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CFD Analysis on Waste Heat Recovery Utilizing Thermo-Electric Generator in Internal Combustion Engine

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***Abstract*- The internal combustion engine (ICE) does no longer correctly convert chemical energy into mechanical energy. A majority of this power is dissipated as heat within the exhaust and coolant. As opposed to directly improving the efficiency of the engine, efforts are being made to improve the efficiency of the engine circuitously by means of the use of a waste heat healing device. Appeared as a promising method of waste heat recovery, the thermoelectric generator (TEG) has been given increasing interest over the complete automotive industry for the ultimate decade. A TEG can convert otherwise wasted thermal energy from engines to strength directly for use in the car systems the usage of Seebeck effect. The Seebeck effect refers back to the voltage that is generated between the hot and cold sides of a conductor or semiconductor while a temperature distinction is maintained among them. This effect forms the idea of the thermocouple and can be employed to generate heat-to-electrical energy**

The present studies work is on to optimization of the design of exhaust heat exchanger via getting rid of the internal fins and converting the cross-sectional place of heat exchanger to triumph over the trouble of pressure drop. The designs of exhaust heat exchangers used in the preceding studies works recovers most heat from an engine exhaust however they have predominant problem of pressure drop or returned pressure that can stops engine functioning. Computational fluid dynamics (CFD) is used within the simulation of the exhaust gases flowing within the heat exchanger. The isothermal modelling approach is utilized in simulation procedure of the heat exchanger. The thermal simulation is finished 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 formed 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 fashioned heat exchanger with steadily growing go sectional area minimizes pressure drop and gives better temperature at the surface and heat transfer rate.

Index terms- Waste Heat Recovery, Internal Combustion Engine, Seebeck Effect, Thermo-electric Generator, CFD, ANSYS

I. INTRODUCTION

The power issue and the demand for alternative sources, which might be necessary to lessen the dependency on fossil fuels, are vital for all countries. Currently, electricity is considered a commodity for the improvement of a country, offering social and monetary boom. But, there's an energy crisis that has evidenced the bounds of the power deliver to satisfy the growing demand [1, 2]. Therefore, its miles crucial to are trying to find new alternative sources that stand out as environmentally sustainable solutions, so one can diversify the power matrix and as a consequence minimize the environmental affects, by prioritizing the substitution by means of renewable resources [3]. These days, lots have been mentioned about clean and renewable power resources, and therefore, the strength that has been acquired from the waste heat recuperation seems as an opportunity, inside renewable power.

Modern-day Internal Combustion Engines are on common approximately 25% efficient [1] beneath ordinary driving conditions but can range from 20% to 45% relying at the engine kind and running conditions. The remaining 55%–80% will be wasted as heat in both the coolant and the exhaust gases. A waste heat recovery system has the capability to transform a number of this waste heat into electricity and consequently reduce the fuel intake of the automobile with the aid of lowering the load on the car alternator. There are several approaches to improving the overall thermal efficiency of vehicles, including turbocharging, the Rankine cycle model and the thermoelectric generator (TEG). These three technologies all have their own advantages and disadvantages.

Compared to other waste heat recovery technologies, the use of TEGs in a waste heat recovery system has many desirable attributes such as silence, small size, scalability and durability. Their key attribute is that they have no moving parts and no chemical reactions therefore there is little maintenance required due to wear and corrosion. Their efficiency is relatively low compared with a Rankine cycle waste heat recovery system [4] but as there are no costs associated with waste heat, efficiency is not the most important factor.

The thermoelectric effect has been known since 1821, when it was discovered by Thomas Johann Seebeck. The Seebeck effect refers to the voltage that is generated between the hot and cold sides of a conductor or semiconductor when a temperature difference is maintained between them. This effect forms the basis of the thermocouple and can be employed to generate heat-to-electrical energy [6, 7].

