

Thermal Analysis and Comparison of Heat Exchangers Attached to Thermoelectric Generator

Satish Eppar¹, Surendra Patil²

P.G. Student, Department of Mechanical Engineering, Shri Shivaji College of Engineering and Management Studies
Parbhani, Maharashtra, India¹

Assistant Professor, Department of Mechanical Engineering, Shri Shivaji College of Engineering and Management
Studies Parbhani, Maharashtra, India²

ABSTRACT: Thermoelectric generators are widely used in order to recover waste heat from different heat generating devices. Their performance is greatly influenced by thermal capacity and heat transfer rate of the coupled heat exchanger. The objective of this study is to suggest two heat exchanger designs, comparative analysis of these designs and finally suggesting the better option. In this paper the analysis of heat exchanger is done in two ways. One is by simulating in NX 16.0 software where the performance of the heat exchangers is simulated and studied by means of a steady state 3D turbulent model with a heat conduction module. In order to simulate actual working conditions of heat exchanger, a hot block with an electric heater is induced in the model. Other method includes analysis using a specially designed test rig. Here TEG recovers heat from a heated block and rejects heat to the heat exchangers and the analysis is done analytically. The comparative analysis will lead us to a single better heat exchanger device which would give the better results.

KEYWORDS: TEG, heat exchanger, thermal performance, temperature difference.

I. INTRODUCTION

Approximately 40% of the fuel energy is lost in exhaust gas according to energy balance of a combustion engine, which intensifies the energy crisis and environment pollution. As one way to recover waste heat, Thermoelectric generation (TEG) technology can recover waste heat from the exhaust and convert thermal energy into electrical energy with the advantages of being highly reliable, zero emission, low noise and involving no moving parts. Thermoelectric modules (TEMs) made of semiconductor materials are sandwiched between the heat exchanger and the cooling unit in an exhaust-based thermoelectric generation. This sandwich structure is kept by the clamping devices. Exhaust gas flows into the hot-side heat exchanger through a bypass to form the hot source. Cooling water pumps into the cooling water tanks to form the cooler. The electric power is generated as a result of the temperature difference based on the Seebeck effect.

The thermal performance of a heat exchanger, which is important for an integrated solar cell/module and thermoelectric generator (TEG) system, has been paid little attention to date. From a comprehensive literature review, it is found that the performance analysis of a heat exchanger for TEG application is usually done by using a simple 1D heat conduction theory. For example, free convection heat transfer and heat conduction in a flat-plate heat exchanger of TEG for an ocean thermal energy conversion (OTEC) system was analysed by Henderson [1] with a 1D heat transfer theory. Consequently, the heat exchanger-TEG system performance was investigated and a relationship between the TEG element area-to-length ratio and the temperature difference across the TEG and resulting electric power generation was obtained.

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II. CONSTRUCTION OF TEG

A single thermoelectric couple is constructed from two 'pellets' of semiconductor material usually made from Bismuth Telluride (Bi_2Te_3). One of these pellets is doped with acceptor impurity to create a P-type pellet; the other is doped with donor impurity to produce an N-type pellet. The two pellets are physically linked together on one side, usually with a small strip of copper, and mounted between two ceramic outer plates that provide electrical isolation and structural integrity.

For thermoelectric power generation, if a temperature difference is maintained between two sides of the thermoelectric couple, thermal energy will move through the device with this heat and an electrical voltage, called the Seebeck voltage, will be created. If a resistive load is connected across the thermoelectric couple's output terminals, electrical current will flow in the load and a voltage will be generated at the load. Practical thermoelectric modules are constructed with several of these thermoelectric couples connected electrically in series and thermally in parallel. Standard thermoelectric modules typically contain a minimum of three couples, rising to one hundred and twenty seven couples for larger devices. A schematic diagram of a single thermoelectric couple connected for thermoelectric power generation, and a side view of a thermoelectric module is shown in figure 1

