Modeling And Simulation of Gas Flow Velocity In Catalytic Converter With Porous

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Abstract:

Stringent emission regulations around the world necessitate the use of high-efficiency catalytic converters in vehicle exhaust systems. Experimental studies are more expensive than computational studies. Also using computational techniques allows one to obtain all the required data for the Catalytic Converter, some of which could not be measured. In the present work, Geometric modeling ceramic monolith substrate with square shaped channel type of Catalytic converter and coated platinum and palladium using fluent software. In this software we are using crate inlet-outlet flanges and housing of the catalytic converter. After design of modeling us done different parameters in Fluent Pre-process like Analysis Type, Domain Type etc.

This project studies the different porosity of porous medium how to affect to flow pressure field under the conditions of same inlet velocity and ceramic diameter by CFD method. Geometric model of the catalytic converter has been establish and meshed by the pre-processing tool of FLUENT. The flow pressure simulation filled contours and curve of center line static pressure distribution of the ceramic porous material show that in the case of other conditions remain unchanged, the less the porosity of the ceramic porous material, the higher the inlet pressure and the more the pressure loss of the porous material. The more Porosity of ceramic is beneficial to exhaust catalytic converter.

Key words: Catalytic Converter, Ceramic material, CFX, FLUENT, Porous.

I.INTRODUCTION

Porous material made with ceramic can be used into two way catalytic converter .The gas speed distribution in the converter is an important factor in the catalytic ability and the effect of catalytic materials. The paper studies on the variation of the gas flow pressure the converter by the computational fluid dynamics methods. There are many CFD commercial software such as PHOENICS, CFX, STAR-CD, FIDIP and FLUENT etc. FLUENT software has a very wide range of applications flexible characteristics of the grid, the strong capabilities of numerical solution comprehensive functionality. This article will study the fluid dynamics of the catalytic converters using the FLUENT software.

Air pollution and global warming is a major issue nowadays. For this reason, emission limits are introduced around the world and continually being made stricter every year. The enforcement of this regulation has led to the compulsory utilization of catalytic converter as an emission treatment to the exhaust gas of vehicles.

1.1. HISTORY

In 1973, General Motors faced new air pollution regulations and needed a way to make its cars conform to the stricter standards. Robert C. Stempel, who at the time was a special assistant to the GM president, was assigned to oversee development of a technology capable of addressing the problem. Under Stempel's guidance, GM built on existing research to produce the first catalytic converter for use in an automobile.

Catalytic converters were first installed in vehicles made in 1975 in response to EPA regulations passed two years earlier tightening auto emissions and requiring a gradual decrease in the lead content of all gasoline.

Since the introduction of stringent emission regulations in the US in the 1970s, car manufacturers have modified their exhaust systems to incorporate catalytic converters for the removal of NOx, CO and hydro carbons. All new cars registered throughout the European Union from 1st January 1993 have to be fitted with catalytic converters. Platinum, palladium and rhodium are the main active components.

A potential problem appears with the release of platinum group metals (PGMs) from the converters into the environment. There is now convincing evidence for the release of platinum group metals (PGMs) into the environment, possibly by abrasion of the auto catalyst. As a result, PGMs are found to have increased in the environment. In recent study, we found that PGMs have increased in road dust since 1984 and particularly 1991.

II.PROBLEM DESCRIPTION

Catalytic converters are used on most vehicles on the road today. They reduce harmful emissions from internal combustion engines (such as oxides of nitrogen, hydrocarbons, and carbon monoxide) that are theresult of incomplete combustion. Most new catalytic converters are the ceramic monolith substrate with square channels type and are usually coated with platinum, rhodium, or palladium.
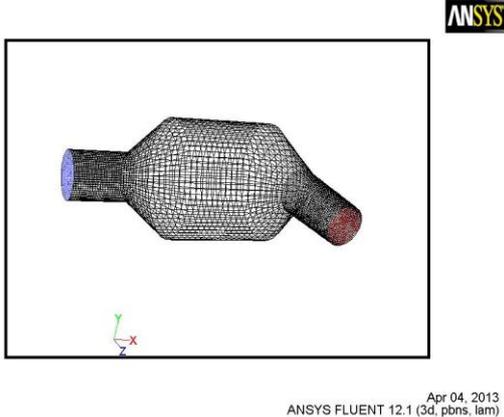

