
Combined Catalyzed Soot Filter and SCR Catalyst System for Diesel Engine Emission Reduction

By

*R.M. Kakwani, K.Voss, J. Patchett & K.Grimston
Engelhard Corporation*

6th Diesel Engine Emissions Reduction (DEER) Workshop

August 20-24, 2000

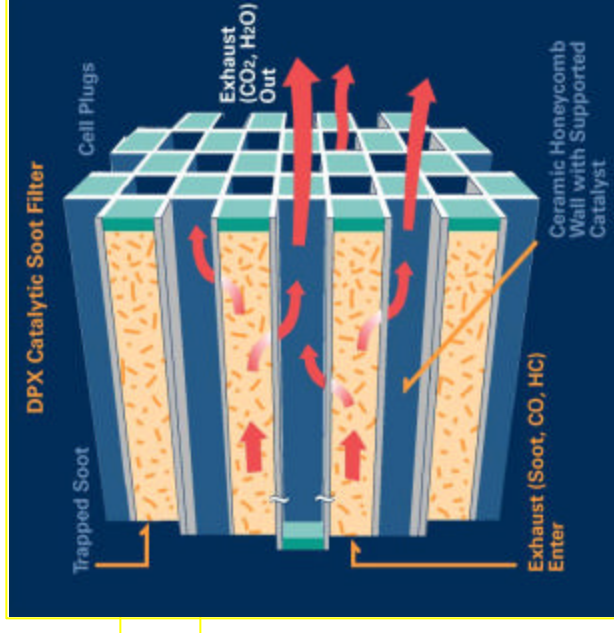
San Diego, California



ENGELHARD
Change the nature of things.

DPX™ Catalytic Soot Filter

- *Substantially reduces particulate emission for diesel vehicles*
- *Up to 90% effective against carbonaceous particulate matter*
- *Significantly reduces CO and HC*
- *Filter regenerates at normal diesel operation temperatures*
- *Removable design for easy cleaning and maintenance*

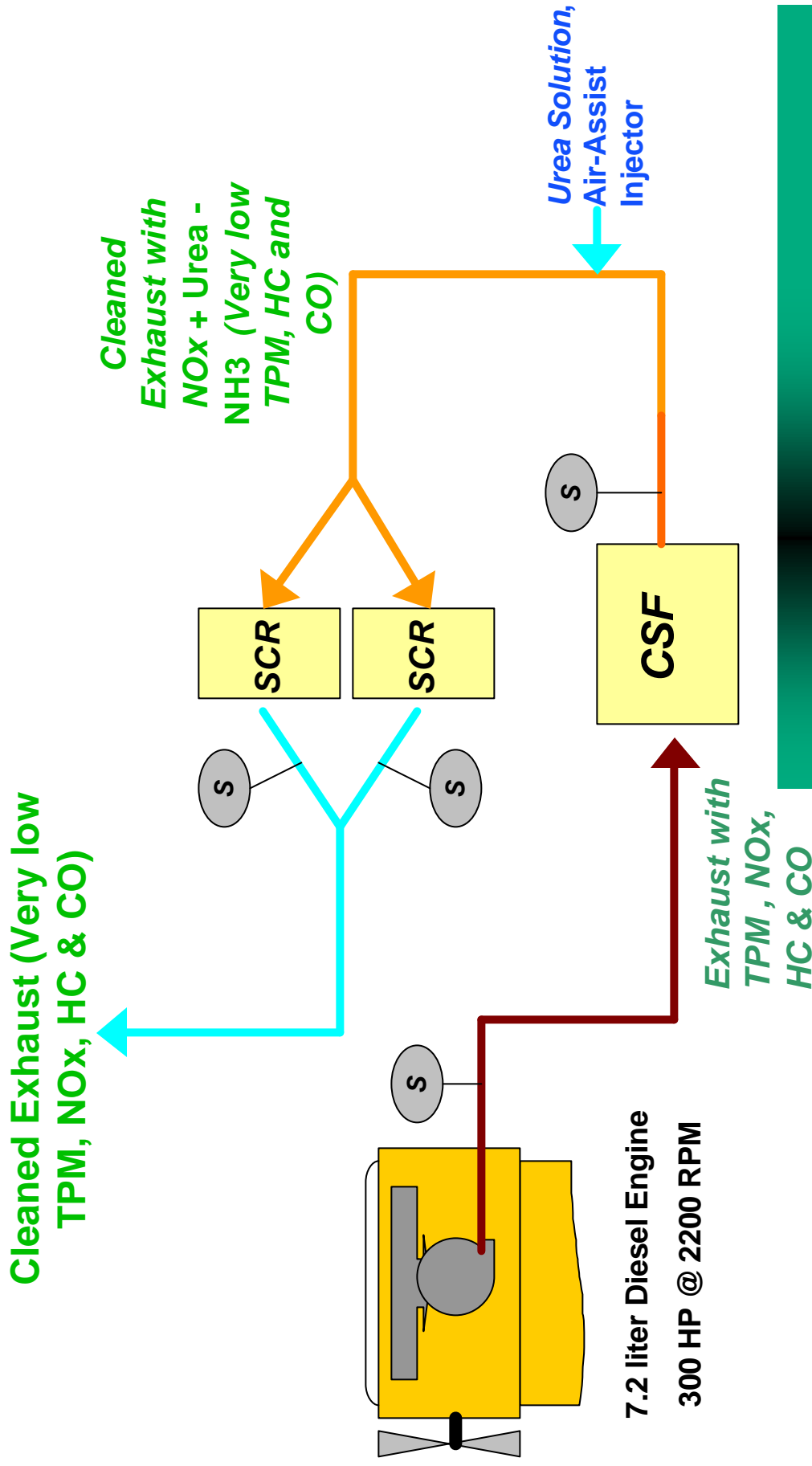


Controlling NOx

NOxCat ZNX™ catalysts

- ***A unique technology for higher temperature applications***
- ***Ideal for simple cycle gas turbines, chemical processes and reciprocating engines***
- ***Most effective at 675°F (357°C) to 1075°F (580°C)***
- ***Highly active zeolite catalytic coatings***
- ***Ceramic structures in composite honeycomb configurations***

Schematic of Engine Bench Set-Up for Testing Combined Catalyzed Soot Filter & SCR Catalyst System

