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To Study the Performance of Thermoelectric Generator using Plate Fin, Round Fin & Square Fin Heat Sinks

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Abstract **Energy cannot be converted into useful work completely, and a large part of it is wasted as heat. As the demand for energy continues to grow, scientists across the world trying to use this waste heat to generate additional electricity and hence increases the overall efficiency. One of the emerging waste heat recovery technologies is "Thermoelectric generator (TEG)", which is being studied in detail in this paper.**

Besides many advantages, there are certain limitations of TEG which include low conversion efficiency and high electrical output resistance. In order to increase the efficiency of TEG, the temperature of the cold plate should decrease. The temperature decrease of cold plate with the help of different heat sinks is the main focus of this report. The report further includes the heat transfer analysis of different fin configuration and their contribution in power development and efficiency of TEG. We found that the maximum efficiency of TEG can be achieved through round fin heat sink (RFHS) in forced convection with its width facing the fan.

Keywords — Thermoelectric generator, waste heat recovery, PFHS, RFHS, SFHS.

I. INTRODUCTION

As the civilisation and industrialisation are growing rapidly, there is a depletion of available resources at a very faster rate. It leads to the energy crisis and deterioration of the environment. So there is a need for reduction in the amount of energy consumed or the resource utilized through proper design, planning, elimination of waste and its recovery. This is collectively known as energy Conservation [1]. According to the second law of thermodynamics, there is a need for dumping some thermal energy to the environment in order to get the useful work. The dumped thermal energy is called as waste heat [2]. Generally the potential of the waste heat depend upon the temperature at which the waste heat is dumped. International Energy Agency (IEA) estimated that about 50% of the energy consumed by all industries is released as waste heat [3]. Therefore there is an enormous potential of waste heat is available in all industries, so there is a need to utilise some amount of waste heat by the process called waste heat recovery. In any traditional power generation processes, thermal energy is first converted into mechanical and then to electrical energy however in recent years a huge development has been made on direct conversion of thermal energy to electrical energy [4-5]. Thermoelectric generation of electricity is one of them and is being discussed in this paper.

TEG is one of the waste heat recovery processes which utilises waste thermal energy and directly converts it into additional electricity. The principle behind this conversion is that if a temperature difference is created between the two sides of a thermoelectric (TE) device or module, electricity can be produced. This behavior is due to the "Seebeck effect" which that "whenever two dissimilar materials are joined in such a way that one junction is heated and other is cooled then an electromotive force is generated within the material" [6]. The e.m.f. or the voltage developed is given by $\Delta V = \propto_{AB} \Delta T$, Where $\propto_{AB}$ = Seebeck Coefficient. Another similar phenomenon which is also important in thermoelectric effect is Peltier Effect which gives $Q_p = \Pi_{AB} I$, Where Q_p= Heat evolved or absorbed and Π_{AB} = Peltier coefficient [6]. The voltage generated is very small so to get an appreciated voltage many hot and cold junction combinations are connected in series, but this does not work, as the connecting wire opposes the electron movement and net voltage generated is zero [7]. Researchers later found that TE effect are prominent in semiconductor as they have high seebeck coefficient [8]. A typical TE module composed of two ceramic plates which provide electrical insulation to the TE elements that are connected electrically in series and thermally in parallel between the ceramics [9]. TE devices have many advantages over other waste heat recovery processes such as they are environment friendly, compact size and reliable Because of the above advantages, thermoelectric devices have wide range of applications such as in military, medical, aerospace, industrial and at home [9]. Generally, the performance of a TEG is evaluated by two parameters, output power and overall conversion efficiency. The

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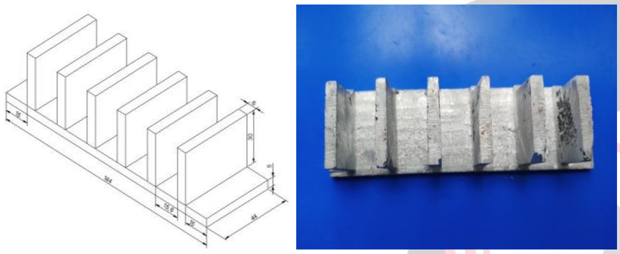
performance also depends on figure of merit (ZT), greater the value of value of ZT, greater will be the conversion efficiency [10]. Generally ZT value is between 0.8 and 1 at room temperature [11]. The conversion efficiency depends on the temperature difference between hot plate and cold heat sink. Heat sinks increase the surface area of contact with surrounding fluid which ultimately increases the heat transfer rate [12]. To quantify heat transfer through the heat sinks, the convective heat transfer coefficient and heat transfer area must be known. The behavior of different heat sinks is observed in natural and forced convection and its effect on the performance of TEG.

