

Particulate Filter Design for High Performance Diesel Engine Application

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ABSTRACT

A catalyzed ceramic filter has been used on diesel engines for diesel particulate matter emission control. A key design criteria for a diesel particulate filter is to maximize DPF performance, i.e. low back pressure and compact size as well as near continuous regeneration operation. Based upon the modeling and deep understanding of material properties, a DPF system design has been successfully applied on a high performance diesel engine exhaust system, such as the Audi R10 TDI, the first diesel racing car that won the most prestigious endurance race in the world: the 24 hours of Le Mans in both 2006 and 2007. The design concept can be used for other materials and applications

INTRODUCTION

The diesel engine, with its high efficiency and lean burn combustion process, has demonstrated advantages of high torque output, fuel economy and fast acceleration performance. Gracing today's street, about 50% of the passenger cars in Europe are powered by a diesel engine. Audi Sport, spearheading technology innovation, has challenged the world by introducing the revolutionary race car Audi R10 TDI, powered by a 5.5 liter TDI V12 diesel engine in 2005. The idea is not only to have superior power efficiency but also very low emissions. To help achieve this goal, an aftertreatment system featuring a catalyzed diesel particulate filter system has been developed for Audi R10 TDI exhaust system.

The design of Audi R10 TDI exhaust aftertreatment system has been extremely challenging. Unlike road vehicle cars, there are very demanding requirements: packaging space and system weight must be kept to a minimum; the exhaust system back pressure must be kept very low with a minimum impact on engine power. Self soot cleaning up of the collected soot is a must, as

well as the entire system must survive the tough race conditions without the necessity to replace the filter during a race. In addition, racing puts high pressure on fast development, delivery and teamwork To meet all above requirements, Audi and Dow worked together and using a scientific approach to successfully design the emission system for the Audi R10 TDI race car with its diesel V12 TDI that won both the 12 hours Sebring race, the 24 hours Le Mans races and ALMS LMP1 championship in 2006 and 2007 [1, 2, 3, 4].

THE V12 TDI FOR THE 24TH OF LE MANS

Since 1940, for more than 50 years, there were several attempts to win the hardest endurance race of the world with diesel engine. Audi who has pioneered the introduction of the first direct injection passenger engine TDI has developed an innovative powerplant for its purpose. The detailed design of V12 TDI engine and R10 can be found [5].

In current internal combustion engine development, satisfaction of the emission legislation is the key target. It is mandatory to compliance exhaust emission regulation for all commercial road vehicles, but less so for race cars. However, Audi has used exhaust gas control system in motorsport since 1990. It goes without saying that this fact also contributed to the decision, derived from Audi brand's innovative claim, to equip the R10 TDI with fully functioning particulate filter technology. The emission system must meet the following requirements:

- Low back pressure level
- Low weight
- Compact
- High filtration efficiency
- Fast regeneration without using additives
- Excellent durability without maintenance

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With these requirements in mind, an emission system development approach in combining engine duty cycles has been conducted in the process of material and catalyst selection.

Figure 1 and 2 is overview of V12 TDI engine and its emission system on the R10 TDI.



Figure 1. V12 TDI® engine equipped on Audi R10 TDI

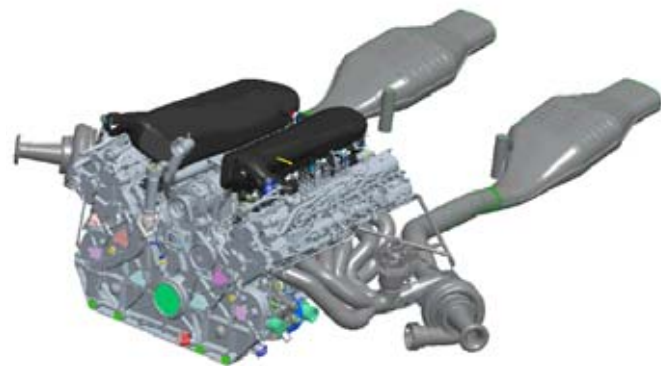


Figure 2. Emission system configuration on Audi R10 TDI®

DIESEL PARTICULATE FILTERS OF ACM

It is well known that a wall flow type of filter can effectively reduce smoke and particulate matter. However, it is challenge that such a DPF system must meet the restriction of low back pressure across the DPF in combining low weight and compact space. Another criterion of this emission system design in this application is that the accumulated soot must be self regenerated during the operation.

Ideally, there should be no considerable back pressure fluctuation whether the filter is in a clean condition or at soot loading cycle, which means that such a filter surface can handle certain amount of soot loading without increasing pressure across the filter wall.

Previous development work has discovered that a needle or fiber type of surface microstructure on the filter wall could meet this requirement [6].

Diesel particulate filter used in this design is made from a new advanced mullite ceramic material (ACM) by converting a honeycomb extrusion of a mullite precursor to a unique surface structure through a catalytic gas-solid synthesis reaction. The DPF open microstructure that results from the interlocked network of elongated ceramic grains that are grown in the synthesis process. This microstructure produces a combination of good strength at high porosity and high material permeability for a given pore size distribution. The scanning electron micrograph (SEM) of an ACM honeycomb is shown in Figure 3.

The ACM grains intergrow during their synthesis and are fused together. The result is a strong ceramic network with open connected pores. Through control of the reaction temperature and pressure of the catalytic gas, the nucleation and growth of the ACM can be controllably varied, resulting in control of the size of the crystal grains. In turn, the size of the pores within an ACM DPF is determined by the size of the crystal grains. Thus the pore size of an ACM DPF can be tailored to the specific needs of application.

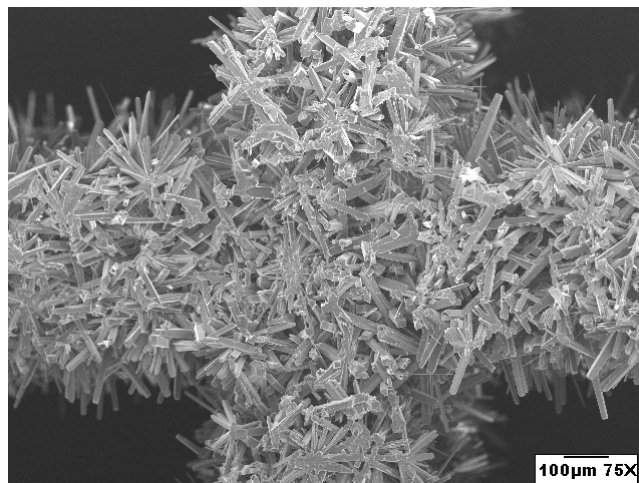


Figure 3. Scanning electron micrograph of a cross section fracture surface of an ACM honeycomb.

To understand the micro structure impact on the filter performance, a reconstruction technique method is used to obtain the porosity distribution across the filter wall and then a Lattice Boltzmann model is used to track the projected location of the soot trapping profile within the filter wall and filtration surface. The detailed Lattice Boltzmann model and its analysis can be found in [6]. Figure 4 and 5 are the summary of porosity distribution of the filter wall as well as its soot loading and distribution.