

Exhaust Emissions and Its Control Technology for an Internal Combustion Engine

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ABSTRACT

The automobiles play an important role in the transport system. With an increase in population and living standard, the transport vehicles as well as car population is increasing day by day. In addition to this there is steep increase in the number of two wheelers during the last two decades. All these are increasing exhaust pollution and particularly in metros as density of these vehicles in metros are very high.

The main pollutants contributed by I.C. engines are CO, NOX unburned hydro-carbons (HC) and other particulate emissions. Other sources such as Electric power stations industrial and domestic fuel consumers also add pollution like NOX, SO₂ and particulate matters. In addition to this, all fuel burning systems emit CO₂ in large quantities and this is more concerned with the Green House Effect which is going to decide the health of earth.

Lot of efforts are made to reduce the air pollution from petrol and diesel engines and regulations for emission limits are also imposed in USA and in a few cities of India. An extensive analysis of energy usage and pollution shows that alternative power systems are still a long way behind the conventional ones. Further developments in petrol and diesel engines, combined with improvements in the vehicles, will make fuel consumption reduction of 40% or more in the future cars. This, in turn, will reduce the CO₂ emissions, a gas which is responsible for greenhouse effect.

Keywords: Exhaust pollution, Hydro-carbons, NO_x emission, Petrol engines, diesel engines, CO Emissions, SO₂ Emissions, CO₂ Emissions, Particulate matters, Green house effect .

I. Introduction

Undesirable emissions in internal combustion engines are of major concern because of their negative impact on air quality, human health, and global warming. Therefore, there is a concerted effort by most governments to control them. Undesirable emissions include unburned hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM), we present the U.S. and European emissions standards, both for gasoline and diesel operated engines, and strategies to control the undesirable

emissions. The role of engine design, vehicle operating variables, fuel quality, and emission control devices in minimizing the above-listed pollutants are also detailed. "Emissions" is a collective term that is used to describe the undesired gases and particles which are released into the air or emitted by various sources. Its amount and the type change with a change in the industrial activity, technology, and a number of other factors, such as air pollution regulations and emissions controls. The U.S. Environmental Protection Agency (EPA) is primarily concerned with emissions that are or can be harmful to the public at large. EPA considers carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO₂), ozone (O₃), particulate matter (PM), and sulphur dioxide (SO₂) as the pollutants of primary concern, called the Criteria Pollutants. These pollutants originate from the following four types of sources. 1. Point sources, which include facilities such as factories and electric power plants. 2. Mobile sources, which include cars and trucks but also lawn mowers, airplanes, and anything else that moves and releases pollutants into the air. 3. Biogenic sources, which include trees and vegetation, gas seeps, and microbial activity. 4. Area sources, which consist of smaller stationary sources such as dry cleaners and degreasing operations.

Gasoline and diesel fuels are mixtures of hydrocarbons, compounds which contain hydrogen and carbon atoms. In a "perfect" engine, oxygen in the air would convert all the hydrogen in the fuel to water and all the carbon in the fuel to carbon dioxide. Nitrogen in the air would remain unaffected. In reality, the combustion process cannot be "perfect," and automotive engines emit several types of pollutants.

II. "Perfect" Combustion

FUEL (hydrocarbons) + AIR (oxygen and nitrogen)

CARBON DIOXIDE + water + unaffected nitrogen

Typical Engine Combustion:

FUEL + AIR UNBURNED HYDROCARBONS +

NITROGEN OXIDES

+ CARBON MONOXIDE + CARBON DIOXIDE +

water

III. Exhaust Pollutants

• HYDROCARBONS

Hydrocarbon emissions result when fuel molecules in the engine do not burn or burn only partially. Hydrocarbons react in the presence of nitrogen oxides and sunlight to form ground-level ozone, a major component of smog. Ozone irritates the eyes, damages the lungs, and aggravates respiratory problems. It is our most widespread and intractable urban air pollution problem. A number of exhaust hydrocarbons are also toxic, with the potential to cause cancer.

• NITROGEN OXIDES (NO_x)

Under the high pressure and temperature conditions in an engine, nitrogen and oxygen atoms in the air react to form various nitrogen oxides, collectively known as NO_x. Nitrogen oxides, like hydrocarbons, are precursors to the formation of ozone. They also contribute to the formation of acid rain.

• CARBON MONOXIDE

Carbon monoxide (CO) is a product of incomplete combustion and occurs when carbon in the fuel is partially oxidized rather than fully oxidized to carbon dioxide (CO₂). Carbon monoxide reduces the flow of oxygen in the blood stream and is particularly dangerous to persons with heart disease.

• CARBON DIOXIDE

In recent years, the U.S. Environmental Protection Agency (EPA) has started to view carbon dioxide, a product of "perfect" combustion, as a pollution concern. Carbon dioxide does not directly impair human health, but it is a "greenhouse gas" that traps the earth's heat and contributes to the potential for global warming.

Evaporative Emissions

Hydrocarbon pollutants also escape into the air through fuel evaporation. With today's efficient exhaust emission controls and today's gasoline formulations, evaporative losses can account for a majority of the total hydrocarbon pollution from current model cars on hot days when ozone levels are highest. Evaporative emissions occur several ways:

DIURNAL: Gasoline evaporation increases as the temperature rises during the day, heating the fuel tank and venting gasoline vapours.

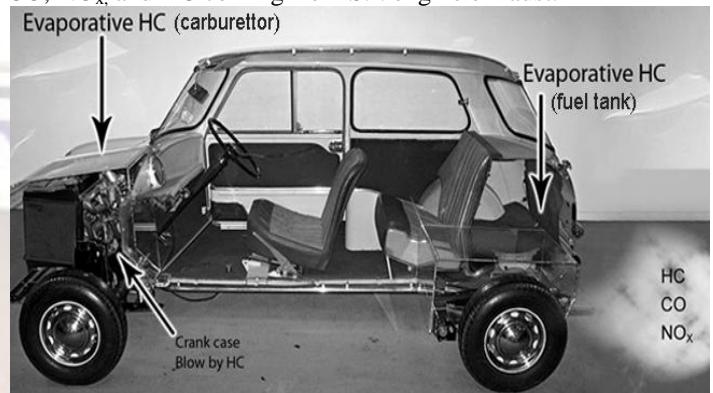
RUNNING LOSSES: The hot engine and exhaust system can vaporise gasoline when the car is running.

HOT SOAK: The engine remains hot for a period of time after the car is turned off, and gasoline evaporation continues when the car is parked.

REFUELING: Gasoline vapours are always present in fuel tanks. These vapours are forced out when the tank is filled with liquid fuel.

Si engine emissions

S.I. engine emissions are divided into three categories as exhaust emission, evaporative emission and crank case emission. The major constituents which contribute to air pollution are CO, NO_x, and HC coming from S.I. engine exhaust.