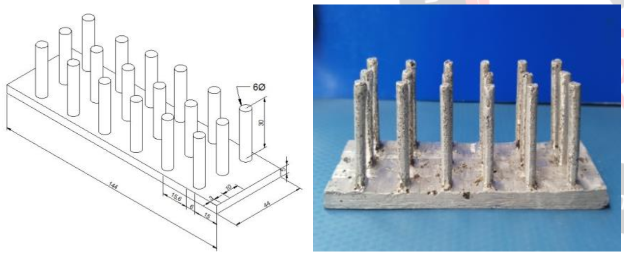
II. HEAT SINK DESIGN

There are many designs of fins for heat sinks, but they generally comprise a base and a number of protrusions (fins) attached to this base. The basic fin designs which are presented below are (a) Plate fin heat sink (PFHS), (b) Round fin heat sink (RFHS) and (c) Square fin heat sink (SFHS). These heat sinks are made in such a way that they have same fin spacing and fin thickness.



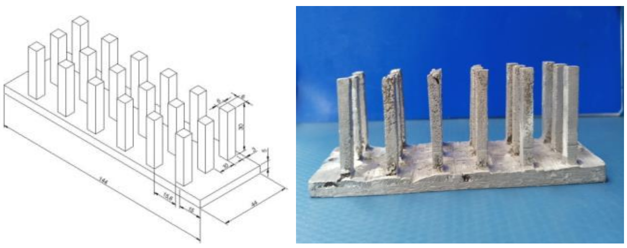
(a) (b)

Fig 1: Isometric view (a) and Pictorial view (b) of PFHS



(a) (b)

Fig 2: Isometric view (a) and Pictorial view (b) of RFHS



(a) (b)

Fig 3: Isometric view (a) and Pictorial view (b) of RFHS

Table 1: Dimensions of the heat sinks are:

PARAMETERS	DIMENSIONS (mm)
Length of the base plate	144
Width of the base plate	44
Thickness of the base plate	5
Fin spacing along the length	15.6
Fin spacing along the width	10
Fin thickness	6

There are many method of manufacturing of heat sinks like extrusion, stamping, casting, machining, forging, folding and bonding. Based on purpose, performance, cost, volume and complexity, we have used casting method for the manufacturing of heat sinks. The complex pattern for casting is produced using 3-D Printer.

III. EXPERIMENTAL SET UP

The performance of the heat sinks and also the performance of the TEG using different heat sinks are experimentally determined and later compared for both natural convection (Fig 4) and forced convection (Fig 5).

A. Natural Convection:

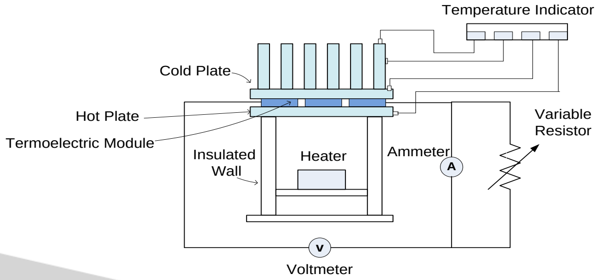


Fig 4: Schematic diagram of experimental setup (Natural Convection)

Power supply is given to the heater of 350 Watts. Hot plate is heated and on the other hand, heat is being removed from heat sink through fins. A combination of 3 units of thermoelectric generator is connected in series and is sandwiched between hot and cold plate heat sink. Because of the temperature gradient between hot and cold plate, a voltage is generated and current is flown in the circuit. For 1 hour, temperatures of the hot plate, cold plate, fin tip and surface temperatures are carefully noted using temperature indicators. The corresponding voltage and current produced by TEG is also measured using multimeter. The experiment is repeated for round and square fin heat sink.

B. Forced Convection:

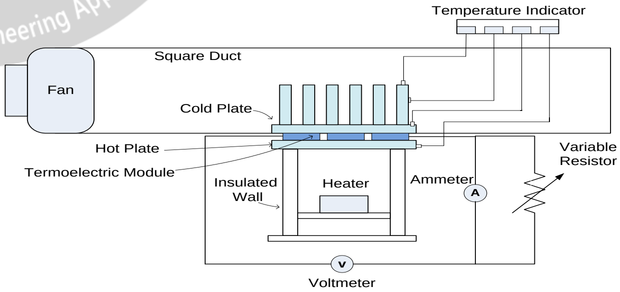


Fig 5: Schematic diagram of experimental setup (Forced Convection)

In the previous setup of natural convection, an additional square duct of cross section 20cm×20cm along with a fan is installed. The velocity of air through the duct is measured using anemometer. Different heat sinks are tested one by one in the same manner as that of natural convection, except this time forced air is passed through the heat sink.

IV. OBSERVATION

The comparisons of different heat sinks based on the various parameters are shown below. The positions of heat sink in forced convection also cause the variation in

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experimental outcomes, so they have also been considered in the comparison. RFHS (1), SFHS (1) are the positions when width facing fan and RFHS (2), SFHS (2) are positions when length facing the fan.

