

A Study on Performance Enhancement of Heat Exchanger in Thermoelectric Generator using CFD

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Abstract

According to the energy balance of the combustion engine, efficiency of internal combustion engine is around 30%, remaining energy is wasted as exhaust gas, which has a high percentage of loss 40%, and rest are wasted in lubrication, cooling water and radiation. In order to increase the efficiency of engine lot of researchers try to recover waste energy from the exhaust gas, among that thermoelectric generator (TEG), plays an important role in recovering waste energy from the exhaust gas. Thermoelectric generator efficiency depends on the shape of heat exchanger, the size of the fins and material of the thermoelectric element. In this paper, four different configurations of heat exchange modeled and compared through Computational Fluid Dynamics (CFD) software. They are Fishbone shape, accordion shape, and serial plate and empty cavity heat exchangers. The Serial plate has better heat transfer rate than Fishbone, accordion and empty cavity heat exchanger.

Keywords: CFD, thermo-electric generator, heat exchanger, waste heat recovery

I. INTRODUCTION

Some of the fuel energy are converted into electrical energy for the basic electric load of automobiles. Electrical load increases due to comfort, driving performance and power transmission. It causes further reduction in efficiency of IC engines. Even though the efficiency of the alternator is high, the ratio between the electric energy produced and the fuel consumed is very low. However the power produced from exhaust gas very low, it decreases 6-10% of fuel consumption. Karri et al analyzed applications of TEG modules in an SUV in steady state operation, it saves 2-2.3% of fuel. Su et al. Studied the thermal optimization of automotive exhaust based heat exchanger for a thermoelectric generator that the brass heat exchanger with accordion shape is selected to form hot side of its uniform distribution of temperature. Prathamesh Ramade et al. Studied design and performance of exhaust based thermoelectric generator found that double stacked type cold side gives better temperature gradient across TEG. Counterflow type arrangement enhances the effective heat transfer also insulation used for the area not covered by TEG modules avoids heat losses. Shengqiang Bai et al developed the numerical model and found that serial plate has maximum heat transfer with the cost of high-pressure drop and empty cavity transfer low heat and less pressure drop. Dongyi Zhou studied cylindrical shape exhaust based thermoelectric generator that the number of fins can enhance the heat transfer efficiency, but the pressure drop of the exhaust as well. In cylindrical automobile exhaust, thermoelectric generator system with octagon channel 16 fins gives the better result. Yongming Shi et al studied compact thermoelectric generators based on the extended three-dimensional thermal contact interface found that 3D thermal extensional structures, every Thermoelectric modules(TEM) of the TEG can contact with the heat source completely and the thermal energy can transfer to all TEM efficiently. Yu et al developed the numerical model and found that the performance of TEG modules is improved with an increment of vehicle speed. Weng and Huang studied that increase number of TEG may not necessarily generate more power and proper coverage of TEG on the heat exchanger is important. The current study proposes different internal structure heat exchanger: fish-bone, accordion shape, serial plate and empty cavity. CFD models were developed and compare the heat transfer under same working condition.

II. SIMULATION OF HEAT EXCHANGER

The Computational fluid dynamics (CFD) software is used to simulate exhaust flow, the temperature distribution within the heat exchanger.

A. Theory and Boundary condition

The computing domain includes solid and fluid portion. In fluid domains, the equation of mass, momentum and energy conservation are solved to model fluid flow, mass and heat transfer. The Equation of heat transfer is solved for solid domains.

The continuity equation is

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho U) = 0 \quad (1)$$

The momentum equation is

$$\frac{\partial(\rho U)}{\partial t} - \nabla(\rho U U) = -\nabla p + \nabla \tau + S_M \quad (2)$$

The energy equation is

$$\frac{\partial(\rho h_{tot})}{\partial t} - \frac{\partial \rho}{\partial t} + \nabla(\rho U h_{tot}) = \nabla(\lambda \nabla T) + \nabla(U \tau) + U S_M + S_E \quad (3)$$