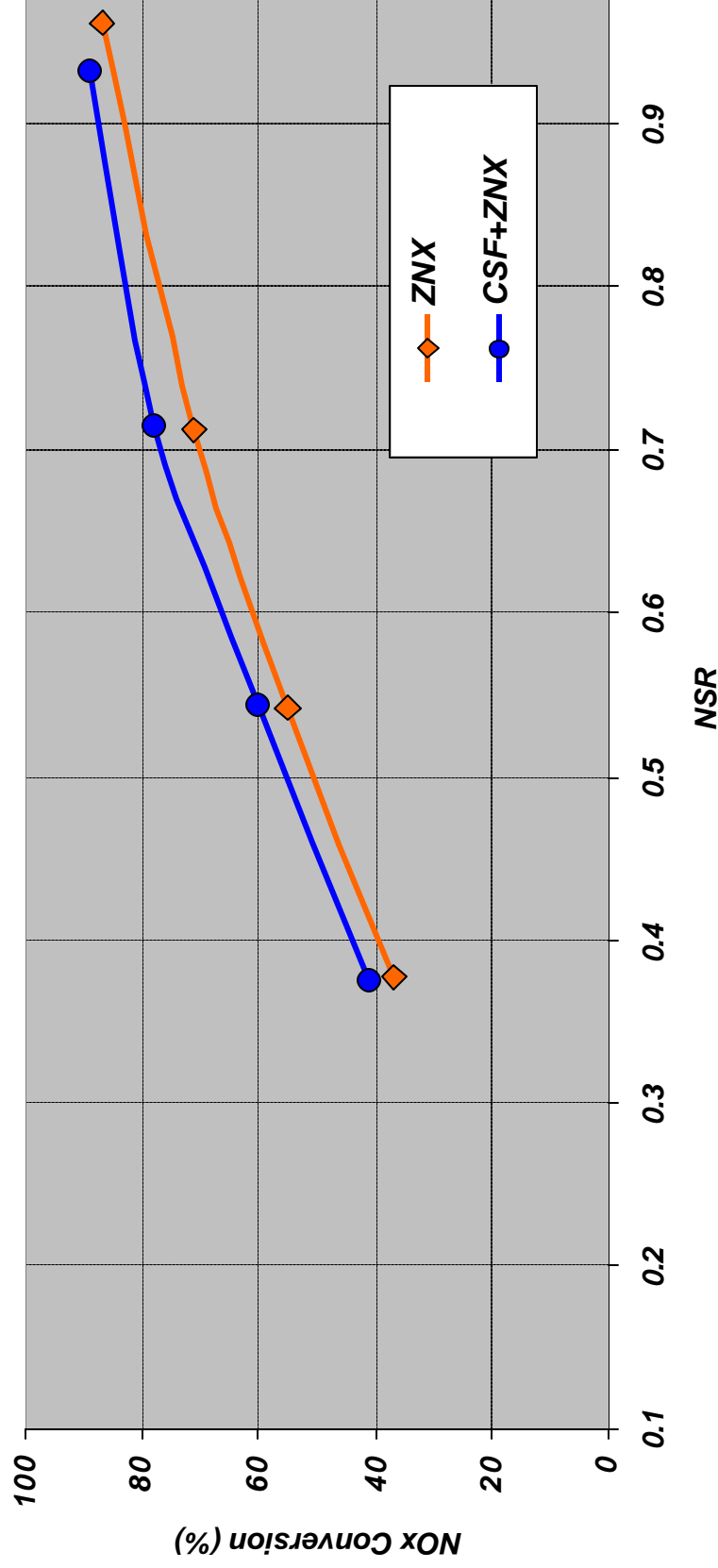


ENGELHARD

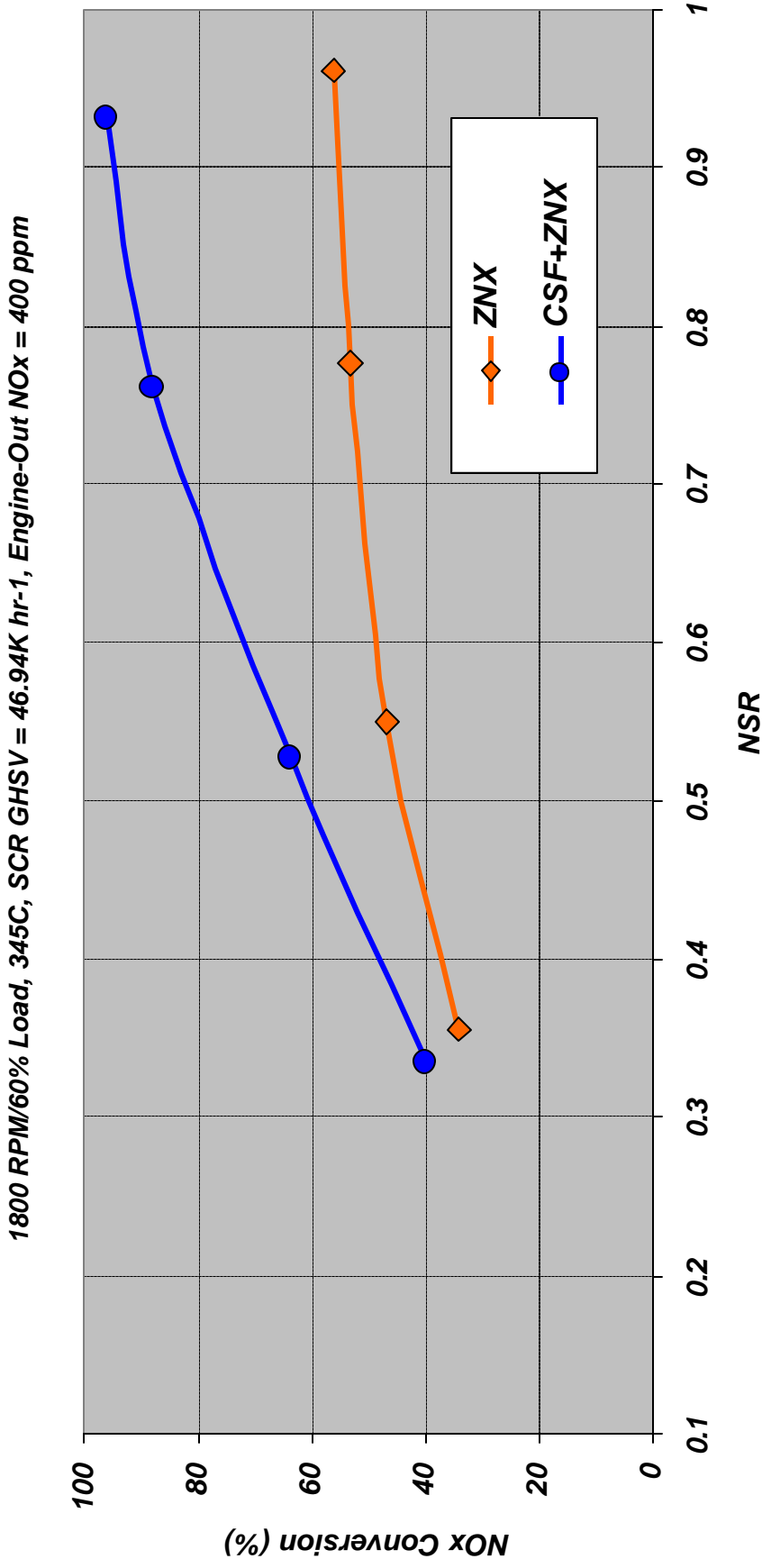
Change the nature of things.