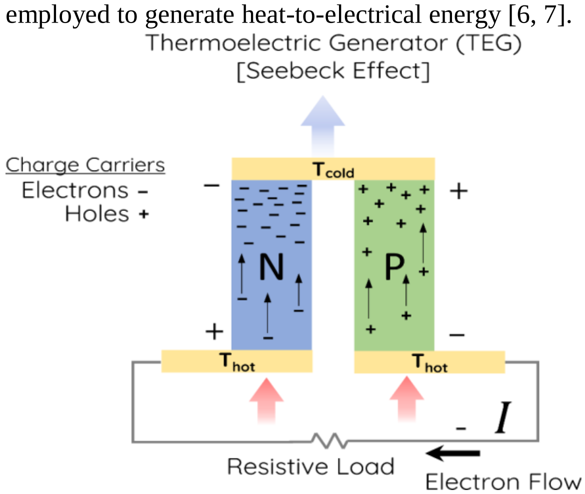

Figure 1: Seebeck Effect

II. LITERATURE REVIEW

With progressively strict energy use rules, numerous experts and engineers include targeting the occupations of waste heating recovery technology for automotive programs. Viewed as a method that is promising of heat healing, the thermoelectric generator (TEG) happens to be offered growing interest throughout the entire automobile industry for any last decade. So in this chapter, we provide a review that is brief on the waste heat recovery where the heat energy is transformed to electric power by employing thermoelectric generator TEG techniques. This literature that is brief reviews some of these aspects. Aided by the development of high-tech thermo-electric materials, direct transformation of waste heat into electric power has attracted many studies, experiments and research to improve on the low efficiency of thermoelectric generators and also try to mitigate the barriers to large scale and commercial production. The extensive technology has allowed for the incorporation of nanotechnology in the development of the thermoelectric generators. Application of the thermoelectric generators technology in the car industry has been very wanting because of the impact of the exhaust energy and carbon released into the environment. The price of mass flow and working limit of pressure fall of a car exhaust gas system makes a challenge that is double designing an efficient exhaust heat exchanger system. This literature that is brief product reviews a few of these aspects.

2.1 Previous Work

Kim et al. [2011] concluded from tests designed on the exhausts to recover the wasted energy from the engine victimizing the generators. The waste heat and the exhausting gases pass through the designed exhausted pipe as heat is absorbed on the pipes. The absorbed waste heat is transmitted through an inserted thermoelectric material facet while waste not absorbed is released from the system by the cool water placed at the other facet of the heat sink. The system converted about 350W from the heat that passed through.

Meng et al. [2012] the simulation results reiterated the Seebeck effect where the thermal properties of thermoelectric materials affected quantity of power recovered and the conversion efficiency of the generators. The facet with low temperature is connected to the engine and cooling is achieved by the flow rate of the waste heat.

Yongming Shi at el. [2015] the thermal cell can manipulate the productivity results of thermoelectric machines. Nevertheless, the analysis by the software shows that the heat energy is not applicable and is limited to a home heating room for the thermal cell. Therefore, lightweight thermoelectric turbines cantered on enhanced thermal communications program needs to be created and produced. The test was conducted using 3-D thermoelectric materials extensional designed, with improved properties and examined the thermal contact with the small thermo turbines. The analysis concludes that the thermal flow was parallel to the thermocouples and in the direction of heat flow across the 3-D thermoelectric construction, therefore, reducing the need for thermal contact neighbourhood. The test yield about 5.58v, 829mW over an area of $3600mm^2$ within 900 seconds.

M.Takashiri et al. [2007] have become completed Bismuth–telluride based alloy thinner movie thermoelectric generator was fabricated by way of a flash evaporation technique. The maximum result power on the thin movie thermoelectric creator results proved they are not sufficient to provide just the power needed for the thermoelectric generator. As well as improving the show with the generator they put hydrogen annealing process.

Niu et al. and Bai et al. [2014] conducted the analysis that is numerical of the system of internal combustion motor for the healing of waste heat utilizing thermoelectric generators. The research was made to investigate the result of bafflers on heat exchange price and force fall across the channel as well as from the performance of TEGs.

Du et al. [2015] analyzed the effect of coolant, circulation plan, and circulation rate and bafflers location on the results of thermoelectric creator coupled with fatigue. The outcome revealed that for high-power production, liquid cooling with lower flow velocity can be used than air cooling. The overall performance of TEGs may be furthermore increased by bafflers in the front of a TEG module which tips the cooling media and develop sufficient temperature difference. Atmosphere cooling can be significant when air conditioning environment flow is free to make use of but the air that is using with bafflers leads to drive losses.

