Thermo Electric Generator

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Abstract -- Thermal management and energy crisis have been two major problems in this 21st century. Engine exhaust has tremendous amount of energy which can be recovered by waste heat recovery systems. The thermoelectric concept is seen as a perfect solution for recovering waste heat from engine exhaust and converts in to electric energy. Since the use of semiconductor materials for thermoelectric applications, there has been a huge quest for improving its figure of merits (ZT) to make it commercially viable. This synopsis report presents the simulation and experimental validation study on the transient behavior of a proposed combined exhaust heat recovery device and thermoelectric power generation system. The proposed system consists of waste heat recovery that provides a heat flux source for thermoelectric generators. In this research, thermoelectric generator device are consist of two major part, first one is exhaust recovery device and second one is thermoelectric generation system. In the first phase of study, optimize the waste heat recovery system design, performed cfd analysis and get heat and temperature data then cfd model coupled with thermoelectric model, find out the thermoelectric effect on particular devices. This paper presents of numerical simulation for several the thermoelectric materials. Numerical simulation is carried out by using a finite element package ANSYS.

Indexed Terms -- Thermoelectric Generator (TEG), Thermoelectric Material (TEM) Automotive Exhaust, Numerical Simulation.

I. INTRODUCTION

Thermoelectric generators are all solid- state devices that convert heat into space probes such as the Voyager missions of NASA.1 Compared to large, traditional heat engines, thermoelectric generators have lower efficiency. But for small applications, thermoelectric can Become competitive because they are compact, simple (inexpensive) and scale able. 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. A thermoelectric produces electrical power from heat flow across a temperature gradient. As the heat flows from hot to cold, free charge a carrier (electrons or holes) in the materials are also driven to the cold end. The resulting voltage (V) is proportional to the temperature difference (ΔT) via the Seebeck coefficient, α, ($V = \alpha \Delta T$). By connecting an electron conducting (n-type) and hole conducting (p-type) material in series, a net voltage is produced that can be driven through a load. A good thermoelectric material has a Seebeck coefficient between 100μV/K and 300μV/K; thus, in order to achieve a few volts at the load, many thermoelectric couples need to be connected in series to make the thermoelectric device. A thermoelectric generator convert's heat (Q) into electrical power (P) with efficiency η.

$$P = \eta Q \qquad (1)$$

The amount of heat, Q, that can be directed though the thermoelectric materials frequently depends on the size of the heat exchangers used to harvest the heat on the hot side and reject it on the cold side. The thermoelectric systems have been the subject of major advances in recent years, due to the development of semiconductors and the incorporation of the thermoelectric devices into domestic appliances. Generally, if a thermal gradient is applied to a solid, it will always be accompanied by an electric field in the opposite direction. This process is called as the thermoelectric effect. Thermoelectric material applications include refrigeration or electric power generation. The efficiency of a thermoelectric material is given by the figure of merit, Z, which is defined as [2]:

$$Z = \alpha^2\sigma/k, \ [1/k]. \qquad (2)$$

Where:

α - Material's Seebeck coefficient, V/K,

σ - Electrical conductivity of material, S/m, k – Thermal conductivity of material, W/ (m. K).

The numerator in equation (2) is called the power factor. Therefore, the most useful method in order to describe and compare the quality and thermoelectric efficiency of different material systems is the dimensionless figure of merit (ZT), where T is the temperature of interest. Therefore, equation (2) can be rewritten as:

$$ZT = \alpha^2\sigma T/k \qquad (3)$$

II. THERMO ELECTRIC GENERATOR CONCEPTS

In 1822 the German Scientist Seebeck discovered that a loop of two dissimilar metals developed an e.m.f. when the two junctions were kept at different temperatures. This effect has long been used in thermo-couples to measure temperatures. This phenomenon offers one method of producing electrical energy directly from the heat.

