EMISSION REGULATION AND CONTROL SYSTEMS

There has been a great concern, in recent years, that the I C Engines are responsible for too much atmospheric pollution, which is detrimental to human health & environment. Thus concerted efforts are being made to reduce the responsible pollutants emitted from the exhaust system without sacrificing power & fuel consumption.

Air pollution can be defined as an addition to our atmosphere of any material which will have a deleterious effect on life upon our planet. Besides IC engines other sources such as electric power stations, industrial and domestic fuel consumers also add pollution.

MECHANISM OF POLLUTANTS FORMATION (VTU JAN 2007)
(MAIN POLLUTANTS EMITTED BY PETROL ENGINE (VTU FEB 2006))

Pollutants are produced by the incomplete burning of the air-fuel mixture in the combustion chamber. The major pollutants emitted from the exhaust due to incomplete combustion are:

- Carbon monoxide (CO)
- Hydrocarbons (HC)
- Oxides of nitrogen (NO).

Other products produced are acetylene, aldehydes etc. If, however, combustion is complete- - the only products being expelled from the exhaust would be water vapour which is harmless, and carbon dioxide, which is an inert gas and, as such it is not directly harmful to humans.

CARBON MONOXIDE (CO) :

It is a colour less gas of about the same density as air. It is a poisonous gas which, when inhaled, replaces the oxygen in the blood stream so that the body's metabolism can not function correctly. Small amounts of CO concentrations, when breathed in, slow down physical and mental activity and produces headaches, while large concentration will kill.

Mechanism of formation of CO

CO is intermediate product of combustion remains in exhaust if the oxidation of CO to $C0_2$ is not complete. Theoretically , it can be said that petrol engine exhaust is free of CO if the air fuel ratio is 15. However, some CO is always present in the exhaust even at lean mixture and can be as high as 1%. CO is generally formed when the mixture is rich in fuel. The amount of CO formed increases the mixture becomes more and more rich in fuel. A small amount of CO will come out of the exhaust even when the mixture is slightly lean in fuel. This is due to the fact that equilibrium is not established when the products pass to the exhaust. At the high temperature developed during the combustion, the products formed are unstable, and the following reactions take place before the equilibrium is established.

$$2H_2O + O_2 \rightarrow 2(1-y)\,H_20 + 2yH_2 + yO_2$$

where, y is the fraction of H_20 dissociated.

$$C + 0_2 \rightarrow C0_2 \rightarrow + (1-x)CO_2 + x\,CO + x/2\,O_2$$

As the products cool down to exhaust temperature, major part of CO reacts with oxygen form CO_2 However, a relatively small amount of CO will remain in exhaust, its concentration creasing with rich mixtures.

2. HYDROCARBONS (HC):

The unburnt hydrocarbons emission is the direct result of incomplete combustion. The emission amount of hydrocarbon is closely related to design variables and combustion chamber design and operating variables such as A:F ratio, speed, load and mode of operation as idling, running or accelerating. Surface to volume ratio and wall quenching greatly affects in formation of HC. Hydrocarbons, derived from unburnt fuel emitted, by exhausts, engine crankcase fumes and vapour escaping from the carburetor are also harmful to health.

Mechanism of formation of HC

Due to existence of local very rich mixture pockets at much lower temperatures than combustion chambers, unburnt hydrocarbons may appear in the exhaust.The hydrocarbons also appear due to flame quenching near the metallic walls.

A significant portion of this unburnt hydrocarbon may burn during expansion and exhaust strokes if the oxygen concentration and exhaust temperature is suitable for complete oxidation Otherwise a large amount of hydrocarbon will go out with the exhaust gases.

3. OXIDES OF NITROGEN (NO):

Oxides of N_2 generally occur mainly in the form of NO and $N0_2$. These are generally formed at high temperature. Hence high temperature and availability of 0_2 are the main reason for the formation of N0 and NO_2 .Many other oxides like N_2O_4, N_2O, N_2O_3 ,N_2O_5 are also formed in low concentration but they decompose spontaneously at ambient conditions of NO_2. The maximum NO_x levels are observed with A:F ratios of about 10% above stoichiometric. Oxides of nitrogen and other obnoxious substances are produced in very small quantities and, in certain environments, can cause pollution, while prolonged exposure is dangerous to health.

