ENGINE EMISSION

INTRODUCTION

- IC engine produces power by burning fuel and converting chemical energy into mechanical energy. These fuels mainly contain carbon and hydrogen in various combinations.
- Only a part is converted into mechanical energy and rest is wasted (about 70%).
- **Primary pollutants** released into atmosphere are: -
  - *Carbon monoxide (CO).*
  - *Unburnt Hydrocarbons (HC).*
  - *Oxides of Nitrogen (NO_x).*

CHEMICAL REACTION AND GENERATION OF POLLUTANTS DURING COMBUSTION

- **Chemical reaction during combustion** is: -

$$HC + N_2 + O_2 \longrightarrow CO_2 + N_2 + H_2O + \underbrace{CO + NO_x + HC}_{\text{Air Pollutants}}$$

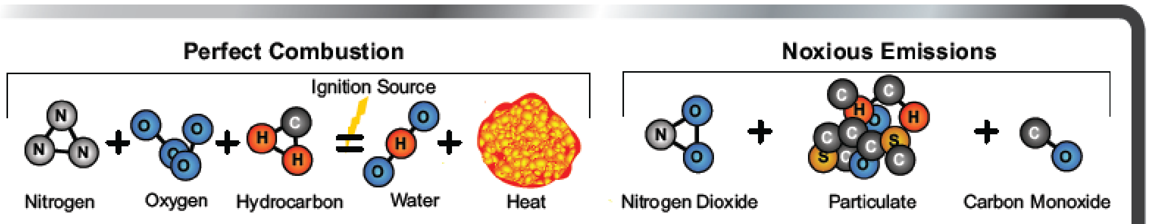


FIGURE 7-7 Perfect combustion compared to imperfect combustion. Imperfect combustion produces harmful emissions.

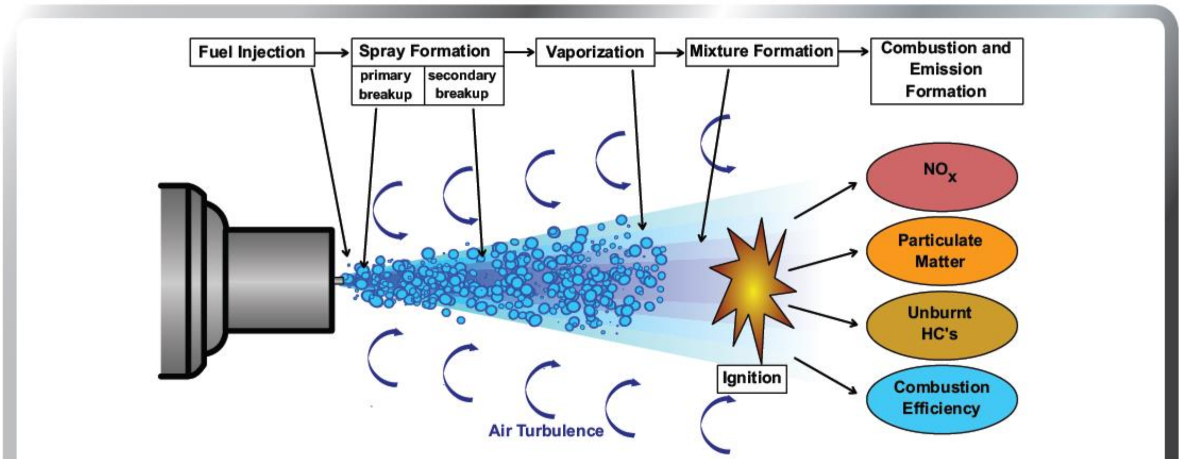
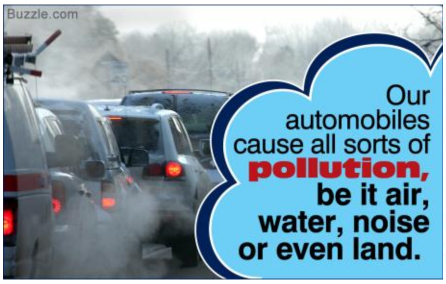
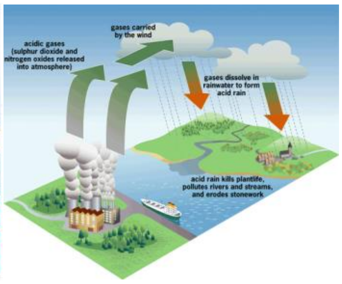


FIGURE 7-8 Formation of gaseous emissions takes place in the combustion chamber.

- **Stoichiometric (Chemically perfect)** combustion ratio for various Air-fuel mixtures: -
    - *Petrol - 14.7:1 (1 gm. Of petrol and 12.2 litres of air)*
    - *Diesel – 14.6:1*
    - *CNG – 17.2:1*
    - *LPG– 15.5:1*
- **Harmful effects** of Automobile Pollution are: -

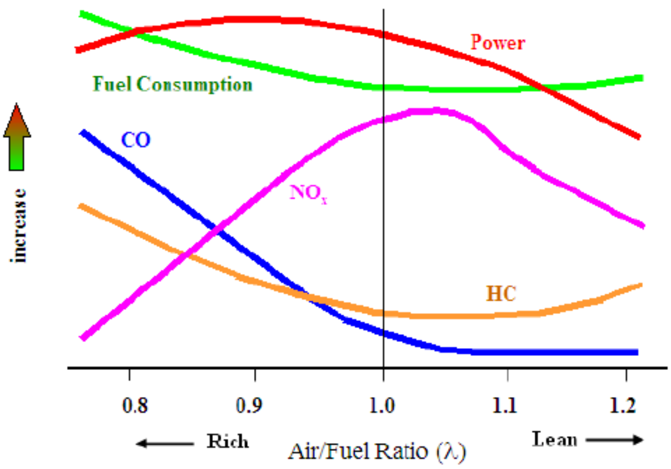


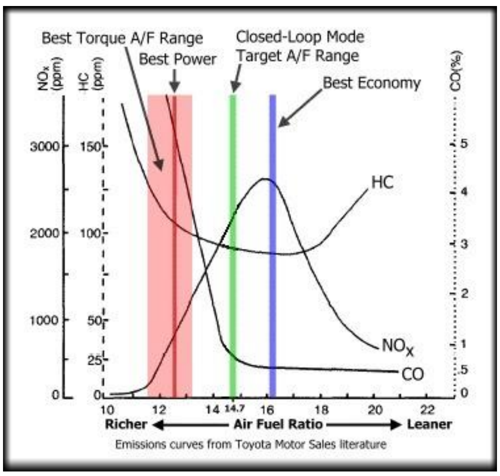


Auto Emissions affect	How Auto Emission harmful -
Human beings	Co = Carbon monoxide - Reduces ability of blood to carry oxygen – HEART disease
Animals	HC = Hydro carbons - Drowsiness , Eye irritation, Cough & Cancer NOx = Nitrogen oxides (NO + NO2) - Bronchial infection, Head ache & Cold
Vegetation	PM= Particulate matter - Respiratory Inflamation, Cough & Throat infection.

EFFECT OF AIR-FUEL RATIO (1) ON POLLUTANT GENERATION

The effect of air-fuel ratio on power, specific fuel consumption, generation of pollutants (CO, HC and NO_x) are shown in the graphs below and explained thereafter: -





- ***Carbon monoxide (CO)*** is generated when incomplete combustion occurs due to insufficient air in the air-fuel mixture by following chemical reaction: -

  $$2C + O_2 = 2CO$$

  However non-toxic CO_2 is generated when the air-fuel mixture contains sufficient air i.e: -

  $$C + O_2 = CO_2$$

The air-fuel ratio is the primary factor affecting the generation of CO and CO_2 as shown in the graphs above. The reductions in the CO emissions can be achieved using a lean air-fuel ratio. However, *an excessive lean air-fuel ratio tends to cause HC emissions and lead to reduced engine power. The CO_2 content of the exhaust gas is greatest with slightly lean air-fuel mixture and further decreases with leaner ratios as a result of increase in the amount of unburnt fuel.*

- The term ***Hydro-carbon (HC)*** applies to a group of chemical compounds composed of hydrogen and carbon. The complete combustion of carbon in the fuel results in the generation of CO_2. Furthermore, another outcome of complete combustion is that the H_2 content of the fuel combines with O_2 to form H_2O (water).

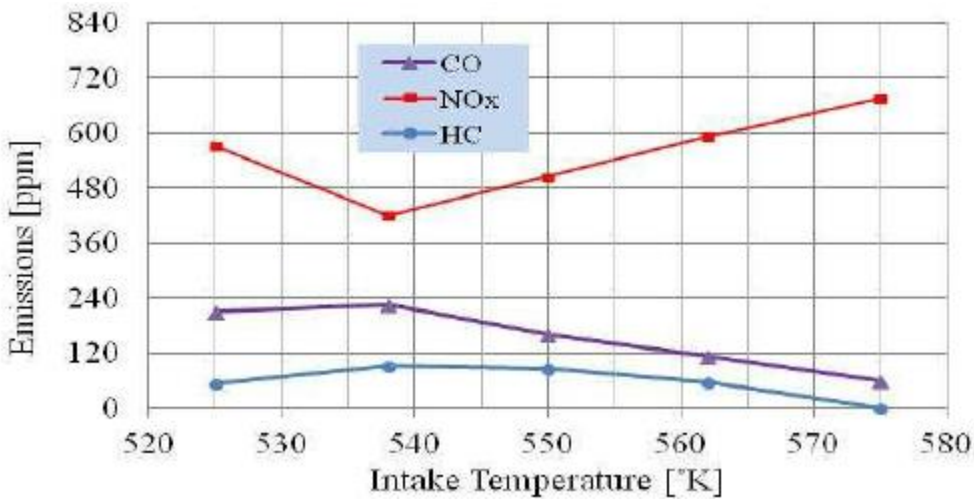
  The hydrocarbons are emitted from the exhaust pipe as a result of unburnt or partially burnt fuel particles. *Generation of hydrocarbon reduces as the air-fuel ratio increases and is the lowest around stoichiometric ratio. However, this keeps increasing as the air-fuel mixture gets leaner.* This is primarily due to lowering of combustion chamber temperature in this region which tends to quench the flame near comparatively cool cylinder walls which leave some of the air-fuel mixture unburnt.

- The term ***Nitrogen Oxides (NO_x)*** applies to chemical compounds of nitrogen and oxygen. Typically, these compounds are generated when substances are burnt at high temperatures. *The precise compound generated depends upon the extent to which nitrogen and oxygen combine i.e. the extent of oxidation.* If N_2 and O_2 exist at high temperature, a chemical reaction takes place and NO is generated as below: -

  $$N_2 + O_2 = 2NO$$

  When NO comers in contact with oxygen, it turns into NO_2 and the major proportion of NO_x in the exhaust gas consists of NO and NO_2. As seen from the graphs above, *the NO_x content of the exhaust gas is greatest when air-fuel ratio is near the stoichiometric value and decreases sharply as the air-fuel mixture gets richer or leaner.* Furthermore, the combustion temperature has a significant effect upon NO_x generation i.e. *increases in the peak combustion temperature lead to sharp increases in the NO_x content of the exhaust gas.*

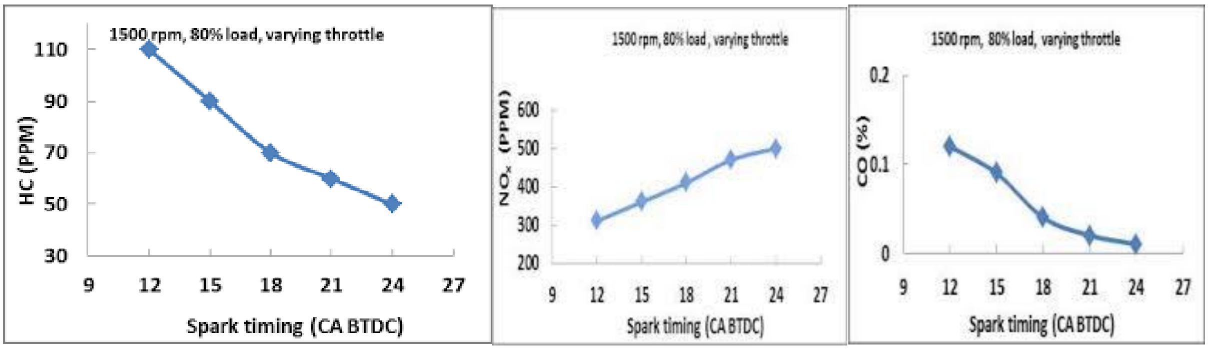
  It should be noted that ***whereas the HC and CO emissions are caused by incomplete combustion, NO_x emissions are greatest when complete combustion is taking place.*** *In order to reduce the level of NO_x emissions, it will be necessary to reduce the peak combustion temperature.* However, this technique leads to reduction in engine power. The effect of combustion chamber temperature on NO_x, HC and CO is shown in the graph below: -

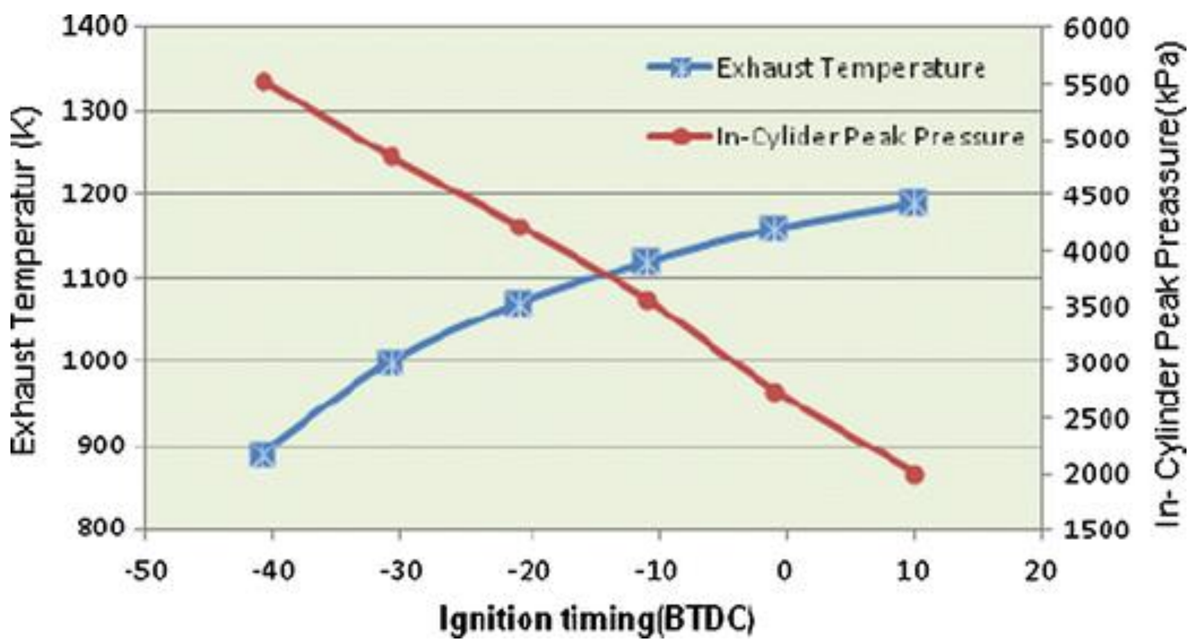


- The term ***Particulate Matter or Smoke (PM)*** is used to describe the collection of small particles that make up the smoke. *It is basically carbon or soot particles on which some organic compounds such as unburnt hydrocarbon are absorbed.*

  The smoke is always main concern in diesel engines because it is clearly visible, particularly at high engine loads.