The relative amounts depend on engine design and operating conditions but are of order, NO_x -> 500-1000 ppm (20 gm/kg of fuel), CO -> 122% (200gm/kg of fuel) and HC -> 43000 ppm (25 gm/kg of fuel). Fuel evaporation from fuel tank and carburettor exists even after engine shut down and these are unburned hydrocarbons. However in most modern engines, these non-exhaust unburned HCs effectively controlled by returning the blow by gases from the crank case to the engine. Intake system by venting the fuel tank and a vapour absorbing carbon canister which is purged as sum of the engine intake air during normal engine operation. The order constituent includes SO₂ and lead compounds. The petrol rarely contains sulphur therefore; SO₂ is not a pollutant from s.i. engine exhaust. Petrol contains lead in small percentages but its effect is more serious on human health. Therefore Delhi govt has restricted the use of petrol without lead. One of the most important variables in determining S.I. emission is the fuel air equivalence ratio. The SI engine is always operated at stoichiometric or slightly rich mixture. At the starting of the engine, very rich mixture is supplied as vaporization is very slow. Thus, until the engine warms up and this enrichment is stopped, CO and HC emissions are high. At part load conditions, lean mixture can be used which will reduce HC and CO emissions and moderate NO_x emissions. Use of recycled exhaust to dilute the engine intake mixture lowers the NO_x level but deteriorates combustion quality. Exhaust gas recirculation (EGR). Method is used with stoichiometric mixtures in many engines to reduce emissions. The sources of pollution are mainly three as mentioned earlier, the engine exhaust, (CO,

NO_x , HC), the crankcase breather (HC) and direct evaporation of petrol from carburettor and fuel tank particularly in hot weather(HC).

CI engine emissions



Diesel combustion is heterogeneous in nature, unlike spark-ignited engines where the combustible mixture is predominantly homogeneous. In diesel engines fuel is injected into a cylinder filled with high temperature compressed air. Emissions formed as a result of burning this heterogeneous air/fuel mixture depend on the prevailing conditions not only during combustion, but also during the expansion and especially prior to the exhaust valve opening. Mixture preparation during the ignition delay, fuel ignition quality, residence time at different combustion temperatures, expansion duration, and general engine design features play a very important role in emission formation. In essence, the concentration of the different emission species in the exhaust is the result of their formation, and their reduction in the exhaust system. Incomplete combustion products formed in the early stages of combustion may be oxidized later during the expansion stroke. Mixing of unburned hydrocarbons with oxidizing gases, high combustion chamber temperature, and adequate residence time for the oxidation process permit more complete combustion. In most cases, once nitric oxide (NO) is formed it is not decomposed, but may increase in concentration during the rest of the combustion process if the temperature remains high.

IV. Euro norms

The exhaust gases from IC engines mainly contain unburned hydrocarbons(HC),carbon mono oxide(CO), and nitrogen oxides(NO_x), which are mainly responsible for air pollution which cause health hazards and bad effects on the crops also. Therefore, the govt. has imposed on emission standards which limit the amount of each pollution emitted by the engine into the atmosphere. The govt. of India has accepted the emission norms laid down

by European countries and these are known as “Euro- Norms”

Table 1 Vehicle emission performance standard

Standard	Reference	Date	Region
India 2000	Euro 1	2000	Nationwide
Bharat Stage II	Euro 2	2001	NCR^* , Mumbai, Kolkata, Chennai
		2003.04	NCR^* , 12 Cities†
		2005.04	Nationwide
Bharat Stage III	Euro 3	2005.04	NCR^* , 12 Cities†
		2010.04	Nationwide
Bharat Stage IV	Euro 4	2010.04	NCR^* , 12 Cities†

* National Capital Region (Delhi)

† Mumbai, Kolkata, Chennai, Bengaluru, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, Lucknow, Sholapur, and Agra

The above standards apply to all new 4-wheel vehicles sold and registered in the respective regions. In addition, the National Auto Fuel Policy introduces certain emission requirements for interstate buses with routes originating or terminating in Delhi or the other 10 cities.

V. Trucks and buses

Emission standards for new heavy-duty diesel engines—applicable to vehicles of $\text{GVW} > 3,500 \text{ kg}$ —are listed. Emissions are tested over the ECE R49 13-mode test (through the Euro II stage) Emission Standards for Diesel Truck and Bus Engines, g/kWh

Year	Reference	CO	HC	NOx	PM
1992	-	17.3-32.6	2.7-3.7	-	-
1996	-	11.20	2.40	14.4	-
2000	Euro I	4.5	1.1	8.0	0.36*
2005†	Euro II	4.0	1.1	7.0	0.15
2010†	Euro III	2.1	0.66	5.0	0.10

* 0.612 for engines below 85 kW

† earlier introduction in selected regions,

VI. Light duty diesel vehicles

Emission standards for light-duty diesel vehicles ($\text{GVW} \leq 3,500 \text{ kg}$) are summarized in

Table 3. Ranges of emission limits refer to different classes (by reference mass) of light commercial vehicles; compare the EU light-duty vehicle emission standards page for details on the Euro 1 and later standards. The lowest limit in each range applies to passenger cars (GVW ≤ 2,500 kg; up to 6 seats).

Table 3 Emission Standards for Light-Duty Diesel Vehicles, g/km

Year	Reference	CO	HC	HC+NOx	PM
1992	-	17.3-32.6	2.7-3.7	-	-
1996	-	5.0-9.0	-	2.0-4.0	-
2000	Euro 1	2.72-6.90	-	0.97-1.70	0.14-0.25
2005†	Euro 2	1.0-1.5	-	0.7-1.2	0.08-0.17

† earlier introduction in selected regions

Emissions were measured over an Indian test cycle.

Engines for use in light-duty vehicles can be also emission tested using an engine dynamometer. The respective emission standards are listed in Table 4.

Table 4 Emission Standards for Light-Duty Diesel Engines, g/kWh

Year	Reference	CO	HC	NOx	PM
1992	-	14.0	3.5	18.0	-
1996	-	11.20	2.40	14.4	-
2000	Euro I	4.5	1.1	8.0	0.36*
2005†	Euro II	4.0	1.1	7.0	0.15

* 0.612 for engines below 85 kW

† earlier introduction in selected regions, see Table 1

Light duty gasoline vehicles

4-wheel vehicles

Emissions standards for gasoline vehicles (GVW ≤ 3,500 kg) are summarized in Table 5. Ranges of emission limits refer to different classes of light commercial vehicles. The lowest limit in each range applies to passenger cars (GVW ≤ 2,500 kg; up to 6 seats).

Table 5 Emission Standards for Gasoline Vehicles (GVW ≤ 3,500 kg), g/km

Year	Reference	CO	HC	HC+NOx
1991	-	14.3-27.1	2.0-2.9	-
1996	-	8.68-12.4	-	3.00-4.36

1998*	-	4.34-6.20	-	1.50-2.18
2000	Euro 1	2.72-6.90	-	0.97-1.70
2005†	Euro 2	2.2-5.0	-	0.5-0.7

* for catalytic converter fitted vehicles

† earlier introduction in selected regions, see Table 1

VII. 3- and 2-wheel vehicles

Emission standards for 3- and 2-wheel gasoline vehicles are listed in the following tables.

