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Advanced Materials and Regeneration Control for Cost-Effective and Low-Backpressure DPF Systems in On-road and Off-road Heavy-Duty Applications

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This paper presents a comprehensive and systematic evaluation of design parameters governing the performance of heavy-duty diesel particulate filters (DPFs) for on-road and off-road applications under increasingly stringent global emission regulations. With tightening limits on particulate matter (PM), particle number (PN), and nitrogen oxides (NOx), DPFs have become essential components of modern heavy-duty aftertreatment systems, requiring robust performance across a wide range of exhaust temperatures, flow rates, and regeneration strategies. The study addresses the inherent trade-offs among key DPF performance requirements—namely filtration efficiency, pressure drop, regeneration robustness, soot mass limit (SML), durability, and cost—by treating DPF design as a multi-dimensional optimization problem rather than a simple material comparison. The combined effects of substrate material properties, pore structure, and cell geometry are investigated through Drop-To-Idle (DTI) regeneration testing and filtration efficiency evaluation using engine dynamometer, as well as burner rig pressure drop evaluation. Particular emphasis is placed on regeneration survivability, as active regeneration represents one of the most thermally severe operating scenarios encountered in real vehicle use. Experimental results demonstrate that substrate bulk density is a dominant factor influencing regeneration temperature behavior. Figure 1 shows the inlet temperature and exhaust mass flow profiles during the DTI test, as well as the internal DPF temperature evolution at a soot load of 6 g/L. Low-bulk-density cordierite-based DPFs enable lower regeneration target inlet temperatures compared with silicon carbide (SiC) DPFs while maintaining sufficient thermal durability. This behavior is clearly illustrated in Figure 2, which compares the maximum internal DPF temperatures measured during DTI testing as a function of soot load for coated SiC and cordierite DPF at 6g/L of soot. Despite operating at a reduced inlet temperature, the cordierite DPF exhibits peak temperatures below typical design limits (~900 °C) and achieves an approximately 1 g/L improvement in SML relative to the SiC DPF under worst-case conditions. Beyond material selection, the paper shows that pore structure parameters—specifically porosity and mean pore size—must be optimized concurrently, as they strongly influence filtration efficiency, soot-loaded pressure drop behavior, and regeneration robustness. Furthermore, the paper mentions that advanced cell geometries such as Asymmetric Cell Technology (ACT) provide significant benefits by increasing inlet channel volume and ash storage capacity, thereby mitigating pressure drop increases caused by both soot and ash accumulation and enabling potential DPF downsizing. Importantly, the study emphasizes that simultaneous maximization of all performance attributes is neither practical nor necessary for real applications due to unavoidable trade-offs. Instead, the proposed design framework offers practical and flexible guidance that allows performance priorities to be defined according to specific application requirements, operating conditions, regulatory constraints, and cost targets. By sequentially selecting substrate material, optimizing pore structure, and tailoring cell geometry, the framework supports application-specific optimization of heavy-duty DPF systems capable of meeting both current and future emission regulations.

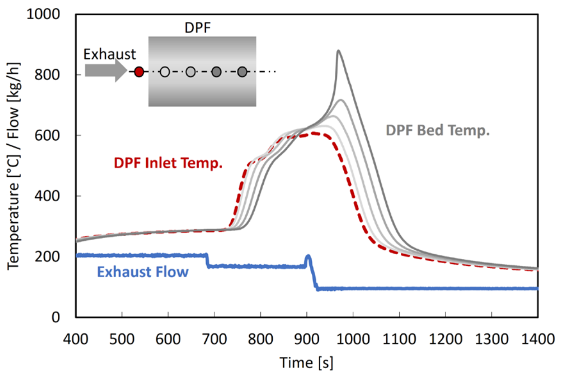

Fig.1 Inlet temperature and exhaust mass flow profiles during DTI testing, and internal DPF temperature evolution at a soot load of 6 g/L.

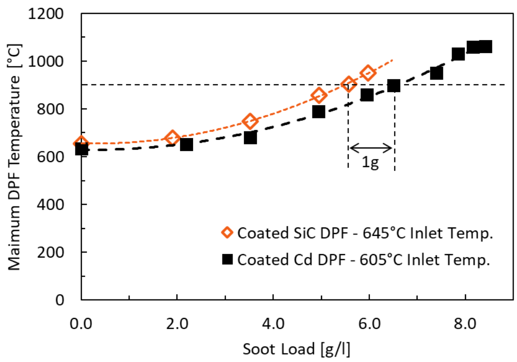

Fig.2 Comparison of Maximum DPF Temperatures During Drop-To-Idle Testing for SiC and Cordierite DPFs.

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