Principle of Working:
Thermo-electric generator is a device which converts heat energy (thermal energy) into electrical energy through semi-conductor or conductor. Consider a loop made of two dissimilar metals as shown in fig. and two junctions are maintained at T h (hot junction temp.) and T c (cold junction temp.) then the voltage developed in the open loop is given by:

$$V = \alpha s_{1\text{-}2}\ \Delta T \qquad (4)$$

Where $\alpha s_{1\text{-}2}$ is the see-beck coefficient. In most cases $\alpha s_{1\text{-}2}$ is depend on temperature, so that for larger temperature difference it is more accurate to express

$$V = \int^{T1}(\alpha s1 - 2)dT \qquad (5)$$

Therefore, we have to select the combination of the materials for the given temperature difference (Th-Tc) so the value of V becomes maximum.

$$\alpha s_{\ 1\text{-}2} = \lim_{\Delta T\text{-}0} \Delta V/\ \Delta T = dV/Dt \qquad (6)$$

The See beck coefficient depends upon the choice of the materials and cannot be attributed to either material above. It has unit of volt per degree.

III. LITERATURE REVIEW

Yongming Shi at el. [1]:
The thermal contact can influence the output performance of thermoelectric generators. However, in some applications, the heat source cannot afford an enough heating area for thermal contact. Therefore, compact thermoelectric generators based on optimized thermal contact interface should be designed and developed. In this paper, three- dimensional thermal extensional structures are designed, simulated, implemented and tested to optimize the thermal contact interface of compact thermoelectric generators. The result indicates that the compact thermoelectric generators based on three- dimensional thermal extensional structures can reduce the requirement of thermal contact area and make the heat flow directionally transferred to thermoelectric modules along the three-dimensional structure. In only 3600 mm^2 thermal contact area, the compact thermoelectric generators based on the three dimensional structure can generate 5.58 V and 829 m W within 900 s.

C.Q. Su at el. [2]:
Thermoelectric technology has revealed the potential for automotive exhaust-based thermoelectric generator (TEG), which contributes to the improvement of the fuel economy of the engine-powered vehicle. As a major factor, thermal capacity and heat transfer of the heat exchanger affect the performance of TEG effectively. With the thermal energy of exhaust gas harvested by thermoelectric modules, a temperature gradient appears on the heat exchanger surface, so as the interior flow distribution of the heat exchanger. In order to achieve uniform temperature distribution and higher interface temperature, the thermal characteristics of heat exchangers with various heat transfer enhancement features are studied, such as internal structure, material and surface area. Combining the computational fluid dynamics simulations and infrared test on a high- performance engine with a dynamometer, the thermal performance of the heat exchanger is evaluated. Simulation and experiment results show that a plate-shaped heat exchanger made of brass with accordion-shaped internal structure achieves a relatively ideal performance, which can

practically improve overall thermal performance of the TEG.

Ashwin Date at el. [3]:
This paper presents the theoretical analysis and experimental validation on the transient behavior of a proposed combined solar water heating and thermoelectric power generation system. The proposed system consists of concentrated solar thermal device that provides a high heat flux source for thermoelectric generators. Thermoelectric generators are passively cooled using the heat pipes that are embedded inside a heat spreader block. The heat pipe condenser is immersed in a water tank. The immersed liquid cooling technique offers high heat transfer coefficient for cooling of the thermoelectric generators as well as a way to scavenge the heat through water heating that can be used for domestic or industrial purpose. Theoretical analysis develops the governing equations for the proposed system. Results from a scaled down lab setup are used to validate the theoretical analysis. For a flux of 50,000 W/m2 a temperature difference of 75 º C across the thermoelectric generator can be achieved and the hot water can be heated up to 80 º C which can be used for domestic or industrial applications. With 75 º C temperature difference across the TEG hot and cold side, an open circuit voltage of 3.02 V can be generated for each thermoelectric generator with dimensions of 40 mm.

S Bari at el. [4]:
Higher depletion rate and increasing price of fossil fuels have motivated many researchers to harness energy from the waste heat from internal combustion engines, and thus improve the overall efficiency. Among the waste heat recovery methods, the bottoming rankine cycle is the most promising. In this technique, the recovered heat is used to produce additional power using turbine. In order to maximize the additional power production, an effective heat exchanger design is necessary. The main focus of the current research was to design heat exchangers which needed to be pancake- shaped to be retrofitted into a vehicle. The heat exchanges chosen were shell and U-tube type. CFD simulations were carried out to optimize the design of the heat exchangers and calculate the additional power that could be achievable by using these optimized pancake-shaped heat exchangers.

