80 HP PLASMA ASSISTED CATALYST SYSTEM

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The Us economy is linked to efficient heavy vehicle transportation and diesel remains the fuel of choice for mass transportation of goods and services. Diesel engines remain the most reliable and cost effective system for commerce. Recent deleterious effects of diesel exhaust on health and environment have led to an urgent need for cost effective technologies that would bring about reduction in NOx and PM. CARB estimates on-road diesel mobile source will contribute almost 50% NOx and 78% PM emissions by 2010. As a result recent Federal and State mandates have been adopted to reduce emissions from diesel exhaust to 1 Gm/bhp.-Hr of NOx and 0.05 Gm/bhp-hr of PM by the year 2007. The 2007 standard is to be achieved in a stepwise manner starting with the standards for 2002 namely 2 Gm/bhp-hr NOx and 0.1 Gm/bhp-hr of PM. 2002 standards are likely to be met by most engine manufacturer by some modified form of exhaust gas recirculation (EGR) system or by employing a sophisticated engine control system. Importance of cost effective technology requirement is further exaggerated by the fact that in recent years diesel engine production have increased dramatically see figure 1 and has out stripped the gasoline engine production almost 4:1 see figure 2.

Currently gasoline engine employs a 3-way catalytic system for NOx and HC reduction and in order for the 3-way system to work the engine is run near stoichimetric air : fuel ratio so that exhaust has virtually no oxygen. This strategy has resulted in a poorer efficiency and hence less efficient utilization of our natural resources. By contrast diesel engine operate on a lean burn principals i.e. air rich and currently there are no commercial technologies available for treating NOx and PM. Technologies being considered for reducing NOx from lean burn (diesel) exhaust are; Lean NOx catalyst systems, NOx adsorber system, Selective Catalytic Reduction systems and plasma assisted catalyst system. Of all these technologies Plasma assisted catalyst system is probably the most attractive since it can use currently available fuel onboard.

Noxtech under the work sponsored by DOE is developing plasma assisted catalyst technology for treating NOx and PM from a lean burn (diesel) exhausts. The plasma generated is a non-equilibrium or non-thermal plasma followed by reaction of the exhaust species from plasma reactor with a suitable hydrocarbon in the catalytic reactor.

Noxtech has successfully demonstrated an 80 Hp Plasma Assisted Catalyst system and is in the process of developing a 250 HP Plasma Assisted Catalyst system.

Noxtech's 80-Hp advance plasma assisted catalyst system is comparable to a muffler size specifically it is 14" in diameter and only 40" tall. Operating space velocity for the catalyst bed is 30,000 HR^{-1} Overall pressure drop through the system is only 22" H_2O.

Plasma assisted catalyst system consists of a co-axial plasma reactor operating in series with catalytic reactor. Current Plasma reactor is powered via Thyratron based power supply. First generation of the system consumes 17 Joules per Liter of energy in the plasma reactor and requires a 3.5 to 4 HC/NOx ratio. Advance Plasma Assisted catalyst system by Noxtech has successfully demonstrated 73% NOx reduction on a steady state basis. Figure 3 shows the current 80 HP PAC system developed and installed at Noxtech facility. The Thyratron based power source for the plasma is located in a housing at the extreme right, the bottom part of the system is the non-thermal plasma reactor measuring only 6" in diameter and 15" tall. The top section is the catalytic reactor measuring 14" in diameter X 19" tall. Exhaust from the Diesel engine enters the plasma rector which is powered by the plasma power supply where it reacts in

the presence of hydrocarbon to form higher oxides of nitrogen such as NO_2 which are than reacted downstream in the catalytic reactor to form less harmfully and unregulated compounds of nitrogen.

For a successful Plasma Assisted Catalyst system four elements have to be integrated and have to work in harmony namely:

1 Plasma Reactor 2. Catalytic Reactor 3. Power Supply 4. HC injection System.

Plasma reactor

Atmospheric non-thermal plasma reactor oxidizes the product of diesel exhaust to form higher oxides. The electron dissociation takes place at low or process temperature and the free radicals produced are highly energetic but short-lived. The parameter which effect the performance of the plasma reactor are operating voltage, system capacitance and inductance and in the case of pulsed corona the time duration for each pulse. Shorter the pulse more efficient is the plasma energy deposition into the system. A good plasma reactor has to be matched with the proper power supply for it to work efficiently.

Plasma Power Supply

For plasma to be generated high voltage is required currently Noxtech's plasma reactor requires only 8KV thus paving a way for a solid-state power supply to be used. Solid-State power supply being developed uses commercially available components. Solid-state power supply currently being developed with a matched plasma reactor to operate with a 80-Hp Plasma Assisted Catalyst system is shown in Figure 4. Current power supply produces a pulse of 100 nanoseconds or less and the overall system impedance is matched with the plasma reactor being developed. Present power supply produces 350-A and operate at a frequency of 50 KHz or higher and at 8KV. The power supply being developed is modular in type so it can be easily scaled to larger system such as 200 and 250 HP.

