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# Virtual Analysis of Waste Heat Recovery System in Automobile Exhaust Gases for Hybrid Vehicles

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**ABSTRACT:** Waste heat can be recovered from automotive exhaust gases in the form of electrical energy by using thermoelectric modules at the expense of temperature contrast between the heat exchanger and the ambient temperature conditions. The inner topological structure of the heat exchanger is a very big influence on the temperature obtained on the surface of the heat exchanger. Dimpled structures have been found to have a very effective heat exchange rate with negligible fluid stream pressure drop. This project deals with the influence of the variation of the size of the dimpled structure on the temperature obtained on the surface of the heat exchanger. A total of 8 models including 4 inline arrangements and 4 staggered arrangements with different dimple diameters have been taken into consideration. Computational fluid dynamics analysis for each of the models has been carried out and surface temperature contours of the interior surface for each of the models are obtained. The Surface temperature contours have been further studied to determine the most effective model with the highest heat exchange rate. Thermo electric power generation calculation is done using SiGe and 275 W can be harvested by installing waste heat recovery unit.

**KEYWORDS:** Dimpled structure, Heat Exchanger, Thermoelectric, Waste Heat Recovery.

## I. INTRODUCTION

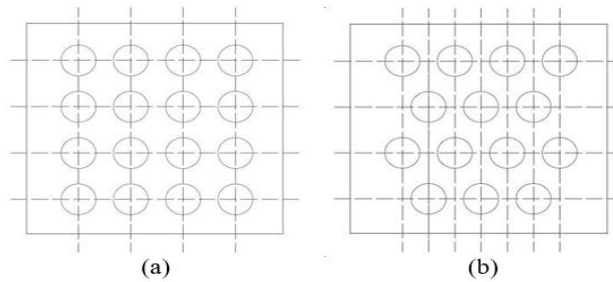
Climate change and global warming has been one of the biggest challenges to mankind in the recent times. Of the many environmental and public health risks associated with burning fossil fuels, the most serious in terms of its universal and potentially irreversible consequences is global warming. Electric is considered as the future mode of transportation. Main challenge in complete electric vehicles is its range and charging time. Some varieties of hybrid electric vehicles use IC engines to directly power the motor or to charge the battery which in turn used to power the motor. Thus, the plugin hybrid electric vehicles eliminate the risk of range anxiety and also provide the opportunity to charge while driving. Waste heat recovery from engine exhaust gases seems to be a highly effective approach towards reduction of global pollution level as well as a productive step towards conservation of energy. Waste heat can be recovered using the waste heat recovery unit. A waste heat recovery unit is a heat exchanger that transfers heat from exhaust gases to the surface where thermo electric modules are fixed. Thermo electric generator (TEG) is a device that converts heat energy into direct electric energy. TEG works based on the Seebeck effect. Thermo electric generators are compact, solid-state, noise-free, and doesn't involve any moving parts.

## II. LITERATURE SURVEY

Factors affecting the heat transfer rate are found to be, thermal conductivity of heat exchanger material, area of contact between fluid and internal structure, difference between exhaust gas and ambient air temperature and thickness of the waste heat recovery unit. The efficiency of the TEG increases with the increase in temperature difference between the surface of the heat exchanger and the ambient air. Also, the area of contact increases the increase in heat transfer. So, it is important to ensure that the maximum heat transfer from the exhaust gases to the surface of the heat exchanger. To achieve maximum surface temperature, the internal structures are modified.

Extensive research has been carried out by using various inner topologies. The basic topologies studied are Inserted fins, Cylindrical grooves, Dimpled structures and Baffles.

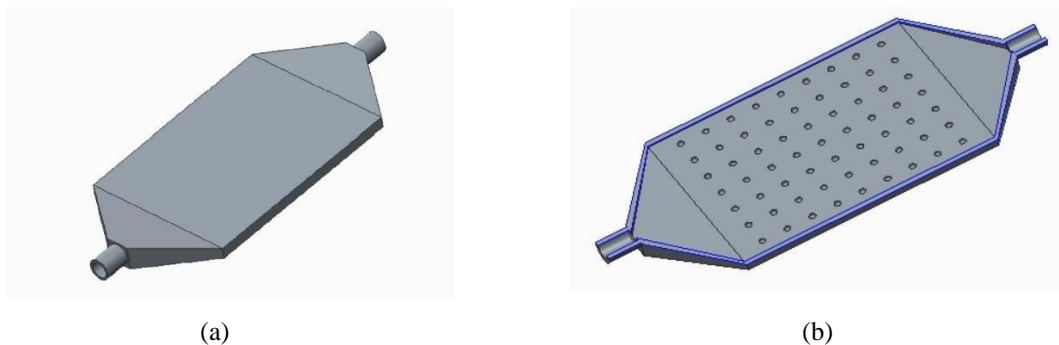
Even though they increase the heat exchange rate, pressure drop occurs in fluid stream. Dimpled structures have increased heat transfer rate while maintaining the fluid pressure. From the literature study the significant factors which improves the heat transfer rate for the dimple structures are diameter of the dimple and arrangement of the dimple. Fig. 1. (a) and (b) shows inline and staggered arrangement of the dimple structures respectively.



