Design, Fabrication and Performance Analysis of Automotive Exhaust Gas Waste-Heat Recovery module using Thermoelectric Technology

Dissertaion-2

Submitted in partial fulfillment of the requirement for the award of degree

Of

Master of Technology

IN

MECHANICAL ENGINEERING

By

Sayed Abdullah Rehan

11609678

Under the guidance of

Minesh Vohra

15783

SCHOOL OF MECHANICAL ENGINEERING

LOVELY PROFESSIONAL UNIVERSITY

PHAGWAR, PUNJAB

LOVELY PROFESSIONAL UNIVERSITY

Transforming Education, Transforming India

TOPIC APPROVAL PERFORMA

School of Mechanical Engineering

Program : P17K::M.Tech. (Thermal Engineering) [Full Time]

COURSE CODE : MEC604 **REGULAR/BACKLOG :** Regular **GROUP NUMBER :** MERGD0219

Supervisor Name : Minesh Vohra **UID :** 15783 **Designation :** Assistant Professor

Qualification : _____ **Research Experience :** _____

SR.NO.	NAME OF STUDENT	REGISTRATION NO	BATCH	SECTION	CONTACT NUMBER
1	Sayed Abdullah Rehan	11609678	2016	M1673	8879928759

SPECIALIZATION AREA : Automobile Engineering **Supervisor Signature:** _____

PROPOSED TOPIC : Design Fabrication and Performance Analysis of Automotive Exhaust gas Waste-Heat Recovery module using Thermoelectric Technology

Qualitative Assessment of Proposed Topic by PAC		
Sr.No.	Parameter	Rating (out of 10)
1	Project Novelty: Potential of the project to create new knowledge	6.50
2	Project Feasibility: Project can be timely carried out in-house with low-cost and available resources in the University by the students.	7.00
3	Project Academic Inputs: Project topic is relevant and makes extensive use of academic inputs in UG program and serves as a culminating effort for core study area of the degree program.	7.00
4	Project Supervision: Project supervisor's is technically competent to guide students, resolve any issues, and impart necessary skills.	7.00
5	Social Applicability: Project work intends to solve a practical problem.	7.00
6	Future Scope: Project has potential to become basis of future research work, publication or patent.	7.50

PAC Committee Members		
PAC Member 1 Name: Minesh Vohra	UID: 15783	Recommended (Y/N): NA
PAC Member 2 Name: Vijay Shankar	UID: 16474	Recommended (Y/N): NA
PAC Member 3 Name: Sudhanshu Dogra	UID: 16900	Recommended (Y/N): Yes
DAA Nominee Name: Kamal Hassan	UID: 17469	Recommended (Y/N): Yes

Final Topic Approved by PAC: **Design Fabrication and Performance Analysis of Automotive Exhaust gas Waste-Heat Recovery module using Thermoelectric Technology**

Overall Remarks: Approved

PAC CHAIRPERSON Name: 12174::Gurpreet Singh Phull **Approval Date:** 11 Nov 2017

CERTIFICATE

I hereby certify that the work being presented in the dissertation entitled "Design, Fabrication and Performance Analysis of Automotive Exhaust Gas Waste-Heat Recovery module using Thermoelectric Technology" in partial fulfillment of the requirement of the award of the Degree of master of technology and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of Minesh Vohra , Assistant Professor, School of Mechanical Engineering, Lovely Professional University. The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

Date : 28/11/2017

Sayed Abdullah Rehan
11609678

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date: 28/11/2017

Minesh Vohra (15783)
Asst. Prof.

Sudhanshu Dogra
(HOD)

COD (ME)

Signature of Examiner

CONTENTS

ACKNOWLEDGEMENT

I wish to express heartfelt and sincere gratitude to MINESH VOHRA, Assistant Professor, Lovely Professional University, for his excellent guidance and encouragement during the course of this dissertation work. I also thanks to him for his tremendous motivation and moral support throughout the report. His feedback and editorial comments were also valuable for writing of this dissertation.

A heart full and sincere gratitude to **Mr. Gurpreet Singh Phull**, (COS) and **Mr. Sudhanshu Dogra** (HOD) of Mechanical Engineering, Lovely Professional University.

I would like to thank all the staff of Mechanical Department of **LOVELY PROFESSIONAL UNIVERSITY** for their help and co-operation during course of this project.

I am grateful to my *PARENTS* and *FRIENDS* for their support and encouragement directly or indirectly in completing this project.

SAYED ABDULLAH REHAN

(11609678)

ABSTRACT

In this experimental investigation focuses on the high-performance heat transfer and thermoelectric conversion to manufacture a thermoelectric generator system setup at the I.C engine exhaust pipe. In this experimental setup we used four-stroke, single cylinder I.C engine whose displacement is 109.2 c.c. This entire system consists a heat absorber, thermoelectric generator module and the heat sink. The staggered fins arrangement is done on both heat sink and heat absorber. The staggered pin-fin is placed into the duct to form the heat absorber, as duct installed at the exhaust of the engine so continuously heat passes through the heat absorber. The staggered fins on heat absorber could increases the heat-exchange surface area by doing so thermoelectric conversion increases. The result of this experiment exhibit that the system retrieve considerable amount of waste heat from I.C engine which can be further useful for power automobile devices.

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

I.C	-	Internal combustion
TEG	-	Thermoelectric generator
cc	-	Cubic centimeter
cm	-	Centimeter
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
NO_X	-	Nitrogen oxide
$^{\circ}C$	-	Degree Celsius
S.I	-	Spark ignition
Rpm	-	Revolution per minute

Chapter 1: INTRODUCTION

A generation of electricity can be leisurely by using a thermoelectric generator. The working conditions behind the thermoelectric generator is a "Seebeck *effect*". A seebeck effect was discovered in 1821 by a Thomas Johann Seebeck and it stated as "whenever there is a temperature difference between the two junctions in a loop, made up of two dissimilar conductors, thermal electromotive force is produced in the loop. Such a loop is known as a thermoelectric generator. The emf originated are proportional to the temperature difference between the two junctions. The power produced P is

$$P = Q_H - Q_C$$

$$P = I^2 R_L$$

Where Q_H heat flow rate into hot junction and Q_C dissipated heat flow rate from cold junction.

In thermoelectric generator a conversion took place directly heat into electricity. A thermoelectric generator offers several distinguishable advantages over other power plants. It has a saliently features namely compactness, lightweight, noiseless operation, highly reliable, safe power sources, and no moving parts. Now-a-days thermoelectric generators are using for the small scale as well as large scale applications also. The remarkable advantage of thermoelectric generator is that it can operated by low grade waste heat (< 200°c) of automobiles. Lowest maintence cost of any other power generation sources is also good advantages and perfectly for automobile exhaust heat recovery. So, finally the waste heat from automobile vehicle has a potential of power generation by used of thermoelectric generator. A thermoelectric generator is being intended for high tech applications such as military, telecommunication, aerospace, and controlled of unmanned vehicles. A thermoelectric generators are also be used to provide the small amounts of electricity to remote region for example northern Sweden.