EFFECT OF SPARK TIMING ON POLLUTANT GENERATION





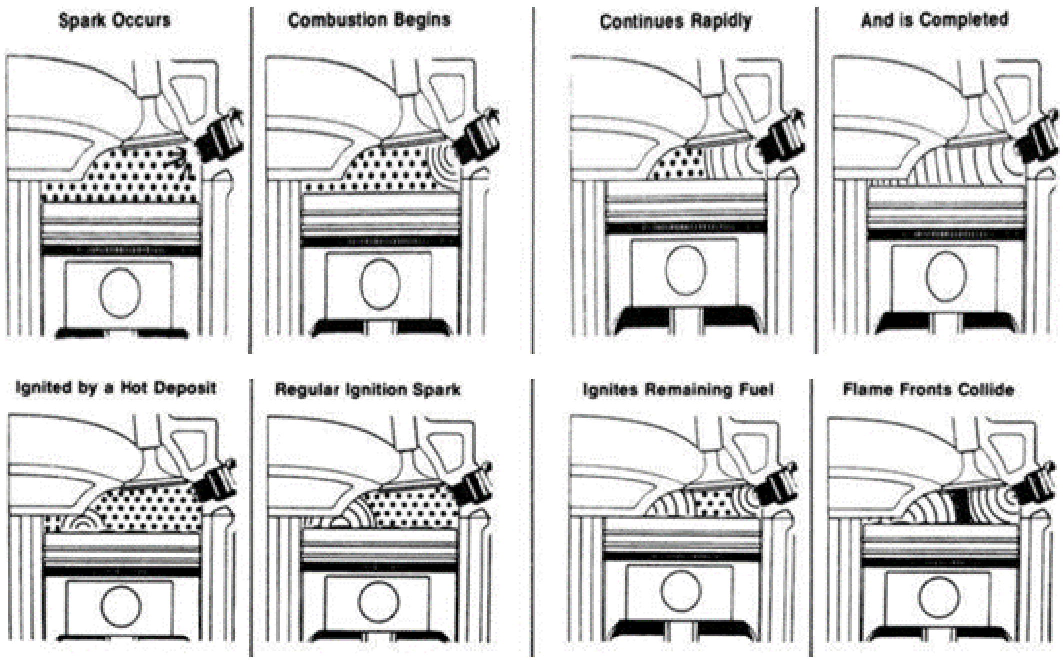
The effect of spark timing CABTDC (Crank Angle Before Top Dead Centre) on HC, NOx and CO are shown in the graphs above. Also, the effect of ignition timing on “Exhaust gas temperature” and “In-cylinder Peak Pressure” are also graphically shown.

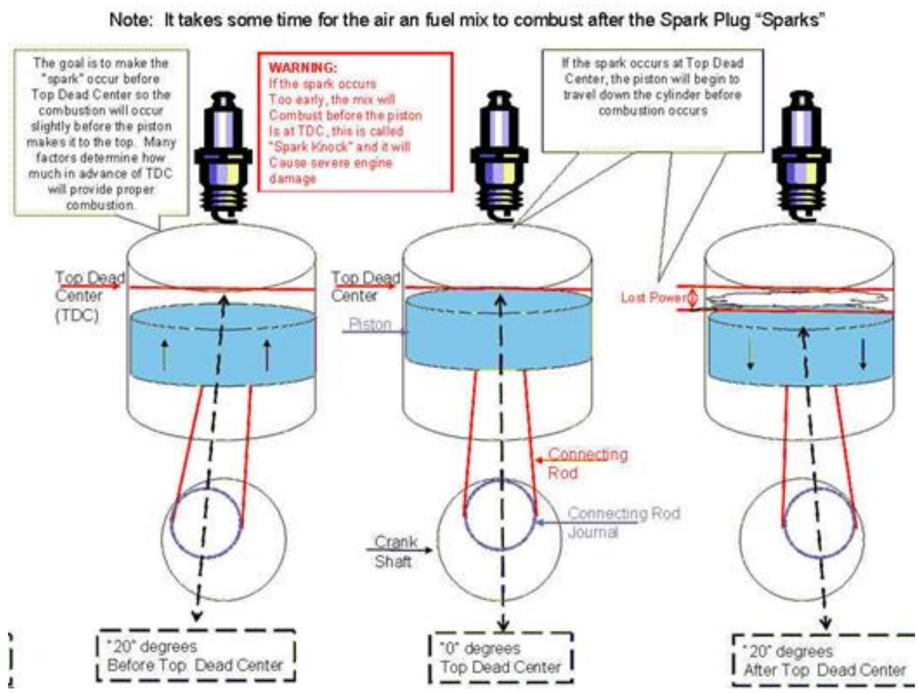
Ignition is dependent on “Quality of spark (ability to ignite the Air-fuel mixture}”. *Quality is dependent on “Duration and Timing of spark”.*

“Timing advance" refers to the number of degrees before top dead centre (BTDC) that the spark will ignite the air-fuel mixture in the combustion chamber during the compression stroke.

“Retarded timing “can be defined as changing the timing so that fuel ignition happens later than the manufacturer's specified time.

Combustion process with spark advance and retardation is pictorially shown below: -





Hydrocarbon emission decreases with increased spark advance. The better combustion at advanced timing effects in reduction of the hydrocarbon emission.

It is found that ***CO emission decreases with increased spark advance.*** This is due to higher peak pressure at advanced timing which promotes better combustion resulting in reduction of CO emissions.

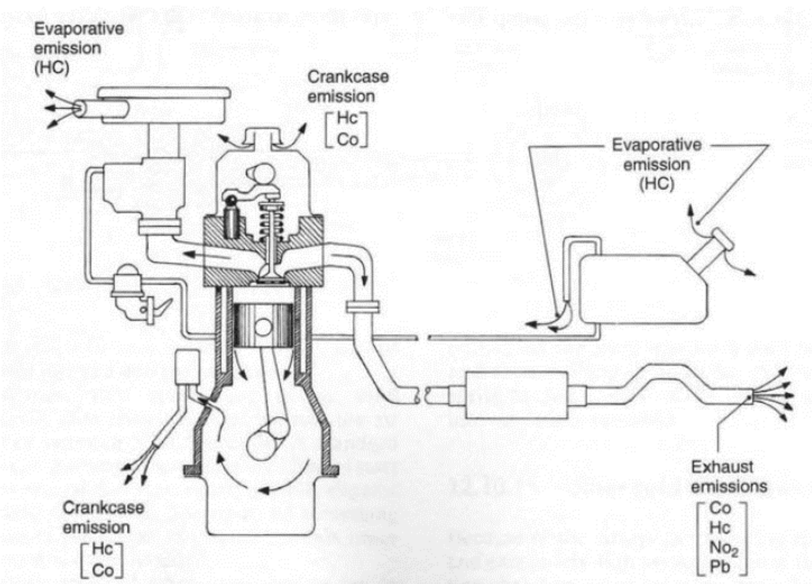
NO_x emission increases with advance in spark timing. Emissions of nitrogen oxides (NO_x) depends upon temperature and residence time, as temperature increases and residence time increases NOx formation increases. Spark advanced increases peak pressure and residence time. Hence NO_x emission increases with increase in spark advance.

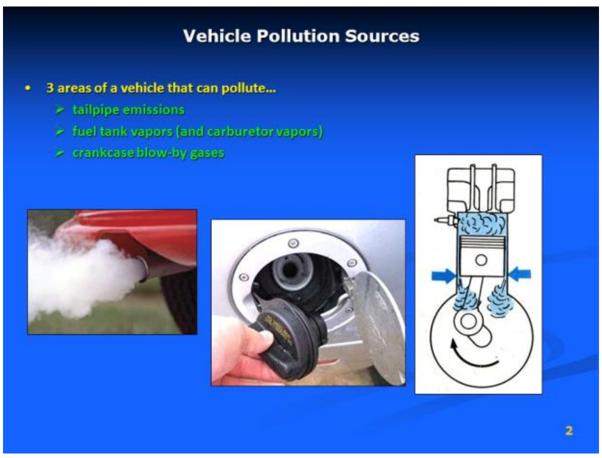
SOURCES OF AIR POLLUTION FROM AUTOMOBILES

There are ***"Four sources of air pollutants"*** from the automobile. These are: -

- ***Engine crank case*** - ***20%***
- ***Air cleaner or Carburettor***
- ***Fuel Tank*** - ***20%***
- ***Exhaust Tail Pipe*** - ***60%***
- ***Particulates (Dust, soot, lead, carbon etc.)*** - ***Traces***

These emission points in a motor vehicle are schematically shown below: -





Each of the above types of emissions are controlled by separate *"**Vehicle Emission Control Technologies**"* which are: -

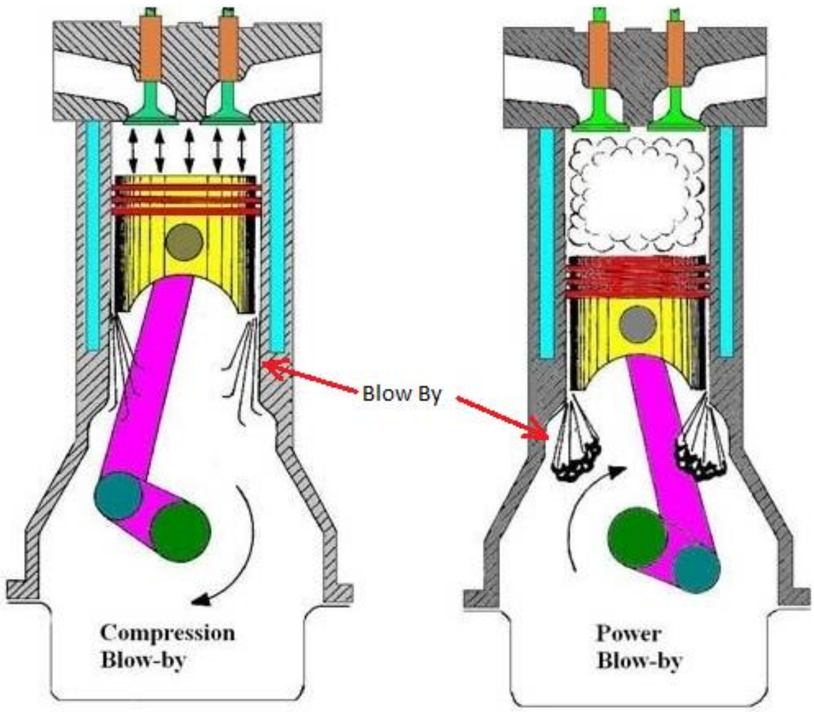
- ***"Crankcase Emission Control System"*** which sends blow by gases back through the engine to be burned thereby preventing their escape to atmosphere.
- ***"Evaporative Emission Control System"*** which traps fuel escaping from air cleaner, carburettor (if used) and fuel tank which are then returned to the engine and burnt.
- ***"Exhaust Emission Control System"*** which include a variety of engine management system, emission control devices. These systems work to reduce the pollutants in the exhaust gas finally being discharged to the atmosphere.

Each of the above technologies are explained in detail below.

CRANKCASE EMISSION CONTROL SYSTEM

The air-fuel mixture in an engine never burns completely. The unburnt fuel and other gases like *unburnt air- fuel mixture hydrocarbons or burnt (or partially burnt) products of combustion, carbon dioxide, water (steam) or carbon monoxide* generated during final stages of combustion can leak past the engine's piston rings into the crankcase. This leakage is termed as ***"Blow by"*** and the gases leaked are called as ***"Blow by gases"***. The blow by gas must be removed from the crank case before it condenses and reacts with the engine oil to form sludge. As a result, the engine will fail to lubricate the engine properly and moving parts like pistons, piston rings, valves, bearings and other internal moving parts of the engine will wear out very fast and prematurely fail.

Blow-by can occur in compression as well as power strokes as illustrated in the picture below:-

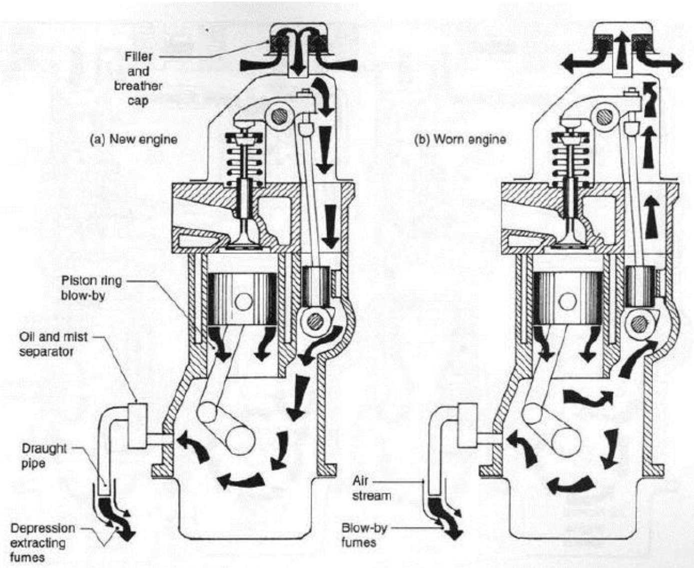


Blow by in crankcase is controlled by "Crankcase Ventilation System". ***There are two types of crankcase ventilation systems viz: -***

- ***Road Draught Crankcase Ventilation System***
- ***Positive Crankcase Ventilation System (PCV)***

Each of the above systems are described below in detail.

