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Computational Analysis of Catalytic Converter Light-off Temperature in Exhaust System of IC Engine

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*Abstract:**Catalytic Converter of an engine becomes operational whenever it reaches light-off temperature (200^0C to 225^0C). During cold conditions Catalytic Converter takes more time to reach light-off temperature, due to engine components take more time to warm up. In these situations the placement of the Catalytic Converter plays an important role. In this proposed work the exhaust gas flow analyzed and studied the variation of temperature with time to optimize the location of catalytic converter.***

Key words:**Catalytic converter, Exhaustgas, warm-up and light-off temperature.**

1. Introduction

The development of power units with low environmental impact has become one of the most interesting challenges in the automotive technology. From the perspective of environmental protection, researchers must further decrease exhaust emissions of gasoline engines for automobiles. Many efforts are being made to reduce air pollution from automotive engineemissions. Standards, which are developed to control the different undesirable species, are becoming more stringent requiring the reduction of engine emissions, as well as the use of after-treatment systems in the exhaust system. In minimizing these emissions Catalytic converter plays an important role. The main reaction taking place inside the catalytic converter is conversion of carbon monoxide to carbon-di-oxide and conversion of NO_x to nitrogen and water. For these reactions to occur a sufficient temperature is necessary i.e., until that temperature is reached the pollutants will pass through to atmosphere untreated. The effectiveness of these converters depends on the exhaust gas temperature, which is fairly low during cold-start (Gallopoulos, 1992; Boam et al., 1995). Since catalysts are effective only at high temperature, emissions are far moresignificant during the initial part (cold phase) of a trip when engine and catalyst are cold. The after treatment systems used on spark ignition engines to limit the tailpipe emissions of HC, CO and NOx are exposed to a wide range of temperature conditions which affect its performance and durability characteristics. So it is necessary to understand the transient response of the flow model and variation of other thermal parameters in the exhaust system.
Some of the previous researches which are conducted related to catalytic convertor light off temperature are as follows

Mesut DURAT, Zekeriya PARLAK, Murat KAPSIZ, Adnan PARLAK veFerit FIÇICI (2013), in their work “Experimental analysis on thermal performance of exhaust system of a SI engine” have done an experimental analysis of the exhaust system to know about light-off temperature of the catalytic converter and thermal interaction between the wall and gas.
Brendan Carberry, Georg Grasi, StephaneGuerinand Francois Jayat, RomanKonieczny(2005) in“Pre-Turbocharger Catalyst – Fast catalyst light-off evaluation” have stated that for the catalytic converter to work with an efficiency of 35% the minimum temperature required is around 250^0C.
F. Fortunato, F. Quadrini and S.Bova (2005) in“Catalyst Light-off Evaluation Using CFD Simulation of the exhaust manifold” have used an experimental NEDC cycle for the test and stated that the first 195s of the cycle is cold start condition and temperature variation during this time is transient.
P. J. Shayler, D. J. Hayden and T. Ma(1999) in “Exhaust System Heat Transfer and Catalytic Converter Performance” have studied of variation of exhaust gas temperature inside the manifold and its effect on the performance of the catalytic converter.

2. Analysis Setup

a. Modelling

A 3-D CAD model of the exhaust header is created using the PRO-E Wildfire 5. The dimensions of the model are taken from a 4 cylinder water cooled engine of normal Indian sedan car.

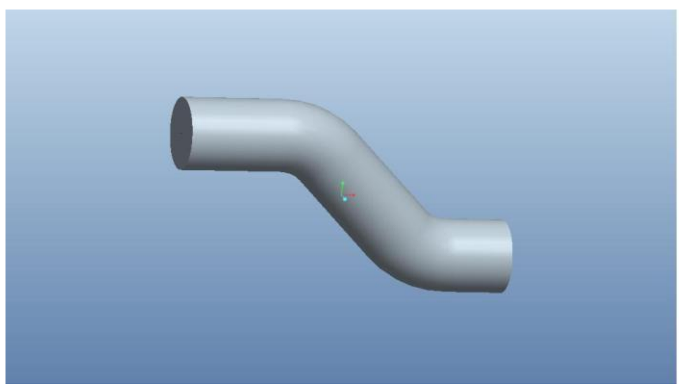

Fig.1 - PRO-E Model

b. Mesh generation

The model is imported to latest version of ANSYS Workbench, checked for faults in the design modeller and exported to mesh generator. Mesh is generated with a limiting value of 1.5mm element size.

