MODELING AND SIMULATION OF EGR COOLER WITH DIFFERENT TYPES OF FINNED TUBE FOR DIESEL ENGINE

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Abstract: Exhaust gas recirculation (EGR) system is one of the post processing techniques and, it is widely used to meet emission standards. And it has been considered as the most effective means to reduce NOx emission from diesel engine. EGR cooler is a simple heat exchanger in which exhaust gas is cooled with the help of coolant from engine itself. Our objective is to improve the effectiveness of shell and tube type heat exchanger; So that exhaust gas recirculated will be cooled more, in this way combustion chamber temperature will be lowered and it reduces NOx emission. Therefore, we create different models 1, 2, 3 and 4. Model-1 is a simple shell and tube type and simulated its result on ANSYS fluent 16.0. Then in model-2 we replaced simple tubes by triangular finned type circular tube and get increased effectiveness of the same cooler. And in the model-3, we replace the plane tube in same model by rectangular finned tube, and in the Model-4, we replace simple tubes by Trapezoidal fin type tubes. Now compared all the four models by their effectiveness and suggest to use most effective Model-4 among them. And we predict the NOx emission for different EGR rate for effective Models-4.

Key word*:* Fin, Effectiveness, LMTD, NTU and EGR, NOx.

1. INTRODUCTION

Major problem faced by today's world is environmental pollution. Of this vehicular traffic is a major contributor. Exhaust gases from vehicles includes CO, CO_2, HC, NOx. Out of this NOx is particularly very harmful. These are one of the chief constituents of smog, which have an adverse effect on ecological systems. They also contribute to the formation of acid rain. NOx also causes breathing illness in human beings.

In internal combustion engines exhaust gas recirculation (EGR) is a, oxides of nitrogen (NOx) emissions reduction technique used in petrol/gasoline and diesel engines. EGR works by recirculating a portion of an engine's exhaust gas back to the engine cylinders. The principle of EGR is to recirculate about 10% to 30% of the exhaust gases back into the inlet manifold where it mixed with the fresh air and this will reduce the quantity of O2 available for combustion. This reduces the O2 concentration and dilutes the intake charge and reduces the peak combustion temperature inside the combustion chamber which will simultaneously reduce the NOx formation. About 15% recycle of exhaust gas will reduce NOx emission by about 80% [1].

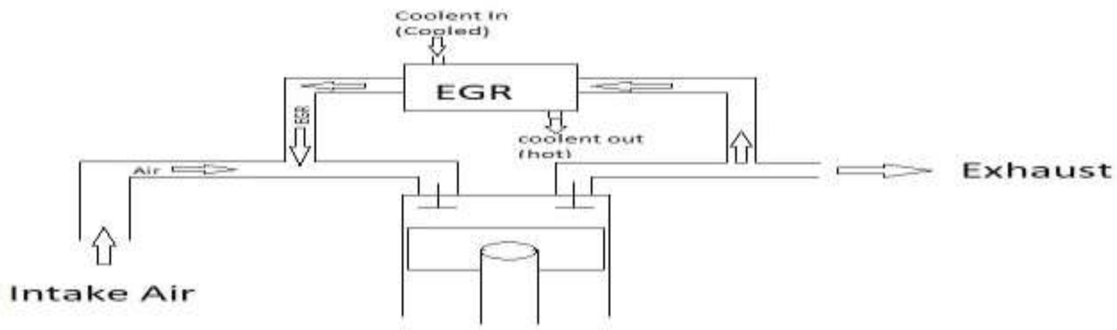


Figure: - 1.1 schematic diagram of EGR Cooler

Better fuel economy and higher power with lower maintenance cost has increased the popularity of diesel engine vehicles are for bulk movement of goods, Diesel engines also used to power stationary/ mobile equipment, and to generate electricity more economically than any other device in this size range. In most of the global car markets, diesel car record sales have been observed in recent years. The exhorting anticipation of additional improvements in diesel fuel and diesel vehicle sales in future have forced diesel engine manufacturers to upgrade the technology in terms of power, fuel economy and emissions [2].

