

Catalyst Performance of Monolith-Type Diesel Particulate Filter having Microgear-Design based on Asymmetric Hexagonal Channel Geometry

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ABSTRACT

The diesel particulate filter (DPF) has been used in the automobile industry for around a decade. As a key technology for emissions control the DPF design needs to be increasingly optimized to expand its function to deal with any emission not just particulate matter (PM). NO_x emission regulations need to be met as well as CO₂ targets through minimizing any fuel penalty. Cost is extremely important to deliver an effective after-treatment catalyst. Aluminum titanate and cordierite-based material DPFs are very cost effective in part because their properties allow monolith-manufacturing. Furthermore, geometrical design of the DPF channel structure can contribute to multi-functionalization of the DPF to provide further advantages. Square and asymmetric square-designed channel structures have been utilized on current after-treatment DPF systems. Additionally, asymmetric hexagonal-designed channel technology has recently been shown to provide lower backpressure and higher ash-capacity for longer DPF lifetime usage. A key concept is to increase the geometric surface area on the inlet channels of a DPF for soot and ash-loading. Asymmetric hexagonal channels can have 1.3 times higher surface area. For further functionalization of emissions control technology it can be advantageous to increase the catalyst loading on the DPF, for instance, Selective Catalytic Reduction (SCR) catalyst coatings. Herein, a unique higher surface area design named as microgear-shaped channels has been developed. Catalyst performance and filter substrate testing using hot-gas bench systems have been validated. Thanks to its higher geometric surface area the microgear design can contact soot particles more effectively and soot combustion could be improved. In addition, HC and NO oxidation performance carried out on engine dynamometer testing showed improved activity.

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INTRODUCTION

In a worldwide trend to realize a sustainable society on the global scale, the automobile industry has been highlighted as a key contributor. Diesel engine technology has been offering a potential solution for CO₂ reduction because of its higher fuel efficiency. In order to achieve the challenging European fleet average target of 95 g/km CO₂ in 2020, development of electric and hybrid-electric vehicle technologies have been rapidly progressed. However, diesel-based technology remains one of the major factors in delivering effective emissions control, and continues to develop and respond to future requirements. The Diesel Particulate Filter (DPF) is a key component of the diesel after-treatment system and has contributed to the significant decrease in tailpipe PM emissions from diesel cars for more than 10 years. DPF devices started to be introduced on passenger cars in 2000 [1]. Following the tightening of regulations to lower PM emissions and the subsequent introduction of particle number (PN) limits the DPF has become a standard device in diesel after-treatment systems. Such after-treatment devices can lead to a fuel penalty on vehicles; especially a DPF with a high pressure drop (dp). Designs for lower pressure drop and higher robustness, i.e. higher soot mass limit, can help to minimize the penalty.

Additionally, Euro 6 regulations were introduced in 2014 and focus particularly on NO_x reduction. DeNO_x technologies such as Selective Catalytic Reduction (SCR) catalysts have been developed and introduced to the market [2]. In order to reduce NO_x emissions under low temperature driving cycles there can be a NO_x-PM trade off in the combustion system, and low NO_x calibrations can lead to an increase in PM from the engine. Therefore, a DPF is still required to maintain sufficient robustness for filtration and soot mass limit. Furthermore, due to the introduction of SCR on DPF technology (SCR-F®) lower dp filters are required as this technology is generally used at higher washcoat loadings than those used in CDPF products. Low dp is typically achieved through using higher porosity filters (>50% porosity) in these applications. High porosity filters themselves open up opportunities to increase functionality of DPF coatings. Recent development of six-way coating technology (SWC®) and diesel cold start concept catalysts (dCSC™) [3, 4] have successfully been applied to DPF substrates. Such technologies are aimed at reducing NO_x emissions, particularly under the wider range of conditions that will be assessed as part of Real Driving Emissions (RDE) regulations. Control of coating particle size, zoning and use of advanced materials all allow for optimized functionality when