ROAD DRAUGHT CRANKCASE VENTILATION SYSTEM



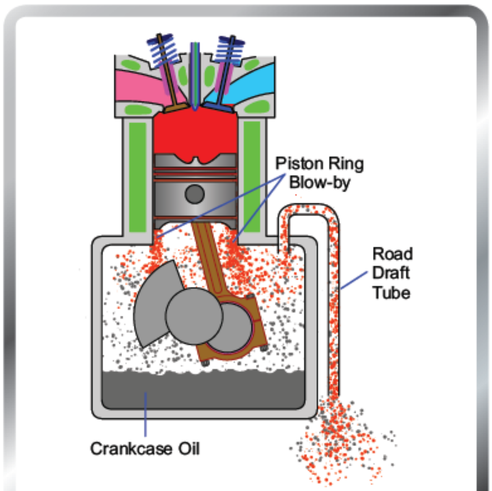


FIGURE 7-9 Blow-by from diesel engines consists mostly of air leaking past the piston rings and mixing with fine oil droplets picked up from the crankcase.

This method of ventilating the crankcase incorporates a pipe whose outlet is exposed to the air stream passing between the underside of the vehicle and the road surface when the vehicle is in motion. Consequently, as the vehicle moves, the relative velocity between the air and the moving pipe creates a depression (vacuum) which increases with the speed of the vehicle. At the same time, if there is a head-on or side-wind blowing, this will further increase the magnitude of the depression at the draught pipe exit.

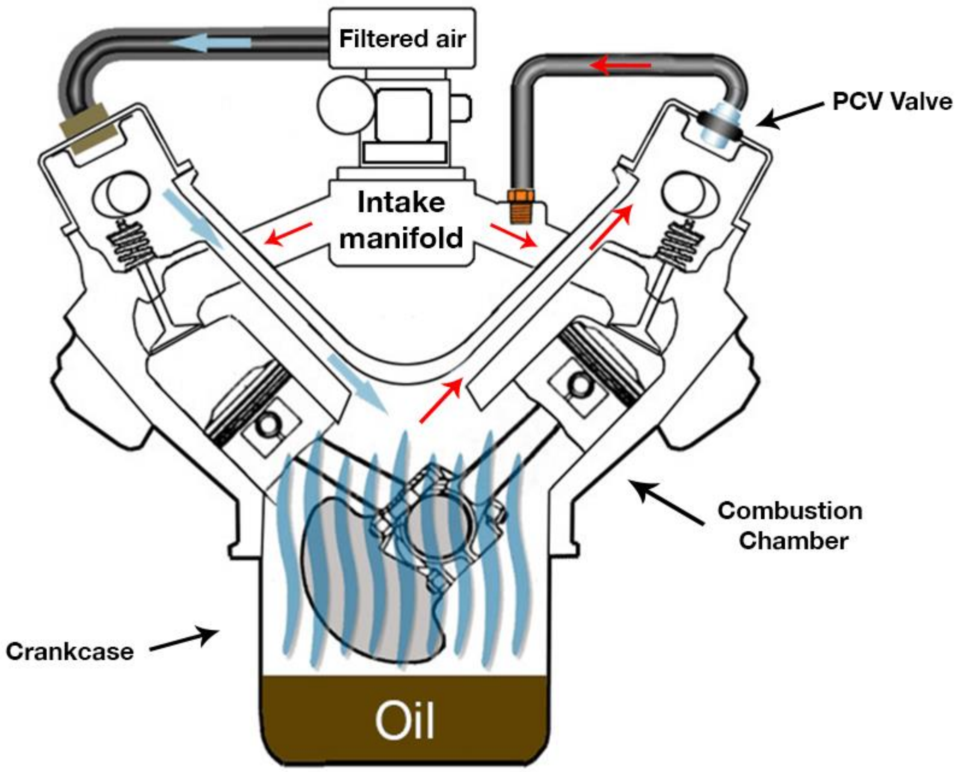
Internal gas circulation is achieved by having a ***vented filler and breather cap*** in the top of the rocker cover and an ***outlet pipe low down in the side of the crankcase*** as shown in figures (a) and (b) above. Thus, when the vehicle movement is sufficient to create a draught depression at the exit pipe, air will enter the rocker cover through the filler cap, pass down the push-rod and camshaft passages, where it then enters the crankcase. The rotating crankshaft webs and balance weights then establish a circular partial vacuum path for the fresh air and blow-by gases to follow, and these gases are then ejected into the atmosphere via the oil and mist separator and draught pipe ***(Figure – a).*** Oil mist, which is caught up with the air and fumes on their way through to the draught pipe, passes through ***baffles*** installed in the ***oil separator container*** which cause most of the oil mist to condense. It is then drained back to the engine's sump, whereas the majority of the air and gases is permitted to escape.

At high engine speeds, and particularly with a worn engine, the pressure build-up in the crankcase may exceed the extraction capability of the draught pipe, this causes the air and gas in the crankcase to reverse their flow direction. Some of the air, gas and oil mist are therefore forced to move up to the rocker cover, where they are then expelled to the atmosphere by way of the filler cap wire-mesh ***(Figure - b)***. An indication that there is a significant amount of piston blow-by, possibly due to a worn engine is the excessive amount of oil splashed outside the filler cap and rocker cover.

At speeds below about 40 kmph there is insufficient relative air movement around the draught pipe to create the necessary air circulation within the engine's crankcase. Therefore, the gas and vapour build-up and its condensation in the crankcase and rocker cover will contaminate the lubricant, thus reducing the oil's effectiveness in minimizing wear between bearing rubbing pairs.

The unacceptable limitation of this system of crankcase ventilation, due to the expulsion of gas and fume vapour (HC and CO) into the atmosphere thereby contributing to air pollution, has made this method of internal purging of the engine obsolete.

POSITIVE CRANKCASE VENTILATION SYSTEM



The positive crankcase ventilation system ***uses manifold vacuum to purge the crankcase blow-by fumes.*** *The fumes are then aspirated back into the engine where they are reburned.* The sequence of various processes is explained below: -

- *Combustion gases blow past the piston rings, which pressurizes the crankcase with contaminated air containing oil vapor and unburnt fuel. This contaminated air is commonly referred to as "blow-by".*
- *Vacuum from the intake manifold draws the blow-by out of the crankcase through the PCV valve and into the intake manifold.*
- *The evacuated crankcase air is displaced by clean, filtered air which is drawn from the engine's air intake and passed through to the crankcase.*
- *Meanwhile, the contaminated air (blow-by) passes through the intake manifold and into the combustion chamber, where it leaves harmful deposits and reduces the octane rating of the air/fuel mix when it is ignited and then passed through the exhaust.*

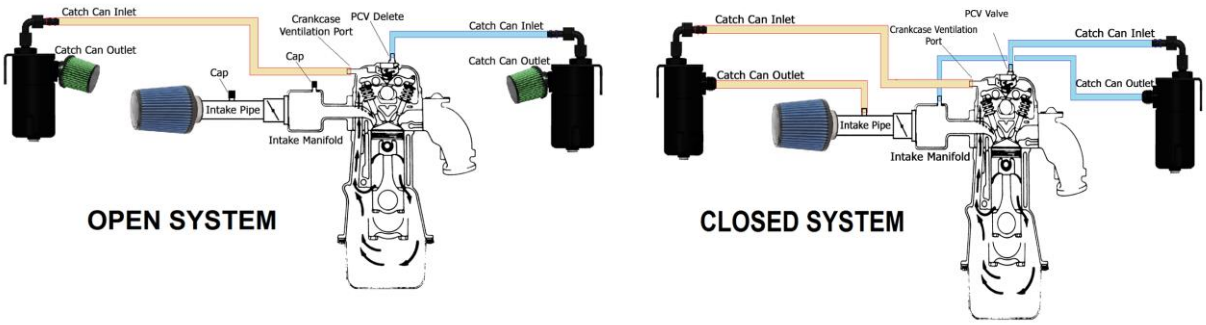
It may be noted that the PCV system provides benefit for the environment and the engine by reducing the air pollution and increasing the fuel economy. The failure of the PCV system can shorten the life of the engine by allowing harmful exhaust gases to remain inside the engine, leading to corrosion and accelerated wear.

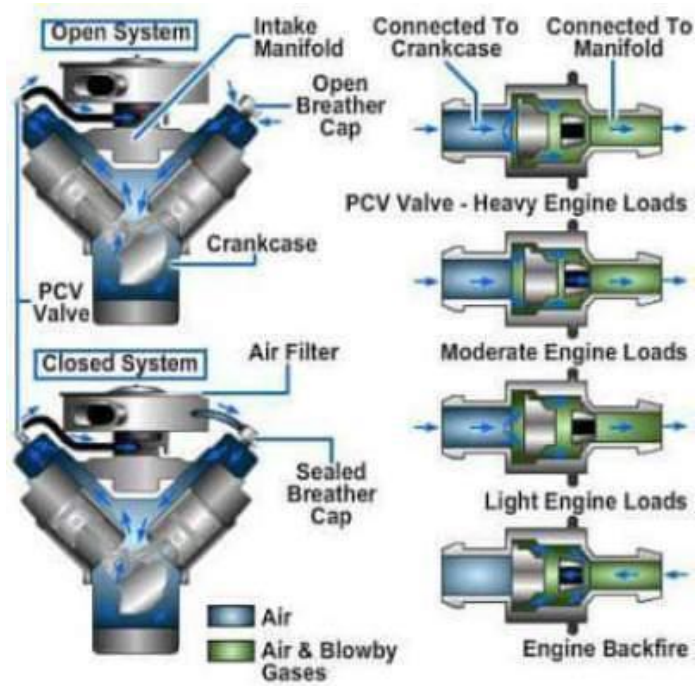
“OPEN” AND “CLOSED” TYPE POSITIVE CRANKCASE VENTILATION SYSTEM

Positive crankcase systems are of two types viz: -

- ***Open Type Crankcase Ventilation System***
- ***Closed Type Crankcase Ventilation System***

Both types of positive crankcase ventilation systems are explained below.

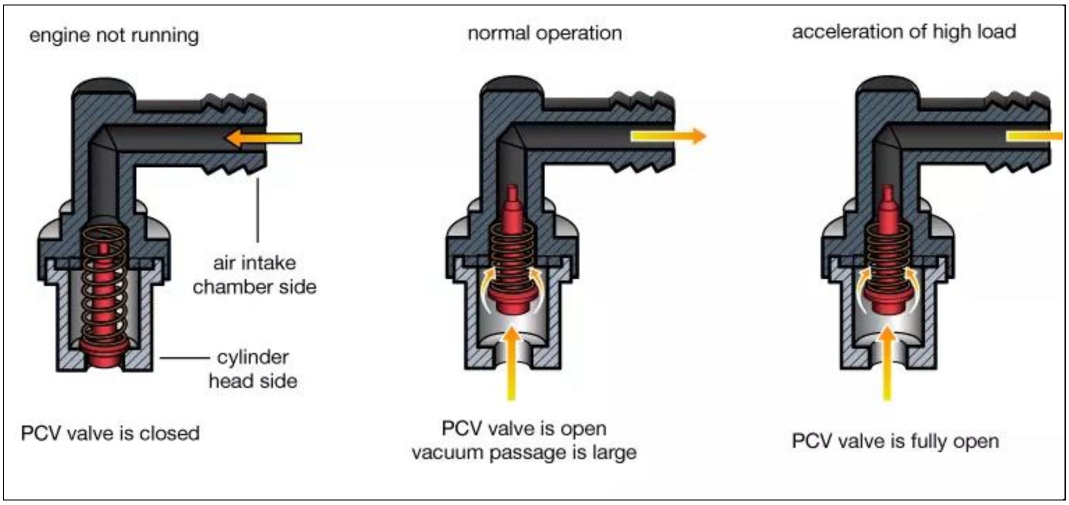




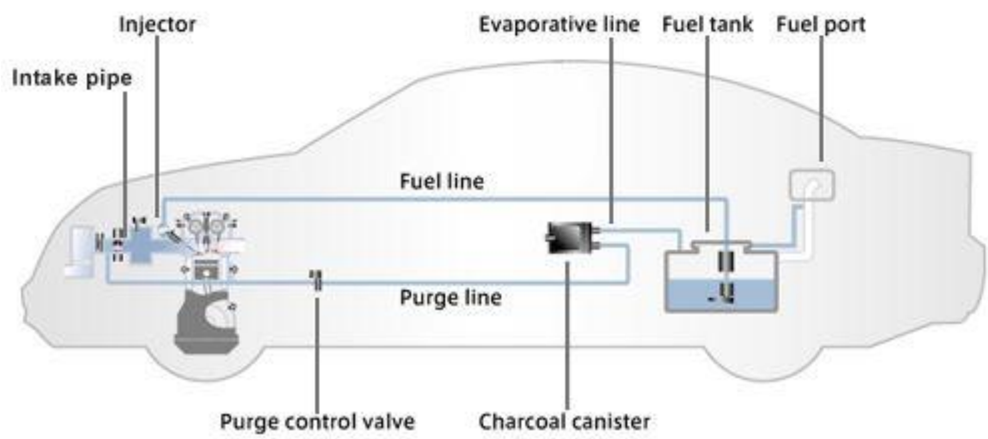
In *“Open PCV System”,* air enters crank case through vented oil filler cap. This presents no problem as long as the vapor volume is minimal. However, when the crankcase vapor becomes excessive it is forced back through the vented oil filler cap and into the open atmosphere. The open PCV system, though successful at removing contaminated vapours from the crankcase, is not completely effective as a pollution control device. This setup can produce a strong fuel-like smell in the cabin and outside of the vehicle when not moving, and will not pass any visual emissions inspection.