In present year pollution increases due to various harmful gases occurs due to globalization, industrial development and transportation industries. In these transportation industries internal combustion engines are the main power source. In Comparison to petrol and diesel engine, diesel engines have high thermal efficiency because of high compression ratio and lean air-fuel mixture. High compression ratio leads to high temperature. Due to the lean air-fuel mixture, extra oxygen is present in the cylinder for complete combustion. This oxygen reacts with nitrogen and produces pollutants like oxides of nitrogen.

1.2 FORMATION OF NOx:

Oxides of nitrogen is produced in very small quantities can cause pollution. While prolonged exposure of oxides of nitrogen is dangerous to health. Oxides of nitrogen which occurs only in the engine exhaust are a combination of nitric oxide (NO) and nitrogen dioxide (NO_2). Nitrogen and oxygen react at relatively high temperature. NO is formed inside the combustion chamber in post-flame combustion process in the high temperature region. The high peak combustion temperature and availability of oxygen are the main reasons for the formation of NOx. [3]. In the presence of oxygen inside the combustion chamber at high combustion temperatures the following chemical reactions will takes place behind the flame. Zeldovich mechanism for formation of nitric oxide.

$$N_2 + O = NO + N$$
$$N + O_2 = NO + O$$
$$N_2 + OH = NO + H$$

1.3 EXHAUST GAS RECIRCULATION:

EGR is a useful method for reducing NOx formation. EGR is a method in which a portion of engine exhaust gas is recirculated to the combustion chamber through intake system. This reduces the O_2 concentration in the combustion chamber. The specific heat of the EGR is much higher than fresh air hence EGR increases the heat capacity of the intake charge, thus decreasing the temperature rise for the same heat release [4].

1.3.1 Different Types of EGR Systems:

1.3.1.1 Classification Based on Temperature

Hot EGR: Exhaust gas is re-circulated without being cooled, resulting in the increased charge temperature [4].

Fully cooled EGR: Exhaust gas is cooled before re-circulation in to the combustion chamber by the means of a water-cooled heat exchanger [4]. In this case, condensed water enters the cylinder and produces undesirable effects.

Partly cooled EGR: To avoid the water condensation, the temperature of exhaust gas is kept just above its dew point temperature [4]. The dew point is the temperature to which air must be cooled to become saturated with water vapor. When further cooled, the airborne water vapor will condense to form liquid water (dew). When air cools to its dew point through contact with a surface that is colder than the air, water will condense on the surface.

1.3.1.2 Classification Based on Configuration

Long Route System (LR): In LR system the pressure drops across the air intake and the stagnation pressure in the exhaust gas stream cause the EGR possible [4]. Stagnation pressure is the static pressure at a stagnation point in a fluid flow. The pressure at a point in a fluid is called the static pressure. At a stagnation point the fluid velocity is zero and all kinetic energy has been converted into pressure energy.

Short Route System (SR): - These systems are mainly the method used to set up a positive pressure difference across the EGR circuit. [4]

1.3.1.3 Classification Based on Pressure

Low Pressure Route System: The passage for EGR is provided from downstream of turbine to upstream side of compressor [4].

High Pressure Route System: The EGR is passed from upstream of the turbine to the downstream of the compressor [4].

1.4. INTRODUCTION OF FINS:

Fins are the extended surfaces designed to Increase heat transfer rate for a fixed surface temperature, or lower surface temperature for a fixed heat transfer rate.

1.4.1 Types of Fins:

Figure 1.2: - Types of Fins

1.4.2 Heat Transfer from Finned Surfaces

The rate of heat transfer from a surface at a temperature Ts to the surrounding medium at T∞ is given by Newton's law of cooling as,

$$\dot{Q}_{conv} = hA_s(T_s - T_\infty)$$

where.

As=The heat transfer surface area and

h =The convection heat transfer coefficient

Ts=Surface temperature
T∞=Ambient temperature

The two ways to increase the rate of heat transfer: -
(1) To increase the convection heat transfer coefficient
(2) To increase the surface area. [7]

As Increasing heat transfer coefficient may require the installation of a pump or fan, or replacing the existing one with a larger one, but this approach may or may not be practical. Besides, it may not be adequate [7].

The alternative is to increase the surface area by attaching to the surface, extended surfaces called fins made of highly conductive materials. Finned surfaces are manufactured by extruding, welding, or wrapping a thin metal sheet on a surface. Fins enhance heat transfer from a surface by exposing a larger surface area to convection and radiation. Finned surfaces are commonly used in practice to enhance heat transfer, and they often increase the rate of heat transfer from a surface [7].

