VEHICULAR EMISSION CONTROL TECHNIQUES

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Abstract— The catastrophe is nearing. If the two World war is between human being then the third one is between human being and the nature. The biggest Problem of the 21st century is the greenhouse effects which have their source in the vehicular emission. Vehicular emission contains primary greenhouse gases- carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other pollutants- carbon monoxide (CO), total nitrogen oxides (NO_X), sulfur dioxide (SO_2), and particulate matter which all are responsible for a number of adverse environmental effect such as photochemical smog, death of rain forests, acid rain, health hazards and reduced atmospheric visibility. This paper reviews the new paradigm of emission control techniques.

Keywords— Emission control, Catalyst, SCR, Fuel Injection, HCCI, Reformulation.

I. INTRODUCTION

In today's world, the Internal Combustion (IC) Engine is the key to the entire transportation sector. Without the transportation performed by the millions of vehicles on road and at the sea, we would not have reached modern living standards. Petrol and Diesel are at the present principal fuels used for IC Engines. These fuels are on the verge of getting extinct and during combustion these fuels release a substantial amount of pollutants into the atmosphere and create environment related problems. The IC Engine is known as one of the major sources of air pollutants in the environment. The fuel oxidation process in the engine generates not only useful power, but also a considerable amount of pollutant emissions including carbon dioxide (CO_2), carbon monoxide (CO), unburned hydrocarbon (HC), nitrogen oxide (NO_X), and particulate matter (PM). CO_2 is mainly responsible for the global warming issues it creates a reflective layer in the atmospherethat reflects heat from the Earth back to the Earth's surface increasing the Earth's average temperature. CO is a very dangerous substance since it reduces the oxygen carrying capacity of the blood stream. The high flame temperature generated during combustion process is responsible for NO_X formation which causes various health problems and also contributes to acid rain and global warming issues. The development of efficient IC engines with low emissions is necessitated by strict regulations on exhaust gas composition and fuel economy. Increasing concern over the potential global warming effects, reducing the exhaust emissions and increasing the fuel economy of IC engines become an important area of research.

II. EMISSION CONTROL TECHNIQUES.

Various emission control technologies exist for IC engine which can afford substantial reduction in all pollutants listed above. However depending on whether the engine is being run rich, lean or stiochiometricallyand the emission control technology used, the targeted emissions vary as do the levels of control.

III. CATALYST TECHNOLOGIES

A. Substrate& Coating Technologies

The technology of the substrates, on which the active catalyst is supported, has seen great progress. In 1974, ceramic substrates had a cell density of 200 cells per square inch (cpsi) of cross section (31 cells/cm^2) and a wall thickness of 0.012 inch or 12 mil (0.305mm). By the end of the 70's the cell density had increased through 300 to 400 cpsi and wall thickness had been reduced by 50% to 6 mil. Now 400, 600 and 900 and even 1200 cpsi substrates are available and wall thickness can be reduced to 2 mil–almost 0.05mm. This progress in ceramic and metal substrate technology has major benefits. A larger catalyst surface area can be incorporated into a given converter volume and this allows better conversion efficiency and durability. The thin wall reduce thermal capacity and limit pressure losses.

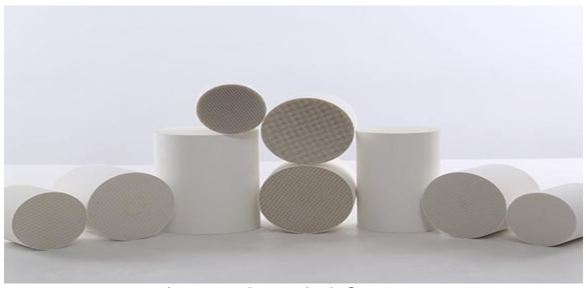

Figure 1: Ceramic Substrates.

