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Analysis and Design Methodology for Thermoelectric Power Generation System from Waste Heat

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Abstract - *This paper combines heat transfer and thermoelectric conversion techniques to create a thermoelectric generator device for a single-cylinder, four-stroke petrol engine. The system is made up of heat absorbers, thermoelectric generator, Thermoelectric Generator (TEG) modules, and an external heat sink. To achieve the goal of absorbing heat and increasing thermoelectric conversion efficiently, the heat exchanger surface area and heat-exchange time could be increased. Thermoelectric generators convert waste heat into energy directly. This technology will also help energy conversion systems work better overall. Despite the fact that TEG production is limited by available technologies, feasible electricity generation is possible from waste heat generated by automobiles. The effect of using passive heat sinks and heat absorbers made of a flat plate with fins of various cross-sectional areas and materials with forced convection heat transfer, as well as how current, voltage, and power are varied, is investigated and presented in tabular format in the current numerical analysis. By plotting the results of the analytical and numerical method on relevant graph, the results of both methods were compared*

Key Words: *:* Waste heat recovery, pin-fins, thermoelectric power generation system, heat-sink, heat-absorber

1. INTRODUCTION

Waste heat recovery (WHR) is the most concerned of all the studies undertaken, owing to the extensive availability and high usability of suitable materials [1].

The advantages of WHR, according to the Indian Bureau of Energy Efficiency, include lower process usage and prices, lower emissions and equipment sizes, and lower auxiliary energy consumption.

Although there are a variety of devices that can provide WHR, most automotive and aerospace applications use the thermoelectric generator (TEG).

A thermoelectric power generator is a long-lasting system that uses the seebeck effect to transform waste heat energy into electrical energy. Most engines have a 30 percent performance rating, with the majority of the expended energy being lost as heat [2].

In order to reduce fuel consumption, it is becoming increasingly important to find renewable energy sources and improve engine performance. The aim of this project is to see if missing energy can be retrieved in the form of electricity and used to power a vehicle's lights (such as headlights, taillights, and dashboard lights). Thermoelectric Power Generators will be investigated as potential solutions for recovering this wasted energy and the overall engine performance. Electrons can transport both heat and energy [3].

Study [4-16] has presented use of thermoelectric module used for power generation from waste heat from Godrej Vikhroli Power Plant [4] and from computing process [5].

Electrons travels from hot end to cold end. There is a temperature gradient formed in thermoelectric material. The seebeck effect is the term referring to this phenomenon, and it is the basis for the thermal generator.

The global oil shortage is worsening, as we all know, and much focus is being put on environmental sustainability and energy supply recovery. Waste heat from coolant, flue gases, and steam power stations are just a few examples.

TEG is lightweight and quiet, with no moving parts and the ability to transform excess exhaust heat into energy directly.

It is discovered that increasing modules don't actually increase the power capacity but ultimately the average power generation is reduced with the increase in modules.[6]

2. PROBLEM DEFINITION

In the operation of an internal combustion engine, heat energy accounts for about 70% of the energy lost. This heat triggers issues such as banging, jamming, thermal pressures, and the breakdown of certain I.C. engine components.[3] Despite the fact that heat is a weak source of energy, it can be transformed into a valuable type of energy such as electricity.

On darker nights and bad weather conditions it is necessary to use led lights. But these lights work on the automobile battery. So, the entire load of the sensors and lights for hours of driving is taken by the battery which is very high due to presence of various sensors, screen visuals, head and tail lights, signal lights, etc [3].

3. DESCRIPTION OF PARTS

HEAT SINK

Heat sink is a device which is exposed to the atmosphere to dissipate the heat which produces temperature gradient between two ends of the thermoelectric module, as its main function is to carry away the heat from source and to enhance the working of TEG (refer Fig. 1).

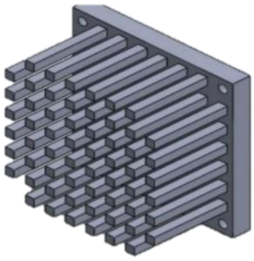

Fig - 1: CAD Model of Heat sink

HEAT ABSORBER

This device is situated inside the duct to carry away the heat from the exhaust gases of the engine. Heat absorber (refer Fig. 2) produces turbulence and make a close contact with the heat exchanging surface which leads to produce maximum temperature gradient of between hot and cold end of TEG to increase the efficiency and to increase the electromotive force. The system acts as a noise reducer and suppresses the noise of the engine [7].

