Methods of Thermoelectric Generation From Waste Heat

Mr. Manjunath V B [1], Mr. Adesh Bhil[2], Mr. Mallesh Jakanur[3]
[1] Assistant Professor, Dept of Mech. Engineering
[1, 2, 3] Holy Mary Institute of Technology & Science, Hyderabad, India

Abstract- *The waste heat from energy company consumption sectors, when rejected into atmosphere, are useless and it contributes to global warming. Nowadays industrial activities and energy sectors (power stations, oil refineries, coke ovens, etc.) are the most energy consuming sectors worldwide and, consequently, the responsible for the release of large quantities of industrial waste heat to the environment by means of hot exhaust gases, cooling media and heat lost from hot equipment surfaces and heated products. Recovering and reusing these waste heats would provide an attractive opportunity for a low-carbon and less costly energy resource.*

Thermoelectric generator is the one of the method which helps to recover this waste heat, designing of thermoelectric generator was based on the range of temperature produced in industries and the objective is to generate optimum power with optimum material, Comsol Multiphysics software is the tool, which has been used to get the simulation results. High manganese silicide(HMS) has been chosen according to the properties of waste heat from industries, the simulation results shows that thermoelectric generator can be a good way to recover waste heat from local industries and converted to useful power, for instance to supply small sensing electronic equipment in the plant.

Keywords- Thermoelectric generator; Waste heat recovery; Thermo-electric system; Thermo-electric manufacturing; Thermoelectric power generation. Nozzle hole, Brake power, Emission analysis, VCR Engine

I. INTRODUCTION

The manufacturing or process industry consumes vast amount of energy and around its half eventually lost as waste heat to the environment in the form of flue gases and radiant heat energy. There is a clear need to improve the situation by capturing at least some of the waste heat (harvesting) and converting it back into useful energy such as electricity to supply for instance small sensing electronic devices of the plant system, to increase the efficiency of system. Also, recuperating it, helps to reduce the emission which contributes to global warming. There are a lot of technologies which are being used to capture the waste heat; these different methods which are normally used to recover waste heat, differ each other with respect to the intensity of waste heat, for instance some of them are not adequate for low temperature, others require moving part to converts waste heat into useful energy, and others are not environmental friendly.

This study is focusing on thermoelectric generators, which use thermoelectric effects to produce power. This technology is an interesting one, for direct heat to power conversion. Thermoelectric generators present potential applications in the conversion of low level thermal energy into electrical power. Especially in the case of waste heat recovery, it is unnecessary to consider the cost of the thermal energy input, and there are additional advantages, such as energy saving and emission reduction, so the low efficiency problem is no longer the most important issue that we have to take into account [1]**.**Thermoelectric generators work even at low temperature applications**,** there are a renewable energy sources and do not produce noise. This project is focusing on the design, modeling and manufacturing thermoelectric generator for waste heat recovery applicable in local industries, by using COMSOL metaphysics software as the tool. The design is based on the shape of the chimney, environment and cost of manufacturing; cost is found by considering all materials used in process, this helps to give conclusion weather the system should be adopted in local processing industries.

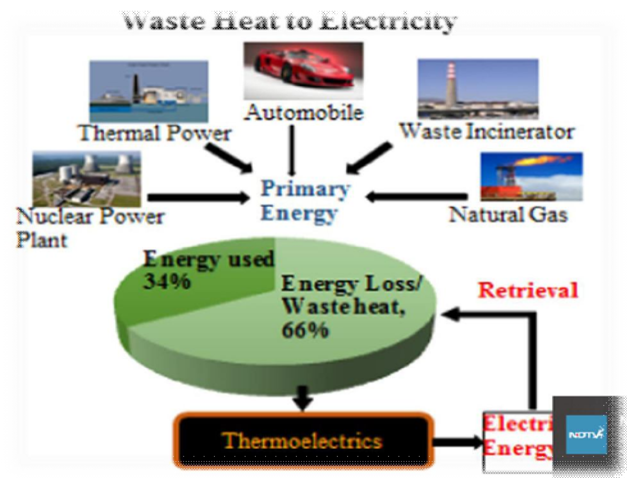


Figure 1: Thermoelectric generation of electricity offers a way to recapture some of the enormous amounts of wasted energy lost during industrial activities

