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CFD ANALYSIS OF EXHAUST HEAT EXCHANGER FOR THERMO-ELECTRIC POWER GENERATION

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ABSTRACT
In thermo-electric power generation an exhaust heat exchanger is used for recovering exhaust heat and a thermo-electric module is used for converting heat into electricity.This research work focus on optimization of the design of exhaust heat exchanger by removing the internal fins and changing the cross-sectional area of heat exchanger to minimize the problem of pressure drop.The designs of exhaust heat exchangers used in the previous research works recovers maximum heat from an engine exhaust but they have main problem of pressure drop or back pressure which can stops engine functioning. Computational fluid dynamics (CFD) is used in the simulation of the exhaust gases flowing inside the heat exchanger. The isothermal modelling technique is used in simulation process of the heat exchanger. The thermal simulation is done on heat exchanger to check the surface temperature, heat transfer rate, and pressure drop in three different driving cycles (urban driving, suburban driving and max. power driving) for a vehicle with 1.2 L petrol engine. The Rectangular shaped heat exchanger is used in exhaust manifold of internal combustion engine (ICE) is modelled numerically to recoverthe lost heat from engine exhaust. We find the Rectangular shaped heat exchanger with gradually increasing cross sectional area minimizes pressure drop and gives better temperature at the surface and increase the heat transfer rate

KEYWORDS: Exhaust gases, CFD, Waste heat recovery, Thermo-Electric power, Exhaust Heat Exchanger, Thermo-Electric module.

I. INTRODUCTION
Thermo-electric power generation is based on the principle of See beck effect. When two different materials (metals or semiconductors) is connected and a temperature gradient is created between the hot and cold junctions of the metals a voltage is generated, i.e., See beck voltage. Hence TEGs acts power generators on the basis of see beck effect. Thermo-electric power generation have a capability to recover some exhaust heat from I.C. Engine. A flow diagram below shows the conversion of exhaust gases heat into electrical power applied to an IC engine using thermoelectric power generator. Thermo-electric generator voltage can be used for providing electrical power back up for auxiliary systems such as air conditioner and minor car electronics. The size of the alternator can also be reduced which consumes shaft power. If atheist 6% of exhaust heat could be converted into electrical power, it will save approximately same quantity of driving energy. It will be possible to reduce fuel consumption about 10 %, hence TEGs system can be profitable in the automobile industry.

Thermoelectric Module
The thermo-electric module is a device, which is used for converting the heat energy into electrical energy. It is based on the principles of See beck effect. The module is designed and created by a unique technology for converting heat energy directly into electricity. The thermoelectric module made of Bi2Te3 and can work at temperatures as high as 400°C continuously andintermittently up to 500°C without degrading. The thermoelectric module produces DC voltage when there is a temperature gradient across themodule. The voltage produced is proportional to the temperature gradientacross the module and hence more electricity will generate when temperature gradient increases. The unique technology also ensures the modules can withstand large temperaturerange cycling without degrading. The standard modules are in single anddouble ceramic plate

pattern. The ceramic plate'spartitions are thermally conductive and electrically non-conductive. Currently, modules are available in size of 40mm x 40mm and 56mm x 56mm.

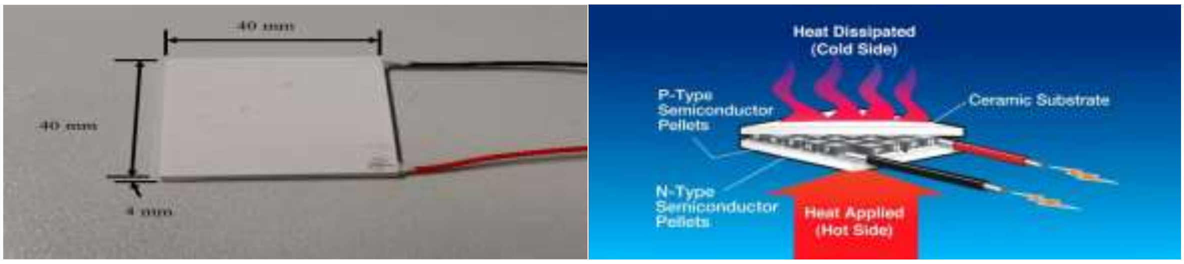

Fig. The Thermoelectric Generator (TEG) module type TEC1-TEP1-1264-1.5

II. LITERATURE SURVEY

G. Murali , G. Vikram (2016)- CFD models having solid field, fluid field and solid-fluid field coalesce are generated for different heat exchangers profile to stimulate turbulence and temperature contours operating at same condition. Comparing four different heat exchangers, the serial plate has high rate of heat transfer compared with other heat exchangers. Serial plate heat exchanger pushes the exhaust gases to flow backwards by passing through baffles increasing the rate of heat transfer at the surface of heat exchanger and increasing problem of pressure drop.