Figure: 2.1. Mesh geometry of Catalytic Converter
In this project Set up a porous zone for the substrate with appropriate resistances. Calculate a solution for gas flow through the catalytic converter using the pressure- based solver. Plot pressure and velocity distribution on specified planes of the geometry. Determine the pressure drop through the substrate and the degree of non-uniformity of flow through cross sections of the geometry using X-Y plots and numerical reports

III.PROBLEM FORMULATION

The catalytic converter modeled here is shown in Figure. The nitrogen gas flows in through the inlet with a uniform velocity of 22.6 m/s, passes through a ceramic monolith substrate with square shaped channels, and then exits through the outlet.
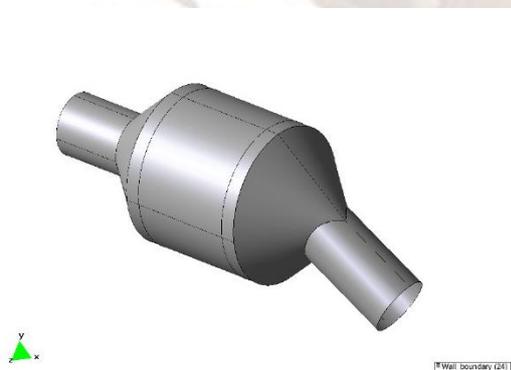

Figure:3: Geometry of Catalytic Converter

While the flow in the inlet and outlet sections is turbulent, the flow through the substrate is laminar and is characterized by inertial and viscous loss coefficients in the flow (X) direction. The substrate is impermeable in other directions, which is modeled using loss coefficients whose values are three orders of magnitude higher than in the X direction.

3.1.PARAMETERS:

- user mode: General Model
- Analysis Type: Steady State
- Domain Type: Multiple Domain
- Fluid Type: Nitrogen Gas
- Turbulence Model : K-Epsilon
- Heat Transfer: Thermal Energy
- Boundary Conditions: Inlet (Subsonic), outlet (Subsonic),Wall :No slip
- Domain Interface: Fluid-Porous

IV.MODELLING

Modeling of flows through a porous medium requires a modified formulation of the Navier-Stokes equations, which reduces to their classical form and includes additional resistance terms induced by the porous region.
The incompressible Navier-Stokes equations in a given domain Ω and time interval $(0,t)$ can be written as

$$\rho\left(\frac{\partial u}{\partial t} + (u.\nabla)u\right) - \mu\nabla^2 u + \nabla p = f on \Omega X(0,t)$$
$$\nabla \cdot u = 0 \text{ on } \Omega x(0,t)$$

where u = u(x,t) denotes the velocity vector, p = p(x,t) the pressure field, ρ the constant density, μ the dynamic viscosity coefficient and f represents the external body forces acting on the fluid (i.e. gravity).

In the case of solids, small velocities can be considered and $(u \cdot \nabla)u$ term is neglected. Therefore, assuming an incompressible flow (constant density) in a certain domain Ω and considering the mass conservation equation, also called continuity equation, the Navier-Stokes equation can be written as follows:

$$\rho\left(\frac{\partial u}{\partial t}\right) - \mu\nabla^2 u + \nabla p = f on \Omega X(0,t)$$

$$\nabla \cdot u = 0 \text{ on } \Omega x(0,t)$$

The general form of the Navier-Stokes equation is valid for the flow inside pores of the porous medium but its solution cannot be generalized to describe the flow in porous region. Therefore, the general form of Navier-Stokes equation must be modified to describe the flow through porous media. To this aim, Darcy's law is used to describe the linear relation between the velocity u and gradient of pressure p in the porous medium. It defines the permeability resistance of the flow in a porous media:

$$\nabla p = - \mu Du \text{ in } \Omega p x(0,t)$$

Where Ω_p is the porous domain, D the Darcy's law resistance matrix and u the velocity vector. In the case of considering an homogeneous porous media, D is a diagonal matrix with coefficients $1/\alpha$, where α is the permeability coefficient.
The Reynolds number is defined as:

$$Re = \frac{\rho UL}{\mu}$$

Where U and L a characteristic velocity and a characteristic length scale, respectively. In order to characterize the inertial effects, it is possible to define the Reynolds number associated to the pores:

$$Rep = \frac{\rho U \delta}{\mu}$$

Where δ is the characteristic pore size. Whereas Darcy law is reliable for values of $Re_p < 1$, otherwise it is necessary to consider a more general model which accounts also for the inertial effects, such as:

$$\nabla p = - (\mu Du + \tfrac{1}{2}\rho Cu|u|) \text{ in } \Omega p x(0,t)$$

Where C the inertial resistance matrix.