In *"Closed PCV System",* vented oil filler cap is not used. Instead air is drawn into crank case through a connecting pipe with air cleaner. The resultant mixture is led back to intake manifold through a plunger type PCV valve. The oil filler cap in this system is NOT vented. Consequently, excess vapor will be carried back to the air filter housing and from there into the intake manifold. The closed system prevents vapor, whether normal or excessive, from reaching the open atmosphere. ***The closed system is very effective as an air pollution control device.***

The ***"PCV Valve"*** is normally held open by a spring, but *high manifold vacuum will cause the valve to close.* When the valve is closed, the amount of air entering the manifold from the crankcase ventilator system is reduced to prevent diluting or cleaning out the fuel-air mixture from the carburettor. Operation of PCV valve under various engine operating conditions are shown in the picture below: -



EVAPORATIVE EMISSION (EVAP) CONTROL SYSTEM

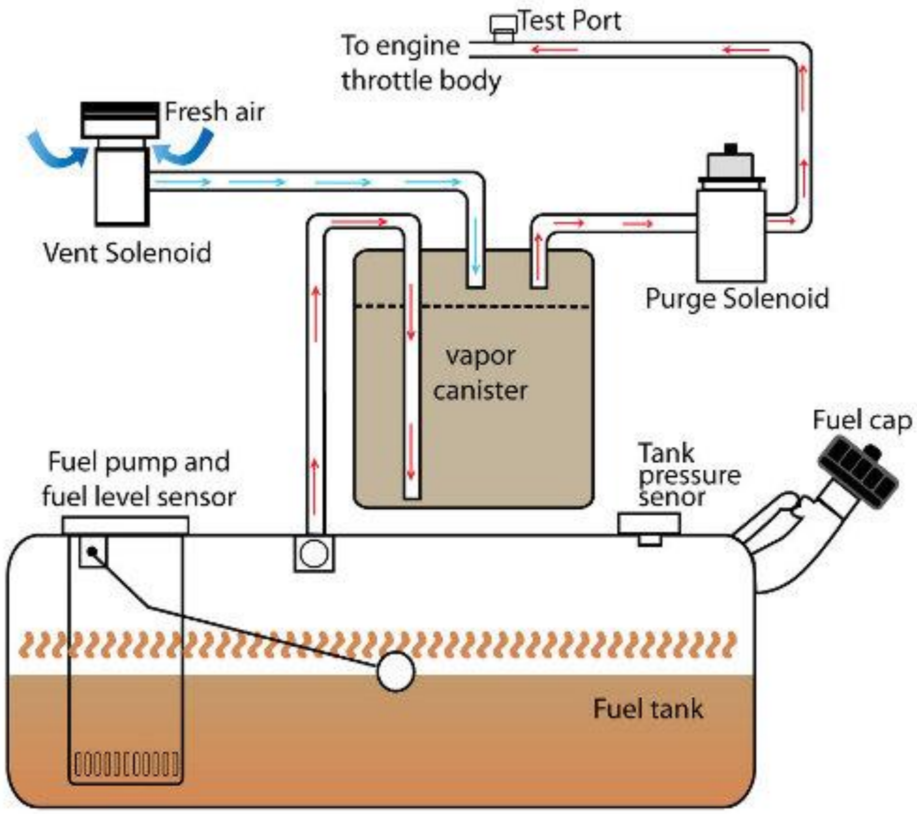


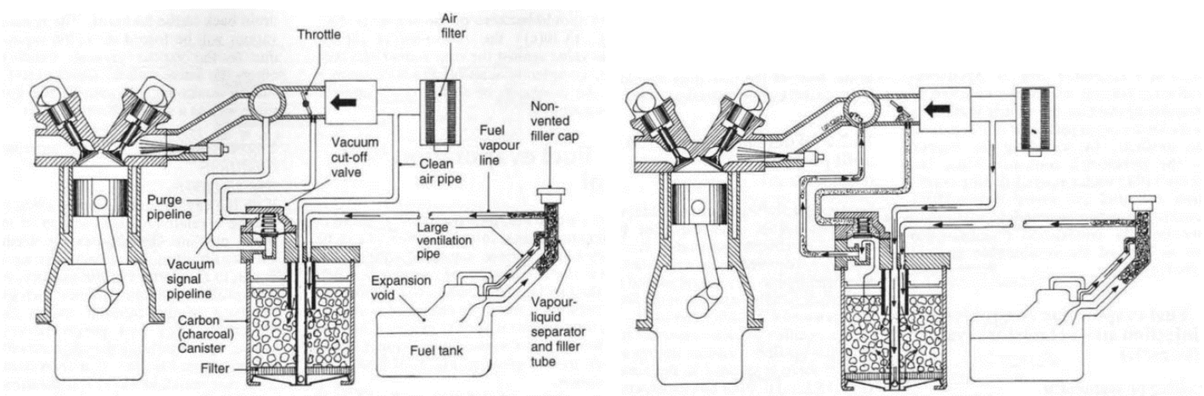
An evaporative emission (EVAP) control system is designed to minimise the escape of fuel vapours (HCs) to atmosphere from the ***fuel tank*** and carburettor ***float chamber.*** The petrol in the fuel tank and carburettor evaporates away through the vent holes due to the temperature effect in the absence of an EVAP system (or vapour recovery system). These petrol vapours passing out of the fuel tank and carburettor pollute the atmosphere and are known as *"Evaporative Emission".* An evaporative emission control system captures these petrol vapours and prevents them from escaping into the air, thus reducing pollution.

AN EVAP system is designed for controlling HC emission by collecting fuel vapours from fuel tank and carburettor fuel bowl vents (applicable only for petrol engines using carburettor) when the engine is shut off. The fuel vapours are led to an ***“Activated Charcoal Canister”*** which adsorbs the vapours. Later when the engine starts, fresh air flows through the canister and picks up the fuel vapours ***(known as purging)*** which then flows to the intake manifold and becomes part of the air-fuel mixture entering the combustion chamber. *All EVAP systems use a “Liquid Vapour Separator” to prevent liquid fuel reaching the crank case or Vapour storage canister.*

Activated charcoal is used because of its large surface area which is 1100 Sqm/Gram. Normally about 300~625 grams of activated charcoal are used. This means 33,000 ~6,87,500 Sqm!!!

Schematic of EVAP systems (under idle/stationary and normal running conditions) are shown below: -





(a) Engine idle and stationary conditions

(b) Engine normal running conditions

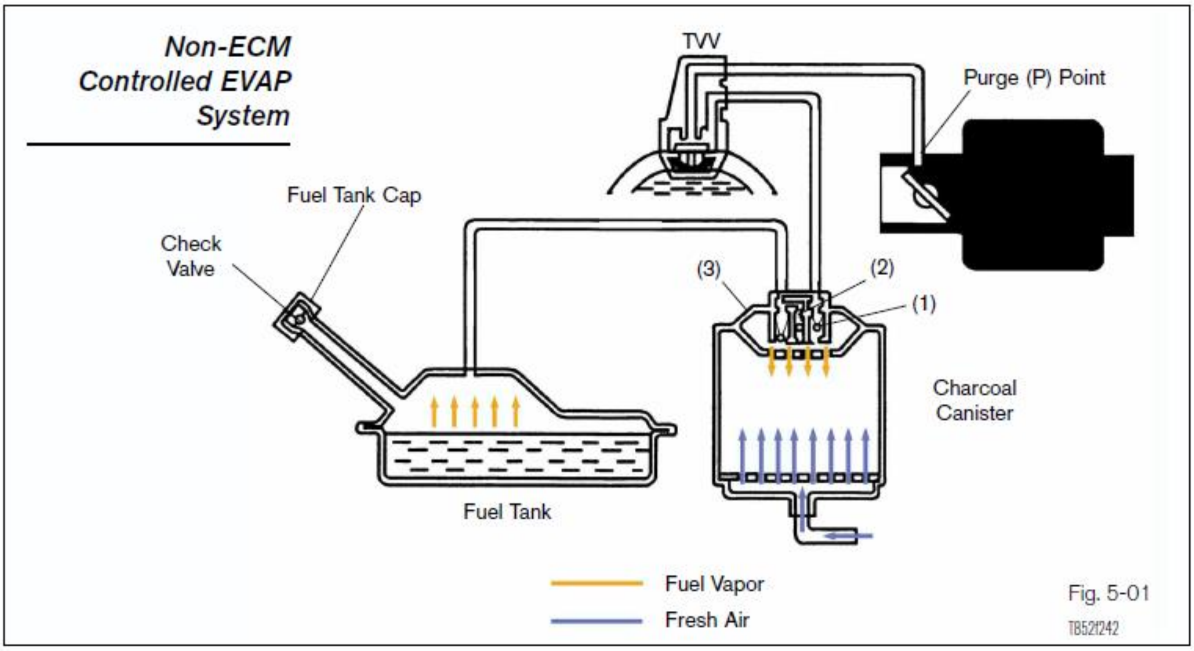
There are two types of EVAP systems viz: -

- ***Market Research:*** *To identify potential market gaps for new products.*
- ***New Product Idea:*** *Generate a new product idea from outcome of market research.*
- ***Product Design Specification (PDS):*** *Develop a product design specification with help of R&D department.*
-

Operation of both types of systems are explained below *(reference TOYOTA Technical Training Manual).*

- **Non-ECM Controlled EVAP System**

Non-ECM controlled EVAP systems typically use the following components:
• Fuel tank.
• Fuel tank cap (with vacuum check valve).
• Charcoal canister (with vacuum and pressure check valves).
• Thermo Vacuum Valve (TVV).
• Ported vacuum purge port (port P on throttle body).



When fuel vapour pressure in the fuel tank is higher than the set value of the EVAP two-way valve (2 and 3), the valve opens and regulates the flow of fuel vapour to the evaporative emission control cannister. *Sometimes, traces of liquid vapour go along with the vapours. In that case, the vapours and liquids are separated in the fuel tank itself by a separator. The vapour goes through the separator and liquid fuel is returned to the fuel tanks.*

The fuel vapours flow to the ***charcoal cannister*** where they are ***adsorbed*** and retained.

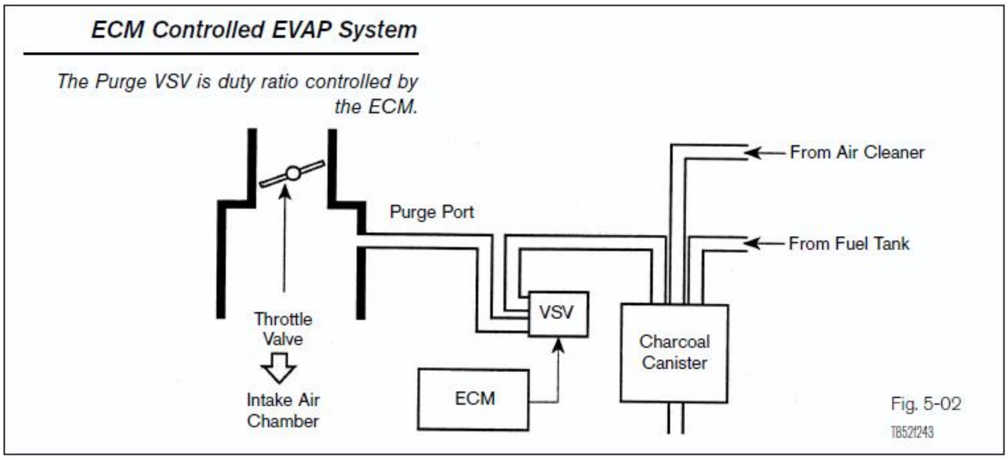
When the engine is running, stored fuel vapours are purged from the canister whenever the throttle has opened past the purge port (port P) and coolant temperature is above a certain point *(usually around 54°C).* Fuel vapours flow from the high-pressure area in the canister, past check valve No.1 in the canister, through the Thermo Vacuum Valve (TVV), to the low-pressure area in the throttle body. *Atmospheric pressure is allowed into the canister through a filter located on the bottom of the canister.* This ensures that purge flow is constantly maintained whenever purge vacuum is applied to the canister. When coolant temperature falls below a certain point *(usually around 35°C)*, the TVV prevents purge from taking place by blocking the vacuum signal to check valve No.1.

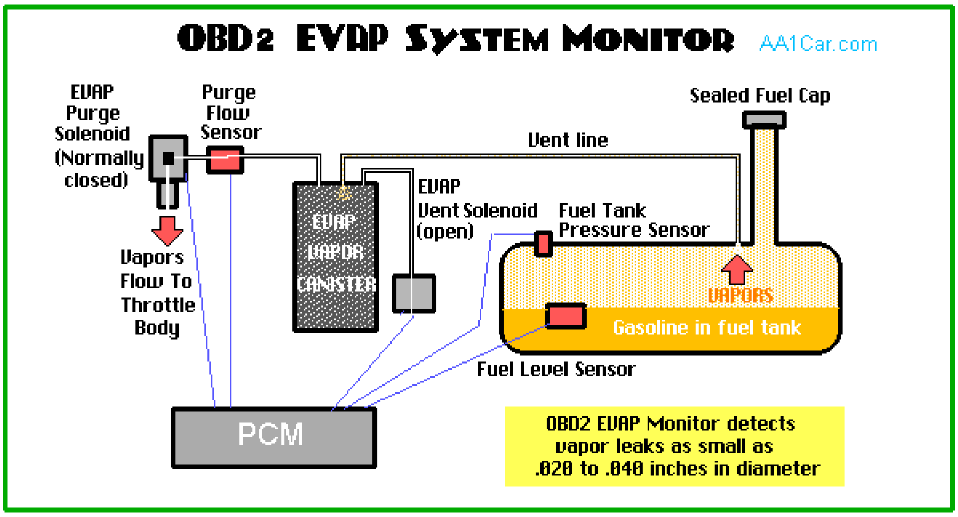
***Function of TVV** is to ensure that the purging of cannister is prevented before the engine reaches the operating temperature. This arrangement is important because purging at idling speed or when engine is cold causes problems such as **rough running and increased emissions** because of additional fuel vapour drawn into the intake manifold.*

- **ECM Controlled EVAP System**

ECM (Engine Control Module) controlled EVAP systems were introduced to provide a more precise control and maintain driveability. The ECM will adjust the fuel injection duration based on oxygen sensor or air/fuel ratio sensor signal. ECM controlled EVAP systems typically use the following components:

• Fuel tank.
• Fuel tank cap (with vacuum check valve).
• Charcoal canister (with vacuum and pressure check valves).
• Purge VSV (Vacuum controlled Solenoid Valve).





