ISSN: 0976-3376

Available Online at http://www.journalajst.com

ASIAN JOURNAL OF SCIENCE AND TECHNOLOGY

Asian Journal of Science and Technology
Vol. 08, Issue, 04, pp.4697-4700, April, 2017

RESEARCH ARTICLE

COMPUTATIONAL ANALYSIS OF CATALYST LIGHT-OFF TEMPERATURE IN EXHAUST SYSTEM OF AN IC ENGINE

[1,*]Vijaygouda M. Hiregoudar, [2]Srivatsa S and [3]Praveenkumar B. S.

[1]School of Mechanical and Building Science, VIT University, Vellore – 632014, Tamilnadu, India
[2]R & D Engineer, Tata Motors, Pune, India
[3]Assistant Professor, Sanjay Ghodawat Institute, Kolhapur, Maharashtra, India

ARTICLE INFO

Article History:
Received 18th January, 2017
Received in revised form
07th February, 2017
Accepted 13th March, 2017
Published online 30th April, 2017

Key words:
Catalytic converter,
Exhaust header,
Transient analysis,
Light-off temperature.

ABSTRACT

Catalytic converter of an engine becomes operational at a temperature of around 200 to 225˚C. During cold conditions engine components take more time to warm up, similarly the catalytic converter also takes more than usual time to reach light-off temperature, which means exhaust gases will escape untreated. In these situations the placement of the catalytic converter plays an important role, i.e. if it is placed too near to head of exhaust, time required to reach light-off temperature will be less and if it is too far, time taken will be large. In our work we have analyzed the exhaust gas flow and studied the variation of temperature with time and optimize the location of catalytic converter. We have used Pro-E Wild fire-5 for geometry modeling and ANSYS FLUENT and CFD for analysis purpose.

Notations:
K= Thermal conductivity (W/m^2K), μ= Dynamic Viscosity (Kg/m s), ρ= Density (Kg/m^3), T= Temperature (K), t= Time (s), h= Convective heat transfer coefficient (W/m^2 K), C_p= Specific heat at constant pressure (J/Kg K), P= Pressure (bar), v= Velocity (m/s) and $\dot{m}$= Mass flow rate (Kg/s).

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 engine emissions. 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).

Corresponding author: Vijaygouda M. Hiregoudar,
School of Mechanical and Building Science, VIT University, Vellore – 632014, Tamilnadu, India.

Since catalysts are effective only at high temperature, emissions are far more significant 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.

Literature review

Mesut DURAT, Zekeriya PARLAK, Murat KAPSIZ, Adnan PARLAK ve Ferit 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.

Shayler, P. J., 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.

Brendan Carberry, Georg Grasi, Stephane Guerin and Francois Jayat, Roman Konieczny (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^{0}C. 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.

Analysis setup

1. *Modeling*

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.

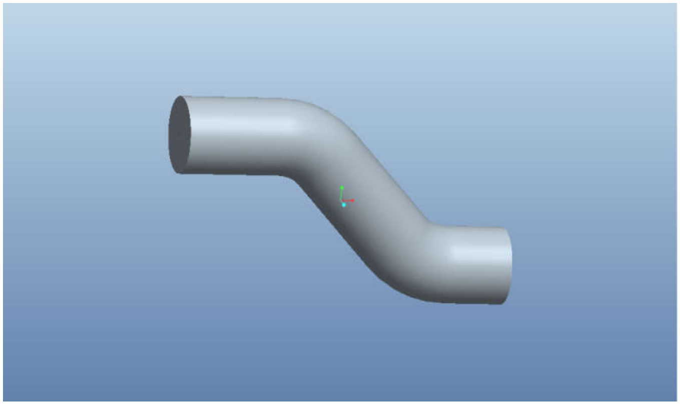


Fig. 1. PRO-E Model

2. *Mesh generation*

The model is imported to latest version of ANSYS Workbench, checked for faults in the design modeler and exported to mesh generator. Mesh is generated with a limiting value of 1.5mm element size. 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 center and surface. Then the named sections like Inlet, Outlet and Wall are created, and then exported to FLUENT.