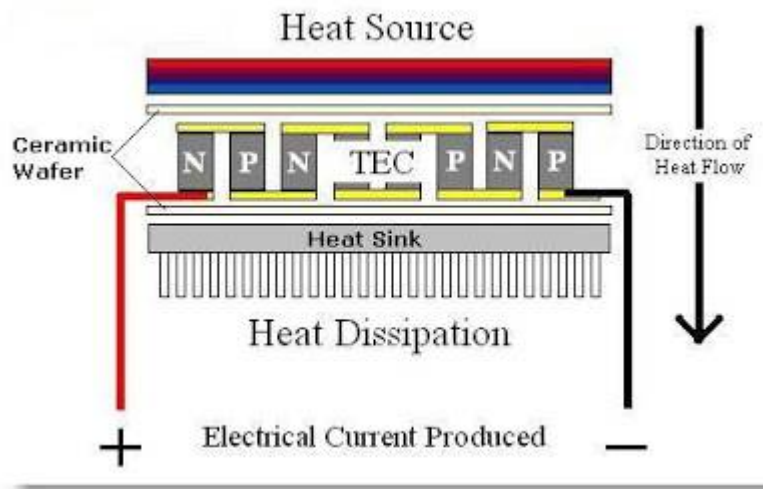


Figure 1: construction of TEG

III. ROLE OF HEAT EXCHANGER IN PERFORMANCE OF TEG

A thermoelectric pair can be used to generate electric power, since Seebeck effect indicates that if the junctions of two thermoelectric legs type "p" and "n" are exposed to different temperatures, an electric current is induced. On the other hand, if an external electric source supplies power to the thermoelectric pair, Peltier effect states that one junction absorbs heat whereas the other one generates heat, so that the thermoelectric pair performs like a thermal machine that receives electric work, removes heat from a cold reservoir and emits heat to a hot reservoir. There are in the market different types of Peltier modules, composed of several thermoelectric pairs connected electrically in series and thermally in parallel. Figure 1 shows an average thermoelectric module working as refrigerator.

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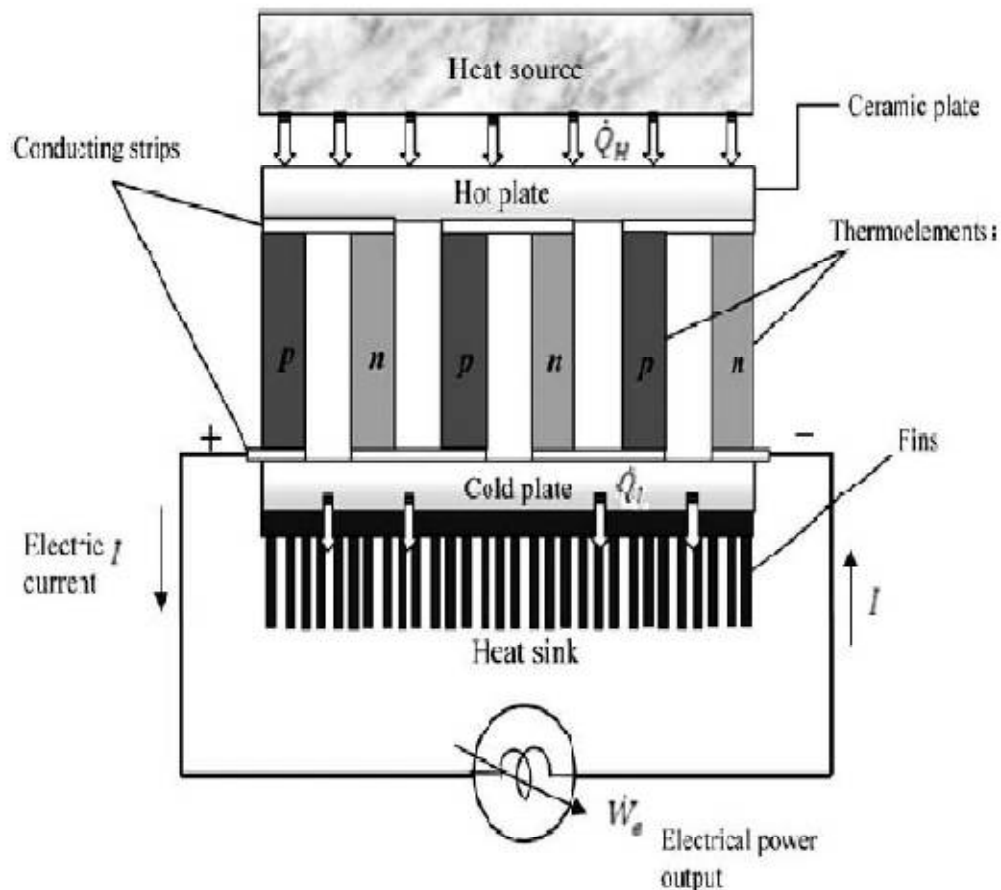


Figure 2: TEG module

In order to improve the heat transfer both in the hot and the cold side, a heat exchanger must be installed at either side of the Peltier module to increase the heat transfer area. The Peltier module is a small device that emits –or absorbs– large amounts of heat, so that the heat density or heat flux is significantly high. The face of a Peltier module is so small that increasing the heat transfer surface area of the heat exchanger (finned dissipater and cold plate in Figure 1) is virtually useless, since the effectiveness of the heat exchanger decreases as more heat transfer surface area is added. This makes difficult to attain proper heat transfer. Therefore, efficiencies of thermoelectric modules and thermoelectric devices in general, designed for either generation or refrigeration purpose, depend to a great extent on the thermal resistances of the heat exchangers installed at either side of the modules.