In the analysis of fins, we consider steady operation with no heat generation in the fin, and we assume the thermal conductivity k of the material to remain constant. We also assume the convection heat transfer coefficient to be constant and uniform over the entire surface of the fin for convenience in the analysis [7].

Application of Fin

- Electric motor and transformers
- Evaporators and condensers of refrigeration and air conditioning system.
- I. C. Engines
- Condensers and economizers of thermal power plant.
- Cooling of electronics components.

2. ENGINE SPECIFICATION:

Description	Specification
Displacement	1248cc
Induction Type	Turbocharger
Bore x Stoke	69.6mmx82mm
Maximum power (ps/rpm)	75/4000
Compression ratio	17.7
EGR System	Cooled
Maximum torque (kgf-m)	190
RPM	2000

Mass flow of air into the engine, m_a = 0.0246 kg/sec
m_g = 0.02542 kg/sec
We use 20 % of exhaust gas into the engine cylinder:
m_g = 0.20 x 0.02542=0.005084
We start our design calculation for 20% mass of the exhaust gas in EGR cooler,
Inlet condition: P_1 = 1.2 bar, T_1 = 318 K
Exhaust Temperature T4 = 963 K

Properties of fluid: - [10]

S.no.	Properties	Hot gas	Coolant
1	Density(kg/m^3)	0.35	990.1
2	Thermal conductivity(W/m-K)	0.065	0.637
3	Viscosity(kg/m-s)	4.15*10^{-5}	0.596*10^{-3}
4	Prandtl number	0.714	3.91
5	Mass flow rate(kg/sec)	0.005	0.01
6	Specific heat(j/kg-K)	11.32	4180
7	Inlet temperature(K)	963	318

3. DESIGN OF EGR COOLER

3.1 NTU Method:

Effectiveness for counter flow EGR cooler

$$\varepsilon = \frac{1-\exp[-NTU(1-R)]}{1-R\exp[-NTU(1-R)]}$$

After substituting the values,
ε = 28.1 %
Hot gas exit temperature

$$\varepsilon = \frac{Ch(Thi-Tho)}{Cmin(Thi-Tci)}$$

Tho = 783 K
Cold fluid exit temperature

Tco = 343 K

3.2 KERN`S METHOD FOR DESIGN OF EGR COOLER:

Since in the design of heat exchanger, tube diameter, tube thickness and tube material are independent variable.
Taking dimension of EGR cooler.
Tube material = Aluminum (k=237 W/m-k)
Tube outer diameter = 15.9 mm [11]
Tube thickness = 1.6 mm [11]
And taking tube length 100 mm for 1mm thick sheet [11]

$$Re = \frac{\rho u d_i}{\mu_t}$$

Re = 1671.96
Nusselt number
$Nu_t = 0.24Re^{0.8}Pr^{0.4}$
$Nu_t = 7.948$
Heat transfer coefficient
$h_t = Nu\ k_t/d_i$
$h_t = 40.68$ W/m^2-K

3.3 Calculation of EGR Cooler Effectiveness

3.3.1 TRAPEZOIDAL FIN

Number of fin=6
Fins height=3mm
Fins larger width=0.6 mm
Fins smaller width=0.3 mm
Fins length=100mm
T_{ho}=745.07 K (by calculation)
Effectiveness of EGR cooler for rectangular fin =33.78%

Figure: - Trapezoidal fin tube

3.3.2 RECTANGULAR FIN

Number of fin=6
Fins height=3mm
Fins width=0.3 mm
Fins length=100mm
T_{ho}=750.5 K (by calculation)
Effectiveness of EGR cooler for rectangular fin =32.9%

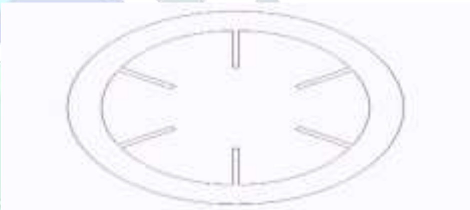


Figure: - Rectangular fin tube

3.3.3 TRIANGULAR FIN

Number of fin=6
Fins height=3mm
Fins width=0.3 mm
Fins length=100mm
T_{ho}=755.1 K (by calculation)
Effectiveness of EGR cooler for triangular fin =32.22%