Table 6 Emission Standards for 3-Wheel Gasoline Vehicles, g/km

Year	CO	HC	HC+NOx
1991	12-30	8-12	-
1996	6.75	-	5.40
2000	4.00	-	2.00
2005 (BS II)	2.25	-	2.00

Table 7 Emission Standards for 2-Wheel Gasoline Vehicles, g/km

Year	CO	HC	HC+NOx
1991	12-30	8-12	-
1996	5.50	-	3.60

VIII. Overview of the emission norms in India

1991 - Idle CO Limits for Gasoline Vehicles and Free Acceleration Smoke for Diesel Vehicles, Mass Emission Norms for Gasoline Vehicles.

1992 - Mass Emission Norms for Diesel Vehicles.

1996 - Revision of Mass Emission Norms for Gasoline and Diesel Vehicles, mandatory fitment of Catalytic Converter for Cars in Metros on Unleaded Gasoline.

1998 - Cold Start Norms Introduced.

2000 - India 2000 (Eq. to Euro I) Norms, Modified IDC (Indian Driving Cycle), Bharat Stage II Norms for Delhi.

2001 - Bharat Stage II (Eq. to Euro II) Norms for All Metros, Emission Norms for CNG & LPG Vehicles.

2003 - Bharat Stage II (Eq. to Euro II) Norms for 11 major cities.

2005 - From 1 April Bharat Stage III (Eq. to Euro III) Norms for 11 major cities.

2010 - Bharat Stage III Emission Norms for 4-wheeler for entire country whereas Bharat Stage IV (Eq. to Euro IV) for 13 major cities. Bharat Stage IV also has norms on OBD (similar to Euro III but diluted)

Emission Standards

The NOx and PM Law introduces emission standards for specified categories of in-use highway vehicles including commercial goods (cargo) vehicles such as trucks and vans, buses, and special purpose motor vehicles, irrespective of the fuel type. The regulation also applies to diesel powered passenger cars (but not to gasoline cars).

In-use vehicles in the specified categories must meet 1997/98 emission standards for the respective new vehicle type (in the case of heavy duty engines NOx = 4.5 g/kWh, PM = 0.25 g/kWh). In other words, the 1997/98 new vehicle standards are retroactively applied to older vehicles already on the road. Vehicle owners have two methods to comply:

Replace old vehicles with newer, cleaner models

Retrofit old vehicles with approved NOx and PM control devices

Vehicles have a grace period, between 9 and 12 years from the initial registration, to comply. The grace period depends on the vehicle type, as follows:

Light commercial vehicles (GVW \leq 2500 kg): 8 years

Heavy commercial vehicles (GVW $>$ 2500 kg): 9 years

Micro buses (11-29 seats): 10 years

Large buses (\geq 30 seats): 12 years

Special vehicles (based on a cargo truck or bus): 10 years

Diesel passenger cars: 9 years

Furthermore, the regulation allows fulfilment of its requirements to be postponed by an additional 0.5-2.5 years, depending on the age of the vehicle. This delay was introduced in part to harmonize the NOx and PM Law with the Tokyo diesel retrofit program. The NOx and PM Law is enforced in connection with Japanese vehicle inspection program, where non-complying vehicles cannot undergo the inspection in the designated areas. This, in turn, may trigger an injunction on the vehicle operation under the Road Transport Vehicle Law.

IX. Measurement techniques used to measure pollutants

Methods of gas concentration measurement:

Broadly the gas concentration methods may be classified as Non separation methods and Separation methods. In the former there is no effort made to isolate the candidate gas from the gas mixture. In the latter the candidate gas is physically separated before being measured.

(i) Non separation methods:

- (a) Non Dispersive Infrared Analysed (NDIR)
- (b) Differential Absorption LIDAR (DIAL)
- (c) Chemiluminescence NOx detection

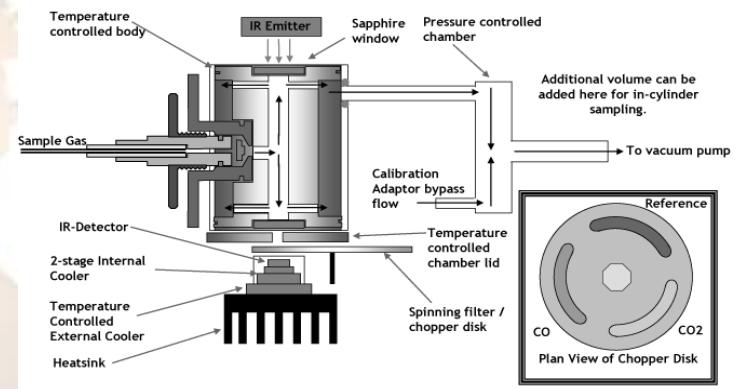
(ii) Separation methods:

- (a) Gas Chromatography
- (b) Orsat gas analyser

We shall describe a few of the methods available in these two broad categories.

(1) Non Dispersive Infrared Analysed (NDIR)

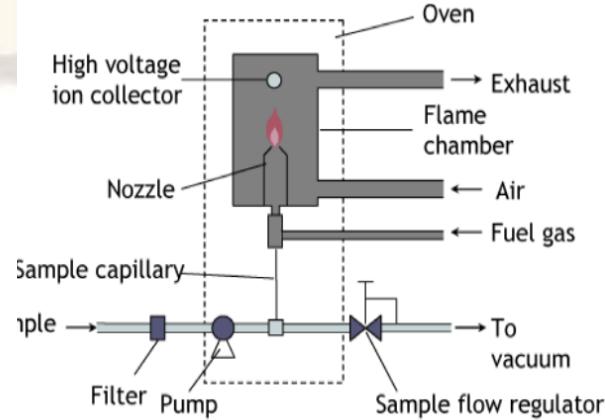
Non-Dispersive Infra-Red (NDIR) detectors are the industry standard method of measuring the concentration of carbon oxides (CO & CO₂). Each constituent gas in a sample will absorb some infra-red at a particular frequency. By shining an infra-red beam through a sample cell (containing CO or CO₂), and measuring the amount of infra-red absorbed by the sample at the necessary wavelength, NDIR detector is able to measure the volumetric concentration of CO or CO₂ in the sample. A chopper wheel mounted in front of the detector continually corrects the offset and gain of the analyser, and allows a single sampling head to measure the concentrations of two different gases. The Combustion Fast NDIR uses a unique sampling system, coupled to miniaturised NDIR technology to give millisecond response times. The Combustion Fast NDIR has two remote Sampling Heads controlled by a Main Control Unit, and is capable of sampling CO & CO₂ simultaneously in two locations.



