

**LECTURE NOTES ON AUTOMOTIVE POLLUTION CONTROL
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I. INTRODUCTION

POLLUTION:

The mixing of unwanted and undesirable substances into our surroundings that cause undesirable effects on both living and non-living things is known as pollution.

AIR POLLUTION:

Air pollution is defined as the addition of unwanted and undesirable things to our atmosphere that have harmful effect upon our planned life.

MAJOR SOURCES OF AIR POLLUTION:

1. Automotive Engines
2. Electrical power generating stations
3. Industrial and domestic fuel consumption
4. Refuse burning of industrial processing, wastes etc.,

SOURCES OF POLLUTANTS FROM GASOLINE ENGINE:

There are four possible sources of atmospheric pollution from a petrol engine powered vehicle. They are

1. Fuel Tank
2. Carburetor
3. Crank case
4. Engine

The number of pollutants contributed by the above-mentioned sources are as follows.

- | | |
|--------------------------------|--|
| a. Fuel tank evaporative loss | 5 to 10 % of HC |
| b. Carburetor evaporative loss | 5 % of HC |
| c. Crank case blow by | 20 to 35 % of HC |
| d. Tail Pipe exhaust | 50 to 60 % of HC and almost all Co and NO _x |

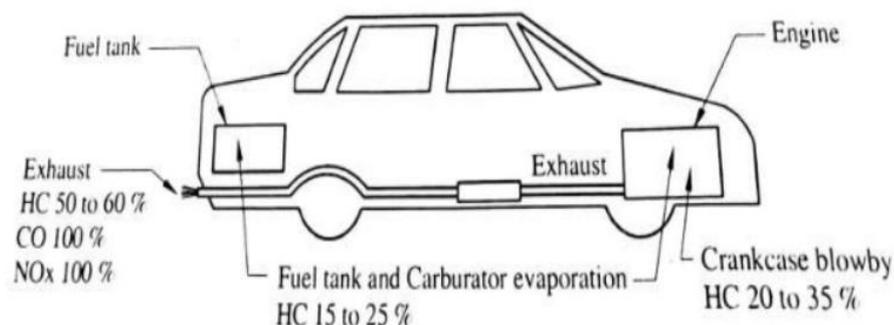


Fig.1 Pollutant in Automobile

Emittance as a Pollutant:

An Emittance is said to be a pollutant when it has some harmful effect upon our surroundings.

The primary source of energy for our automotive vehicles is crude oil from underground which typically contains varying amounts of Sulphur. Much of the Sulphur is removed during refining of automotive fuels. Thus the final fuel is hydrocarbon with only a small amount of Sulphur. If we neglect Sulphur and consider complete combustion, only water and carbon dioxide would appear in the exhaust.

Water is not generally considered undesirable and therefore it is not considered as a pollutant. Likewise, carbon dioxide is also not considered as pollutant in earlier days. But due to increase in global warming due to CO₂ which is a greenhouse gas, now a days CO₂ is also considered as unwanted one.

Then apart from this we get Sulphur dioxide a pollutant which is a product of complete combustion. Apart from this all the compounds currently considered as pollutants are the result of imperfect or incomplete combustion.

Pollutants	Pollutant Effects
Unburned Hydro Carbons (UBHC)	Photochemical Smog
Nitric Oxide	Toxic, Photochemical Smog
Carbon monoxide	Toxic
Lead compounds	Toxic

Smoke combines with fog and forms a dense invisible layer in the atmosphere which is known as Smog. The effect of Smog is that it reduces visibility.

Effect of Pollutants on Environment:

a. Unburned Hydro Carbons (UBHC):

The major sources of UBHC in an automobile are the engine exhaust, evaporative losses from fuel system, blow by loss and scavenging in case of 2-stroke petrol engines.

Unburned or partially burned hydrocarbons in gaseous form combine with oxides of nitrogen in the presence of sunlight to form photochemical smog.



The products of photochemical smog cause watering and burning of the eyes and affect the respiratory system, especially when the respiratory system is marginal for other reasons.

Some of the high molecular weight aromatic hydrocarbons have been shown to be carcinogenic in animals. Some of the unburned hydrocarbons also serve as particulate matter in atmosphere.

b. Carbon monoxide:

Carbon monoxide is formed during combustion in engine only when there is insufficient supply of air. The main source is the engine exhaust.