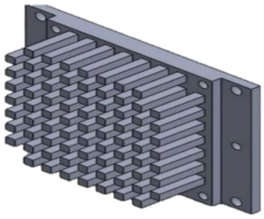

Fig - 2: CAD Model of Heat absorber

CENTRAL BAFFLE BOX

The main role of a baffle is to guide the flow of exhaust gases [5], to get the temperature difference (refer Fig. 3). Despite the fact that the baffle structure increases heat transfer.

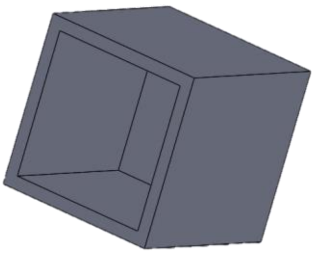

Fig - 3: CAD Model of Central baffle box

DUCT

Ducts and pipes (refer Fig. 4 and 5) are conduits or passages used to deliver or remove fluids. The flue gases flow into the duct and around the heat absorbers. It also holds the entire system together.

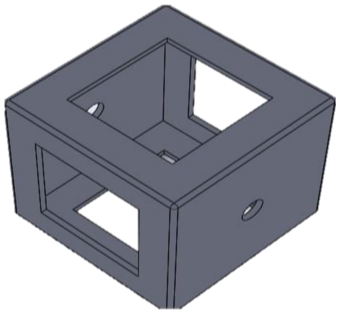

Fig - 4: CAD Model of Duct

EXHAUST INPUT AND OUTPUT PIPES

The hot air coming from the engine enters through the exhaust inlet pipe into the duct, where hot air loses its heat and further exits to the atmosphere through the output pipe.

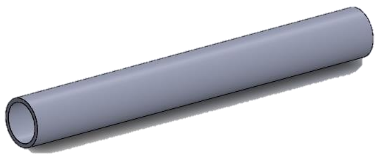

Fig - 5: CAD Model of Exhaust input and output pipes

TEG MODULE

TEG module (refer Fig. 6) is a flat ceramic coated plate constructed by arranging p and n junction adjacent to each other which acts as thermoelectric device.

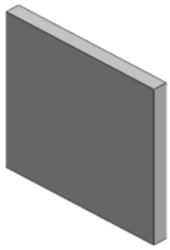

Fig - 6: CAD Moddel of Teg module

In figure 7 the invisibility of the duct is increase to show the internal components. The figure 11 depicts the actual assembly of thermoelectric generator.

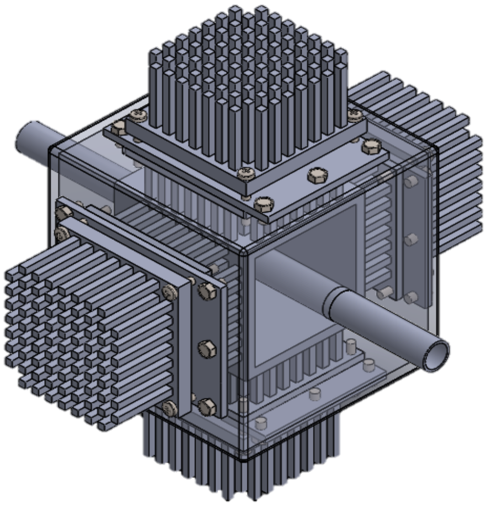

Fig - 7: CAD model of TEPG System

4. METHODOLOGY:

PROBLEM IDENTIFICATION:

Out of the energy liberated from the ignition of fuel 70 percent of it is lost in the form of it either through the walls by conduction or through the flue gases. This heat triggers issues such as banging, jamming, thermal pressures, and the breakdown of certain I.C. engine components. Major heat losses occur through the exhaust.

