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A Study on the Fluid Dynamic of Catalytic Converter in Exhaust Pipe

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Abstract

The need to maximize the exhaust pipe inside surface and to minimize exhaust resistance And Find the best point between the exhaust and the duration of contact between the two surfaces. Exhaust gas mass flow On the whole cross section of catalytic converters more uniform distribution will contribute to its usability. Based on the flow rate of fluid traces given color, Exhaust fluid resistance in the porous catalyst can be estimated, from the efficiency of the catalytic converter that is very important

Key words : Exhaust Pipe, Catalytic converter, Porous Media

1. Introduction

Transportation is responsible for a large part of global emissions. This problematic has led to governments to establish very stringent conditions for the maximum emissions levels [1]. Post-treatment systems need to be further developed in order to meet with these emissions requirements. A large part of the current studies is devoted to find efficient catalysts to improve the reaction efficiency, but one can also optimize the performance of these equipments by acting on the flow distribution inside the catalytic converter.

The emission caused by vehicles is an import issue in these times. In order to reduce the exhaust gas pollution governments are prescribing technical requirements for the production of cars, especially the exhaust system of the car [2]. One of the first laws dealing with exhaust gases was passed by the government of California (USA) in the early 1960s. The European Community passed first laws in order to reduce exhaust gas pollution in 1970.

Since than many laws in many countries followed. The current restriction in the European Union are the Euro 5 and Euro 6 standards for reduction of pollutant emissions from light vehicles.

Over the years, automakers have made many refinements to car engines and fuel systems to keep up with these laws [3]. One of these changes came about in 1975 with an interesting device called a catalytic converter. The job of the catalytic converter is to convert harmful pollutants into less harmful emissions before they ever leave the car's-exhaust system.

When designing an automobile catalytic converter, the engineer faces a compromise between minimizing the catalyst's resistance to the exhaust flow while maximizing the catalyst's internal surface area and duration that the exhaust gases are in contact with that surface area. Therefore, a more uniform distribution of the exhaust mass flow rate over the catalyst's cross sections favors its serviceability [4].

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To consider the influence of the catalysts' porous medium permeability type on the exhaust mass flow rate distribution over the catalysts' cross sections. Observe the behavior of the exhaust gas flow trajectories distributed uniformly over the model's inlet and passing through the porous catalysts.

Since 1981, "three-way" (oxidation-reduction) catalytic converters have been used in vehicle emission control systems in the United States and Canada; many other countries have also adopted stringent vehicle emission regulations that in effect require three-way converters on gasoline-powered vehicles. The reduction and oxidation catalysts are typically contained in a common housing, however in some instances they may be housed separately.

Three-way catalytic converters (TWC) have the additional advantage of controlling the emission of nitrogen oxides (NOx), in particular nitrous oxide, a greenhouse gas over three hundred times more potent than carbon dioxide, a precursor to acid rain and currently the most ozone-depleting substance. Technological improvements including three-way catalytic converters have led to motor vehicle nitrous oxide emissions in the US falling to 8.2% of anthropogenic nitrous oxide emissions in 2008, from a high of 17.77% in 1998[5].

2. Governing equations

Regarding this reactor physics, geometries such as pack beds or parallel tubes could be assumed as porous media. There are several equations to calculate the porosity, tortuosity, permeability and other parameters of porous media [6].

The permeability k is the measure of the flow conductance in the matrix. There are several theories about calculating permeability, most of which are calculated by Navier Stokesand Darcy law. One of them is hydraulic radius model by Carmanand Kozeny theory based on a model of flow through solid matrices using the concept of hydraulic radius, which is often called the Carman–Kozeny theory. According this theory, the hydraulic diameter is defined as:

$$d_h = \frac{4 \cdot \varepsilon}{A_0(1 - \varepsilon)} = \frac{4 \cdot V_{void}}{surf \cdot area}$$

where ε is the volume porosity and A0 is the specific surface area of porous media, where

$$A_0 = \frac{surf \cdot area}{volume}$$

Porosity is the effective porosity of the porous medium, defined as the volume fraction of the interconnected pores with respect to the total porous medium volume.

the porous medium resistance as k = △P×S / (m×L) (in units of s^-1), where the right-side parameters are referred to a tested parallelepiped sample of the porous medium, having the S cross-sectional area and the L length in the selected sample direction, in which the mass flow rate through the sample is equal to m under the pressure difference of △P between the sample opposite sides in this direction .