II. OBJECTIVES

The objectives of this PAPER is to design and modeling a thermoelectric generator for waste heat recovery (module and heat exchanger) and calculate the optimum power with respect to optimum materials, by means of Comsol Multiphysics software. Input data are real waste heat values, from local industry which is 3B Fiberglass Company**.** Figure 3 shows purpose in the details, where the electricity can be produced when there is heat at one side and cold at the other side. The following points were considered to full fill the task:

- Assessing thermoelectric material
- Study how to use the waste heat as renewable energy sources
- Application of Thermoelectric in industry for waste heat recovery
- 3-D modeling of the thermoelectric generator in Comsol Multiphysics
- Using Comsol Multiphysics to optimize final module, considering cost per unity power.

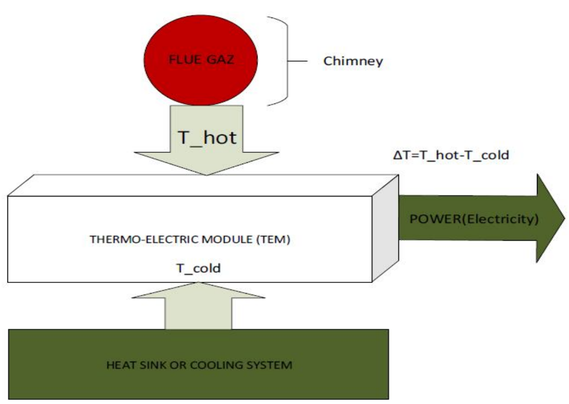


Figure 2: Block Diagram of Thermoelectric Generator Principle

2.1. KEY ASSUMPTIONS AND LIMITATIONS

The thesis will only focus on research of three thermoelectric materials in detail, skutterudites, bismuth telluride and silicide, the thermoelectric generator is modeled and sized per data from the local industry whose name is 3B fiber glass refining.

Design will be focusing on a simple design by considering the heat flow as 1 Dimensional construct by considering the heat conduction in Chimney thickness as lossless.

III. LITERATURE REVIEW

This part talks about waste heat, where it comes from, the way we can capture these waste heat and use it, so that to improve overall efficiency of the plant.

3.1. WASTE HEAT RECOVERY

Industrial waste heat refers to energy that is generated in industrial processes without being put to practical use. Sources of waste heat include hot combustion gases discharged to the atmosphere, heated products exiting industrial processes, and heat transfer from hot equipment surfaces. The waste heat temperature is a key factor determining waste heat recovery feasibility. Waste heat temperatures can vary significantly, with cooling water returns having low temperatures around 100- 200°F [40-90°C] and glass melting furnaces having flue temperatures above 2,400°F [1,320°C].

In order to enable heat transfer and recovery, it is necessary that the waste heat source temperature is higher than the heat sink temperature. Moreover, the magnitude of the temperature difference between the heat source and sink is an important determinant of waste heat's utility or "quality".

So far, today's electrical energy production is mostly affected by generators, based on electromagnetic induction. Reciprocating steam engines, internal combustion engines, and steam and gas turbines have been coupled with such generators in utilizing chemical heat sources such as oil, coal and natural gas and nuclear heat for the production of electrical energy. Renewable energy sources like geothermal energy, solar energy and biomass energy are also being added to the list of heat sources used in modern electric power plants. Furthermore, solar energy provides hydropower indirectly. All these power plants have, however, a common disadvantage; the conversion of thermal energy into electric energy is accomplished by the utilization of moving and wear-subjected machine equipment.

3.2. THERMOELECTRICITY

The term thermoelectricity refers to the phenomena in which a flux of electric charge is caused by a temperature gradient or the opposite in which a flux of heat is caused by an electric potential gradient. (Phenomena in which a temperature difference generates electricity or vice versa) These phenomena include three effects; the See-beck, Peltier and Thomson effect. The German physicist Thomas Johann Seebeck discovered the first of the thermoelectric effects in 1821. He found that a circuit made out of two dissimilar metals would deflect a compass needle if their junctions were kept at two different temperatures. Initially, he thought that this effect was due to magnetism induced by the temperature difference, but it was realized that it was due to an induced electrical current. The second of the effects was observed by the French watchmaker Jean Charles Athanase Peltier in 1834.

