SAE TECHNICAL PAPER SERIES

2004-01-1292

Technical Advantages of Urea SCR for Light-Duty and Heavy-Duty Diesel Vehicle Applications

Christine Lambert and Robert Hammerle
Ford Research & Advanced Engineering

Ralph McGill
Oak Ridge National Laboratory

Magdi Khair and Christopher Sharp
Southwest Research Institute

Reprinted From: Diesel Exhaust Emission Control (SP-1860)

SAE International™

2004 SAE World Congress
Detroit, Michigan
March 8-11, 2004

ISBN 0 7680 1426-3
9 780768 014266

For permission and licensing requests contact:

SAE Permissions
400 Commonwealth Drive
Warrendale, PA 15096-0001-USA
Email: permissions@sae.org
Fax: 724-772-4891
Tel: 724-772-4028

SAE® Global Mobility Database®

All SAE papers, standards, and selected books are abstracted and indexed in the Global Mobility Database.

For multiple print copies contact:

SAE Customer Service
Tel: 877-606-7323 (inside USA and Canada)
Tel: 724-776-4970 (outside USA)
Fax: 724-776-1615
Email: CustomerService@sae.org

ISBN 0-7680-1319-4

Positions and opinions advanced in this paper are those of the author(s) and not necessarily those of SAE. The author is solely responsible for the content of the paper. A process is available by which discussions will be printed with the paper if it is published in SAE Transactions.

Persons wishing to submit papers to be considered for presentation or publication by SAE should send the manuscript or a 300 word abstract of a proposed manuscript to: Secretary, Engineering Meetings Board, SAE.

Printed in USA

2004-01-1292

Technical Advantages of Urea SCR for Light-Duty and Heavy-Duty Diesel Vehicle Applications

Christine Lambert and Robert Hammerle
Ford Research & Advanced Engineering

Ralph McGill
Oak Ridge National Laboratory

Magdi Khair and Christopher Sharp
Southwest Research Institute

ABSTRACT

The 2007 emission standards for both light-duty and heavy-duty diesel vehicles remain a challenge. A level of about 90% NOx conversion is required to meet the standards. Technologies that have the most potential to achieve very high NOx conversion at low temperatures of diesel exhaust are lean NOx traps (LNTs) and Selective Catalytic Reduction (SCR) of NOx using aqueous urea, typically known as Urea SCR. The LNT has the advantage of requiring no new infrastructure, and does not pose any new customer compliance issues. However, Urea SCR has high and durable NOx conversion in a wider temperature window, a lower equivalent fuel penalty, and lower system cost. On a technical basis, Urea SCR has the best chance of meeting the 2007 NOx targets. This paper reviews the results of some demonstration programs for both light- and heavy-duty applications.

INTRODUCTION

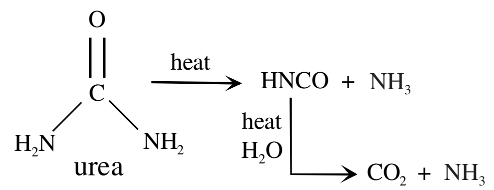
Reduction of NOx in the lean exhaust gas of diesel engines is not trivial. The 2007 NOx standards represent a 90+% reduction from previous standards as shown in Table 1. Also shown are NMOG (Non-Methane Organic Gases), NMHC (Non-Methane Hydrocarbon), CO (Carbon Monoxide) and PM (Particulate Matter) standards. In general, the two leading technologies for very high NOx conversion are Lean NOx Traps (LNTs) and Selective Catalytic Reduction of NOx using aqueous urea (Urea SCR).

LNTs contain an oxidative component such as Pt that oxidizes engine-out NO to NO_2 and a storage component (typically an alkali metal salt) that forms a nitrate

During rich (low oxygen) conditions, the nitrate compound releases NOx that is then reduced to N_2.