Catalytic reactor

First generation of Noxtech's catalytic reactor, which has a volume of a standard acoustic muffler. The reactor treats the exhaust at 30,000 HR^{-1} space velocity. Catalyst developed for the work can tolerate sulfur and contains no precious metals. At steady state the catalyst has demonstrated consistently better than 73% NOx reduction using gaseous hydrocarbon as reductant the results of steady state and at three different loads is presented in figure 5 and 6 respectively with the test condition used to achieve this results.
In addition to the steady state and load testing the system was also tested for other by-products being formed with a Nicolet 550 FTIR the results obtained are shown in figure 7.

On-board HC injection system

For successful commercialization of a Plasma Assisted Catalyst system form of hydrocarbon used for the reducing NOx and PM emissions is an important constitutes. Noxtech has developed a system that uses NO. 2 Diesel fuel as the reductant for the PAC system reacts preferentially with oxides of nitrogen such as NO_2 to reduce them to less harmful and

unregulated compounds of nitrogen. On initial testing the system has demonstrated it can produce over 90% NO_2 conversion in catalytic reactor.

In conclusions Noxtech has demonstrated all the critical elements of a Plasma Assisted catalyst system, which are required for a successful commercial product. Although much developmental work is required to demonstrate a commercially capable prototype initial system works well. Further more Noxtech has demonstrated a practical Plasma Assisted catalyst system. With additional design and development the Plasma Assisted system can be made into a commercial device to treat NOx and PM from lean (diesel) exhaust.

Next year Noxtech's plans to fully integrate the 80 HP PAC system with a solid state supply with a matched plasma reactor and to make the 80 HP PAC system available for third party testing. Additionally Noxtech plans to successfully scale the 80-Hp PAC system to 200-250 HP system

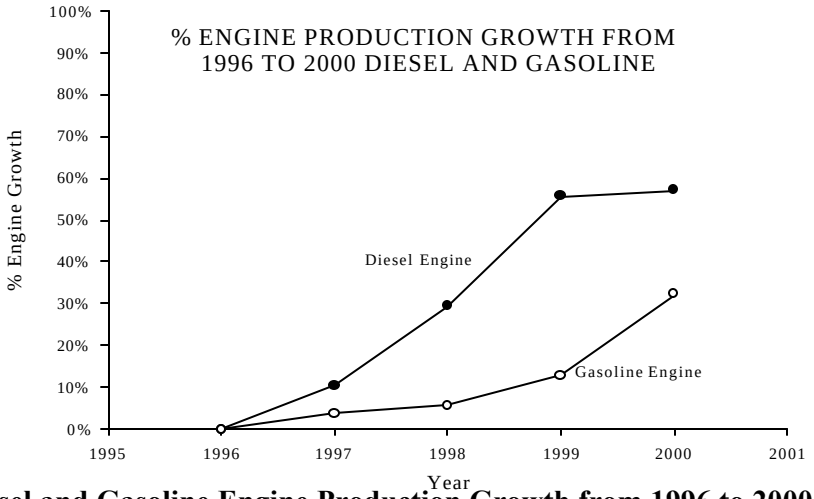

Figure 1: Diesel and Gasoline Engine Production Growth from 1996 to 2000 in North America