LOOKING FOR APPROPRIATE SOLUTION:

Piezoelectric generation, thermionic generation, thermo-photovoltaic generation, thermoelectric generation, Rankine cycle, Stirling cycle, refrigeration, and mechanical turbo-compounding are some methods of heat recovery from I. C. engine exhaust gases, but these methods are complicated in nature, cumbersome in scale, and expensive.

Thermoelectric generation, on the other hand, is simple to build. As a result, we chose a thermoelectric generation system to recycle excess exhaust heat from an internal combustion engine (refer Fig, 8).

The thermoelectric cooler (TEC) and thermoelectric generator (TEG) are two modules in the thermoelectric generation method; we are using a thermoelectric generator (TEG) for the purpose.

SELECTION OF MATERIALS:

Following are the thermal materials which have great heat absorbing and releasing capacity.

Gold (K=314 W/mK)
Silver (K=406 W/mK)
Copper (K=380 W/mK)
Aluminium 6061 (K=167 W/mK)
From cost considerations we selected Copper and Aluminium 6061 alloy for our analysis.

PARAMETER CONSIDERATIONS AND DESIGN PROCESS FLOW:

Table- 1: Properties of the ambient air at 30 °C

Parameter	Symbol	Value
Temperature	Ta	30°C = 303K
Specific Heat at constant pressure	Cp	1007 J/Kg K
Density	ρ	1.164 Kg/m³
Thermal Conductivity	K	0.02588 W/mK
Thermal Diffusivity	α	2.208 x10-5 m²/s
Dynamic Viscosity	μ	1.872x10-5 Kg/m-s
Prandtl Number	Pr	0.7292

Assumptions:

- The convection coefficient is obtained by considering forced convection. It is assumed that fin has a finite length and insulated tip.
- The convective heat transfer coefficient of the fins is constant and uniform over the entire surface of fins.
- The temperature of exhaust gases coming from engine exhaust was from 110°C to 150°C. So, 150°C was assumed.
- Radiation heat transfer is neglected.
- The fluid is considered incompressible with constant properties (Air) at 30°C as shown in Table 1.

Fig - 8: Design process for heat sink and absorber plate

In Fig. 9, Design process for fins is elaborated with the help of flow chart. 60 number of fins are required to dissipate 54.792 W of heat from one side of TEPG system. So, temperature differential of 60 °C is achieved. Calculations for heat-sink and heat absorber were performed, only heat-absorber plate is extended so that it can firmly rest on duct and keeping the length of heat absorber fins as 15 mm.

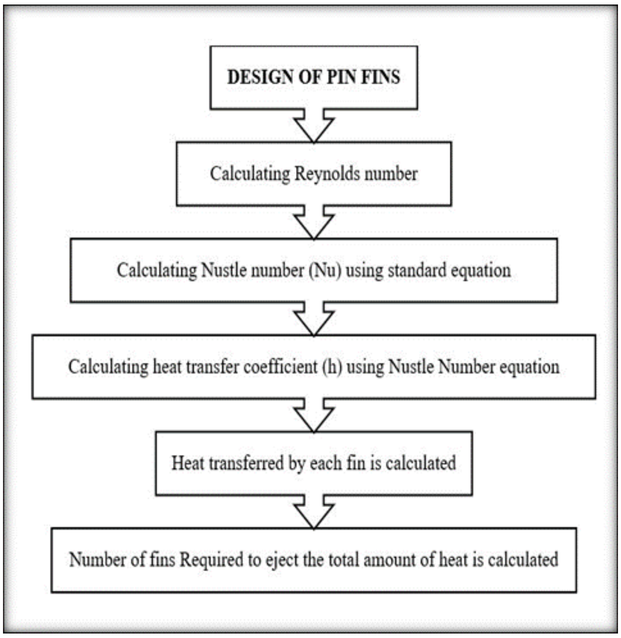

Fig - 9: Process plan for pin fin design

FINITE ELEMENT ANALYSIS SETUP:

The ambient air flowing over the fins at 303 K with heat transfer coefficient hcf =28.47 W/m²K