NOx Conversion Performance of SCR Catalyst vs. CSF+SCR System as a Function of NSR at 470 C SCR Inlet Temperature

1800 RPM/100% Load, 470C, SCR GHSV = 51.33K hr⁻¹, Engine-Out NOx = 780 ppm

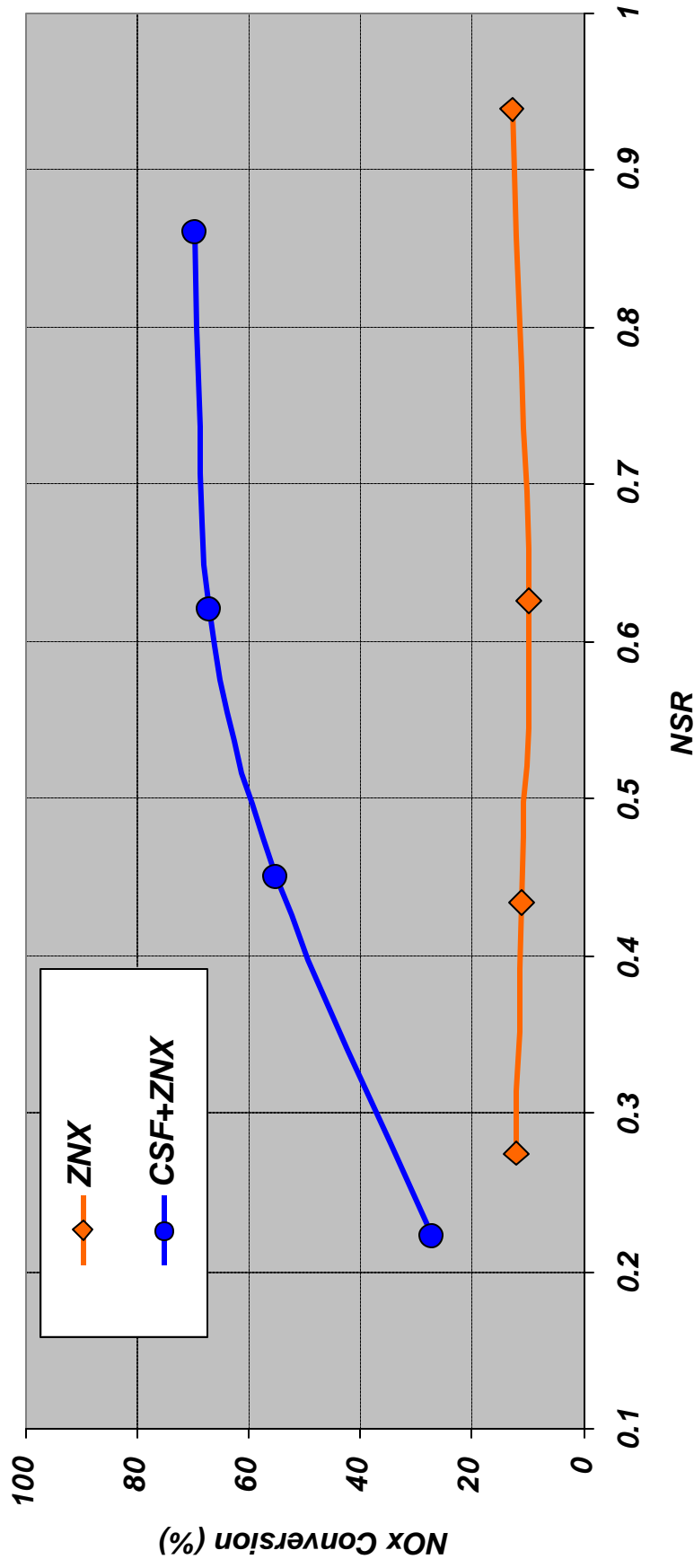


NOx Conversion Performance of SCR Catalyst vs. CSF+SCR as a Function of NSR at 345 C SCR Inlet Temperature



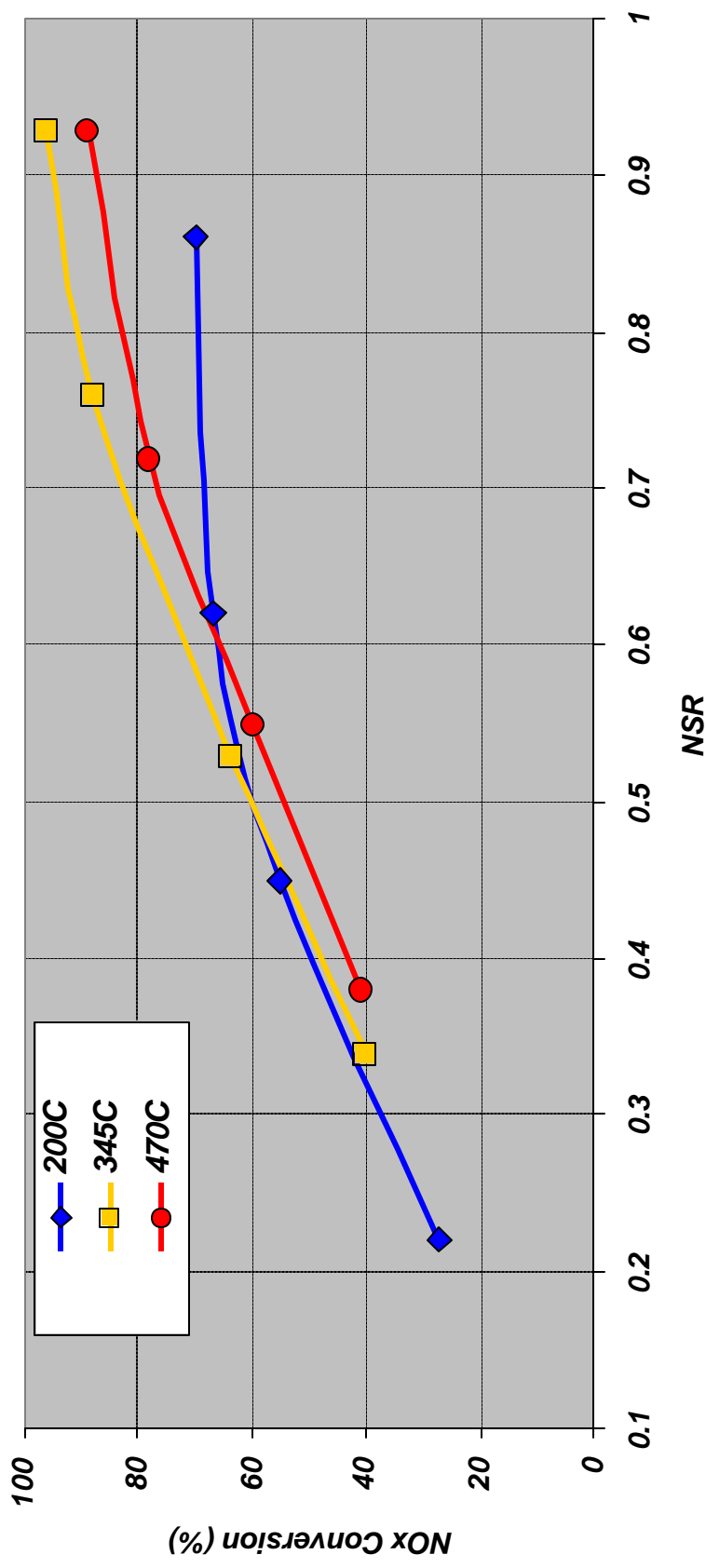
NOx Conversion Performance of SCR Catalyst vs. CSF+SCR as a Function of NSR at 200 C SCR Inlet Temperature