### III. DESIGN OF WASTE HEAT RECOVERY UNIT

Design of experiment is one of the statistical techniques used to study the effect of multiple variables simultaneously. All designed experiments require a certain number of factors and levels to observe the results of the test conditions. Following things are considered while designing the waste heat recovery unit. Factors considered are dimple diameter and arrangement of the dimple, Responses are maximum surface temperature and pressure drop across the waste heat exchanger, Levels of the factors considered are 4 level for dimple diameter 10,15,20,25 mm and 2 level for arrangement which are Inline and Staggered.

Type of experiment considered is full factorial using the above-mentioned levels and factors. Total of 8 experiments with combination of levels and factors are designed. The material chosen for waste heat recovery system is copper since it has higher thermal conductivity. The dimension of waste heat recovery system is 400 mm in length 300 mm in width and the thickness is 2 mm. Fig 2. Shows the CAD model of waste heat recovery unit. Fig 2. (a), (b) shows the basic shape of the waste heat recovery unit and the horizontal cross section of the waste heat recovery unit respectively.



### IV. COMPUTATIONAL FLUID DYNAMIC ANALYSIS

Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis to solve differential equations involving fluid flows. The governing equations and the boundary conditions are used to solve for the fluid flow. CFD analysis is done to find the temperature of the surface due to engine exhaust gases flowing through the waste heat recovery unit.

Computational fluid dynamic (CFD) analysis is done using Ansys Fluent Software. Preprocessing is done to make the Computer aided design (CAD) model liable for analysis. In model preparation stage, the CAD model is imported and

the solid and fluid domain is defined. Inlet and outlet of the fluid is also defined. To fix the mesh size the model is meshed with mesh size of 0.75mm, 0.9mm, 1mm, 1.5mm and 2 mm and analysis is carried out. The accuracy of the results became stable at 1mm. Then, the model is meshed with tetrahedral element with the mesh size of 1 mm. Solid domain material properties is given as copper and the fluid domain is fixed as air.

Analysis is done by setting the solver type as pressure based and flow type as steady. Energy equations are used as governing equations to solve for temperatures. Since the flow is turbulence, turbulence modelling is done with standard k-e model with standard wall function. Since we are focusing on the area near the wall, the standard wall function settings are chosen. Inlet boundary conditions are set as velocity inlet type. Inlet air velocity and inlet air temperature is given as 40 m/s and 873 K respectively. Outlet boundary conditions are fixed as outlet flow type and outlet pressure is given as 1 atm. Hybrid initialization is then done. The number of iterations is fixed by solving for 500 iterations. By observing the convergence graph is the value of the residuals became stable after 200 iterations. Thus, the number of iterations is then fixed for 200 iterations and solution is obtained.

Analysis results can be better understood by viewing the contours than looking at the values. Temperature and pressure contours are obtained. To better understand the temperature distribution of the waste heat recovery unit multiple temperature contours are obtained. The temperature contours are Wall temperature src, which denotes surface wall temperature, Horizontal cross section wall temperature and Vertical cross section wall temperature.