The conservation of energy equation in solid domain is

$$\frac{\partial(\rho h)}{\partial t} + \nabla(\rho U_s h) = \nabla(\lambda \nabla T) + S_E \quad (4)$$

For comparison purpose, four structures (accordion, Fishbone, serial plate and empty cavity) were made with same dimensions as shown in fig 2. The exhaust flow in the heat exchanger fully turbulent, the standard k-epsilon model is adopted in the simulation. As near wall area processing, the natural convection heat transfer coefficient and the environment temperature are set. The exhaust gas of the automobile was approximately 500-700C° in temperature when discharged from the engine. For the simulation gas inlet temperature set to 400C°. The inlet flow velocity set to 20 m/s based on working characteristics of the engine. The gauge pressure set to 0 Pascal. The heat transfer coefficient heat exchanger and air set to 20 W/(m²/k), environmental temperature set to 25C°. A better mesh quality provides a more accurate solution. The density of the mesh is required to be sufficiently high in order to capture all the flow features, but on the same note, it should not be so high that it captures unnecessary details of the flow, thus wasting more time. The model was obtained using symmetrical plane only half of the whole body used to reduce mesh quantity; the high number of mesh quantity increases the complexity of simulation as shown in table 1.

III. RESULT AND DISCUSSIONS

The structures of heat exchanger modified by inserting baffles, it produces macroturbulent enhance the heat transfer rate according to fluid dynamic theories. However greater heat transfer coefficient, better the heat transfer quantity. High surface area, high heat transfer coefficient and turbulent flow they are important factors to increase the efficiency of heat transfer. The extruded surface in flow line increase the surface area contact with the hot fluid, it increases the heat transfer. To increase further heat transfer turbulent flow requires, because when a fluid flow, it creates boundary layer along the wall of the body. Turbulent flow breaks the boundary layer and increases the heat transfer from the fluid. In fig.4.the exhaust gas enters into heat exchangers suddenly it loses its energy. Due to high velocity the fluid flow over the fins, it creates eddy near centre edge of fins. This causes transfer more heat than corner. wherever eddy forms it transfer better heat as shown in fig .4.In serial plate shown in fig .5, it has large eddy compare with other heat exchangers because a sudden change in direction of fluid flow it lose some energy and creates eddy leads to breaking of the boundary layer. It increases heat transfer. Another reason for big eddy was the height of fin higher than fish-bone structured heat exchanger. The accordion structure seems like less turbulent but the depth of fin, transfer more heat because of its structure as shown in fig.6.In empty cavity no extruded surface to increase heat transfer , no baffles to create eddy and no option to break the boundary layer. Hence, it has low heat transfer rate shown in fig 7. The heat transfer can be approached by adding turbulence to enhance the fluid disturbance and damage the boundary layer. The serial plate has maximum heat transfer rate 4062W accordion, fish-bone, empty cavity has 3468W, 3092W and 1568W respectively as shown in fig.3. The 4 structures differed in heat transfer rates and can be ordered by the decreasing heat transfer as follows: serial plate, accordion shape, fish-bone shape and empty cavity. For the empty cavity, the exhaust expanded gradually at the inlet because of an absence of fins. As shown in fig 7.it has no eddy hence, it transfer low heat. Compared with empty cavity, Fishbone has small fins it creates eddy along the exhaust flow it enhances the heat transfer as shown in fig 4. The Accordion and serial plate create big eddy compare with fishbone it enhances more heat transfer. Results both transfer more heat than other two heat exchangers as shown in figs 5-6.

IV. CONCLUSION

CFD models with the solid domain, fluid domain and solid-fluid interface domain were developed for four different heat exchangers to stimulate turbulence and temperature field under the same operating condition.comparing four different heat exchangers, the serial plate has maximum heat transfer 4062W compare with other heat exchangers, the accordion has second better heat transfer 3468W, both has internal fins which create eddy it enhance the heat transfer along the flow of exhaust gas.eddy size depends upon the size and position of fins along the flow line. In between fishbone has fins, it does not create large eddy because fin height smaller than serial and accordionThe fishbone heat transfer was 3092W which higher than empty cavity but lower than accordion and serial plate.Empty cavity achieved low heat transfer 1568W due to the absence of internal fins.Serial plate forces the exhaust gas to flow back by 10 baffles, enhanced the heat transfer with heat exchanger wall and had the maximum heat transfer rate of all structures.This rate was 62%,24% and 15% greater than empty cavity,fishbone and accordion shape respectively.