The toxicity of carbon monoxide is well known. The hemoglobin the human blood which carries oxygen to various parts of the body has great affinity towards carbon monoxide than for oxygen. When a human is exposed to an atmosphere containing carbon monoxide, the oxygen carrying capacity of the blood is reduced and results in the formation of carboxy hemoglobin. Due to this the human is subjected to various ill effects and ultimately leads to death.

The toxic effects of carbon monoxide are dependent both on time and concentration as shown in the diagram.

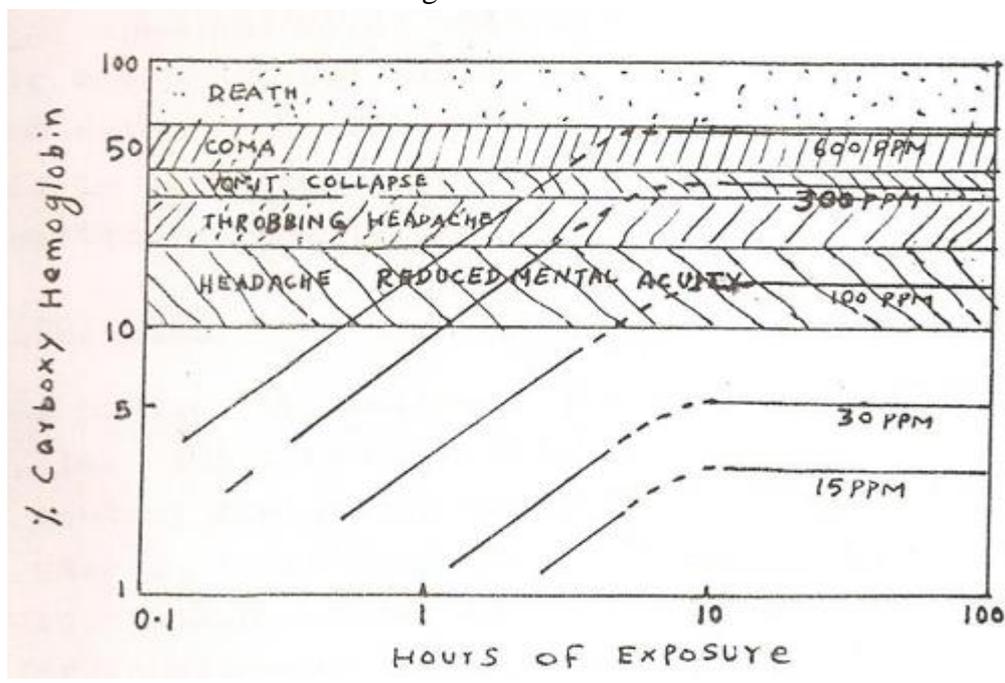


Fig.2 Toxicity of carbon monoxide

c. Oxides of Nitrogen (NO_x):

Oxides of nitrogen (NO, NO₂, N₂O₂ etc) are formed at higher combustion temperature present in engines and the engine exhaust is the major source.

Like carbon monoxide, oxides of nitrogen also tend to settle on the hemoglobin in blood. Their most undesirable effect is their tendency to join with moisture in the lungs to form dilute nitric acid. Because the amounts formed are minute and dilute, their effect is very small but over a long period of time can be cumulatively undesirable, especially when the respiratory problems for other reasons are found.

Another effect is that, the oxides of nitrogen are also one of the essential components for the formation of photochemical smog.

d. Sulphur dioxide:

Sulphur dioxide from automotive vehicle is very less when compared to that emitted by burning coal. Sulphur dioxide combines with moisture in atmosphere and forms sulphuric acid at higher temperatures. This comes to the earth as acid rain.

Much of the Sulphur dioxide combines with other materials in the atmosphere and forms sulphates which ultimately form particulate matter.

e. Particulates:

Particulate matter comes from hydrocarbons, lead additives and Sulphur dioxide. If lead is used with the fuel to control combustion almost 70% of the lead is airborne with the exhaust gasses. In that 30% of the particulates rapidly settle to the ground while remaining remains in the atmosphere. Lead is well known toxic compound

