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Overview of Diesel particulate filter systems sizing approaches

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HIGHLIGHTS

- Application of particulate filters to large Diesel engines is moving at slow pace.
- Rational sizing of the filters becomes essential in these applications.
- An overview of Diesel particulate filter systems sizing approaches is presented.
- An improved filter sizing methodology is necessary for large engines.
- Filter system design improvements may significantly reduce filter size.

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ABSTRACT

Although application of Diesel particulate filters in modern automotive Diesel engines is commonplace, their introduction to large Diesels as locomotive or marine engines is moving at a slower pace. One important reason for this delay is the large volume of filter required which is not easy to accommodate in this type of equipment. Thus, rational sizing of the filters becomes essential in these applications. It is observed that DPF systems for large Diesel engines are usually oversized. Possible reasons are discussed in this paper. With the present status of technology and the concern for compact and cost-optimized exhaust treatment systems a new design methodology is needed. This paper summarizes progress in the specific fields of application and attempts to formulate a filter sizing methodology that would lead to feasible solutions with regard to space requirements and backpressure penalty.

Contents

1. Introduction

Today, application of Diesel particulate filters (DPF) [1] is commonplace in automotive Diesel engines. As particulate emissions standards become increasingly stringent for heavy duty engines and off-road machinery, Diesel particulate filters are also introduced to these engine categories. On the other hand, the evolution of emissions standards and aftertreatment technology resulted in the priority of NOx aftertreatment by means of SCR (selective catalytic reduction) over particulate in heavy duty engines [2–6]. DPF may be applied in the near future to big inland waterway vessels,

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Nomenclature

Δp	pressure drop [Pa]
L	filter length [m]
D	filter diameter [m]
cpsi	cells density [cells/in.^{2}]
w_w	filter wall thickness [m]
α	channel Δp coefficient
$\Re$	ideal gas constant [J/mol·K]
μ	dynamic viscosity of exhaust gas [kg/m·s]
M_g	molecular mass of exhaust gas [kg/kmol]
$k_0$soot	layer permeability [m^2]
k_w	ceramic wall permeability [m^2]
d	channel hydraulic diameter [m]
ρ_s	soot layer density [kg/m^3]
N	number of open channels
A_f	total filtration area [m^2]
V_d	engine displacement [m^3]
w	soot layer thickness [m]

Abbreviations

DPF	Diesel Particulate Filter
SiC	Silicon Carbide
SOF	soluble organic fraction
VOF	volatile organic fraction

or even to ships in specific congested areas with strict emissions regulation. Filter material is Silicon Carbide (SiC), Fig. 1, and cordierite [7] (2MgO-2Al_2O3-5SiO_2, Fig. 2). Filtration efficiency varies in the range 70–95% of total particulate matter. Higher efficiency, exceeding 95% is reported in the literature for the solid particulate fraction, which involves elemental carbon and metal ash. However, much lower efficiencies are reported for the soluble organic fraction (SOF) of the particulate [8–10]. A large variety of filter system design concepts and regeneration techniques (filter cleaning by incineration of the accumulated particulate) exist to date, at various production stages [11–19]. Table 1 presents a classification according to the main regeneration techniques employed. Different regeneration techniques may be combined in a single system (e.g. engine management combined with catalytic fuel additives) [20,21].

The need for a compact size of DPF to be fitted underhood, close to the engine to keep exhaust temperatures high, along with the mass produced of millions of units since 2000, resulted in compact sizes of DPF for passenger car application [17,20].

On the other hand, DPF for large engines are not yet mass produced and in several cases tend to be rather oversized. The reasons could be related to the low degree of commercialization, but also to some unrealistic requirements of conformance tests that are discussed here. As a matter of fact, most of the systems in production stage are oversized, leading to higher installation costs, unnecessary reduction in useful space and other side effects. These problems could be partially eliminated by proper sizing of the filter. The reduction of filter size, in addition to the reduction of the equipment cost, leads to increased filter temperature levels, due to reduced thermal inertia and heat losses of the filter.

Fig. 2. Cordierite filter for an off-highway machine.

Fig. 1 shows a photo of SiC Particulate filter for a 2-L automotive Diesel engine, with a higher magnification photo showing the soot layer deposited inside the channel and an electron microscopy photo showing the texture of the different porous layers. Fig. 2 shows a cordierite filter for an off-road machine (loader). Cordierite is selected in most cases for off-highway machinery. The design

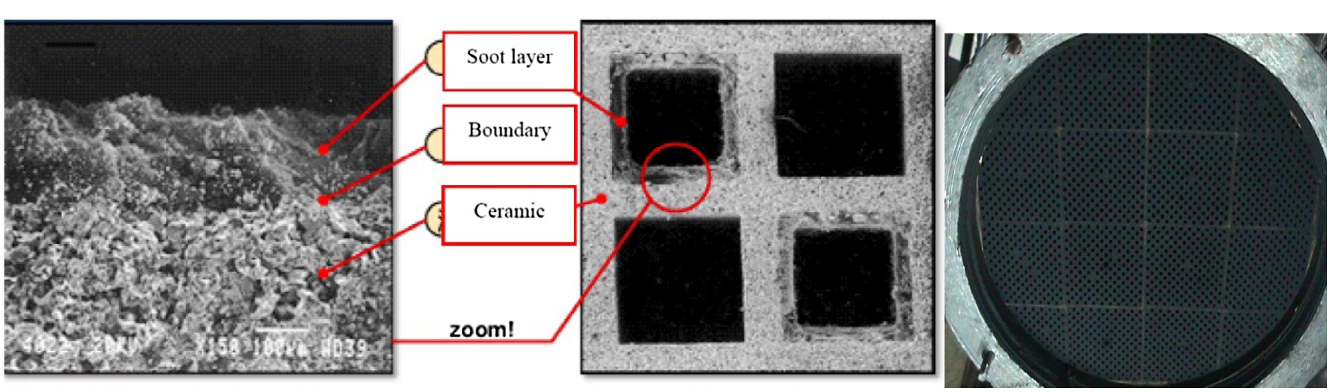

Fig. 1. SiC Particulate filter for a 2-L automotive Diesel engine, with higher magnification photo showing the soot layer deposited inside the channel and an electron microscopy photo showing the texture of the different porous layers [22].