carefully paired with the substrate properties. To ensure long-term usage of the DPF it is also important to have increased capacity for ash materials that come mainly from the lubricant oil [5]. DPF designs have recently been improved by modifying the substrate/material properties of ceramics, for example, internal porosity control [6]. It has also been proposed that the geometrical channel design of a ceramic filter substrate should be considered in conjunction with other functions such as backpressure response, filtration efficiency, thermal shock resistance, ash capacity, and catalyst performance [7, 8]. Early channel designs were symmetric and square. To increase ash capacity asymmetric types of channel have been developed where the inlet channels are larger than the outlet. More recently novel designs such as asymmetric hexagonal channels [9, 10] could give further advantages. It has been reported that Aluminum Titanate-based DPF with asymmetric hexagonal cell geometry structure is a promising filter design because of its extremely low dp at both the initial stage (without soot), and after soot deposition. This paper highlights the DPF performance with a unique channel design named as 'microgear' structure, which is a designed based on asymmetric hexagonal channel cells. Figure 1 shows a photograph of the inlet channel face with the microgear design of DPF, where the inlet channel wall is intentionally curved within each channel, and the outlet channel wall is flat. This concept is mainly to generate a higher surface area to filter soot particles, but could also be used for higher catalyst loadings such as those required on SCR® applications. As a primary study, the target application focused on a CDPF catalyst coating with a lower washcoat amount. Results show that the microgear design with higher surface area can be more effective in contacting soot particles and can have higher soot combustion efficiency. Furthermore, HC and NO oxidation performance evaluated on engine dynamometer testing showed the microgear design had higher activity. These results demonstrate that the geometrical cell design of a DPF substrate can impact catalytic performance.

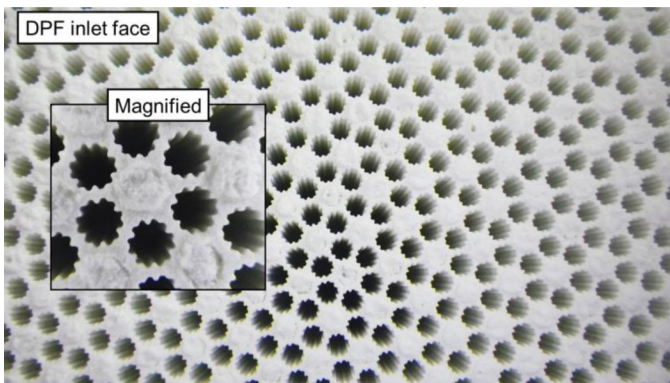


Figure 1. Feature of Microgear design

EXPERIMENTAL

The evaluated filters were wall-flow type comprising aluminum titanate ceramic-based material. The channel design was asymmetric hexagonal structure with an Inlet:Outlet ratio of 2:1 (HEX2). Details

of standard and microgear wall designs are shown in Table 1. A precious metal containing alumina-based washcoat was prepared and applied to the DPF substrates using established coating methods. Coated substrates were dried and calcined at 500°C. The catalyzed Pt/Pd samples were then compared. Backpressure, soot loading and regeneration performance were evaluated using a Combustion Diesel Particulate Generator (DPG) with no DOC configuration. Soot-loaded backpressure was evaluated on 250 kg/h flow rate, and at 250°C temperature by checking differential pressure between front and rear position of DPF. Regeneration testing was conducted using a simulated Drop-to-Idle (DTI) condition for thermal shock resistance of the DPF substrate, and controlled regeneration was performed for soot combustion efficiency performance. As a representative parameters during the DTI condition, temperature and mass flow were precisely controlled. After temperature at inlet DPF face reached to 600°C, the idle mode started. The mass flow before and after idle mode was set up as 105 and 45 kg/h, respectively.

Engine dynamometer testing was carried out on a Euro 6 bench mounted diesel engine with 2.0 litre displacement. The engine was run using low sulfur diesel fuel (<10 ppm S) with no DOC configuration in the setup. Catalyzed DPF samples were inserted into quick-canning assemblies and fitted close coupled to the turbocharger. Light off testing was performed on samples that had been hydrothermally aged at 800°C for 16 hours using 10% water. Light off tests were carried out by steadily increasing the load on the engine to increase the exhaust gas temperature at inlet DPF face. The light off temperature for carbon monoxide (CO) and hydrocarbon (HC) was determined as a T50 value, which represents the catalyst inlet temperature at which 50% conversion of the engine out pollutant is achieved. The NO oxidation performance was expressed as the percentage of NO₂ in NOx post-catalyst measured at 280°C inlet temperature.

RESULTS AND DISCUSSION

1. DPF Specification

Table 1 shows the properties for the microgear shaped and standard hexagonal shaped channels of aluminum titanate-based ceramic DPF. Each parameter of cell geometry design were established based on the numerical analysis and experimental results, taking into consideration backpressure, heat mass related to thermal durability, and ash capacity with asymmetric hexagonal channel geometry as it has been published [9]. Herein, backpressure is considered at two stages, firstly before soot loading and secondly after soot loading. For initial backpressure the degree of cell asymmetry is a major parameter. A higher ratio of inlet:outlet volume can give higher backpressure, but ash capacity is increased allowing for longer usage [11]. Based on the tool design for manufacturing process, cell density and wall thickness was estimated. The specific filtration area of the microgear design was calculated as 1.5 m² L⁻¹, which is 25 % higher than that of a standard type.