1800 RPM/14% Load, 200C, SCR GHSV = 28.31K hr-1, Engine-Out NOx = 200 ppm



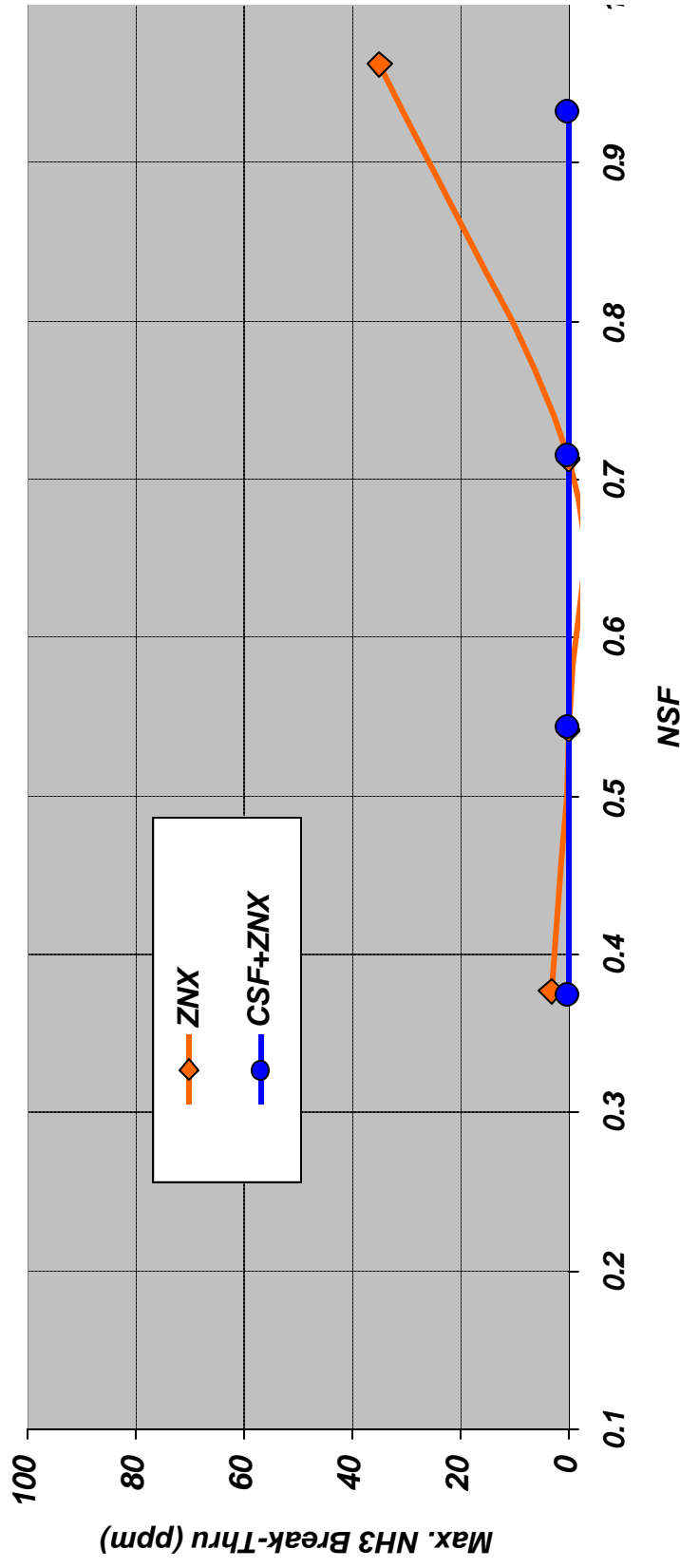
Engine Test Results for CSF+SCR System

NOx Conversion vs. NSR



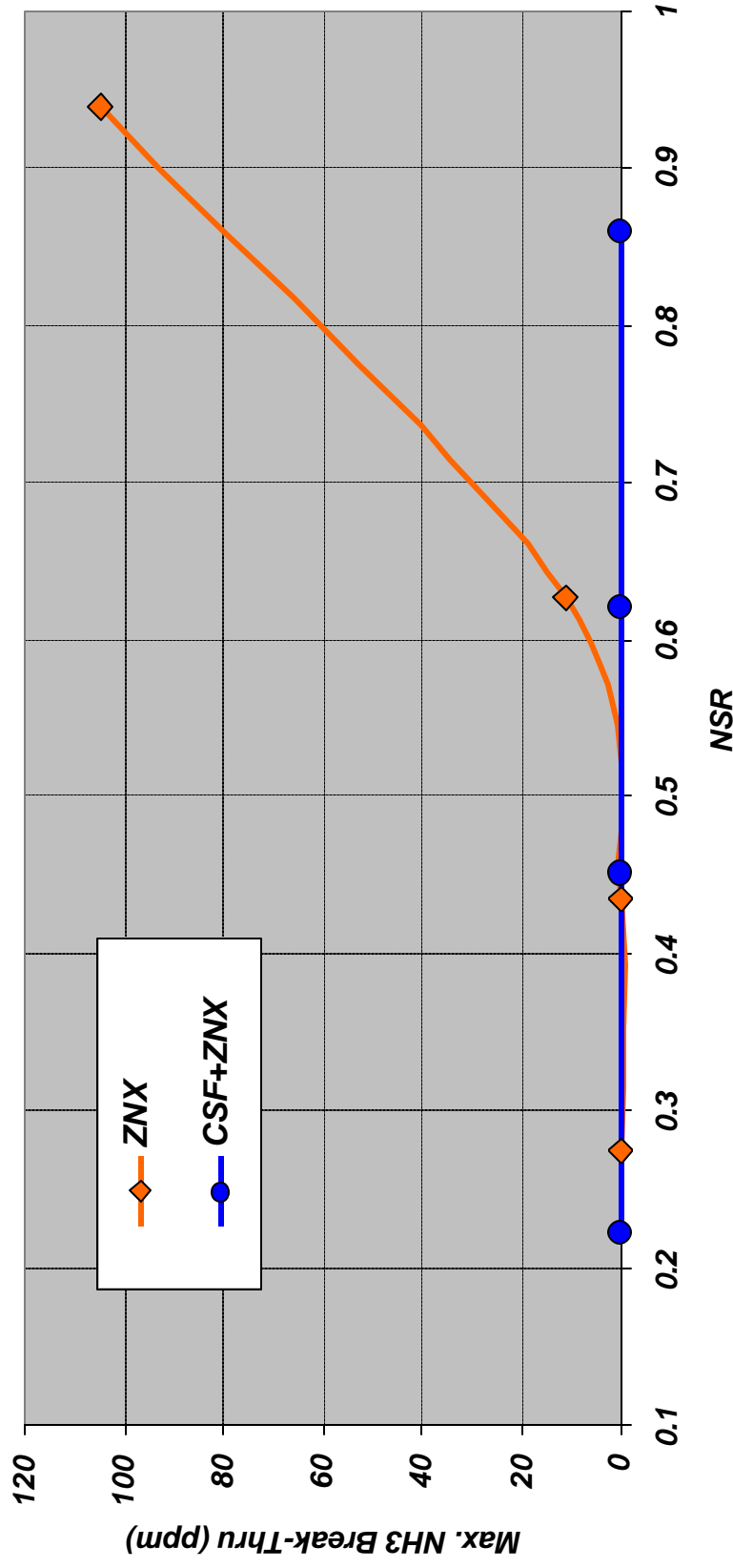
Maximum NH₃ slip for SCR vs. CSF+SCR System as a Function of NSF at 470 C SCR Inlet Temperature