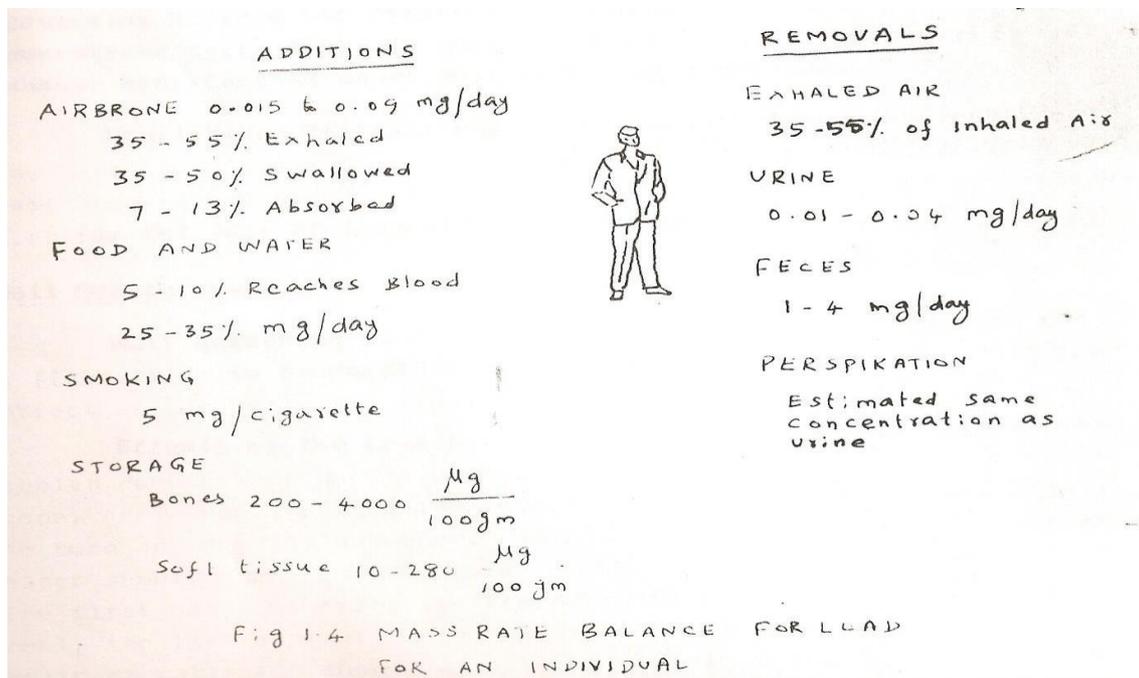


Fig.3 Mass Rate Balance for Load for an Individual

Particulates when inhaled or taken along with food leads to respiratory problems and other infections.

Particulates when settle on the ground they spoil the nature of the object on which they are settling. Lead, a particulate is a slow poison and ultimately leads to death.

Greenhouse effect

Greenhouse effect, a warming of Earth's surface and troposphere (the lowest layer of the atmosphere) caused by the presence of water vapour, carbon dioxide, methane, and certain other gases in the air. Of those gases, known as greenhouse gases, water vapour has the largest effect.

The atmosphere allows most of the visible light from the Sun to pass through and reach Earth's surface. As Earth's surface is heated by sunlight, it radiates part of this energy back toward space as infrared radiation. This radiation, unlike visible light, tends to be absorbed by the greenhouse gases in the atmosphere, raising its temperature. The heated atmosphere in turn radiates infrared radiation back toward Earth's surface. Without the heating caused by the greenhouse effect, Earth's average surface temperature would be only about $-18\text{ }^{\circ}\text{C}$ ($0\text{ }^{\circ}\text{F}$). On Venus the very high concentration of carbon dioxide in the atmosphere causes an extreme greenhouse effect resulting in surface temperatures as high as $450\text{ }^{\circ}\text{C}$ ($840\text{ }^{\circ}\text{F}$). Although the greenhouse effect is a naturally occurring phenomenon, it is possible that the effect could be intensified by the emission of greenhouse gases into the atmosphere as the result of human activity. From the beginning of the Industrial Revolution through the end of the 20th century, the amount of carbon dioxide in the atmosphere increased by roughly 30 percent and the amount of methane more than doubled. A number of scientists have predicted that human-related increases in atmospheric carbon dioxide and other greenhouse gases could lead by the end of the 21st century to an increase in the global average temperature of $3\text{--}4\text{ }^{\circ}\text{C}$ ($5.4\text{--}7.2\text{ }^{\circ}\text{F}$) relative to the 1986–2005 average. This global warming could alter Earth's climates and thereby produce new patterns and extremes of drought and rainfall and possibly disrupt food production in certain regions.

