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What are the Ultimate Limits of Integrated Emission Controls Strategies?

3. ETH-Workshop on Nanoparticle Measurements
9-10 August 1999

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Limits of integrated emission controls strategies - demonstration on a US heavy duty engine

Results presented thanks for the courtesy of Dr. Magdi KHAIR, Southwest Research Insitute

Leaving the laboratory surrounding which was the area of many of the papers presented so far, I would like to invite you for a trip back in the real word, on the other side of the Atlantic. You are certainly aware of the Consent Decree which was established between EPA, DOJ and nearly all the Heavy Duty Engines producers after the "scandal" of dual mapping providing a right control of NOx during Transient FTP, while NOx measured on some steady state pointswere as high as x 4 the limits.
In the first slide the main decision of the settlement are described with especially noticeable item 4 : Not To Exceed modal factor is 1.25 which means in other words that whatever is the point selected NOx could not exceed 5.0 g/bhph NOx when limit is 4.0 on the transient FTP.

The Manufacturers of Exhaust Controls Association, an US association with 38 participating companies in which I chair the Diesel Committee, responded positively to the request of EPA to demonstrate which are the true limits of advanced emissions controls strategies, when applied separately or in combination to a modern engine. We targeted the values described in slide 2, the NOx being independent from the sulfur in fuel while PM being lower with lower sulfur. Both values being reduced at about 1/3 of what they are in 1998.

A last generation engine (one of those equipped with dual mapping), was selected, everybody will recognize the DDC series 60 on slide 3.

Different after-treatment and emission controls technologies were tested as listed on slide 4. In MECA we make a clear distinction between after-treatments which are just added on the exhaust line (corresponding well to the concept of retrofit) and the emission controls technologies which implies a certain interaction between the management of the engine and of the emission control technology.

I will discuss essentially the items marked by an arrow where the Fuel-Borne-Catalyst (FBC) Eolys was involved. For us there is a big difference between a fuel additive which could be used for different purposes and a FBC which is used only for its catalytic activity to allow the easy operation of a trap and residues of which are retained in the filter.

Slide 5 show the base emissions of the reference engine with 500 ppm sulfur fuel according to Transient FTP. It is just under the NOx limits of 4.0 g and quite lower than the 0.1 g of PM.

Slide 7 shows the effect of a non-optimized EGR (dual mapping was not eliminated) which reduce NOx by 1/3, with a slight fuel penalty (2%) but a significant increase of PM (x 3), far above the legal limits.

Slide 8 shows the emissions when the same EGR is applied but with a DPF (Diesel Particulate Filter) downstream and Eolys : the NOx remains unchanged, while the PM are reduced to

1/10 of legal limits and fuel penalty is about 5% of original fuel consumption.

A totally different approach is demonstrated on slide 10 when a SCR (Selective Catalytic Reaction) using Urea was used : the NOx are then reduced to 1/3 of the original value while PM are unchanged and fuel economy marginally improved. We must consider that the fact that the engine was not retuned did not allow to get a real benefit on fuel economy.

Slide 12 shows the results obtained while combining a SCR with a DPF (+ Eolys) downstream of the SCR. Introduction of urea was increased to maximize the NOx reduction which is now close to 1/4 of the original value, while PM drop to 1/35 of the original value and fuel economy is improved by 4%.

Worth to recall that nothing was optimized and that expected results after real integration with the engine management are likely to be significantly better especially regarding fuel economy.

In case of combination of 3 technologies, it is predictable that the values of 0.5 g/bhph NOx and 0.01 to 0.03 g/bhph PM would be obtained without deterioration of the fuel economy.

BUT WHAT'S ABOUT THE CERIUM RESIDUES TRAPPING EFFICIENCY IN THE FILTER ?

VERT had evidenced in past years tests that 99.9% of the number of particles estimated to be cerium residues were trapped in most of the candidate filters. EPA requested us to provide a mass balance and to provide the data during the sequence of regeneration as well.

At the end of the MECA program the balance was performed in SwRI showing clearly that there are no difference in the mass balance (99.8%) during the filtration phase compared to VERT number balance. VERT has demonstrated that numbers in exhaust are lower than in the ambient, if we consider that the ambient is close to the 2.8 nanograms per cubic meter of Ce measured in SF Bay area, the low value of 0.4 nanograms per cubic meter in the exhaust is showing the same trend. But we do not claim that we clean the air from its cerium content !

During the regeneration the retention ratio drop to 97.3 %. When we consider that a regeneration will occur every 5 to 10 hours in the most critical conditions and will last a couple of minutes, the integrated retention ratio over time will be higher than 99.5%.