REFERENCES

- [1] Dongyi Zhou, 'Simulation study of cylindrical automobile exhaust thermoelectric generator system', International journal of heat and technology Vol 33, no.2, pp.25-30, 2015.
- [2] Karri MA., Thacher EF., Helenbrook BT., 'Exhaust energy conversion by thermoelectric generator: two case studies', Energy Conversion Management, pp.596-611, 2011.
- [3] Prathamesh Ramade1., Prathamesh Patil., Manoj Shelar., Prof. Shivaji Yadav., Prof. Santosh Trimbake,'Automobile Exhaust Thermo-Electric Generator Design &Performance Analysis' Vol 4, Issue 5, pp. 681-691, 2014.
- [4] Shengqiang Bai., Hongliang Lu., Ting Wu., Xianglin Yin., Xun Shi., Lidong Chen, 'Numerical and experimental analysis of exhaust heat exchangers in automobile thermoelectric generators ', Case Studies in Thermal Engineering, vol 4, pp. 99-112, 2014.
- [5] Su C.Q ., Wang W.S., Liu X., Deng Y.D,'Simulation and experimental study on thermal optimization of the heat exchanger for automotive exhaust-based thermoelectric generators', Case Studies in Thermal Engineering, Vol 4, pp. 85-9, 2014.
- [6] Weng CC., Huang MJ.,' A simulation study of automotive waste heat recovery using a thermoelectric power generator.' International Journal of Thermal Science, pp. 302-309, 2013.
- [7] Yongming Shi., Zhixiang Zhu., Yuan Deng., Wei Zhu., Xin Chen., Yongsheng Zhao.,' A real-sized three-dimensional numerical model of thermoelectric generators at a given thermal input and matched load resistance', Energy Conversion Management,pp.713-720, 2015
- [8] Yu S., Du Q., Diao H.,'Effect of vehicle driving conditions on the performance of thermoelectric generator'. Energy Conversion Management, pp. 363-376, 2015.

FIGURES

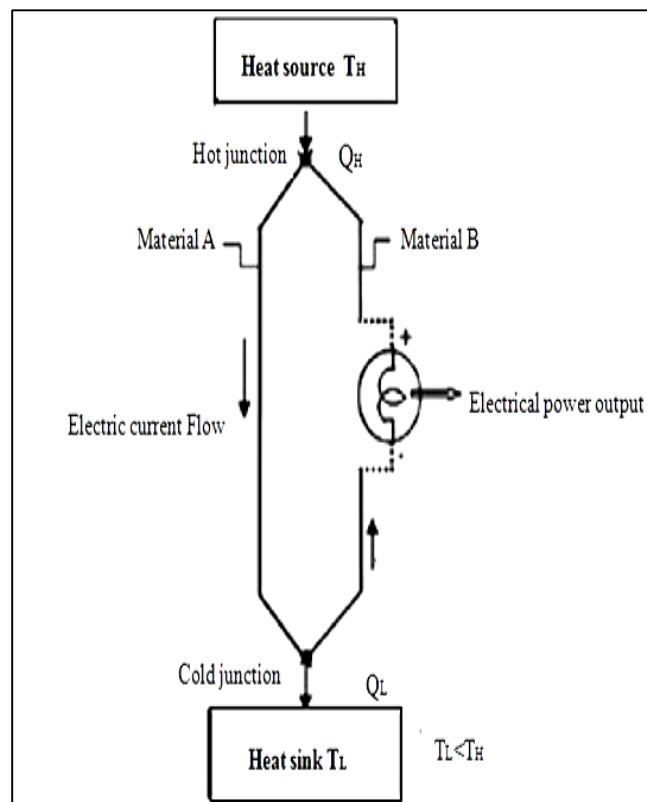
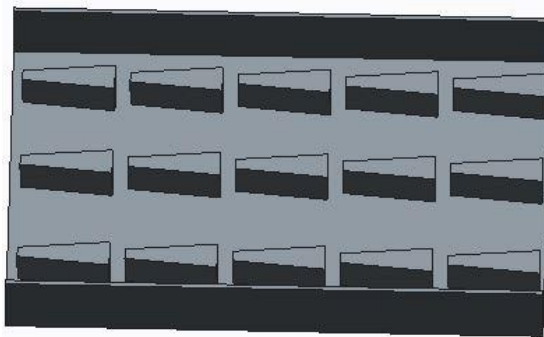
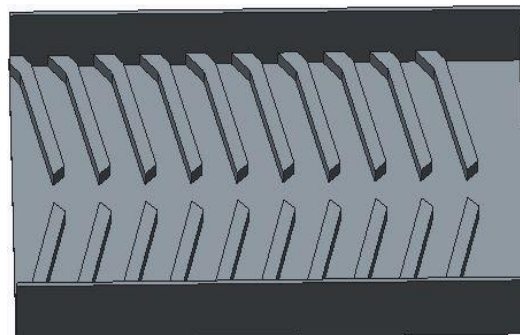