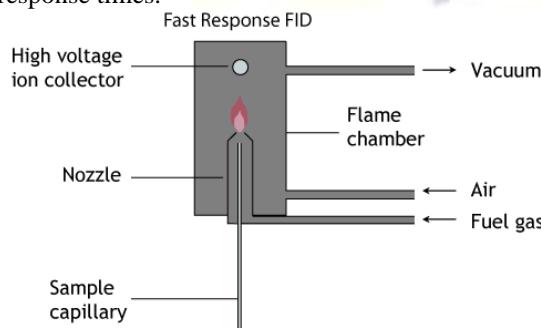
(2) Absorption bands of common gases

The flame ionisation detector (FID) is the industry standard method of measuring hydrocarbon (HC) concentration.

Standard Slow-Response FID



The sample gas is introduced into a hydrogen flame inside the FID. Any hydrocarbons in the sample will produce ions when they are burnt. Ions are detected using a metal collector which is biased with a high DC voltage. The current across this collector is thus proportional to the rate of ionisation which in turn depends upon the concentration of HC in the sample gas. The ionisation process is very rapid, so the slow time response of conventional FIDs is mainly due to sample handling. A typical slow analyser might have a response time of 1-2 seconds. The Combustion HFR fast response FID analysers use conventional detection principles and a unique patented sampling system to give millisecond response times.



The Combustion fast FID consists of a main control unit (MCU) and two remote sampling heads (which house the FIDs). The dual channel nature of the instrument enables simultaneous real-time measurement in two locations allowing, for example, evaluation of catalyst performance.

It is seen that small concentrations of the pollutant gases are measurable based on absorption of radiation of suitable wavelength even when the gas sample contains a mixture of these gases. In principle there is thus no need to separate the candidate gas from the mixture before making the measurement of concentration. One of the most popular methods is the non-dispersive infrared detection where the radiation used is broad band radiation. Just how a particular gas is detected will become clear from the discussion on the acousto-optic detector that follows. Figure shows the constructional details of an acousto-optic cell. The cell consists of a rigid vessel that contains the gas that is to be detected. Collimated infrared radiation is allowed in to the cell through a suitable window. The infrared radiation is chopped using a wheel with a set of holes arranged along the periphery of the wheel. The wheel is rotated at a constant speed using a suitable motor. A pressure transducer (usually a condenser microphone) is placed within the acousto-optic cell as shown.

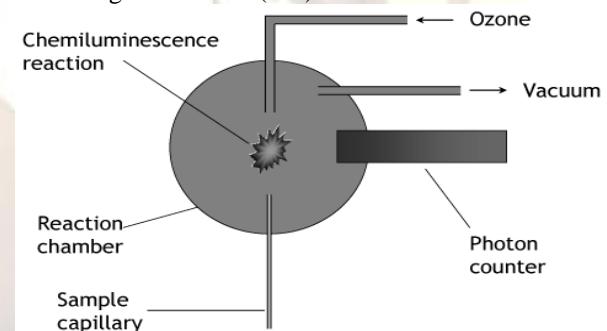
When the infrared radiation passes into the cell a part of it which is in the absorption band of the gas is absorbed by the candidate gas. This heats the gas and since the gas is confined within a rigid

vessel, the volume is held fixed and hence the pressure goes up. When the incoming radiation is chopped (it enters the cell intermittently) the pressure within the cell varies as shown schematically in Figure. The pressure transducer picks up this and generates a signal proportional to the pressure change. The pressure change is a function of the candidate gas concentration within the cell. Any way the cell is initially filled with a certain concentration of the candidate gas and sealed so that the pressure change is proportional to the amount of infrared radiation that enters it.

Now consider the situation shown in Figure where a sample cell is placed in the path of infrared radiation in front of the acousto-optic cell. The sample cell is provided with two windows that allow the infrared radiation to pass through with negligible absorption. If the sample cell contains a certain concentration of the candidate gas that is also contained in the acousto-optic cell the amount of radiation in the absorption band of the candidate passed on to the acousto-optic cell is less than when the sample cell is absent or the sample gas does not contain the candidate gas. It is thus clear that the pressure change in the acousto-optic cell is reduced in direct proportion to the concentration of the candidate gas in the sample cell.

(3) Chemi-luminescence detector (CLD)

It is the industry standard method of measuring nitric oxide (NO) concentration.



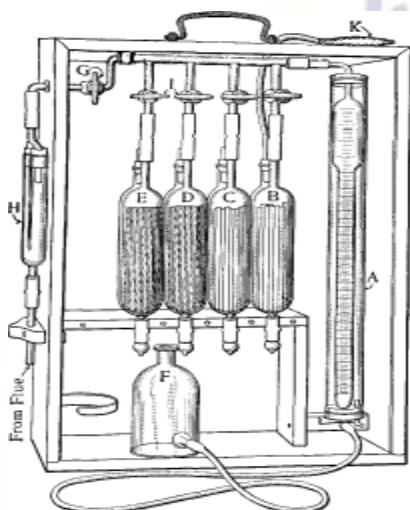
The reaction between NO and O₃ (ozone) emits light. This reaction is the basis for the CLD in which the photons produced are detected by a photo multiplier tube (PMT). The CLD output voltage is proportional to NO concentration. The light-producing reaction is very rapid so careful sample handling is important in a very rapid response instrument. The Combustion Fast CLD uses a unique sampling system coupled with miniaturised CLD technology to give millisecond response times. The Combustion Fast CLD has two remote sampling heads controlled by a Main Control Unit and is capable of simultaneous sampling in two locations.

(4) Orsat gas analyse

Construction: The apparatus consists essentially of a calibrated water-jacketed gas burette

connected by glass capillary tubing to two or three absorption pipettes containing chemical solutions that absorb the gasses it is required to measure. For safety and portability, the apparatus is usually encased in a wooden box. The absorbents are: Potassium Hydroxide (Caustic Potash)
Alkaline pyrogallol
Ammoniacal Cuprous chloride

The base of the gas burette is connected to a levelling bottle to enable readings to be taken at constant pressure and to transfer the gas to and from the absorption media. The burette contains slightly acidulated water with a trace of chemical indicator (typically methyl orange) for colouration.



Method of analysis: By means of a rubber tubing arrangement, the gas to be analysed is drawn into the burette and flushed through several times. Typically, 100mls is withdrawn for ease of calculation. Using the stopcocks that isolate the absorption burettes, the level of gas in the levelling bottle and the burette is adjusted to the zero point of the burette. The gas is then passed into the caustic potash burette, left to stand for about two minutes and then withdrawn, isolating the remaining gas via the stopcock arrangements. The process is repeated to ensure full absorption. After levelling the liquid in the bottle and burette, the remaining volume of gas in the burette indicates the percentage of carbon dioxide absorbed. The same technique is repeated for oxygen, using the pyrogallol, and carbon monoxide using the ammoniacal cuprous chloride.