Considering a modified Navier-Stokes equation in the whole domain including the two source terms associated to the resistance induced by the porous medium (linear Darcy and inertial loss term), the momentum equations become:

$$\rho \frac{\partial u}{\partial t} - \mu \nabla^2 u + \nabla p - (\mu Du + \tfrac{1}{2}\rho Cu|u|) = 0 \text{ in } \square \, x(0t)$$

In the case of considering an homogeneous porous media, D is a diagonal matrix with coefficients $1/\alpha$, where α is the permeability coefficient and C is also a diagonal matrix. Therefore, a modified Darcy's resistance matrix should be used in Tdyn, as follows

$$\rho \frac{\partial u}{\partial t} - \mu \nabla^2 u + \nabla p = \square \, D*u \text{ in } \square \, x(0t)$$

$$D* = D + \tfrac{1}{2}\mu \rho u|u|$$

where I is the identity matrix. It should be noted that in laminar flows through porous media, the pressure p is proportional to velocity u and C can be considered zero ($D^* = D$). Therefore, the Navier-Stokes momentum equations can be rewritten as:

$$\rho \frac{\partial u}{\partial t} - \mu \nabla^2 u + \nabla p = - \mu Du \text{ in } \Omega x(0,t)$$

These momentum equations are resolved by Tdyn in the case of solids, where $(u \cdot \nabla)u$ term vanishes due to small velocities. If $(u \cdot \nabla)u = 0$ can't be neglected in the modelization (i.e. high velocities),then Tdyn should resolve the following

momentum equations in a fluid instead of in a solid:

$$\rho \frac{\partial u}{\partial t} + (u \cdot \nabla)u) - \mu \nabla^2 u + \nabla p = - \mu Du \text{ in } \Omega x(0,t)$$

In order to add the Darcy's resistance matrix D^* an appropriate function should be inserted in Tdyn. See the figure below and "Function syntax" in the Help manual of Tdyn for more details about defining functions

4.1.Geometry And Boundary Conditions:

The following Conditions concerns the analysis of a gas flowing through a catalytic converter. The main objective is to determine the pressure gradient and the velocity distribution through the porous media that fills the catalytic element. This model is intended to exemplify the use of Tdyn capabilities to solve problems involving flow through porous media.
The boundary conditions are applied as shown in the figures below. First, a Wall/Body condition with a Y-Plus wall boundary type is applied to the external surface of the catalytic converter.
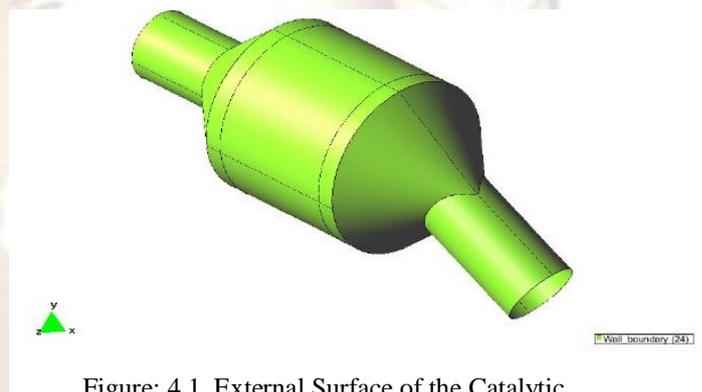