3.2.1. THERMOELECTIC DEVICES

Thermoelectric (TE) devices have attracted much attention in recent years because they can convert waste heat into electrical energy directly. The device is made of semiconductors and is normally the shape of a rectangular parallelepiped [12]. A pair of n- and p-type semiconductors, called a thermocouple, is the basic unit of a thermoelectric module. A schematic drawing of the basic unit is shown in figure 6. The n-type and p-type semiconductors are connected electrically at one end. The electric conductors are marked by * in the figure. TH and TC are the junction temperature and base temperature, respectively. The typical semiconductor pair geometry is as shown in figure 6 and the dimensions of the semiconductors is typically in the order of millimeters [11].A thermoelectric device converts thermal energy to electrical energy by using an array of thermocouples. This device is a reliable source of power for satellites, space probes, and even unmanned facilities. Satellites that fly toward planets that are far away from the sun cannot rely exclusively on solar panels to generate electricity. In the figure 7, Electrons on the hot side of a material are more energized than on the cold side. These electrons will flow from the hot side to the cold side. If a complete circuit can be made, electricity will flow continuously. Semiconductor materials are the most efficient, and are combined in pairs of “p type” and “n type”. The electrons flow from hot to cold in the “n type,” While the electron holes flow from hot to cold in the “p type.” This allows them to be combined electrically in series. Elements are combined in series to increase voltage and power output [13]

3.2.2 THERMOELECTRIC EFFECTS

Thermoelectric effect is defined as the direct conversion of temperature differences to electric voltage and vice versa. A thermoelectric device creates a voltage when there is a different temperature applied on each side. Conversely, when a voltage is applied to such a device, it creates a temperature difference. At the atomic scale, an applied temperature gradient causes charge carrier in the material to diffuse from the hot side to the cold side, thus inducing a thermal current, which is similar to a classical gas that expands when heated, leading a flux of the gas molecules. This effect can be used to generate electricity, measure temperature, or change the temperature of objects. Because the direction of heating and cooling is determined by the polarity of the applied voltage, thermoelectric devices are also efficient temperature controllers. The term ‘‘thermoelectric effect’’ encompasses three separately identified effects: the Seebeck effect, Peltier effect, and Thomson effect. In most textbooks, it is known as the Peltier-Seebeck effect. This name is given due to the independent discoveries of the effect by French physicist Jean Charles Athanase Peltier and Estonian-German physicist Thomas Johann Seebeck. Joule heating, a heat that is generated whenever a voltage is applied across a resistive material, is related, though it is not generally termed as thermoelectric effect.

3.2.3. SEEBECK EFFECT

When a conductive material is subjected to a thermal gradient, charge carriers migrate along the gradient from hot to cold; this is the Seebeck effect; if two dissimilar materials were joined together and the junctions were held at different temperatures (and) a voltage difference was developed that was proportional to the temperature difference .The ratio of the voltage developed to the temperature gradient is related to an intrinsic property of the materials called the Seebeck coefficient or the thermo power [15].

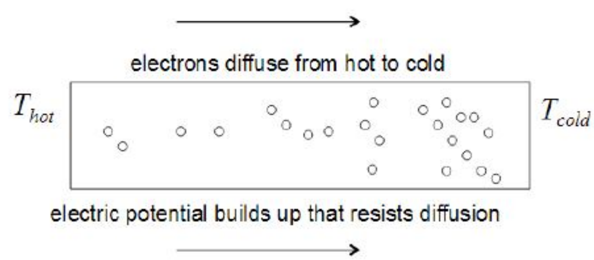


Figure 3: Motion of charge carriers

3.2.4. PELTIER EFFECT

The reverse of the Seebeck effect is also possible: by passing a current through two junctions, you can create a temperature difference. This process was discovered in 1834 by scientist named Peltier, and thus it is called the Peltier effect. This may sound similar to Joule heating described above, but in fact it is not. In Joule heating the current is only increasing the temperature in the material in which it flows. In Peltier effect devices, a temperature difference is created: one junction becomes cooler and one junction becomes hotter [19]. Simply Peltier has observed that if an electrical current is passed through the junction of two dissimilar materials (A and B), heat is either absorbed or rejected at the junction depending on the direction of the current see figure 10; to keep its temperature Constant.