X. Control of emission from SI engines

To reduce atmospheric pollution, two different approaches are followed:

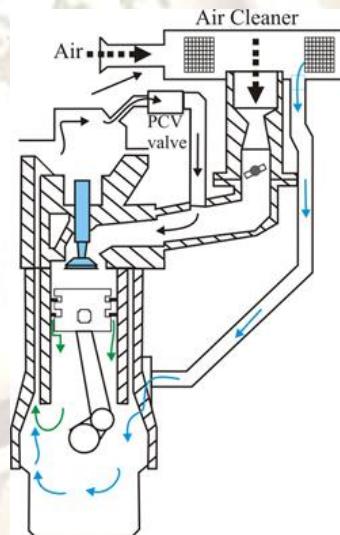
1. To reduce the formation of pollutants in the emission by redesigning the engine system, fuel system, cooling system and ignition system.
2. By destroying the pollutants after these have been formed.

In petrol engines, the main pollutants which are objectionable and are to be reduced are HC, CO and NO_x. The methods used are

Si engine control
Crankcase Emission Control (PCV System)
Evaporative Emission Control
Exhaust Gas Recirculation
Water Injection

Crankcase Emission Control (PCV System)

A small amount of charge in the cylinder leaks past piston rings into crankcase of the reciprocating engines. Near top dead centre (TDC) when the rings change their position in the grooves at the end of compression stroke, combustion has already begun and the cylinder pressures are high. A significant part of charge stored in the piston-ring-cylinder crevice leaks into the crankcase. These gases are known as 'crankcase blow by' and their flow rate increases as the engine is worn out and the piston-cylinder clearances and ring gaps increase. In the homogeneous charge engines, the crankcase blow by gas is high in HC concentration. Only a small fraction of the gas stored in the ring crevices and hence blow by gases may consist of partially burnt mixture. This source contributes about 20 per cent of total hydrocarbons emitted by an uncontrolled car.



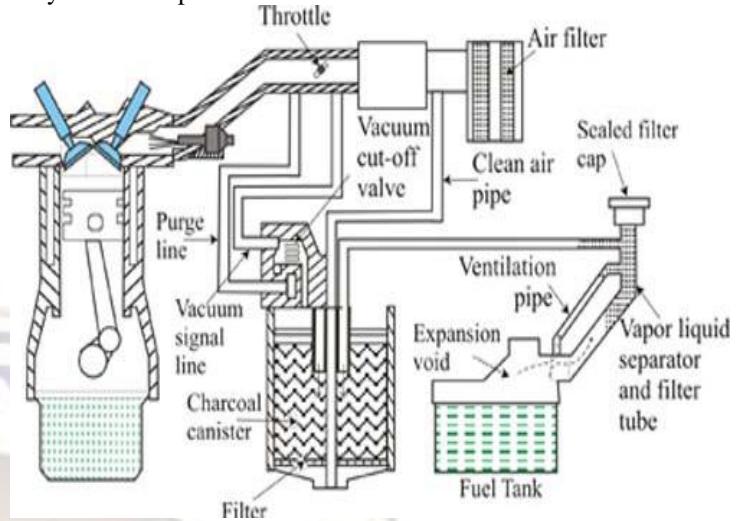
The crankcase blow by gases in the uncontrolled engines was ventilated to atmosphere under the effect of pressure difference occurring naturally between the crankcase and atmosphere. For control of crankcase emissions, the blow by gases are recycled back to the engine assisted by a positive pressure drop between the crankcase and intake manifold. When engine is running and intake charge is throttled the intake manifold is at a lower pressure than the crankcase. The blow-by gases mix with the intake charge to be burned inside the engine cylinder to CO₂ and H₂O. A typical PCV system is shown in Fig. A tube connects crankcase or cylinder head cover to the intake manifold below throttle valve, which leads the blow by gases back to the

engine. Due to suction effect of intake manifold as the pressure in the crankcase falls, ventilation air from the air cleaner is drawn into the crankcase that continuously purges it. A one-way valve (PCV valve) is used to control the flow of blow by gases. PCV valve restricts flow of blow by gases during idling and very light loads which otherwise would cause excessive leaning of the charge by ventilation air. Under normal engine operation, PCV valve is fully open providing free flow of the gases while under high intake manifold vacuum the flow is restricted.

XI. Evaporative Emission Control

In the uncontrolled vehicles, fuel vapours from the fuel tank and carburettor were vented into the atmosphere that constituted about 20% of all hydrocarbon emissions from a gasoline passenger car. From 1970, evaporative emission control was required to be employed on production gasoline vehicles in the USA. The evaporative emission control system consists of a device to store fuel vapours produced in the fuel system due to evaporation. A canister containing activated charcoal is used to store the fuel vapours. The vapours produced in the fuel tank normally collect in the fuel tank itself and are vented to the charcoal canister when fuel vapour pressure becomes excessive. The fuel vapours from the tank and carburettor lead to and adsorbed into the charcoal. In the PFI engines only the fuel tank is connected to the canister. When engine is running, the vacuum created in the intake manifold is used to draw fuel vapours from the canister into the engine. Purging air is sucked through the canister which leads the fuel vapours from canister to the engine. An electronically controlled purge valve is used. During engine acceleration additional mixture enrichment can be tolerated and under these operating conditions the stored fuel vapours are usually purged into the intake manifold. This system is a fully closed system. A sealed fuel tank filler cap is used and a stable fuel tank pressure is maintained by the purging process of the canister. A typical schematic layout of evaporative control system is shown in Fig. Given below are some of the measures adopted to achieve near zero evaporative emissions as required in California; sealed fuel tank is kept under vacuum to prevent permeation of fuel through walls of a polymer fuel tank and leakage of fuel vapours through filler cap. Fuel tubing made of high density polymer or steel to reduce/prevent fuel permeation. Better canister technology and more effective activated charcoal. Employment of refuelling vapour recovery (ORVR) system as during vehicle refuelling maximum share of fuel evaporative emissions escape. A carbon trap to arrest the escape of fuel vapours from intake manifold. When the vehicle is standing and is under

hot soak fuel vapours can escape past the throttle body into atmosphere.



XII. Exhaust Gas Recirculation

Effect of addition of diluents to the intake charge for lowering of combustion temperatures and consequently reducing the formation of NOx has been discussed in Module 2. The heat capacity of the exhaust gas is higher than the air as it contains significant amount of tri-atomic gases CO₂ and water vapours. Therefore, addition of exhaust gas to fresh intake charge has a higher effect in lowering the combustion temperatures compared to simple leaning of the charge.

EGR is defined as a mass per cent of total intake flow

$$EGR = [\dot{m}_{EGR} / \dot{m}_i] (100), \%$$

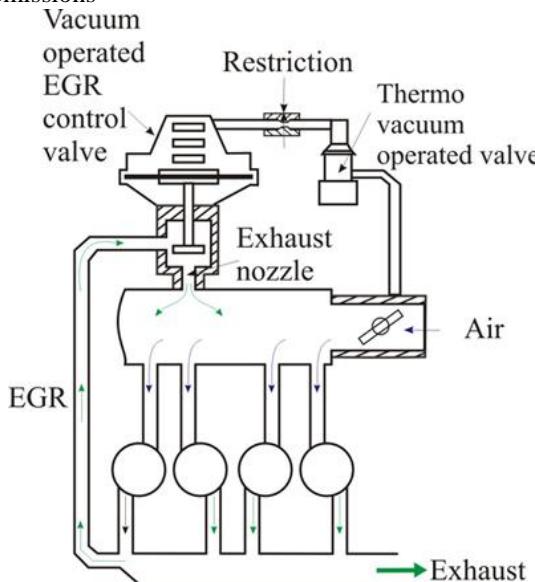
Where "i" is the total mass flow into the engine.