Mechanism of formation of nitric oxide (NO)

At high combustion temperatures, the following chemical reactions take place behind the flame:

$$N_2 + O_2 \rightarrow 2NO$$

$$N_2 + 2H_2O \rightarrow 2NO + 2H_2$$

Chemical equilibrium calculations show that a significant amount of NO will be formed the end of combustion. The majority of NO formed will however decompose at the low temperature of exhaust. But due to very low reaction rate at the exhaust temperature a part of NO formed remains in exhaust. It is far in excess of the equilibrium composition at that temperature as t formation of NO freezes at low exhaust temperatures. The NO formation will be less in rich mixtures than in lean mixtures.

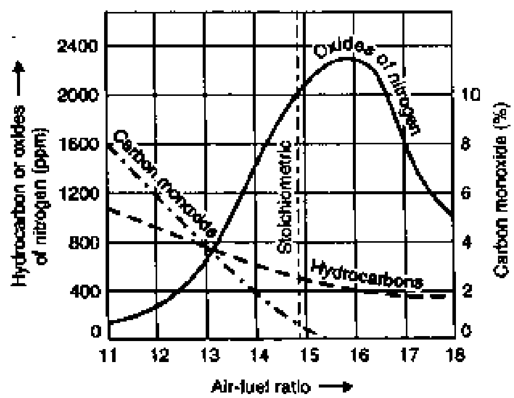
4. SMOKE OR PARTICULATE

Solid particles are usually formed by dehydrogenation, polymerisation and agglomeration. In the combustion process of different hydrocarbons, acetylene (C_2H_2) is formed as intermediate product. These acetylene molecules after simultaneous polymerisation dehydration produce carbon particles, which are the main constituent of the particulate.

5. ALDEHYDES: Due to very slow chemical reaction during delay period in the diesel engines, aldehydes are formed as intermediate products. In some parts of the spray the aldehydes will be left after the initial reactions. These aldehydes may be oxidised in the later part of the cycle, if the mixture temperature is high, and if there is sufficient oxygen. At heavy loads, due to lack of oxygen, an increase in aldehyde emission in the exhaust is observed.

Exhaust Pollutants Versus the A:F ratio:

Figure shows how three main exhaust pollutant products (CO,HC and NO_X) vary from different air-fuel ratio operating on either side of the stochiometric ratio for a very rich mixture (11:1) to very lean mixture (18:1).



- The amount of CO produced in the exhaust is about 8% for an 11: 1 air-fuel, ratio, but this percentage steadily decreases to zero as the mixture is reduced to just beyond the stoichiometric ratio (on the lean side).
- HC produced in the exhaust gases amounts to about 1100 parts per million (ppm) with a rich 11: 1 air-fuel ratio and, as the mixture strength approaches the stoichiometric ratio, it progressively falls to around 500 ppm. A further weakening of the mixture to 18: 1 air-fuel, ratio only reduces HC content to approximately 350 ppm.
- Oxides of nitrogen products formed during combustion are very low at 100 ppm with a rich air-fuel ratio of 11: 1. As the mixture strength approaches the stoichiornetric ratio it rises fairly rapidly to 2000 ppm, and a further reduction of the mixture strength to 15: 1 peaks the oxides of nitrogen to something like 2,300 ppm, weakening the mixture beyond this point rapidly reduces it until, at an 18: 1 air-fuel ratio, it is 1000 ppm.

SOURCES OF POLLUTANTS FROM SI ENGINE (VTU JULY 2007)

The following are the three main sources form which pollutants are emitted from the SI engine:

- The crankcase. Where piston blow-by fumes and oil mist are vented to the atmosphere.
- The fuel system. Where evaporative emissions from the carburetor or petrol injection air intake and fuel tank are vented to the atmosphere.
- The exhaust system. Where the products of incomplete combustion are expelled from the tail pipe into the atmosphere.

