216e Plasma-Catalyst System for Diesel Nox Reduction Using Ethanol and E-Diesel: Laboratory Reactor and Engine Dynamometer Tests

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Direct-injection lean-burn engines – both gasoline- and diesel-fueled – have been receiving considerable attention in recent years due to their superior fuel efficiency. One of the major difficulties impeding the commercial application of the lean-burn engines is the removal of NOx emissions from the engine exhaust. Aimed at lean-NOx emission control in both automotive lean-burn engine exhaust and natural-gas power plants, experimental studies on selective catalytic reduction of NO by hydrocarbons (HC/SCR) under highly oxidizing conditions have been extensively conducted in recent years, as evidenced by the voluminous literature on the subject (e.g., review articles [1,2] and references therein). Despite those efforts, the HC/SCR process still suffers from insufficient catalytic activity, narrow temperature window, undesired byproducts, insufficient durability of catalysts, or a combination thereof. Currently, it is generally accepted that the two of the most effective NOx reduction technologies are the lean NOx storage catalyst technology (LNT) and the selective catalytic reduction of NOx by urea (urea/SCR). In the LNT system, NOx is first stored as nitrates in NOx storage catalysts during lean engine operation, and then reduced periodically by rich exhaust made available through fuel-rich engine operation or external fuel injection. This technology requires low-sulfur fuel because the NOx storage catalyst adsorbs SO2 in preference to NOx. Due to the inherent periodic nature of this process, this system also requires a complex engine control strategy. In the urea/SCR technology, urea is used as the source of the reductant NH3. This technology provides excellent NOx reduction performance over a wide temperature range (200-400°C), but requires a urea infrastructure that needs to be developed as well as an additional onboard urea tank that is tamperproof. Also, an on-board diagnostics for urea delivery and NH3 slip is among the major problems that need to be resolved.

Recently, plasma-assisted catalysis for lean-NOx reduction has emerged as a promising alternative to the more mature LNT and the urea/SCR technologies. In this approach, the exhaust gas is subjected to a strong electric field to generate non-thermal gaseous plasma which in turn produces highly reactive species such as ions, radicals and reaction intermediates. The major role of the plasma reactor is to produce NO2 from NO and partially oxidized hydrocarbons (POHC) from hydrocarbons (HC). The NO2 and POHC then react over suitable SCR catalysts located downstream to produce N2. Thus, it is a modified version of the HC/SCR technology mentioned above. The feasibility of this approach in reducing NOx emissions under highly lean conditions has been demonstrated [3-5]. One of the advantages of the plasma-assisted catalysis is that, by treating the exhaust stream with the gas plasma, the reactants produce highly reactive intermediates to such an extent that the catalyst does not need noble metals.

In this work, we have developed a plasma-assisted catalyst system (PAC) that is capable of reducing NOx under highly lean conditions using E-diesel or ethanol as the reductant. The system consists of a compact, energy-efficient hyperplasma reactor followed by a dual-bed catalytic reactor containing BaY (or NaY) and CuY. The emission reduction potential of the system for NOx reduction in diesel engine exhaust has been evaluated by both steady-state laboratory reactor experiments and engine dynamometer tests, under a wide range of operating conditions by varying the operating parameters such as plasma power density, catalyst temperature, gas space velocity, HC/NOx feed ratio, fuel sulfur contents, etc. An optimum operating strategy for the system has been developed in terms of the two most critical system parameters, namely, the plasma power density and the feed ratio of HC/NOx to the catalytic reactor. We have demonstrated that the plasma/catalyst system can achieve a good NOx conversion (above 90% on average) over a wide temperature range of 200-400°C under steady-state optimum operating conditions, by using a sidestream hyperplasma reactor coupled with E-diesel as the reductant at a diesel engine exhaust gas space velocity of 5000/h for BaY and 20,000/h for CuY on monolithic honeycomb substrates. Thus, the PAC process developed in this work is a promising alternative to the existing lean-NOx reduction technologies such as the lean NOx trap and the urea/SCR technology, even though the high flammability of E-diesel remains a serious issue that needs to be addressed. A reaction mechanism for NOx reduction over the plasma/dual-bed catalysts is discussed in the light of the critical role of plasma in activating NO and ethanol for subsequent catalytic NOx reduction. Also included in the discussion will be the practical aspects of the system performance such as fuel penalty and plasma power consumption as well as the areas of future research needs.

References

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