A greenhouses gases emission is raising the concern of environment. The greenhouse gases are obligated for climate change, global warming, and pollutions and the limitations of the fossil fuel, natural gases, coal, nuclear power sources and renewable energy sources resulted in extensive research into a technologies of generating electrical power. To overcome all of this issues a thermoelectric generators are very helpful up to some extend period of time. A

thermoelectric generator has emerged as a most promising alternative green technology. The conventional type of thermoelectric generator consist a thermocouple of n type and p type elements connected electrically in series and parallel in thermal. Heat is given on the one side of the thermoelectric generator and remains cold on another side of the thermoelectric generator. A voltage will have generated across the thermocouple. The magnitude of the voltage is proportional to the temperature gradients.

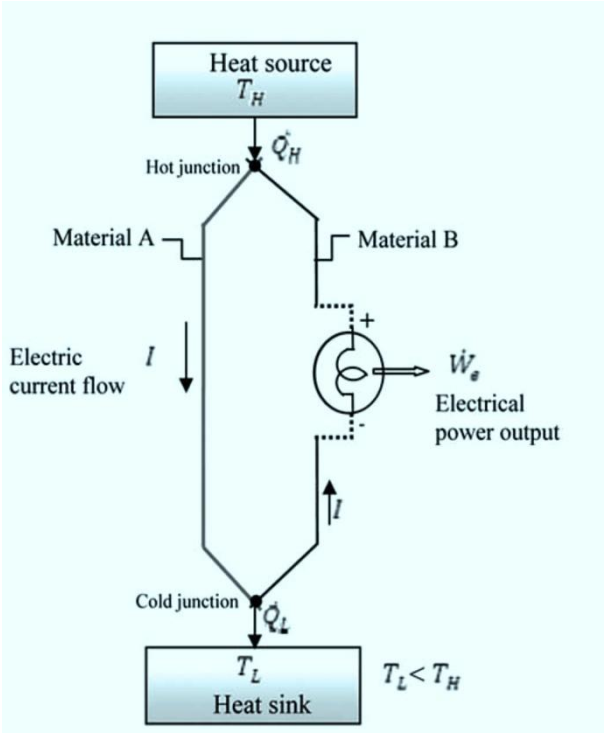

Fig (1). Schematic diagram of thermoelectric power generation.

The basic arrangement and concept of thermoelectric power generation system. The working principles based on seebeck effect. In above figure shows a heat source, from that heat source a rate of heat transfer Q_H transfer to the hot junction and it is rejected at a rate of Q_L to a low temperature of sink maintained at T_L from the cold junction. based on the seebeck effect the heat which flows from the heat sources causes an electrical power generation.

If we use thermoelectric generator for power generation from engine exhaust, this method of power generation would definitely become efficient.

By doing so no need to convert heat energy into mechanical energy than into electrical energy. therefore the important aim in thermoelectric power generation using waste heat energy from automobile or power plant to deduct the price per watt of the device. moreover, price per watt can be deducted by the modification or optimizing the device geometry or by ameliorate the quality of manufacturing or else simply by operating temperature raises.The basic reasons for the generation power from thermoelectric generator are explains below.

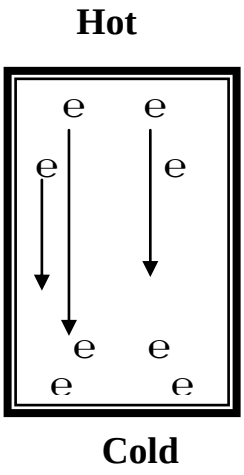

Fig (2) Schematic diagram of flow of electrons

If we take a piece of a metal heat added to the one end and simultaneously cold the other end. The electron surrounding the metal atoms have energy because we are adding heat. This means the hot side of electrons are charged and tends to moved towards the cold end, this eventually hot becomes a positive charge and cold side becomes negative charge.

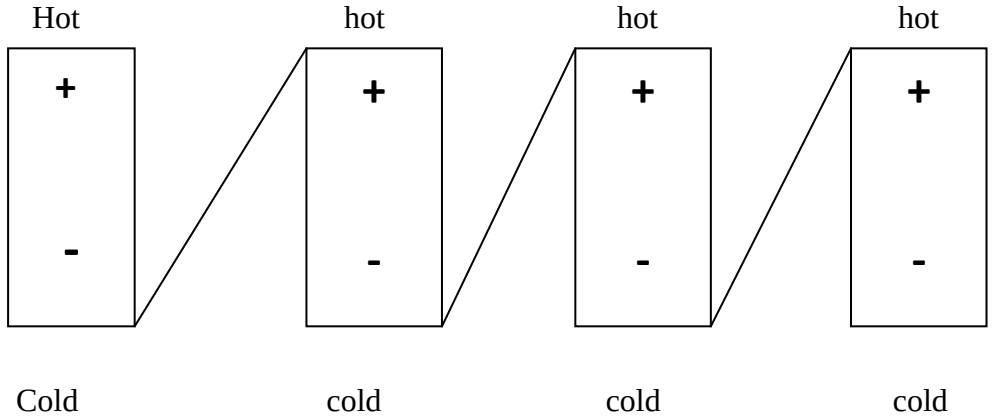

Fig (3) Schematic diagram of flow of electrons in serieswise

This cannot be just solved by connecting lots of piece metals together in serieswise like a battery. The wire which connected are also made up of metal piece. So the scientist solve this

issue is to use the material that conduct electricity using positive charge particle instead of electrons. To overcome this issue scientist come up with new way and new materials . this materials is known as a semiconductor. So now a scientist keep on try to find better material whose electrical conductivity is high and thermal conductivity is low. Today a material used for thermoelectric generator is bismuth telluride (Bi_2 Te_3).An elementary thermoelectric generator consisting of one pair of thermocouple shown in below figure. This pair of thermoelectric module are connected in series and sandwiched between the hot side and cold side of thermoelectric generator below fig (5) shown the thermoelectric generator.

