ISSN: 0971-1260
Vol-22-Issue-16-August-2019

Numerical Analysis of Heat Exchanger of Thermoelectric Generator System at Automobile Exhaust

Sunny Kaura[a], *Prashant Dhiman*[b]

[a]Assistant Professor, School of Mechanical Engineering

Lovely Professional University, Phagwara, Punjab

Email id- kaurasunny@ymail.com

[b]Associate Professor , Department of Mechanical Engineering

National Institute of Technology, Hamirpur, Himachal Pradesh

Abstract

Thermoelectric technology has revealed the latent for Thermoelectric generator (TEG) system which is used in automotive exhaust, mainly the heat transfer of the heat exchanger affects the performance of TEG system effectually. Thermal characteristics of heat exchangers with numerous heat transfer improvement features are being studied in order to attain uniform temperature distribution and higher interface temperature including material, shape, internal structure and also its surface area. Using the simulations in ANSYS FLUENT, the thermal performance of the heat exchanger is evaluated. For this, two different shapes of heat exchangers namely series square and scattered have been considered for the simulation study. Simulation results showed that heat exchanger of brass material having internal structure being scattered shaped, with thickness of 5mm attains fairly better results than the other shapes. Maximum outlet temperature of 502K and maximum heat transfer of 1981W has been obtained resulting in improved thermal performance of heat exchanger.

1. Introduction

The role of energy recovery techniques has become very challenging now a days Because of the global energy emergencies and various other issues related to environmental protection. As per study, it was found that nearly 40 % of the fuel chemical energy gets wasted in the form of exhaust gases which is being discharged into the atmosphere according to Shengqiang Bai[2]. Hence the waste heat recovery problem is very significant, for which one way is to use TEG system for increasing fuel economy. Recovering waste heat by this system is based on Seebeck

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

effect, by which heat could be directly converted into electricity utilizing thermo-electric materials. In TEG system, temperature gradient is being converted into useful voltage which can be further utilized for providing power to some auxiliary systems like minor car electronics and so on. The TEG system is more reliable, flexible and even robust as compared to conventional power generators. Moreover, C.Q.Su [3] told in his paper that the absence of any real working fluid or any moving part make its application more attractive because of no noise along with vibration problem.X.Liu [1]. told that a TEG system, as shown in Figure 1, consists mainly of exhaust heat exchanger and thermoelectric modules which are inserted between exhaust heat exchanger and the cooling unit where inserted structure is held by clamping devices .Y. D. Deng[5] in his paper told that Exhaust gas flows into the heat exchanger's hot-side through a bypass to form the hot source whereas Cooling water pumps into the cooling water tanks to form the cooler. The main challenge lies in the exhaust heat exchanger, as it should meet the requirements of TEG system and should not hinder the vehicle operation at the same time.

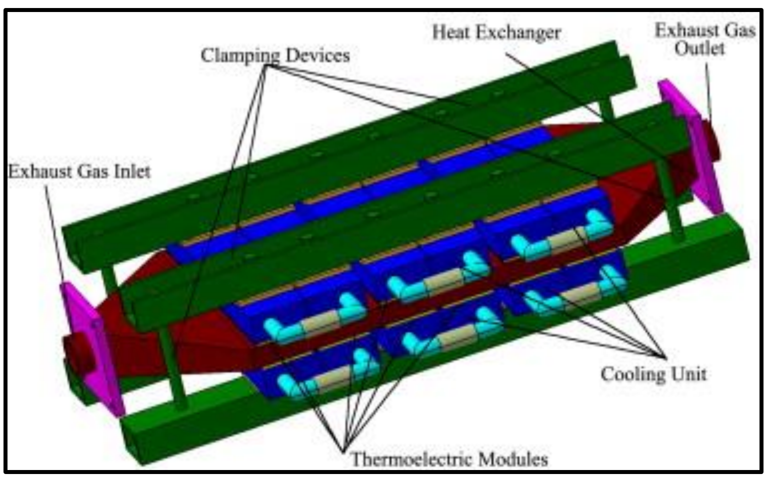

Figure 1: Schematic Diagram of TEG system

For improving the thermoelectric efficiency, the various parameters demanding optimization involves exhaust heat exchanger shape, material and surface area along with internal structure according to X. Liu[1] .J.C.Chung[4] in his paper investigated a thermoelectric energy generation system, where the major focus was on the use of high temperatures even up to 200 ℃ for ensuring TEG reliability in case of diesel engines emitting very hot exhaust gases ranging 200℃–300℃ at the outlet . C.T. Hsu [7] in his paper constructed a heat exchanger in which he