Brito et al., Martins et al., Gonclaves et al. [2016] created spend heat healing program which makes use of temperatures tube to recoup heating from the exhaust gases and will act as a heating provider to side that is hot of modules and on additional part for cooling impact water sink was utilized. For constant working temperatures, a variable conductance temperatures pipeline was applied as opposed to a standard heat pipeline. A VCHP helped thermos electric module for energy generation consists incompressible non-condensable gaseous heat in the pipe. This research presented the potential utilization of temperatures pipes as a device that is efficient in transferring heating from hot fatigue gases to TEGs. The operating temperature from the temperatures tube had been held steady because TEGs can fail once run over their rated max temperature.

III.PROBLEM IDENTIFICATION AND OBJECTIVES

The exhaust waste or truely waste heat may be described as strength lost and emitted into the surroundings in particular from combustion strategies. This energy is of extremely good importance regarding MDGs which envisions a smooth environment. This waste warmness reduces the performance of machines, therefore, growing the energy price at the same time as additionally polluting the environment. The efforts to the faucet and recover the exhaust heat power immediately to power in the car industry led to many studies and many experiments and the subsequent can be deduced from them:

- The warmth conversion efficiencies of the TEGs from the thermoelectric materials. This became approximately three% of the overall warmness of electricity wasted.
- The expected output from the TEGs fell below the effects for the reason that systems were no longer running optimally.
- There were tries to reinforce the efficiency even though the designs were not optimized.

The main objectives of my research work are as follows:-

- Designing a new heat exchanger profile.
- The fluid flow analysis (CFD) works to study the temperature variations and pressure drop on the heat exchanger model.
- Calculating the power output by using thermoelectric generator voltage equations.
- Converting the low efficiency of the TEG module into high by using a booster circuit.

- Result analysis.
- The determine effect of the increase in a temperature gradient in the exchanger in a tube section.
- To study the mass flow rate in the cross-flow exchanger and how temperature gradient and velocity affect it.
- The effect of increasing the transfer coefficient on the conversion rate.
- To determine the effect of the pressure drop in the heat transfer.

IV. METHODOLOGY

Computational fluid dynamics is the pc primarily based evaluation through which we will examine the numerous such things as fluid flow, pressure distribution, rate of heat transfer and complex thermal issues.The CFD gives whole evaluation and prediction of the fluid glide hassle with the assist of the subsequent tools:-

- Mathematical model (partial differential equations).
- Numerical approach (discretization and solution of the hassle).
- Software equipment (pre and post processing, solver).

The boost converter is a device that is used to boost the magnitude of the DC input voltage. It converts the fixed input DC voltage into variable DC voltage. The boost converters use the switched inductors, with a switching device which can be the MOSFET. This boost converter is also called step-up converter as the magnitude of the output voltage is greater than that of input voltage.

4.1 Formulas used for calculating Thermo-electric power

1. Seeback voltage

When two ends of the thermoelectric module are held at different temperatures, an emf is produced in the thermoelectric module which is proportional to the temperature difference.” The potential difference can be obtained as $V = \alpha\Delta T$.

V = Seebeck voltage

$V = \alpha \Delta T$

Where, ΔT temperature difference of hot and cold side $\Delta T = T_h - T_c$ (K)

T_h = Temperature at hot side of thermoelectric module.

T_c = Temperature at cold side of thermoelectric module.

And α is the Seebeck Coefficient or thermo-power expressed in μV.

2. Booster voltage

The boost converter is a tool that can be used to improve the magnitude associated with DC input voltage. It converts the fixed input DC voltage into variable DC voltage and it more than that of input voltage.

$V_{out} = V_{in} / 1 - D$

Where V_{out} is the output voltage after boosting.

V_{in} is the input voltage.

D is the duty cycle of booster circuit.

The boost converters use the switched inductors, with a switching device which may be the MOSFET. This boost converter is also called step-up converter since the magnitude of the output voltage.

V. GEOMETRY SETUP AND MODELLING

In this study the 2D design of heat exchanger is developed to 3D model on Pro-E software. After designing the model it is transferred to ANSYS V.14 for CFD analysis. 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.