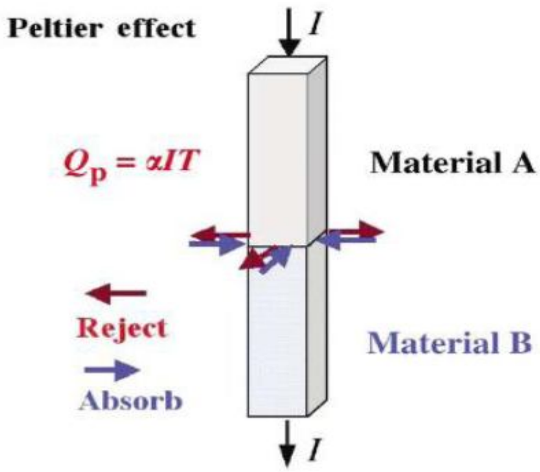


Figure 4: A schematic illustrating the Peltier effect between two dissimilar materials.

3.2.5 THOMSON EFFECT

Generation or absorption of heat in a current carrying conductor with a temperature gradient, Since charge carriers in the model semiconductor are considered free particles, each carrier is associated with thermal energy (3/2) kT (appendix-A). Thus, when a particle moves from lower to higher temperature it will absorb heat from its vicinity, and when it moves the other way it will deliver heat to it. When a charge carrier moves back and forth between two points with different temperatures, heat absorbed at the hotter point will be emitted at the colder point without any net charge flow, thus it contributes to heat conduction. When the net flow of charge carriers is not zero, as under the effect of an electric field, there will be net emission or absorption of heat along the conductor that depends on the flow direction. Thus, 6 both thermal conduction and the Thomson effect are a result of changing the heat content of the charge carriers as they move along the temperature gradient. Thermal conduction is the result of balanced carrier movement with zero average flow, and the Thomson effect is a result of a deviation from this balance.

IV. MODELING OF THE DEVICES

To properly perform a thermal analysis, the practical aspects of the underlying complex phenomenon must be known and so assumptions and simplifications must be made. Taking that into consideration, steady state is assumed, the heat losses due to radiation are neglected, the gap between the thermocouples is assumed perfectly isolated, the axial heat conduction within the thermocouples is ignored since the heat transfer in the y-direction is assumed to dominate and the current flow in the thermocouple is also assumed to be one-dimensional in the y-direction [20], no parallel leakage loss. Following these assumptions, the energy balance equation for an infinitesimal element dy, depicted in figure 34, can be given by:

$$Q - (Q_y + \frac{dQ_y}{dy} dy) + \frac{I^2 \rho}{A} dy = 0$$

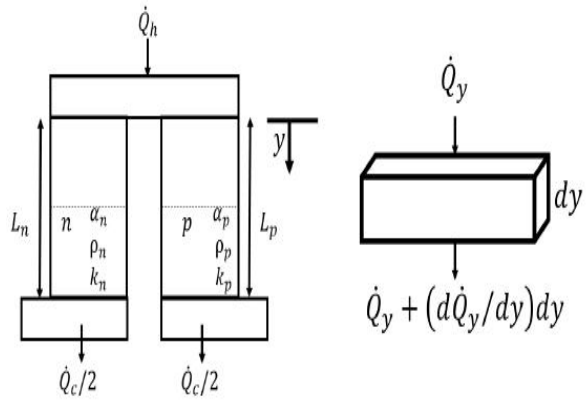
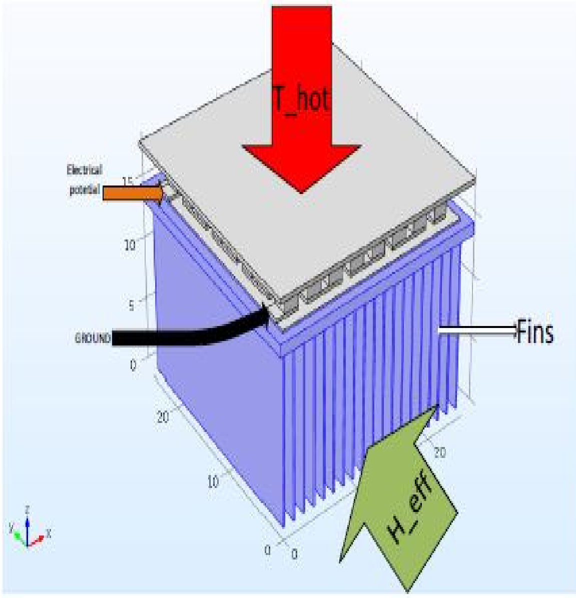