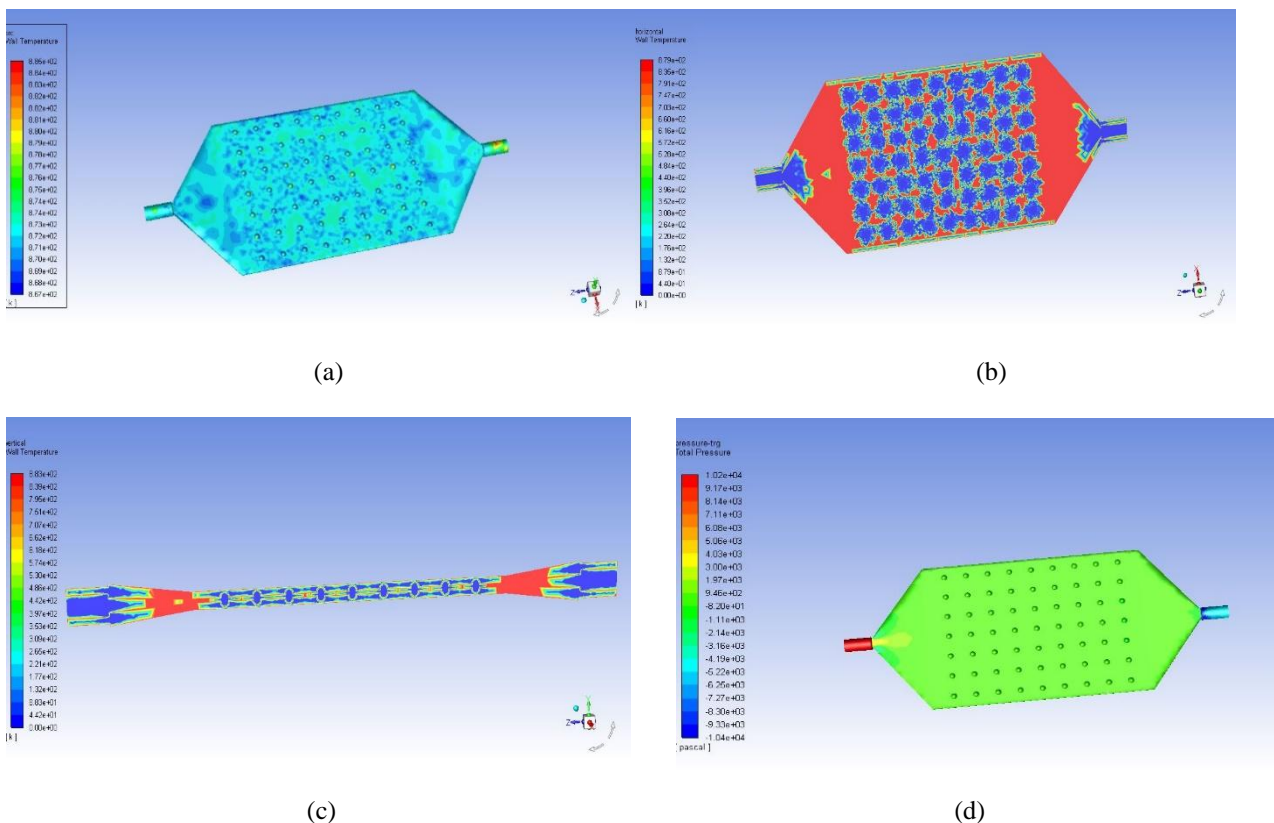


Fig. 4. Shows the results of the CFD Analysis. (a) shows the maximum surface temperature which is the response variable. (b) shows the horizontal cross section wall temperature, (c) shows the temperature distribution along the vertical cross section and (d) shows the total pressure contour which denotes the fluid domain pressure. Total pressure contour is used to get the pressure drop, which is one of the response variables. This whole process is repeated for all the 8 experiments and the corresponding contours are obtained.

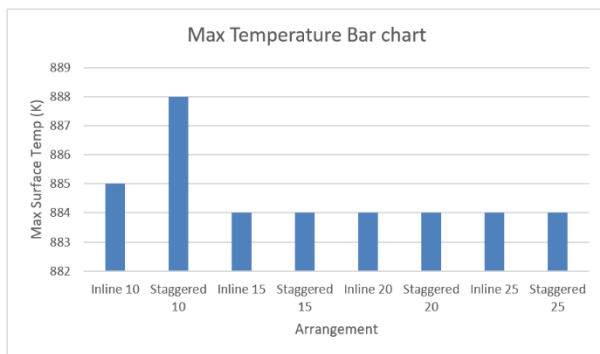


V. RESULTS AND DISCUSSION

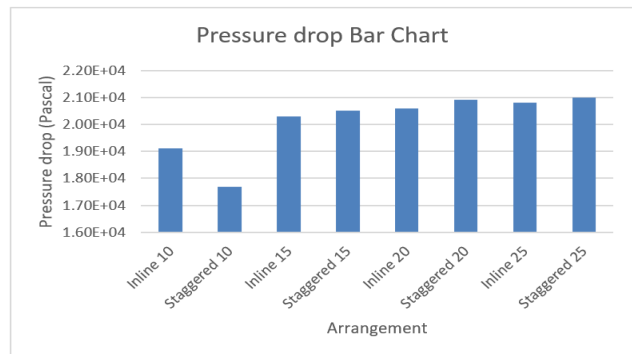
Analysis of all experiments are carried out and the values of the response variable is noted down in Table I. It shows the full factorial table with experimental results.