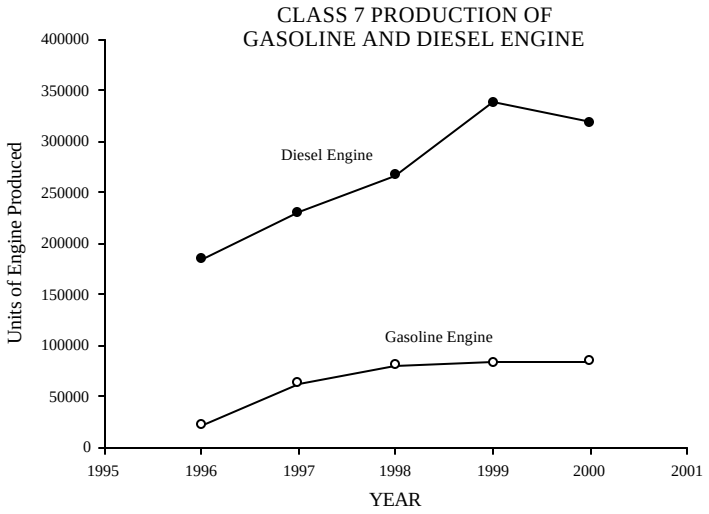

Figure 2: Class 7 Engine production from 1996 to 2000

FIGURE 3: NOXTECH'S 80 HP ADVANCE PLASMA ASSISTED CATALYST SYSTEM

FIGURE 4: SOLID-STATE POWER SUPPLY FOR THE 80-HP PAC SYSTEM

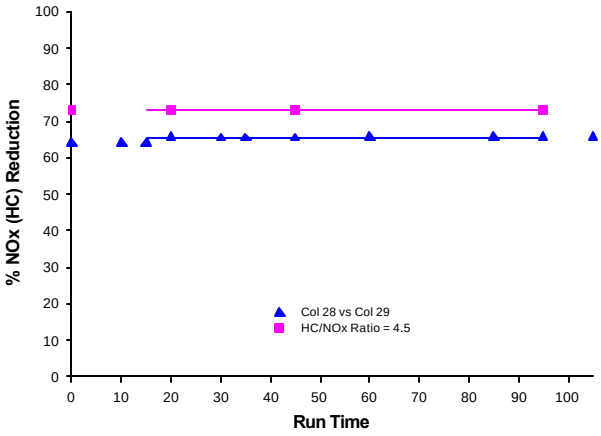

FIGURE 5: STEADY STATE TESTING OF NOXTECH'S 80 HP ADVANCE PAC SYSTEM

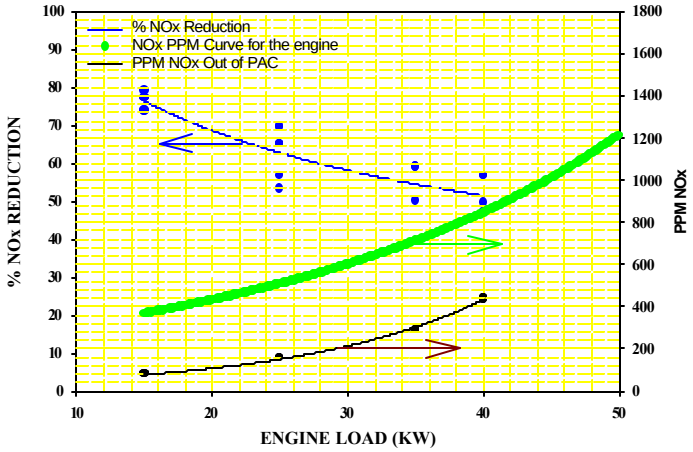

FIGURE 6: LOAD TESTING OF NOXTECH'S ADVANCE 80-HP PAC SYSTEM

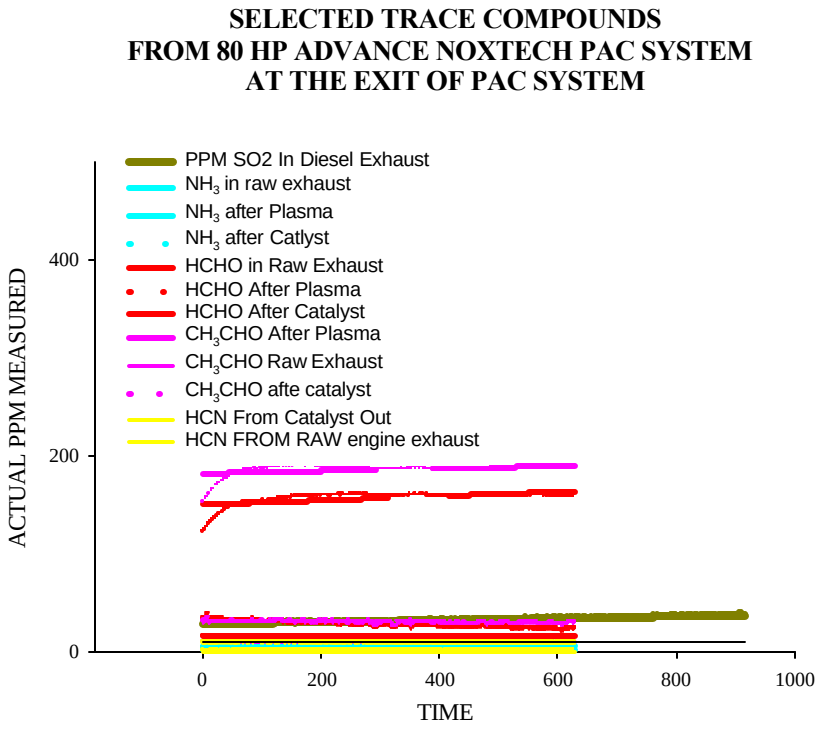

FIGURE 7: TRACE COMPOUND MEASURED FROM 80-HP PAC SYSTEM USING NICOLET 550 FTIR