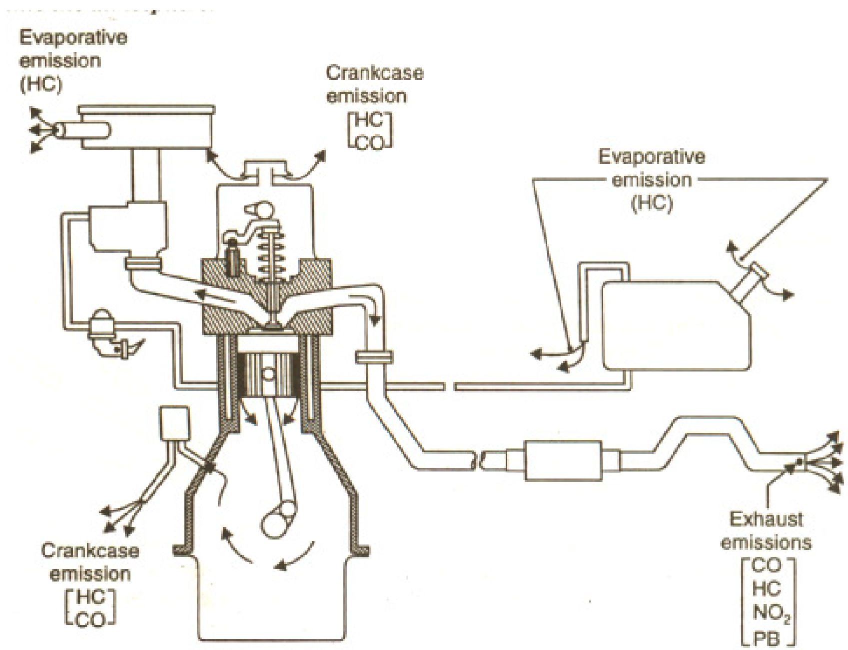
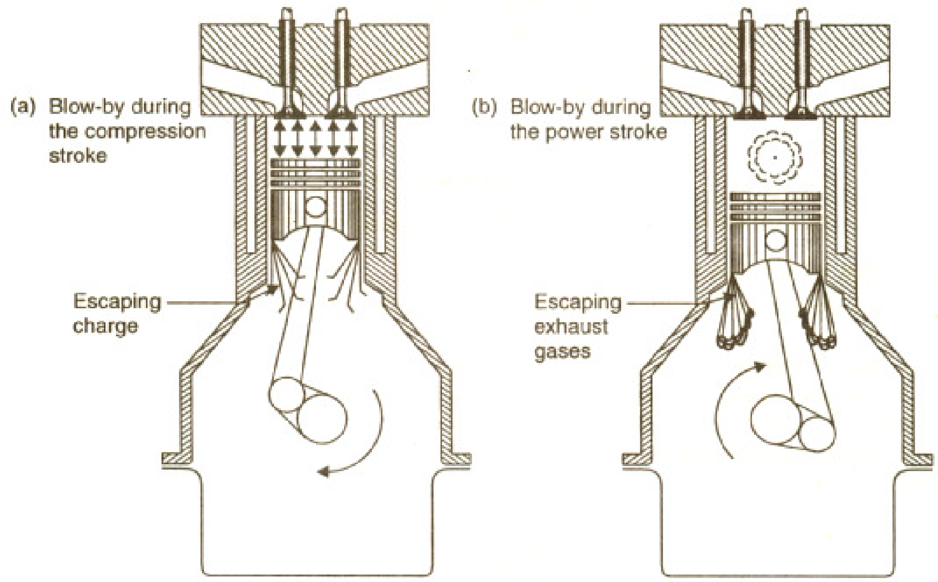


Fig. 18.2. Spark ignition engine emissions.

Crankcase Emission

The piston and its rings are designed to form a gas-tight seal between the sliding piston and cylinder walls. However, in practice there will always be some compressed charge and burnt fumes escape during compression and power stroke to crankcase. These gases are usually unburnt air-fuel mixture hydrocarbons, or burnt (or partially burnt) products of combustion, $C0_2$, H_2O (steam) or CO. These products also contaminate the lubricating oils.



Evaporative Emission

Evaporative emissions account for 15 to 25% of total hydrocarbon emission from a gasoline engine. The following are two main sources of evaporative emissions:

- The fuel tank
- The carburettor.

(i) Fuel tank losses. The main factors governing the tank emissions are fuel volatility and the ambient temperature but the tank design and location can also influence the emissions as location affects the temperature. Insulation of tank and vapour collection systems have all been explored with a view to reduce the tank emission.

(ii) Carburettor losses. Although most internally vented carburettors have an external vent which opens at idle throttle position, the existing pressure forces prevent outflow of vapours to the atmosphere. Internally vented carburettor may enrich the mixture which in turn increases exhaust emission.