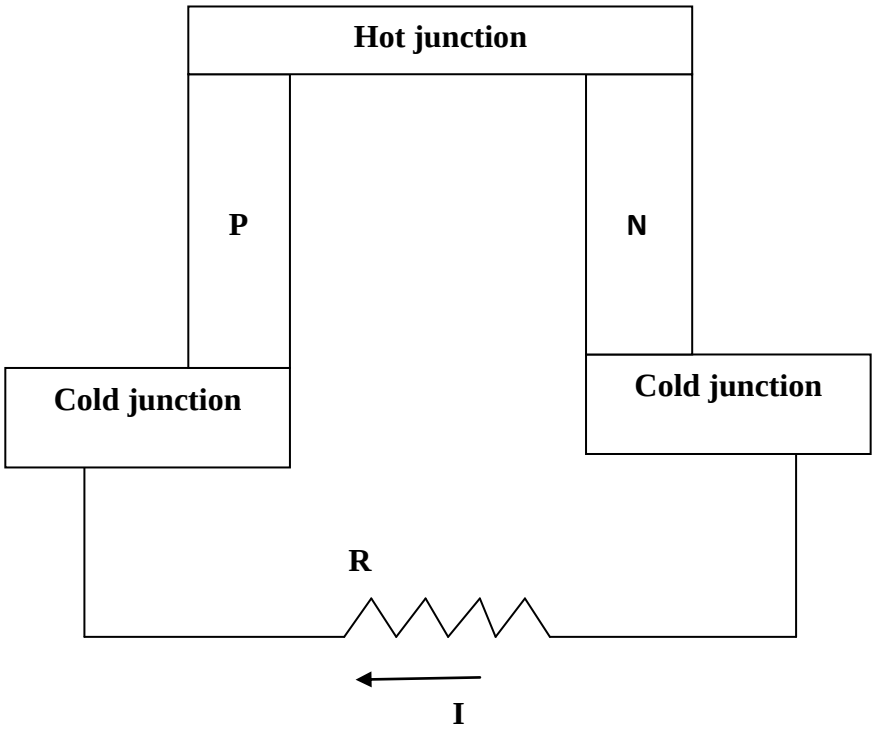

Fig (4) Diagram of one pair of thermoelectric couple.

Fig (5) Thermoelectric Generator.

Chapter 2: Objective of the Study

The entire system setup was based on the thermoelectric generator. The system consists a heat absorber, thermoelectric generator modules and heat sink. So further scope of this experimental setup is the material of the thermoelectric generator, Nanostructured materials is emerged to enhanced the ZT of thermoelectric generator module. Usage of graphene which exhibits a highest electrical conductivity can also be act as a further scope. And furthermore, the fins types and arrangement such as rectangular fins, circular and square fins, hydrofoil and elliptical fins, simple and staggered arrangement of fins. The engine displacement increases, the exhaust heat also increases thereby generation of power will be increases. Hence the study is based on the experimental setup in order to find an existing possibility of recovering waste heat from exhaust of I.C engine and also to design and manufacture one system that can achieved the aim of generate electricity by using thermoelectric generator. The generation of electricity could be used for automobile devices. The aim of the project is not to control the waste heat from I.C engine but to utilization of that waste heat into the power generation by using suitable devices like thermoelectric generator.

Chapter 3: Literature Review

In this literature review on the experiments conducted by a various researchers presented. A brief elucidation of using thermoelectric generator where a heat sources are available no matter either it is in waste form of heat or any kind of heat sources. A literature review gives an overview on the distinguishable paper published on various aspects by different researchers and their works on thermoelectric generator energy conversion system. Finally, this reviewed ends with methodology used.

A thermoelectric generator was ascertained in the end of 19^{th} century. Direct heat energy converts into the electrical energy by using a thermoelectric generator. A thermoelectric generator can also works on the waste heat it does not matter whether the heat comes from exhaust of I.C engine or may be from conventional diesel or gas power plant. As we all aware of global warming, climate change and the global energy crisis is day by day becomes aggravated and much accent is being placed on environment protection and the recovery of energy resources

Karri *et al.* [1] canvassed the efficiency of thermoelectric generator by using of waste heat of a sports utility vehicle (SUV) and natural gas power generator engine. Differentiation between the two types of thermoelectric module which has higher availability ratio were being used for the generation of power. First one is bismuth telluride (Bi_2Te_3), and second is quantum-well (QW) device. Both thermoelectric module were being used by SUV and CNG engines under the similar conditions, the generations of power are more by using QW device thermoelectric module.

Champier *et al.* [2] shows by his works that electricity generation is possible with the biomass cook stove by used of thermoelectric generator. By experimental setup he proves that 6 watts of power can generated by using thermoelectric generator. Olaya *et al.* [3] shows the remarkable high ZT values of thermoelectric generator, a nanostructured materials emerged as an option to enhanced the figure of merit ZT of thermoelectric generator. A thermoelectric device layered compiled of electrochemically exfoliated graphene (EEG) and a polystryrene sulfonate and gold nanoparticles were prepared.

Jadhav *et al*. [4]. System setup show the thermoelectric generator being used for four stroke I.C engine. The system converts the permissive waste heat from the 4 stroke engine exhaust

manifold into an electrical energy using thermoelectric generator. It consist of two TEG connected thermally in parallel and electrically in series by doing so increment in voltage shows. A 4 stroke single cylinder engine and its displacement is 92.20cc is used. A generated electricity increases as speed of the engine increases, in 6000 rpm an generated voltage is 11.80 v.

Yadav *et al.* [5] intended and demonstrate the usage of cost-efficient and flexible thermoelectric generator on flexible fiber substrate. They reasoned that a innovation can be effectively implement in creating a flexible thermoelectric generator for waste heat recovery by vehicle and diesel/petroleum power plant and other applications. Mins *et al.* [6] he recently created a novel tube-shape thermoelectric module for the generation of electricity. A generation power increases as compared with conventional type thermoelectric generator with his design thermoelectric module.

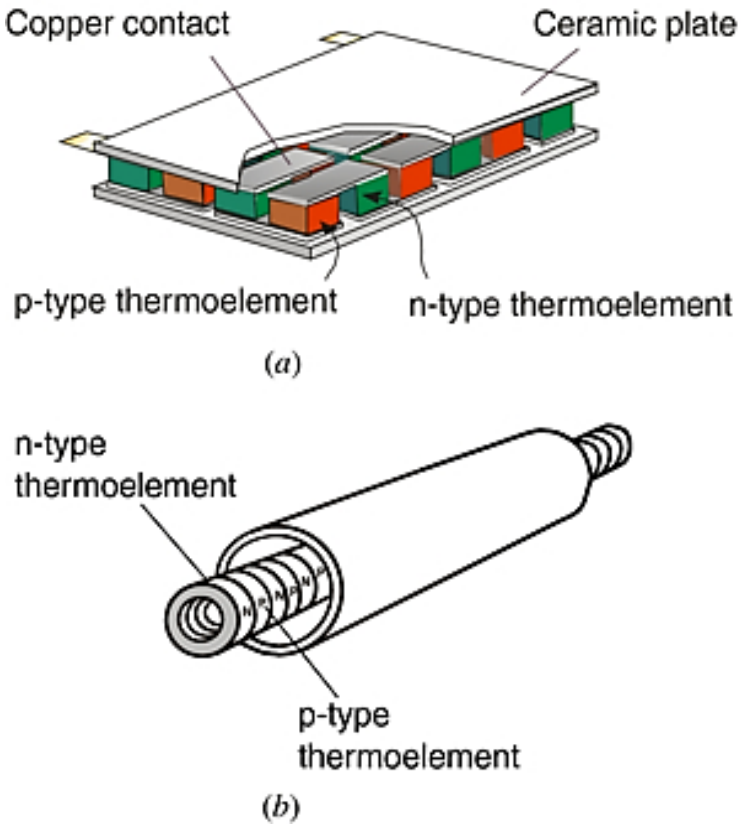

Fig (6) Diagram of thermoelectric generator. (a) basic thermoelectric generator.