		Arrangement	Maximum surface temperature (K)	Pressure drop (Pa)
Dimple Diameter (mm)	10	Inline	885	$1.91 \times 10^4$
		Staggered	888	$1.77 \times 10^4$
	15	Inline	884	$2.03 \times 10^4$
		Staggered	884	$2.05 \times 10^4$
	20	Inline	884	$2.06 \times 10^4$
		Staggered	884	$2.09 \times 10^4$
	25	Inline	884	$2.08 \times 10^4$
		Staggered	884	$2.10 \times 10^4$

A. Maximum Surface Temperature and Pressure drop Chart:



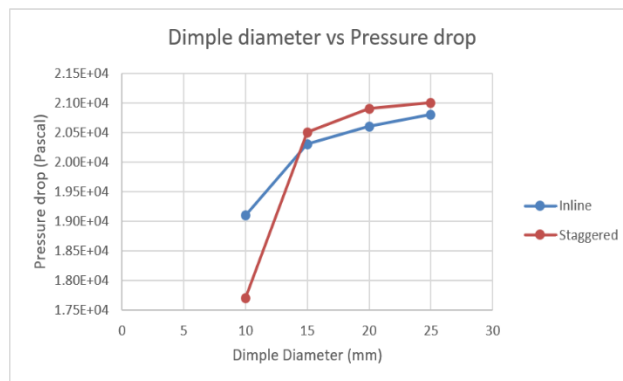
(a)



(b)

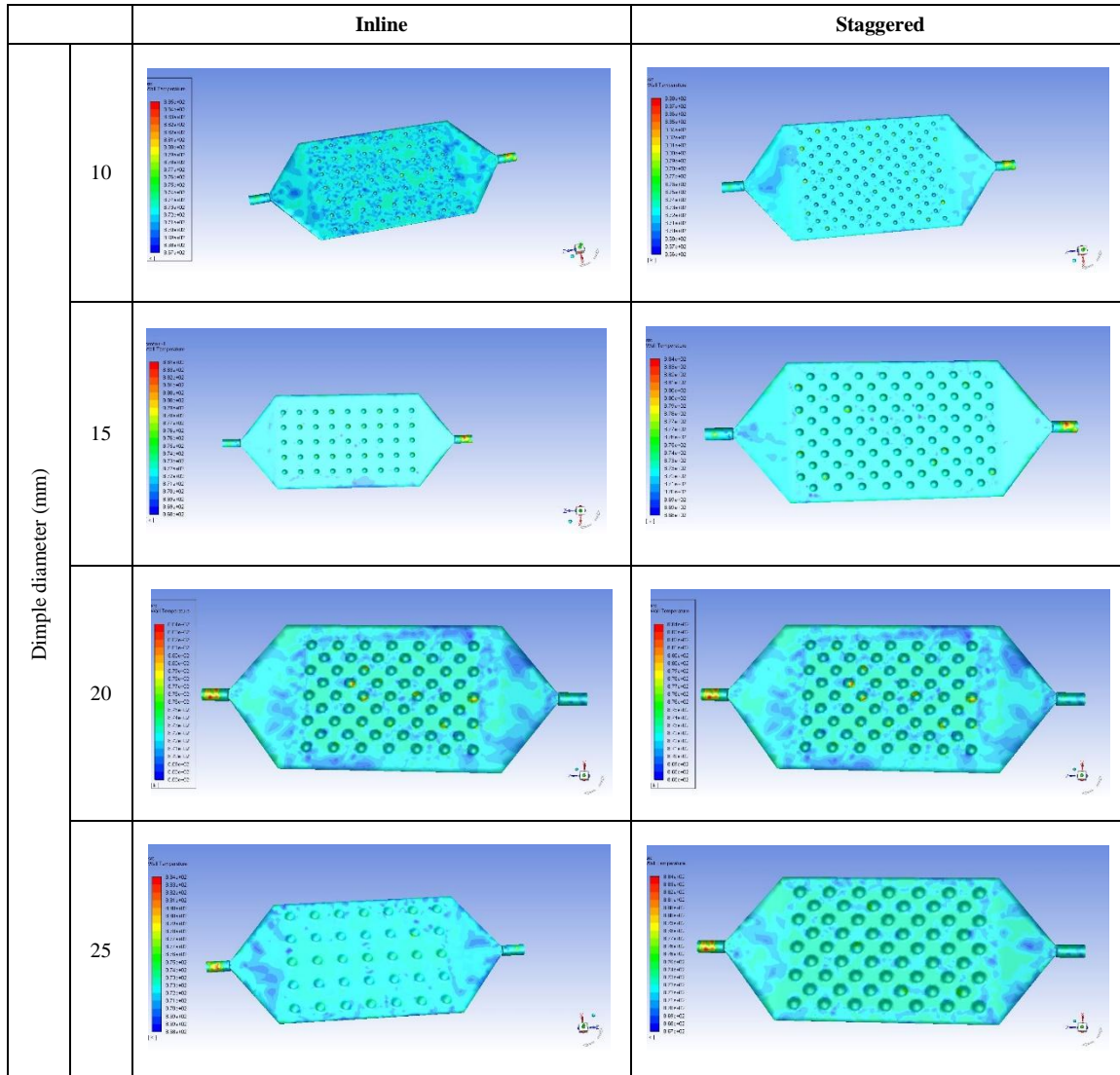
Fig.5 (a) and (b) shows that staggered arrangement with 10mm as dimple diameter has maximum surface temperature chart and least pressure drop.