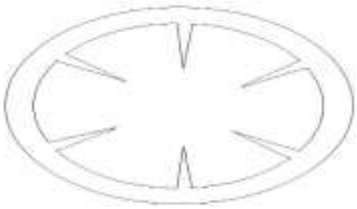
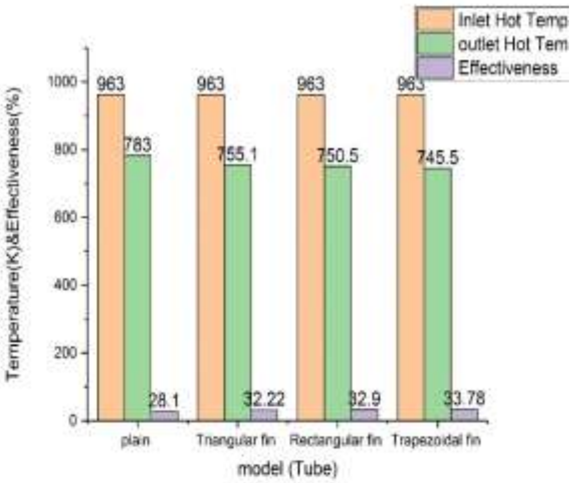


Figure: - Triangular fin tube

3.4 Comparison of finned tube

MODEL	Inlet hot temp. (K)	Outlet hot temp. (K)	Effectiveness
Plain tube	963	783	28.10%
Triangular fin tube	963	755.1	32.22%
Rectangular fin tube	963	750.5	32.90%
Trapezoidal fin tube	963	745.5	33.78%



4. MODELLING

4.1 Modelling of the EGR cooler in PTC Creo 2.0

S.No.	Description	Values
1	Shell inner dia.	70 mm
2	Bundle dia.	62.56 mm
3	Shell thickness	1.2mm
4	Tube inner dia.	12.7 mm
5	Tube thickness	1.6 mm
6	Tube length	100 mm
7	Number of tube	6

