A REVIEW ON NUMERICAL ANALYSIS OF EXHAUST HEAT-EXCHANGER IN AUTOMOBILE THERMOELECTRIC GENERATOR

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ABSTRACT

The world is facing a historical increase in energy demand and energy consumption. Regenerating energy sources are considered as solution of both environment issue and energy demand. A major part of the heat supplied in an internal combustion engine is not realized as work output, but dumped into the atmosphere as waste heat. If this waste heat energy is tapped and converted into usable energy, the overall efficiency of an engine can be improved. The percentage of energy rejected to the environment through exhaust gas which can be potentially recovered is approximately 30-40% of the energy supplied by the fuel depending on engine load. Being one of the promising new devices for an automotive waste heat recovery, thermoelectric generators (TEG) will become one of the most important and outstanding devices in the future. Thermoelectric modules which are used as thermoelectric generators are solid state devices that are used to convert thermal energy from a temperature gradient to electrical energy and it works on basic principle of Seebeck effect. Ideal heat exchangers recover as much heat as possible from an engine exhaust at the cost of an acceptable pressure drop. They provide primary heat for a thermoelectric generator (TEG), and their capacity and efficiency is dependent on the material, shape, and type of the heat exchanger Therefore in this research paper study of different internal structure Thickness of heat exchanger plate, Surface area of heat exchanger, Materials has been studied which were designed to increase heat transfer and to reduce pressure drop.

Keyword: - *Thermoelectric generator, Waste heat recovery, Heat exchanger*

1. INTRODUCTION

Various thermodynamic cycles have been proposed and studied for low-grade waste heat recovery. An absorption cooling cycle in hybrid and electric vehicles transfers waste heat from the battery pack and exhaust gases into the boiler of ejector for cabin cooling. [9] An open steam power cycle [9], A combined thermoelectric generator [9] and organic Rankine cycle [10]. Usually, the disadvantage of these cycles is the secondary fluid circuit composed of a pump, an evaporator, an expander and a condenser; the circuit increases vehicle weight and mechanical complexity and reduces available volume. The thermoelectric generator system takes the advantage of no moving parts, silent operation, and very reliable, therefore better suited waste heat recovery from automobile exhausts than the above cycles. [11]

Being one of the promising new devices for an automotive waste heat recovery, Thermoelectric generators (TEG) will become one of the most important and outstanding devices in the future. A thermoelectric power generator is a solid state device that provides direct energy conversion from thermal energy (heat) due to a temperature gradient into electrical energy based on “Seebeck effect”. The thermoelectric power cycle, with charge carriers (electrons) serving as the working fluid, follows the fundamental laws of thermodynamics and intimately resembles the power cycle of a conventional heat engine. The basic theory and operation of thermoelectric based systems have been developed for many years. Thermoelectric power generation is based on a phenomenon called “Seebeck effect” discovered by Thomas Seebeck in 1821. When a temperature difference is established between the hot and cold junctions of two dissimilar materials (metals or semiconductors) a voltage is generated, i.e., Seebeck voltage. In fact, this phenomenon is applied to thermocouples that are extensively used for temperature measurements. Based on this Seebeck effect, thermoelectric devices can act as electrical power generators. [8]

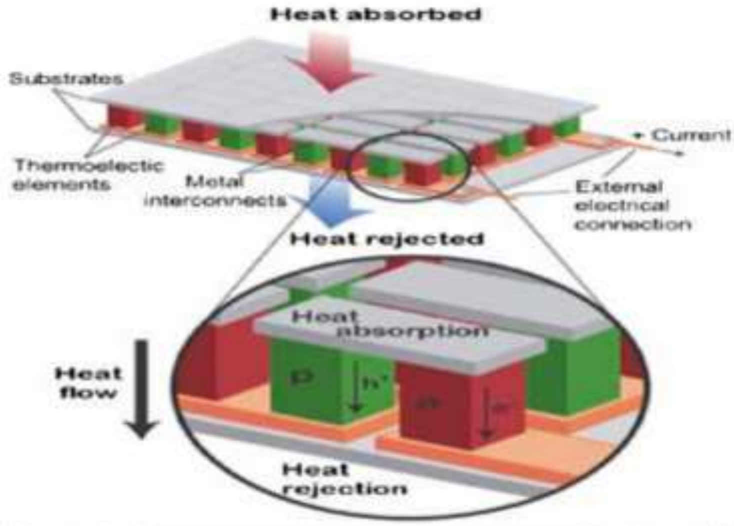

Fig -1: Thermoelectric module [9]