B. Dimple Diameter Vs Pressure drop plot:



From the Fig.6. We can see the trend in the pressure drop as the dimple diameter increases there is an increase in pressure drop for both inline and staggered arrangement. We can also see that for almost all the diameter for staggered arrangement, the pressure drop is higher than the inline arrangement.

C. Comparison of Surface Wall temperature contour of all experiments



From the Table II, the following can be observed. Even though the maximum temperature of the inline and staggered are the same but the maximum temperature spots is more in staggered arrangement. Staggered arrangement shows uniform temperature distribution when compared with inline arrangement.

D. Thermoelectric Power Generation Calculation

Thermoelectric power generation calculation is done to know how much energy can be harvested using the waste heat recovery unit. The voltage output from a single thermoelectric generator is calculated by

$$V_{out} = N \times \alpha_{AB} \times \Delta T \tag{1}$$

Where, N denotes the number of connected TEG,  $\Delta T$  denotes the temperature difference between the hot and the cold side and  $\alpha_{AB}$  denotes the Seebeck coefficient of the thermoelectric materials.

Figure of merit, ZT is a dimensionless number used to express the efficiency of the thermoelectric generator. Power output calculation is done by taking SiGe as the thermoelectric material. Peak ZT of SiGe thermoelectric is 1. The maximum surface temperature obtained from the experiment is 888 K and the ambient air temperature is assumed as 22 C<sup>0</sup> or 295 K. By substituting in the values in the equation (1). The voltage output of 1 TEG is 0.243 V.

The actual power output from the single TEG is calculated using the formula,

$$P = (V_{out})^2 \times R_L / (R_{TEG} + R_L)^2 \quad (2)$$

$R_L$  denotes the load resistance and  $R_{TEG}$  denotes the internal load resistance across the TEG. By substituting the values in the equation (2). The power output from 1 TEG is calculated as 1.793 Watt. Space requirement for placing 1 TEG is 15mm × 15mm area. Total of 150 TEG can be placed on the surface of the waste heat recovery unit. Thus, the total power output from the waste heat recovery unit is 275 W.

## VI. CONCLUSION

Dimple structures have positive effect on the heat transfer rate. The model with staggered arrangement of 10 mm dimple diameter has the maximum surface temperature with least pressure drop across the waste heat recovery unit. 275 W can be harvested by using the automobile exhaust gases.

Thus, the waste heat from the IC engines is converted into electrical energy using the waste heat recovery unit. Harvested energy from the exhaust gases can be used to charge the battery in the hybrid vehicles. This increases the range of the battery-operated vehicle, reducing the range anxiety. By installing the waste heat recovery less fossil fuel is burnt which reduces the global pollution level.

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