TUBE

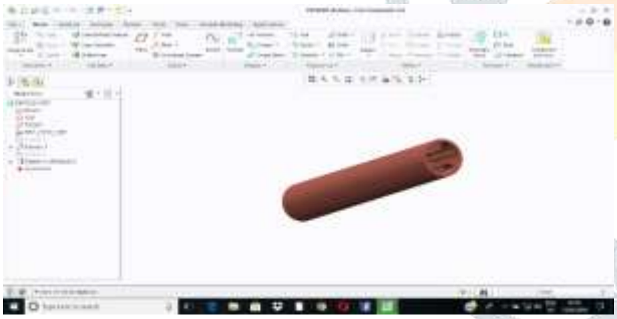


Figure 4.1.1: - Tube

CYLINDRICAL HEAD

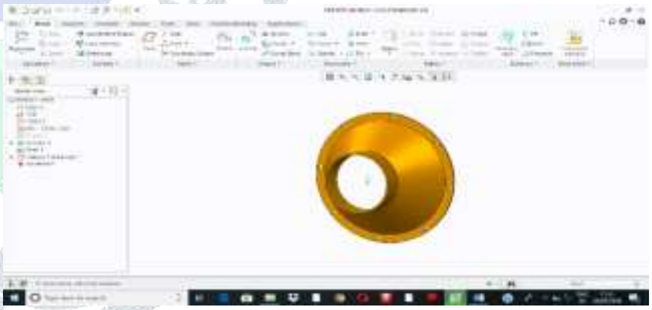


Figure 4.1.2: -Cylinder Head

TUBE SHEET MODEL

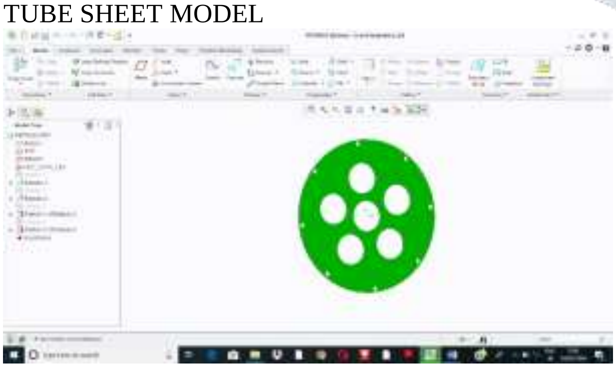


Figure 4.1.3: - Tube Sheet Model

SHELL

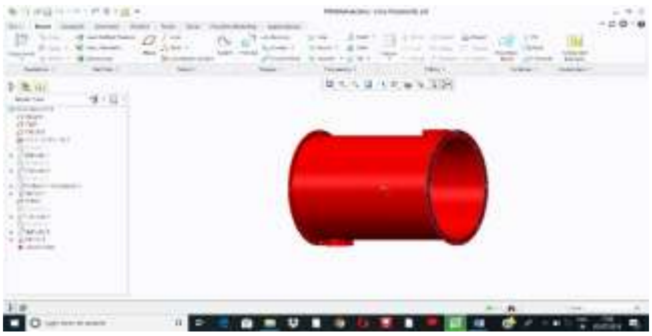


Figure 4.1.4: -Shell

ASSEMBLY MODEL

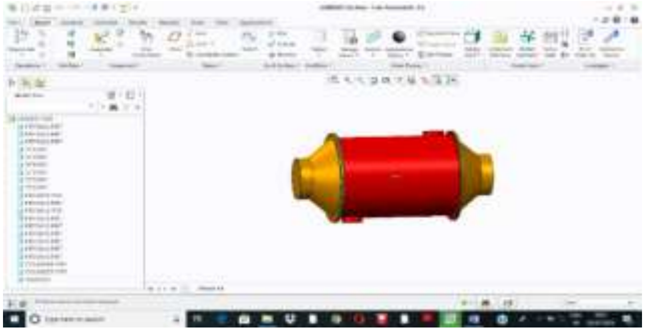


Figure 4.1.5: -Assembly Model

EXPLODED VIEW OF ASSEMBLY

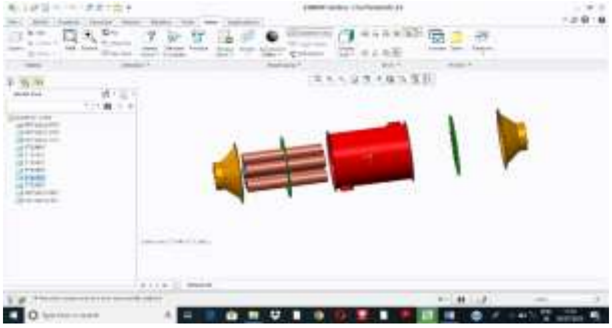


Figure 4.1.6: -Exploded view of Assembly

EGR COOLER ASSEMBLY WITH FLUID MODEL

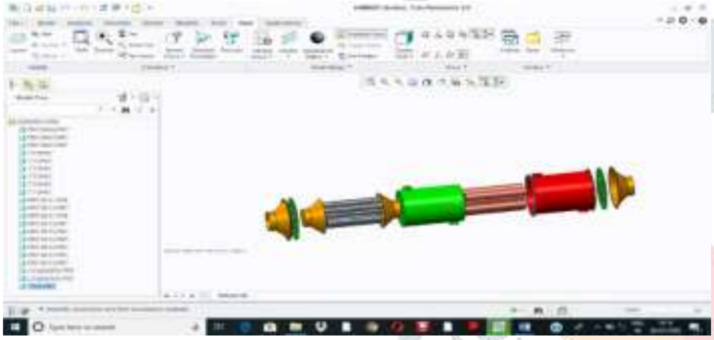


Figure 4.1.7: -EGR Cooler Assembly with Fluid Model

5 CFD SIMULATION AND ANALYSIS

5.1 Solution with fluent various step in ANSYS (fluent) as follows:

1. Import geometry

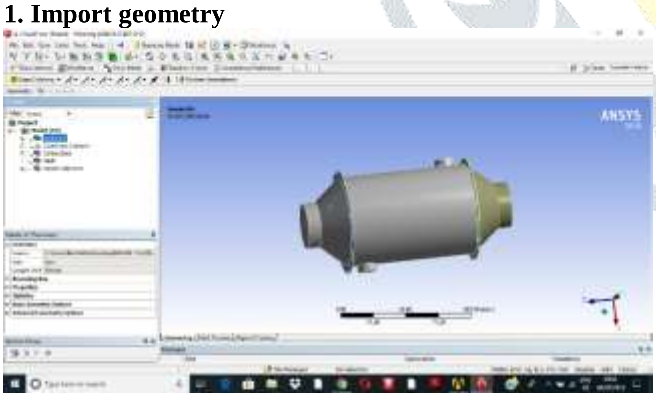


Figure 5.1.1: -Import EGR cooler

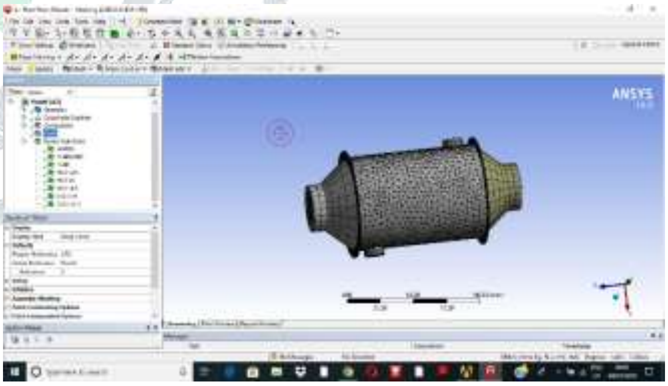


Figure 5.1.2: -Meshing of EGR cooler for simple tube (Model-1)

2.Generation of mesh