P M Meena et al (2016) - An theoretical model of TEG will can be made based on thermodynamic theory, semiconductor thermoelectric theory, and law of conservation of energy, the equations of power output and current of thermoelectric generator (TEG). According to the analysis the power output per unit area is independent of the thermo legs and of their cross sectional area. The power output is max. at a certain thermocouple length and depends on other parameters. Hence to improve the performance of TEGs by modifying the parameters and design methodology.

Rohan mathai chandy et al (2015) – In this work a circular heat exchanger with fins attached with the TEGs for recovering waste heat from an automobile exhaust pipe is analysed by performing CFD analysis. As the temperature increases voltage produced also increased as voltage is proportional to the temperature difference. It is analysed that the heat exchanger attached between muffler and catalytic converter gives more uniform flow distribution, lower back pressure, and higher surface temperature.

P. Mohamed Shameer et al (2015) - In this research work TEG is fabricated for a two wheeler silencer. The performance of the engine will not be affected because only the surface heat of the silencer is drawn out. The main aim of this research is to transfer the surface exhaust heat to avoid the accidents (Burn-outs) caused by the overheated silencers, and to transfer the recovered heat to useful electric energy. The output could be increased by connecting TEGs in series, so that the voltage gets added up leading to increased power. The energy produced from this system is utilized in powering any auxiliary devices in a vehicle directly or it could be stored in a battery and then used later.

D. T. Kashid et al (2015) - The research work is on design and analyze the effectiveness of heat exchanger for thermo-electric power generation using exhaust heat energy from IC engine. The heat exchangers are assembled in sandwich arrangement with TEGs between them. Thermal grease is spread on the surfaces where TEG modules are attached to increase the heat transfer. It was found that Double stacked type heat exchanger gives better temperature gradient across the TEG. Counter flow type arrangement enhances the effective heat transfer.

Shengqiang Bai et al (2014) - Six types of exhaust heat exchangers are designed and their models are analyzed on CFD to compare rate of heat transfer and pressure drop in driving conditions for a car with a 1.2 L gasoline engine. The result showed that the serial plate HEx increased heat transfer by 7 baffles and transferred the maximum heat of 1737 W. It also has a maximum pressure drop of 9.7 kPa in a suburban driving cycle. The numerical results for the pipe structure and an empty cavity were verified by experiments. At maximum power driving condition, only the inclined plate and empty cavity structure undergoes a pressure drop less than 80 kPa, and the largest pressure drop exceeds 190 kPa.

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Dipak Patil et al (2013) – The study focus on different working condition i.e. rate of mass flow, fluid temperatures and correct place of thermoelectric module. The electric power produced from TEG is observed to be a strong function of mass flow rate and inlet exhaust temperature. The heat exchanger should be highly efficient which is necessary to enhance the amount of heat energy extracted from exhaust gas. It is observed that exhaust gas parameters and heat exchanger structure have a significant effect on the power output and the pressure drop. It is also identified that the potentials of the technologies when incorporated with other devices to maximize the performance of the vehicles.

Hazli Rafis et al (2013)– A DC to DC voltage Booster for boosting voltage from Thermoelectric Cooler (TEC) with high temperature is demonstrated. Since voltage output by TEC is very low between 0.2 to 0.8 Volts, it cannot be utilized in vehicle. In this circuit design integrated circuit is introduced as DC-DC boost converter. The booster circuit can boost input voltage down to 0.7 V and produce a high adjustable output voltage ranging from 2.7 to 5.5 Volts. The booster circuit performance was checked at various operating conditions and voltage output is estimated.

Olle Hogblom et al (2012)- In this work, a transient 3D CFD model for simulation of exhaust gas flow, rate of heat transfer and power output is developed. The model works under critical design parameters for TEG-EGR to be verified and design criteria for the TEG to be mentioned. Besides the theory of See beck effects, the thermal simulations of model gives detailed analysis of the temperature gradients in the gas phase and inside the TEGs. CFD model is a valuable tool to identify bottlenecks, improve design and select optimal TE materials and operating conditions. CFD analysis shows that the greatest heat transfer resistance is in the gaseous phase and it is not possible to change this to get a larger temperature gradient over the thermo-electric elements without effecting on the maximum allowable pressure drop in the system.