Fig. 1: Basic setup of thermoelectric modul



a)



b)

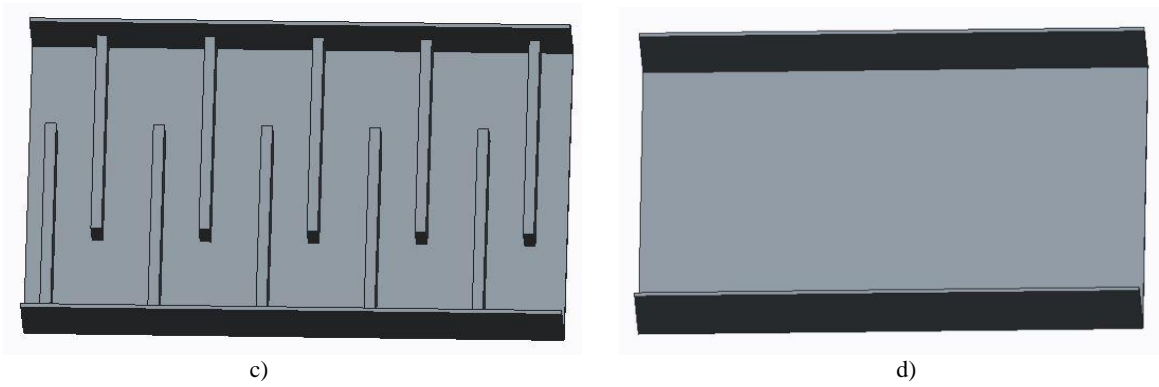


Fig. 2: a) Accordion shape, b) Fishbone shape, c) serial plate and d) empty cavity

Table – 1

Mesh quantity

Heat exchangers	Nodes	Elements
Accordion shape	195231	866249
Fish-bone shape	206686	887792
Serial plate	232194	739421
Empty cavity	176712	521681