B. Nonselective Catalytic Reduction and Three-Way Catalysts

NSCR has been used to control NO_X emissions from rich-burn engines for over 15 years. The systems have demonstrated the ability to achieve greater than 98 percent reduction. Over 3000 rich burn IC engines have been equipped with NSCR technology in the U.S alone. Engines in excess of 250hp have been equipped with NSCR. In the presence of CO and

NMHC in the engine exhaust, the catalyst converts NO_X to nitrogen and oxygen. NSCR reduces NO_X, CO, and NMHC emissions if an engine is operated stoichiometrically. NSCR used in this manner is defined as a three-way conversion catalyst. Three-Way catalysts are the main auto catalyst technology used to control emission from gasoline engines. The catalyst uses a ceramic or metallic substrate with an active coating incorporating alumina, ceria and other oxides and combination of the precious metals-platinum, palladium and rhodium. Three-way catalysts operate in closed-loop system including a lambda or oxygen sensor to regulate the air-to-fuel ratio on gasoline engines. The catalyst can then simultaneously oxidize CO and HC to CO_2 and water while reducing NO_X to nitrogen.

C. Selective Catalytic Reduction

SCR was originally developed and used to reduce NO_X emissions from coal, oil, gas fired power stations, marine vessels and stationary diesel engines. SCR technology permits the NO_X reduction reaction to take place in an oxidizing atmosphere. It is called "Selective" because the catalytic reduction of NO_X with ammonia (NH_3) as a reductant occurs preferentially to the oxidation of NH_3 with oxygen. The reaction that occurs over the catalyst bed using ammonia is as follows:

$$4NO+4NH_3+O_2 \rightarrow 4N_2+6H_2O$$

$$2NO_2+4NH_3+O_2 \rightarrow 3N_2+6H_2O$$

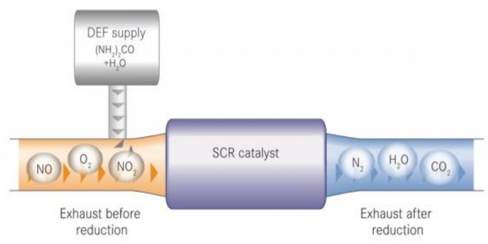

Figure 2: Selective Catalytic Reduction (SCR)

In Europe SCR technology is now fitted to most new heavy-duty diesel vehicles (i.e. truck and bus) and non-road mobile machinery such as construction equipment. A growing number of diesel light-duty vehicles and passenger cars are also equipped with SCR systems. The efficiency of SCR for NO_Xreduction also offers a benefit for fuel consumption. It allows diesel engine developers to take advantage of the trade-off between NO_X, PM and fuel consumption and calibrate the engine in a lower area of fuel consumption than if they had to reduce $NO_X$by engine measures alone. Particulate emissions are also lowered and SCR catalytic converters can be used alone or in combination with a particulate filter.

D. Oxidation Catalysts

Oxidation catalysts have been used on off-road mobile source lean-burn engines for almost 30 years. More recently, they have been applied to on-road lean-burn engines as well. In fact, over 350,000 oxidation catalysts were equipped to on-road diesel engines in 1994 alone. In the U.S, over 500 stationary lean-burn IC engines have been outfitted with oxidation catalysts. Oxidationcatalysts contain precious metals impregnated onto a high geometric surface area carrier and are placed in the exhaust stream. They are very effective in controlling CO and NMHC emissions. CO can be reduced by greater than 98 percent and NMHC emissions can be reduced by over 90 percent. They are also used to reduce particulate emissions of diesel engines by oxidizing the soluble organic fraction of the particulate reduction of over 30 percent can be achieved.