Thermoelectric systems can be easily designed to operate with small heat sources and small temperature differences. Such small generators could be mass produced for use in automotive waste heat recovery or home co-generation of heat and electricity. By converting the waste heat into electricity, engine performance, efficiency, reliability, and design flexibility could be improved significantly. Thermoelectric generator having number of thermoelectric modules arranged parallel to each other and electrically connected in series. The single thermoelectric module having P– Type & N – Type legs, Substrates the material above & below the legs & base material as shown in Fig. 1. [12]

2. LITRETURE REVIEW

Ting Wu et al. [1] designed six different exhaust heat exchangers within the same shell, and their computational fluid dynamics (CFD) models were developed to compare heat transfer and pressure drop in typical driving cycles for a vehicle with a 1.2 L gasoline engine. For the purpose of comparison, 6 structures were made with a shell of 280mm X 110mm X 30mm with the inlet and outlet of 40mm in diameter for 5 of the structures. 6 structures are compared regarding heat transfer and pressure drop under urban driving, suburban driving and maximum power output.

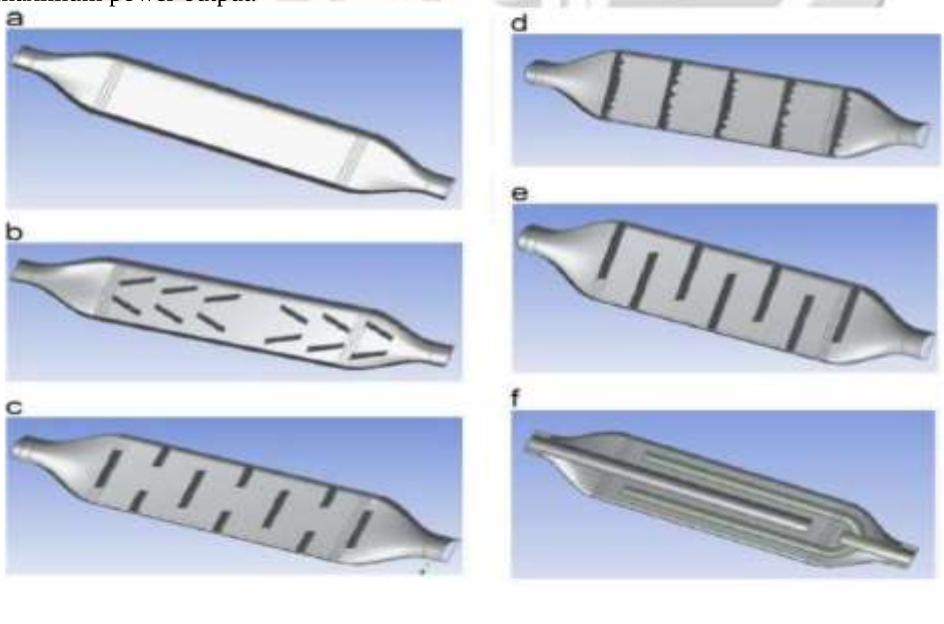

Fig -2 Internal structures (a) Empty cavity, (b) inclined plate, (c) parallel plate structure, (d) separate plate with holes, (e) serial plate structure and(f) pipe structure [1]

Among the 6 heat exchangers, the pipe structure has the 2nd greatest pressure drop and the 4th greatest heat transfer rate. The serial plate structure with 7 baffles had the maximum heat transfer rate of all the structures, at 1737W. The serial plate also had a maximum pressure drop of 9.7 kPa, 200% and 115% more than the parallel and separate plates, respectively. Only the inclined plate and the empty cavity structure had pressure drops less than 80 kPa. They suggested that bypass mechanism with a differential pressure switch is necessary for the engine's stability and reliability if pressure is more than 80 kPa.