In this meshing model-1, Number of nodes are 67420 and Number of Elements are 125225

There are two types of meshing is available in ANSYS fluent fine meshing and coarse meshing. For above model fine meshing is used. Meshing is fine at the center of the model which is automatic adopted by the ANSYS mesh generating tool. At the curve portion meshing is also fine. Tetrahedral meshing is used for the meshing purpose automatic adopted by the ANSYS mesh generation tool.

A tetrahedral has 4 vertices, 6 edges and is bounded by 4 triangular faces. In most cases tetrahedral volume mesh can be generated automatically.

Tetrahedral elements can fit better complex geometry. If your geometry is simple, the best option is to mesh it with hexahedral elements but curved geometries, acute angles or similar then go with tetrahedral.

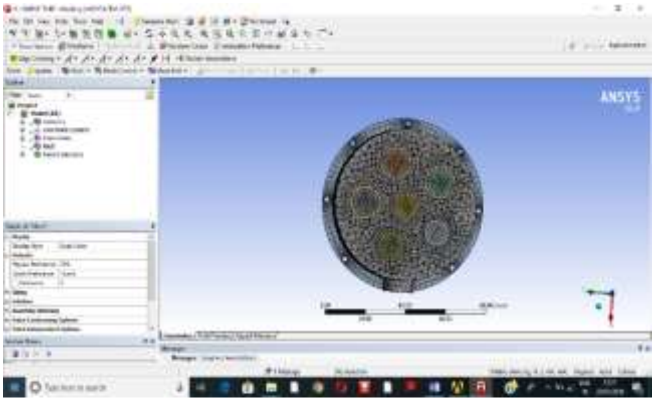


Figure 5.1.3: -Meshing of EGR cooler for simple tube sectional view (Model-1)

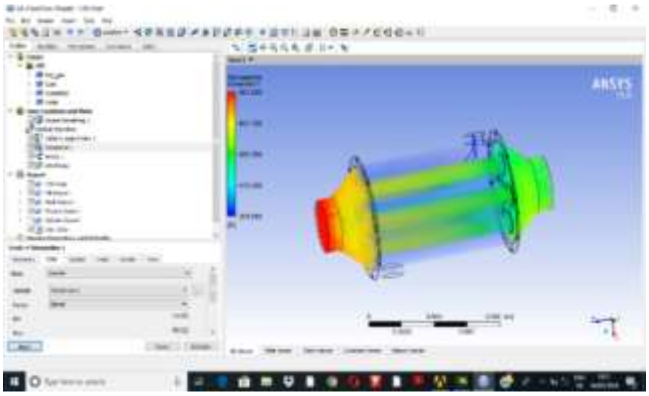


Fig 5.1.4: - temperature contour of simple tube (Model-1)