1800 RPM/100% Load, 470C, SCR GHSV = 51.33K hr⁻¹, Engine-Out NO_x = 780 ppm



Maximum NH₃ slip for SCR vs. CSF+SCR System as a Function of NSR at 200 C SCR Inlet Temperature

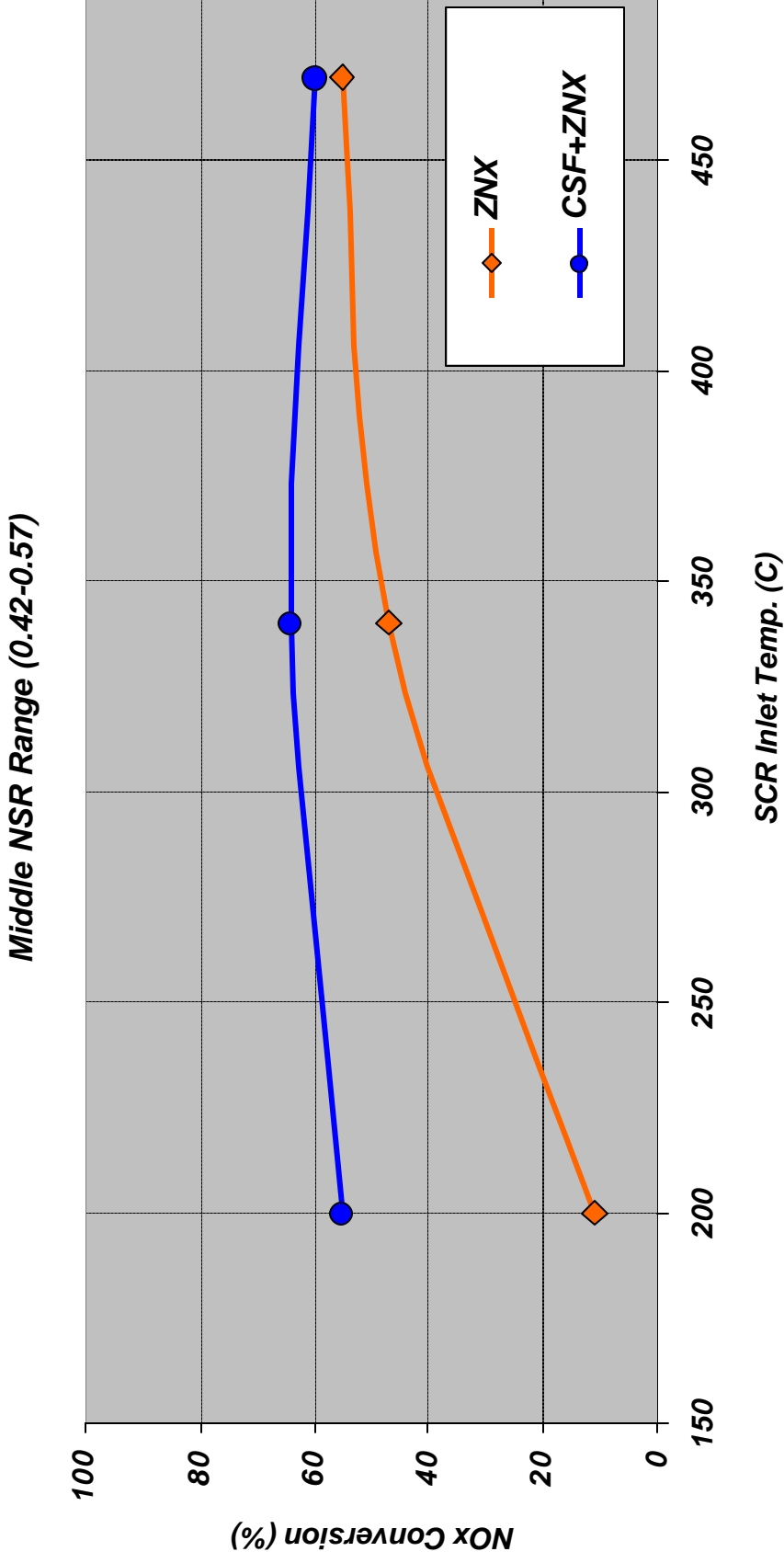
1800 RPM/14% Load, 200C, SCR GHSV = 28.31K hr⁻¹, Engine-Out NO_x = 200 ppm



ENGELHARD

Change the nature of things.