X. Liu at al. [2] built an energy-harvesting system which extracts heat from an automotive exhaust pipe and turns the heat into electricity by using thermoelectric power generators. The plate-shaped heat exchanger of TEG is connected to the exhaust pipe of diameter 36 mm on both sides. The section of the plate-shaped exchanger of 5 mm thickness is a 400mm long by 290 mm wide rectangle. Two three dimensional models of heat exchangers with different internal structures were designed by arranging internal baffles**.**

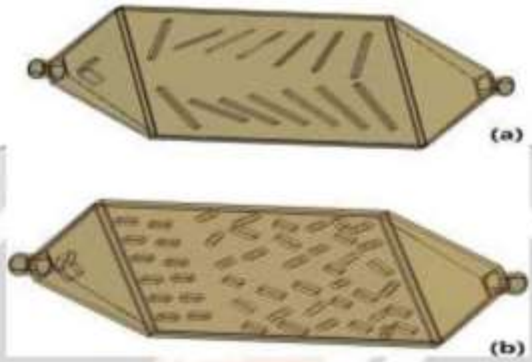

Fig -3 Block diagram of (a) fishbone-shaped heat exchanger and (b) chaos shaped heat exchanger [2]

There are called fishbone-shaped and chaos-shaped heat exchangers. The chaos-shape has slightly higher interface temperature at the inlet, and much higher at the outlet and middle. The temperature of outlet of the chaos-shaped heat exchanger is 220oC on average while the fishbone-shaped is only 190oC. Moreover, the chaos design shows better uniformity. Thus, they concluded that heat exchanger with chaos internal shape is more ideal for TEG application. Heat exchanger thickness of 3 mm, 5 mm and 8mm were taken for simulation comparison, using the chaos-shaped structure and the same boundary conditions. From which 5 mm thickness heat exchanger is selected. To further verify 60 pieces of TMs were placed on the front and back surface of the heat exchanger, the maximum electrical power output of fishbone shaped TEG is 160.21 W while the chaos-shaped is 183.24 W. Considering the agreement between the experimental results and the CFD flow simulation results, a heat exchanger with chaos shape and thickness of 5 mm is selected to form the hot side.

C.Q. Su et al. [3] studied about the thermal characteristics of heat exchangers such as internal structure, material and surface area. Computational fluid dynamics (CFD) software is used to simulate the exhaust gas flow within the heat exchanger, presenting the temperature distribution.

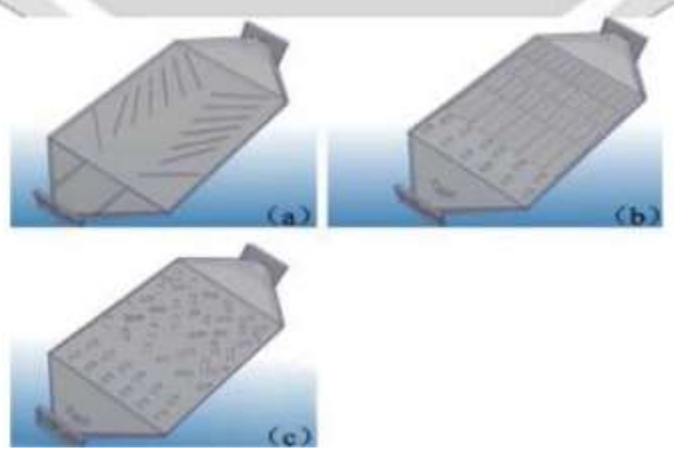

Fig -4 Three-dimensional model of the (a) fishbone-shaped, (b) accordion-shaped and (c) scatter-shaped heat exchanger [3]

Internal structure, material and thickness of the heat exchanger are changed to obtain the ideal thermal field simulation results. The geometrical model of the heat exchanger including fishbone-shaped internal structure, accordion-shaped internal structure, and scatter-shaped internal structure are compared in terms of temperature distribution. These heat exchangers with different surface areas are designed, which are 598 mm X 250 mm, 660mm X 305 mm and 775mm X 365 mm. Pictures of the surface temperature field on the heat exchanger made of iron and brass with 5mm thickness of plate are taken by the infrared thermal imaging system. Modules on the brass exchanger have higher output power than those on the iron heat exchanger. According to the agreement between the infrared experimental results and the CFD simulation results, a brass heat exchanger with accordion shape and surface area (660mm X305 mm) was selected to form the hot side.

