© 2016 IJSRSET | Volume 2 | Issue 5 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Development of Thermoelectric Generators for the Waste Heat Recovery

Kaleru Sai Kiran[1], Dr. V. V. Prathibha Bharathi[2]

[1]Student, Department of Mechanical Engineering, Malla Reddy College of Engineering, Hyderabad, Telangana, India
[2]Professor, Department of Mechanical Engineering, Malla Reddy College of Engineering, Hyderabad, Telangana, India

ABSTRACT

To design and analyse a model that can utilize the waste heat energy from various sources like heat energy obtained the car engines exhaust system and to convert obtained heat energy into electricity for multipurpose use in automobiles. Many considerations have been taken to make this system economical, easy to implement and does not produce any burden on car efficiency or engine efficiency. The model has been developed to simulate coupled thermal and electrical energy transfer processes in a thermoelectric generator (TEG) designed for automotive waste heat recovery systems. Conventional bismuth telluride is considered for thermoelectric modules (TEMs) for conversion of waste heat from exhaust into usable electrical power. Heat transfer between the hot exhaust gas and the hot side of the TEMs is enhanced with the use of a plate-fin heat exchanger integrated within the TEG and using forced conventional cooling on the cold side. The TEG is discretized along the exhaust flow direction using a finite-volume method. Detailed results are provided for local and global heat transfer and electric power generation. During the research, thermoelectric device is tested in a variety of configurations with the goal of demonstrating a thermoelectric-powered fan.

Keywords: Thermo-Electric Module, Peltier Effect, Exhaust System, Bismuth Telluride, Plate-Fin Heat Exchanger, Thermoelectric-Powered Fan.

I. INTRODUCTION

Our addiction to electricity has generated a concurrent addiction to fossil fuels. However, the reserves of fossil fuels will soon be depleted, since oil is a limited resource. Over the years, the cost of electricity has risen to unprecedented levels due the limited supply of oil and economic and political factors. Thus, renewable energy is a more attractive alternative to electricity generation, as it will also provide a cleaner environment for future generations. In the world today, there are many great solutions to renewable energy, but some are unfeasible. In this proposed project, a device will be created to introduce a way for humans to create renewable energy using thermoelectric devices.

This project aims to provide a source of renewable energy that overcomes the limitations of current methods. 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. These satellites will have to use an alternative energy source, such as thermoelectric devices, to generate their power. Thermoelectric devices for deep-space missions use a radioactive material, like plutonium, to generate heat, and thermocouples to convert the heat to electricity. Since a thermoelectric device has no moving parts, it is reliable and can generate electricity for many years. Studies have been done on improving the efficiency of thermoelectric generator by incorporating other technologies, like nanotechnology. By achieving a better efficiency, thermoelectric devices would need less radioactive material to produce the same amount of power, making the power generation system lighter. Less radioactive material will also decrease the cost of spaceflight launches.

II. DESIGN CONSTRAINTS

Essentially the goal is to remove sufficient heat from the device so that it does not overheat, while retaining the largest temperature at the hot side of the TE module to generate power. There are two broad categories in terms of geometrical configurations: the thermoelectric module can either be thermally in series or in parallel with the main heat sink. Furthermore, flow conditions considered for the chosen geometry must include both forced convection for the steady state and natural convection for the start-up transient. The following constraints are required:

- Constraint 1: Maximum junction temperature of 125 C
- Constraint 2: Create the largest possible temperature difference across thermoelectric module given constraint 1
- Constraint 3: Thermal contact can only be made on one side of the device (usually the case for power devices)

An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it.

III. THERMAL CIRCUIT AND FEM SIMULATION

A thermally series configuration, as show in figure 1, is not feasible simply because, while it would provide the largest temperature difference across the thermoelectric module, the thermal resistance of the TE module is so large that efficient heat removal is impossible, even with forced convection.

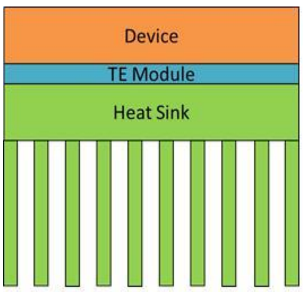

Figure 1: Thermally Series Configuration

This leaves a parallel configuration as the only alternative. Regardless of the exact geometry, the general simplified DC thermal circuit for any parallel configuration will have the same structure in steady state.