C. Ramesh Kumar et al (2011) – The experimental analysis is done to measure performance of TEGs under various different types operating conditions. The thermo-electric modules on heat exchanger was tested in the engine test setup. Different designs of heat exchangers were modelled and CFD analysis is performed study the mass flow rate & rate of heat transfer characteristics. From the thermal simulation results it is observed that rectangular shaped heat exchanger satisfy our conditions. The study shoes that energy can be utilized from the exhaust gases and in future TEG can change the size of the alternator in automobiles.

III. METHODOLOGY

Design Optimization of Exhaust Heat Exchanger

The methodology for design optimization of exhaust heat exchanger used for exhaust gases heat recovery has been described. The power generation using thermoelectric generator depends upon lots of factor like temperature gradient, correct size of heat exchanger, correct use of module and lots of other parameter .So this project emphasizes the methodology that has been used for correct power generation by using systematic use of resources and sequence them in correct form to take maximum advantage of this technology for generating power. Let us take the entire parameter one by one which is coming in the design of exhaust heat exchanger.

CFD Computational Tool: This section describes about the CFD tools which are required for the CFD analysis of the problem. There are the three main elements for the processing of the CFD simulations: the pre-processor, solver, and post-processor are described.

CFD Governing Equations: In this section summarisation of the governing equations are given that are used in to solve the fluid flow and heat transfer mathematically. This solution is based on the principle of conservation of mass, momentum, and energy. CFD Computational equations are given below:-

- This equation is a mass conservation equation:-

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0.$$

- This is the rate of change of momentum equation:-

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_j}{\partial x_i}\right) - \frac{\partial p}{\partial x_j}.$$

- This is the energy equation:-

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$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left(\frac{k}{C_p}\frac{\partial u_j}{\partial x_i}\right).$$

Where velocity vector **u** (with components of the velocities *u*, *v*, and *w* in the direction of *x*, *y*, and *z*), pressure P, density ρ, viscosity μ, temperature T, and heat conductivity k. The changes in these given fluid properties can occur over space because this project works on only steady state condition.

Dimensions of Exhaust Heat Exchanger

The Exhaust heat exchanger is designed on the basis of previous research paper design data. The heat exchanger has been modified by giving gradual increasing cross sectional area.

S.NO.	SPECIFICATIONS	DIMENSIONS (mm)
1.	Length	300 mm
2.	Thickness	5 mm
3.	Inlet Area	110 x 110 mm^2
4.	Outlet Area	165 x 165 mm^2
5.	Manifold Inlet Diameter	80 mm
6.	Manifold Outlet Diameter	80 mm

Modelling Of Exhaust Heat Exchanger

The heat exchangers made up of aluminum have inlet and outlet manifold diameters as 80mm, the area at inlet as 110x110mm and at the outlet 165x165mm. The wall thickness is about 5mm. From inlet of the heat exchanger the cross section is found to be increasing gradually to the outlet, which provides smooth interaction of the exhaust gas with the exchanger walls. This causes the high temperature exhaust gas to diffuse in the entire lateral area rather than concentrating in the central region. Threedimensionalviews andcrosssectional viewofthe heatexchangersare showninFig.

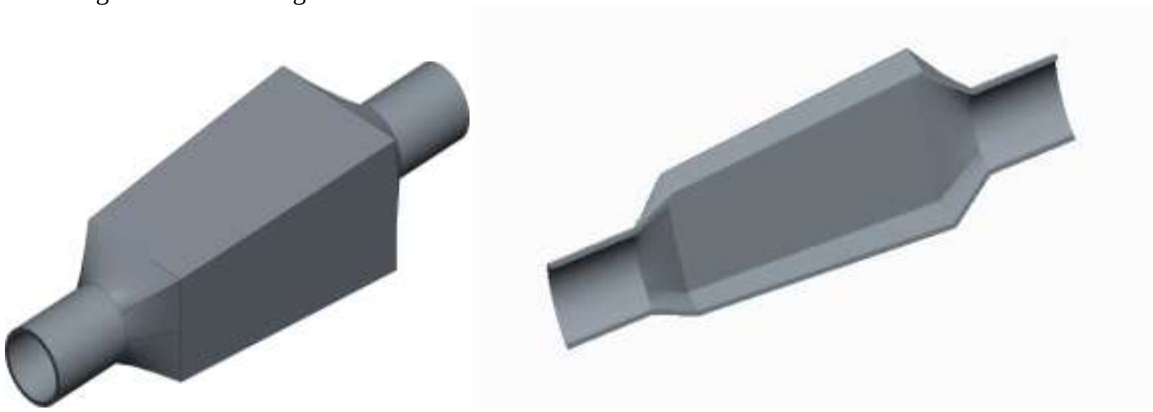

Fig. Three Dimensional View and Cross Sectional View of Rectangular Heat Exchanger