Table 1. Dimensions of Rectangular Exhaust heat exchanger

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

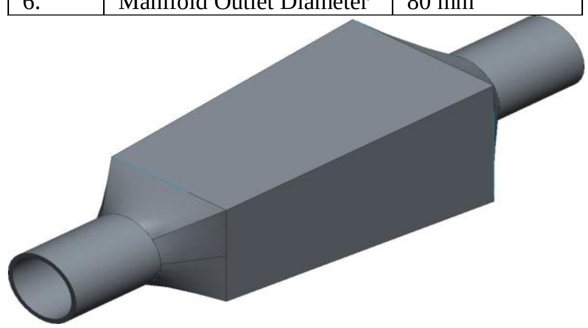

Figure 2. Three Dimensional View of Rectangular Heat Exchanger.

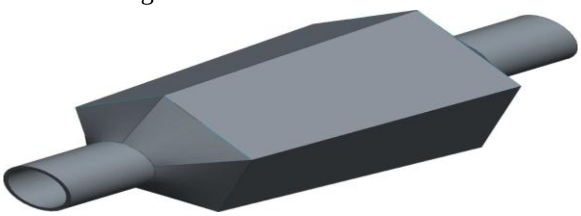

Figure 3. Three Dimensional View of Pentagonal Heat Exchanger.

A part that is different of exchanger is selected plus the names are fond of them to ensure boundary conditions may be applied.

- ❖ The Inlet temperature: 573K, 673K, 873K and with 300 KPa Inlet Pressure with considering outlet pressure to atmospheric air pressure.
- ❖ The mass flow rates for different conditions are as follows; Urban: 5.7 g/sec, Suburban: 14.4 g/sec, Maximum power: 80.1 g/sec.
- ❖ As Near wall area processing with standard wall function, the convection temperature transfer coefficient and also the environment temperature are set.

In representation associated with the unit it is guaranteed that the movement of exhaust gases for the temperatures exchanger are totally turbulent and viscosity that is molecular neglected, so that the standard k–ε model was used in the CFD representation. The standard wall function, the natural convective heat transfer coefficient and the environmental temperature are set at near wall area.

VI. RESULTS AND DISCUSSIONS

After using all boundary condition we have acquired the next results which are shown in figure. The CFD simulation results such as the heat contour are shown in Fig. The rectangular-shape design presents an improved uniform temperature circulation. Considering the temperature distribution, the warmth exchanger with rectangular form structure that is internal much more perfect for TEG. The heat area in the heat exchanger plays an important part in thermoelectric energy conversion in three aspects such as for example: firstly, it determined the offered thermoelectric material by optimum continues operating temperature; next, it impacts the vitality conversion efficiency of temperature to electricity; thirdly, dominates the thermal stresses in device degree and component amount. A non-uniform thermal stress may trigger overall performance deterioration and permanent harm to the TEG component.

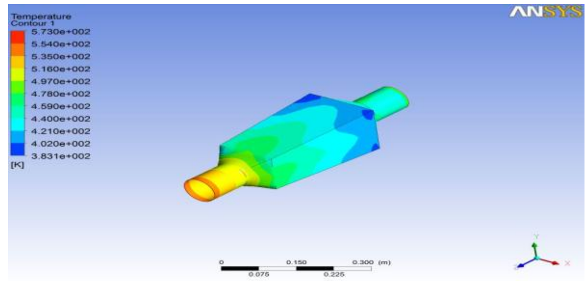

Figure 4. Surface Temperature contour of rectangular heat exchanger for urban driving cycle condition.

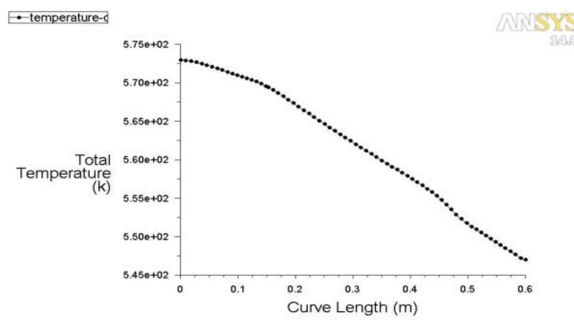

Figure 5.Total Temperature graph of rectangular heat exchanger for urban driving cycle condition.