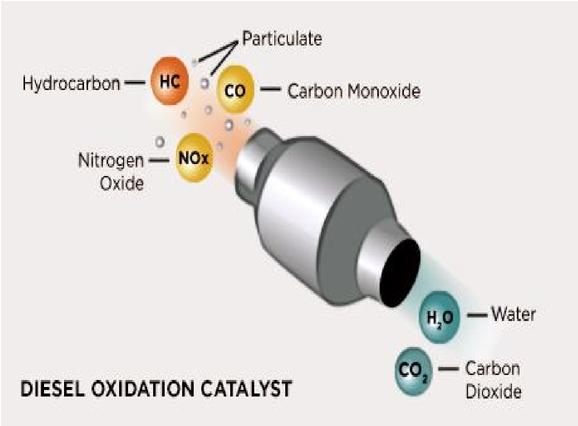

Figure 3: Oxidation Catalyst

E. Lean NO_X Catalyst

A small amount of diesel fuel (equivalent to approximately a three percent fuel penalty) can be injected upstream of the catalyst to provide the additional hydrocarbons needed to significantly reduce NO_X emissions. At the same time, CO and NMHC emissions are reduced dramatically. Although a relatively new technology, one stationary diesel engine has been equipped with a Lean-NO_X catalyst and NO_X emissions are being reduced by 80 percent, CO by 60 percent and NMHC emissions by 60 percent.

IV.MODIFICATION IN ENGINE DESIGN

Engine modification relate to changing the combustion process itself to reduce the formation of emissions. However, changes which decrease NO_X often increase the engine-out emissions of PM, and vice versa. For example, lowering the maximum temperature reached during combustion reduces NO_X emissions, but inhibits the complete oxidation of soot, thereby increasing particulate emissions. This is known as NO_X-PM tradeoff and presents a critical challenge to diesel emission reduction strategies. Changing the engine parameters may also effects fuel economy, requiring the optimization of NO_X,PM, and fuel economy for the specific application.

Potential NO_X and PM Emission Reductions through Engine Modifications

Technology	Reduction Potential NO_X	Reduction Potential PM	Issues
Combustion cylinder Alternations	10%	10%	
Increased EGR	5 to 15%	Increase	Unstable combustion, engine wear, packaging
EGR with improved air handling	5 to 15%	15 to 25%	Fuel economy
Fuel Injection Systems	(-5) to 0%	20%	Cost, complexity
Total Engine Modification	10 to 25%	40 to 50%	NO_x-PM trade-off/optimization.
HCCI combustion	65 to 70%	60 to 95%	Difficult to operate over all loads and speeds

Sources: Arcoumanis and Schindler 1997; Dickey et al. 1998; Georgi et al. 1997, Heywood 1988; Krieger et al. 1997.

A. Fuel Injection Strategies

Advanced fuel injection systems are a major enabler for diesel engines. New systems must allow for high fuel injection pressures (up to 1500 to 2000 times atmospheric, while traditional pump systems reach a maximum of about 900 times atmospheric) and flexible injection rate shaping while meeting demanding durability, cost, and packaging constraints. High fuel injection pressures reduce particulate emissions by forcing smaller droplets in the fuel spray (called fuel atomization), which increases air-fuel mixing. Traditional injection systems build up the pressure for each injection using pumps powered directly by the engine, so that the pressure available for injection is limited by the engine speed. Such systems cannot reach sufficiently high pressures during all driving modes to achieve substantial emissions reductions.

Injection Rate Shaping: With injection rate shaping, the fuel flow is varied during the injection period, effectively tailoring the injection event to achieve low emissions. One example is Pilot Injection, in which a very small amount of the fuel is injected early, allowing for a smaller and more delayed main injection event and reduced NO_X emissions. Post injections are a second type of rate shaping in which a small quantity of fuel is injected very late in the expansion stroke. This provides hydrocarbon supplementation to the exhaust stream, allowing for more efficient exhaust control technologies.