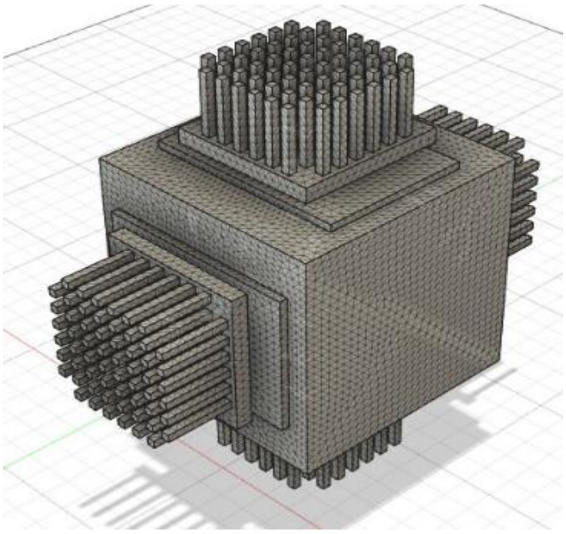

Fig - 10: Imported model in Fusion 360

In Figure 10 CAD model is imported in Fusion 360 environment.

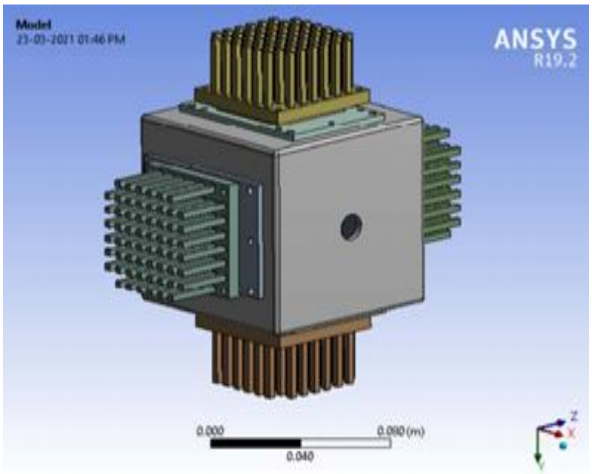

Fig - 11: Imported model in ANSYS

In Figure 11 CAD model is imported in ANSYS R19.2 environment.

The model (refer Fig. 10 and 11) was loaded with following boundary conditions for numerical analysis as shown in Table 2. The heat transfer coefficient for ambient air flowing over the heatsink is 28.47 W/m²K.The ambient temperature throughout the analysis was taken to be 303K. The initial temperature when vehicle is stationary is in equilibrium with the ambient conditions. When the vehicle is in motion the flow of air over the fins is assumed as U= 3m/s. The heat transfer coefficient for exhaust gases flowing through the duct is assumed to be 35 W/m²K according to the standard forced convection range.

Table- 2: Boundary conditions for numerical analysis

Boundary Conditions	Symbols	Values
Ambient Temperature	Ta	303 K
Initial Temperature Value of the system	T1	303 K
Heat Transfer Coefficient for ambient air	hcf	28.47 W/m²K.
Heat Transfer Coefficient for hot exhaust gases	hhf	35 W/m²K
Temperature of Exhaust gases entering the Duct	Tg	150C = 423 K

MESHING:

Finite Element Analysis is done using Autodesk Fusion 360 and Ansys 19.2.

Steady State Thermal analysis was performed by loading the model using boundary conditions given in the Table 2.

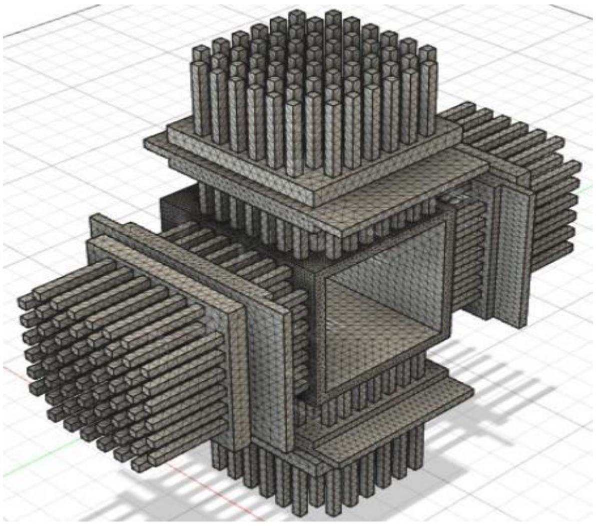

Fig - 12: Tetrahedron meshing in Fusion 360

In Figure 12 the model is meshed (refer Fig, 12) using tetrahedron (simplex) type of meshing and the size of each element is 3 mm.

