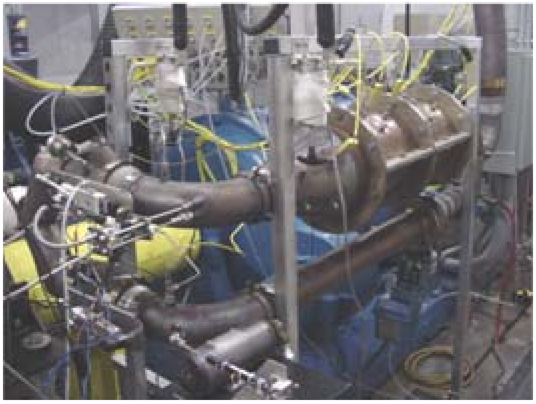
Practical Lean NO_x Trap Technology Achieves High Fuel Efficiency and Low Emissions

NO_x Trap Regeneration System Optimized in Gas Engine

Background

Lean-burn combustion (with high air-to-fuel ratio) is used in natural gas reciprocating engines for better fuel economy, enhanced engine durability, and lower emissions levels. In 2004, ORNL lean NO_x trap (LNT) experiments successfully met and surpassed the 2010 target for the Advanced Reciprocating Engine Systems (ARES) Program to reduce nitrogen oxide (NO_x) emissions to less than 0.1 g/hp-hr.

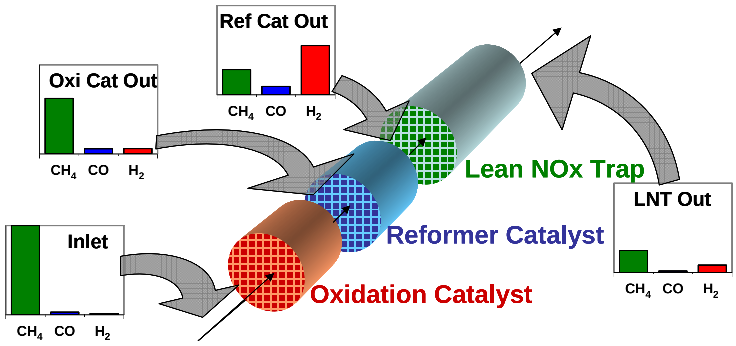


A state-of-the-art lean engine used at ORNL to evaluate a lean NO_x trap.

Hereto, reduction of NO_x required the use of potentially toxic chemicals (such as ammonia and urea) in the selective catalytic reduction (SCR) process. The LNT process eliminates the complexity, costs, and emissions associated with such chemicals by its ability to use natural gas as the sole fuel/chemical source; however, the additional catalysts and natural gas consumption needed for NO_x reduction represent some penalties. FY05/06 research therefore focused on characterizing and improving the catalyst system and fuel controls to optimize fuel efficiency.

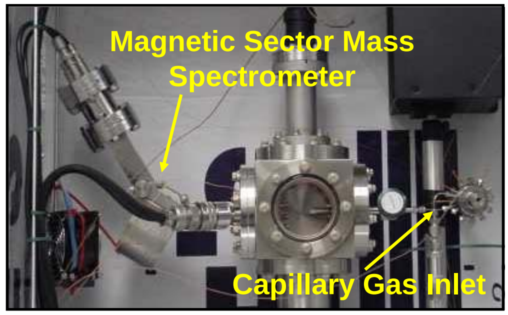
Technology

The LNT is a catalytic surface that adsorbs NO_x from the engine exhaust. When this trap is saturated, most of the exhaust flow is shunted to a parallel and symmetrical path while the "idled" trap is regenerated. Rich-burn conditions are created by briefly introducing a small amount of the engine's natural gas supply into the "idling" fraction of the exhaust flow just upstream of the oxidation catalyst. The oxidation and reformer catalysts break down methane in the natural gas into reactants, carbon monoxide (CO) and hydrogen (H_2), which then quickly reduce the trapped NO_x. This resultant LNT exhaust is harmless N_2, carbon dioxide (CO_2) and water. When the NO_x trap in the other path becomes saturated, the two flows and are reversed.



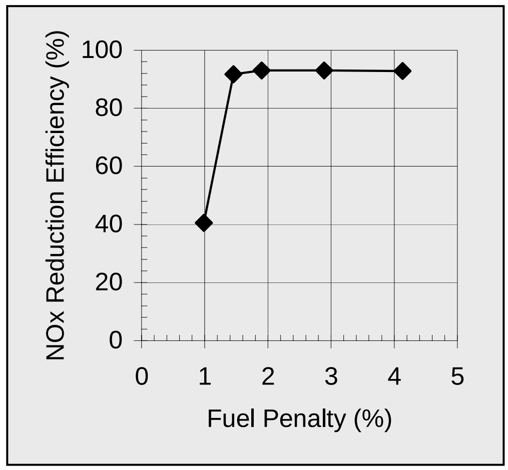
Exhaust Species vs. Position in Lean NO_x Trap Catalyst System. *Oxidation and reformer catalysts are positioned upstream of the lean NO_x trap to convert CH_4 in natural gas to CO and H_2 which are preferred reductants. Sample data shows CH_4, CO, and H_2 at various positions in the exhaust system.*

In FY05, ORNL completed a study characterizing the exhaust chemistry at each position in the LNT catalyst system. The results show the importance of both partial oxidation and reforming processes in the utilization of natural gas for LNT regeneration. The production of H_2 is greatly enhanced by the reformer catalyst that utilizes Rh to catalytically produce H_2 from CH_4 and H_2O. A unique technique developed in a another project at ORNL, SpaciMS, was used to make the H_2 measurements in the study. The SpaciMS technique is highly sensitive and responsive due to a novel method of collecting the gas sample through a hollow capillary that can be inserted into any exhaust stream; a magnetic sector mass spectrometer is then used to detect the hydrogen gas.



SpaciMS Analytical Tool developed at ORNL

The study found that NO_x reduction efficiency is not a linear function of fuel penalty. "Fuel penalty" was defined as the amount of excess fuel delivered for catalyst regeneration relative to the amount of fuel consumed for engine operation. A 12% fuel difference exists between stoichiometric and lean engine combustion, so fuel penalties significantly less than this amount are desired. Results showed that NO_x reduction efficiency increased with increasing fuel penalty until NO_x performance plateaus at >90%. Once sufficient H_2 is produced from the natural gas injected into the catalyst system, additional fuel use does not increase NO_x reduction efficiency. In the example shown to the right, the optimal fuel penalty of 1.4% yields the most fuel effective NO_x reduction performance.



Benefits

Full characterization of the LNT catalyst regeneration process allows the fuel penalty to be minimized. As LNT technology continues to be optimized for maximum efficiency, it will enable reciprocating engines to be sited even in states with the most stringent environmental regulations.

Future Work

Next steps in LNT research at ORNL include

- characterization of oxidation and reforming catalyst durability as catalysts are exposed to varying quantities of SO_2 present in natural gas, and
- collaboration with industry to develop a commercial product which can reliably switch between LNT systems during regeneration.

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