When the engine has reached predetermined parameters (closed loop, engine temp. above 52ºC, stored fuel vapours are purged from the canister whenever the purge VSV is opened by the ECM. At the appropriate time, the ECM will turn on the purge VSV. This will allow the low pressure in the intake manifold to draw the fuel vapours out of the charcoal canister. The vapours will then be burned in the combustion chamber.

The ECM controlled EVAP system goes into purge mode only when following conditions are satisfied: -

- *A pre-determined length of time must have elapsed after the engine start-up.*
- *The engine coolant temperature sensor must indicate that the coolant temperature is within a predetermined range.*
- *The engine must run with the throttle in a partly open position, for a considerable period of time.*
- *The engine speed must be higher than a pre-determined level.*

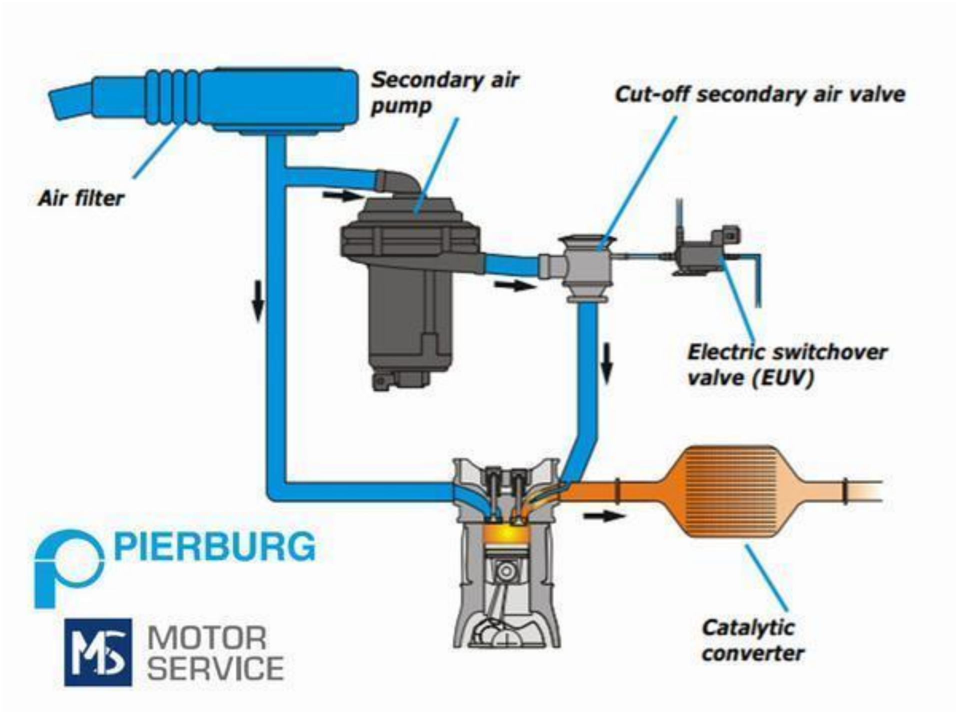
EXHAUST EMISSION CONTROL SYSTEM

After the exhaust gases come out of the engine cylinder, they can be treated by following methods: -

- ***Secondary Air Injection***
- ***Exhaust Gas Recirculation System***
- ***Catalytic Convertor System***
- ***Selective Catalytic Reduction (SCR)***

Each of the above technologies are explained in detail subsequently.

SECONDARY AIR INJECTION SYSTEM



In this system, *the **air injection pump** (driven electrically in modern cars) blows fresh air into the exhaust stream under certain operating conditions. The air is blown through the air lines and air manifold into a series of **air injection tubes which are located opposite to the exhaust valves.** The oxygen in the air helps in burning of the unburnt fuel particles present in the exhaust manifold.*

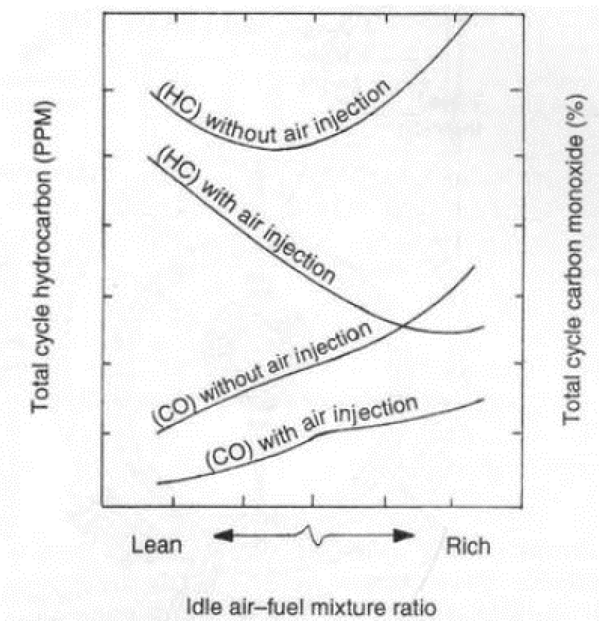
This system further lowers the HC and CO values during the cold start phase *when the catalytic converter is not yet active.* A conversion rate of over 90% is achieved using a 3-way catalytic converter in stoichiometrically operated gasoline engines. On average, up to 80% of the emissions of a driving cycle are emitted during a cold start. *However, because the catalytic converter only works effectively from temperatures of approx. 300°C – 350°C, the emissions must be lowered during the cold start phase using different measures.* This is the task of the secondary air system.

If there is sufficient residual oxygen in the exhaust system and the temperature is high enough, the HC and CO react in a secondary reaction to form CO_2 and H_2O.

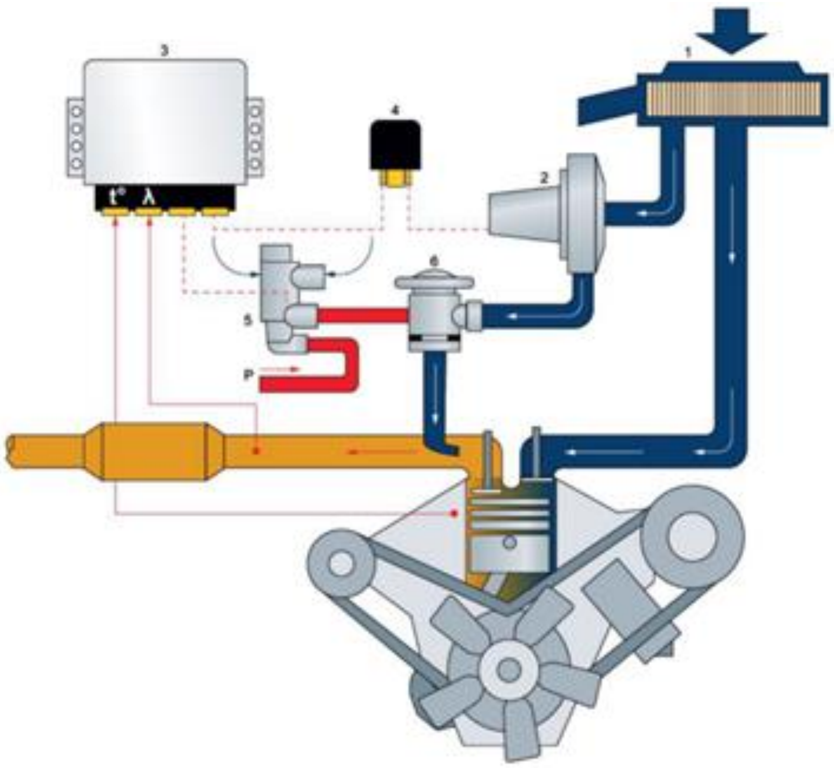
To ensure there is enough oxygen for the reaction during the cold start phase, when the mixture is very rich, air is added to the exhaust flow. *For vehicles with a three-way catalytic converter and a **lambda control,** the secondary air system is switched off after approx. 100 seconds.* The operating temperature of the catalytic converter is quickly reached through the heat generated in the secondary reaction.

The secondary air can be supplied *actively or passively.* In the ***passive system (pulse air injection system),*** fluctuations in pressure in the exhaust system are utilised. Additional air is drawn in via a timed valve due to the vacuum created through the flow speed in the exhaust pipe. In an ***active system,*** the secondary air is blown in by a pump. This system allows better control.

A comparison of carbon monoxide and hydrocarbon emission with and without air injection, *when varying the air-fuel mixture strength **during idling and low engine speeds*** shows a marked reduction in both carbon monoxide and hydrocarbon emission when air injection is introduced into the exhaust system is shown in the graph below: -



- **Operation of Secondary Air Injection System**



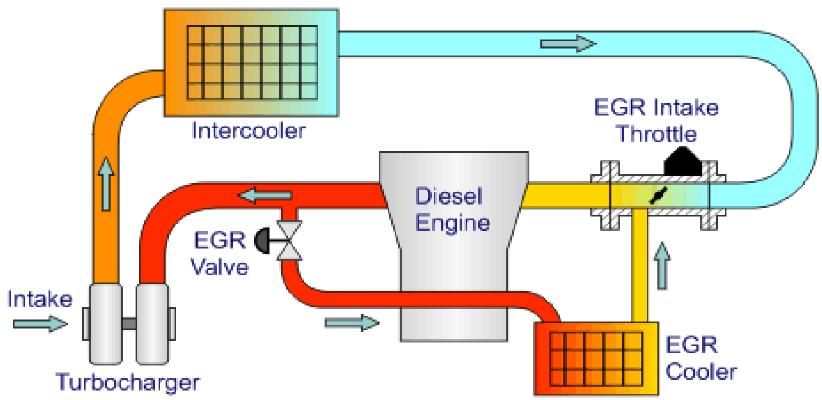
1. Air filter **2. Secondary air pump 3.** ECU **4.** Control relay **5.** Change-over valve **6.** Combination valve

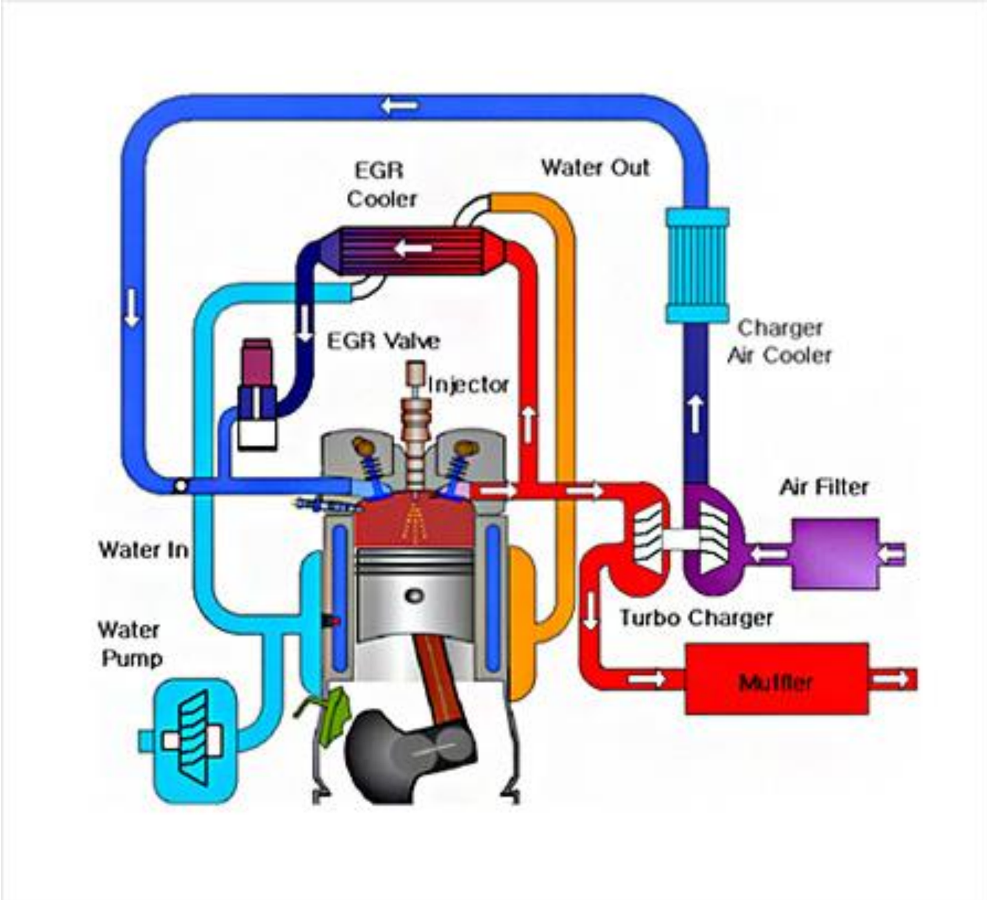
Refer the figure above. The active secondary air system usually consists of ***an electric pump*** (see figure above), the ***control relay, a pneumatic control valve and a combination valve.*** The system is controlled by the engine control unit.