With totally dry particles, which could not combine with any volatile fraction, such as the residues of cerium, the number balance is in exact correlation with the mass balance.

Thank you for your attention.

What are the Ultimate Limits of Integrated Emission Controls Strategies?

Demonstration on a US Heavy Duty Engine (courtesy of SwRI)

Jacques LEMAIRE, Rhodia

EPA Settlement of 1998

1. **2004 Standards Must Be Met in 2002**
2. **2.4 g/bhp-hr NOx + NMHC or 2.5 if NMHC<0.5**
3. **Added 13 Mode Euro III-Type Test [ESC]**
4. **N-T-E Modal Limit Factor is 1.25**
5. **New Smoke Test Requirements**
6. **Eliminated Past A/B/T**

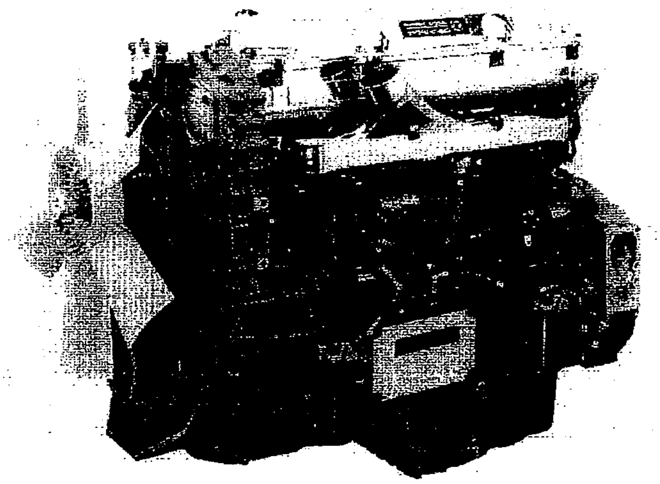
MECA HD Program And Objective

Demonstration of Advanced Emission Control Technologies Enabling Diesel-Powered HDEs to Achieve Very Low Emission Levels

Sulfur, ppm	500	50
NOx+NMHC/PM, g/bhp-hr	1.5/0.03	1.5/0.01

Test Engine

- 1998 Emission Calibration
- 400 hp Rated Output (Nominal)
- Rated Speed 1800 rpm
- Max. Torque Speed 1200 rpm
- Turbocharged/Intercooled/ In-Line 6 Cylinders

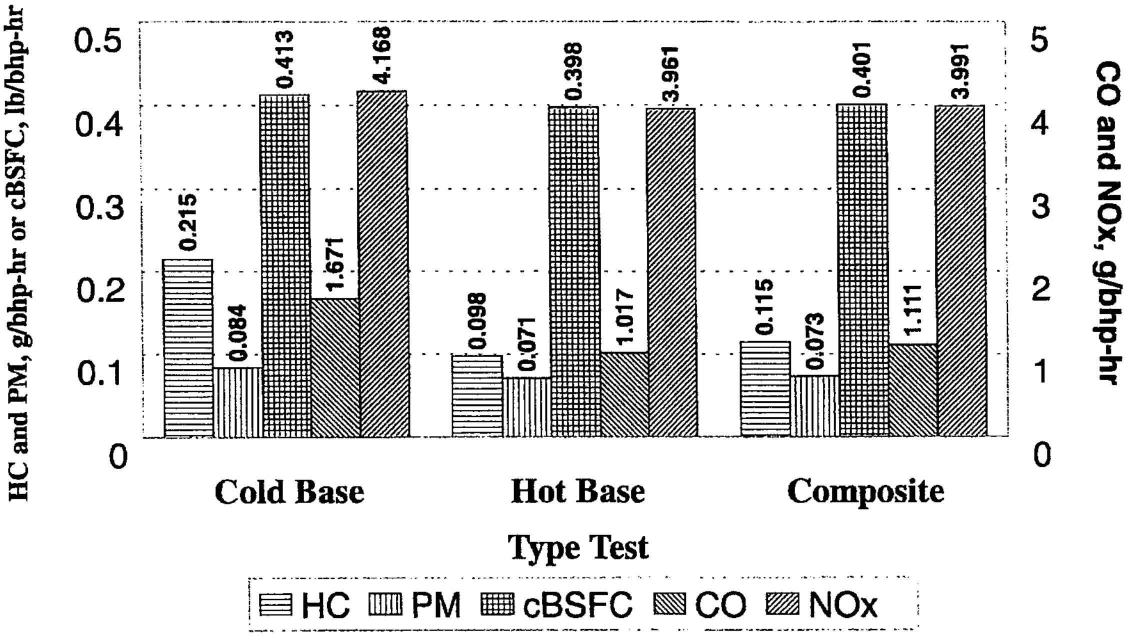


Aftertreatment & Emission Control Technologies

- Diesel Oxidation Catalyst (DOC)
- Diesel Particulate Filters (DPF--w/o FBC)
- EGR -- EGR+DOC -- EGR+DPF
- SCR -- SCR+DOC -- SCR+DPF
- DPF and Fuel-Borne Catalyst (FBC)
- Combination Systems