Figure 5: Schematic of the heat rate in a thermocouple

Material consideration in terms of cost, while modeling is important and it helps to use minimum cost as possible without affecting power output. This part describes how to model a thermoelectric generator with consideration of material and performance. In situations where there is excess heat (i.e., fuel/heat is free) the maximum power condition m=1 is most appropriate and yields the lowest cost. In situations where heat is costly, the maximum efficiency condition may be more appropriate.

4.1 MODELING AND SIMULATION IN COMSOL MULTIPHYSICS

COMSOL Multiphysics® is a general-purpose software platform, based on advanced numerical methods, for modeling and simulating physics-based problems. With COMSOL Multiphysics, you will be able to account for coupled or Multiphysics phenomena. With more than 30 add-on products to choose from, you can further expand the simulation platform with dedicated physics interfaces and tools for electrical, mechanical, fluid flow, and chemical applications. Additional interfacing products connect your COMSOL Multiphysics simulations with technical computing, CAD, and ECAD software. The problems we want to solve in real life are always based on Multiphysics phenomena. Thus, it's required to consider interaction between two or more physics domains at one time. COMSOL Multiphysics is defined for solving these complex problems. The program offers unique user-friendly working environment and provides wide range of tools for the fast and the effective analysis. COMSOL Multiphysics allows you to minimize the needs for physical prototypes, shorten product development times and achieve substantial savings in the development process



V. RESULTS AND DISCUSSIONS

This chapter is talking about the output results and analysis of the results. When the simulation is finished, the results of the thermoelectric generator performance, including the temperature supplied to the hot side, the generated current I, the output power P, open circuit voltage V, and the efficiency, were obtained. Figure 46 shows a temperature distribution of the thermoelectric module; the hot temperature has been applied to the upper side as you can see and for the cold side temperature as we are using heat sink to cool, effectiveness heat transfer coefficient is used instead of ambient temperature which has been taken is 2^0C and the surface temperature at the cold substrate side 10^0C. As indicated in Figure the temperature distributions are the same at the same level(Height) in all thermoelectric elements due to its parallel thermally arranged and clearly the cooling is good.

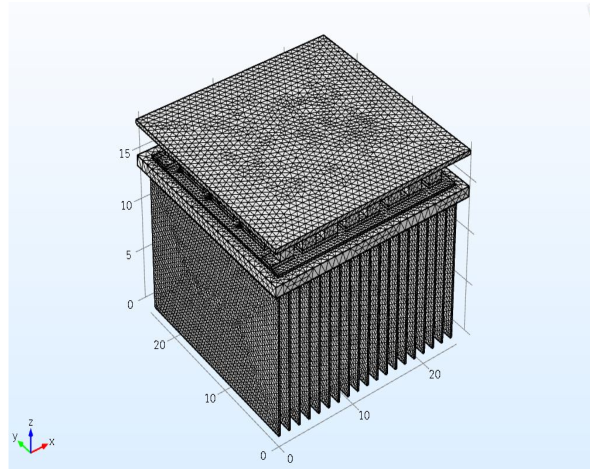


Figure 6: 3D Full COMSOL model System (boundary condition)