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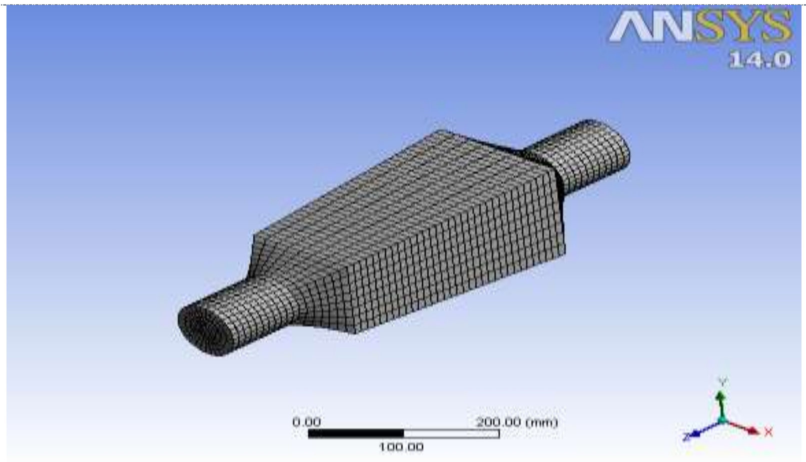


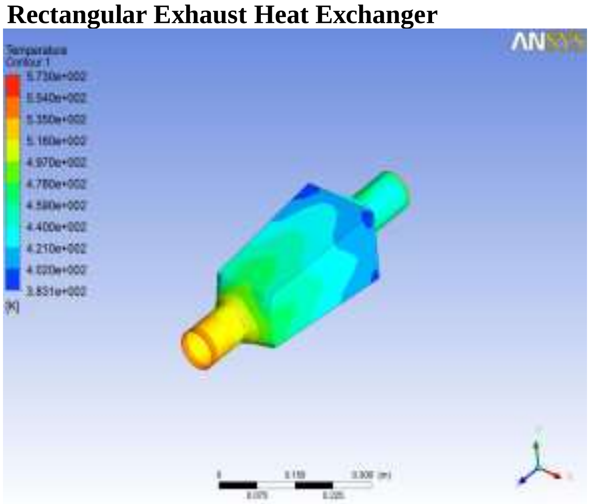
Fig. Meshing of Rectangular heat exchanger

Cfd Analysis Of Exhaust Heat Exchanger

The computational fluid dynamics(CFD) isused to simulate the exhaust gas flow with in the heat exchanger. The isothermal modeling approach is followed during simulation. CFD Analysis is done on ANSYS V.14. Computational fluid dynamics is the computer based analysis by which we can analyze the various things like fluid flow, pressure distribution, heat transfer, and related to the phenomenon in the chemical reactions. And the CFD simulation software is predicted to the impact of the fluid throughout the designing as well as during the end of the use.

Result Simulation: The rectangular-shaped design presents a better uniform temperature distribution. Considering the temperature distribution, the exhaust heat exchanger with rectangular shape cross sectional area is observed to be more ideal for TEG. The temperature field on the heat exchanger plays an important role in thermoelectric energy conversion in three aspects such as: firstly, it determined the available thermoelectric material by maximum continues operating temperature; secondly, it affects the energy conversion efficiency of heat to electricity; thirdly, dominates the thermal stresses in device level and module level. A non-uniform thermal stress may cause performance deterioration and permanent damage to the TEG modules.The simulations are done in three engine loads such as; urban, suburban driving and maximum power and the results were plotted below.