Ting Ma at el. [5]:
In this paper, the effect of longitudinal vortex generators (LVGs) on the performance of a large-scale thermoelectric power generator (TEG) with a plate-fin heat exchanger is investigated. The fluid-thermal-electric multi-physics coupled model for the TEG is established on the COMSOL® platform, in which the Seebeck, Peltier, Thomson, and Joule heating effects are taken into account. The equivalent thermal-electrical properties of the TE module are used in the numerical simulation. The results indicate that the LVGs could produce complex transverse vortices in the cross section downstream from the LVGs, thus enhancing the heat transfer and electric performances of the TEG compared with a TEG without LVGs.

M.Takashiri (2007) et al. [6]:
Has been done Bismuth–telluride based alloy thin film thermoelectric generator was fabricated by a flash evaporation method. The maximum output power of the thin film thermoelectric generator in this study is still not enough to apply as a power source for microelectronic devices. And for improving the performance of the generator they used hydrogen annealing process [6].

IV. THERMOELECTRIC MATERIALS

Lead telluride (PbTe), Bismuth telluride (Bi2Te3), Bismuth sulfide(Bi2S3),Antimony telluride (Sb2Te3), Tin telluride (SnTe), indium arsenide, germanium telluride (GeTe), cesium sulfide (CeS), zinc antimonied (ZnSb) Lead telluride (PbTe), a compound of lead and tellurium, containing small amounts of either bismuth (n-type) or sodium (p-type) has been commonly used in recent times for thermoelectric converters.

a) Conventional Thermoelectric Materials:
Thermoelectric materials (those which are employed in commercial applications) can be conveniently divided into three groupings based on the temperature range of operation, as shown in Figure. Alloys based on Bismuth (Bi) in combinations with Antimony (An), Tellurium (Te) or Selenium (Se) are referred to as low

temperature materials and can be used at temperatures up to around 450K. [9- 11]The intermediate temperature range - up to around 850K is the regime of materials based on alloys of Lead (Pb) while thermo elements employed at the highest temperatures are fabricated from SiGe alloys and operate up to 1300K as shown in figure 2. Efforts have focused primarily on improving the material's figure-of-merit, and hence the conversion, by reducing the lattice thermal conductivity [1].

V. APPLICATION OF TEG'S

Thermoelectric generator is a useful and environment friendly device with the advent of semiconductor materials the efficiency of a TEG can even be an alternative for the conventional heat engines. For the sustainable development of humankind and to stop climate change as outlined in the Kyoto Protocol.

The use of conventional energy sources such as fossil fuels will have to be limited in the very near future.

As one such alternative, thermoelectric energy has many favorable characteristics light weight, small scale, and low manufacturing cost [1].

Thermoelectric generators have been used in military, aerospace, instrument, industrial and commercial products, as a power- generation device for specific purposes.

Researchers have been concerned about the physical properties of thermoelectric materials and the manufacturing technique of thermoelectric modules [2]. With the advent of semiconductor materials the efficiency of a thermoelectric generator can even be an alternative for the conventional heat engines [3].

So, the mathematical modeling of a simple thermoelectric generator can also replace the elaborate task of simulating an actual complex power plant, heat engine or refrigerator.

A TEG produces a voltage when there is a temperature difference between the hot- side and cold-side of TEG.

Thermoelectric effect includes See beck effect, Peltier effect and Thomson effect; it also accompanies with other effects, such as Joule an effect and Fourier effect. Thermoelectric generation is a technology for directly converting- thermal energy into electrical energy, it has no moving parts, is compact, quiet, highly reliable and environmentally friendly. Because of these merits.

a) Application Waste Heat From Exhaust Gases Generated From Automotive:

Since 1914 the possibility of using thermoelectric power generation to recover some of waste heat energy from reciprocating engines has been explored and patented. A schematic diagram (figure) showing this patent of converting waste heat into electrical power applied to an internal combustion engine using a thermoelectric power generator is shown in Figure. In this invention, the exhaust gases in the pipe provide the heat source to the thermoelectric power generator, whereas the heat sink (cold side) is suggested to be provided by circulation of cooling water as shown in figure 3.

b) Thermoelectric power generators offer several distinct advantages over other technologies:

1. They are extremely and silent in operation since they have no mechanical moving parts and requires considerably less maintenance;
2. They are simple, compact and safe;
3. They have very small size and virtually weightless;
4. They are capable of operating at elevated temperatures;
5. They are suited for small-scale and remote applications
6. Typical of rural power supply, where there is limited or no electricity;
7. They are environmentally friendly;
8. They are not position-dependent; and
9. They are flexible power sources.