In this DC thermal circuit, R_{te}, the thermoelectric module's thermal resistance, can be assumed to be much larger than the combined thermal resistance of the other branch, so that very little heat passes through the thermoelectric branch. R_{hs} depends on the geometry and heat sink material, while $R_{hs\ air}$ depends on the surface area of the fins and air speed in the forced convection case. We also assume that we have no control over R_{te}, since the surface area available for the TE module will necessarily be on the order of the size of the device. With these assumptions, the original design constraints amount to a maximization of the high side temperature up to T_{junct} by increasing $R_{hs\mathbf{1}}$ and $R_{hs\ air\mathbf{1}}$ while minimizing the heat sink resistances in the top branch so that as much of the temperature difference as possible appears across R_{te}. We propose one possible configuration, shown in figure 2, which allows us to modify these parameters.

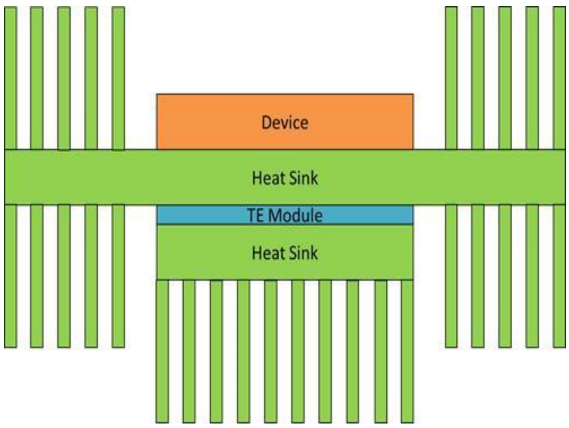

Figure 2: Thermally Parallel Configuration

In the proposed configuration, the TE module is placed at the hottest point of the heat sink, so that as long as constraint 1 is met, constraint 2 is also met. $R_{hs\ air}$ can be modified by changing the number of fins in the main heat sink and the thermoelectric heat sink, and $R_{hs\mathbf{1}}$ and $R_{hs\mathbf{2}}$ can be changed by altering the dimensions of the main heat sink.

In the simulation, the device is a volumetric heat source producing 2000 W and the thermoelectric module has the same length and width as the device, with a thickness of 3.4 mm (roughly the thickness of a commercial Peltier cooler). In accordance with the assumption that heat can only be removed from one side of the device, the top surface has a thermal insulation boundary condition.

The device is immersed in a box of air in which represents open space. The heat equation is solved on the solid and coupled to the incompressible Navier-Stokes equations on the fluid domain via continuity for heat and the no-slip condition for fluid flow. The no-slip boundary condition on walls is a common approximation made in computational fluid dynamics for low and intermediate velocities, and greatly simplifies the computation as long as the ns are not close enough together that boundary overlap effects occur.

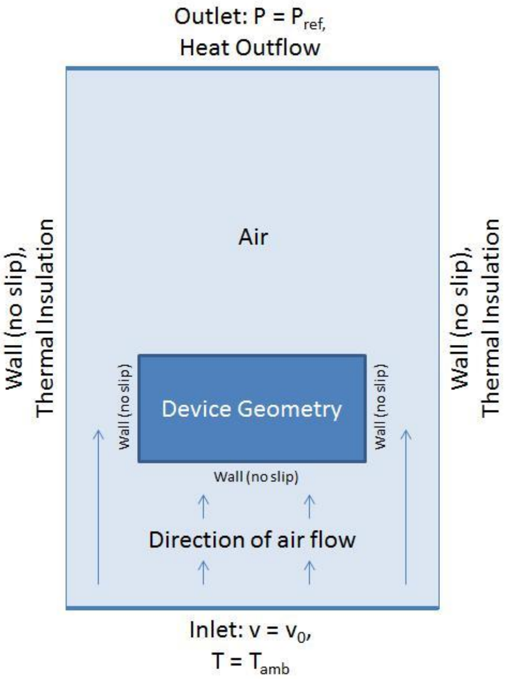

Figure 3 : shows the boundary conditions for the steady-state forced convection simulations.

The inlet boundary conditions are constant temperature and velocity profile and the outlet boundary conditions are constant pressure and heat out flow. The heat out flow condition in COMSOL is identical to thermal insulation and states that the only heat transfer is by convection. The side walls of the fluid domain also have the thermal insulation condition and no-slip walls which, for a large enough box approximates a large open domain.