A. Comparison based on 'Temperature variation along the fin of heat sink'.

A.1. Forced Convection:

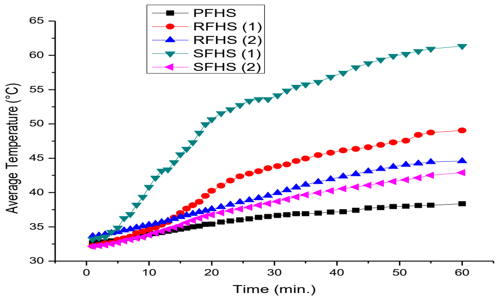

Fig 6: Variation of average temperature with time

Figure 6 shows the variation of average temperature of heat sink along the height of the fin. The observation is done under forced convection. The slope of the curves show decreases with time and almost zero after one hour. The fin SFHS (1) shows highest and PFHS has the lowest variation of temperature in forced convection. It is also observed that RFHS and SFHS with width facing fan shows better performance than length facing the fan.

A.2. Natural Convection

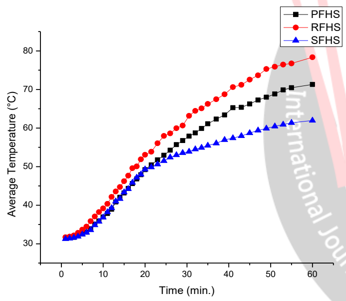

Fig 7: Variation of average temperature with time

Fig 7 shows the variation of average temperature of the heat sinks along the height for natural convection. In this condition RFHS shows highest and SFHS shows lowest variation.

B. Comparison based on 'heat transfer'.

B.1. Forced Convection:

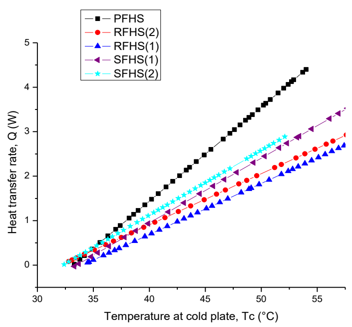

Fig 8: Variation of heat transfer with temperature at cold plate

Fig 8 shows the variation of heat transfer rate of the different heat sinks in forced convection. The linear nature of curves shows that heat transfer rate is proportional to the temperature at cold plate. It can also be seen that PFHS has the highest heat transfer rate and RFHS (1) has the lowest among the heat sinks. Here also RFHS and SFHS with width facing fan shows better performance than length facing the fan.

B.2. Natural Convection:

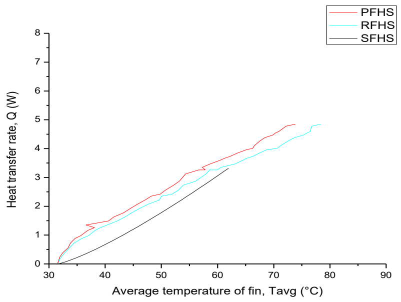

Fig 9: Variation of heat transfer with temperature at cold plate

Fig 9 shows the variation of heat transfer rate of different heat sinks in natural convection. The curve shows the PFHS fin has the highest heat transfer rate and SFHS has the lowest.

C. Comparison based on 'power developed by TEG'.

C.1. Forced Convection:

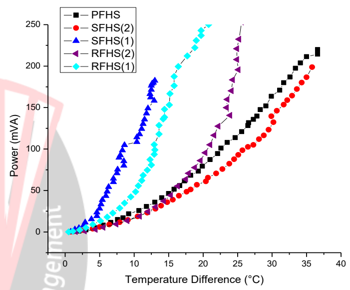

Fig 10: Variation of power developed by TEG with temperature difference

Fig 8 shows the variation of power developed by TEG with temperature difference. The power develop varies linearly up to certain temperature difference and after that it increases rapidly. These curves also show that RFHS and SFHS with width facing fan shows better performance than length facing the fan.

C.2. Natural Convection:

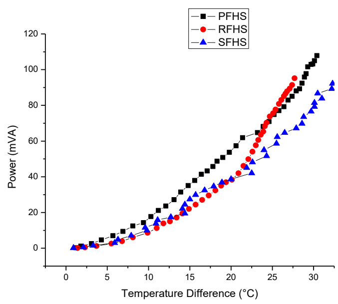

Fig 11: Variation of power developed by TEG with temperature difference

Fig 11 shows the power developed by TEG with temperature difference in natural convection. The slope of the curve is increasing nature, which means that the

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power develops increases rapidly after certain temperature difference.

V. Result and Discussion

A. Assumptions made in the development of this report:

- The ambient temperature is assumed to be constant.
- There is very less contact resistance between TEG and plates and hence they are neglected.
- Temperatures encounter this report is very low, hence the effect of radiation is also neglected.

B. The following results have been found:

- The maximum efficiency and effectiveness can be achieved through RFHS.
- The maximum power developed by TEG through RFSH in forced convection with width facing the fan.
- The minimum power developed by TEG through SFSH in natural convection with length facing the fan.
- Maximum heat transfer is obtained by PFSH both in natural and forced convection.

VI. Conclusion

This report concluded that the forced convection helps to develop maximum thermoelectric power. RFHS gives the better result in both natural and forced convection. This report further concludes that for the better performance of TEG, width of heat sink should face the air current rather than length of the heat sink. This report also shows that, though natural convection gives more temperature difference between hot and cold plat but forced convection gives more thermoelectric power.

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