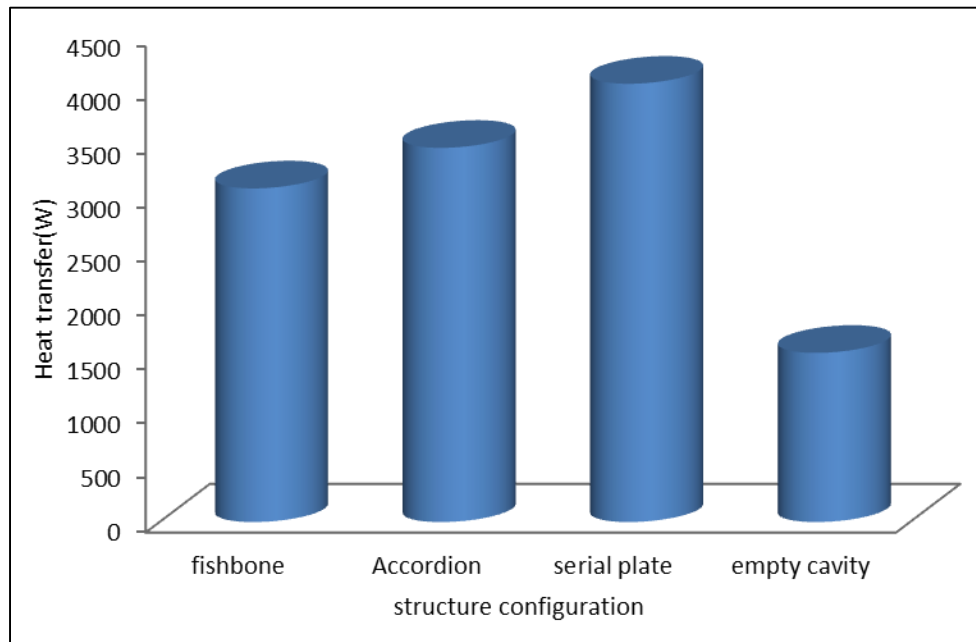
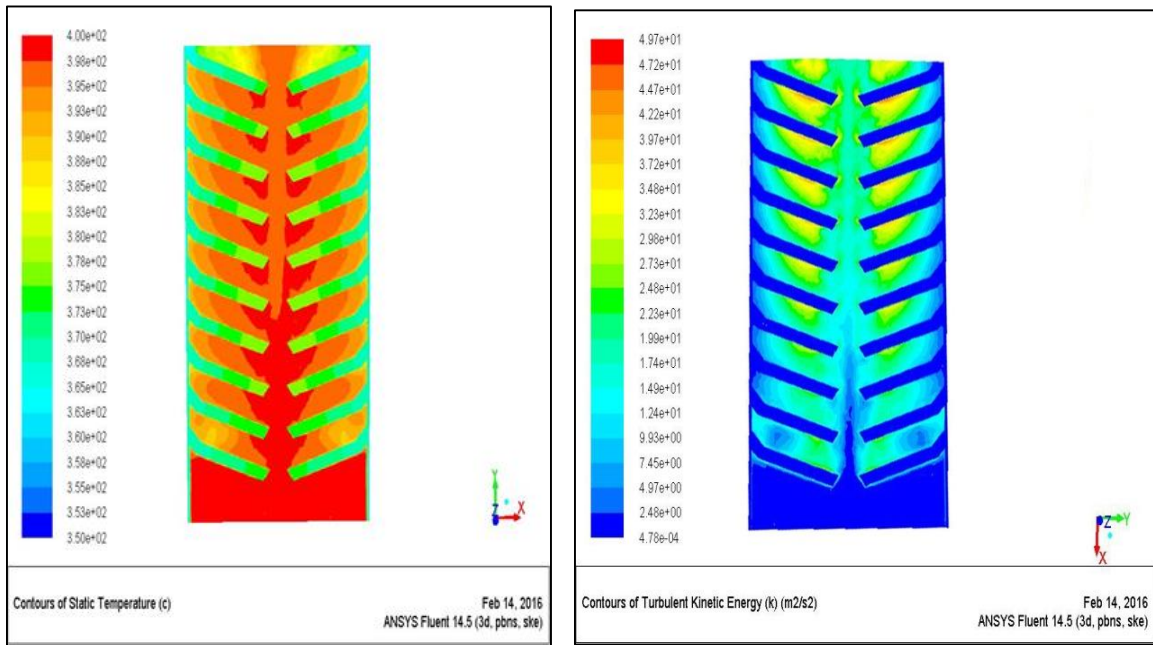
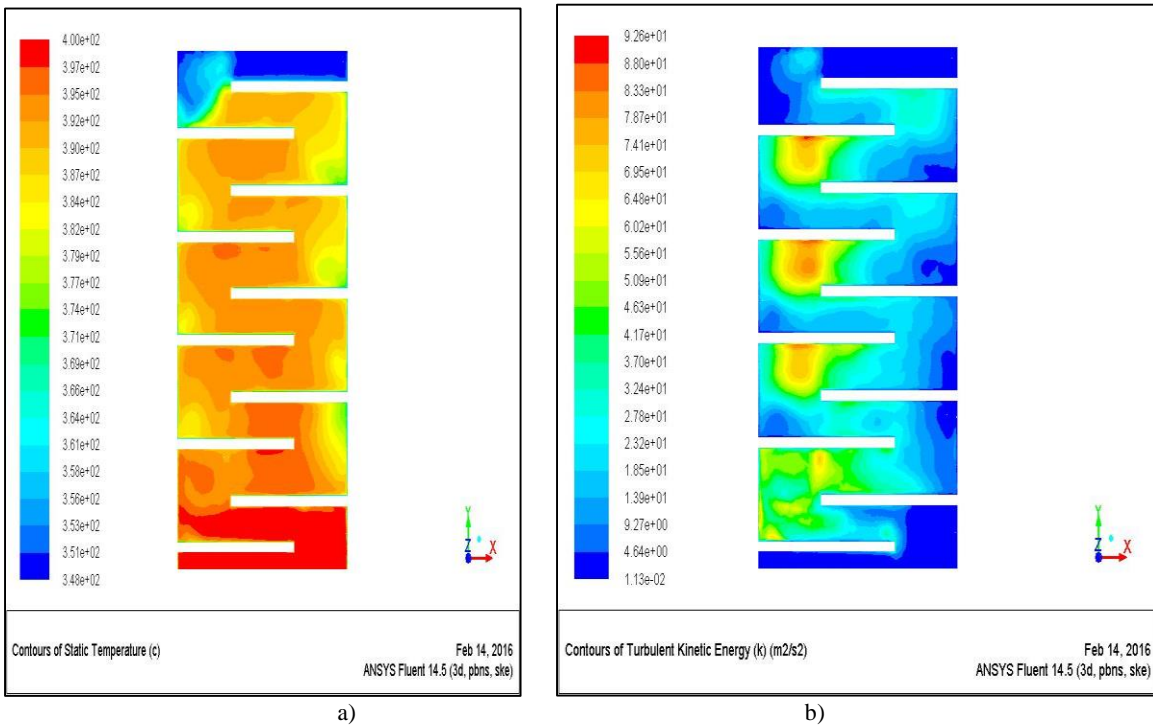