Figure: 4.1. External Surface of the Catalytic Converter

A Fix Velocity condition is further applied to the inlet surface of the model (in blue in the figure below) so that the velocity vector is fixed there to the value v = (22.6, 0.0, 0.0) m/s. Finally, a Pressure Field condition is used to fix the the dynamic pressure to zero at the outlet surface of the control volume (in red in the figure below).
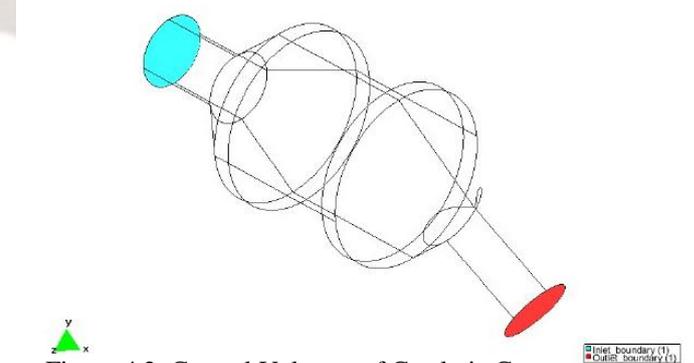

Figure:4.2. Control Volumes of Catalytic Converter

4.2. Materials:

Two different materials are used in order to simulate the gas flowing through the catalyst converter. Fluid flow properties, density and viscosity, are the same in both materials and correspond to those of nitrogen gas. The two materials only differ on the values of the Darcy's law matrix. While the first one has a null matrix, the second one has assigned a Darcy matrix incorporating the resistance and inertial effects of the porous media. Hence, the first material is applied to the inlet and outlet channel regions of thecatalyst converter (in blue in the figure below), while the second one is applied to the intermediate volume corresponding to the porous media (in yellow in the figure below).
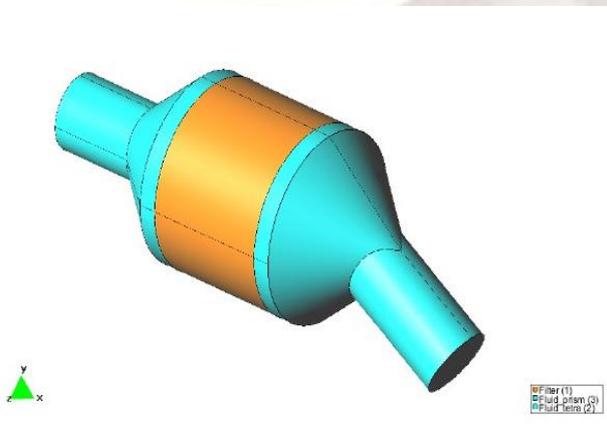

Figure: 4.3.Materials of the catalytic Converter

The Darcy's law matrix used to model the porous media is taken to be diagonal but anisotropic. The corresponding values of the viscous (D) and inertial (C) resistance terms are those in the table below Note that the components of the Darcy's matrix are given with respect to the global axis system (X, Y, Z) Note that the components of the Darcy's matrix are given with respect to the global axis system (X, Y, Z) so that the geometry must be conveniently oriented.

V.RESULTS AND DISCUSSIONS

5.1. Graphical Results:
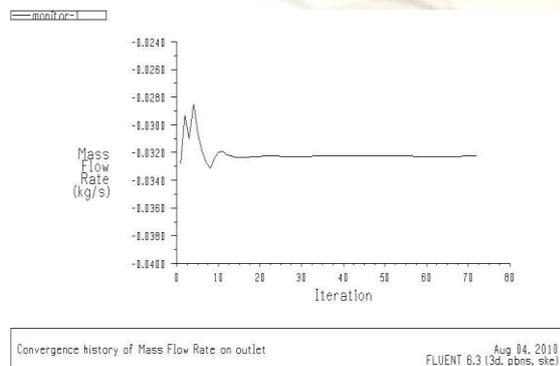
Graph: 5.1. Surface Monitor Plot of Mass Flow Rate with Number of Iterations

After running fluent software the values of mass flow rate changes at different iteration we can observer in the Garaph .The Graph changes at different direction with respect to Mass Flow rates.After some iterations garph comes constant values (minor difference).
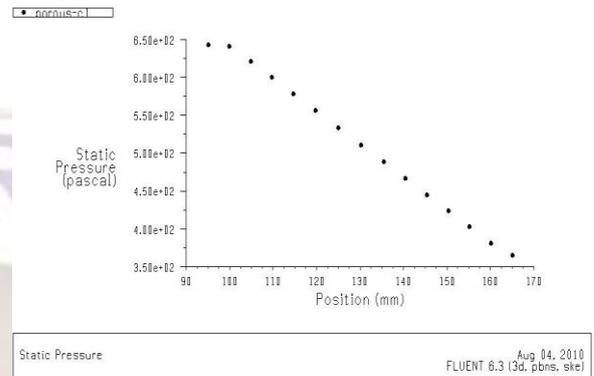

Figure: 5.2. Plot of the Static Pressure on the porous-cl Line Surface

The above Graph shown the Static Pressure on the porous-cl Line Surface the pressure drop across the porous substrate can be seen to be roughly 300 Pa.

