


Editorial

# Present Challenges in Catalytic Emission Control for Internal Combustion Engines

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Mobility in the modern world relies on heterogeneous catalysis. Catalysis is not only the cornerstone of the production of both fossil and sustainable fuels, but also makes possible the removal of harmful components from engine exhaust. Despite the ongoing electrification trend seen especially in the passenger car segment, internal combustion engines will be used in the years to come in hybrid powertrains, heavy-duty and off-road markets, and shipping, etc. Therefore, the catalytic aftertreatment systems will continue to be developed in order to improve conversion efficiency, stability, and to reduce the amount of required precious metals.

Diesel oxidation catalysts (DOC) and three-way catalysts (TWC) are indispensable components of any modern exhaust gas aftertreatment system. They comprise a major fraction of the worldwide demand for precious metals and, consequently, are foremost contributors to the high costs of the aftertreatment system. Improvement in the activity and stability of noble metal sites is required for driving the costs down while fulfilling stringent environmental regulations. Hence, it is equally important to precisely identify active species as well as to understand their structural dynamics and aging phenomena. This includes the complex interactions within bimetallic noble metal particles and with the carrier material. To understand processes occurring during catalyst operation and ageing, and to develop representative rapid testing protocols, Giuliano et al. evaluated the activity, surface properties, morphology and noble metal dispersion of a commercial PdRh TWC after real driving and laboratory simulated ageing [1]. Schütz et al., in turn, systematically demonstrated the influence of hydrothermal aging conditions on the morphology and chemical state of the active metals, and their activity in NO and CO oxidation for model Pt/Al<sub>2</sub>O<sub>3</sub>, Pd/Al<sub>2</sub>O<sub>3</sub> and Pt-Pd/Al<sub>2</sub>O<sub>3</sub> DOCs [2]. Dolcet et al. investigated dynamics and structure-activity correlations of highly dispersed Pt single sites and clusters supported on ceria during CO oxidation [3]. Understanding structural peculiarities and deactivation phenomena enables options to regenerate aged catalysts. Such possibility for *in situ* regeneration of deactivated Rh-based TWCs by applying rapid engine braking was demonstrated by Alikin et al. [4].

Selective catalytic reduction (NH<sub>3</sub>-SCR) is the most widely used approach to remove NO<sub>x</sub> from exhaust of lean-burn engines. Also in this case, deriving structure-activity relationships is currently regarded as a main path to obtain more efficient and durable catalysts at lower costs. In this respect, Shen and Hess propose a new high surface area mesoporous VO<sub>x</sub>/TiO<sub>2</sub>/SBA-15 catalyst containing highly dispersed VO<sub>x</sub> oligomeric species and showing a wider temperature window for operation compared with other catalysts with similar



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composition [5]. Another approach to improve the low-temperature performance of SCR catalysts is to locate them closer to the engine, before DOC and turbocharger, which results in exposure to higher pressure but also to unburnt hydrocarbons. The impact of such conditions on the performance of Cu- and Fe-zeolites was systematically studied by Zengel et al. [6]. Water is a major component in the exhaust gas heavily influencing all reactions in the aftertreatment system. Using temperature programmed desorption studies Villamaina et al. demonstrate and quantify the competition between water and ammonia—the primary NO<sub>x</sub> reducing agent—for adsorption on the active sites in state-of-the-art Cu-CHA zeolites used for NH<sub>3</sub>-SCR [7].

Despite contemporary aftertreatment systems being very efficient in dealing with emissions from combustion engines working in cruise mode, a slip of toxic emissions occurs during the cold start, before the catalysts reach the optimal working temperature. An efficient strategy to meet the stricter emission control regulations is to adsorb the pollutants (hydrocarbons, NO<sub>x</sub>) on the so-called traps, and later desorb and convert them at higher temperature. Modified zeolites have been demonstrated as efficient hydrocarbon traps. The hydrocarbon retention efficiency of different zeolite frameworks (CHA, MFI, BEA) modified with La was investigated in detail using temperature programmed studies and DRIFTS by Jonsson et al. [8]. Different performance trends were identified by Toops et al. [9] for the same zeolite types when modified with Pd and Ag during hydrocarbon and NO<sub>x</sub> storage. In addition to the composition of the trapping material, the composition of the gaseous feed seem to affect the hydrocarbon storage at low temperatures. In this regard, pronounced effects of water and CO on the performance of Pd/BEA hydrocarbon traps were further reported by Zelinsky and Epling [10].

Better catalyst materials can only improve the overall aftertreatment efficiency when developed in tandem with accurate sensing and engine control systems. An additional challenge is currently represented by the extreme conditions encountered during engine operation, such as the cold start and start-stop operation mode (especially important for hybrid vehicles [11]), combined with very cold or very hot environments [12]. To illustrate but also to overcome this difficulty, the performance of modern gasoline particulate filters (GPF) under extreme conditions was evaluated by Giechaskiel et al. [12], and several solutions for improved thermal management were modelled by Souliotis et al. [11].

Summing up, this issue illustrates the broadness of the exhaust gas aftertreatment catalysis field and comprises the most important research topics related to the emissions of internal combustion engines, including CO and HCs oxidation, HCs and NO<sub>x</sub> traps, NO<sub>x</sub> reduction, and particulate matter filtration. On another axis, the whole life-cycle of an emission control catalyst is covered, starting from synthesis, operation to catalyst deactivation and regeneration. Furthermore, we are especially happy to see the equally important experimental and modelling studies reported in this issue. We would like to thank all authors for sharing their valuable work and the reviewers for careful reading and useful recommendations, as well as employees of the Catalysts Editorial Office (Caroline Zhan, Szabolcs Kohr and others) for their support in preparing this Special Issue.

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