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Implementation of Al-Distribution on the Performance of a Catalytic Converter

[1]M. Achudhan, [2]Dr. Premjaikumar
[1]Research scholar [2]Professor
Barath University, Tamilnadu, India

Abstract-

The converter and the exhaust manifold constitute significant heat sources that increase the underhood air temperature and the direct radiation to surrounding components with limited heat tolerance. These so called warm up systems were already efficient enough to avoid the usage of more complex external supplemental heat systems. In order to define the most efficient insulation method, the heat transfer modes need to be analyzed. In the past, catalytic converters have been insulated internally by the mat surrounding the ceramic substrate but also by adding an external heat shield. The insulation mat is a mixture of ceramic fiber and vermiculite, which expands at high temperature and mechanically holds the catalyst to compensate for the difference in expansion between the ceramic substrate and the metallic can. Later, the internal insulation alone was found to be sufficient. This allowed removal of the heat shield, which was often a source of audible noise.

Keywords: Catalytic Converter, Inlet Diffuser, Pollutant, Conversion Efficiency, Flow Distribution

I. INTRODUCTION

The introduction of the catalytic converter into the engine compartment has led to severe requirements for thermal insulation. The converter and the exhaust manifold constitute significant heat sources that increase the underhood air temperature and the direct radiation to surrounding components with limited heat tolerance. The first step in improving emission performance was to move a fraction of the total required catalyst volume into the engine compartment to take better advantage of the hot exhaust gases for early catalyst light off. These so called warm up systems were already efficient enough to avoid the usage of more complex external supplemental heat systems. In order to define the most efficient insulation method, the heat transfer modes need to be analyzed. In the past, catalytic converters have been insulated internally by the mat surrounding the ceramic substrate but also by adding an external heat shield. The insulation mat is a mixture of ceramic fiber and vermiculite, which expands at high temperature and mechanically holds the catalyst to compensate for the difference in expansion between the ceramic substrate and the metallic can. Later, the internal insulation alone was found to be sufficient. This allowed removal of the heat shield, which was often a source of audible noise.

The catalytic converter was created was to provide a sustainable solution for automobiles. Before the catalytic converter, there was absolutely no filtering of the toxic automotive exhaust. And while engineers today are working to perfect the technology by reducing cold-start emissions, it is important to see how far this technology has come. Cold-start emissions are a very small portion of the total possible emissions an automobile engine has the ability to produce. It is important to note that this paper focuses on the remaining improvement, reduction of the cold-start emissions, to further improve catalytic converter technology. Currently the converter is being changed to eliminate all toxins in automotive exhaust.

II. CATALYTIC CONVERTER DESIGN

Passenger vehicle manufacturers have made tremendous progress in reducing emissions since the introduction of the first automotive catalytic converter in the mid-1970s.

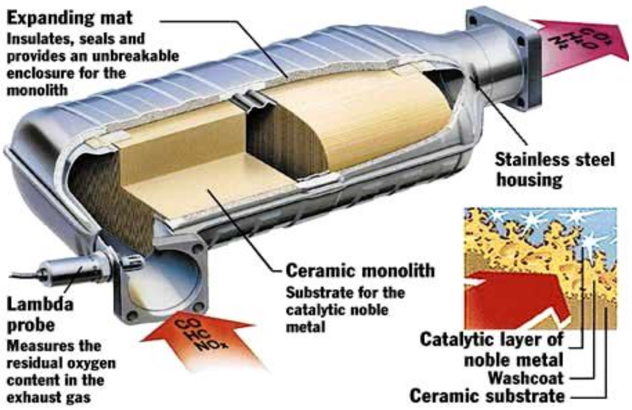


Figure 1.: Structure of Catalytic converter

Early converters, called "two-way" converters, burned a percentage of the unused hydrocarbons (HC) and carbon monoxide (CO) produced by the relatively inefficient, low compression engines of the day. Two-way (oxidizing) converters burn HC and CO molecules with the assistance of a precious metals catalyst. This process "converts" these harmful gasses into water vapor and carbon dioxide (CO2). The two-way catalytic converters are most effective when used with engines that have a lean air/fuel mix because this condition provides ample oxygen to "burn" the pollutants by the structure of Catalytic Converter as shown in figure 1..