TEMPERATURE DISTRIBUTION:

After the analysis, we obtained the following temperature difference as shown in the Table 3 for both cross-sectional areas and materials (refer Fig. 13 to 15).

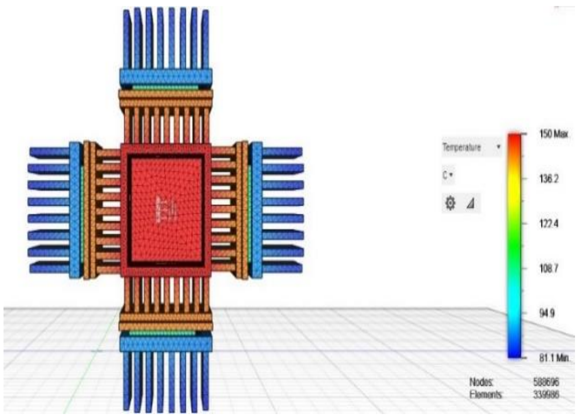

Fig - 13: Temperature distribution on TEPG system

In Figure 13 temperature distribution on TEPG system is shown. It is seen that where temperature is maximum (150°C) it is highlighted in dark red colour an as the temperature decreases linearly to 81.1°C, the colour changes to light blue which represents lowest temperature.

In Figure 14 we can observe how temperature varies on the hot side of TEG module with help of the different colours as shown in the legend of the figure 15. Highest temperature on hot side is reached to about 149°C.

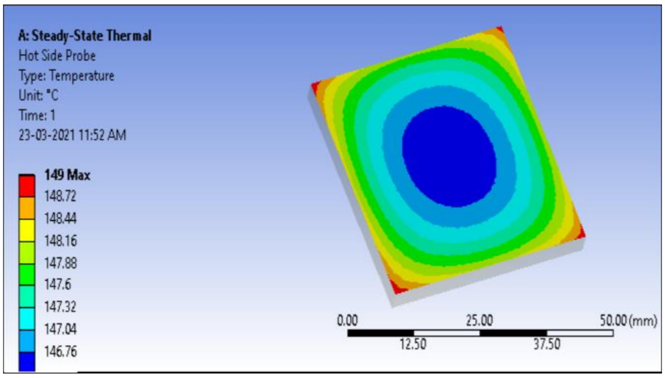

Fig - 14: Temperature distribution on hot side of TEG module

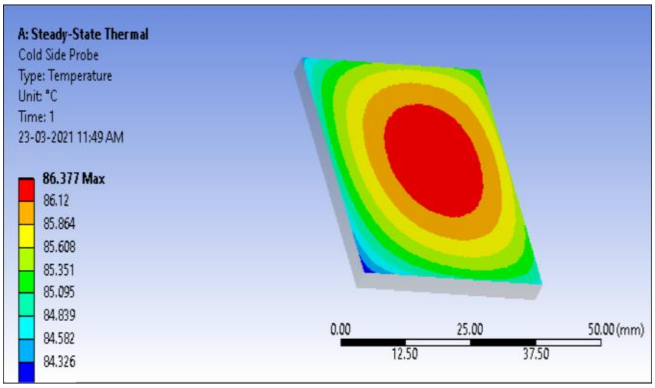

Fig - 15: Temperature distribution on cold side of TEG module

In Figure 15 we can observe how temperature varies on the cold side of TEG module with help of the different colours as shown in the legend of the figure. Lowest temperature on cold side is reached to about 84.33.

Similarly, number of analysis were performed on Fusion360 (Simulation) and ANSYS R 19.2 to obtain results from different material and different shape fins as shown in Table 3. The above figures were of Aluminium square shape fins.