IV. EXPERIMENTATION AND COMPUTATION METHOD

Two heat exchangers are designed, one is a tube exchanger and the other is a fin exchanger, as shown in Fig.3. The heat exchanger is firmly attached to the top surface of a TEG by a pressure load by applying thermal glue. The water flow in the exchanger absorbs the heat discharged by the TEG when it generates electric power. The TEG is heated underneath through its substrate by an electrical heater inside the hot block. As a result, the interface between the exchanger and the TEG is kept at a lower temperature, but the interface between the hot block and the TEG is at a higher temperature. Eventually, a temperature difference is established between both sides of the TEG and electrical power is generated.

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To deal with an uneven distribution of temperature on the interfaces between the TEG and both the hot block and heat exchanger, three components must be considered simultaneously in a heat transfer simulation.

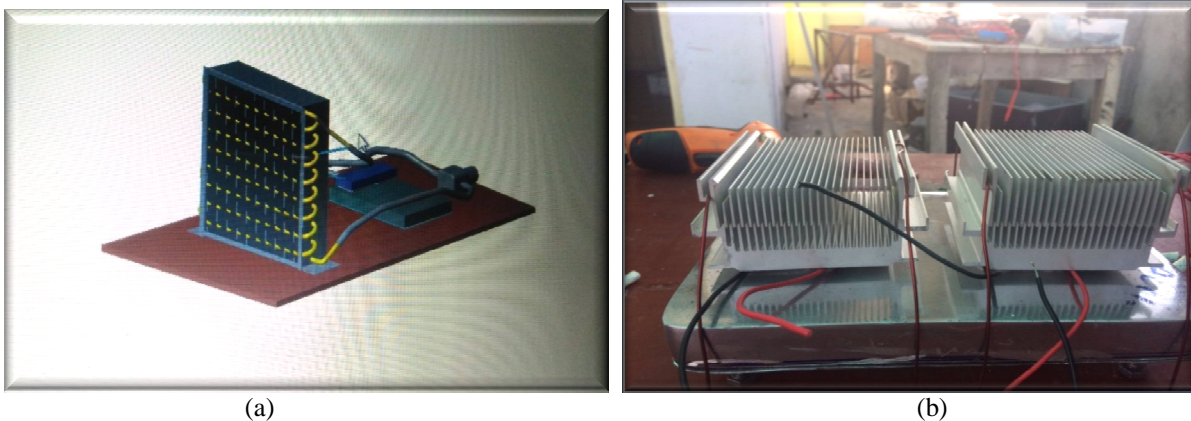


Figure 3: (a) Tube Type Heat Exchanger, (b) Fin Type Heat Exchanger

The TEG structure is simplified to a solid structure so as to make the heat transfer analysis easy, see Fig. 2. This simplified structure keeps its thermal behaviour being equivalent to the TEG based on a 1D heat conduction theory. In the simplification, a few assumptions are made: (1) the materials of each component of the TEG are homogenous and their thermal resistance, heat specific capacity and density are constant and independent of temperature; (2) the thermal contact effect inside the TEG and on the interfaces between both the heater and heat exchanger and the TEG are negligible; (3) the effects of the air inside the TEG on the free heat convection and the equivalent density of the TEG are not taken into account. The heat conductivity of the copper straps is two-orders of magnitude larger than those of the legs and substrates, thus the heat resistance in the copper straps is also ignored. Additionally, the copper straps are as thin as 0.2 mm, so their contribution to the equivalent density of the TEG is excluded.