Common Rail Injection System: At the forefront of advanced injection technologies is the common rail system. These systems have one reservoir of pressurized fuel (called the rail) available to the injectors at all times, regardless of engine load or speed. Current technology allows for stable pilot injections as well as injection pressures up to 1000 bar, at engine speeds as low as 1500 rpm (Ashley 1997). However, such high pressures create the potential for accidental fuel leaks and the need for highly precise manufacturing-making the common rail an expensive technology that can account for up to 30-40% of the total engine cost (Ashley, 1997).

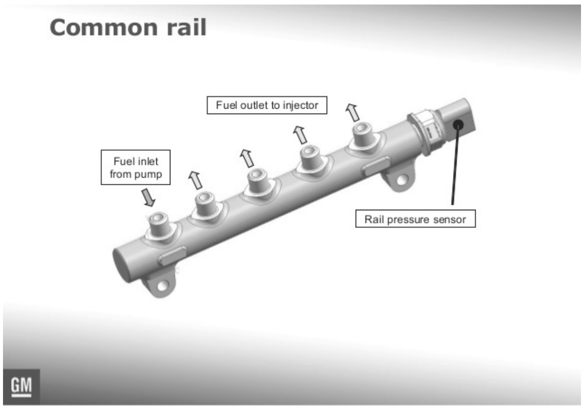

Figure 4: Common Rail System

B. Exhaust Gas Recirculation

EGR process involves by passing a calculated volume (mass) of engine out exhaust back to engine to mix with fresh intake. Exhaust gases mainly consists of CO_2 and H_2O, which are already combusted during previous cycle, they do not burn again when they are recirculate. However, the recycled gases act as a diluent, which reduces the peak gas temperatures and hence lowers the NO_X emissions (Heywood 1988). The recycled gases may also be cooled (called cooled EGR) to further reduce NO_X emissions, but this adds to the cost and complexity of the engine plumbing (Krieger et al.1998). EGR is defined as a mass per cent of total intake flow,

EGR= $[m_{EGR}/m_i] \times 100$ %, Where “i” is the total mass flow into the engine.

Typically, only about 5 to 10 % EGR rates are employed. At higher EGR rates, frequency of partial and complete misfire cycles increases resulting in unacceptably higher HC emissions and loss in fuel economy and power. EGR systems are made to operate mostly in the part-load range. These are deactivated at engine idle, because large amount of residual gas is already present in the cylinder. Many times the system is deactivated at full throttle conditions as the vehicle rarely operates under these conditions during city operation.

A schematic layout of EGR system is shown in Fig. An EGR control valve is used to regulate flow of EGR depending upon engine operating conditions. The intake manifold pressure or exhaust back pressure may be used to control EGR rate as these parameters vary with engine load. In the modern engines, EGR rate is controlled by the engine electronic control unit. A pressure sensor in the exhaust or intake provides signal to the electronic control module of the engine, which in its turn regulates the operation of the EGR valve.

Electronically controlled EGR valves actuated by high-response stepper motor are being used onmodern engines. Their fast response during transient operation makes it possible to reduce NO_X more than what is obtained by use of a mechanically controlled EGR valves. Effectively a lower rate of EGR can be employed to obtain the same reduction in NO_X that result in a lower penalty on HC emissions.

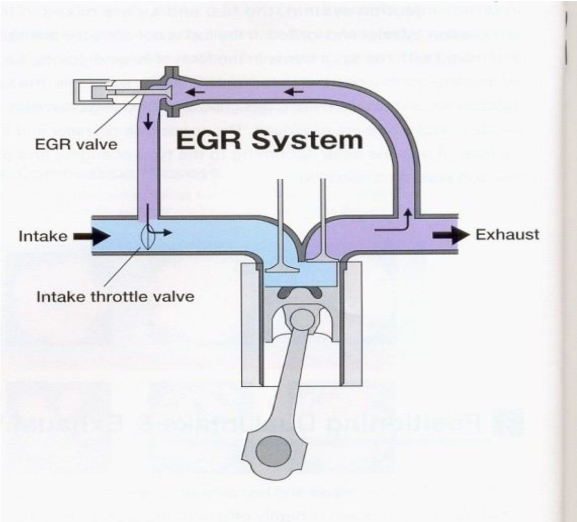

Figure 5: Exhaust Gas Recirculation.