(b) A novel tube-shaped thermoelectric generator.

Glatz *et al.* [7] he concluded that the range 80-150 μm should be the length of thermocouple in thermoelectric generator a material of a generator is Bi_2Te_3. His design of micro thermoelectric power generator with polymer based wafer level fabrication process.

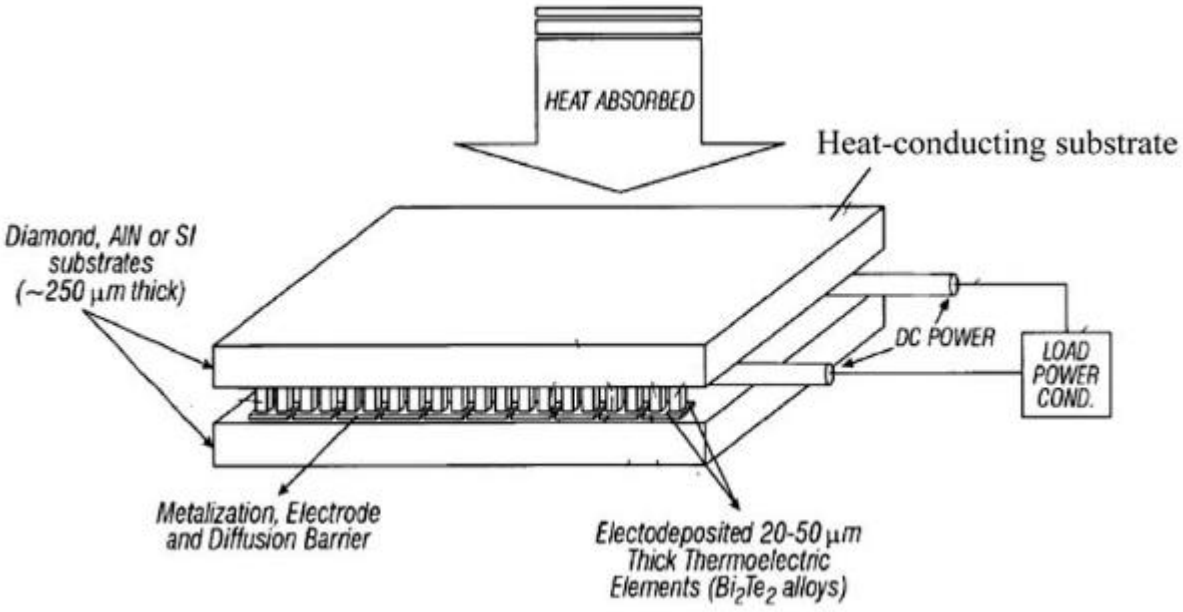

Fig (7) Schematic diagram of micro thermoelectric generator and can be used for power generation from waste heat of automobile.

Jeng *et al.* [8]. he concluded an actual four stroke single cylinder of 35.8 cc I.C engine was used for the experimental setup on a test of generation of electricity by exhaust of engine and design a pin-fin arrangement type with including inside a thermoelectric generator. Because of his design pin-fin could increases the heat surface area and could increased the time of a heat, due to this a power generation from thermoelectric generator increases. he concluded that power 2.5w generated at an speed of engine is 5400 rpm.

Chapter 4: Experimental Setup and Calculations

A thermoelectric generator a device which create power by heat, it works on squander warm likewise, In thermoelectric generator a change occurred straightforwardly warm into power. A thermoelectric generators offers a few discernable points of interest over other power plants. It has a notably includes in particular smallness, lightweight, quiet operation, profoundly solid, safe power sources, and no moving parts. Presently a-days thermoelectric generators are utilizing for the little scale and additionally expansive scale applications moreover. The striking favorable position of thermoelectric generator is that it can worked by poor quality waste warmth (< 200°c) of cars. Most minimal maintence cost of some other power age sources is additionally great points of interest and splendidly for car fumes warm recuperation. Along these lines, at last the waste warmth from car vehicle has a capability of energy age by utilized of thermoelectric generator. Presently we have a bunches of auto and bicycles moving around and squander their fumes warmth and picks up only contamination and carbon emanation which prompts an Earth-wide temperature boost and environmental change issues. To defeats this issues or possibly to lessened contamination until our non-traditional sources progresses toward becoming possibilities of energy age with high proficiency. The thermoelectric generator can possibly produce power without a mechanical vitality which implies it is an immediate vitality change framework. It can produce power specifically with warm vitality into electrical vitality. A thermoelectric generator has a favorable circumstances, for example, they are to a great degree solid and silent in operation, simple to deal with, minimal and safe to utilize, additionally, they are eco-accommodating in nature. A thermoelectric generator has being utilized for Eco-drive observes right off the bat made by Native. A 66% vitality misfortune as heat can be effortlessly changed over into power by utilizing thermoelectric generator.

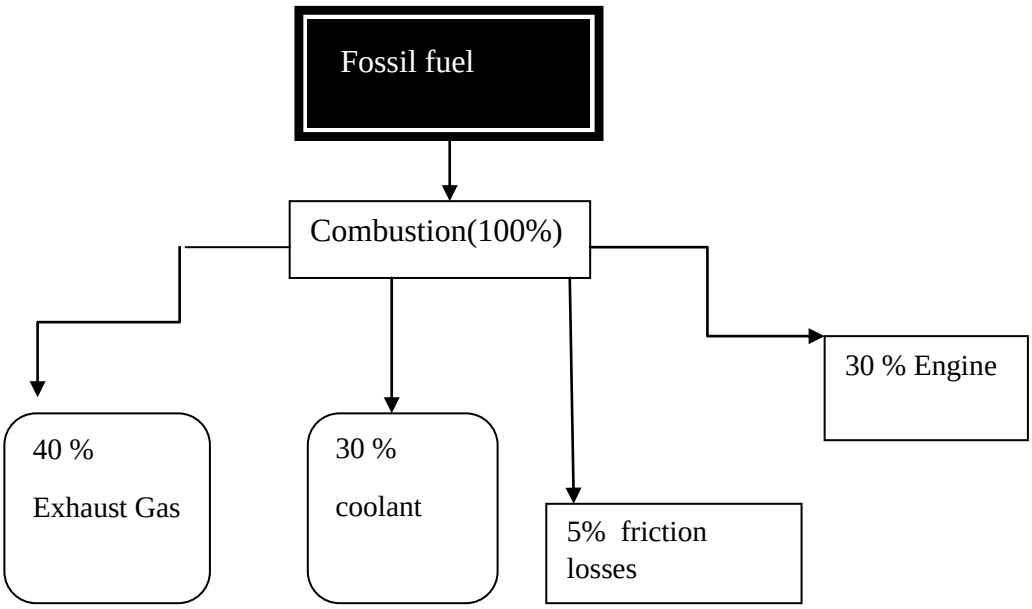

Figure (8) Schematic diagram represents the combustion usage of an I.C engine

We draw this thermoelectric transformation system by utilizing CREO programming. It is outline such that, when warm from engine exhaust go by tube and embedded in this system, the turbulence will made and in view of this turbulence heat stays for while in this system, so by doing this a thermoelectric generator gets warm sources. In this fig (11) comprise a four thermoelectric generator which is set between the warmth source safeguard and heat sink. A rate of heat exchange increases by including number of fins. The material of this system is aluminum alloys with anode, so that it cannot effect by corrosions.