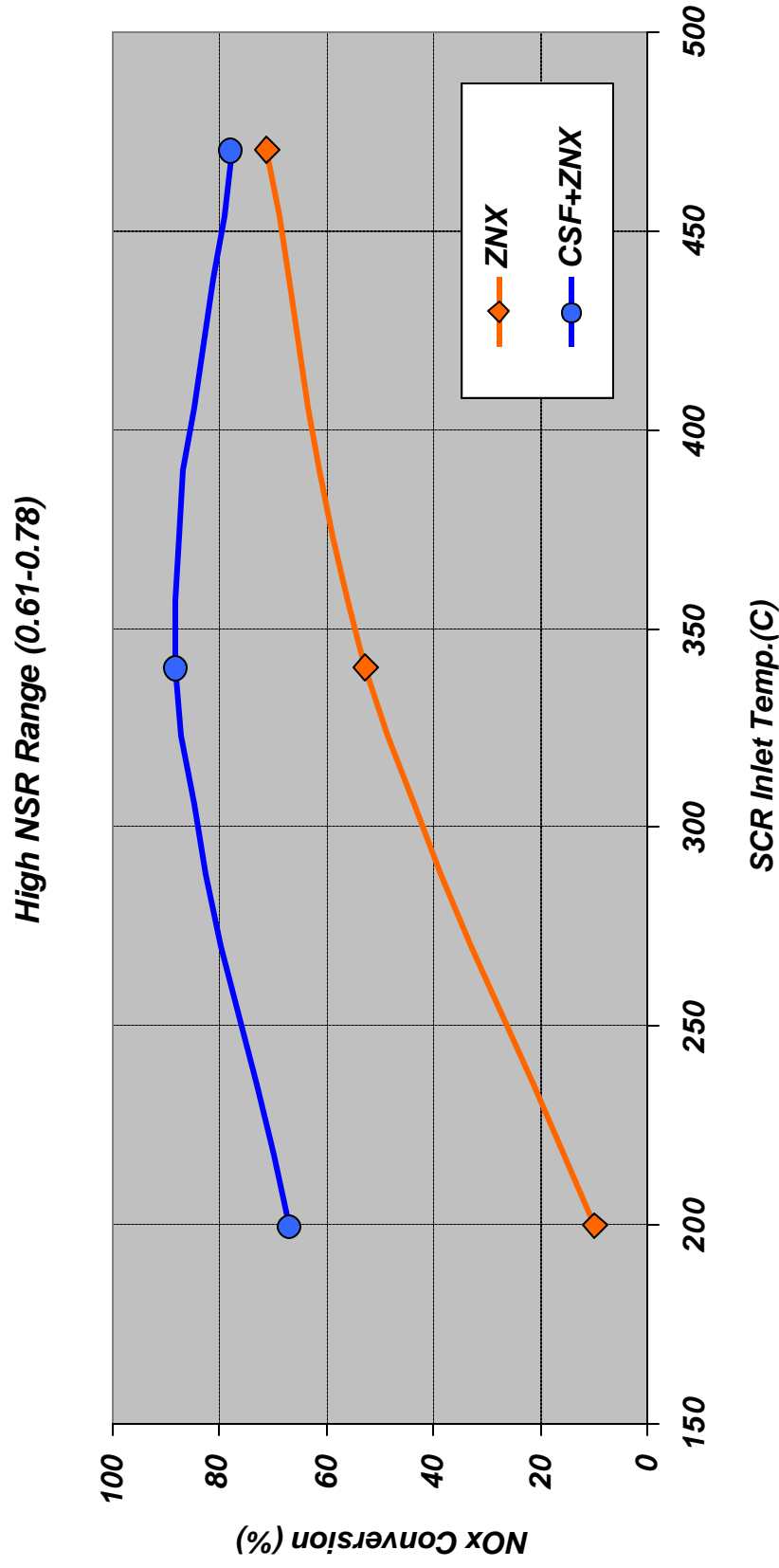
NOx Conversion Performance of SCR Catalyst vs. CSF+SCR as a Function of Inlet Temperature for Middle Range of NSR Values



ENGELHARD

Change the nature of things.

NOx Conversion Performance of SCR Catalyst vs. CSF+SCR as a Function of Inlet Temperature for High Range of NSR Values



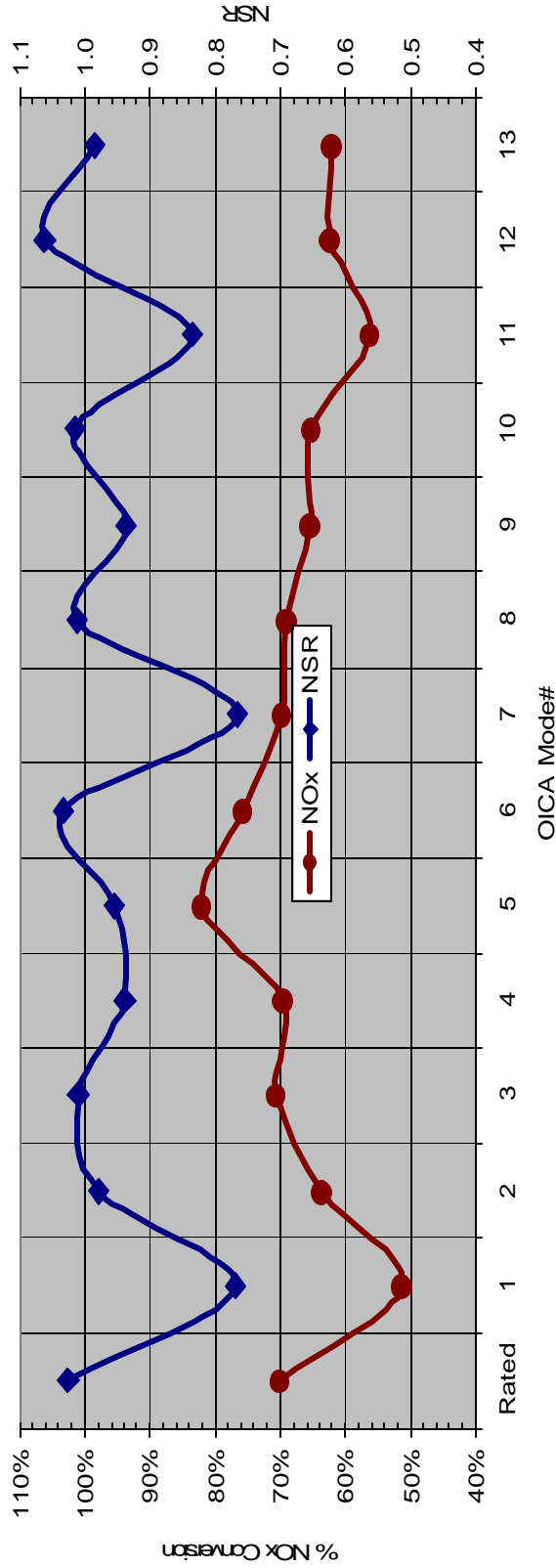
ENGELHARD

Change the nature of things.