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 on

modern engines. Their fast response during transient operation makes it possible to reduce NOx 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 NOx that result in a lower penalty on HC emissions



XIII. Water Injection

Water has been added to the high performance, reciprocating aero SI engines during Second World War to suppress engine knock. Water addition to intake charge has been investigated by many researchers to reduce NOx formation. Water addition to intake charge is another form of charge dilution to reduce combustion temperatures.

Water has been directly injected into intake manifold or used as water-fuel emulsion. Emulsifying chemicals in about 2 per cent by volume are added to form water-gasoline emulsions. The stability of emulsion may be around a few days. The addition of emulsifiers usually reduces the fuel octane number. With water addition ranging from 10 to 30% by volume of gasoline, large reductions in NOx are possible However; high increase in HC is observed although only a slight increase in CO occurs.

Sometimes a small improvement in BSFC with small addition of water is observed but the BSFC increases with higher amounts of water addition. This approach has not been found practical due to harmful effects of water addition as HC and BSFC increase, and corrosion of engine components is also encountered.

XIV. Control of emission from diesel engine

The need to control the emissions from automobiles gave rise to the computerization of the automobile. Hydrocarbons, carbon monoxide and

oxides of nitrogen are created during the combustion process and are emitted into the atmosphere from the tail pipe. The clean air act of 1977 set limits as to the amount of each of these pollutants that could be emitted from an automobile. The manufacturers answer was the addition of certain pollution control devices and the creation of a self-adjusting engine. An oxygen sensor was installed in the exhaust system and would measure the fuel content of the exhaust stream. It then would send a signal to a microprocessor, which would analyse the reading and operate a fuel mixture or air mixture device to create the proper air/fuel ratio. PM emissions from stationary diesel engines are more of a concern than those for IC engines using other fuels. Several emission control technologies exist for diesel engine PM control. Oxidation or lean- NOx catalyst can be used to not only reduce the gaseous emissions associated with the use of diesel engines but further provide significant PM control. Likewise, diesel particulate filter systems can be used to achieve up to and greater than 90 percent PM control while in some instances, also providing reductions in the gaseous emissions. Additionally, special ceramic coatings applied to the combustion zone surfaces of the piston crown, valve faces, and head have shown the ability to significantly reduce NOx and PM emissions in diesel engines. These ceramic coatings can be used by themselves or combined with an oxidation catalyst to give even greater reduction of PM. Ceramic engine coatings change the combustion characteristics such that less dry, carbon soot, is produced. Also, when combined with an oxidation catalyst, ceramic coatings allow retarding of the engine to reduce NOx, while CO and particulates are maintained at low levels. In the case of gaseous fuels, ceramic coatings have shown the ability to allow the user to operate their engines with timing significantly advanced generating higher power levels. Also, wider ranges of fuel composition and ambient air temperature fluctuations are tolerated without the deleterious effects of pre combustion. Tests are currently underway to evaluate the effects of the coatings on specific emissions from gaseous fuelled engines. Emission control technology for stationary IC engines is currently available and can be used to provide substantial reductions in the CO, NMHC, NOx, and PM emissions from these sources in a cost effective manner.

XV. Gaseous Emission Control of Stationary IC Engines

Catalyst Control Technologies

The principle behind a catalyst for control of the gaseous emissions of a stationary IC engine is that the catalyst causes chemical reactions without being changed or consumed. An emission control catalyst system consists of a steel housing, whose

size is dependent on the size of the engine for which it is being used, that contains a metal or ceramic structure which acts as a catalyst support or substrate.

There are no moving parts, just acres of interior surfaces on the substrate coated with either base or precious catalytic metals such as platinum (Pt), rhodium (Rh), palladium (Pd), and vanadium (V) depending on targeted pollutants. Catalysts transform pollutants into harmless gases by causing chemical reactions in the exhaust stream. These reactions differ depending on the technology being used which further depends on whether the engine is operating rich, lean, or stoichiometric. In any case, emission control catalysts all serve to eliminate NOx, CO, and NMHC to varying degrees.

The selection of an emission control technology for gaseous emissions depends not only on the targeted pollutants but also the engine type and operating mode, i.e. speed and load. In some instances with rich burn engines, NOx alone may be controlled accompanied by modest, if any, reductions in CO and NMHC. Whereas in the case of stoichiometric and lean burn engines, significant reductions in all three pollutants can be achieved.

Note: NSCR - non selective catalytic reduction, SCR - selective catalytic reduction. Different emission control technologies have to be applied to stationary IC engines depending on their air to fuel ratio. This is due to the fact that the exhaust gas composition differs depending on whether the engine is operated in a rich, lean, or stoichiometric burn condition. Engine operating mode (speed and load) as it affects exhaust gas temperature also has to be considered. NSCR can achieve substantial NOx reductions for rich burn engines. This same catalyst technology is referred to as a three-way catalyst when the engine is operated at the stoichiometric point ($\phi=1$) where not only is NOx reduced but so are CO and NMHC. Conversely, lean NOx and oxidation catalysts provide little, if any, emission control in a rich-burn environment. However in a lean-burn environment, oxidation catalysts provide significant reductions in both CO and NMHC, and lean-NOx catalysts provide reductions in NOx, CO, and NMHC. Table 4 outlines the different catalyst technologies available for use on stationary IC engines and the typical reductions that can be achieved (the performance of some catalyst formulations will deviate somewhat from those shown).

XVI. Nonselective Catalytic Reduction (NSCR) and Three-way Catalysts

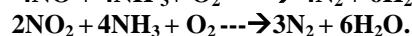
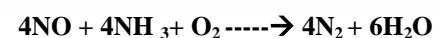
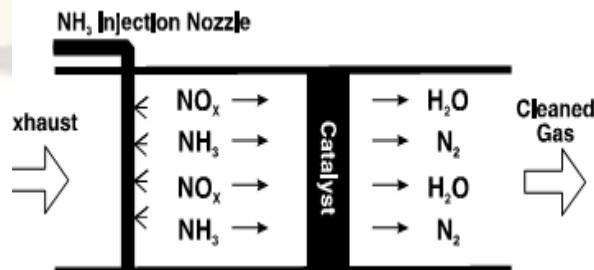
NSCR has been used to control NOx emissions from rich-burn engines for over 15 years. The systems have demonstrated the ability to achieve greater than 98 percent reduction. Over 3000 rich burn IC engines have been equipped with

NSCR technology in the U.S. alone. Engines in excess of 250 hp have been equipped with NSCR. In the presence of CO and NMHC in the engine exhaust, the catalyst converts NOx to nitrogen and oxygen, NSCR reduces NOx, CO, and NMHC emissions if an engine is operated stoichiometrically. NSCR used in this manner is defined as a three-way conversion catalyst. In order for conversion efficiencies to remain high, the air to fuel ratio must remain within a fairly narrow window of the stoichiometric point ($\phi=1$). NOx conversion efficiency drops dramatically when the engine is run in the lean regime, while NMHC and CO conversion efficiency also declines somewhat. Three-way catalysts are installed on over 1000 stationary IC engines in the U.S. and have been in use for over 10 years.