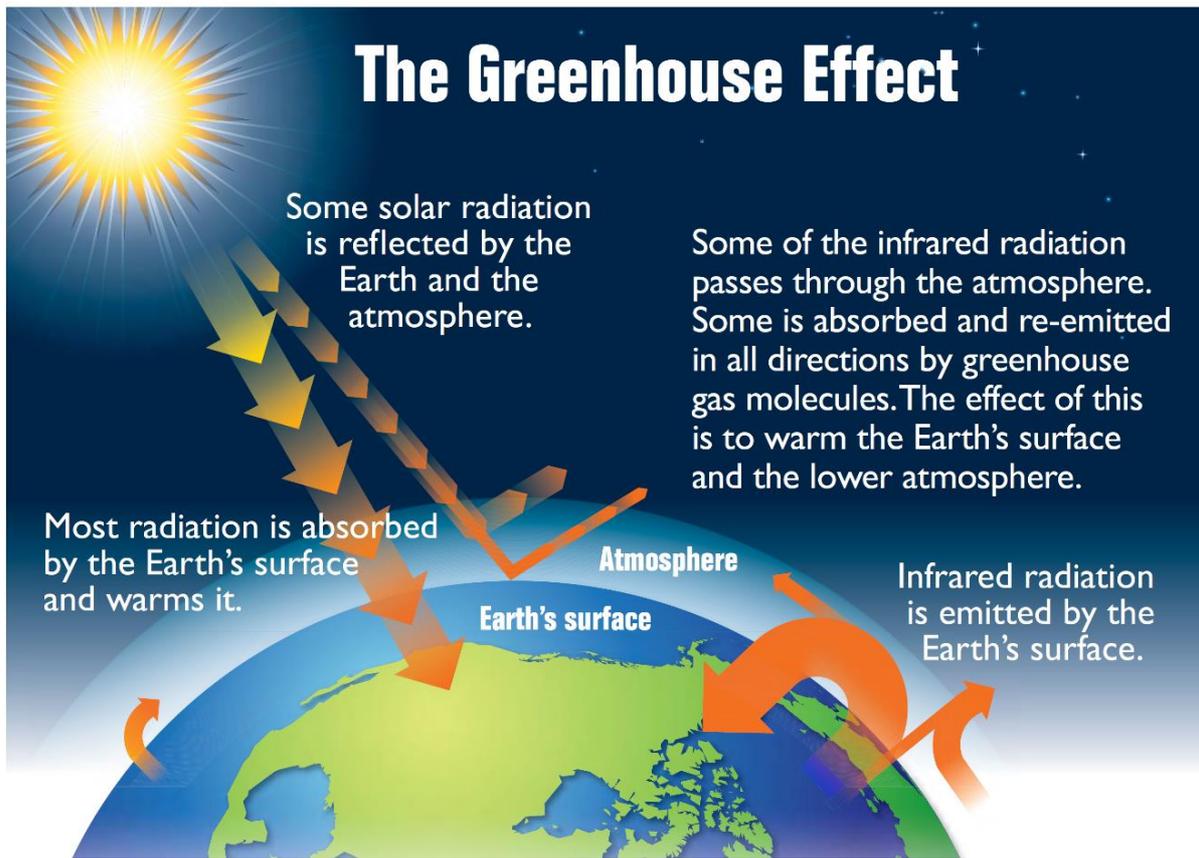


Fig.4 Green House Effect

Global Warming

A gradual increase in the overall temperature of the earth's atmosphere generally attributed to the green house effect caused by increased levels of carbon dioxide, CFCs and other pollutants.

Causes of Global Warming

Global Warming occurs when carbon di-oxide (CO_2) and other air pollutants and green house gases collect in the atmosphere and absorb sunlight and solar radiation that have bounced off the earth's surface.

1. Deforestation.
2. Greenhouse Effect
3. Process of recovering Fossil Fuels.

Effects of Global Warming

1. Increased melting of Ice caps.
2. Rise in sea levels.
3. Desertification.
4. Hurricane and Cyclones.
5. Spread of Diseases.
6. Agriculture.
7. Heat Waves.

8. Longer/ Shorter Seasons.
9. Crops.
10. Ocean's
11. Animal Extinction.

EFFECTS OF AIR POLLUTION

1. Acidification:

Chemical reactions involving air pollutants can create acidic compounds which can cause harm to vegetation and buildings. Sometimes, when an air pollutant, such as sulfuric acid combines with the water droplets that make up clouds, the water droplets become acidic, forming acid rain. When acid rain falls over an area, it can kill trees and harm animals, fish, and other wildlife.