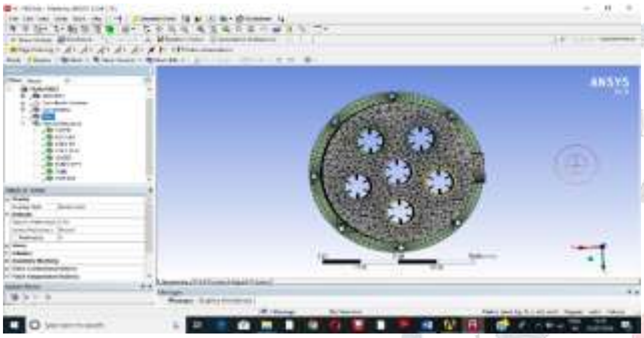


Figure 5.1.5: -Meshing of EGR cooler for triangular fin tube sectional view (Model-2)

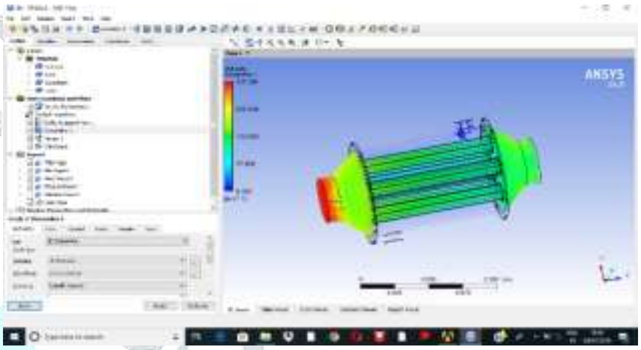


Fig 5.1.6: temperature contour of triangular fin tube (Model-2)

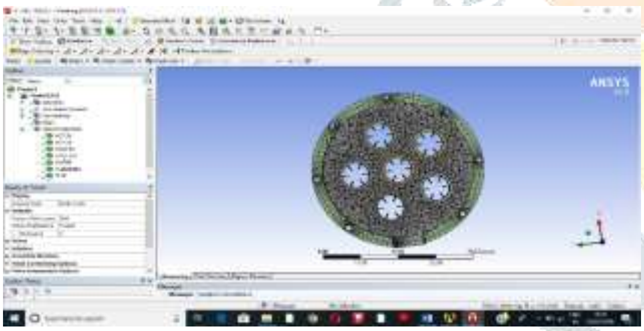


Figure 5.1.7: -Meshing of EGR cooler for Rectangular fin tube sectional view (Model-3)

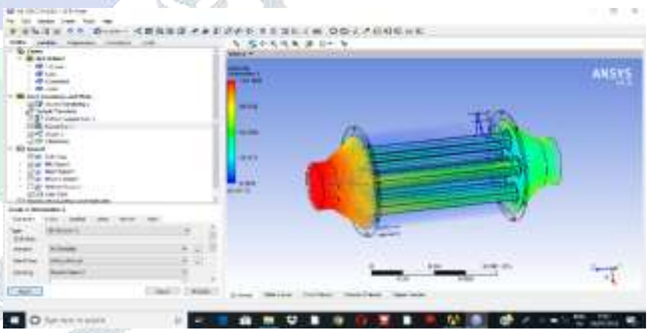


Fig 5.1.8: temperature contour of rectangular fin tube (Model-3)

Model	Inlet hot temp. (K)	Outlet hot temp. (K)	Inlet cold temp. (K)	Outlet cold temp. (K)	Effectiveness
Plan tube	963	650	318	346.14	48.52%
Triangular fin tube	963	615	318	352.2	53.95%
rectangular fin tube	963	601	318	362.2	56.12%
Trapezoidal fin tube	963	590	318	370.2	57.83%

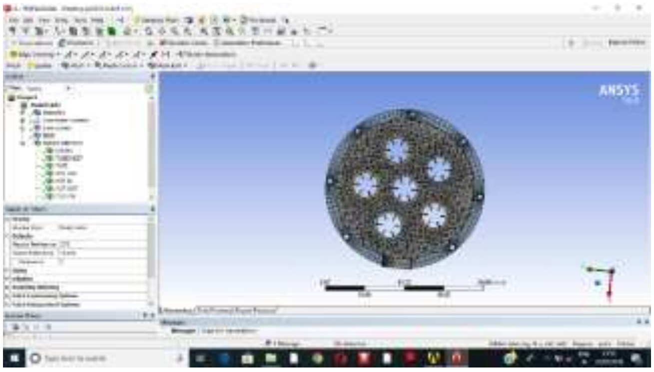


Figure 5.1.9: -Meshing of EGR cooler for trapezoidal fin tube sectional view (Model-4)