EXHAUST EMISSION

The different constituents which are exhausted from S.I. engine and different factors which will affect percentages of different constituents are discussed below:

Hydrocarbons (HC)

The emission amount of HC (due to incomplete combustion) is closely related to

Design variables, Operating variables and engine condition. The Surface to volume ratio greatly affects the HC emission. Higher the S/V ratio, higher the HC emission irrespective of whether mixture is rich or lean. When the Mixture supplied is lean or rich, the flame propagation becomes weak which causes in turn causes incomplete combustion and results in HC emission.

Carbon Mono oxide (HC)

If the oxidation of CO to CO is not complete, CO remains in the exhaust. It can be said theoretically that, the petrol engine exhaust can be made free from CO by operating it at A/F ratio = 15. However, some CO is always present in the exhaust even at lean mixture and can be as high as 1 per cent. CO emissions are lowest during acceleration and at steady speeds. They are, however, high during idling and reach maximum during deceleration.

Oxides of nitrogen (NO)

Oxides of nitrogen occur mainly in the form of NO and NO and are generally formed at high temperature. • The maximum NO levels are observed with A/F ratios of about 10 percent above stoichiometric. It has also been observed that NO increases with increasing manifold pressure, engine load and compression ratio. This characteristic is different from HC and CO emission which is nearly independent of engine load except for idling and deceleration.

Lead emission

Lead emissions come only from S.I. engines. In the fuel, lead is present as antiknock agents in SI Engine. It may not be possible to eliminate lead completely from all petrols immediately because a large number of existing engines rely upon the lubrication provided by a lead film to prevent rapid wear of exhaust valve seats.

SI ENGINE EMISSION CONTROL (VTU JULY 2007)

The main methods, among various methods, for S.I. engine emission control are:

- Modification in the engine design and operating parameters.
- Treatment of exhaust products of combustion.
- Modification of the fuels.

Modification in the Engine Design and Operating Parameters

- Modification of combustion chamber involves avoiding flame quenching zones where combustion might otherwise be incomplete and resulting in high HC emission. This includes: Reduction of surface to volume (SAT) ratio, Reduced space around piston ring
- Lower compression ratio: Lower compression ratio reduces the quenching effect by reducing the quenching area, thus reducing HC.Lower compression ratio also reduces NO emissions due to lower maximum temperature. Lower compression, however, reduces thermal efficiency and increases fuel consumption.

Treatment of exhaust products of combustion.

The exhaust gas coming out of exhaust manifold is treated to reduce JIC and CO emissions. The devices used to accomplish are After burner , Exhaust manifold reactor and Catalytic converter.

After-burner: is a burner where air is supplied to the exhaust gases and mixture is burnt with the help of ignition system. The HC and CO which are formed in the engine combustion because of inadequate 02 and inadequate time to burn are further brunt by providing air in a separate box, known as after-burner.

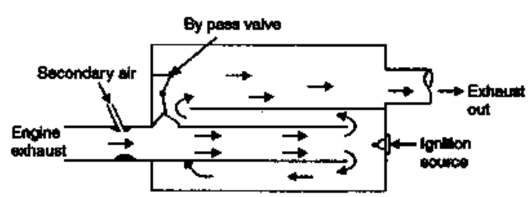


Fig. 18.6. Direct flame after-burner.

Exhaust manifold reactor is a further development of after-burner where the design is changed so as to minimize the heat loss and to provide sufficient time for mixing of exhaust and secondary air. 3. Catalytic converter:

A catalytic converter is a device which is placed in the vehicle exhaust system to reduce HC and CO by oxidizing catalyst and NO by reducing catalyst.

Modification of the fuels

The ability of a fuel to burn in mixtures leaner than stoichiometric ratio is a rough indication of its potential emission reducing characteristics and reduced fuel consumption. If gasoline is changed to propane as engine fuel CO emission can substantially be reduced with reduced HC and NO and in changing from propane to methane the CO as well HC emission touch zero level and only the NO remains as a significant factor.• From pollution point of view both methane and steam reformed hexane are very attractive fuels but we are unable to use at present for want of technological progress.