While the system is working, the ***electric pump (2)*** is switched on by the ***engine control unit (3)*** via the ***control relay (4).*** The ***pneumatic control valve (5)*** is actuated at the same time. The valve opens and the vacuum from the intake pipe operates the ***combination valve (6).***

The vacuum causes the combination valve to open and the additional air conveyed by the pump is pumped into the exhaust pipe behind the exhaust valves. *As soon as the lambda control becomes active, the secondary air system is deactivated. The engine control unit deactivates the electric pump and the pneumatic control valve. The combination valve is also closed, preventing hot exhaust emissions from reaching the electric pump and damaging it.*

EXHAUST GAS RECIRCULATION (EGR) SYSTEM



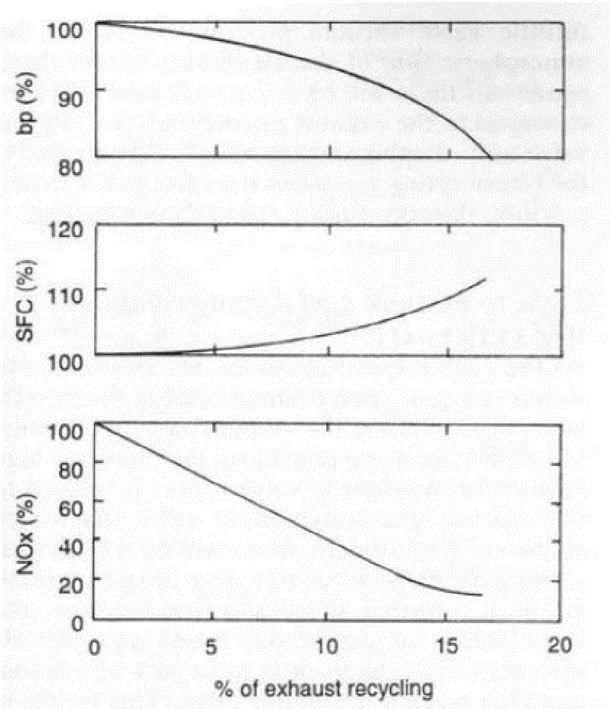


*An **"Exhaust Gas Recirculation System (EGR)"** returns some of the exhaust gas **(about 6 ~ 13%)** to the intake manifold under certain conditions.* This type of arrangement increases the proportion of inert gases (e.g. Carbon dioxide, Water vapour and Nitrogen) in the air entering the cylinders, thus lowering the peak combustion temperature which suppresses the generation of NO_x. *This is because, at lower temperature, little of nitrogen in the air combines with oxygen to form NO_x. Most of the nitrogen is simply carried out with the exhaust gas**. It has been estimated that 16% lowering of peak temperature would produce roughly 85% reduction of nitric oxide concentration in the ejected exhaust gases.***

The application of EGR reduces the speed of combustion. In order to prevent unstable combustion, ***EGR can only be used** under certain conditions (typically during constant speed operation and within a limited range of throttle opening angles). **EGR at cruising and acceleration (48~112 Kmph) is most desirable when NO_x formation is the highest.***

*The **EGR can not be used** when the engine is cold, during idling speed, high speed or high loads operation or during deceleration.*

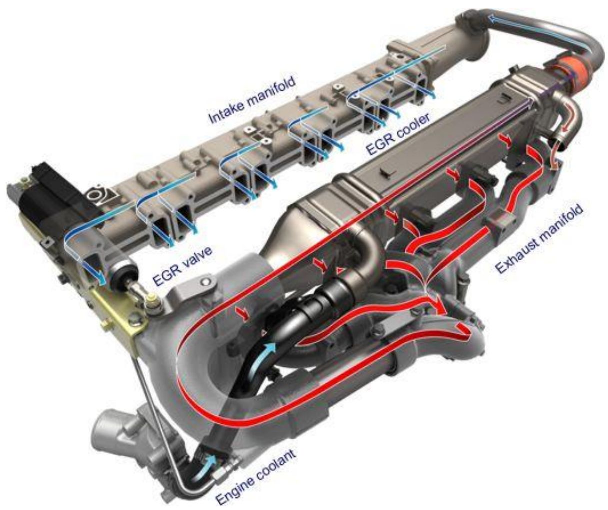
*The direct effects of exhaust gas recirculation on **brake power, specific fuel consumption and nitrogen oxides emissions** relative to the percentage of recirculated exhaust gas,* have been studied experimentally by testing an engine operating with a **fixed throttle setting, constant ignition timing and constant air-fuel ratio.** These results are plotted on the graphs below: -

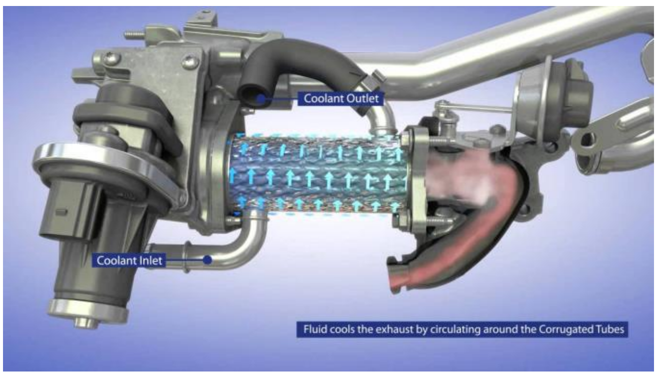


EGR Conflict: Less NOx, but O_2 dilution means more than HC and CO.

Some of the Indian Auto manufacturers using EGR system are Ashok Leyland for heavy and light vehicles, Tata Motors also for heavy and light vehicles, all the light vehicles companies like Hyundai, Mahindra, Honda, and Toyota etc.

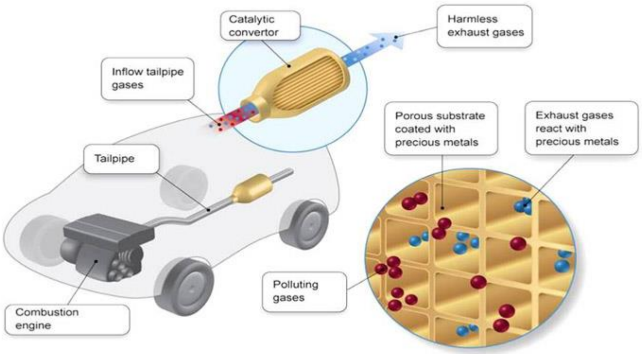
Actual EGR system of a Scania Euro-IV compliant engine and a Borg-warner EGR system are shown below: -

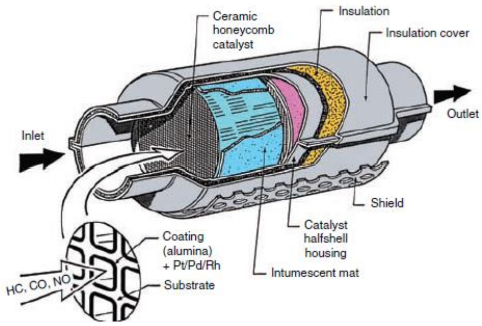




CATALYTIC CONVERTOR SYSTEM (CAT)

*A **"Catalytic Converter System"** is an emission control device that converts toxic gases and pollutants in exhaust gas to less toxic pollutants by causing a redox reaction (an oxidation and a reduction reaction) in the presence of catalysts.* The catalyst material is typically a combination of precious metals such as ***Platinum, Rhodium and Palladium***. Catalytic converters are used with internal combustion engines fuelled by either petrol (gasoline) or diesel including lean-burn engines as well as kerosene heaters and stoves.





Use of catalysis for promoting chemical reaction is evident from the data below: -

- ***HC and CO oxidise at temperature > 973^{o} K***
- ***Temperature of engine exhaust = 673 ~ 873^{o} K***
- ***In presence of Platinum (catalyst), oxidation happens at 573^{o} K.***

Oxidation Catalyst

The oxidation catalyst consists of ***Platinum and Palladium.*** The oxidation catalyst converts CO and HC to CO_2 and H_2O by combining with oxygen as per following chemical reaction: -

$$2CO + O_2 = 2CO_2$$

$$C_xH_{4x} + 2xO_2 = xCO_2 + 2xH_2O$$

Reduction Catalyst

The reduction catalyst consists of ***Platinum and Rhodium.*** The reduction catalyst converts NO_x to N_2 and O_2 by removing oxygen as per following chemical reaction: -

$$xNO_x = N_x + xO_x$$

Types of Catalytic Convertors

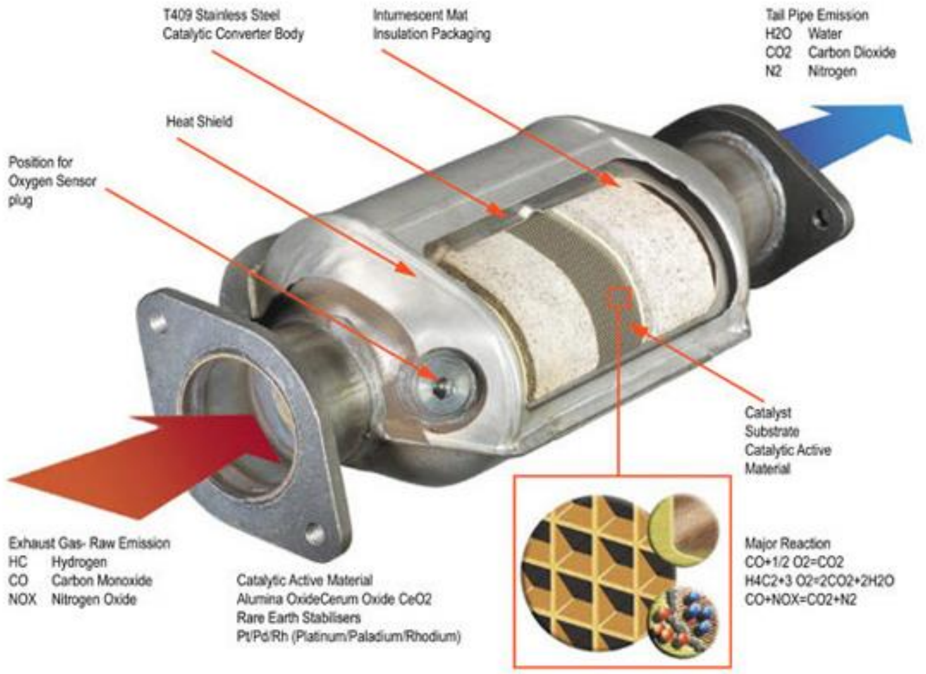
Catalytic convertors can be of two types viz. ***"2-Way Catalytic Convertor" and "3-Way Catalytic Convertor".*** A 2-Way Catalytic Convertor removes the CO and HC components (2-components only) through oxidation to form carbon dioxide and water. A 3-Way Catalytic Convertor additionally removes oxygen from NO_x components to form nitrogen.

A large catalyst surface area is necessary for exposure to the exhaust gas.

Most vehicles have a catalytic convertor installed mid-way along the exhaust pipe, although some designs used in low emission vehicles have the convertor located immediately after the exhaust manifold.

Two-way catalytic converter is widely used on diesel engines to reduce hydrocarbon and carbon monoxide emissions. *They were also used on petrol engines in American- and Canadian-market automobiles until 1981.* ***Because of their inability to control oxides of nitrogen, they have been superseded by three-way converters.***

Three-Way Catalytic Convertor



As already explained, the 3-way catalytic convertor removes all the three pollutants i.e. HC, CO and NO_x by redox reactions. The catalyst is coated on *Aluminium Oxide substrate* through which exhaust gas passes. The core is placed inside a *stainless-steel wire mesh* for protection against mechanical damage and thermal shocks caused by temperature extremes. The convertor is provided with a heat shield to limit the surface temperature to safe values. It is also provided with an *oxygen sensor* to measure oxygen content in exhaust gas which is provided as an input to ECU for controlling the air-fuel ratio and activating other engine management controls.

*The **first set catalyst is the "Reduction Catalyst (Platinum – Rhodium)"** which removes NO_x and releases nitrogen and oxygen. This oxygen along with HC and CO passes on to the **second set catalyst which is the "Oxidation Catalyst (Platinum – palladium)".** This catalyst then oxidises them to carbon dioxide and water.*

The three-way catalytic convertor can have a ***single bed*** or ***dual bed design***. A single bed arrangement contains a single catalytic bed. A dual bed design (as shown in the picture above) contains two catalytic beds in series. The first catalysis is effective on NO_x, HC and CO and the second catalytic bed is effective on HC and CO.

Precautions to be followed while using Catalytic Converter:

- ***Wrong Fuel: -***

  ONLY UNLEADED PETROL TO USE. Lead forms coating over catalyst elements effecting contact hence chemical reaction of exhaust gases.

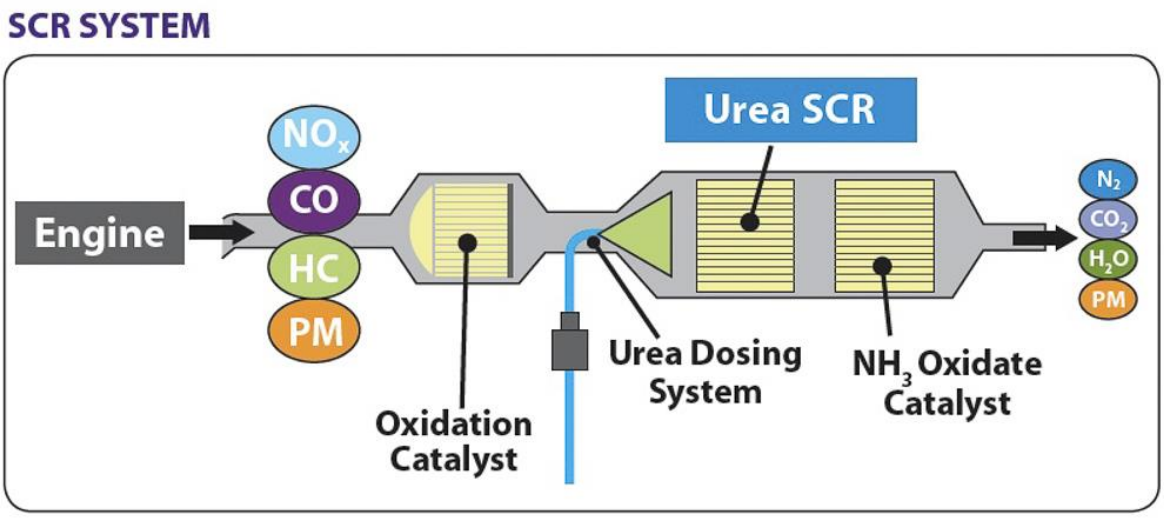
- ***Raw Fuel in Convertor: -***

  If there are too much unburned hydrocarbons going into the catalytic converter, it greatly increases the temperature inside the converter. This increased temperature causes the platinum to be oxidized into platinum oxide, thus eliminating the platinum catalyst.