The major drawback of thermoelectric power generator is their relatively low conversion efficiency (typically ~5%). This has been a major cause in restricting their use in electrical power generation to specialized fields with extensive applications where reliability is a major consideration and cost is not. Applications over the past decade included industrial instruments, military, medical and aerospace, and applications for portable or remote power generation. However, in recent years, an increasing concern of environmental issues of emissions, in particular global warming has resulted in extensive research into nonconventional technologies of generating electrical power and thermoelectric power generation has emerged as a promising alternative green technology. Thermoelectric generators range over 15 orders of magnitude from the milli- microwatt gas miniature thermocouple arrays, integrated into a semiconductor chip to the multi-hundred watt isotopic powered generators deployed in space exploration. Generator applications can conveniently be categorized by their source of heat into fossil fuel, isotopic and waste heat powered.

VI. DESIGN OPTIMIZATION

The performance of a thermoelectric generator is dependent on many variables that could be optimized globally to find the optimum design. However, by using a reduced variable approach to the design problem, many interdependencies of the design variables are eliminated, which allows a better understanding of the effect of each variable [12-13]. The first goal of the design process is to evaluate the highest possible thermoelectric efficiency for all hot- and cold-side temperatures (of the thermoelectric generator, not the heat sinks), which may be viable. This will produce an optimized efficiency that is only a function of the thermoelectric hot- and cold-side temperatures:

$$\eta = \eta_{max} (T_h, T_c) \qquad (7)$$

The presumption is that any other variables (such as materials chosen, interface temperatures, geometry, current, etc.) that may be required for the calculation of efficiency can be optimized given a T_h and T_c. This is true for the thermoelectric material interface temperatures, but less true for size of metal interconnect and contact resistance.

VII. NUMERICAL SIMULATION

Numerical simulation is carried out by using a finite element package ANSYS. This package operates with three stages: preprocessor, solver and postprocessor. The procedure for doing a static thermoelectricity analysis consists of following main steps: create the physics environment, build and mesh the model assign physics attributes to each region within the model, apply boundary conditions and loads (excitation), obtain the solution, review the results. In order to define the physics environment for an analysis, it is necessary to use the ANSYS preprocessor (PREP7) and to establish a mathematical simulation model of the physical problem [14-15]. In order to do this, the following steps are presented below: set GUI Preferences, define the analysis title, define element types and options, define element coordinate systems, set real constants and define a system of units, define material properties. ANSYS includes three elements which can be used in modeling the thermoelectricity phenomenon. Element types establish the physics of the problem domain. Depending on the nature of the problem, it is necessary to define several element types to model the different physics regions in the model.

VIII. CONCLUSIONS

An analytical model of TEG will be developed based on thermodynamic theory, semiconductor thermoelectric theory, and law of conservation of energy, the equations of output power and current of thermoelectric generator (TEG). From above various papers studied result shown that the efficiency and power generated by various methods of thermoelectric generator (TEG) is very low. According to the analysis the output power per area is independent of the number of the thermo legs and of their cross- sectional area. Instead it depends just on the ratio of the cross sectional areas of insulation and of the length of the thermo legs. The power shows a maximum for a certain thermocouple length depending on the other parameters so to improve the performance of thermoelectric generator (TEG) by modifying the parameters and design methodology. To calculate the exact performance of a thermoelectric devices analytically, it is simplest to use a reduced variables approach that will separate the intensive properties and variables (such as temperature gradient, Seebeck coefficient, current density, heat flux density) from the extensive ones (e.g., voltage, temperature difference, power output, area, length, resistance, load resistance).

IX. FUTURE SCOPES

Vast quantities of untapped natural heat is available together with huge amount of waste heat, most of which is below 100^0C and is discharged into the environment. Thermoelectric generation is an environmentally friendly technology which can convert this unused heat, and in particular lower temperature heat, into electricity. This technology has been successfully demonstrated on a laboratory scale and in prototype commercial systems. Collaboration between University and Industry has resulted in research and development in this area of thermoelectric technology progressing rapidly In the near future thermoelectric waste heat recovery make a significant contribution over a wide range of applications, in reducing fossil fuel consumption and global warming.

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