Temperature Contours On Rectangular Exhaust Heat Exchanger



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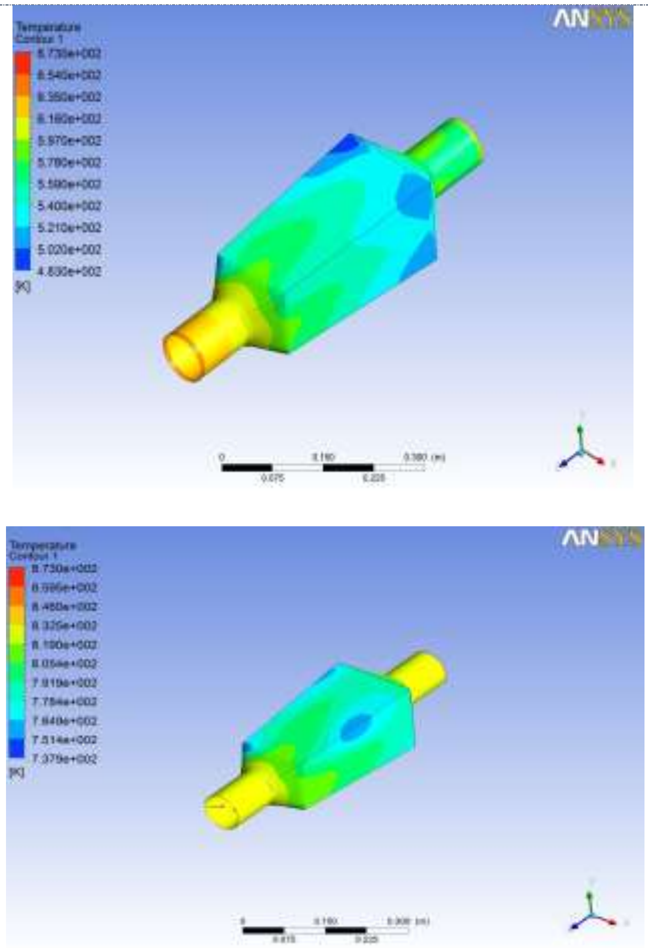
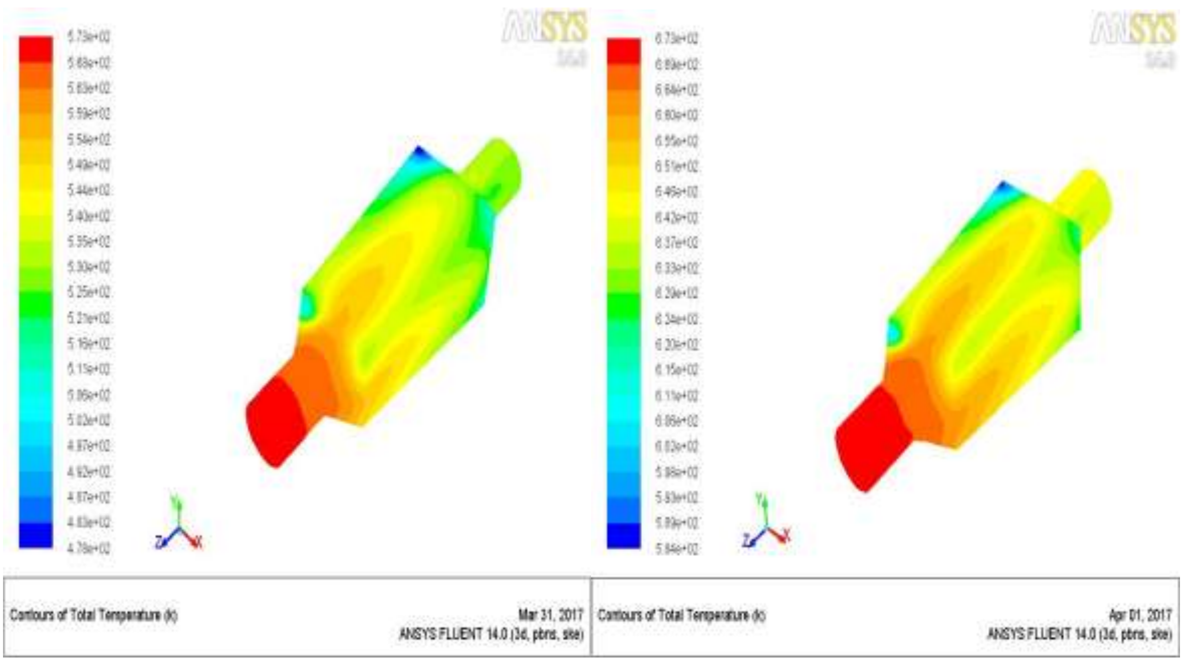


Fig. Temperature contour on Rectangular Heat Exchanger for Urban, Sub Urban andMax. Power driving cycle condition.