Fig.1 is the catalyst model. In order to simulate conditions in the gas flow in porous media, take the most basic model to test. The unit system is SI, and analysis type is internal, no additional physical capabilities are considered. In order to rule out other external factors, initial conditions chose pressure with 1 atm and temperature at 293.2 K. At the boundary conditions, set the velocity normal to face to 10 m/s and opening the fluid exits the model to an area of static atmospheric pressure.

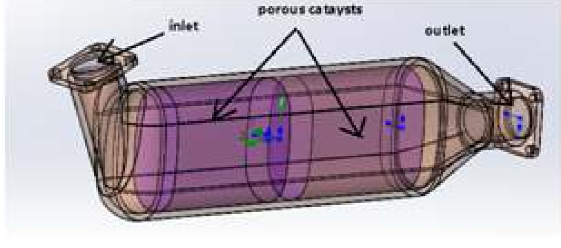

Fig. 1. Catalyst model

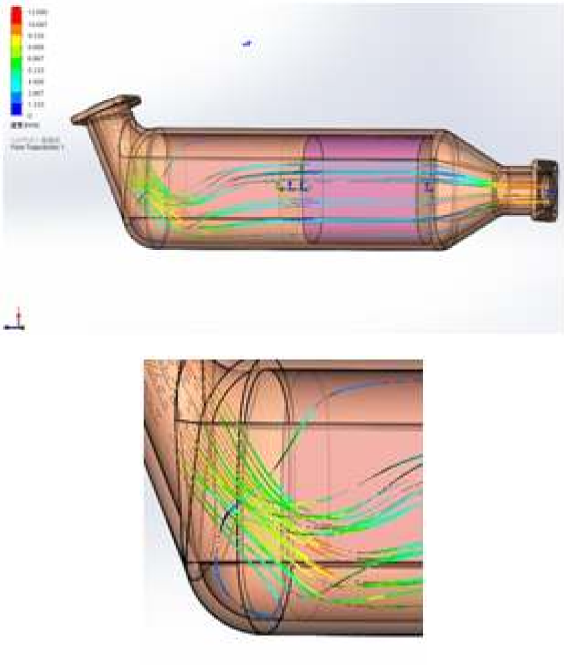

Fig. 2. isotropic porous catalyst

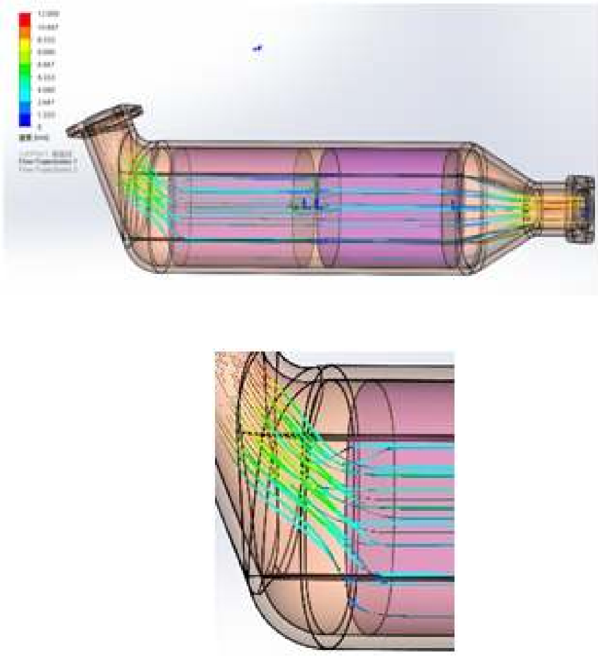

Fig. 3. unidirectional porous catalyst

And defined the porous medium, chose the medium's Porosity to 0.5. Porosity is the effective porosity of the porous medium, defined as the volume fraction of the interconnected pores with respect to the total porous medium volume; here, the porosity is equal to 0.5. The porosity will govern the exhaust flow velocity in the porous medium channels, which, in turn, governs the exhaust gas residence in the porous catalyst and, therefore, the catalyst efficiency.

First, consider Isotropic type penetration, which is the permeability does not change with the direction of the internal medium. Then, consider unidirectional type penetration, infiltration is only in one direction.

3. Simulation and results

In order to observe the distribution of mass non-uniformity in the flow cross section of the catalyst, the inlet will be displayed in the model uniform distribution of the flow trace.

Fig.2 is a flow trajectory of isotropic porous catalyst and Fig.3 is a flow trajectory of unidirectional porous catalyst.

Fig.4 is a velocity contour of isotropic porous catalyst and Fig.5 is a velocity contour of unidirectional porous catalyst.

In order to see the model of the pressure value, define the surface of the target, define inlet velocity as the inner surface of the inlet cover, select Use for Conv as objective convergence control, create SG Inlet Av Total Pressure table. static pressure choose the inner surface of the outlet cover, select Total Pressure of Av, select Use for Conv accepted as a control convergence targets.