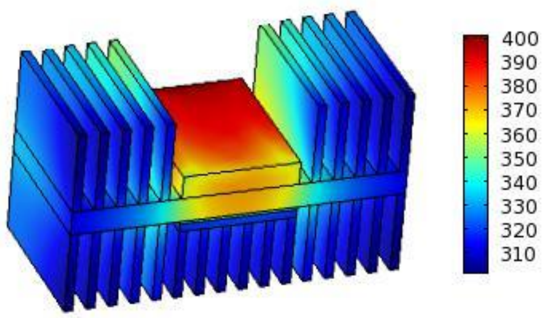

Figure 4 : Surface Temperature, Forced Convection

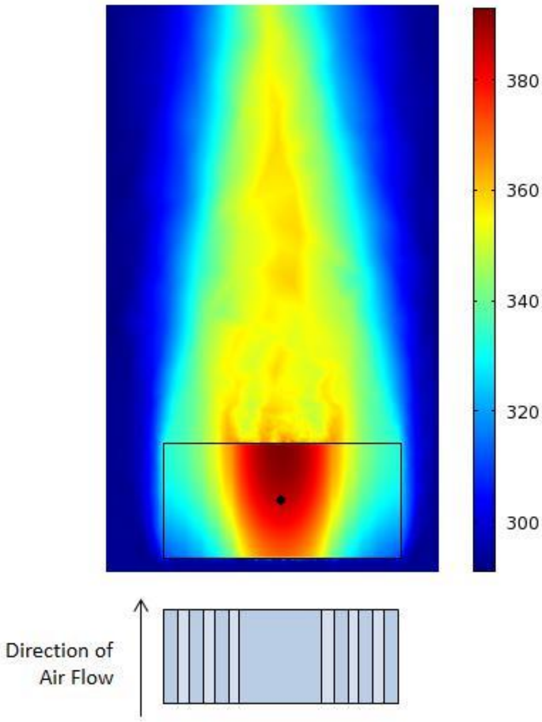

Figure 5 : Cross Sectional Temperature, Forced Convection

The rectangular outline in figure 5 represents the position of the device, and the point denotes the axis along which figure 6, the temperature profile, is plotted. The orientation of the in figure 5 is the same as in figure 5. In figure 6, the temperature profile goes linearly from x = 0 mm, the top of the IGBT (Insulated gate bipolar transistor) to x = 16 mm, the tip of the thermoelectric heat sink's fins.

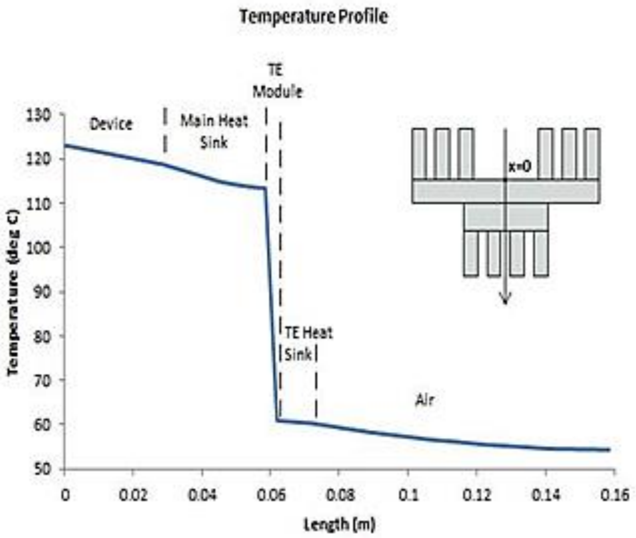

Figure 6 : Temperature Profile, Forced Convection

With an inlet velocity of 2 m/s, we see a drop of approximately 60^0 C across the thermoelectric module in steady state, quite good considering the highest temperature in the system is just under 125^0C. Integrating the heat flux into the TE module results in a value of 250 W. Assuming an average efficiency of 4% for the thermoelectric module, around 10 W of power will be recovered.