Temperature Distribution Inside Exhaust Heat Exchanger



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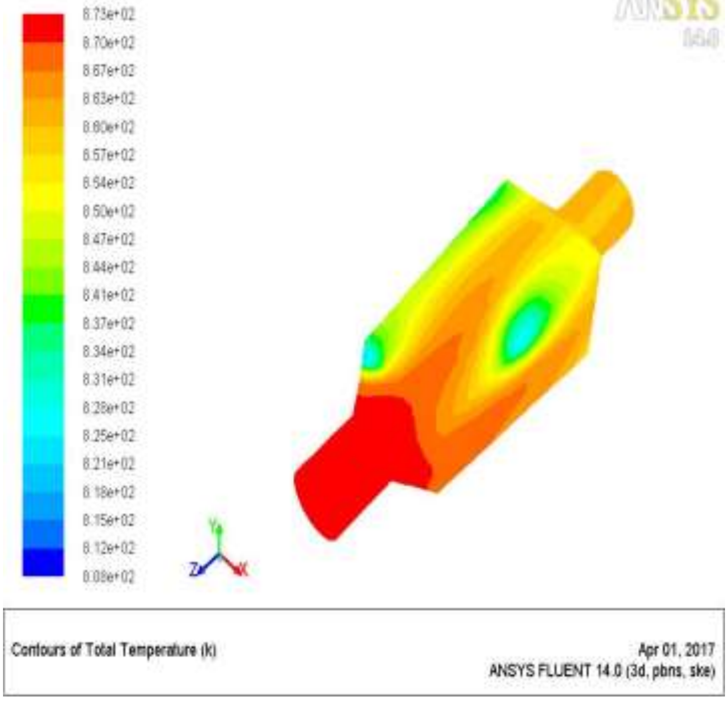
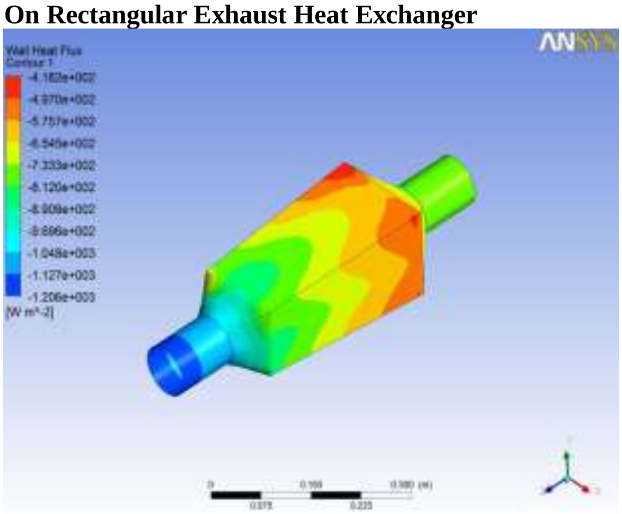


Fig. Total Temperature contour of rectangular heat exchanger for Urban, Sub urban driving cycle condition and Max. Power driving cycle condition.

Wall Heat Flux Contours On Rectangular Exhaust Heat Exchanger



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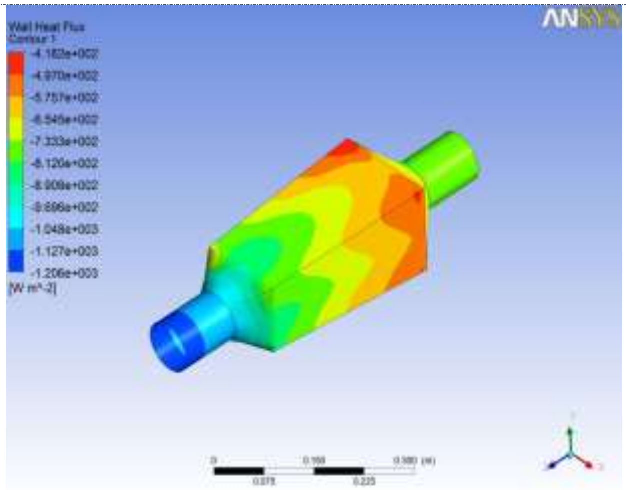

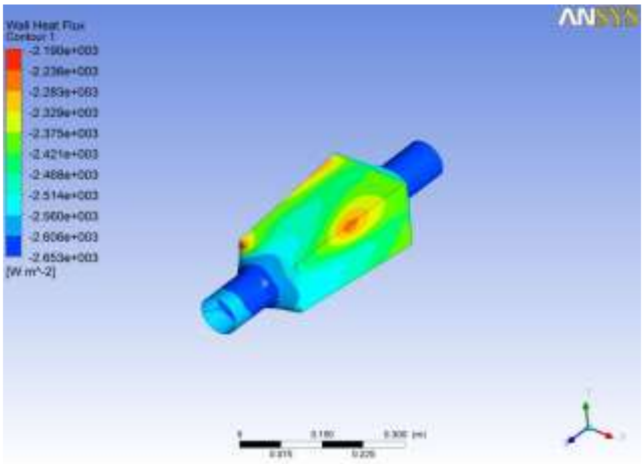

Fig. Wall heat flux contours of rectangular exhaust heat exchanger for urban, suburban and Max. Power driving conditions.