3. *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 - 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. A stationary wall with no slip boundary condition and a constant convective heat transfer coefficient of 50 W/m^2 K was created and free stream air temperature was specified as 300K. Calculations were initialized with inlet mass flow rate and SIMPLE, second order upwind scheme was used to run it.

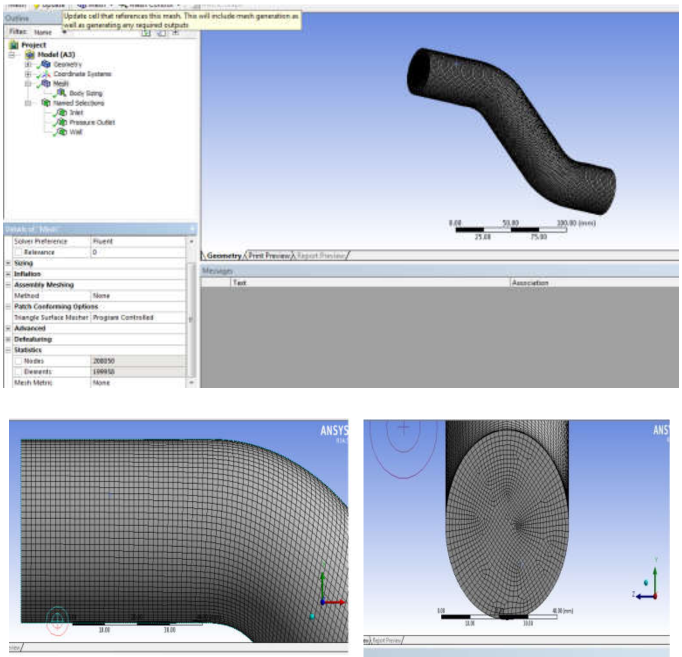


Fig. 2. Meshing

Table 1. Property and Values

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)	1.7894x10^{-5}

Following are the boundary conditions used.

Table 2. Physical Quantity and Value

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)

Results of steady analysis

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 amost a consant temperature of 673K is maintained.

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 ANSYS 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].

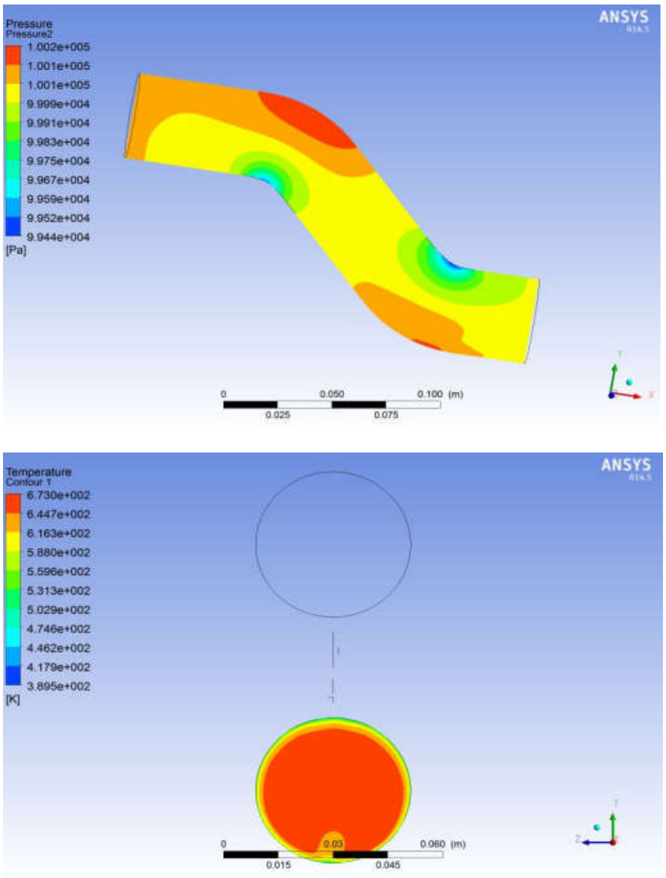


Fig. 3. Variation of Pressure and Temperature at the outlet

1. Inlet temperature: T_{inlet} =1.5t+359.3 ^{0}C …@
2. Thermal conductivity: K = $8.459\times10^{-3}+5.7\times10^{-5}T_{inlet}$
3. Dynamic viscosity: $\mu = 1.384\times10^{-5}+2.68\times10^{-8}T_{inlet}$