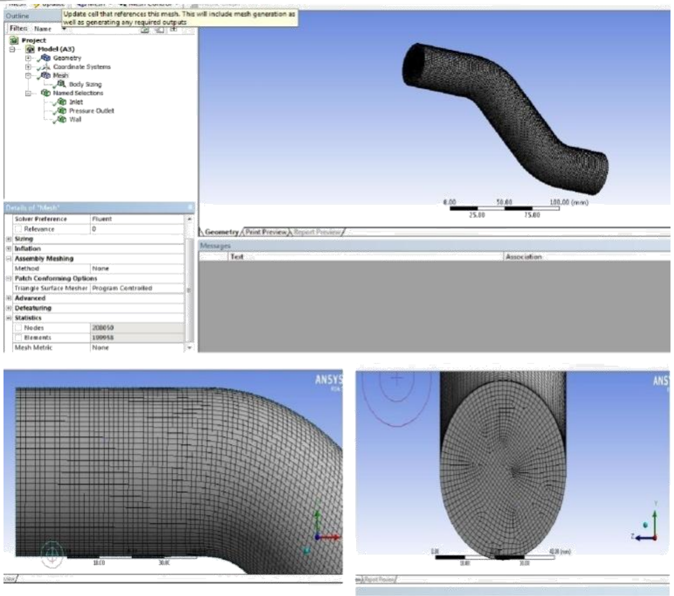

Fig.2 - Mesh generation

Hexagonal shaped meshes which gives more accurate results are created with 2, 08,050 nodes and 1, 99,958 elements. A comparative study was done by changing the mesh size and was found that the above stated mesh gives accurate results with minimum calculation period. From the figure it can be seen that the hexagonal shape of the mesh is maintained both at the centre and surface. Then the named sections like Inlet, Outlet and Wall are created, and then exported to FLUENT.

c.FLUENT Analysis

A 3-D double precision calculation method was selected and mesh was checked for fault diagnosis. At first a steady, pressure based analysis was carried out. For this a realizable K k- ϵ turbulent model with enhanced wall treatment was used. Energy equations along with Continuity and Momentum equation are used for the calculations. Air with following properties was used for the fluid domain.

Table 2.1 Properties of air

Property	Value
Density (Kg/m^3)	1.225
Thermal conductivity (W/m K)	0.0242
Specific heat (J/Kg K)	1006.43
Viscosity (Kg/m s)	1.7894×10^{-5}

The Following boundary are used to do analysis

Table 2.2 boundary conditions

Physical quantity	Value
Inlet mass flow rate (Kg/s)	0.04
Supersonic gauge pressure (bar)	0
Inlet temperature (K)	673
Outlet gauge pressure (bar)	0
Outlet temperature (K)	300
Operating pressure (bar)	1 (abs)

3. Transient Analysis

Since in practical cases the variation of temperature inside the exhaust manifold is varying continuously, the results of steady state analysis would not be of greater use. So we have conducted a transient analysis where the temperature of the gas will be varying with time. Here the model after meshing was exported to ASYS CFX software. Analysis type is selected as transient with total run time of 195s and a time step of 1s each. For fluid domain a material was created with the name of 'Exhaust gas.' The properties of the gas were varied continuously with the inlet temperature and are given by the following relations [1].

1. Inlet temperature:1.5t+ 359.3^{o}C………@
2. Thermal conductivity: $K = 8.459 \times 10^{-3} + 5.7 \times 10^{-5} T_{inlet}$
3. Dynamic viscosity: $\mu = 1.384 \times 10^{-5} + 2.68 \times 10^{-8} T_{inlet}$

The density and specific heat values of the gas were specified as constants with ρ =1.2 Kg/m^3 and C_p = 1006J/Kg K. A scalable K - ϵ turbulent model is used for the iterations with following boundary conditions.