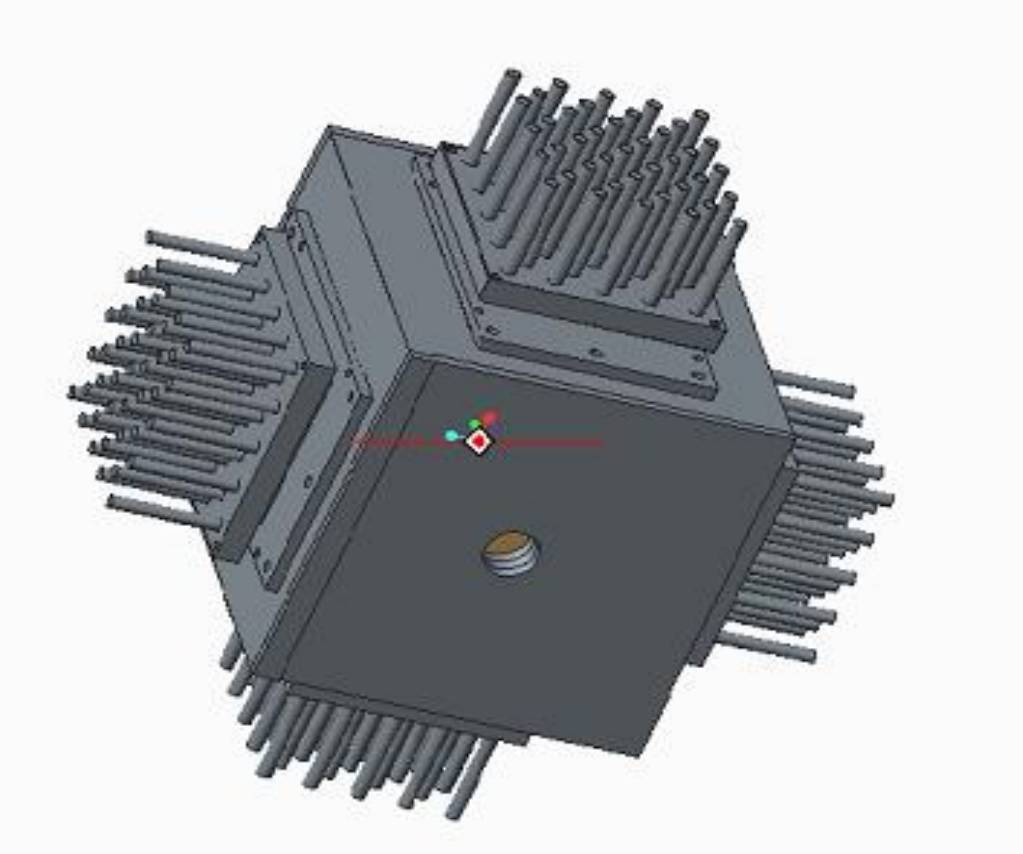

Fig (9) Show a Thermoelectric conversion device

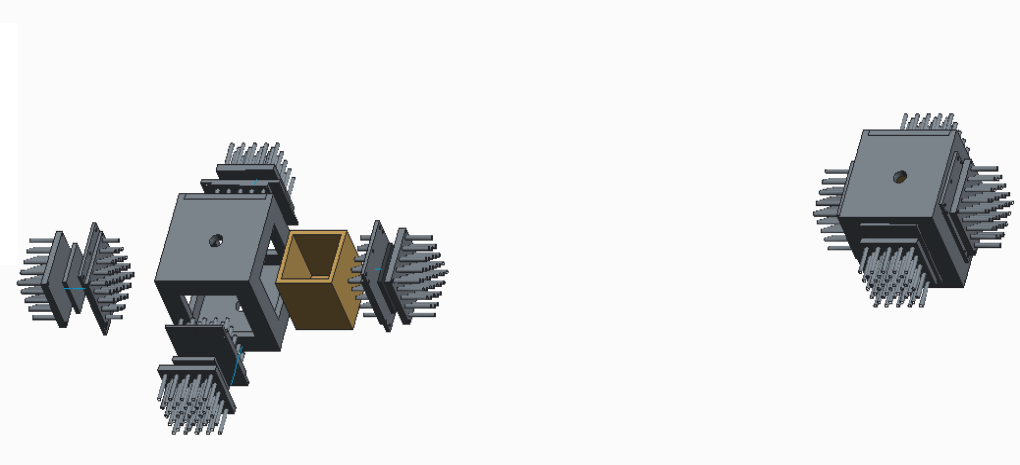

Fig (10) Show the exploded view of Thermoelectric conversion device

.