EPA Transient Emissions

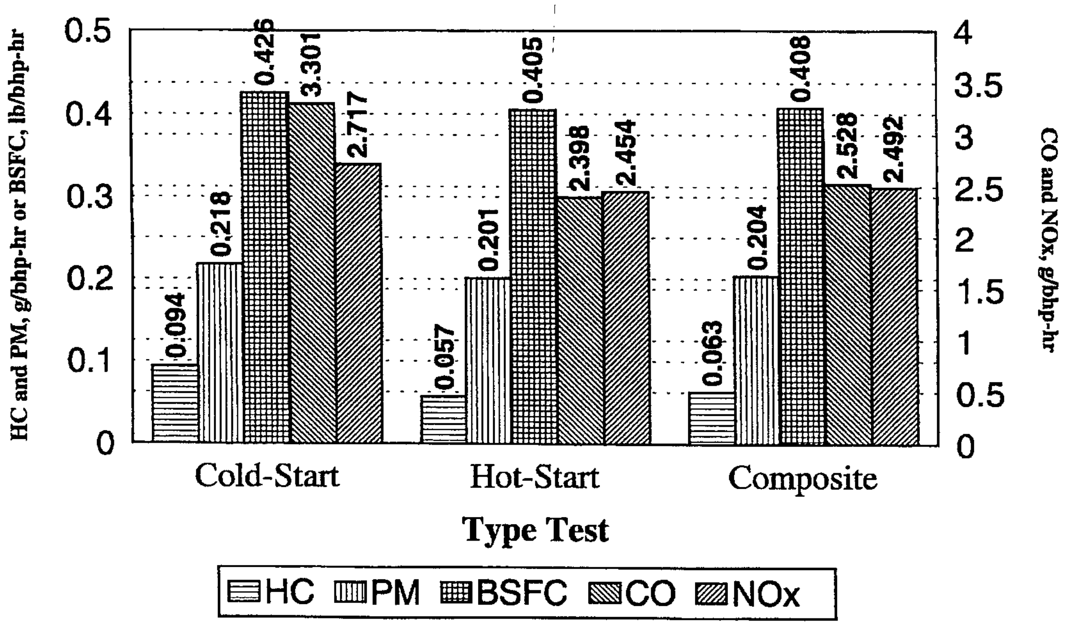
Engine Baseline 500 ppm Sulfur Fuel



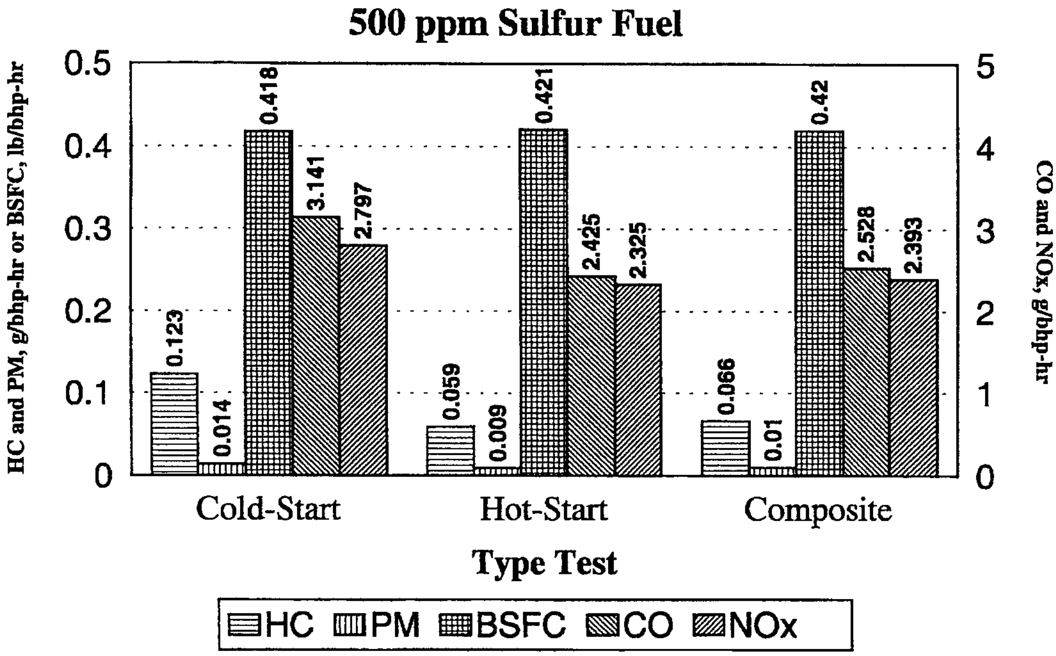
EGR Effects

Effect of EGR on EPA Transient Emissions

500 ppm Sulfur Fuel

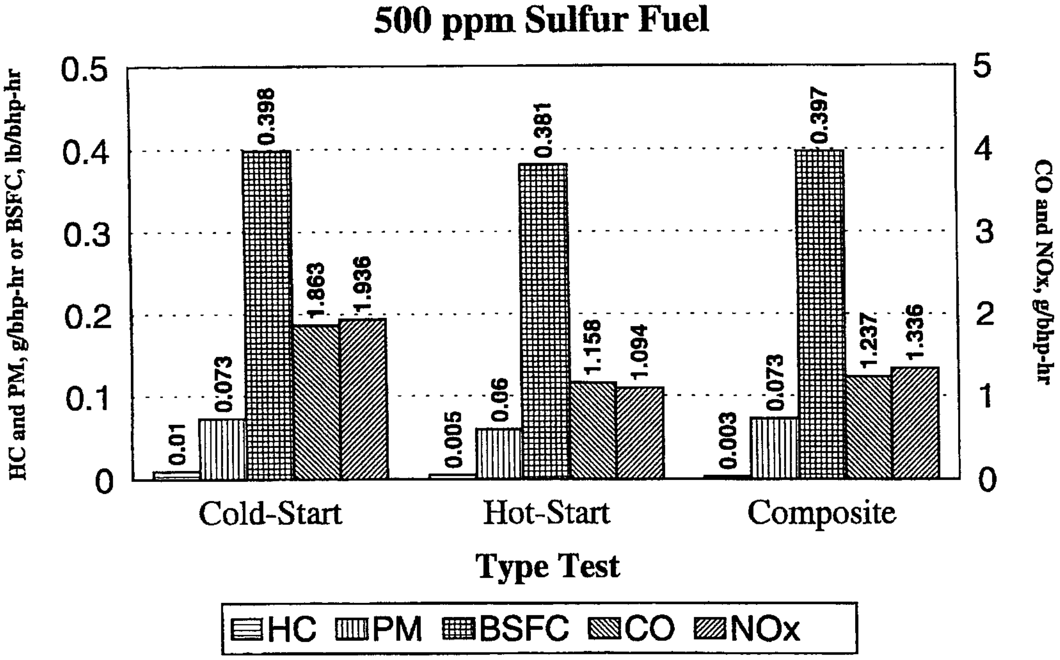


Effect of EGR+DPF+Eolys on EPA Transient Emissions



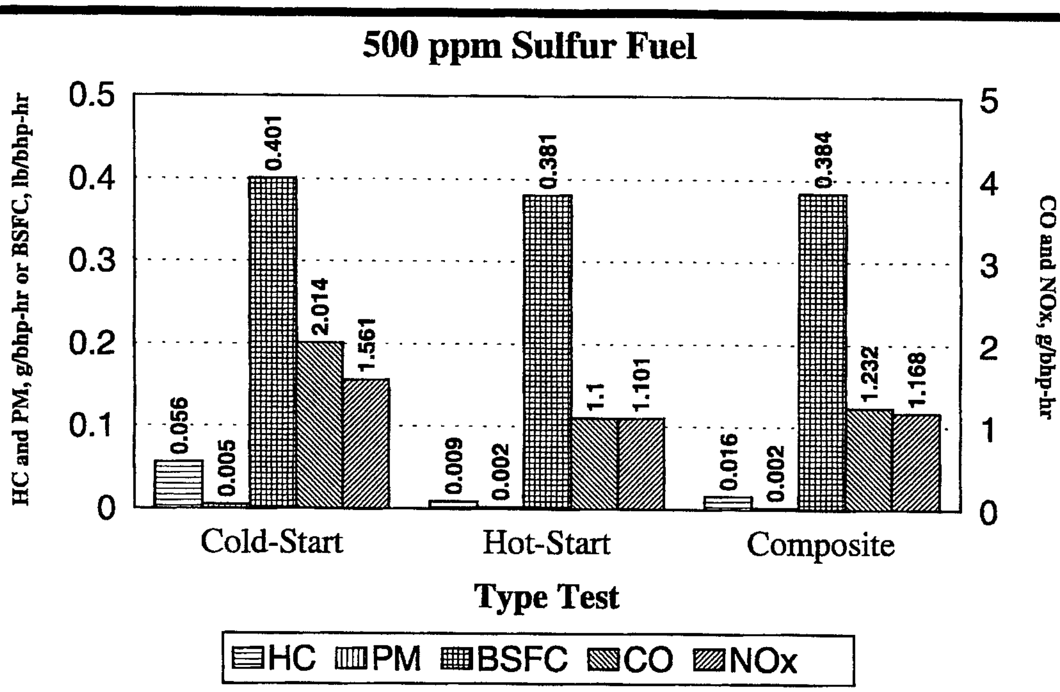
SCR Effects

Effect of SCR on EPA Transient Emissions