XVII. Selective Catalytic Reduction (SCR)

SCR is a method of controlling NOx emissions from lean-burn stationary IC engines. The technology was first patented in 1959 in the U.S. and has been used on over 700 NOx generating sources worldwide, some of which are stationary IC engines. Lean-burn engines are characterized by an oxygen-rich exhaust, thereby making the reduction of NOx virtually impossible using NSCR catalyst technology. However, introducing a reducing agent such as ammonia, urea, or others makes the necessary chemical reactions possible. The reactions that occur over the catalyst bed using ammonia are as follows: NOx emissions can be reduced by greater than 90 per cent. This approach is called selective catalytic reduction (SCR) because with the reducing agent present, the catalyst selectively targets NOx reduction alone. A schematic of a typical SCR system is shown in Figure 4. As shown, the reducing agent is injected upstream of the catalyst bed. The amount of reagent injected is calibrated by measuring the NOx concentration upstream of the catalyst (and possibly downstream) or by its predicted concentration knowing the engine's operating parameters.

Figure 4: Selective Catalytic Reduction



Both precious metal and base metal catalysts have been used in SCR systems. Base metal catalysts, typically vanadium and titanium, are

used for exhaust gas temperatures between 450EF and 800EF. For higher temperatures (675EF to 1100EF), zeolite catalysts may be used. Both the base metal and zeolite catalysts are sulphur tolerant for diesel engine exhaust. Precious metal SCR catalysts are useful for low temperatures (350EF to 550EF). When using precious metal SCR catalysts, attention should be paid to the fuel sulphur content and the appropriate formulation selected.

XVIII. 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. Oxidation catalysts 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. As previously shown in Table 4, CO can be reduced by greater than 98 per cent and NMHC emissions can be reduced by over 90 per cent. They are also used to reduce particulate emissions of diesel engines by oxidizing the soluble organic fraction of the particulate - reductions of over 30 per cent can be achieved. Oxidation catalysts also serve to eliminate the characteristic odour associated with diesel exhaust by oxidizing the aldehyde and acrogenic emissions.

XIX. Particulate Emission Control of Stationary IC Engines

Particulate matter (PM) emission control of stationary IC engines is a concern for diesel engines which emit a relatively high amount of particulate compared to engines using other fuels. Diesel particulate emissions are composed of a variety of compounds from fuel and lube oil combustion, as well as engine wear and sulphate from diesel fuel sulphur. The majority of the particulate consists of carbon and the soluble organic fraction (SOF) consisting of unburned fuel and unburned lube oil. Both oxidation catalysts and diesel particulate filters can be used to substantially reduce diesel PM emissions.

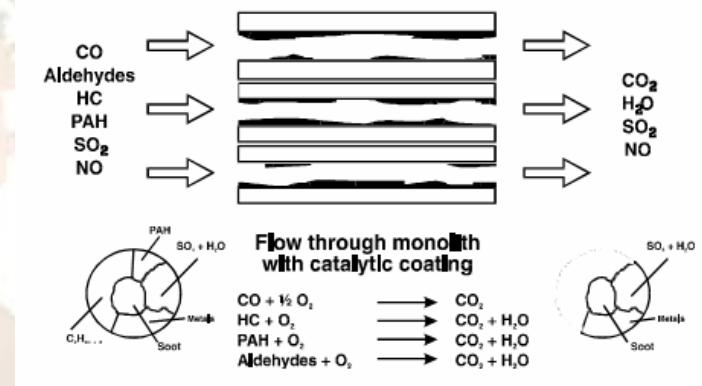
Diesel Oxidation Catalysts

Recently, a catalyst system has been approved with EPA's urban bus retrofit/rebuild program. The program requires that particulate emissions be reduced by at least 25 per cent. Other investigations reported in SAE papers substantiate that 25 per cent PM reductions are easily achieved. SAE Paper No. 900600 reported that catalysts will reduce 90 per cent of the SOF resulting in a 40 to 50 per cent reduction in total PM emissions. The

sulphur content of diesel fuel is critical to applying catalyst technology. Catalysts used to oxidize the SOF of the particulate can also oxidize sulphur dioxide to form sulphates, which is counted as part of the particulate.

Catalyst formulations have been developed which selectively oxidize the SOF while minimizing oxidation of the sulphur dioxide. However, the lower the sulphur content in the fuel, the greater the opportunity to maximize the effectiveness of oxidation catalyst technology. As for gaseous emission control, the cost of using an oxidation catalyst for PM control is approximately \$9-10/bhp. As noted earlier, 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 150 stationary diesel engines have been outfitted with oxidation catalysts.

DIESEL OXIDATION CATALYST Functional Diagram



Diesel Particulate Filters (DPF) or Trap Oxidizer System

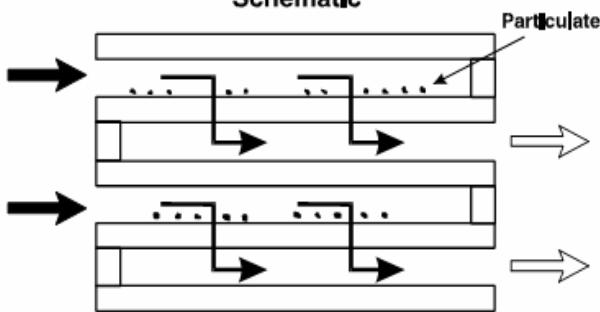
The trap oxidizer system consists of a filter positioned in the exhaust stream designed to collect a significant fraction of the particulate emissions while allowing the exhaust gases to pass through the system. Since the volume of PM generated by a diesel engine is sufficient to fill up and plug a reasonably sized DPF over time, some means of disposing of this trapped particulate must be provided. The most promising means of disposal is to burn or oxidize the particulate in the trap, thus regenerating, or cleansing, the DPF of collected particulate. A complete trap oxidizer system consists of the filter and the means to facilitate the regeneration.

Filter Material. A number of filter materials have been tested, including ceramic monoliths, woven silica fibre coils, ceramic foam, mat-like ceramic fibres, wire mesh, and sintered metal substrates.

Collection efficiencies of these filters range from 50 per cent to over 90 per cent. Excellent filter efficiency has rarely been a problem with the various filter materials listed above, but work has continued with the materials, for example, to: (1) optimize high filter efficiency with accompanying low back pressure, (2) improve the radial flow of oxidation through the filter during regeneration, and (3) improve the mechanical strength of the filter designs.