Table- 3: Comparison of temperatures

Material and Cross section of fins	**Autodesk Fusion 360**		**Ansys 19.2**	
	Hot Side °C	**Cold Side °C**	**Hot Side °C**	**Cold Side °C**
Aluminium Circular	143	92	147.4	89.5

Aluminium Square	143.6	87	147.3	85.4
Copper Circular	148	91.6	148.9	89.5
Copper Square	147.8	87.6	148.9	85.49

Table 3 compares hot and cold side temperatures achieved using Autodesk Fusion 360 and ANSYS R19.2. The highest temperature difference is achieved in both software. For copper square shape fins and the lowest temperature difference we get is for aluminium circular shape fins.

5. RESULTS AND DISCUSSION:

Power, voltage and current outputs for different materials and different shape of fins are compared in Table 4 below. The maximum power is obtained for copper square shaped fins and the minimum power is obtained for aluminium circular shaped fins. If we change the shape of aluminium circular fins to square cross-section, the generated power output is very close to the power output generated by copper square fins. So based on economical criterion we selected aluminium square shaped fins.

From the results it is observed square cross-section has larger perimeter than circular cross-section. Ultimately the surface area for heat transfer for square cross-sectional area will be greater than that of circular cross-section. Copper has higher thermal conductivity than aluminium. If we neglect the cost criterion then our best choice is copper with squared shape fins. But if we view cost as our major criterion, it will be economical to use aluminium squared shape fins.

Table 4: Outputs

Material and shape of fins	Temperature Difference (°C)	Power (Watts)	Voltage (V)	Current (Amp)
Aluminium circular fins	51	1.94	3.53	0.55
Copper circular fins	56.4	2.34	3.88	0.6
Aluminium square fins	56.67	2.42	3.95	0.61
Copper square fins	60.14	2.69	4.16	0.65

COMPARISON OF ANALYTICAL AND FEM RESULTS:

Since we selected aluminium square shaped fins as the best choice power output and economical criterion its voltage, current, power and temperature difference are compared as shown in the Chart 1.

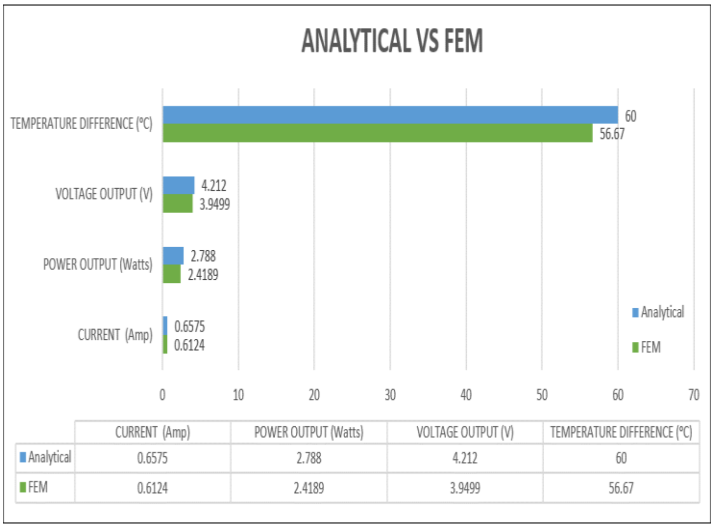

Chart- 1: Analytica vs FEM comparison for aluminium squared shape fins

In Chart 1 we can see analytically calculated results approximately matches with numerical analysis results.

6. CONCLUSIONS:

The construction of copper square fins seems to be the most effective based on the performance. We can use Aluminum Square fins for approximately same power output to make the TEG system more economical when compared to copper circular fins. Aluminum has the ability to absorb heat very quickly. Its density is comparatively less than that of copper which makes Aluminum lighter.

As a result, the environment friendly power generation system can be used for both domestic and industrial purpose at a reasonable cost. Since waste exhaust heat from the silencer is drawn out and converted into electrical energy, which leads to improve the engine performance. The main goal of this paper is to recover the heat and convert it into useful electrical energy. This goal has been accomplished in this paper.