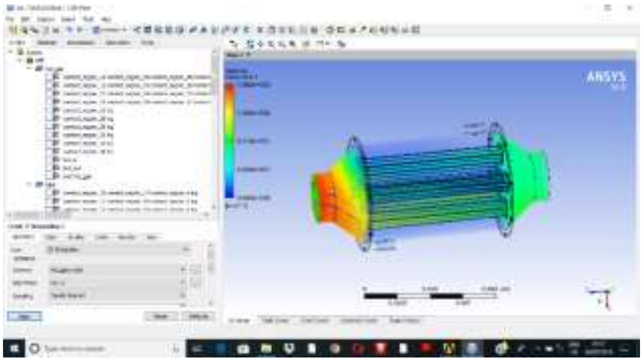
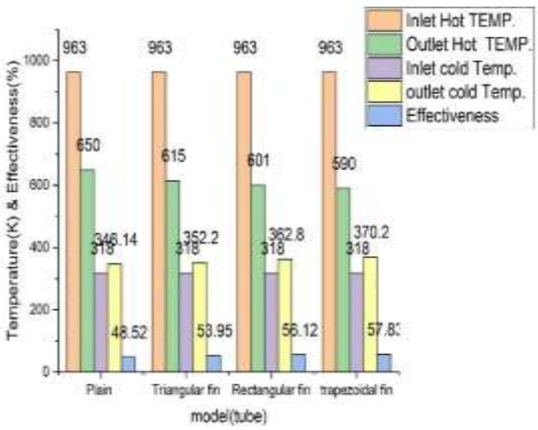


Fig 5.1.10: temperature contour of Trapezoidal fin tube (Model-4)

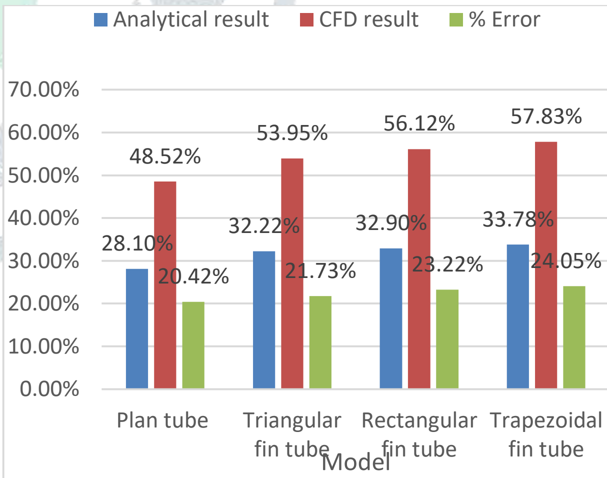
6 RESULTS

6.1 Result Comparison



6.2 Analytical and CFD result comparison

Model	Analytical result	CFD result	% Error
Plan tube	28.10%	48.52%	20.42%
Triangular fin tube	32.22%	53.95%	21.73%
Rectangular fin tube	32.90%	56.12%	23.22%
Trapezoidal fin tube	33.78%	57.83%	24.05%



7.CONCLUSION

EGR coolers are designed in the different ways to increase the performance of them to reduce the engine emissions. There is various type of EGR coolers designed to use in the diesel engine to increase the surface area such as EGR cooler with trapezoidal fin tube, rectangular fin tube and with triangular fin tube, and because of this heat transfer rate would increase and the effectiveness of EGR cooler will increase.

In these cases, on four types of EGR cooler, two types of analysis are done first one is analytical and second is the CFD analysis. We create four models of EGR cooler which are designed to check which type of EGR cooler is most effective out of these, Model-1 type of EGR cooler is consist of plain tube. Model-2 consist of internally triangular fins tube along its length and model-3 consist of internally rectangular fin tube and model-4 consist of trapezoidal fin tube on its surface in order to increase its effectiveness. The maximum effectiveness is seen in case of the EGR cooler with trapezoidal fin tube.

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