

“Design Optimization & CFD Analysis of Exhaust Heat Exchanger for Thermo-Electric Power Generation”: A Review”

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Abstract: In recent years with the advancement of thermo-electric materials, direct conversion of heat energy into electrical energy becomes possible. Thermoelectric technology is used for recovering heat energy losses from engine exhaust gases. The power generated by thermoelectric technology is called as thermoelectric power. 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. The present research work is on to optimization of the design of exhaust heat exchanger by removing the internal fins and changing the cross-sectional area of heat exchanger to overcome 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 stop 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 recover the lost heat from engine exhaust. The result shows that Rectangular shaped heat exchanger with gradually increasing cross sectional area minimizes pressure drop and gives better temperature at the surface and heat transfer rate.

Keywords: Exhaust gases, waste heat recovery, Thermo-Electric power, Exhaust Heat Exchanger, Thermo-Electric module.

Introduction:

In automobiles, big and heavy alternators are connected to the engines in order to meet the increasing electrical demands of different accessories. An alternator which operates at an efficiency of 50 to 62% consumes about 1 to 5% of the rated engine work output. About 40% of the thermal energy of the fuel injected to an IC engine is rejected in the form of exhaust gases as waste heat. If approximately 6% of waste heat can be utilized from the engines exhaust, it can fulfill the electrical requirements of our automobiles and it would have been possible to reduce the fuel consumptions about 10%. As compared to heat rejected through coolant and lubricating oil a lot of heat is expelled through exhaust gases at very high temperatures. Thus a thermo-electric generator (TEG) can be used for converting energy from exhaust heat. TEG is similar to a heat engine which is used convert the heat energy into electrical energy and it basically works on the principle of Seebeck effect. Moreover TEGs are environmental friendly, highly reliable, operate smoothly and quietly, requires less maintenance.

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.

Dr. P M Meena (PhD-IITB) 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.

Nevil Patel 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.

T. venkateshan et al (2015) - 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.

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 Seebeck 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.

Methodology:

The three-dimensional model of rectangular heat exchanger is modified by providing a new design. The formula of convective heat transfer $Q = h A \Delta T$, shows that heat convection increases by the heat transfer area A . This is achieved by providing a sufficient conduction surface. Another approach is to increase the convective heat transfer coefficient h . Theory of fluid dynamics suggests that under the condition of Reynolds number $Re > 104$, macro turbulent fluid flow is a significant factor for improving the rate of heat transfer. Moreover, the greater the convective heat transfer coefficient h , the better the rate of heat transfers. The thermal resistance of turbulent flow of convection mostly exists in the boundary layer. More coalition between the temperature field and velocity field, more improvement in the rate of heat transfer. According to both the theories mentioned above, the rate of heat transfer can be increased by adding turbulent devices or altering the geometry to increase the fluid turbulence and damage the fluid boundary layer. 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.

Conclusion:

In this study rectangular shaped heat exchangers will model using PRO-E Software. The computational fluid dynamics (CFD) analysis of the models done using ANSYS V.14 FLUENT. The flow in the heat exchanger have considered to be unsteady and turbulent and traditional wall law has applied. The governing equations will be solved iteratively with simple algorithm. The pressure, velocity contours and temperature distribution of the model will obtained after the solving the boundary problem on CFD. The results of the CFD analysis revealed that the surface temperature attained in rectangular model is better as compared to the previous models, which suits the TEM requirements. The rectangular heat exchanger shows comparatively low pressure drop as well as better heat transfer rate. From the velocity contour it is very clear that in rectangular shaped TEG the exhaust is distributed uniformly over the profile. Therefore, it led to the conclusion that rectangular shaped TEG has better for thermoelectric power generation.

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