- ***Convertor Operation Precautions: -***

  - Do not use wrong fuel e.g. leaded petrol.
  - Avoid pumping of raw fuel into convertor.
  - Ensure convertor temperature not to exceed 1090-degree K else it will melt.
  - Do not idle for more than 10-minutes.
  - Do not crank for more than 60-seconds.
  - Use jumper cables for starting.
  - Ensure no spark plug miss-firing.

SELECTIVE CATALYTIC REDUCTION (SCR)



"Selective Catalytic Reduction (SCR)" is an advanced active emissions control technology system that injects a liquid-reductant agent through a special catalyst into the exhaust stream of a diesel engine. The reductant source is usually ***"Automotive-grade Urea, otherwise known as Diesel Exhaust Fluid (DEF).*** ***The DEF sets off a chemical reaction that converts nitrogen oxides into nitrogen, water and tiny amounts of carbon dioxide (CO2), natural components of the air we breathe, which is then expelled through the vehicle tailpipe.***

DEF is known in various names such as AdBlue, AUS32 and consists of 32.50% urea and 67.50% deionized water. ***In India, this is known as AUS32 (Aqueous Urea Solution).***

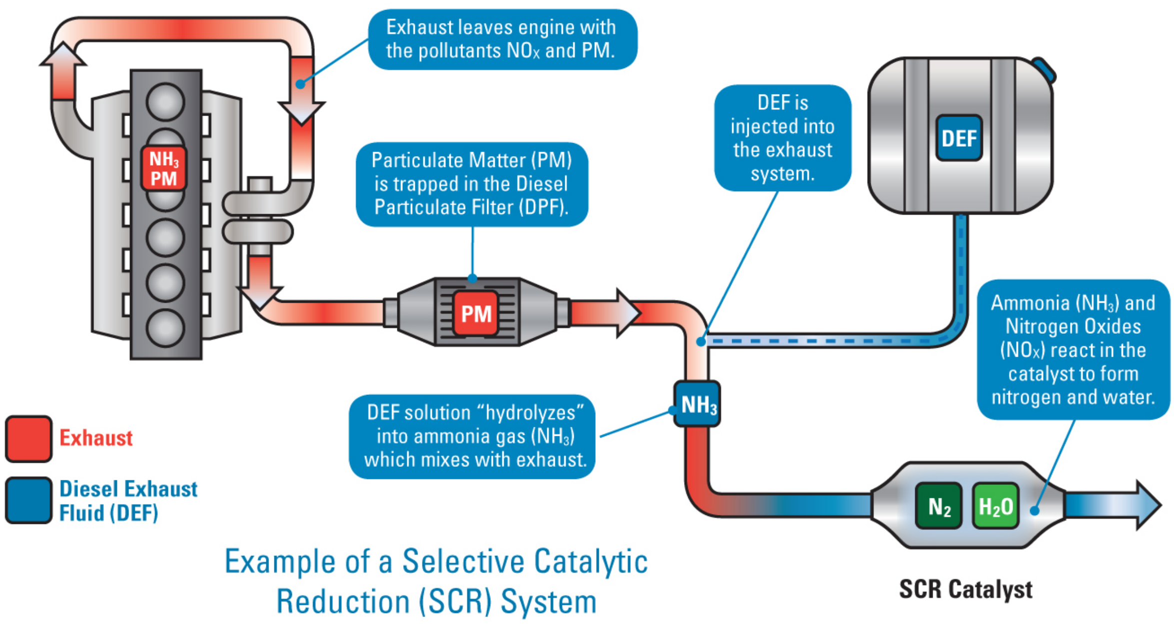
SCR technology is designed to permit nitrogen oxide (NOx) reduction reactions to take place in an oxidizing atmosphere. ***It is called "Selective"*** *because it reduces levels of NO_x using ammonia as a reductant within a catalyst system.* The chemical reaction is known as "reduction" where the DEF is the reducing agent that reacts with NO_x to convert the pollutants into nitrogen, water and tiny amounts of CO_2. The DEF can be rapidly broken down to produce the oxidizing ammonia in the exhaust stream. ***SCR technology alone can achieve NOx***

reductions up to 90%. *This system is widely used in heavy duty diesel engines for automotive, marine (cargo vessels, ferries, tug boat) and for stationary applications. This has also found growing number of applications in diesel passenger vehicles.*

The chemical reaction taking place due to AdBlue injection is as follows: -

$$\boldsymbol{NO + NO_2 + 2NH_3\ (from\ AdBlue) = 2N_2 + 3H_2O}$$

Schematic diagram of a "SCR system for controlling Diesel engine emissions" is given below:-



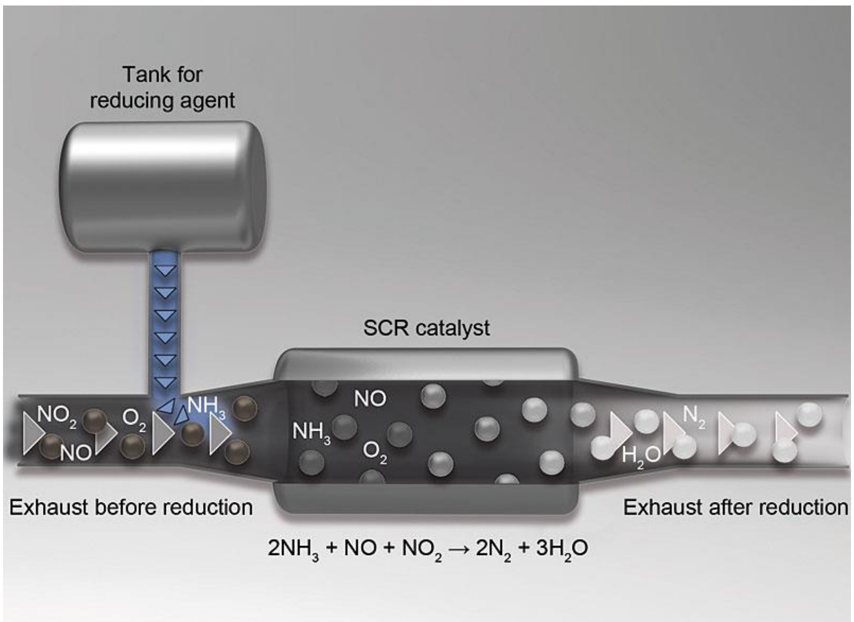


Figure above indicates the chemical reaction taking place in SCR using aqueous urea solution.

The commonly used "Diesel engine exhaust after-treatment sequence" is as below: -

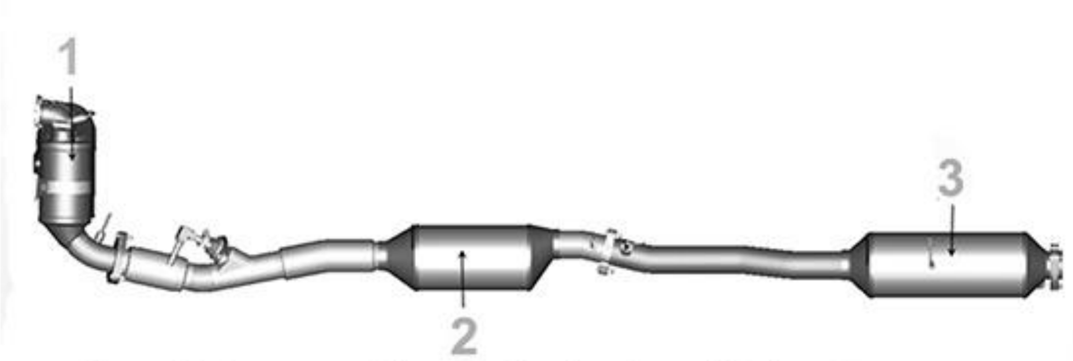
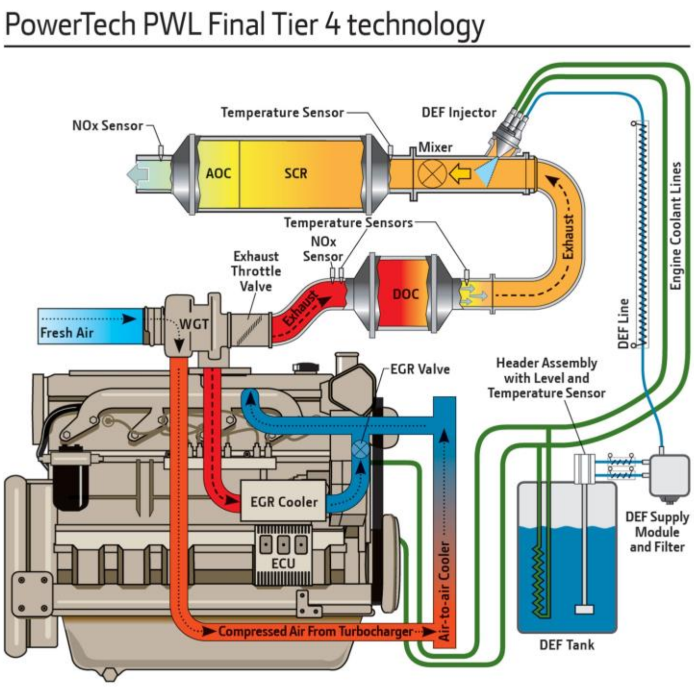


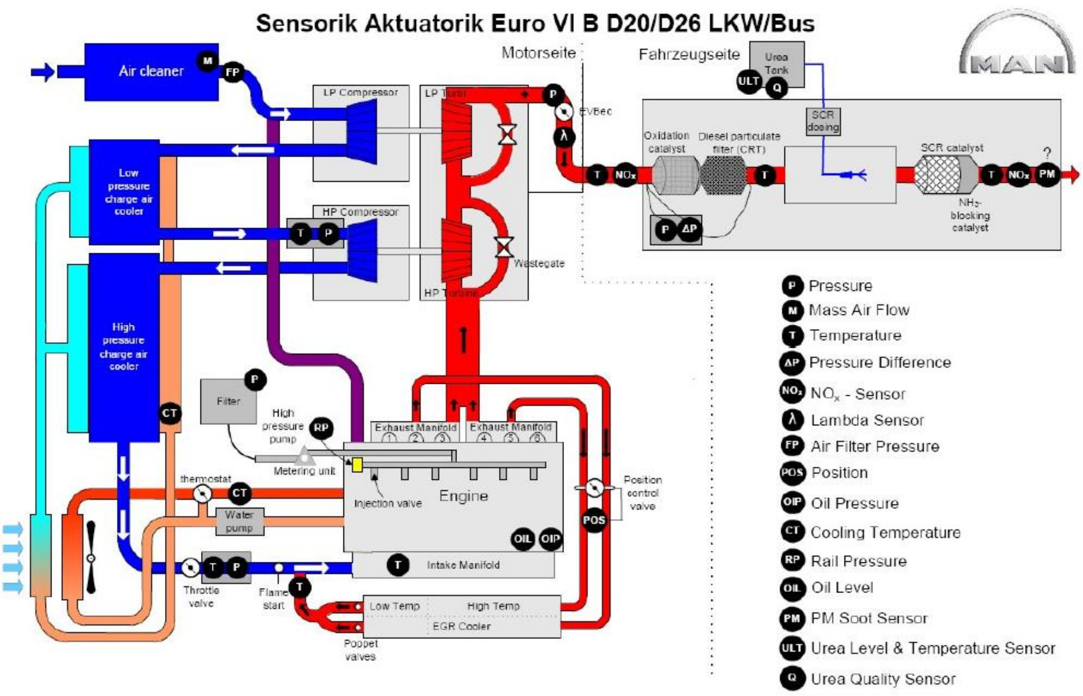
Figure 1: Common Exhaust Aftertreatment System Sequence
1-DOC, 2-DPF, 3-SCR

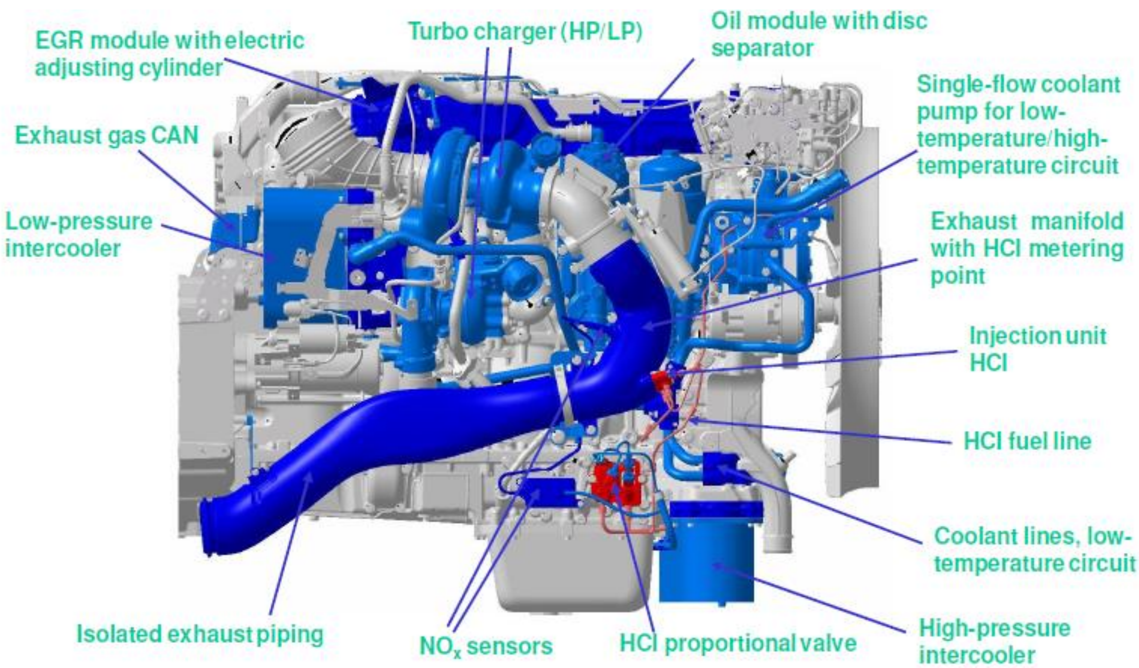
- ***Diesel Oxidation Catalyst (DOC):*** *The DOC is the first device in the after-treatment system. It is a flow through filter that contains precious metals to start the oxidation of hydrocarbons, carbon monoxide and unburned fuel and oil. Both the DOC and the DPF are honeycomb ceramic filters.*
- ***Diesel Particulate Filter (DPF):*** *The DPF is a wall-flow filter that traps any remaining soot that the DOC couldn't oxidize. The soot remains in the DPF until it is regenerated either passively or actively. Passive regeneration occurs when the vehicle's normal operating temperatures and the DPF will oxidise the particulates anywhere between 275-360º Celsius.*

*Figure below shows a **John Deere Tier-4 (Euro Stage-IV) Off-highway 4.5L Diesel Engine** using combined EGR and SCR technologies without DPF for exhaust emission control: -*



*Picture below shows a **MAN (Euro-VI) Truck Diesel Engine with 2-Stage Turbocharging** using combined EGR and SCR technologies with Oxidation catalyst and DPF for exhaust emission* *control. This engine also uses a HCI (Hydrocarbon Injection System) in exhaust stream to reduce soot build-up in after-treatment systems.*





EURO / BHARAT STAGE NORMS

INTRODUCTION

The emission standards are set by the Government to control the air pollution coming out of motor vehicles. The emission of vehicles are measure in a special laboratory equipped with sophisticated test rigs and benches. The vehicle is run on a "Chassis Dynamometer" on a special pre-decided mode to simulate actual road conditions. The gases (pollutants) coming out of the exhaust pipe are collected in analysers where mass of each pollutant is calculated.