CONTROL OF OXIDES OF NITROGEN (VTU July 07/JAN 07/Aug05/July06)

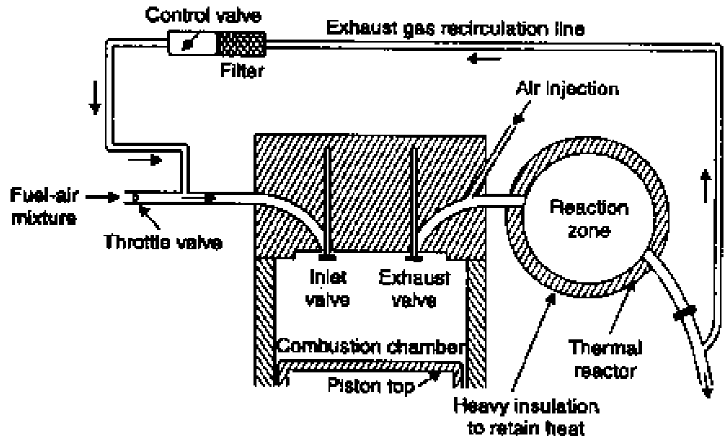
The concentration of oxides of nitrogen in the exhaust is closely related to the peak cycle temperature. The following are the three methods (investigated so far) for reducing peak cycle temperature and thereby reducing NO emission.

- Exhaust gas recirculation (EGR) (VTU Jan 2007)
- Catalyst (VTU Aug 2005/ July 2006)
- Water injection.(VTU Aug 2005/ July 2006)

EXHAUST GAS RECIRCULATION (E G R)

This method is commonly used to reduce NO_x in petrol as well as diesel engines. In S.I engines, about 10 percent recirculation reduces NO_x emission by 50 percent. Unfortu nately, the consequently poorer combustion directly increases HC emission and calls for mixture enrichment to restore combustion regularity which gives a further indirect in crease of both HC and CO.

Figure shows the arrangement of exhaust gas recirculation (EGR) system. A portion (about 10 to 15%) of the exhaust gases is re-circulated to cylinder intake charge, and this reduces the quantity of O_2 available for combustion. The exhaust gas for recirculation is taken through an orifice and passed through control valve for regulation of the quantity of recirculation.



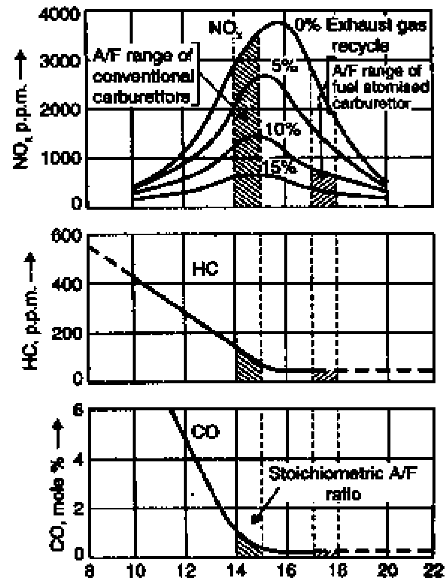


Fig. 16.11. Effect of recycling of gas on NO_x concentration.

The effect of A/F ratio of NO_x emission taking EGR parameter is shown in figure. It may be observed that, maximum emission of NO takes place during lean mixture limits when gas recirculation is least effective. Whereas, for emission of hydro carbon (HC) and carbon monoxide (CO) lean mixture is preferred, 15 percent recycling reduces NO_x by 80 percent but in creases HC and CO by 50 to 80%. These are two conflicting requirements of this emission control system and this problem has been solved by adopting package system which have both NO and HC/CO control devices.

Catalyst. A few types of catalysts have been tested to reduce the emission of NO_x, a copper catalyst has been used in the presence of CO for this purpose. The research is going on to develop a good catalyst. The research is on for newer good catalyst.

Water injection. It has been observed that the specific fuel consumption decreases a few percent at medium water injection rate. Attempts have been made to use water as a device for controlling the $N0_x$ .This method, because of its complexity, is rarely used.