V. COMPUTATIONAL MODEL

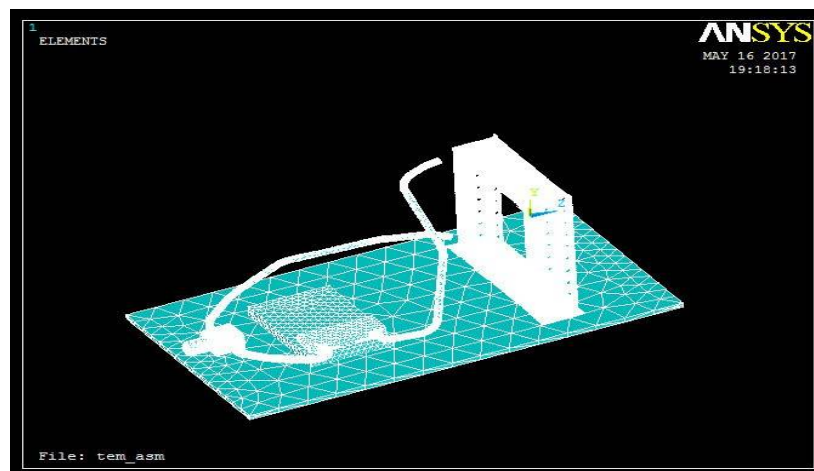


Figure 4: Meshed Model

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The computational domains include the solid domains (hot block, heat exchanger case, fins, inlet and outlet pipes and TEG) and the fluid domain (cooling water). At first, the computational geometrical models are generated in Creo and then read by the ANSYS Design Modeller. Subsequently, the geometrical models are meshed using the ANSYS mesh generator. The numbers of mesh cells used in the tube exchanger are 1.66 million, respectively, see Fig. 3. A tetrahedral mesh is generated in the solid domains of the heat exchanger and the hot block as well as in the fluid domains. Due to the difference in the linear dimensional scale, the mesh at the inlet and outlet tubes of heat exchanger is not fine enough, but is adequate for heat transfer analysis.

VI. EXPERIMENTAL RESULTS

The following are the results obtained by fin type heat exchanger

Sr. No.	Temp. of hot interface (°C)	Temp. at fin side (°C)	Temp. difference (°C)	Power generated by TEG (W)
1	39	29	10	0.31
2	45	31	14	0.71
3	68	40	28	0.88
4	77	42	35	1.63
5	91	49	42	1.94
6	115	55	60	2.20
7	132	59	73	2.90
8	154	66	88	3.28
9	161	71	90	3.90
10	187	75	112	7.40

The following results are obtained by tube type heat exchanger

Sr. No.	Temp. of hot interface (°C)	Temp. at fin side (°C)	Temp. difference (°C)	Power generated by TEG (W)
1	34	22	12	0.43
2	53	23	30	0.88
3	70	26	44	1.9
4	81	31	50	2.4
5	105	33	72	2.9
6	117	38	79	3.2
7	128	42	86	3.8
8	155	45	110	4.6
9	198	46	152	5.5
10	200	47	153	6.8

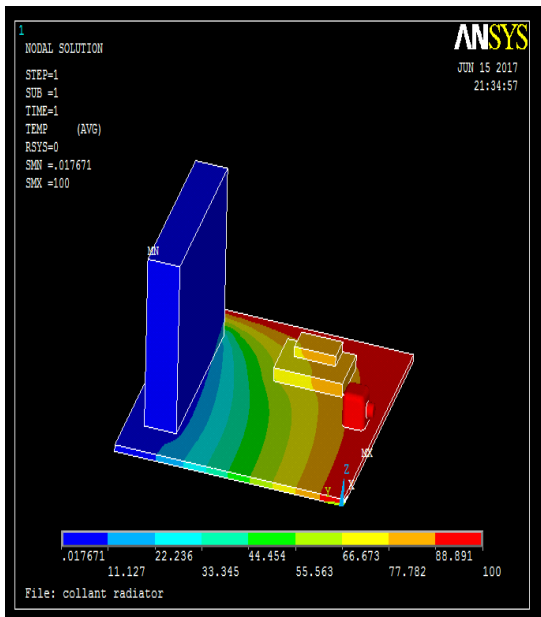
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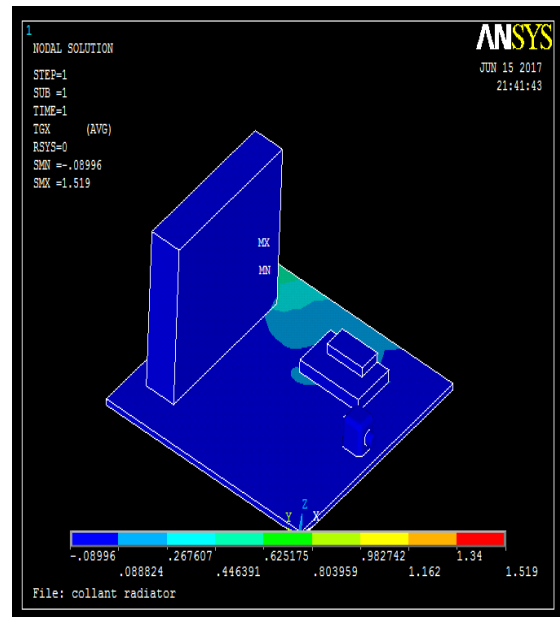
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The results obtained by the ANSYS are as follows