Integrating the pressure drop over the inlet and multiplying by the inlet velocity, we calculate the fan power required to cool the heat sink to be about 5 W. In theory then, it appears that by using an optimized geometry and with an efficient thermoelectric material, using the recovered heat to power the cooling fan in closed loop is possible, at least in steady state. A trade can be made between output power and fan speed (and hence, device temperature) since increasing fan speed lowers the average temperature of the system. Figures 7 and 8 show the total heat flux through the thermoelectric module and temperature, respectively, as functions of fan speed.

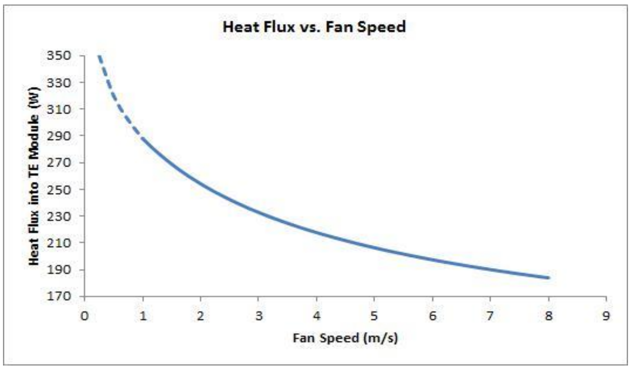

Figure 7: Heat Flux vs. Fan Speed

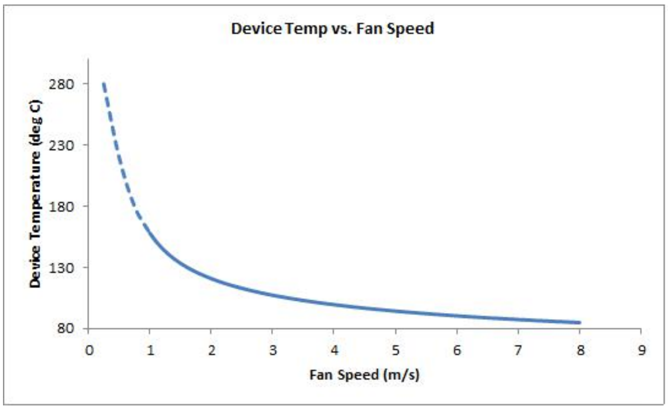

Figure 8 : Device Temperature vs. Fan Speed

The heat flux-vs.-fan speed (Figure 7) and device temperature-vs.-fan speed (Figure 8) are extrapolated below 1 m/s because the forced convection model does not take into account natural convection. At low fan speeds, the steady-state solution approaches a situation where temperature is uniform and no heat flows through either branch, which is unrealistic. If the fan power-vs.-fan speed characteristic is known, then the intersection between the fan power-vs.-fan speed and power generated-vs.-fan speed curves denotes the steady state operating point of the system without any control, as shown in figure 9.

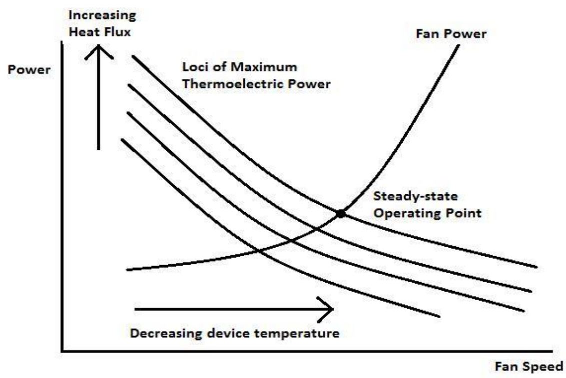

Figure 9: Operating Point

The locuses of maximum thermoelectric power represent the peak power points as functions of input heat and fan speed, with reference to Figure 7, since the peak power generated will be a fixed percentage of the total heat flux through the thermoelectric leg of the geometry. The point shown in figure 9 is the operating point with the least available power output. Therefore, any operating point to the left of the steady-state operating point along the fan power curve is possible with the appropriate control system, trading power output for device temperature while generating excess power.

The components of the control system in figure 10 are:

Plant: The plant includes the heat sinks and thermoelectric module, which may be obtained using the appropriate model, for instance the one developed in this paper.

Maximum power point tracker (MPPT): A controller which measures the input voltage and current and alters the duty cycle of a dc/dc converter to maintain the instantaneous power V I at a maximum. This ensures that the power being output by the TE module remains on the locus of peak power points.

Voltage Regulator and Bus: Creates a constant voltage bus to power the fan and to distribute excess power if the fan is not taking 100% of the power generated.