TOTAL EMISSION CONTROL PACKAGES (VTU Feb 2006)

We know that any method which is used to decrease NO tries to increase HC and CO and vice-versa. Thus it is of paramount importance to develop a method/system which should reduce emissions of NO HC, CO to a desired level simultaneously. After a long and detailed experimental study of various possible systems, the following two systems/packages have been developed to achieve the required results

1. Thermal reactor package
2. Catalytic converter package.

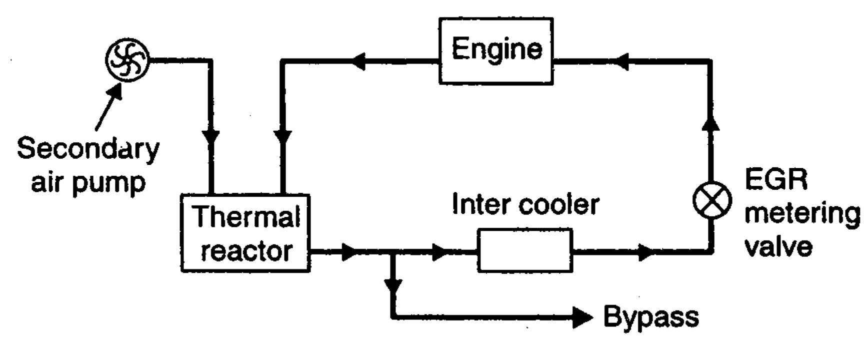
Using this approach, the following are the three basic methods of emission control:

- Thermal reactors, which rely on homogeneous oxidation to control CO and HC;
- Oxidation catalyst for CO and HC;
- Dual catalyst system (here a reduction catalyst for NO and an oxidation catalyst for CO and HC are connected in series).

Thermal reactor package: (VTU July 2007)

A thermal reactor is a chamber which is designed to provide adequate residence time for allowing appreciable oxidation of CO and HC to take place. For enhancing the conversion of CO to CO_2 the exhaust temperature is increased by retarding the spark.

Actual thermal reactor (made of high nickel steel) that is used on a car consists of two enlarged exhaust manifolds which allow greater residence time for burning HC and CO with oxygen in the pumped in air. For keeping a flame constantly burning (and there by assuming complete combustion) a secondary air pump injects fresh air into the reactor; this reduces HC and CO. About 10 to 75 percent of the gas is re-circulated after cooling in the intercooler to reduce the formation of NO_x



In this packing system are also included the following

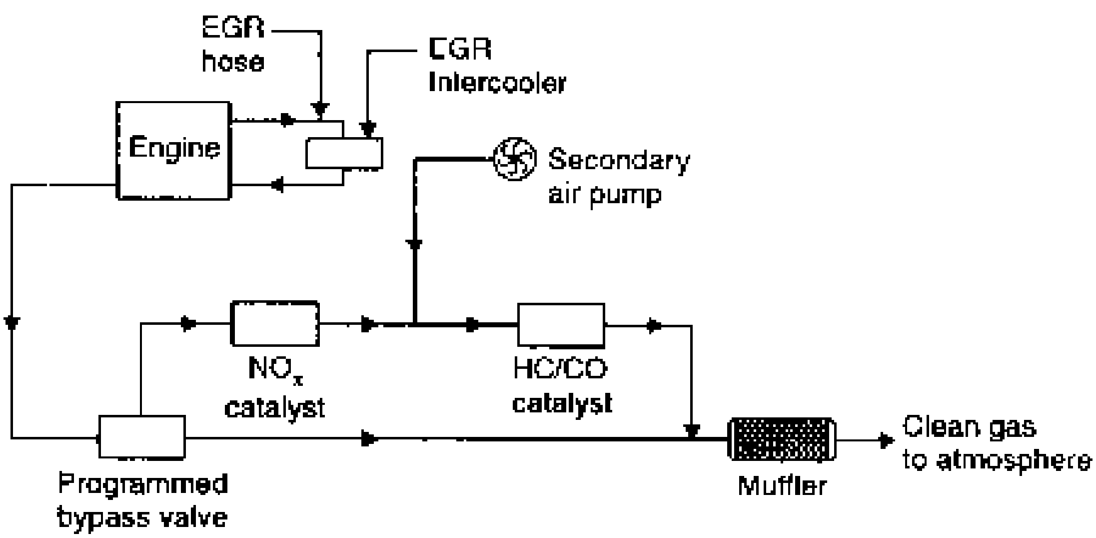
- Enriched and stage carburettor temperature controls;
- Crankcase valve to control blow-by gases;
- Special evaporation control valves.

In this package emission of NO_x ,HC and CO are reduced to a required level but at the cost of 20 per cent less power and 10 per cent more fuel consumption. This converter can be employed for a run of 15000 km.