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

used Bismuth Telluride (Bi_2Te_3) as Thermoelectric modules material for TEG system., that system obtained a total 44 W. Two shapes of exhaust heat exchangers can be used for an automobile exhaust TEGs: box and cylinder shells with internal fins. Martinez A [6] utilized the computational fluid dynamics (CFD) for optimizing the TEG as domestic gas boiler. Results showed that heat exchanger with internal structure of chaos type having 5 mm thickness, achieved relatively ideal thermal performance at around 493 K outside the exhaust heat exchanger, thereby enhancing the thermal performance of TEG. However further research is required for enhancing the temperatures at exhaust heat exchanger outlet (inferring more power output according to Seebeck effect), thereby demanding optimization in heat exchanger design. This research paper focusses over two different exhaust heat exchanger designs namely series square-type and scattered shape-type, possessing different internal structures, for increasing exhaust gas turbulence and thereby improving the heat exchanger effectiveness.

2.Computational Method and Procedure

Computational fluid dynamics (CFD) software is utilized for simulating the flow of exhaust gas within the heat exchanger as well as necessary variations have been performed in the internal structure, thickness and material of the exhaust heat exchanger for obtaining the supreme and optimized thermal field results of simulation.

2.1 CFD Model Description

Two models of exhaust gas heat exchanger, designed in the Design Modular, namely series-square and scattered-type have been proposed for CFD analysis and shown in Figures 2–4. The geometry selected for exhaust gas heat exchanger is a cylindrical shell having dimensions 400 × 290 mm, extended 90 mm on both sides, with 5 mm thickness along with 18 mm height. Brass has been selected as heat exchanger material because of good heat conductivity along with heat convection characteristics as taken in the according to X. Liu[1]. The physical dimensions of the fins modeled in the Design Modular have been shown in the Table 1.

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

Table 1: Physical Dimensions of Modeled Fins

Proposed Model	Number of Fins	Dimension of Fins (mm)	Spacing Between Fins (mm)	Margins on Each Side (mm)	Remarks
Series-square	12	40 × 40 (series pattern)	60	120	—
Scattered-type	—	80 × 10 30 × 60 30 × 120	—	120	Two fins at the inlet side for guiding the flow in either direction

Geometries prepared in Design modular of the proposed shapes of heat exchanger are shown in Figure 1 and 2 respectively for series-square and scattered type shape.