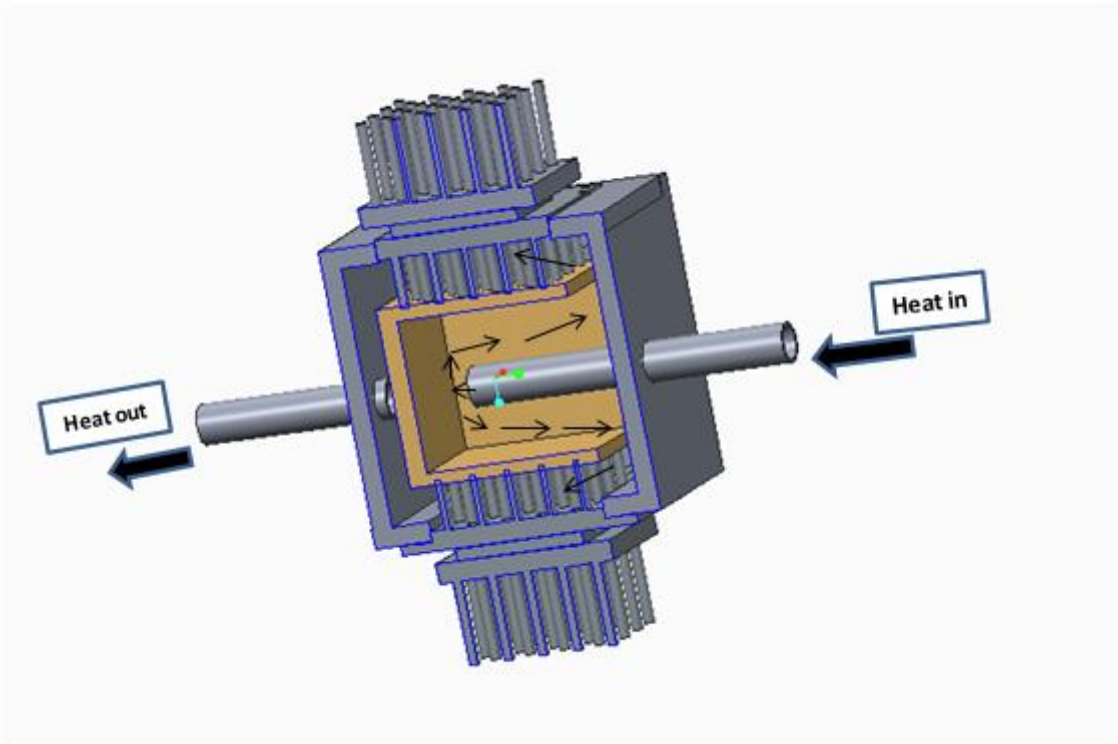

Fig (11) A cross-sectional view of Thermoelectric conversion device with inlet and outlet