You can see at table 1 that the total pressure drop of isotropic porous catalyst is about 120 Pa.

And at table 2 the total pressure drop of unidirectional porous catalyst is about 117 Pa.

4. Conclusions

Trace graph comparing unidirectional and isotropic porous catalyst, we can draw the following conclusions:

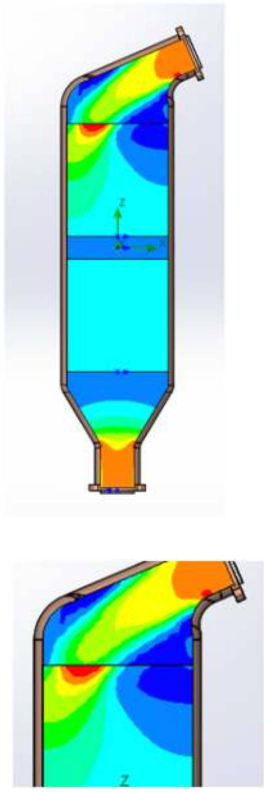

Fig. 4. isotropic porous catalyst

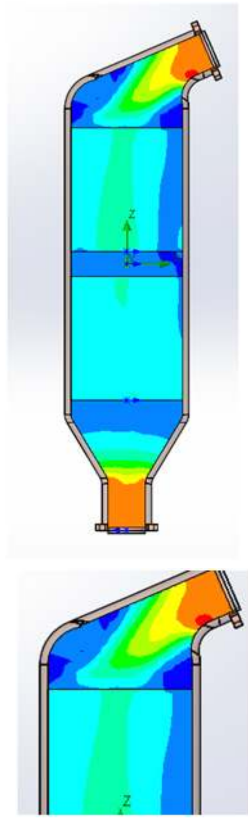

Fig. 5. unidirectional porous catalyst

Table 1. isotropic porous catalyst

Classification	Unit	Value	Averaged value
SG.Inlet Av. Total Pressure	[pa]	101503.9292	101503.7634
SG.Outlet Av Total Pressure	[pa]	101382.4591	101382.4854
Equation Goal 1	[pa]	121.4701302	121.2779321

Table 2. unidirectional porous catalyst

Classification	Unit	Value	Averaged value
SG.Inlet Av. Total Pressure	[pa]	101500.6415	101502.596
SG.Outlet Av Total Pressure	[pa]	101382.8716	101383.1272
Equation Goal 1	[pa]	117.7698971	118.4687464

Since the installation of the inlet tube and bassoon connected asymmetric catalytic converters, causing the fluid at the entrance of non-uniformity. Because of this non-uniformity of the fluid inlet, the front portion of the catalyst flow is not uniform. It is seen that the catalyst type (isotropic or unidirectional) affects both the incoming flow non-uniformity (slightly) and, more substantially, the flow within the catalysts (especially the first catalyst body).

For isotropic example, the front of the catalytic converter into the air closer to the wall than the unidirectional catalytic converter. Thus, the front entrance of the catalyst (about 1/3) than the isotropic flow should be non-uniform flow is more worthy of attention.

Nevertheless, due to the isotropic permeability, the main gas stream expands in the isotropic catalyst and occupies a larger volume in the next part of the body than in the unidirectional catalyst, which, due to its unidirectional permeability, prevents the stream from expanding. So, the flow in the last two-thirds of the first catalyst body is less non-uniform in the isotropic catalyst. Since the distance between the front and rear tube mounted in the two porous media is quite small, although the way of a tube can be seen to determine the direction of flow, in such a short distance from the gas stream without time becomes more uniform.

Therefore, the front portion of the catalytic body occurs at the outlet of the non-uniformity of fluid into the rear of the catalytic body. After that, we can see that the fluid does not change the non-uniformity in the rear of the catalytic body.

Analysis of the flow rate inside the catalytic body. Speed based on the definition of the color scale can be easily identified with a color chart trace values. Seen from the perspective of the whole of the catalyst, the flow rate of the isotropic and unidirectional almost equal to the catalytic body. Therefore, the catalyst residence time in the gas stream, the isotropic and unidirectional catalytic body and no difference.

We can conclude that the isotropic catalyst is more effective than the unidirectional catalyst (of the same resistance to uniform flows), since the flow in it, as a whole, is more uniform. In spite of specifying the same resistance of the catalysts to flow, the overall pressure loss is lower by about 2% in the case of employing the unidirectional catalyst. This difference is due to the different flow non-uniformity both in the catalyst bodies and out of them.

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