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^2 K)	50

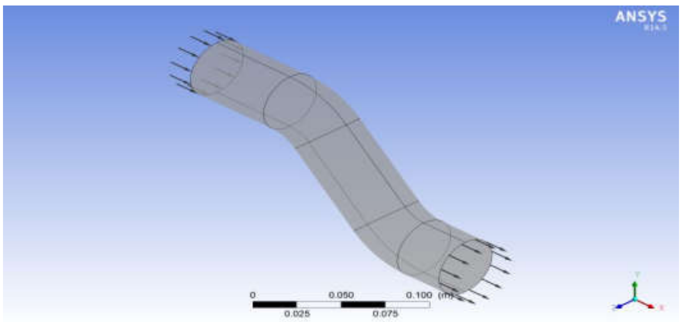


Fig. 4. Boundary conditions in CFX

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.

Results of transient analysis: Total time of 178 min was spent for iterations with above given conditions and then the results were taken.

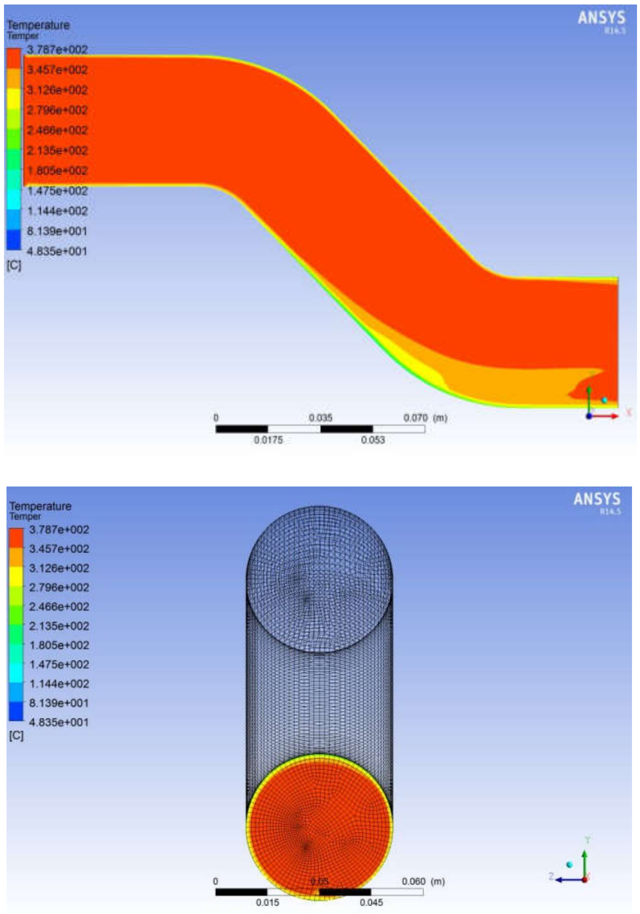


Fig. 5. Variations of temperature at different sections after 195s

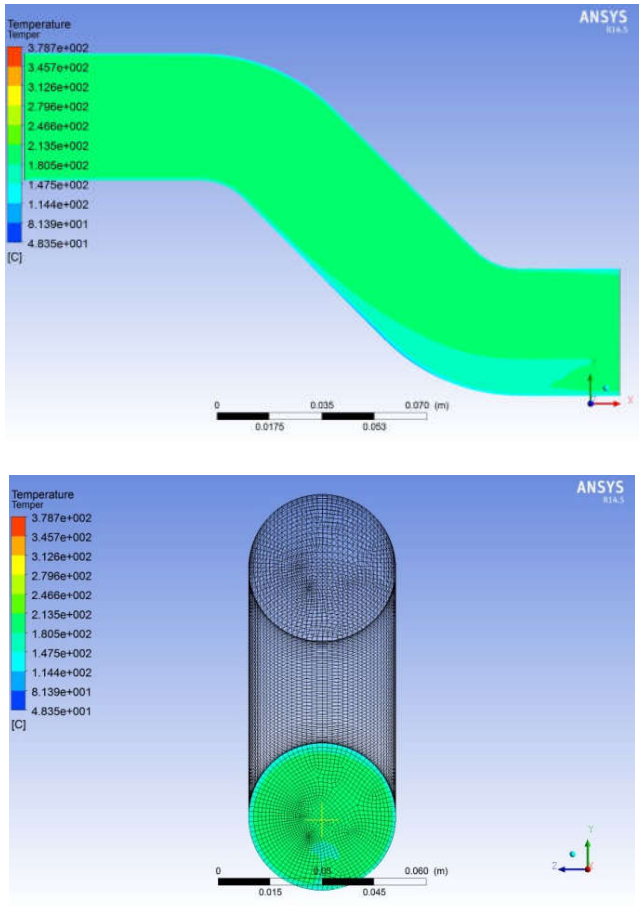
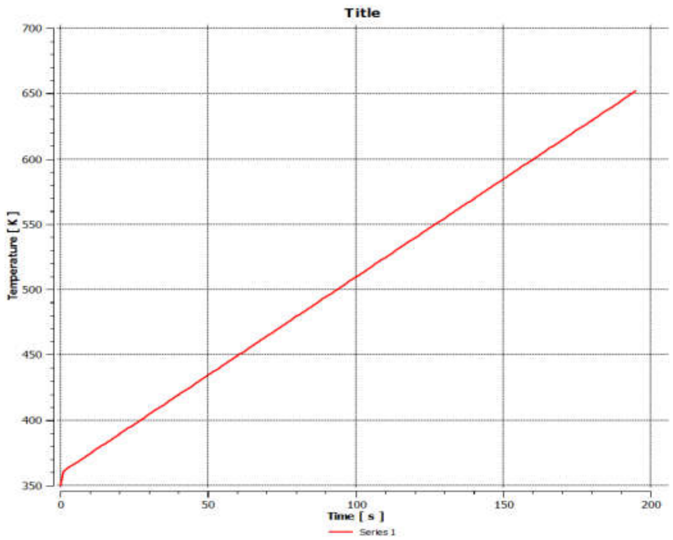


Fig. 6. Variation of temperature after 75s

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 around 350^0C 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 = 75s temperature reaches a value of around 220^0C (fig. 6). Since 200^0C is sufficient enough for catalytic converter to start working, it can be considered as light-off time for the given geometry. A temperature-time plot was created for better understanding of the results. From the graph we can see the variation of temperature v/s time at the center of outlet section. It was also observed that the plot is in good agreement with the plot calculated by [1].



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 75s, which also agrees with the experimental data. It can be stated that the time to reach the light-off temperature of the catalytic converter can be minimized by placing it further close to the exhaust manifold, in that case the back pressure in the system increases, which also has to be taken into account.