SCR Only, ESC Cycle (13-mode OICA) @ 300 HP Rating

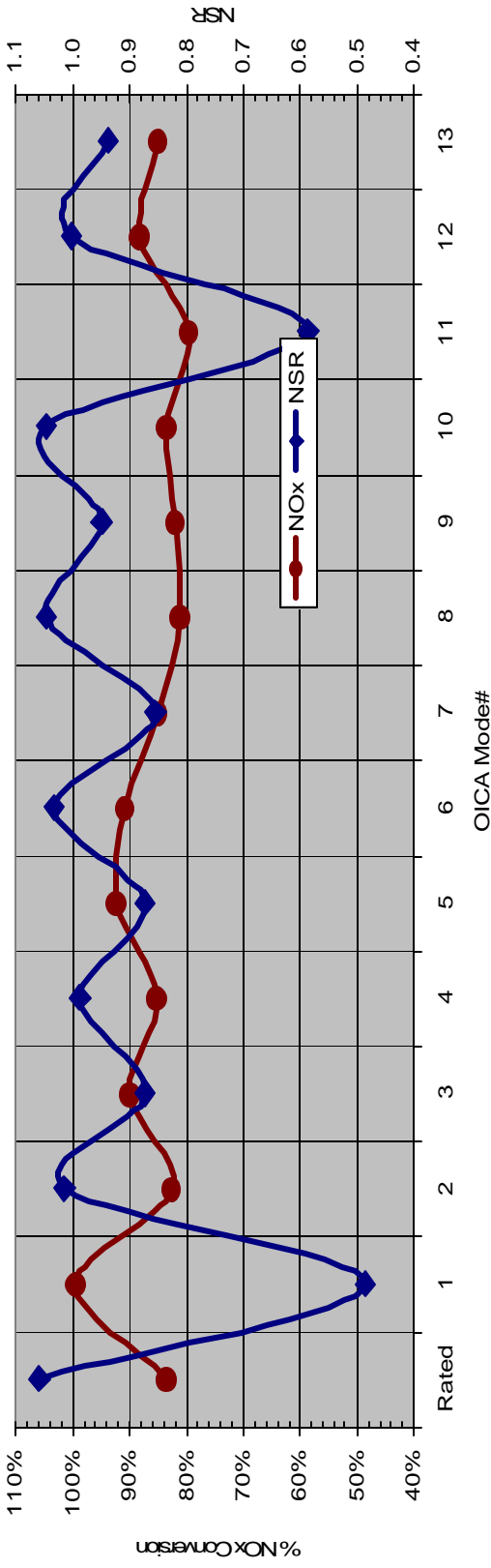
Avg. SCR Inlet Temp. = 357 C
 Avg. SCR Outlet Temp. = 368 C
 Avg. NOx Conversion = 67.3%
 Avg. NSR = 0.985
 NH3 Slip (max) = 241 ppm

Emissions in g/kW-hr		
HC	CO	NOx
Engine Out: 0.09	0.96	6.34
SCR Out: 0.04	0.83	2.07



CSF+SCR, ESC Cycle (13-mode OICA) @ 300 HP Rating

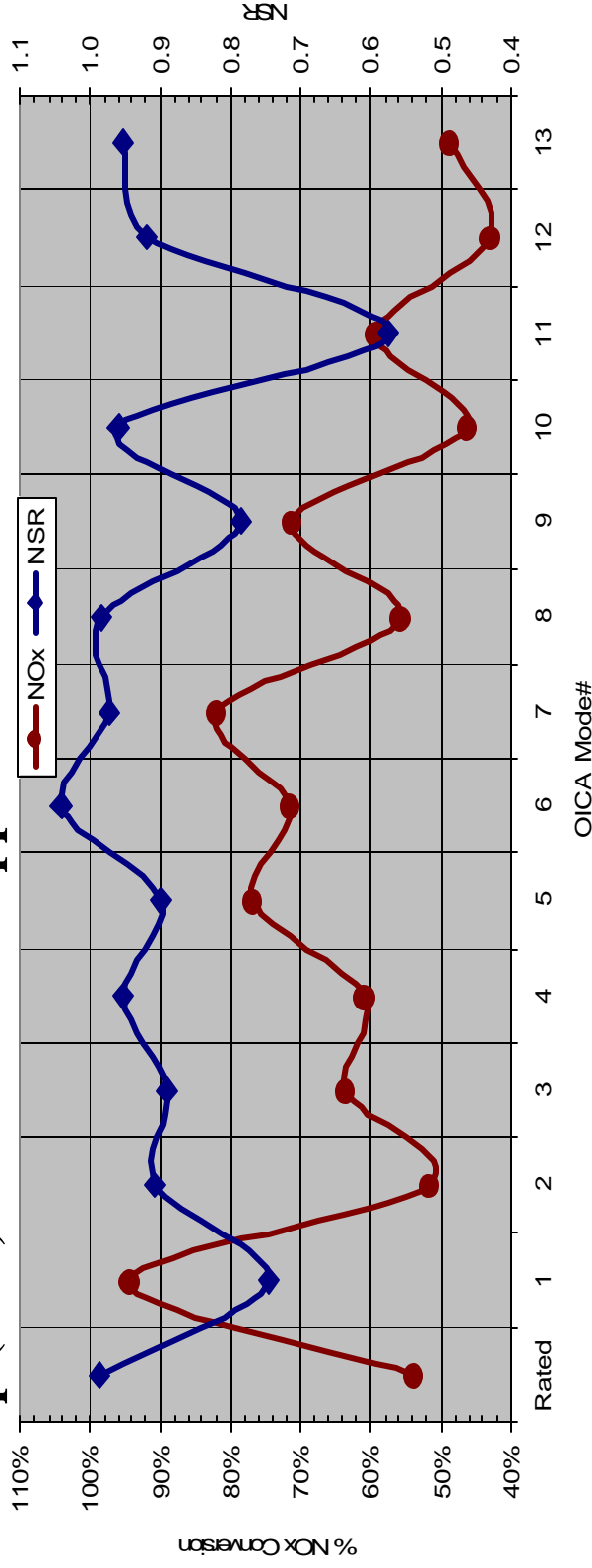
Avg. CSF Inlet Temp.	= 399 C	<u>Emissions in g/kW-hr</u>		
Avg. SCR Inlet Temp.	= 367 C	<u>HC</u>	<u>CO</u>	<u>NOx</u>
Avg. SCR Outlet Temp.	= 376 C	Engine Out:	1.18	6.18
Avg. NOx Conversion	= 85.1%	CSF Out:	0.07	6.17
Avg. NSR	= 0.976	SCR Out:	0.07	0.92
NH3 Slip	= 0 ppm			