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REFERENCES

[1] Jaydeep. V. Joshi and N. M. Patel "Thermoelectric system to generate electricity from waste heat of the flue gases" (2012) Pelagia Research Library Advances in Applied Science Research, pp.1077-1084

[2] D. T. Kashid, S. H. Barhatte and D. S. Ghodake "Thermoelectric Power Generation using Waste-Heat Energy from Internal Combustion Engine", International Journal of Current Engineering and Technology pp.07-15

[3] Sumit Dharmarao "Exhaust heat recovery in I. C. Engine by using thermo electric generator" Conference: International Journal of Research Publications in Engineering and Technology.: Pune volume: Vol.3, Issue 4 April 2017, pp.179-180

[4] R. B. Kolambekar and K. Bhole, "Development of prototype for waste heat energy recovery from thermoelectric system at Godrej vikhroli plant," 2015 International Conference on Nascent Technologies in the Engineering Field (ICNTE), Navi Mumbai, India, 2015, pp.01-06, doi: 10.1109/ICNTE.2015.7029943.

[5] Rishikesh Khadke and Kiran Bhole 2018 IOP Conf. Ser.: Mater. Sci. Eng. 310 012031, pp.01-06.

[6] J. C. Bass, N. B. Elsner, and F. A. Leavitt "Performance of the 1 kw thermoelectric generator for diesel engines" AIP Conference Proceedings 316, pp.295-298 (1994)

[7] Tzer-Ming Jeng, Sheng-Chung Tzeng, Bo-Jun Yang and Yi-Chun Li "Design, Manufacture and Performance Test of the Thermoelectric Generator System for Waste Heat Recovery of Engine Exhaust" (2016) Multidisciplinary Digital Publishing Institute, doi:10.3390, pp.01-16

[8] A K M Mohiuddin "Investigation of aluminium heat sink design with thermoelectric generator" IOP Conf. Ser.: Mater. Sci. Eng. 184 012062 (2017), pp.25-27

[9] Prasanna Gandhi and Kiran Bhole "3D microfabrication using bulk lithography", IMECE2011-62473, pp. 393-399 (2012) https://doi.org/10.1115/IMECE2011-62473

[10] Kiran Bhole, Sunil Ekshinge and Prasanna Gandhi "Fabrication of continuously varying thickness micro-cantilever using bulk lithography process" MSEC2014-4041, V001T01A009 (2014) https://doi.org/10.1115/MSEC2014-4041

[11] Prasanna Gandhi, Naresh Chaudhari and Kiran Bhole, "Fabrication of Textured 3D Microstructures using Bulk Lithography", ASME International Manufacturing Science and Engineering Conference, MSEC Notre Dame, USA, pp. 959-964 (2013) https://doi.org/10.1115/MSEC2012-7357

[12] Kiran Bhole, Prasanna Gandhi, and T. Kundu, "On the Evolution of Cured Voxel in Bulk Photopolymerization upon Gaussian Laser Exposure", Journal of Applied Physics, pp 043105-1-10, Vol. 116, (2014).

[13] Prasanna Gandhi and Kiran Bhole, "Characterization of 'Bulk Lithography' Process for Fabrication of 3D Micro-structures", ASME Journal of Micro and Nano Manufacturing, Vol 1, Dec. 2013, pp. 041002-1-8. https://doi.org/10.1115/1.4025461

[14] Prasanna Gandhi, Suhas Deshmukh, Rahul Ramtekkar, Kiran Bhole, and Alem Baraki, "On-axis Linear Focused Spot Scanning Microstereolithography System: Optomechatronic Design, Analysis and Development", Journal of Advanced Manufacturing Systems, Vol.12, No.1, June 2013, pp. 43-68, https://doi.org/10.1142/S0219686713500030.

[15] Kale Bharatbhushan and Bhole Kiran Suresh (2020) "Controlling the instabilities in the radial Hele-Shaw cell", Int. J. Theoretical and Applied Multiscale Mechanics, Vol. 3, No. 3, pp.245–260 https://doi.org/10.1504/IJTAMM.2020.112780

[16] Sanket S. Devkare, Kiran S. Bhole, Bharatbhushan S. Kale, Chetna Sharma, "Control of viscous fingering of Bingham plastic fluid in lifting plate Hele-Shaw cell", International Conference on Aspects of Materials Science and Engineering, Chandigarh, June 2020, Materials Today Proceedings, 28 (2020) pp. 1920–1926. https://doi.org/10.1016/j.matpr.2020.05.314