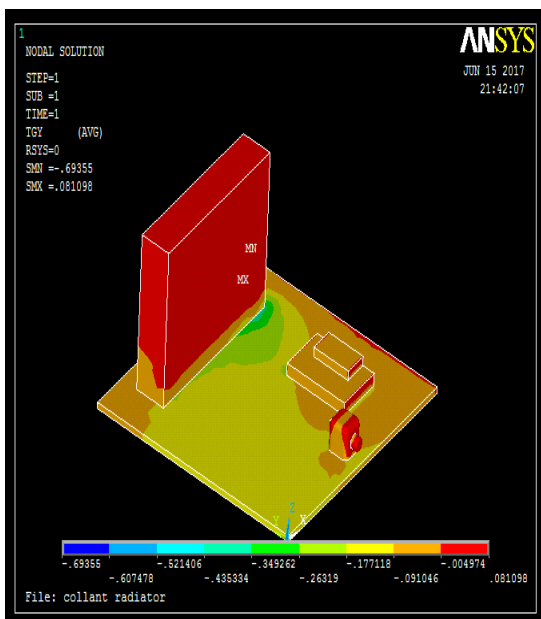
(a)

Fig 5: (a) Nodal Gradient,



(b)

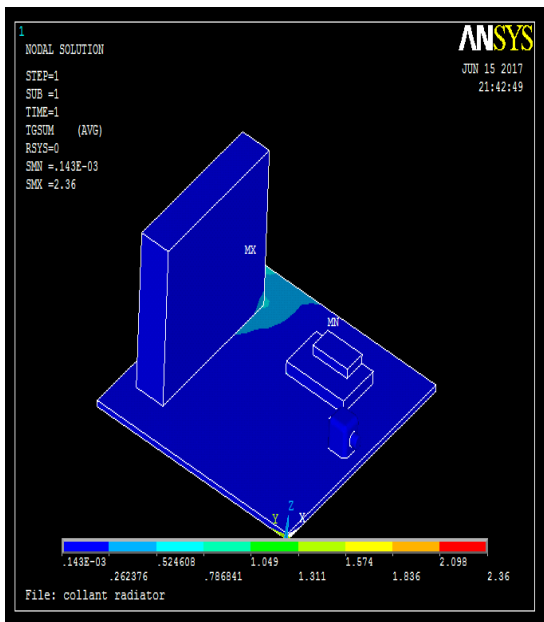
(b) X- Direction of Thermal Gradient



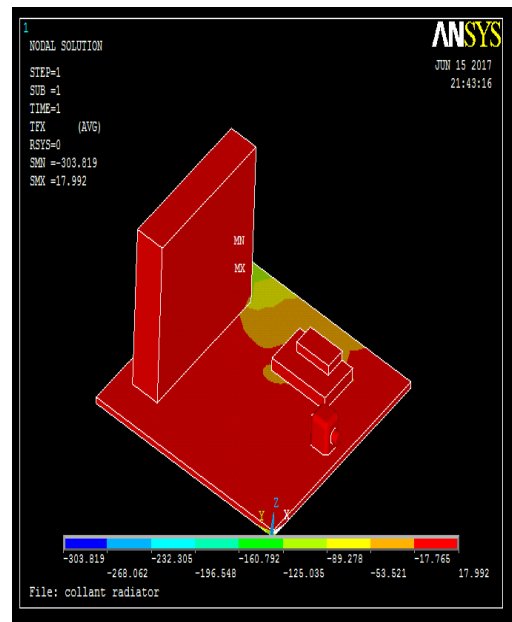
(c)



(d)