DIESEL PARTICULATE FILTER

Schematic



Particulate-gladened diesel exhaust enters the filter but because the cell of the filter is capped at the opposite end, the exhaust cannot exit out the cell. Instead the exhaust gases pass through the porous walls of the cell. The particulate is trapped on the cell wall. The exhaust gases exit the filter through the adjacent cell.

XX. Use of Catalyst and Particulate Filter Control in Conjunction with other Control Strategies

Retarding injection timing slightly or incorporating exhaust gas recirculation (EGR) will reduce NOx emissions of diesel engines by more than 40 per cent. However, both techniques are accompanied by secondary effects. Injection timing retard, while decreasing NOx emissions substantially, increases the emissions of CO, NMHC, and PM and reduces fuel economy. The increase in the other exhaust emissions, however, can be offset with either oxidation catalyst or diesel particulate filter technology. Ceramic engine coatings have been found to offset the fuel economy penalty as well. Employing EGR to diesel engines introduces abrasive diesel particulate into the air intake which could result in increased engine wear and fouling. Using EGR after a diesel particulate filter would supply clean EGR and effectively eliminate this concern.

A variety of emission control technologies exist for controlling NOx, CO, NMHC, and PM. Oxidation catalysts provide significant reductions in CO (90%) and NMHC (90%) from lean burn engines at a cost of \$9-10/bhp. In the case of diesel

engines, PM emissions are also reduced by greater than 25 per cent with no additional cost.

- NSCR can be used to eliminate greater than 90 per cent of NOx emissions from rich burn engines for \$10-15/bhp. NSCR, or three-way catalysts, eliminate over 90 per cent of NOx, CO, and NMHC for engines operated stoichiometrically at a cost of \$10-15/bhp.

- SCR can be used to reduce greater than 90 percent of NOx emissions from lean burn engines at a cost of \$50-125/bhp. More recently, lean NOx catalysts have been applied to stationary lean burn IC engines to provide significant reductions in NOx (80%), CO (60%), and NMHC (60%) at a cost of \$10-20/bhp.

- Although not currently in wide spread use on stationary engines, diesel particulate filter or trap oxidizers provide considerable potential to eliminate more than 90 percent of the PM emissions from stationary diesel engines at a cost of \$30-50/bhp depending on engine size. Catalytic coatings on such DPFs add the advantage of also reducing CO and HC. Ceramic coatings used on the internal combustion surfaces of IC engines can improve performance, reduce emissions or allow a trade off in performance and emission levels not possible using catalyst technology itself. Used in conjunction with catalyst, ceramic coatings have allowed significant reductions in PM and NOx for heavy duty diesels while providing significant performance increases in power and torque. Costs are in the range of \$5-15/bhp.

XXI. Sound pollution and its Control

Sound is another source of pollution which creates uncomforrt feelings to human beings. The sound level of automobiles is always higher than the desired and therefore legislative measures are also imposed to control the sound level below a particular level to build a peaceful environment.

The noise is measured by decibel (dB) which is given by

$$N = 10 \log_{10}(I/I_r)$$

Where N is in decibels, I is the intensity of sounds and I_r is the reference intensity whose unit is W/m^2 . The intensity of sound is doubled when the number of decibel goes up by about 3 as it is logarithmic function.

Engine Noise: The engine is the main source of noise. In most cases, at present control levels, exhaust and intake noise is dominant. Many individual vibrations contribute, excited by the rapid rise of cylinder pressure at the onset of combustion and by the impact of piston on the cylinder wall as it changes the direction at TDC. At rated speed and load, the differences between engine types are within about 5dB. But at comparable operating points near half speed, S.I. engine averages about 20 dB lower than the large diesel.

With cities, the traffic noise is perceived as a major detraction from amenity. The noise levels of different automobiles are listed in the following table.

	dB(A)
Motor cycles above 125cc capacity	86 80
Private cars	82
Light good vehicles	86
Heavy goods vehicles below 200hp	89
Above 200hp	

Maximum permitted noise level at a distance of 75m from the path of the vehicles, being driven within an area providing a clear space of at least 50m radius.

Aircraft noises: Of all the noises, those produced by modern jet engines are by far the worst and the most difficult to do anything about. Ground personnel have to wear special ear protection, and passengers entering or leaving aircraft are protected by noise deflecting barriers. There is a trend, as the noise level at airports increases, to allow passengers to remain entirely indoors by providing movable covered ramps that connect between the aircraft and the terminal building. Propeller driven aircrafts reach their peak sound level at the low frequency of the sound spectrum, but unsuppressed jet exhaust sounds tend to have their maximum at the higher ranges, which are far more penetrating. Aircraft speed has not been found to be related to the noise volume given off by jet engines and there is no reason for engine noises of supersonic to be greater than those of subsonic aircraft. Supersonic aircrafts, however, produce a sonic boom, which can be extremely damaging. There is no way of avoiding the sonic boom nor can much be done in general to reduce noise from jet aircraft.

The sound levels inside certain premises are listed below:

Enclosure	Sound Level (dB)
Jet engine test room	114
Inside bus	92
Inside car in city traffic	85
Heavy traffic(8-16 m away)	75 65
30 m away (average traffic)	46
30 m away (light traffic)	

XXII. Controlling Noise Pollution

Controlling environmental pollution is not merely a regulatory function. Noise as an environmental problem is not an exception. Of all forms of pollution, noise pollution is most carelessly neglected, consciously ignored and willingly accepted. As usual, the government has taken a piecemeal approach to the environment. Many industrialised countries of the world have passed legislations to control and abate noise. In fact, the noise Control Act of 1972 is a major breakthrough in the Federal attempt to eliminate excess noise at every level.

XXIII. Conclusion

The Clean Air Act of 1970 gave EPA broad authority to regulate motor vehicle pollution, and the Agency's emission control policies have become progressively more stringent since the early 1970's. EPA standards dictate how much pollution autos may emit but automakers decide how to achieve the pollution limits. The emission reductions of the 1970's came about because of fundamental improvements in engine design, plus the addition of charcoal canisters to collect hydrocarbon vapours and exhaust gas recirculation valves to reduce nitrogen oxides. The advent of "first generation" catalytic converters in 1975 significantly reduced hydrocarbon and carbon monoxide emissions. The use of converters provided huge indirect benefit as well. Because lead inactivates the catalyst, 1975 saw the widespread introduction of unleaded gasoline. This resulted in dramatic reductions in ambient lead levels and alleviated many serious environmental and human health concerns associated with lead pollution. The next major milestone in vehicle emission control technology came in 1980-81. In response to tighter standards, manufacturers equipped new cars with even more sophisticated emission control systems. These systems generally include a "three-way" catalyst (which converts carbon monoxide and hydrocarbons to carbon dioxide and water, and also helps reduce nitrogen oxides to elemental nitrogen and oxygen), plus an on-board computer and oxygen sensor. This equipment helps optimize the efficiency of the catalytic converter. Vehicle emissions are being further reduced by provisions of the 1990 Clean Air Act. Mobile source provisions include even tighter tailpipe standards, increased durability, improved control of evaporative emissions, and computerized diagnostic systems that identify malfunctioning emission controls.

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