Elements of a thermoelectric generator (TEG)

A thermoelectric generator basically consists of three components (Fig. 2):

- **The support structure**, where the thermoelectric modules are located. The internal part of this structure normally is modified in order to absorb the most part of the heat accumulated in the exhaust gases.
- **The thermoelectric modules**, depending on the range of temperatures, silicon germanium, lead telluride, or bismuth telluride modules are used.
- **The heat dissipation system**, which favours the heat transmission through thermoelectric modules.

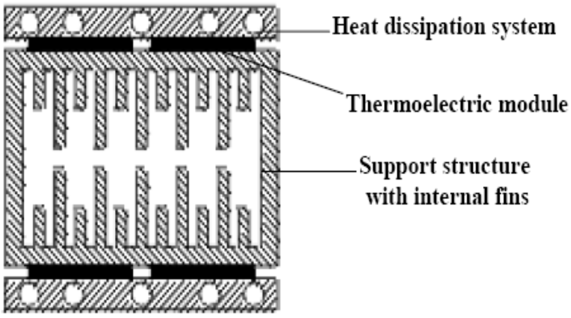


Figure 2: Scheme of a generic thermoelectric generator.

III. SUPPORT STRUCTURE OF THE TEMS

This structure is extremely important in any thermoelectric generator oriented to be used in an automobile due to the following reasons and limitations:

The heat transmission from the exhaust gases to the structure must be done normally in a short length. Usually it is necessary to introduce internal fin heat sinks, or other structures which increase the contact area between the gases and the support structure and raise the turbulence augmenting the average heat convection coefficient. However, the fin heat sinks or bundles are real obstacles in the way of the exhaust gases, generating a pressure drop. This can affect the engine efficiency, even causing a new design of the camshaft.

The available space to mount a thermoelectric generator in an automobile is normally reduced because of the tendency to put more equipment in less space. There are mainly three possible locations for the TEG:

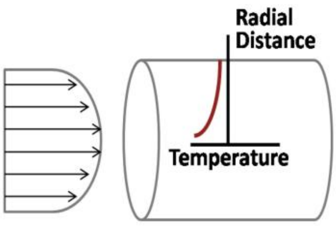
- Just behind the exhaust manifold.
- Between the manifold and the catalyst converter.

Numerical Modeling Aspects

The optimization of three-way catalytic converter relies on catalytic material selection and on chemical and mechanical engineering for its implementation [Jeong and Kim, 2000]. Unfortunately, the experimental optimization based on engine bench and vehicle test is extremely expensive and time-consuming. Hence, reliable and efficient numerical simulations could reduce the number of experiments and would allow interpreting more detail effect of some parameters otherwise neglected. It would certainly help to optimize the converter geometry (such as volume, cross sectional area, monolithic material, channel size, wash coat characteristics, etc.) and determine the effect of various operating conditions and the optimal lay-out of catalyst with considering distance from engine, the effect of warmup catalyst and electrical heating.

Radial Thermal Behavior

The catalytic converter also has a temperature distribution in the radial direction. Figure 3 typically illustrates the flow distribution of gas entering the catalytic converter, showing that the flow rate is greatest at the center. Since the higher flow rate provides greater enthalpy input and correspondingly higher heat transfer, this flow profile results in higher temperatures at the center of the catalytic converter. A typical illustration of the temperature gradient is shown on the right side of Figure 3.



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.

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 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:

$\nabla p = - \mu D u$ in $\Omega p x(0,t)$

V. CONCLUSION

The introduction of the catalytic converter into the engine compartment needs to be accompanied with special care to limit the thermal load on the surrounding components. Only a system approach and a combination of measures could be successful and will insure a good thermal management of the underhood. The converter skin temperature can be reduced using more insulation material. Even though its external surface is increased, which will tend to increase the radiation and convection heat transfer, the net benefit on the component's temperature is still positive. Using insulation material with lower thermal conductivity has a limited value as compared to an increase of the thickness of the regular insulation mat because their cost is very high. This can only be of an interest if severe packaging problems cannot allow just an increase of the thickness of the regular insulation material. Heat radiation plays an important role during the soak condition used as the most critical driving condition to validate the thermal management measures. Therefore the emissivities of the surfaces involved will play an important role. Reducing these emissivities will reduce the temperature of the components adjacent to the manifold converter and the component's emissivity is the most influential one.

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