Catalytic Converter Package: (VTU July 2007,July 2006)

The working principle of this package is to control the emission levels of various pollutants by changing the chemical characteristics of the exhaust gases. The catalytic converter package as com pared to thermal reactor package requires non-leaded fuel as lead reduces the catalytic action.

The major advantage of this converter (as compared to thermal reactor) is that it allows a partial decoupling of emission control from engine operation in that the conversion efficiencies for HC and CO are very high at normal exhaust temperatures.



Converters for HC and CO and NO_x are arranged as shown in the figure. The NO_x catalyst is the first element in the gas flow path, does not cause release of any heat. The next is HC/CO catalyst, which releases heat to such a great extent that may cause overheating and burning of the element. This is taken care of by injecting air through secondary air pump. A bypass valve ahead of converter is used to increase the converter life. For better control of NO_x, exhaust gas is circulated via an intercooler back to air cleaner. For this system, the power loss is about 30% and the fuel consumption is about 10% more than normal.

Oxidizing Systems	Catalytic Converter	Thermal Reactor
Advantages		
Reduction of HC and CO	80-90 %	80-90 %
Reduction of NO	No	No
Reduction of Aldehydes	50% or more	50% or more
Use same design for all vehicles	possible	possible
Life	Up to 80000 km	Up to 165000 km
Disadvantages		
Cost	High	High
Volume	High	Higher
Engine Mounting required	No	Yes
Weight added	Some	Significant
Container durability Problem	Yes	Yes
Raises engine compartment temperature	Depends on location	Yes
Requires Non leaded fuel	Probably	No
Requires air injection	Some do	Some do
Lowers fuel economy	No	Probably yes
Decreases power	Depends on back pressure	Depends on back pressure
Loss of catalytic material due to attrition	Yes	No
May emit other toxic material	Yes	No

EFFECT OF ENGINE EMISSION ON HUMAN HEALTH (VTU July 2007)

The effects of different engine emissions on human health are discussed below:

Sulphur dioxide (SO_2)

- It is an irritant gas and affects the mucous membrane when inhaled. In the presence of water vapour it forms sulphurous and sulphuric acids These acids cause severe bronchospasma at very low levels of concentration.
- Diseases like bronchitis and asthama are aggravated by a high concentration of SO_2

Carbon-monoxide (CO):

- It has a strong affinity (200 times) for combining with the haemoglobin of the blood to form carboxyhaemoglobin. This reduces the ability of the haemoglobin to carry oxygen to the blood tissues.
- CO affects the central nervous system.
- It is also responsible for heart attacks and a high mortality rate.

Oxides of nitrogen (NO_x):

- These are known to cause occupational diseases. It is estimated that eye and nasal irritation will be observed after exposure to about 15 p.p.m. of nitrogen oxide, and pulmonary discomfort after brief exposure to 25 p.p.m. of nitrogen oxide.
- It also aggrevates diseases like bronchitis and asthama.

Hydrocarbon vapours:

- They are primarily irritating.
- They are major contributors to eye and respiratory irritation caused by photochemical smog

Compounds of Incomplete combustion

- Exhaust discharge from IC engines carry compounds of incomplete combustion (polycyclic organic compounds and aliphatic hydrocarbons), which act as carcinogenic agents and are responsible for lungs cancer.

Lead

- Inorganic lead compounds (discharged from vehicles using leaded petrol) cause a variety of human health disorders.
- The effects include gastrointestinal damage, liver and kidney damage, abnormality in fertility and pregnancy etc.

Smoke

- It is visible carbon particles.
- It causes irritation in eyes and lungs, and visibility reduction. It also, causes other respiratory diseases.

Generally speaking, Susceptibility to the effects of exhaust emissions is greatest amongst infants and the elderly. Those with chronic diseases of lungs or heart are thought to be at great risk.

4 stroke I C engine is economical and less pollutant than 2 stroke engine – Justify.

In two-stroke engine the charge has to be compressed outside for scavenging and charging (this consumes some engine power). A part of this charge escapes directly through exhaust ports (short circuiting). Thus power spent in compressing this fraction of the charge is wasted. Particularly in S.I. engines the charge consists of air-fuel mixture. This loss of power and charge is absent in 4-stroke engine. Therefore 4-stroke engine is always economical than 2-stroke engine.

Further the loss of charge increases HC in the exhaust in case of two-stroke engines, Hence 4-stroke engine is also less pollutant than 2-stroke engine.