C. Homogenous Charge Compression Ignition (HCCI)

Engine emissions remain a critical issue affecting the design and operation of IC engines while energy conservation is becoming increasingly important. One approach to favorably address these issues is to achieve homogeneous charge combustion at lower peak temperatures with a high compression ratio which is the ultimate goal of Homogeneous Charge Compression Ignition (HCCI) engines.The HCCI is considered as an alternative to the SI and CI engines due to its capability of producing very low NO_X and operating with higher efficiency, combining the advantages of both the engines. The HCCI concept involves premixing of fuel and air prior to its induction into the cylinder (as is done in the present SI engine) then igniting the fuel-air mixture through the compression process (as is done in current diesel engines). The combustion occurring in an HCCI engine is fundamentally different from that in an SI or diesel engine.Since there is no flame propagation, the air-fuel mixture can be made very lean. The lean mixture burns at a lower temperature compared to a stoichiometric mixture, resulting in significantly less NO_X emissions.

Researchers at Nissan have successfully applied HCCI technology to Nissan's new 4-valve per cylinder direct injection diesel engine series utilizing a common rail injection system. While the engine does not appear to operate in HCCI mode under high loads (and thus does not exhibit NO_X and PM reductions at high loads), the research suggests promising methods for expanding the region of HCCI combustion to higher load conditions. At low load operating conditions, simultaneous reduction of NO_X and PM, without an increase in fuel consumption was observed (Kimura et al. 1998). Nissan has successfully tested the engine over the Japanese driving cycles, but it should be noted that US driving cycles feature higher load conditions than Japanese cycles.

V. MODIFICATION / REFORMULATION OF THE FUELS

Automobile engines and fuels are often considered distinct components by drivers. However, a more accurate view considers the two as one system, because the performance and emissioncharacteristics of an engine are closely linked to fuel properties. Here we discuss the effects of diesel fuel parameters and alternative fuels on compression ignition engine emissions. Potential emission reductions associated with fuel reformulations are listed Table.

Fuel Reformulation	Reduction Potential		Infrastructure Implications
	NO_X	PM	
Petroleum diesel			
a. Increase cetane	0-5%	-	R
b. Decrease density	modest	modest	R
c. Decrease aromatics	0-5%	-	R
d. Decrease sulfur	-	6-12%	R
Alternatives Fuels:			
Neat (BD100)[4]	(-15)-0%	15-25%	NP
20% blend (BD20)	(-5)-0%	5-20%	NP
Dimethyl Ether (DME),neat	50-75%	70-95%	NP,D
Dimethoxy Methane (DMM), 15-30% blends	-	30-70%	NP
Diesel-water emulsifications	1-30%	-	D
R: will require changes and capital investments to oil refineries. NP: will require new production facilities. D: will require changes/additions to the fuel distribution network.			
Sources: Dickey et al. 1998; AFDC 1997; Peckham 1997a; Graboski and McCormick 1997;			

CONCLUSIONS

Emission from mobile sources have raised health and environmental concerns, but a number of technologies exist that can greatly reduce NO_X, CO, NMHC and PM emissions from IC Engines.

Continuous improvement in substrate and coating technologies, as part of an integrated system comprising electronic control, fuel quality and other modification in engine design, allows meeting more and more stringent combustion engines emissions legislations under a wide range of engine operating conditions. The future Euro VI levels are set to 0.08g/kg, indicating remarkable 55% reductions from present Euro V norms for passenger cars and above 75% for heavy duty vehicles. This fact implies that NO reduction is very critical. Research attempts should emphasize and focus on effective techniques to meet the Euro VI standards in general and Euro V standards for India in particular (EPA-2004).

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