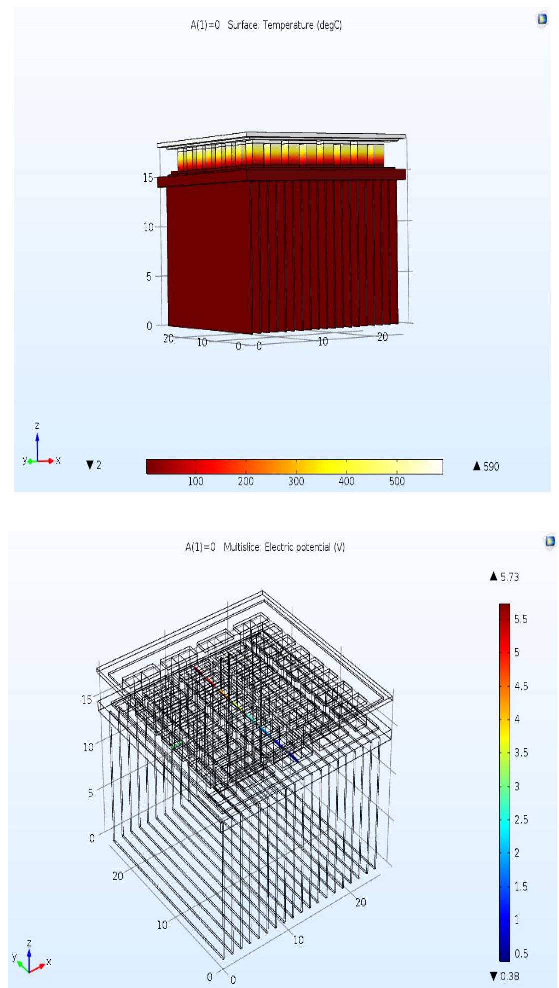


Figure7: Temperature and Voltage distribution *of the thermoelectric module*

The voltage distribution, how it varies with respect to different parameters; for instance, it shows electrical voltage distribution of the thermoelectric module, where the voltage increases with increased number of thermoelectric element couples, this is due to its electrically arranged in series. This proves that, once number of couples increase, electrical potential differences increases. Further analysis shows that the temperature difference is an important parameter; once increases, output voltage increases. There are different parameters that can be changed to get a desired output voltage such as ratio of area to the length of pellet, temperature differences, material properties, number of pellet couples (N), etc.

The output power from the thermoelectric module versus electrical current, obviously, while the electrical current is increasing the power increases till maximum power point. After optimum point the power decreases as the electrical current continuous to increase.as the objective of this thesis, this maximum of 12.1W is obtained with optimum material; at optimum thickness or height of thermoelectric legs, substrates, hot heat exchanger and heat sink, this power is not exactly as the calculated one; the difference is small which is due to the contact resistance error. This simulated power output of 12 W was found with usage of heat sink as cooling system, which is not different to power found without heat sink (appendix E), this means that the designed cooling system is successfully.

VI. CONCLUSION

Waste heat from industries, when are not captured, are useless and contribute to global warming, there are a lot of methods to recover the waste heat generated from local industries but here in this project, research was made on thermoelectric generator for waste heat recovery; which is the renewable energy source.

Thermo-electrics effect are the way electrical potential is generated, by presence of temperature difference and vice versa, and this result depend on material properties of thermocouples and their size, I mean areas and lengths; High manganese silicide (HMS) has been used to make thermo-elements materials.

Design which has been done, including the design and modeling of thermoelectric generator, Heat exchanger on both sides; hot heat exchanger and heat sink (cold side) which helps to predict the real system, it was based on the properties of waste heat from local industries; like temperature range to work with and the Cost per optimum power, where the obtained optimum power was reached with usage of optimum materials. Simulation done by using Comsol Multiphysics is good because it doesn’t consume materials and it is easy to edit when you want to change any parameters.

This paper is focused mainly on thermoelectric generator and different technologies which is used on thermoelectric generators. It includes how thermoelectricity is better than other solar based technology to make electricity. But there is a drawback of thermoelectric generators of its low efficiency or low figure of merit. In this review, different methods are presented to obtain a higher satisfactory efficiency. There is easy solution to gain this higher efficiency with the help of material changing properties and waste heat recovery on the both side junction of thermoelectric module. In the recent years mainly last decades the considerable progresses in materials science and nanotechnologies have brought to a great improvement in the values of the dimensionless figure of merit.

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