Physical quantity	Value
Inlet mass flow (Kg/s)	0.04
Inlet temperature (K)	Expression @
Outlet Pressure (bar)	1 (abs)
Outlet temperature (K)	300
Convective H.T coefficient of wall(W/m^2K)	50

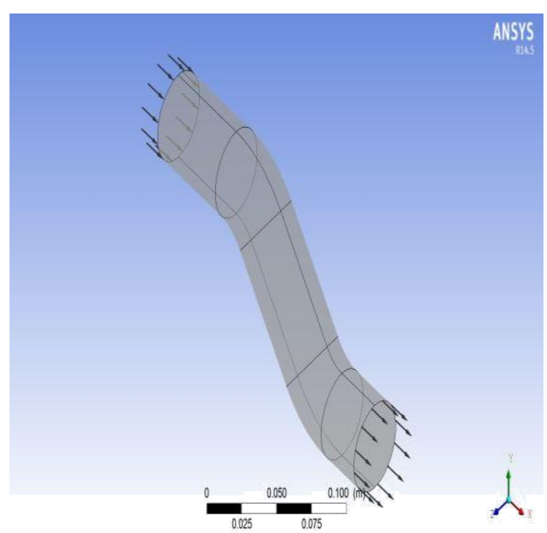

Fig. 3- Boundary conditions in CFX

4. Results

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A. Steady state:

Following are the results of the steady analysis. From the pressure variation contour it can be seen that there is not much change in the value of the pressure inside the manifold, it can also be seen that at blue shaded regions the exhaust gas will accelerate, since at low pressure regions the velocity of the particles will be high. At outlet almost aconstant temperature of 673K is maintained.

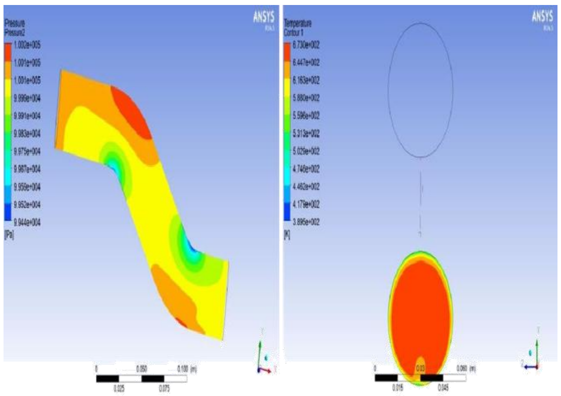


Fig. 4 - Variation of temperature and pressure at outlet

B. Transient analysis

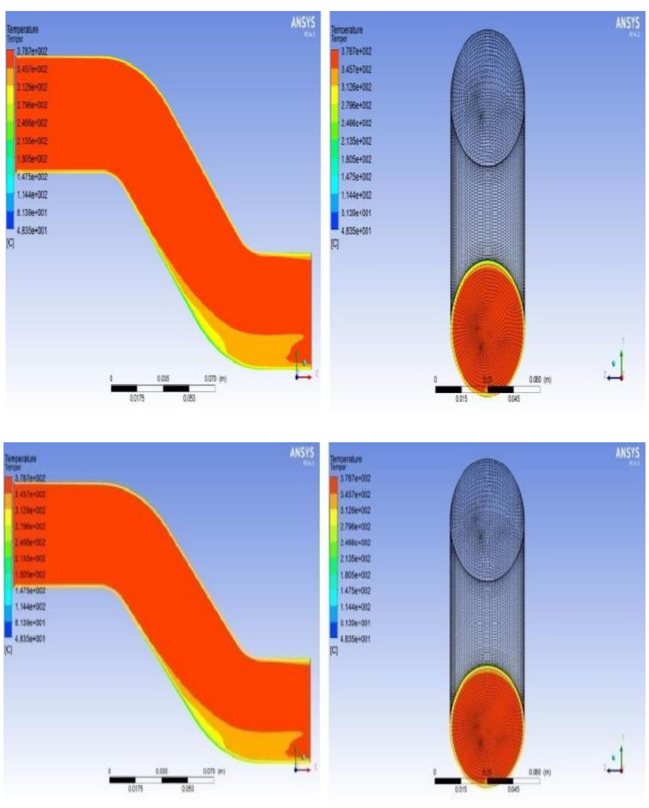


Fig.5 Variation of at different sectionstemperature after 195 sec.