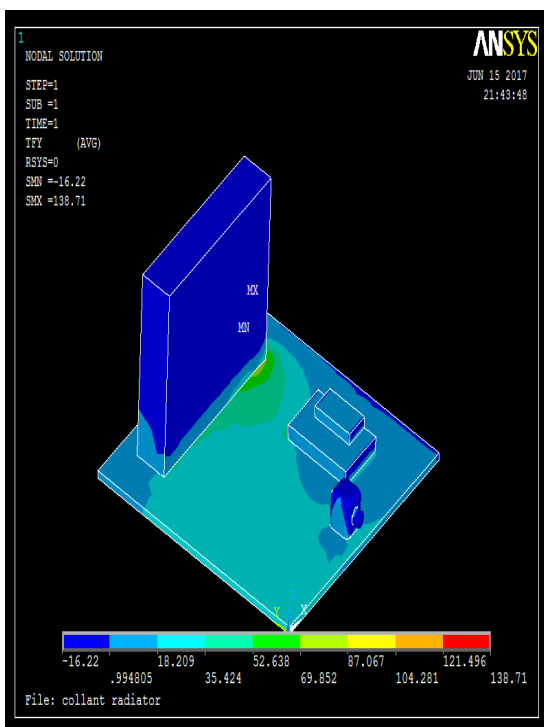


(e)

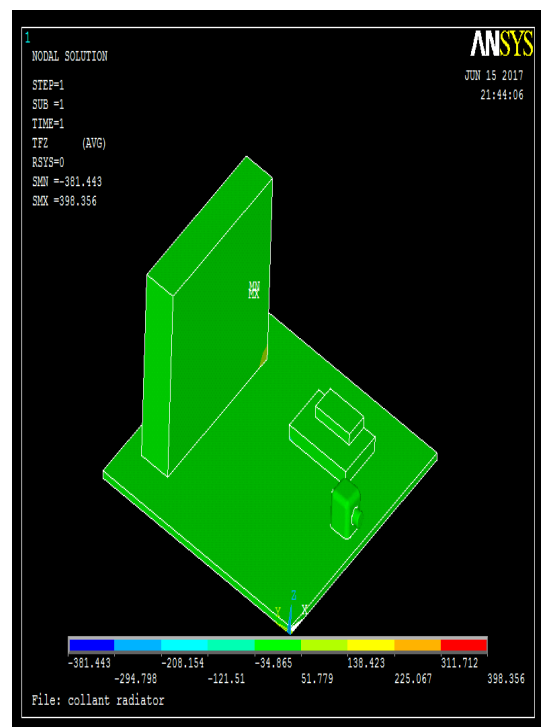


(f)

Fig 6: (c) Direction Of Thermal Gradient, (d) Z-Direction Of Thermal Gradient, (e) Direction Of Thermal Flux, (f) Thermal Gradient Vector Sum



(g)



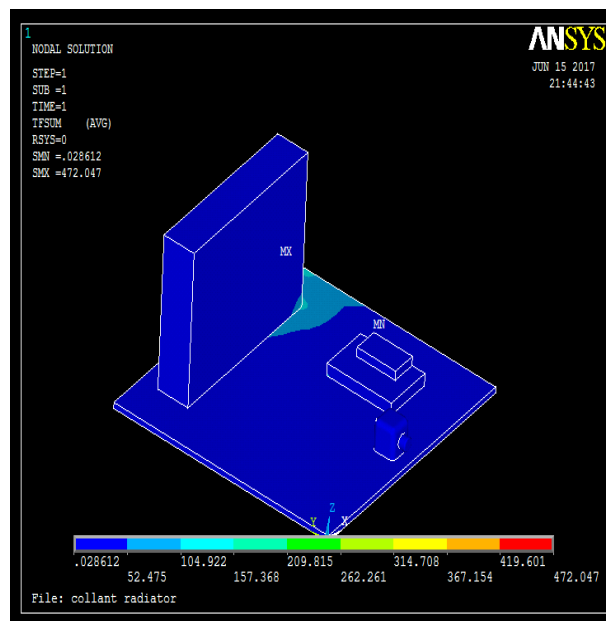
(h)

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(i)

Fig 7: (g) Z- Direction of Thermal Flux, (h) Y- Direction of Thermal Flux, (i) Thermal Flux Vector Sum

VII. CONCLUSION

The current study focuses on the structural optimization of the heat exchanger and the cooling system to increase the waste heat utilization in an automobile. In this work, two alternatives of heat exchangers attached with the TEG used for waste heat recovery from an auto mobile exhaust is analysed. According to the results obtained from the experimentation and ANSYS simulation, water tube type heat exchangers is better option among water tube and fin type heat exchangers to get better performance of the TEG, as it is giving better temp difference between the two surfaces of TEG.

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