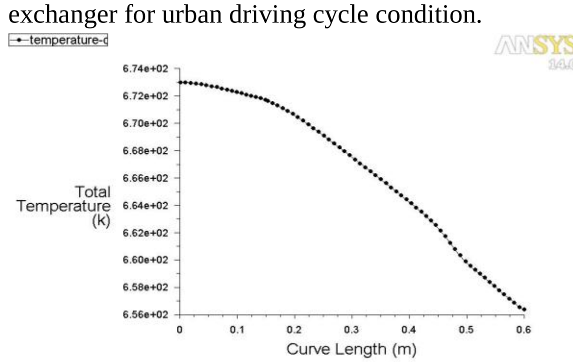

Figure 6.Total Temperature graph of rectangular heat exchanger for Sub-urban driving cycle condition.

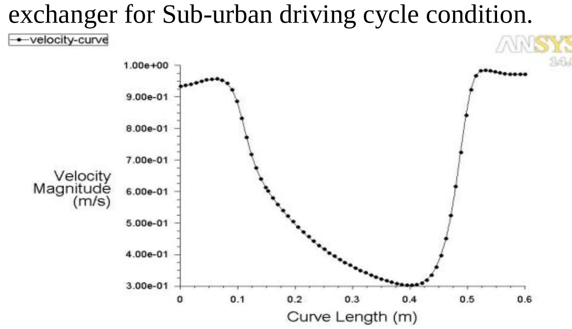

Figure 7. Graph Showing Velocity magnitude for Urban Driving Conditions.

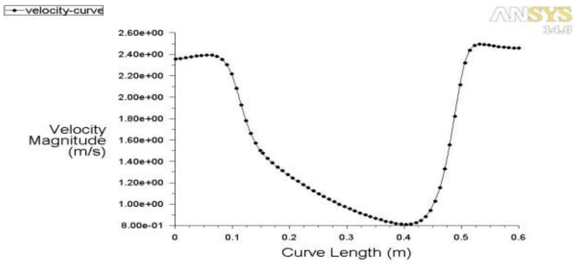

Figure 8. Graph Showing Velocity magnitude for Sub-Urban Driving Conditions.

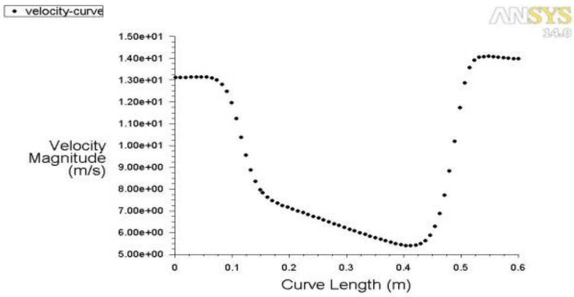

Figure 9 Graph Showing Velocity magnitude for Max. Power Driving Conditions

Table 2. Summary of Thermoelectric Power Generation

Sr. No.	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 Vout (Volts)	Current I(A)	Power P=VI Watt
1	5.7 g/s	573 K	300 KPa	459K	303K	0.0447 V	0.358 V	2.56 Volts	0.25 Amp	0.64 watt
2	14.4 g/s	673 K	300 KPa	555K	303K	0.0723 V	0.578 V	3.85 Volts	0.4 Amp	1.54 watt
3	80.1g/s	873 K	300 KPa	791K	303K	0.1400 V	1.120 V	7.46 Volts	0.75 Amp	5.6 watt

VII.CONCLUSIONS

With this observe rectangular shaped heat exchangers is modeled the application of pro-E software. The fluid that is computational (CFD) evaluation associated with the models become completed the utilization of ANSYS V.14 FLUENT. The float in the heat exchanger become considered become unsteady and turbulent and wall that is traditional converted into used. The governing equations have now been solved iteratively with quick collection of rules. The stress, velocity contours and temperature distribution associated with variation tend to be received following the fixing the boundary problem on CFD.

Positive results of this CFD analysis shown that the surface temperature attained in rectangular model is greater in comparison to the preceding models, which meets the TEM requirements. The rectangular heat exchanger reveals reasonably low-pressure fall along with higher heat transfer fee. The exhaust is sent uniformly over the profile from the rate contour it's far very clear that during rectangular shaped TEG. Consequently, it resulted in the belief that rectangular created TEG become higher for thermoelectric energy generation.

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