Bharat stage emission standards **(BSES)** are emission standards instituted by the *Government of India* to regulate the output of *air pollutants* from *internal combustion engines* and *Spark-ignition engines* equipment including *motor vehicles. These standards are based on European Emission Standards (EURO Standards).* The standards and the timeline for implementation are set by the **Central Pollution Control Board** under the **Ministry of Environment, Forests and Climate Change**. The emission levels as per standards are checked by ***"ARAI (Automotive Research Association of India)", "ICAT (International Centre for Automotive Technology)"*** and ***"VRDE (Vehicle Research and Development Establishment) under DRDO"*** for Defence vehicles.

BRIEF ABOUT ARAI

Automotive Research Association of India (ARAI), established in 1966, is the leading automotive R&D organization of the country set up by the Automotive Industry with the Government of India. ARAI is an autonomous body affiliated to the Ministry of Heavy Industries and Public Enterprises, Government of India. The Department of Scientific and Industrial Research, Ministry of Science and Technology, Government of India, has recognized ARAI as a Scientific and Industrial Research Organisation (SIRO). Further, ***ARAI is one of the prime Testing and Certification Agency notified by Government of India under Rule 126 of Central Motor Vehicle Rules, 1989.***

EURO EMISSION STANDARDS AND IMPLEMENTATION ROADMAP

The various EURO emission standards with their date of introduction are indicated for ***petrol and diesel fuelled passenger cars*** in the tables below: -

Emission Standards for European Countries - Passenger Cars (g/km)

Standard	Implementation Date	CO	HC	NOx	HC + NOx	PM
Petrol						
Euro - I	July - 1992	2.72	-	-	0.97	-
Euro - II	Jan - 1996	2.20	-	-	0.50	-
Euro - III	Jan - 2000	2.30	0.20	0.15	-	-
Euro - IV	Jan - 2005	1.00	0.10	0.08	-	-
Euro - V	Sep - 2009	1.00	0.10	0.06	-	-
Euro - VI	Sep - 2015	1.00	0.10	0.06	-	-

Emission Standards for European Countries - Passenger Cars (g/km)

Standard	Implementation Date	CO	HC	NOx	HC + NOx	PM
Diesel						
Euro - I	July - 1992	2.72	-	-	0.97	0.14
Euro - II	Jan - 1996	1.00	-	-	0.70	0.08
Euro - III	Jan - 2000	0.64	-	0.50	0.56	0.05
Euro - IV	Jan - 2005	0.50	-	0.25	0.30	0.025
Euro - V	Sep - 2009	0.50	-	0.18	0.23	0.005
Euro - VI	Sep - 2015	0.50	-	0.06	0.17	0.005

Automobile emission standards in India are known as "Bharat Stage Standards (BS – Standards)". *The first emission standards were introduced in India in year 1991 for petrol vehicles and in year 1992 for diesel vehicles.*

As already indicated above, the present Indian emission standards are based on European standards. ***The standards based on European standards were first introduced in year 2000.*** All new vehicles manufacture after the implementation date of the standards have to comply with it. However, in year 2017, when BS-IV standards were introduced, the Government of India mandated that all vehicles either sold or manufactured after date of implementation will have to comply with the standard.

Government of India has announced that the country will skip BS-V and go for BS-VI standards tentatively with effect from Apr-2020. *All vehicles either sold or manufactured after date of implementation will have to comply with the standard.*

The various Bharat Stage standards with their date of introduction are indicated for ***petrol and diesel fuelled passenger cars*** in the tables below: -

Indian Emission Standards (Bharat Stage Standards) : Passenger Cars (g/km)

Standard	Implementation Date	CO	HC	NOx	HC + NOx	PM
Petrol						
1991	-	14.30 - 27.10	2.00 - 2.90	-	-	-
1996	-	8.68 - 21.40	-	-	3.00 - 4.36	-
1998	-	4.34 - 6.20	-	-	1.50 - 2.18	-
BS - I	Apr - 2000	2.72	-	-	0.97	-
BS - II	Apr - 2005	2.20 - 5.00	-	-	0.50 - 0.70	-
BS - III	Oct - 2010	2.30 - 5.22	0.20 - 0.29	0.15 - 0.21	-	-
BS - IV	Apr - 2017	1.00 - 2.27	0.10 - 0.16	0.08 - 0.11	-	-
BS - VI	Apr - 2020 (Tentative)	1.00	0.10	0.06	-	0.0045

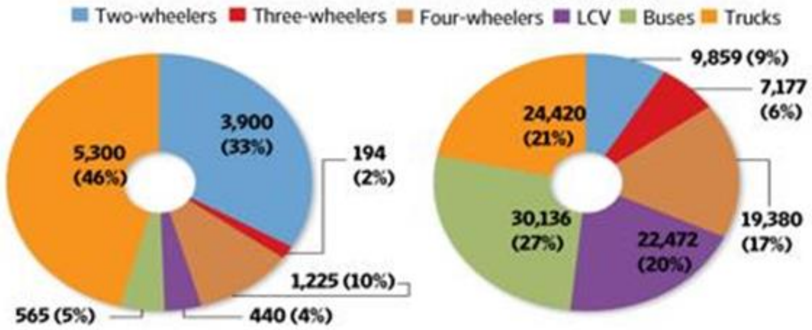
Indian Emission Standards (Bharat Stage Standards) : Passenger Cars (g/km)

Standard	Implementation Date	CO	HC	NOx	HC + NOx	PM
Diesel						
1992		14.30 - 27.10	-	-	4.70 - 6.90	-
1996		5.00 - 9.00	-	-	2.00 - 4.00	-
BS - I	Apr - 2000	2.72 - 6.90	-	-	0.97 - 1.70	0.14 - 0.25
BS - II	Apr - 2005	1.00 - 1.50	-	-	0.70 - 1.20	0.08 - 0.17
BS - III	Oct - 2010	0.64 - 0.95	-	0.50 - 0.78	0.56 - 0.86	0.05 - 0.10
BS - IV	Apr - 2017	0.50 - 0.74	-	0.25 - 0.39	0.30 - 0.46	0.025 - 0.06
BS - VI	Apr - 2020 (Tentative)	0.50	-	0.06	0.17	0.005

POLLUTION CHECK

PM2.5 emitted by various vehicles (in kg/day)

Oxides of nitrogen emitted by various vehicles (in kg/day)

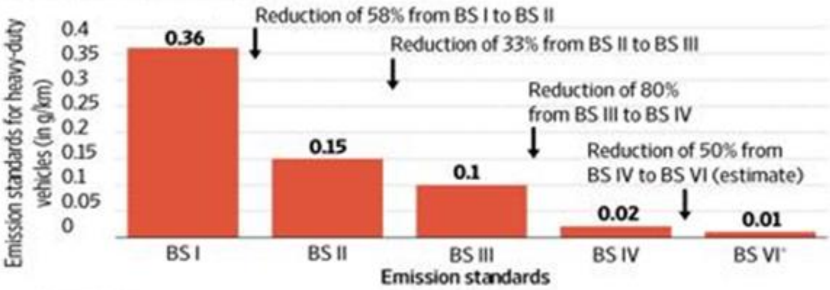


LCV: Light commercial vehicles

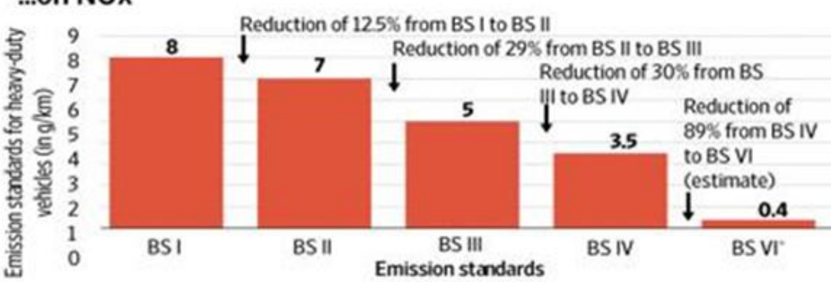
Source: Data as of 2015, IIT-Kanpur

EFFECT OF SUCCESSIVE BHARAT STAGE STANDARDS...

...on particulate matter



...on NOx



*Expected to be launched on 1 April 2020

Source: CSE computation based on data provided by transportpolicy.net

Changes Required for Upgradation To BS-VI Emission Norms

Mechanics of BS-VI

- Bharat Stage VI (BS-VI) norms will take effect in India from **1 April 2020**
- BS-VI is the **most advanced emission standard** for automobiles and is equivalent to Euro-VI norms
- In order to **reduce vehicular pollution**, the government decided to leapfrog from BS-IV to BS-VI
- The new norms make on-board diagnostics **(OBD) mandatory** for all vehicles

- The OBD unit can identify likely **areas of malfunction** by means of default codes stored on a computer
- For two-wheelers, manufacturers will introduce a **fuel injection system**—a first in India

The upgrade from BS-IV to BS-VI: what needs to be done

BS-V requires a specific fitment in the vehicle's engine. BS-VI needs one more, and each comes with issues that need fixing

FOR BS-V: DIESEL PARTICULATE FILTER, OR DPF

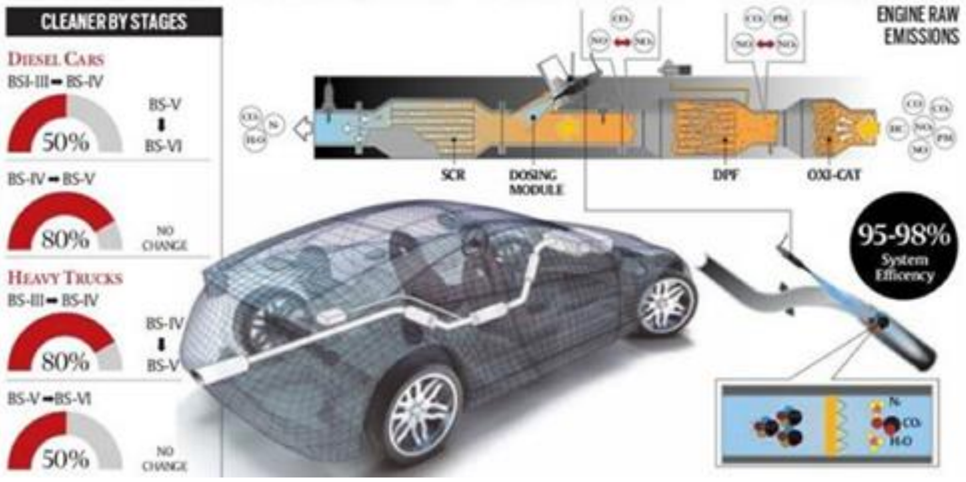
WHAT IS IT? DPF is a cylinder mounted vertically in the engine compartment. Its function is to remove particulate matter, or soot, from the diesel exhaust. It needs temperatures of 600 degrees Celsius, difficult in Indian conditions.

WHAT'S THE PROBLEM? Small cars, popular in India, have limited bonnet space, and will require a major redesign to accommodate DPF. But a bigger bonnet may result in the car breaching the sub-4-metre mark, and losing excise benefits.

FOR BS-VI: SELECTIVE CATALYTIC REDUCTION TECHNOLOGY

WHAT IS IT? An SCR module reduces the oxides of nitrogen in the engine exhaust by injecting an aqueous solution called AUS 32 into the system. AUS 32 contains ammonia, for which a separate container will be needed on board the vehicle.

WHAT'S THE PROBLEM? An anti-defect mechanism is required to put the vehicle in the limp mode if AUS 32 is not refilled. Nationwide infrastructure will be needed for supply of AUS 32, which is safe, but does need careful storage and handling.



ROADMAP FROM BS-IV TO BS-VI

BS-IV

BY APRIL 1, 2015
- All of North India (J&K except Leh & Kargil, Punjab, Haryana, HP, Uttarakhand, Delhi and bordering districts of Rajasthan and Western UP. All of Goa, Kerala, Karnataka, Telangana, Odisha; UTs of Daman & Diu, Dadra & Nagar Haveli, Andaman & Nicobar; parts of Maharashtra and Gujarat.

FUEL SUPPLY COMMENCED

BY APRIL 1, 2016
- Corridor spanning highway link through Gujarat and Rajasthan linking North India to ports on west coast.

FUEL SUPPLY COMMENCED

BY APRIL 1, 2017
- Rest of the Country

BS-V SKIPPED

BS-VI

BY APRIL 1, 2020
As per order issued by the Ministry of Road Transport and Highways on May 22, 2015, all oil marketing companies and other stakeholders are required to switch directly from BS-IV to BS-VI quality fuel.

SOURCE: Report of the Expert Committee on Auto Fuel Vision & Policy 2025, Government of India, 2014