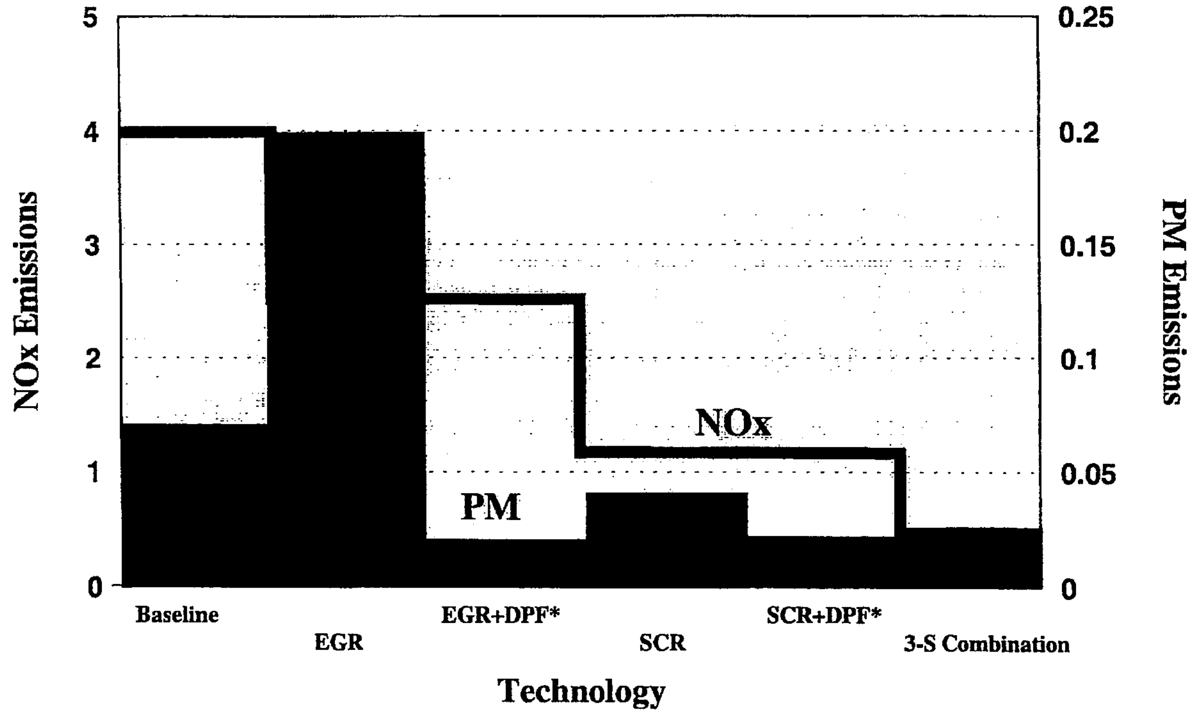
Combination Systems Effects

Effect of SCR+DPF+Eolys on EPA Transient Emissions



Summary and Projection

Summary -- EPA Transient Emissions



** Eolys Technology*

Cerium ResiduesTrapped in Filter

Mass Balance

versus

Number Balance

FIGURE 1. DETROIT DIESEL SERIES 60 TEST ENGINE

TABLE 1. CERIUM TEST RESULTS

Test Condition	Sample, µg/Filter	Total Air Flow, m^3	Sample, µg/m^3	Sample, ng/m^3
Engine-Out (w/o DPF)	257	1478	0.1739	174
DPF-Out (Accumulation)	0.595	1458	0.0004	0.4
DPF-Out (Regeneration)	1.72	364.5	0.0047	4.7

Results in Table 2 indicate that the DPF's cerium retention efficiency while in the particulate accumulation mode was 99.8 percent, and 97.3 percent in the regeneration mode.

EFFICIENCY OF SAME FILTER WITH FUEL DOPED WITH EOLYS™