The reduction of NOx with either ammonia (NH_3) or urea has been used extensively for stationary source emission control. NOx reduction is possible due to the high selectivity of the NH_3 and NOx reaction to form elemental N_2. The typical reaction scheme using urea is as follows:

urea decomposition:



NO_x reduction:

$$4NO + 4NH_3 + O_2 \longrightarrow 4N_2 + 6H_2O$$
$$6NO_2 + 8NH_3 \longrightarrow 7N_2 + 12H_2O$$
$$2NH_3 + NO + NO_2 \longrightarrow 2N_2 + 3H_2O$$

Urea is the preferred means of delivering ammonia onboard a vehicle because it is safely transported and can be easily injected as an aqueous solution. Urea has a very low toxicity and is widely used as a fertilizer. The mixture with the lowest freeze point (eutectic) with about 32.5 wt% urea in water is preferred.

There have been successful light-duty (LD) and heavy-duty (HD) testing of both LNT and Urea SCR on US emission cycles. Table 2 summarizes the most recent results.

Table 1

2007 standards for LD and HD diesel vehicles.

	NMOG/NMHC	CO	NOx	PM
LD Tier 1 diesel (100k mi)[a]	0.31-0.56 g/mi	4.2-7.3 g/mi	0.97-1.53 g/mi	0.10-0.12 g/mi
LD Tier 2 Bin 5 (120k mi)	0.090 g/mi	4.2 g/mi	0.07 g/mi	0.01 g/mi
HD 2004 MY	0.5 g/hp-hr	15.5 g/hp-hr[b]	2.0 g/hp-hr	0.10 g/hp-hr
HD 2007 MY	0.14 g/hp-hr[c]	15.5 g/hp-hr[b]	0.20 g/hp-hr[c]	0.01 g/hp-hr

[a] Tier 1 standards vary according to vehicle weight.
[b] HD CO standard is carried over from 1998 MY.
[c] 2007 NMHC and NOx standards to be phased in from 2007-2010.

Table 2

Summary of reported results from recent diesel technology testing with fresh catalysts.

Application	Technology	Cycle	NOx Conv.	Tailpipe NOx	Ref.
PC	Urea SCR	FTP-75	90+%	0.05 g/mi	1
PC	Urea SCR	US06	90+%	0.05 g/mi	1
PC	LNT (DPNR)	FTP-75	80+% [2]	0.05 g/mi	3
PC	LNT (DPNR)	US06	80+% [2]	0.14 g/mi	3
LDT	Urea SCR	FTP-75	82%	0.17 g/mi	4
LDT	LNT	FTP-75	72%	not reported	5
HDT	Urea SCR	HD FTP	85%	0.86 g/hp-hr	6
HDT	Urea SCR	SET	86%	0.85 g/hp-hr	6
HDT	Urea SCR	HD FTP	90%	0.22 g/hp-hr[a]	7
HDT	Urea SCR	SET	90%	0.18 g/hp-hr	7
HDT	LNT	HD FTP	95%	0.13 g/hp-hr	8[b]
HDT	LNT	SET	94%	0.12 g/hp-hr	8[b]

Notes:
All results obtained with very low sulfur diesel fuel (< 30 ppm).
PC = Passenger Car
LDT = Light-Duty Truck
HDT = Heavy-Duty Truck
DPNR = Diesel Particulate - NOx Reduction
FTP-75: Federal Test Procedure for LD vehicles; cold-start three-bag cycle.
US06: High speed, high load cycle for LD vehicles; part of Supplemental FTP.
HD FTP: Heavy-Duty Federal Test Procedure; transient dynamometer cycle.
SET: Supplemental Emission Test for HD; steady-state points.
[a] Composite results for HD FTP (1/7 cold, 6/7 hot start).
[b] Results obtained with catalyst preconditioning.

The case against using Urea SCR for vehicle applications is twofold: (1) an infrastructure is required to deliver the reductant onboard the vehicle and (2) customer compliance is required to maintain adequate reductant for continuous, high NOx conversion. These issues make Urea SCR difficult to implement, but not

chosen by HD manufacturers to meet Euro IV and Euro V standards [9, 10]. Urea SCR does not have a direct fuel penalty because the engine can be tuned for optimum fuel consumption rather than minimum engine-out NOx, and durability is confirmed for over 500,000 km (>300,000 mi) [9]. Development of an aqueous urea not impossible, especially if an approach like co-fueling of diesel and urea simultaneously is adopted [11,12]. Such an approach requires no extra action by the customer other than normal refueling. In fact, refueling a vehicle equipped with either SCR or LNT emission control technologies can be transparent to the end user.