Scope for future work

- The geometry of the exhaust header can be varied and analysis can be done to minimize the time required for the catalytic converter to reach the light-off temperature.
- Experimental analysis can be done placing catalytic converter at different positions and calculating the percentage reduction/increase in the emissions.

REFERENCES

ANSYS guide for FLUENT and CFX 14.5

Brendan Carberry, Georg Grasi, Stephane Guerin and Francois Jayat, Roman Konieczny, “Pre-Turbocharger Catalyst – Fast catalyst light-off evaluation”, SAE international, 2005.

Fortunato, F., F. Quadrini and S. Bova, 2005. “Catalyst Light-off Evaluation Using CFD Simulation of the exhaust manifold”, SAE technical paper series.

Mesut DURAT, Zekeriya PARLAK, Murat KAPSIZ, Adnan PARLAK ve Ferit FIÇICI, 2013. “Experimental analysis on thermal performance of exhaust system of a spark ignition engine”, *Journal of Thermal Science and Technology*.

Shayler, P. J., D. J. Hayden and T. Ma, 1999. “Exhaust System Heat Transfer and Catalytic Converter Performance”, SAE technical paper series.

Swathi Satish, Mani Prithiviraj and Sridhar Hari, 2012. “Comparison of predictions obtained on an exhaust manifold analysis using conformal and indirect mapped interface”, International Congress on Computational Mechanics and Simulation.

****