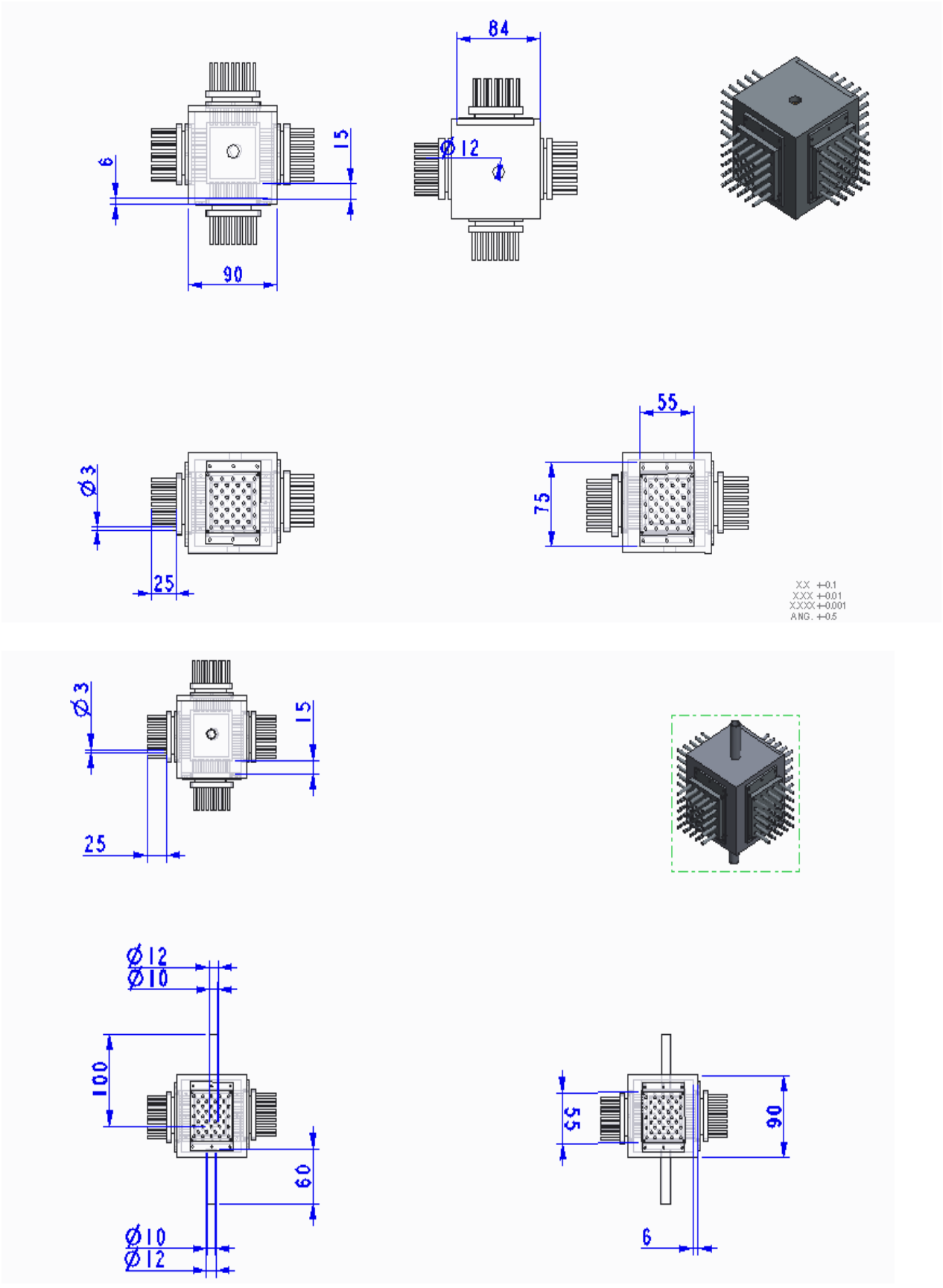

Fig (12) A Thermoelectric conversion device with its dimensions

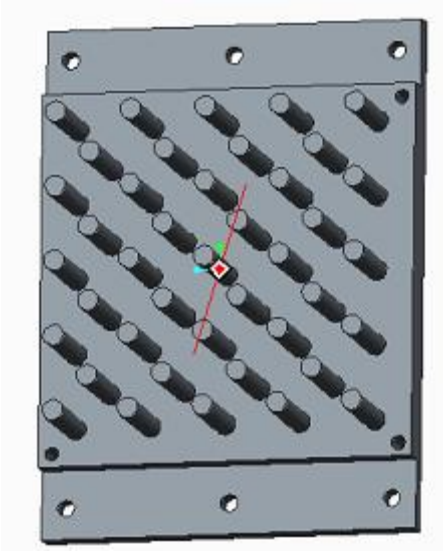

Fig (13) Staggered arrangement of pin-fin absorber

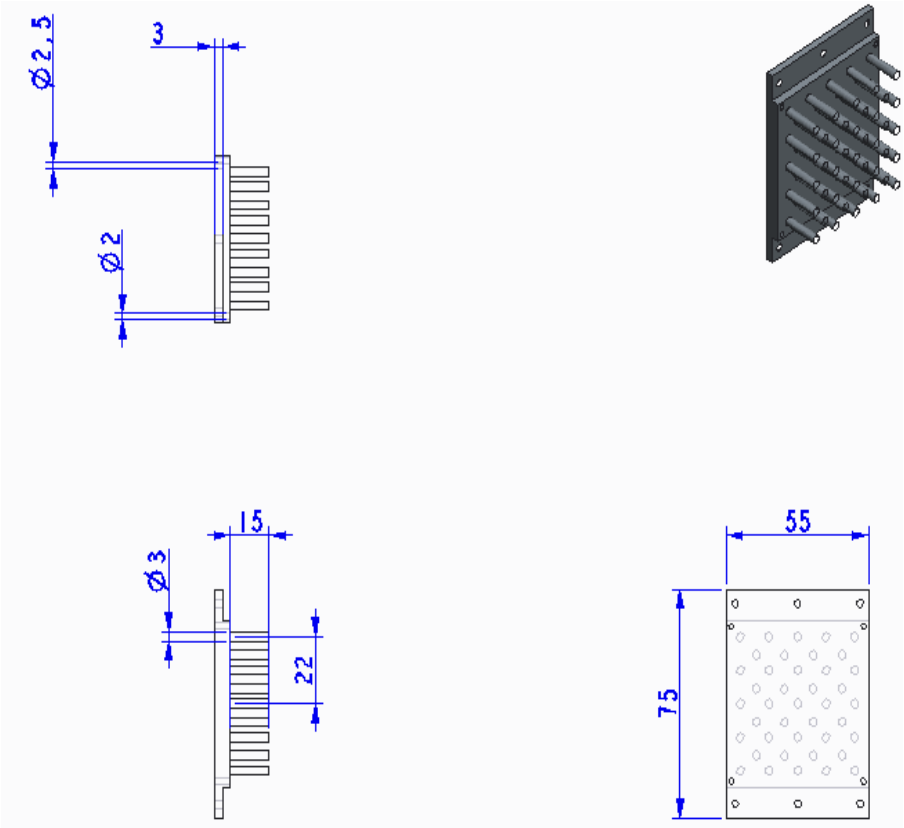

Fig (14) Staggered arrangement of pin-fin absorber including dimensions.

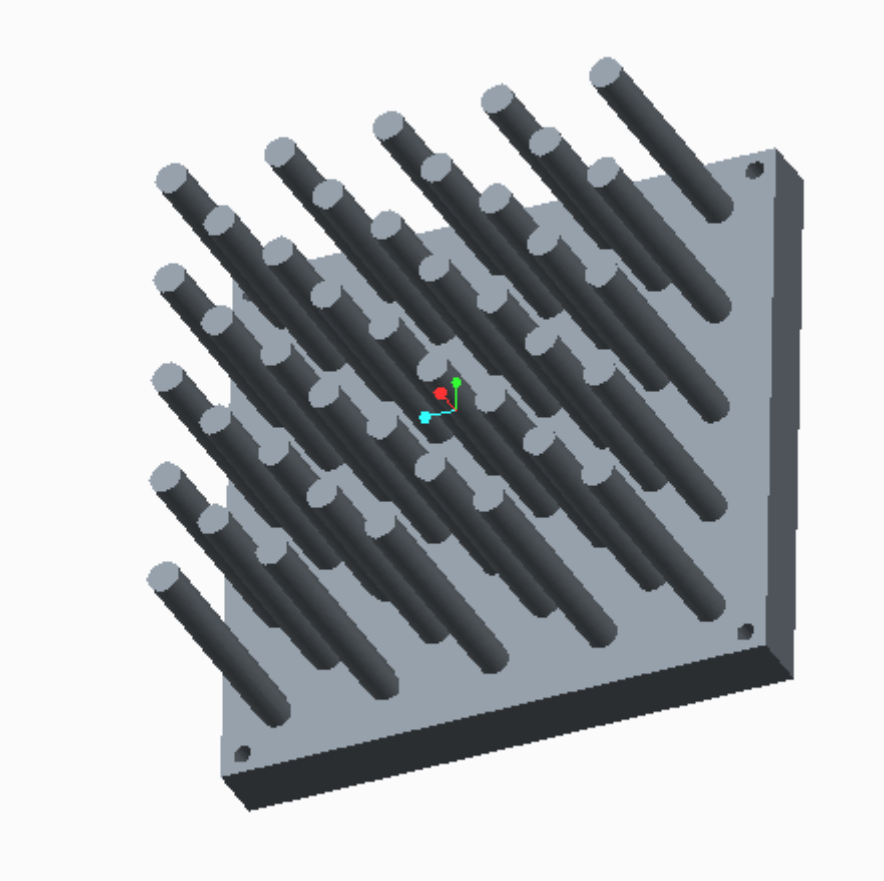

Fig (15) Heat sink

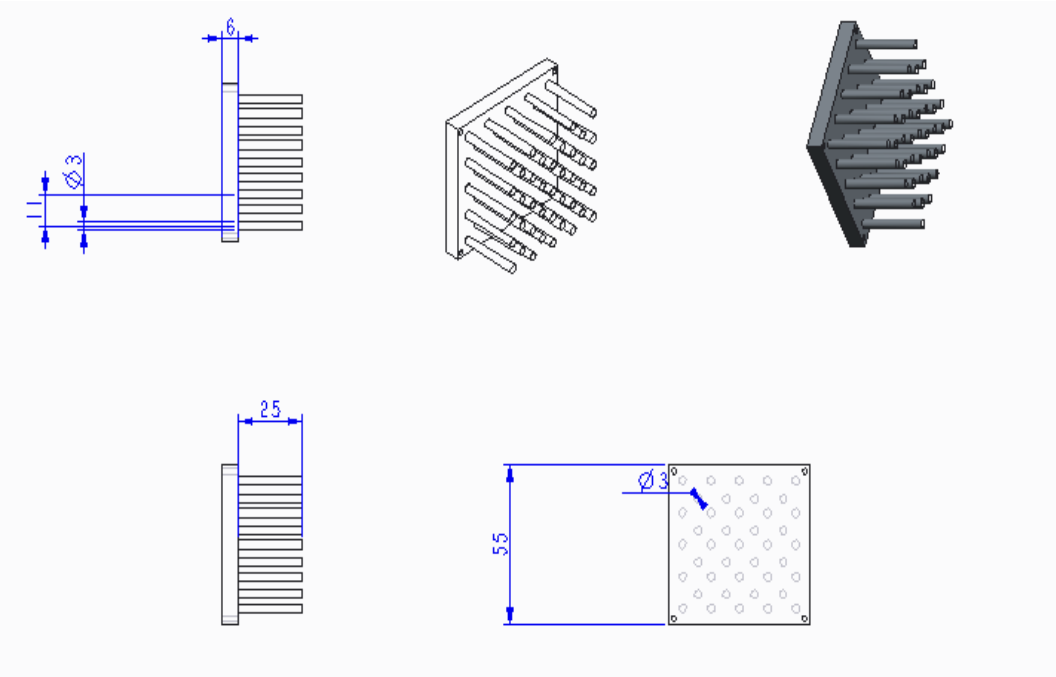

Fig (16) Heat sink including dimension

EXPERIMENTAL SETUP AND CALCULATION

1. Data recorder
2. Thermoelectric Generator
3. Fan
4. I.C Engine
5. Temperature sensor
6. Heat source and heat sink
7. Multimeter
8. Digital thermometer

Specification of I.C engine :

Sr. no	Specification	
1	Displacement	109.2 cc
2	Number of cylinder	1
3	Maximum power	8 Bhp @ 7500 rpm
4	Maximum torque	9 Nm @ 5500rpm
5	Top speed	83 kmph

Table (1) I.C. Engine specifications.