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

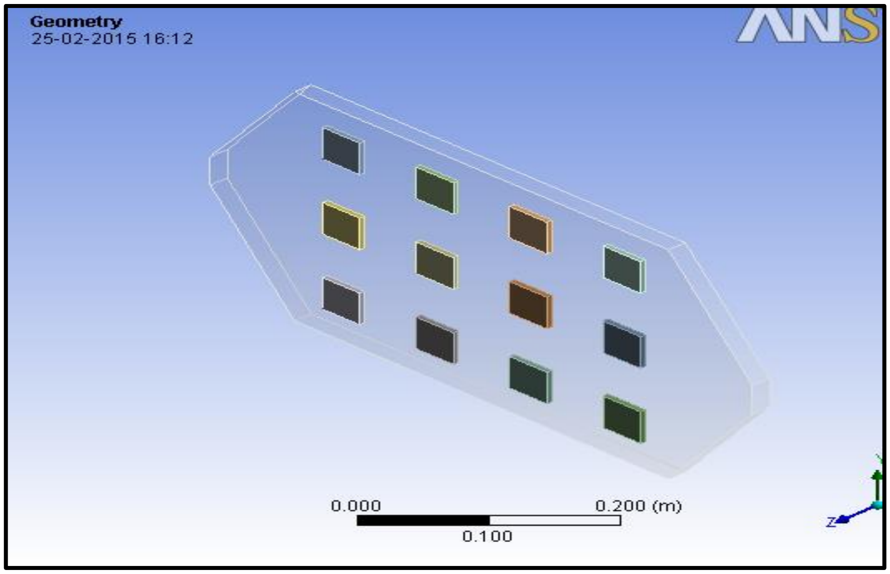

Figure 2: Series-square Heat Exchanger Model

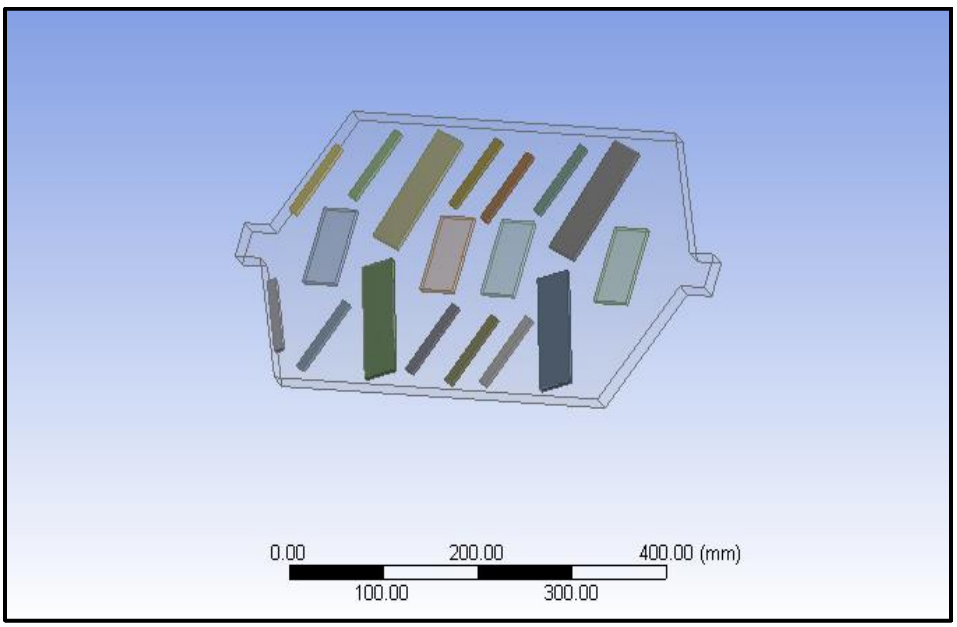

Figure 3: Scattered-type Heat Exchanger Model

Meshing was performed using Finite volume method (FVM) involving tetrahedron meshing method with fine relevance centre. Proximity and curvature size function have been utilized for mesh generation whereas checking along with mesh quality improvement from coarse to fine-type have been performed using grid independence test. The number of elements calculated for series-square and scattered-type internal structure of exhaust heat exchanger in the software are 122102 and 154210, respectively.

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

2.2 Boundary Conditions

A uniform velocity of 15.2 m/s is utilized, with turbulence intensity being calculated as 7.52 % using Equation 1 along with inlet hydraulic diameter considered as 0.336 m. Temperature was taken as 623 K and inlet was assumed to be velocity inlet.

$$I = 0.16 \times (Re)^{-1/8} \qquad \text{Eq. (1)}$$

whereas I is turbulent intensity and Re is Reynolds number. The Re is further calculated using the formulae given in Equation 2.

$$Re = \frac{\rho u L}{\mu} \qquad \text{Eq. (2)}$$

whereas L is the characteristic length or hydraulic diameter.

Pressure outlet is assumed with backflow temperature of 300 K and the convective heat transfer coefficient for brass is considered as 15 W/m^2 K. Top, bottom and the side walls of the heat exchanger are given the shell conduction condition with 5 mm thickness and the least square method has been considered for gradients evaluation as per X. Liu[1].

2.3 Solver and Model Utilized

Fluent pressure-based solver has been utilized because the exhaust air is assumed to be incompressible whereas the convergence speed over the segregated algorithm is significantly improved by using coupled algorithm as it solves momentum and pressure-based continuity equations altogether. The convergence criteria adapted is a scaled residual, of 10^{-3} for the momentum balance, also 10^{-6} for the energy balance, where relative error is under 0.1 % for the total energy conservation of the system, also simulated model has guaranteed that there is fully turbulent flow of exhaust gas in the heat exchanger, with molecular viscosity being neglected, which leads to a realizable k-ε turbulence model with non-equilibrium wall functions as per X. Liu[1]. The continuity, momentum and energy equations are solved by the solver along with turbulent kinetic energy and its rate of dissipation.

3. Results and Discussions

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

The Figure 4–6 represents the post-processing results for the proposed two internal structures, namely series-square and scattered-type exhaust heat exchanger.Moreover, the interface temperature and heat exchanger outlet temperature are also calculated for all the two proposed internal structures.

The results shows that the scattered-shape internal structure is the better among two proposed internal structures because of the maximum turbulance genrated inside the heat exchanger. The introduction of two fins at the inlet side of this heat exchanger for directing the flow towards the side walls generated the velocity streamlines as shown in Figure 6. The scattered-shape internal structure has maximum interface temperature of 457 K and maximum outlet temperaure of 502 K, which geatly increases the power output for TEG system.