Fan Controller: Measures fan current and speed in order to regulate fan speed. The fan speed command can be (1) set based on the difference between the measured thermoelectric power and a reference power, (2) set at a constant value or (3) be allowed to reach the steady state operating point. The fan controller then sends the PWM signals to the inverter which powers the fan.

Fan: A synchronous motor which cools the device and heat sinks.

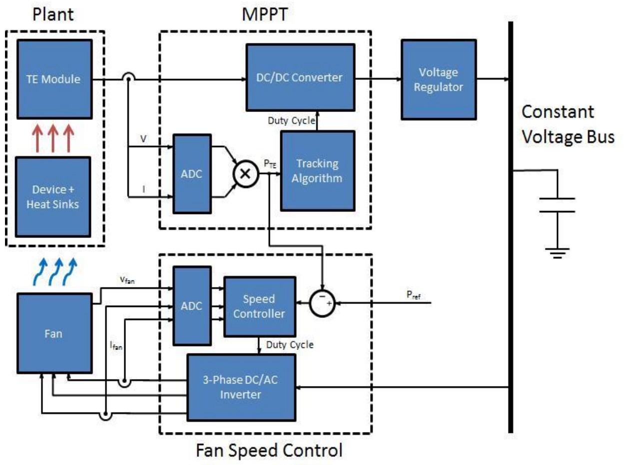

Figure 10 : Control System

The final thing to consider is the start-up behaviour of such a coupled system. Since we have already designed for the system to have the maximum allowed junction temperature in order to recover the largest amount of energy, having the system start in natural convection will shoot T_{junct} past 125^0C.

Assuming the fan gets enough power to turn on at exactly 125^0C, it is of interest to simulate exactly how much higher the temperature rises and for how long. For this purpose we designed another simulation with natural convection conditions, ran that simulation until T_{junct} reached 125^0C, and used the state at that point as the initial conditions for a forced convection simulation. The result is shown in figure 11.

The results of the simulation show that for our test case, the temperature overshoot is on the order of a few degrees over a time scale of tens of seconds.

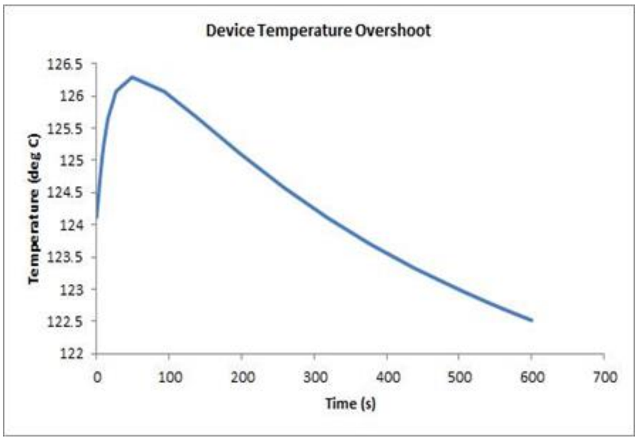

Figure 11 : Temperature Overshoot

The percent overshoot would depend on the geometry of the heat sink and the amount of heat being generated by the device, but these results show any transient temperature rise during start-up is limited in both magnitude and duration.

IV. CONCLUSION

The steady state and transient behaviour of the sample design was investigated, and it was found that a steady state solution where a fan was being driven by power generated from waste heat was theoretically possible, and that the temperature overshoot associated with start-up was relatively minor. A possible control structure for the system was also considered.

V. REFERENCES

[1] A. W. Crook (ed). Pro_ting From Low-Grade Waste Heat. London: Institute of Electrical Engineers, 1994.

[2] D. M. Rowe (ed). CRC Handbook of Thermoelectrics. Danvers, MA: CRC Press, 1995.

[3] Simon Lineykin and Sam Ben-Yaakov. \Analysis of Thermoelectric Coolers by a SPICE-Compatible Equivalent Circuit Model". In: (2005).

[4] R.C. O'Briena et al. \Safe radioisotope thermoelectric generators and heat sources for space applications". In: (2009).

[5] Gang Chen. Nanoscale Energy Transport and Conversion. Oxford: Oxford University Press, 2005.

[6] J. A. Chavez et al. \SPICE Model of Thermoelectric Elements Including Thermal Effects". In: (2000).