Pressure Gradient On Heat Exchangers

The hot exhaust gas flow from engine, when interacts with the walls of exhaust heat exchanger and transfer energy, experiences drop of pressure. As in the case of an I.C engine system, this drop of pressure is equivalent to the rise of atmospheric pressure and causes a drop in output power.The pressure drop is acceptable and decreased by optimizing the design of rectangular heat exchanger.

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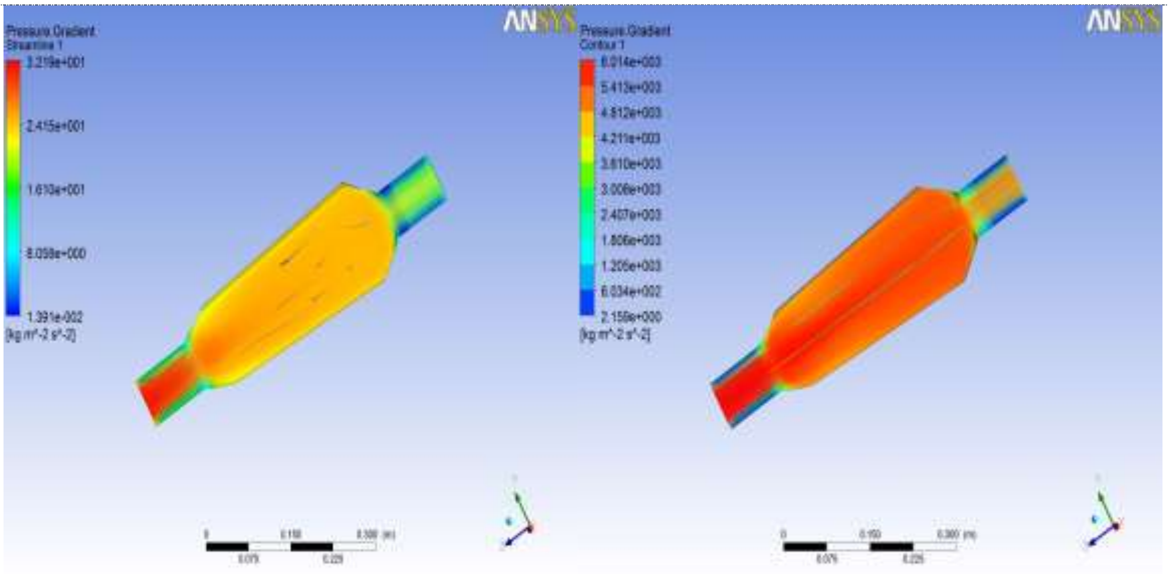
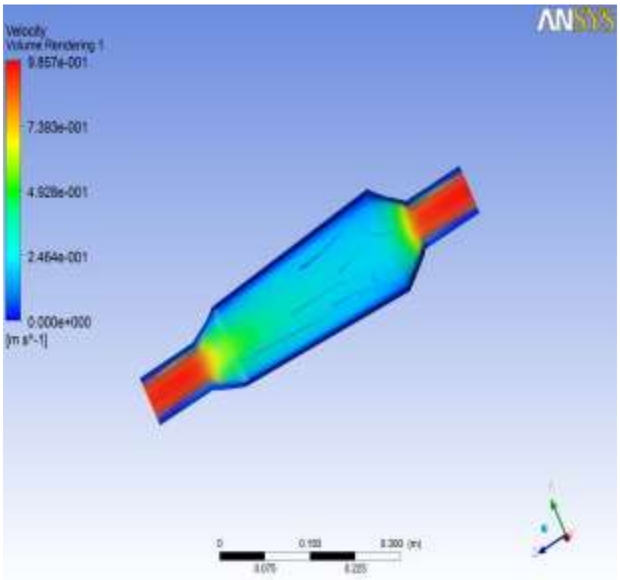


Fig. Pressure gradient contour for urban driving condition and for Max. Power driving condition.

Velocity Distribution Inside Exhaust Heat Exchanger

From the velocity contour it is very clear that in rectangular shaped exhaust heat exchanger the exhaust is distributed uniformly over the profile.