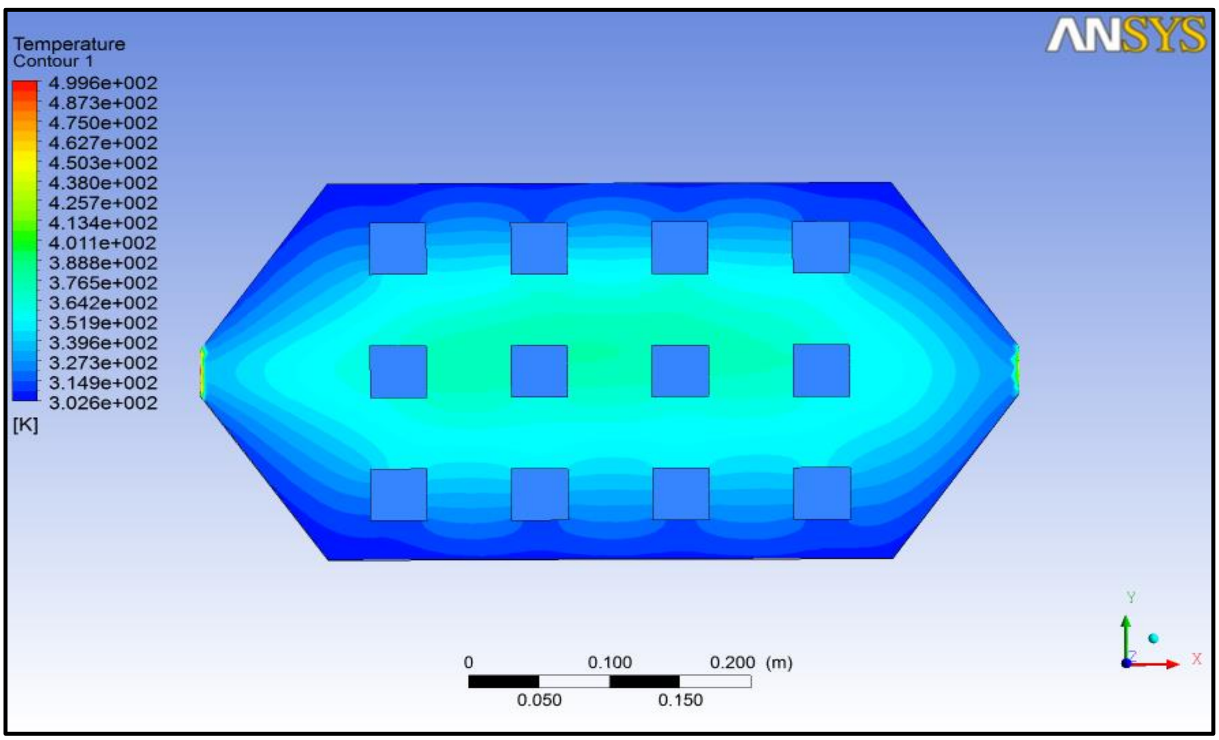

Figure 4: Temperaure Contour for Series-square Shape

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

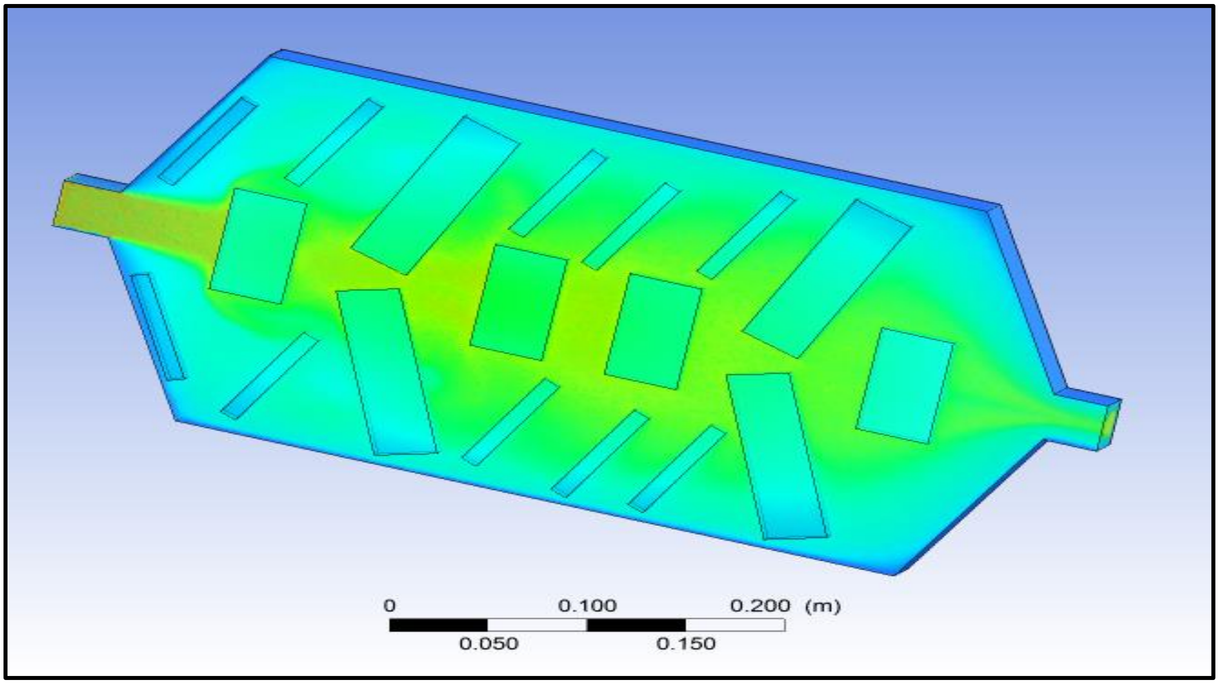

Figure 5: Temprature Contour for Scattered-shape Heat Exchanger

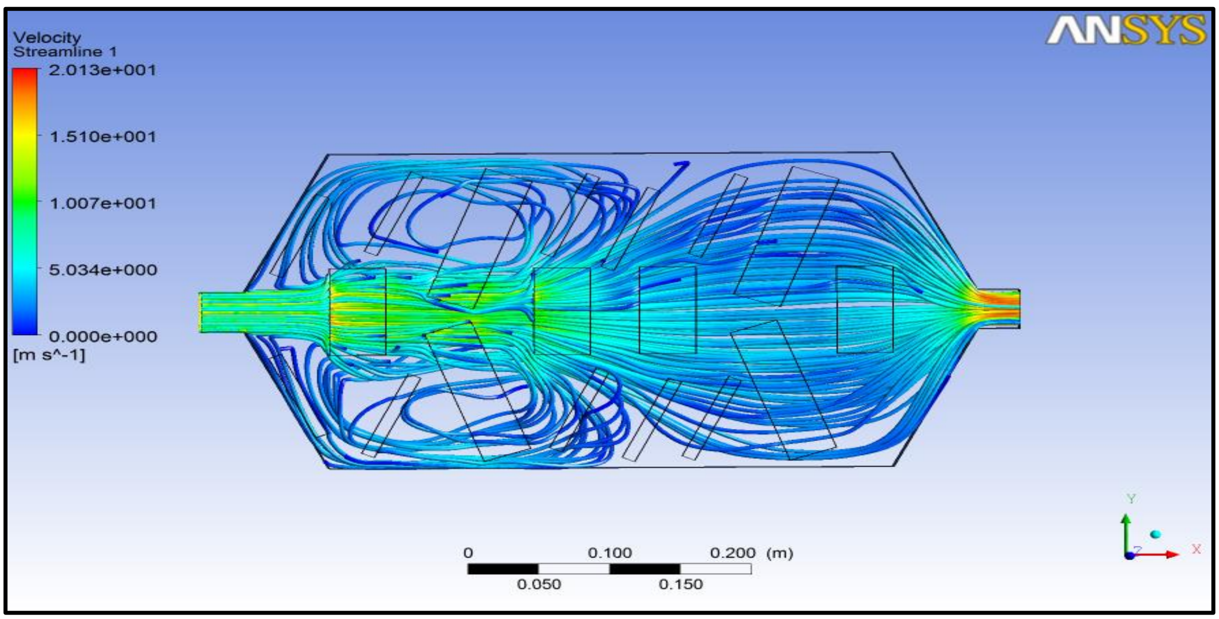

Figure 6: Velocity Streamlines for Scattered-shape Heat Exchanger

Table 2 for Outlet temperature with number of mesh elements for scattered shape

No. of Elements	Outlet Temperature(K)	% Difference
121220	498.1	-

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

132112	499.8	0.3412
154210	502	0.44017

Table 3 for average temperature with number of mesh elements for scattered shape

No. of Elements	Average Temperature(K)	% Difference
121220	453	-
132112	458	1.103
154210	457	0.2183

From above Table 2 and 3, it can be seen that mesh quality is always affecting the results of simulation as above for average and outlet temperature values.