5.2. SIMULATION RESULTS:

The Velocityflow of gases rapidly in the middle section, where the fluid velocity changes as it passes through the porous substrate. The pressure drop can be high, due to the inertial and viscous resistance of the porous media.

The X-velocity component distribution of the fluid flow. In this picture, it becomes evident how the fluid decelerates rapidly when entering to the porous region. It can also be observed how the fluid recirculates before entering the central region of the catalyst (negative values of X-velocity component in dark blue) due to the resistance exherted by the porous media
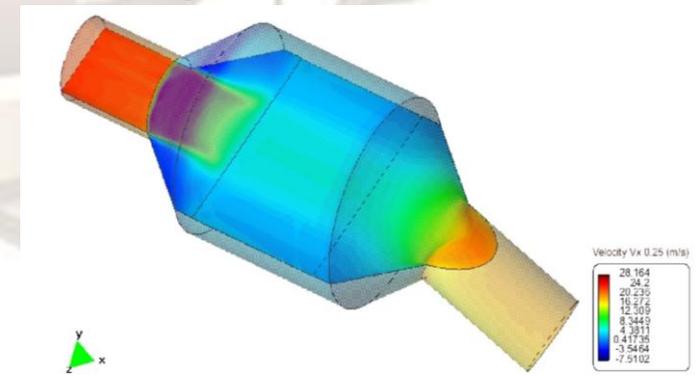

Figure: 5.2.1. Velocity Vectors on the y=0 Plane

The flow pattern shows that the flow enters the catalytic converter as a jet, with recirculation on either side of the jet. As it passes through the porous substrate, it decelerates and straightens out, and exhibits a more uniform velocity distribution.

This allows the metal catalyst present in the substrate to be more effective.
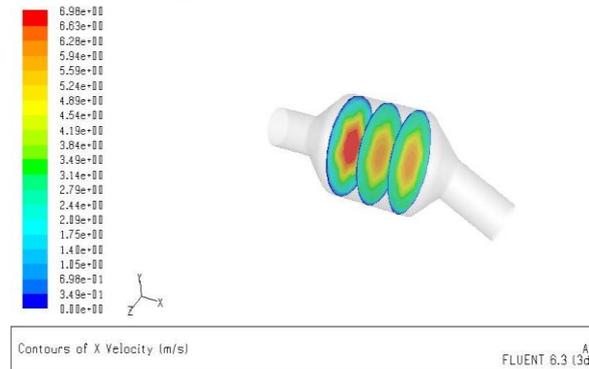

Figure:5.2.2. Contours of the X Velocity on the x=95, x=130, and x=165 Surfaces

The velocity profile becomes more uniform as the fluid passes through the porous media. The velocity is very high at the center (the area in red) just before the nitrogen enters the substrate and then decreases as it passes through and exits the substrate. The area in green, which corresponds to a moderate velocity, increases in extent.

VI.CONCLUSION

In this paper Set up a porous zone for the substrate with appropriate resistances. In this paper we concluded the mass flow rate can be reduces at different iterations and also static pressure can be changes inlet of the catalytic converter to outlet of the catalytic converter. We concluded the pressure drop across the porous media and non-uniformity of the velocity distribution as the fluid goes through the porous media. Calculate a solution for gas flow through the catalytic converter using the pressure-based solver .Plot pressure and velocity distribution on specified planes of the geometry.

The model approach gives better agreement in pressure drop. This present method also possesses lower computational cost based on the less computing time and Different number of Velocity's and Pressures are simulation. A ceramic monolith substrate with square shaped channels model having the parametric studies of wall thicknesses, cell densities, hydraulic diameter, and specific surface areas.A porous media having the different parametric studies of wall thicknesses, cell densities, hydraulic diameter, and specific surface areas. The results also show that a Square - shaped zone gives a good mechanical performance (lower pressure drop)

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