This paper will focus on the technical advantages of Urea SCR over LNT that include wider temperature window for very high NOx conversion, higher resistance to sulfur poisoning, better thermal durability, lower fuel economy penalty, lower system HC emissions, lower greenhouse gas emissions, and lower system cost.

EXPERIMENTAL

LABORATORY TESTING & AGING CONDITIONS: UREA SCR

Fundamental catalyst activity data were obtained at Ford using a laboratory-scale flow reactor system. A round sample core with dimensions of 1" diameter and 1.5" length was taken from a washcoated cordierite monolith obtained from a supplier. The catalyst was a base metal/zeolite type that did not contain vanadium. Simulated diesel exhaust gas flowed through the sample core at a space velocity of 30k h^{-1}, measured at standard conditions. The composition of the feedgas is shown in Table 3. The composition of the inlet NOx was varied from 0 to 80% NO_2 (balance NO).

Table 3

Composition of simulated diesel exhaust gas for SCR activity measurement.

Component	Concentration
O_2	14%
H_2O	4.5%
CO_2	5%
NOx	350 ppm
NH_3	350 ppm
N_2	Balance

Catalyst temperature was maintained with a tube furnace. An FTIR (infrared) spectrometer was used at the reactor outlet to measure NOx and NH_3. Data were taken at catalyst temperatures from approximately 170 to 600°C in order to cover the normal operating range expected on a diesel vehicle. NOx conversion was allowed to equilibrate before raising the catalyst temperature to the next level.

SCR catalysts were aged to represent 120k miles via two modes: low temperature sulfur exposure and core was installed into a tube furnace that was set at 350°C. N_2, O_2, H_2O and CO_2 at the appropriate levels for diesel exhaust were flowed through the catalyst at a space velocity of 30k h^{-1}. SO_3 was generated from SO_2 over a Pt catalyst and added to the gas stream at a level to represent 120k miles of exposure over 24 hours for a range of diesel vehicles from PC to LDT. A future fuel sulfur level of 10 ppm was assumed for this calculation. After aging, NOx performance was measured without any attempts to remove sulfur from the catalyst. Hydrothermal aging was performed at 670°C and 30k h^{-1} with N_2, O_2, H_2O, CO_2 and SO_2 at the appropriate levels. An aging time of 64 hours was chosen to represent well over 120k miles based on Ford's projection of accumulated time at high temperature if a diesel particulate filter is periodically regenerating in the system.

LABORATORY TESTING & AGING CONDITIONS: LNT

Monolith cores of LNT samples were tested at Ford in a similar manner to the SCR catalysts except that the reactor feed gas was operated in a cyclic fashion of lean and rich durations. The feed gas concentration and the duration of lean and rich stages were controlled. A typical cycle for the LNT performance measurement contained 25 s of lean condition and 5 s of rich condition. The lean and rich feedgas conditions are shown in Table 4. Total gas flow was 30k h^{-1}, measured at standard conditions.

Table 4

Composition of simulated diesel exhaust gas for LNT activity measurement.

Component	Concentration (lean)	Concentration (rich)
CO	500 ppm	4%
H_2	167 ppm	1.3%
C_3H_6	300 ppm C_1	5000 ppm C_1
NO	500 ppm	500 ppm
O_2	10%	1%
CO_2	5%	5%
H_2O	5%	5%
N_2	Balance	Balance
Lambda	1.96	0.90

LNTs were aged under the conditions that may occur onboard a vehicle when removing sulfur from the catalyst (deSOx). The deSOx operation is typically done at high temperature (> 600°C) and predominantly rich conditions. For laboratory aging of LNTs, an inlet temperature between 600-700°C was chosen.

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | **sales@docketalarm.com** | **1-866-77-FASTCASE**

fastcase®
Smarter legal research.