SCR Only, ESC Cycle (13-mode OICA) @ 180 HP Rating

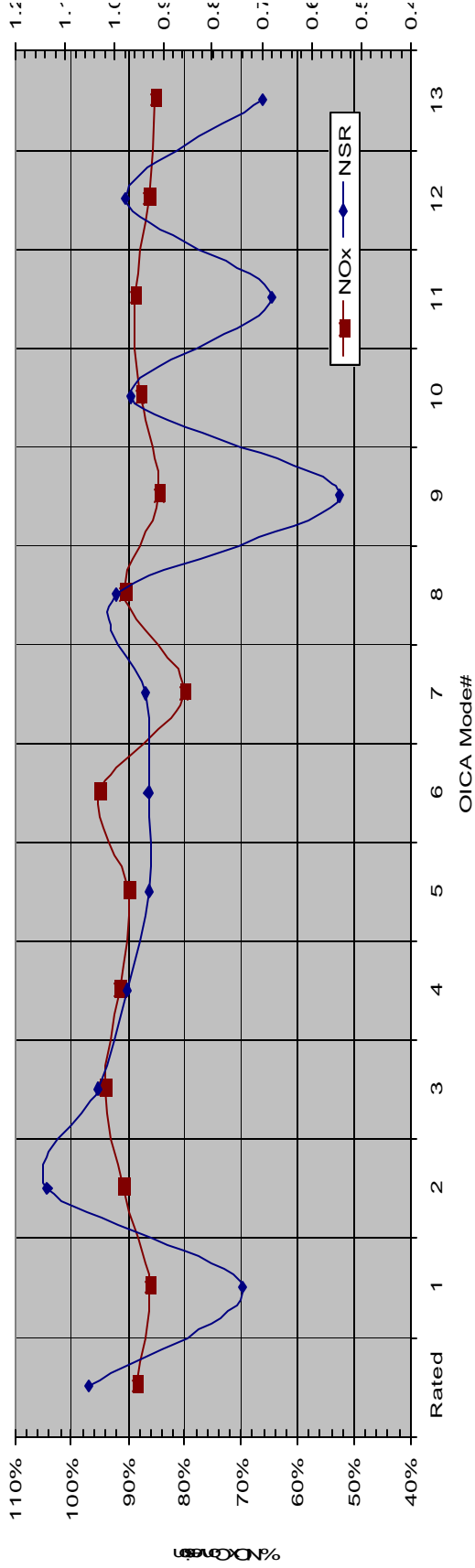
Avg. SCR Inlet Temp. = 288 C
 Avg. SCR Outlet Temp. = 300 C
 Avg. NOx Conversion = 58.2%
 Avg. NSR = 0.921
 NH3 Slip (max) = 310 ppm

Emissions in g/kW-hr		
HC	CO	NOx
Engine Out: 0.17	1.13	6.02
SCR Out: 0.07	1.09	2.51



CSF+SCR, ESC Cycle (13-mode OICA) @ 180 HP Rating

Avg. CSF Inlet Temp.	= 321 C	<u>Emissions in g/kW-hr</u>		
Avg. SCR Inlet Temp.	= 296 C	<u>HC</u>	<u>CO</u>	<u>NOx</u>
Avg. SCR Outlet Temp.	= 303 C	Engine Out:	1.42	6.01
Avg. NOx Conversion	= 89.9%	CSF Out:	0.11	5.98
Avg. NSR	= 0.963	SCR Out:	0.10	0.61
NH3 Slip	= 0 ppm			



Catalyzed Soot Filter + Urea SCR System

ESC Cycles Summary

Rating	Configuration	Temperatures, deg C			Avg. NSR	Avg. NOx Conv.	Max NH3 Slip	SCR Out Emissions, g/kW-hr		
		CSF In	SCR In	SCR Out				HC	CO	NOx
HP						%	ppm			
300	SCR		357	368	0.985	67.3%	241	0.04	0.83	2.07
300	CSF+SCR	399	367	376	0.976	85.1%	0	0.03	0.07	0.92
180	SCR		288	300	0.921	58.2%	310	0.07	1.09	2.51
180	CSF+SCR	321	296	303	0.963	89.9%	0	0.04	0.1	0.61

Combined Catalyzed Soot Filter and SCR Catalyst System for Diesel Engine Emission Reduction

- Summary -

- Steady State Tests Showed:

- ➔ Slight advantage of CSF+SCR as compared to SCR alone at high inlet temperature (470 C). Both configurations achieved 80-90% NOx conversion for NSR=0.8-0.9
- ➔ For lower inlet temperatures (345 C & 200 C) the CSF+SCR configuration achieved substantially better NOx conversion as compared to SCR alone. CSF+SCR attained 70-90% NOx conversion for NSR = 0.7-0.9. The activity for NOx conversion for SCR alone decreased with decreasing inlet temperature while CSF+SCR maintained activity.
- ➔ The CSF+SCR system achieved 70% NOx conversion at 200 C for NSR 0.7-0.85 as compared to 10% for the SCR alone. This indicates that CSF+SCR is viable for light load and light-duty diesel applications.

Combined Catalyzed Soot Filter and SCR Catalyst System for Diesel Engine Emission Reduction

- Summary (Continued) -

- ESC Cycle Testing Showed:
 - ➔ For the 300 HP rating at an average exhaust temperature of 360 C, the SCR catalyst alone achieved 67% cycle NOx reduction at 0.98 NSR with NH3 slip as compared to 85% NOx reduction for the CSF+SCR system with no NH3 slip.
 - ➔ For the 180 HP rating at an average exhaust temperature of 290 C, the SCR catalyst alone achieved 58% cycle NOx reduction at 0.92 NSR with NH3 slip as compared to 90% NOx reduction for the CSF+SCR system at 0.96 NSR with no NH3 slip.
 - ➔ Due to higher NOx conversion and better NH3 utilization with the CSF+SCR system, NH3 slip was substantially reduced.