Total time of 172 minutes were spent for iterations with above given conditions and results were taken.

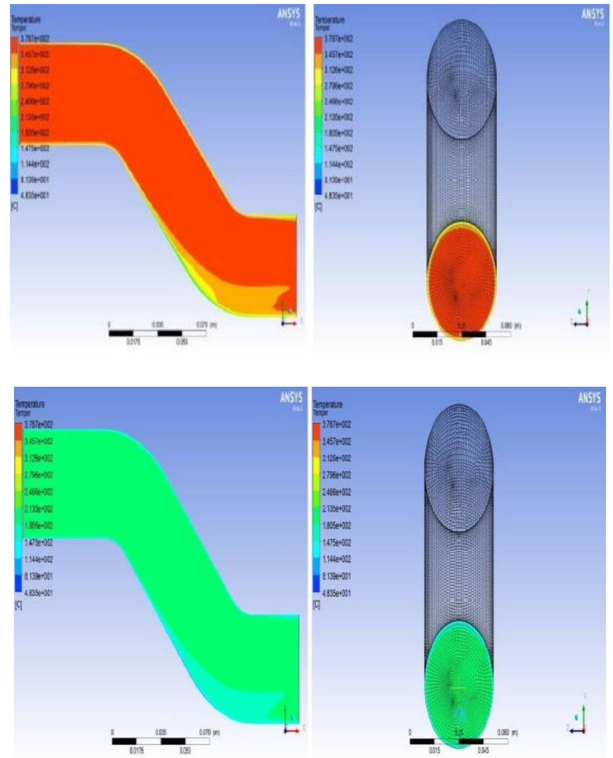
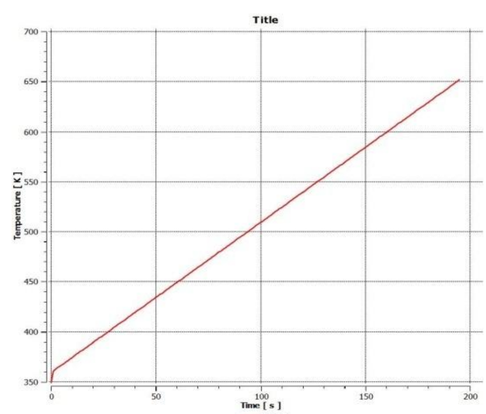


Fig.6. Variation of temperature after 75 sec

The above figure shows the value of temperature at different locations after a time of 195s. In the first picture variation of temperature at the mid plane can be seen and in the second one temperature at the outlet is specified. It can be noted that temperature has reached a value of around350^{0}C at this time, meaning catalytic light-off temperature has been crossed.

After carefully checking the value of temperature at each time steps, it was found that at t = 75 sec temperature reaches a value of around 220 ^{0}C. Since 200^{0}C sufficient for catalytic converter to start working. It can be considered as the light-off time for a given geometry.