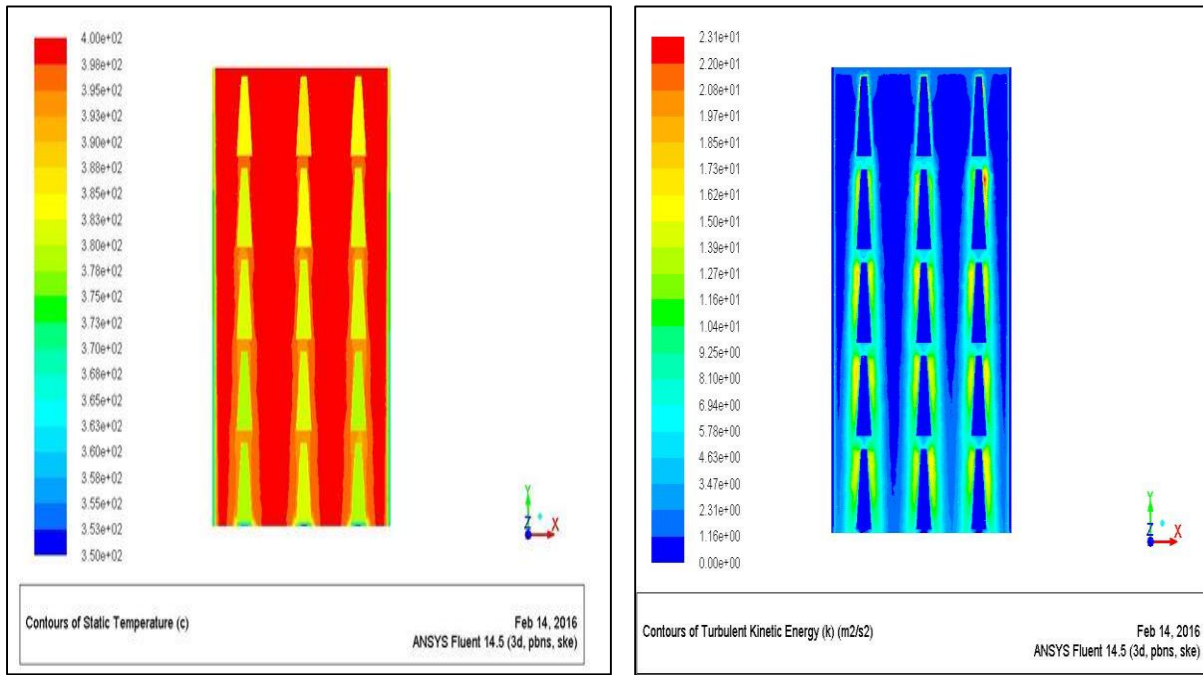
Fig. 3: Performance comparison of heat exchangers