Y. D. DENG et al. [4] studied about thermal performance of the heat exchanger in exhaust-based TEGs. In terms of interface temperature and thermal uniformity, the thermal characteristics of heat exchangers with different internal structures, lengths, and materials are studied.

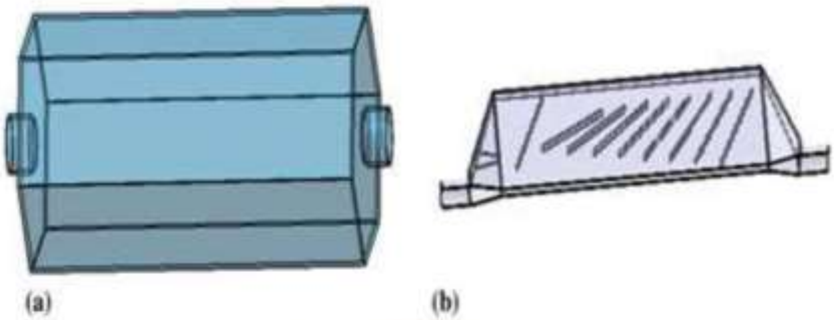

Fig -5 Three-dimensional models of the (a) hexagonal-prism-shape and (b) plate-shaped heat exchanger [4]

CFD was used to simulate the exhaust gas flow within the heat exchanger. Three-dimensional models of plate-shaped and hexagonal prism shaped heat exchangers, are made of brass, were designed and compared. The volume of the hexagonal-prism shaped heat exchanger is about 13.09L, while the volume of the other design is just 2.55L. Therefore, the volume of the hexagonal-prism-shaped heat exchanger is too large, which is not beneficial for waste gas spreading to improve the hot-side temperature. Considering all these factors, the plate-shaped heat exchanger is more suitable for TEG application. Thermal performances of the maze-shaped internal structure and the fishbone-shaped internal structure are relatively ideal. From CFD simulation results, the maze shape has slightly higher interface temperature at the front end but lower at the outlet. However, the fishbone design shows better uniformity. Thus, the heat exchanger with fishbone shape is more ideal for TEG application. Heat exchanger lengths of 480 mm, 560 mm, and 600 mm were taken for simulation comparison, using the fishbone shaped structure and the same boundary conditions. Considering the overall output powers of the TEG, the greater the length, the more modules can be arranged on the TEG. The CFD simulation results were verified by experiments. Considering the agreement between the infrared experimental results and the CFD flow simulation results, a brass heat exchanger with fishbone shape and length of 600 mm is selected to form the hot side.

C.Q. SU et al. [5] studied about the thermal characteristics of the exhaust gas tanks with different internal structures and thicknesses in terms of the interface temperature and the thermal uniformity. Computational fluid dynamics (CFD) software is adopted to simulate the exhaust gas flow within the gas tank. Different three-dimensional models of the internal structure of the gas tanks are designed by changing internal baffles arrangements. Among these, the temperature distribution in the first structure (the 非 shape) and the second structure (the fishbone shape) of the gas tanks are relatively ideal.

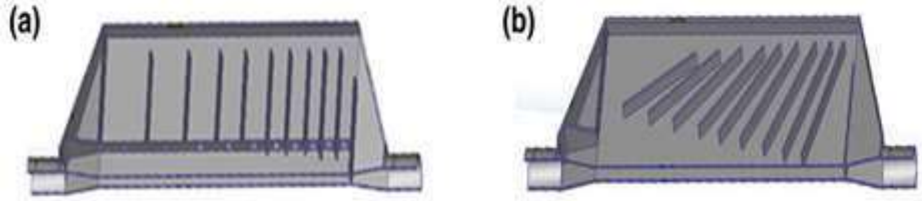

Fig -6 Three-dimensional models of the gas tank with the internal structure of (a) The 非 shape, (b) the fishbone shape [5]

Considering even temperature distribution, the practical effect of the gas tank with the fishbone shape is much better than that with the 非 shape. The interior thicknesses of the gas tanks are 24 mm, 16 mm, and 12 mm, respectively; for simulation comparison, the internal structures of these three gas tanks are the fishbone shape and other boundary conditions are same. The temperature distributions of the three gas tanks are roughly the same: higher in the middle and lower in both sides. The temperature distribution in 12 mm thickness is relatively more uniform. Thermal imaging system is used to shoot the surface temperature distribution on the gas tanks with different internal structures and varied interior thicknesses. From infrared experimental results and the CFD flow simulation results, the gas tank, the internal structure of which is the fishbone shape and the interior thickness of which is 12 mm, was selected to form the hot box.