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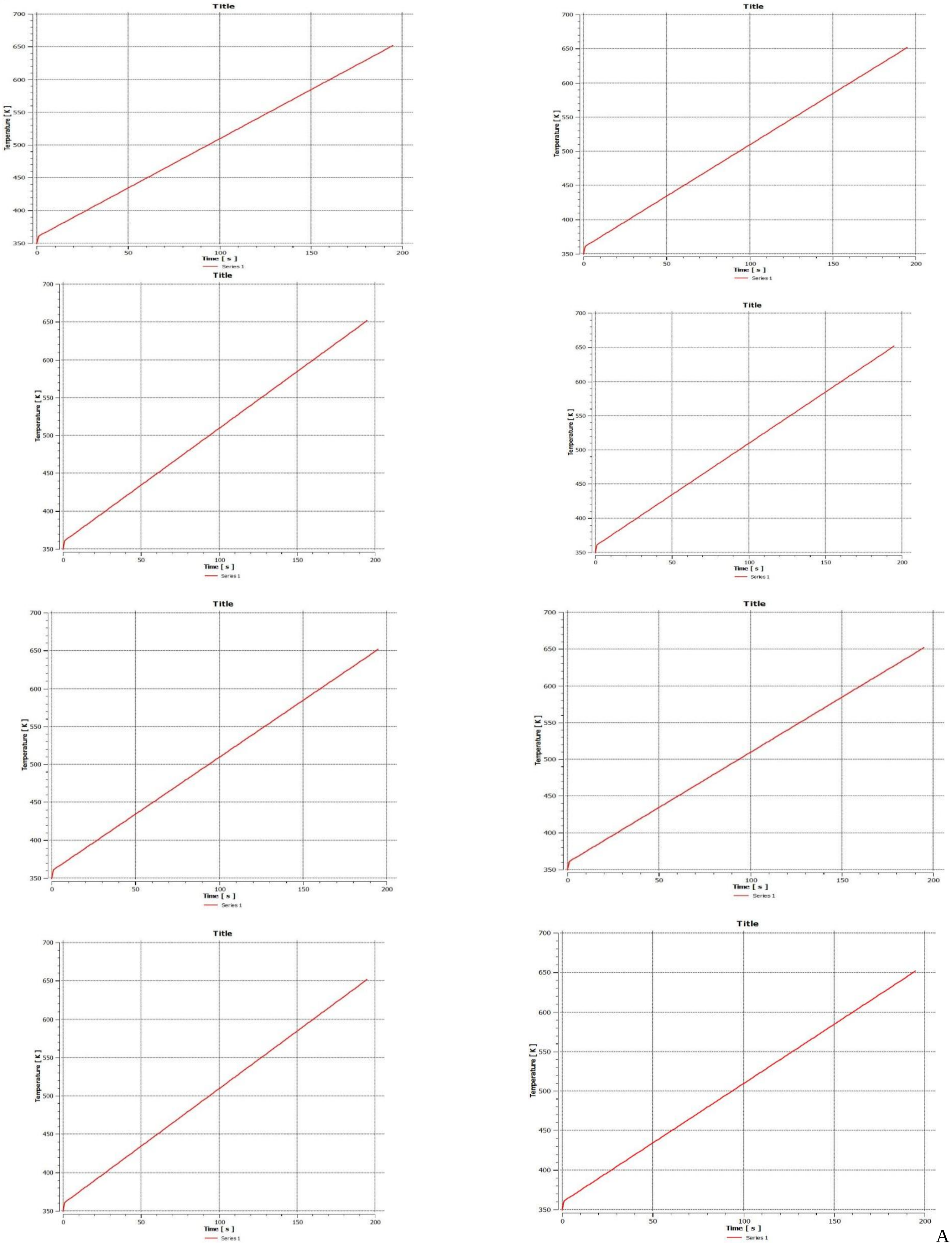

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temperature - time plot was created for better understanding the results from the graph we can see the variation temperature vs time at the centre of outlet section. It was also observed that the plot is in good agreement with the plot calculation by [1].

5. Conclusion

For the given geometry of exhaust header a 3-D flow analysis were done in steady and transient regime successfully. It was seen that the variation of temperature with time got by the results was in good agreement with the previously published experimental data. The time required for the catalytic converter to reach the light-off temperature was found to be around 75sec, which also agrees with the experimental data.

6. Acknowledgement

The task of completion of the project would not have been possible without the support of the Dr.M.Madhavi Head of the Mechanical engineering Department. It therefore makes the task of acknowledging, the role that each one of them played in encouraging us to learn how things work in Research and Development. I also sincerely thank other staff members who helped us to do this work.

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