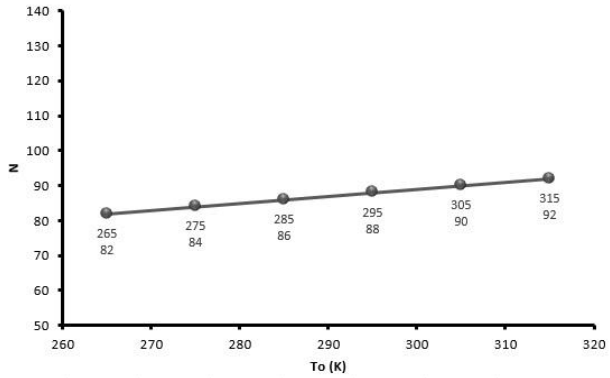

Figure 5. Effect of ambient temperature increment on number of modules

Figures 4 and 5, show the numerical results of maximum exhaust gases and ambient temperatures increment on system efficiency. There are opposite behaviors in which increasing maximum exhaust gases temperature leads to reduction the number of thermo elements and rising ambient temperature increases the initial costs.

Higher gradient in Figure 4 despite Figure 5 shows that the effect of hot exhaust gases temperature on initial costs are much higher than the ambient temperature.

IV. CONCLUSION

The results indicate that in a thermoelectric generator system, the higher exhaust gases temperature leads to efficiency and output power increment and reducing in initial costs. The effect of ambient temperature on output power is too low compared to exhaust gases temperature. Therefore the use of generator in environment with different ambient temperatures is less important than the implementing different temperatures of exhaust gases. If thermoelectric semiconductor can withstand high temperatures, it is desirable to utilize maximum temperature of gases. The higher ambient temperature leads to increase in initial costs and reduce efficiency and output power. The most ideal situation for using generator is the place with the maximum exhaust gases temperature and minimum ambient temperature.

REFERENCES

[1] S.W. Angrist, Direct Energy Conversion, 3rd Ed, Allyn and Bacon Inc., 1982.

[2] G.C. Jain, W.B. Berry, Transport Properties of Solids and Solid State Energy Conversion, Tata McGraw-Hill Pub Co. Ltd., 1972.

[3] L. Hicks, M. Dresselhaus, “Use of quantum-well superlattices to obtain a high figure of merit from nonconventional thermoelectric materials”, Proceedings of the 1993 MRS Fall Meeting, Boston MA (USA), Vol. 326, PP. 413–418, 1994.

[4] J-P. Fleurial, A. Borshchevsky, T. Caillat, D.T. Morelli, G.P. Meisner, “High figure of merit in ce-filled skutterudites”, Proceedings of the 15th International Conference on Thermoelectrics, Pasadena CA (USA), PP. 91-95, 1996.

[5] D.M. Rowe, “Thermoelectric waste heat recovery as a renewable energy source”, International Journal of Innovations in Energy Systems and Power, Vol. 1, No. 1, 2006.

[6] D.M. Rowe, M. Gao, “Evaluation of thermoelectric modules for power generation”, Power Sources, Vol. 73, No. 2, PP. 193-198, 1998.

[7] J. Esarte, M. Gao, D.M. Rowe, “Modelling heat exchangers for thermoelectric generators”, Power Sources, Vol. 93, No.1, PP. 72-76, 2001.

[8] J. Vazquez, A.S. Miguel, R. Palacios, A. Arenas, “State of the art of thermoelectric generators based on heat recovered from the exhaust gasses of automobiles”, Proceedings of the 7th European Workshop on Thermoelectrics, No. 17, Oct 2002.

[9] X. Gou, H. Xiao, S. Yang, “Modeling, experimental study and optimization on low-temperature waste heat thermoelectric generator system”, Applied Energy, Vol. 87, No.1, PP. 3131-3136, 2010.

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