One way is to increase heat transfer is to get more difference of temperature between both sides (hot and cold side). And in this work cold side temperature (water) is given as 363K and the temperature of exhaust gas at outlet of heat exchanger is very crucial, which is different for different shapes analysed here in this work. Below Table 4 is showing the calculated values of this where highest temperature difference comes for scattered shape of heat exchanger and also it has the highest hot side temperature among all other shapes.

Table 4 showing Temperature difference for all shapes

Name of Shape	Cold side Temperature(K)	Hot side Temperature(K)	Temperature Difference
Referred(chaos)	363	493.2	130.2
Series square	363	496.4	133.4
Scattered	363	502	139.0

The main motive of this work was to get more and more heat transfer by varying the already discussed parameters such as material, shape etc. of heat exchanger. Given below is the Table 5 showing the values of maximum heat transfer calculated for the two different shapes of heat exchanger model.

Table 5 for Heat transfer

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

Shape name	Heat transfer (in Watts)
Series square	1825.4
Scattered	1981

4. Conclusion

In this work, CFD analysis was used to analyze the performance of heat exchanger attached with TEGs for recovering waste heat from an automotive exhaust pipe. According to the agreement between the Xi Liu [1] results and this work's simulation results, scattered shape heat exchanger made up of brass, contact area (400mm * 290 mm) and thickness 5mm is selected to form the hot side.

It has reduced the thermal resistance (between the exchanger and the TEMs), and obtain a relatively high surface temperature of 502K and uniform temperature distribution (average temperature being 457K) to improve the efficiency of the TEG.

Although series square shape also showed good results (surface temperature 498.2K which is better than chaos (referred) shape) but in their case exhaust gas was not able to flow completely in each and every part of heat exchanger which is already shown in Figure 5 and 6 for velocity streamlines.

Moreover, maximum heat transfer is also attained by scattered type shape (Q=1981W) and hence can be taken as an optimized shape of heat exchanger for the waste heat recovery purpose in thermoelectric generator (TEG) system.

REFERENCES

[1] X. Liu,Y.D. Deng, K. Zhang, M. Xu, Y.Xu, C.Q. Su,2014."Experiments and simulations on heat exchangers in thermoelectric generator for automotive application". *Applied Thermal Engineering* 71:364-370.

[2] Shengquing Bai,Hongliang Lu,Ting Wu,Xianglin Yin,Xun Shi,Lidong Chan,2014. "Numerical and experimental analysis for exhaust heat exchangers in automobile thermoelectric generators". *Case studies in Thermal Engineering* 4:99–112.

[3] C.Q.Su,X.Liu,2014." Simulation and experimental study on thermal optimization of heat exchanger for automotive exhaust-based thermo electric generators". *Thermal Engineering* 4:85–91.

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

[4] J.C. Chung, W.C. Kim, J.H. Lee, T.U. Yu, 2007." KSME Fall Conference".

[5] Y.D. Deng, X. Liu, S. Chen,2014." Research on the compatibility of the cooling unit in an automotive exhaust-based thermoelectric generator and engine cooling system". *J. Electron. Mater* 43:1815-1823.

[6] Martinez A,VianJG,AstrainD,RodriguezA,BerrioI,2010.".*J.Electron Mater* 39:1463–68.

[7] C.T. Hsu, G.Y. Huang, H.S. Chu, B. Yu, D.J. Yao,2011." Experiments and simulations on low-temperature waste heat harvesting system by thermoelectric power generators". *Applied Energy* 88: 1291-1297.

[8] Birkholz U,Grob E,Stohre U,Voss K,In:Rao KR,editor,1988."Proceedings of the 7th international conference on thermoelectric energy conversion."*Arlington, TX: University of Texasat Arlington* .p.124–8.

[9] Bass J,Elsner, NB,Leavit A.In: Mathiprakisam B,editor ,1995."Proceedings of 13th International conference on thermoelectrics".*AIP Conference Proceeding NewYork* 295– 8.

[10] Kobayashi M,Ikoma,K,Furuya,K,Shimohara,1996."Proceedings on the 15th international conference on thermoelectrics p.373-3.