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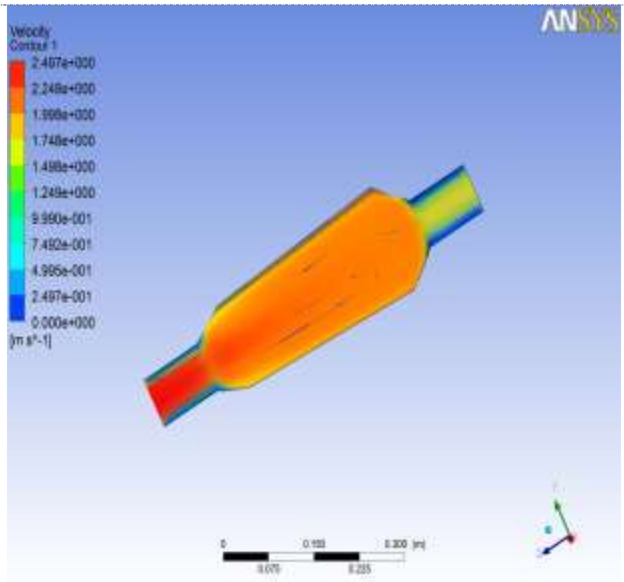

Fig.Velocity Gradient for urban Driving Condition and for Sub urban Driving Condition

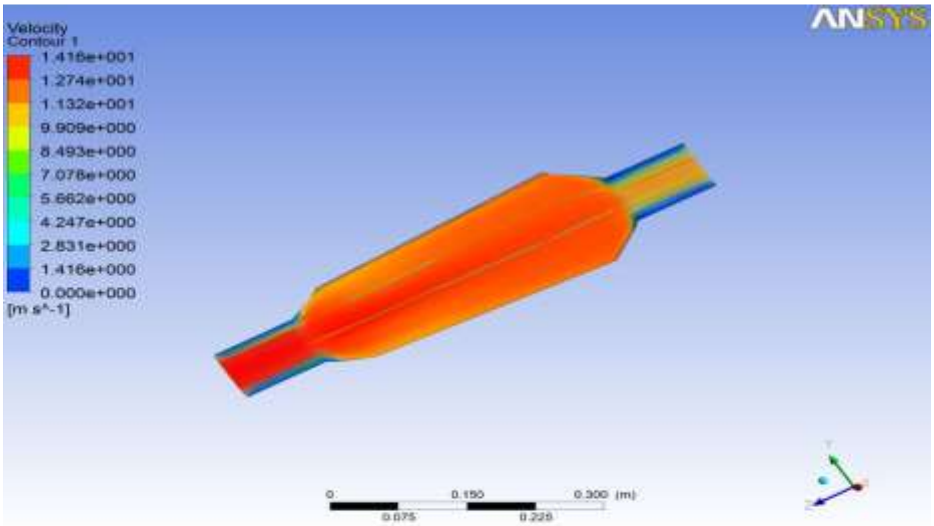

Fig. Velocity Gradient for Max. Power Driving Condition

TABLE Summary of calculated power output for the three driving conditions by TEG.

Mass flow rate (g/s)	Inlet Temp. (K)	Inlet Pressure (KPa)	Hot side surface Temp Th (K)	Cold side Temp Tc (K)	TEG Voltage V (Volts)	Total voltage by 8 TEG module V (Volts)	Voltage after Boosting V_{out} (Volts)	Current I (A)	Power P=VI Watt
5.7 g/s	573 K	300 KPa	459K	303K	0.0447Volts	0.358 V	2.38 Volts	0.25 Amp	0.595watt
14.4 g/s	673 K	300 KPa	555K	303K	0.0723Volts	0.578 V	3.85 Volts	0.4 Amp	1.54 watt
80.1 g/s	873 K	300 KPa	791K	303K	0.1400Volts	1.120 V	7.46 Volts	0.75 Amp	5.6 watt

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IV. CONCLUSION

The results of the CFD analysis revealed that the design optimization of exhaust heat exchanger has significant effect on power generated capacity by TEG module. The temperature contours shows that the surface temperature attained in rectangular shaped exhaust heat exchanger with gradually increasing cross sectional area is uniform and better as compared to the previous models. The optimized rectangular exhaust heat exchanger design gives mean surface temperature of459K for urban driving cycle**,** 555K for sub urban driving cycle and 791 K for maximum power driving cycle. By removing the internal fins from the exhaust heat exchanger the pressure drop is reduced. The pressure gradient is uniform throughout with nominal pressure drop of 24.15 Pa for urban driving cycle, 182.5 Pa for sub urban driving cycle, 5.413 KPa for maximum power driving cycle. From the velocity contour it is very clear that in rectangular shaped TEG the exhaust is distributed uniformly over the profile. The heat transfer rate has been increased as shown by wall heat flux contours. The calculated power generated by TEG module ranges from 0.5 watt to 5.6 watt. Therefore, it led to the conclusion that rectangular shaped exhaust exchanger could be used for thermoelectric power generation.

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