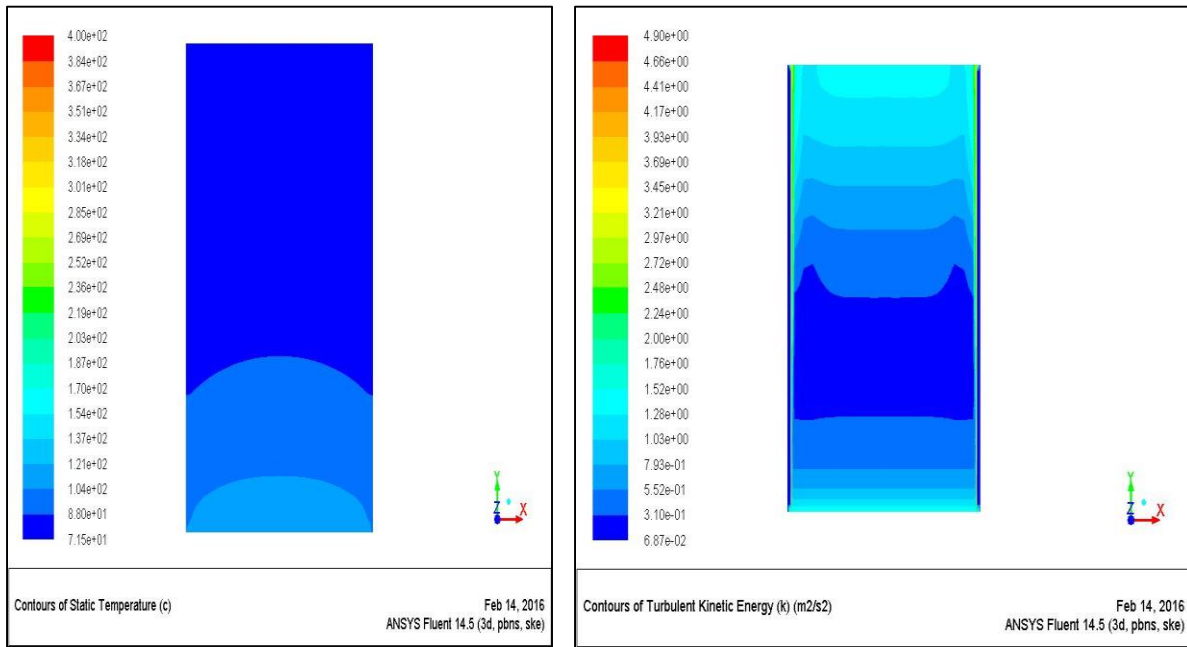
a) b)
Fig. 4: Physical distribution in Fishbone a) temperature field and b) turbulence field



a) b)
Fig. 5: Physical distribution in serial plate a) temperature field and b) turbulence field



a) b)
Fig. 6: Physical distribution in accordion a) temperature field and b) turbulence field



a) b)
Fig. 7: Physical distribution in empty cavity a) temperature field and b) turbulence field