Formula for calculations:

1. Performance of thermoelectric material

$$\boldsymbol{Z} = \boldsymbol{\alpha}/kR$$

Where $\boldsymbol{Z}$ is the thermoelectric material

K is the thermal conductivity

$\boldsymbol{\alpha}$ is Seebeck coefficient is given by:

$$\boldsymbol{\alpha} = -\Delta V/\Delta T$$

Where R is the electric resistivity

2. Heat transfer by convection

$$Q = h\mathrm{A_S}\,(\mathrm{T_S} - \mathrm{T_\infty})$$

Where Q is the rate of heat transfer

h is heat transfer coefficient

$\mathrm{A_S}$ is surface Area

$\mathrm{T_S}$ - $\mathrm{T_\infty}$ is temperature difference

3. The steady rate of heat transfer of a fin

$$Q_{Long\ Fin} = -kA_C \frac{dT}{dx}|_{x=0} = \sqrt{h_p k A_c}(T_b - T_\infty)$$

Where p is a perimeter

A_C is a area of cross-sectional of fin

x is the distance from the fin base

4. Efficience of long fins

$$\eta_{long\ fin} = \frac{Q_{fin}}{Q_{fin\,max}} = \frac{\sqrt{h_p k A_c}(T_b - T_\infty)}{h\mathrm{A_S}\,(\mathrm{T_S} - \mathrm{T_\infty})} = \frac{1}{L}\sqrt{\frac{KA_C}{h_p}} = \frac{1}{aL}$$

Chapter 5: Expected Outcome and Conclusion

An I.C engine of single cylinder, four-stroke and displacement is 109.2 c.c will use in this experimental setup. The expected outcomes of power generation will be around 2W of energy with rpm more than 2500rpm. That much generation is enough to power automobile devices. As the staggered fins used in both heat sink and heat absorber for increasing the rate of heat transfer so, may be voltage generation increases. The potential benefits of thermoelectric generator will be used for power generation from exhaust of I.C engine, which is quite in operation and miniatous cost is less. An I.C engine will used and specification of an I.C engine is four-stroke, single cylinder, 109.2 c.c displacement. Power generation will be raised because of using four thermoelectric generator and system design and manufacturing and staggered fins arrangements used for increasing the rate of heat transfer. An expected output is 10-12 V can be produced. By analysis the reimbursement will be start as soon as possible because of silently features of thermoelectric generator. It may be noted that thermoelectric power generation system won't affect our engine performance.

Chapter 6: Work Plan and Timelines

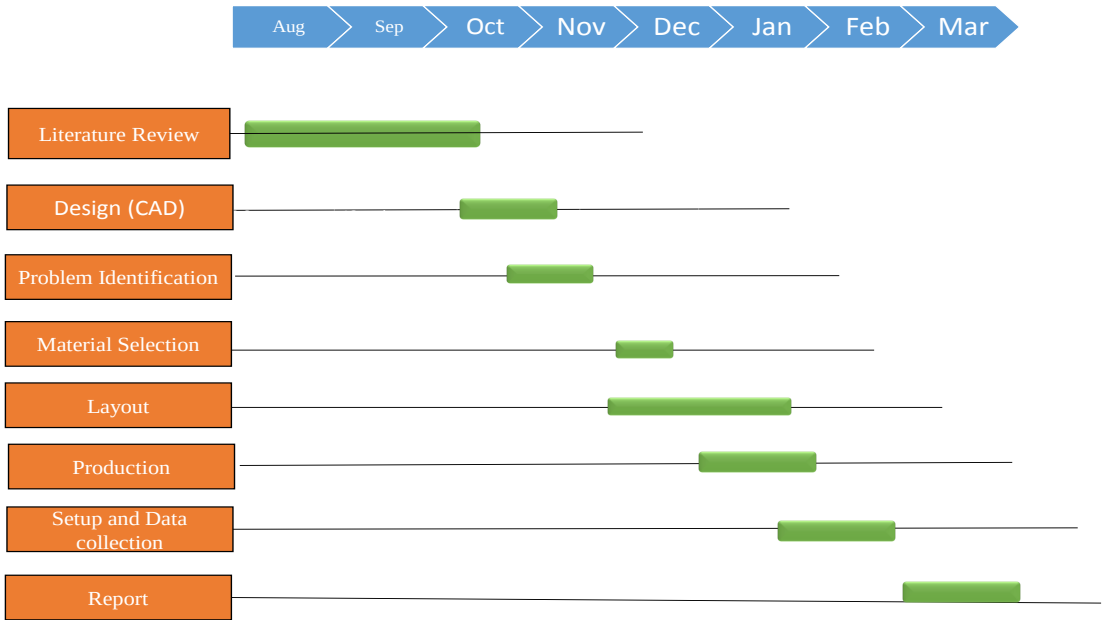

Chart (1) Project Management with timelines

References

[1] Karri, M.A.; Thacher, E.F.; Helenbrook, B.T. Clarkson Exhaust energy conversion by thermoelectric generator: Two case studies. *Energy Convers. Manag.* 2011, 52, 1596-1611.

[2] Champier, D.; Bedecarrats, J,P.; Rivaletto, M.; Strub, F. Thermoelectric power generation from biomass cook stoves. *Energy* 2010, 35, 935-942.

[3] Olaya, D., H urtado-Morales, M., Gomez, D., Alejandro Castaneda-Uribe, O., Juang, Z.-Y., & Hernandez, Y. (2018). Large thermoelectric figure of merit in graphene layered device at low temperature. *2D MATERIALS*, 5(1).

[4] Jadhav, M. G., & Sidhu, J.S. (2017). Design and Fabrictaion of Silencer Waste Heat Power Generation System Using Thermo-Electric Generator. 7(1), 1-14.

[5] A. Yadav, K.P.pipe, and M. Shtein, "Fiber-based flexible thermoelectric power Generator", J Power Sources, Vol. 175, pp. 909-913,2008.

[6] G. Min, and D. M. Rowe, "Ring-structured thermoelectric module" , Semicond Sci Sci Technol, Vol. 22, pp. 880-883, 2007

[7] Glatz W, Muntwyler S, Hierold C. Optimization and fabrication of thick flexible Polymer based micro thermoelectric generator, Sens Actuators 2006; 132:337-345.

[8] Jeng, T.-M., Tzeng, S.-C., Yang, B.-J., & Li,Y.-C. (2016). Design, Manufacture and Performance Test of the Thermoelectric Generator System for Waste Heat Recovery of Engine Exhaust. *Inventions.*