Shekhar R. Gulwade et al. [6] studied about the characteristic of the heat exchanger with enhancement features in order to achieve uniform temperature distribution and higher surface temperature. The different internal structures will be used in the heat exchanger to enhance heat transfer rate. The internal structure of the heat exchanger made up of aluminum of 5 mm thickness, fin thickness is also 5 mm and 20 mm height made up of aluminum.

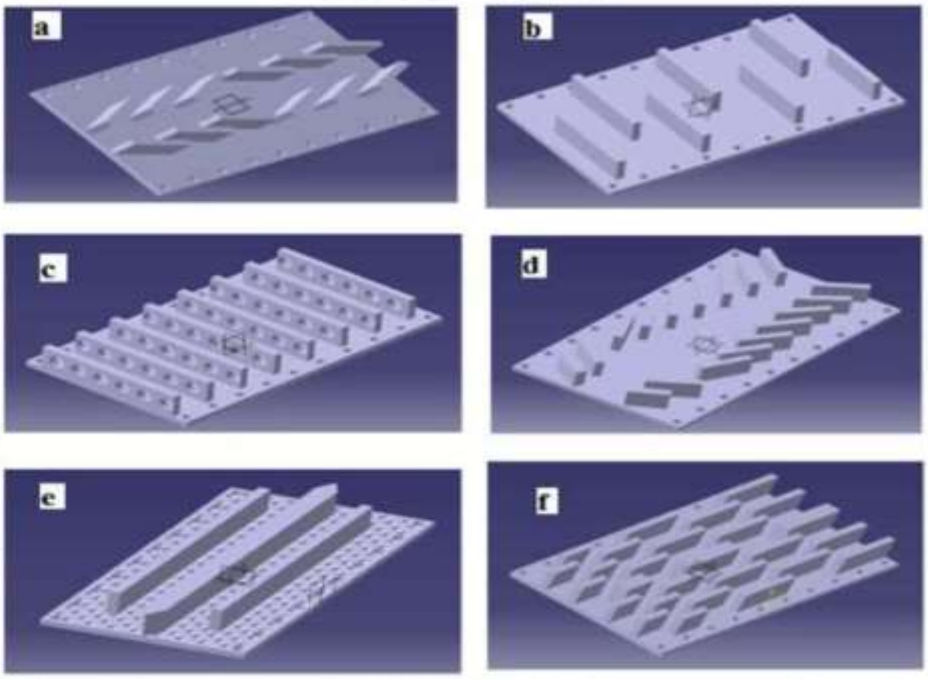

Fig -7 (a) Inclined plate structure, (b) Serial plate structure, (c) Separate plate with holes, (d) Fishbone-shape structure, (e) Dimple surface structure, (f) Accordion-shaped structure [6]

According to the position of the fins on the plate it is divided into number of internal structure such as inclined plate structure, Fishbone-shaped structure, Serial plate structure, Separate plate with holes, Dimple structure, and Accordion-shaped structure. Computational fluid dynamics (CFD) was used to simulate the exhaust gas flow within the heat exchanger, enabling simulation of the interface temperature distribution. Among these, the temperature distribution in the inclined-plate is relatively ideal, as compare to the fishbone shape.

3. CONCLUSIONS

The power generation of exhaust thermoelectric generator depends on heat energy and thermoelectric conversion efficiency. High efficiency of heat exchanger is necessary to increase the amount of heat energy extracted from exhaust gas. In this paper, study about different designs of internal structure, Thickness of heat exchanger plate, Surface area of heat exchanger, Materials has been done to increase heat transfer from exhaust gas.

Power produced by the Thermoelectric Generator is highly depends on the performance of exhaust heat exchanger. So heat absorbed by exhaust heat exchanger needs to be further increase to increase the temperature of hot junction so that more power will produced in thermoelectric generator. As the pressure drop due to exhaust heat exchanger is increased, there is a need of bypass mechanism with pressure switch to reduce pressure drop which needs to be eliminate.

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