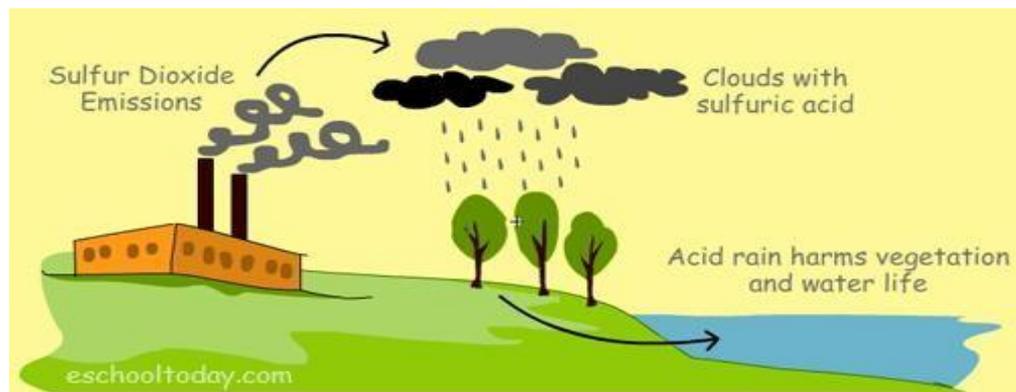


Fig.5 Acidification

Acid rain destroys the leaves of plants. When acid rain infiltrates into soils, it changes the chemistry of the soil making it unfit for many living things that depend on the soil as a habitat or for nutrition. Acid rain also changes the chemistry of the lakes and streams that the rainwater flows into, harming fish and other aquatic life.

Eutrophication:

Rain can carry and deposit the Nitrogen in some pollutants on rivers and soils. This will adversely affect the nutrients in the soil and water bodies. This can result in algae growth in lakes and water bodies, and make conditions for other living organism harmful.

Ground-level ozone:

Chemical reactions involving air pollutants create a poisonous gas ozone (O_3). Gas Ozone can affect people's health and can damage vegetation types and some animal life too.

Particulate matter:

Air pollutants can be in the form of particulate matter which can be very harmful to

our health. The level of effect usually depends on the length of time of exposure, as well the kind and concentration of chemicals and particles exposed to. Short-term effects include irritation to the eyes, nose and throat, and upper respiratory infections such as bronchitis and pneumonia. Others include headaches, nausea, and allergic reactions. Short-term air pollution can aggravate the medical conditions of individuals with asthma and emphysema. Long-term health effects can include chronic respiratory disease, lung cancer, heart disease, and even damage to the brain, nerves, liver, or kidneys. Continual exposure to air pollution affects the lungs of growing children and may aggravate or complicate medical conditions in the elderly.

Effects of Air Pollution: on Human Health, Animals and Atmosphere!

Air pollution has now become a worldwide phenomenon and every individual in one way or the other is facing problems caused by it. Its impact can be seen locally, at regional level as well as at global level.

At local and regional levels its manifestations are in the form of alterations in (i) visibility, (ii) intensity of sunshine, (iii) precipitation amount, and (iv) acid rain. Its global effects are. (i) Change in natural climate by rise of temperature, melting of snow, (ii) increase in carbon dioxide, (iii) increase in particulates, (iv) holes in ozone layer, etc. Several aspects of air pollution, such as effects on the ozone layer, greenhouse effect, smog and acid rain have already been discussed.

The effects of air pollution can be grouped under the following heads:

- (i) Effects on human health,
- (ii) Effects on animals and plants,
- (iii) Effects on atmosphere, and
- (iv) Other effects.

1. Effects on Human Health:

Some environmental poisons can cause acute illness and even death. Others may be harmful, but the disease may take years or even decades to appear. Air pollution mainly affects the respiratory system.

Bronchitis, emphysema, asthma and lung cancer are some of the chronic diseases caused due to exposure to polluted air. It is feared that lung cancer is caused mainly due to polluted air because carcinogens are found in it. Its mortality rate is higher in urban areas.

Figure shows the various effects of air pollution on the human body. Sulfur dioxide is the most serious and widespread air pollutant. Its lower concentration is a cause of

spasms in the smooth muscle of bronchioles and its higher concentration induces increased mucus production.

Sulfur dioxide is also considered to cause cough, shortness of breath, spasm of the larynx and acute irritation to the membranes of the eyes. It also acts as an allergenic agent. When it reacts with some compounds, sulfuric acid is formed which may damage lungs.

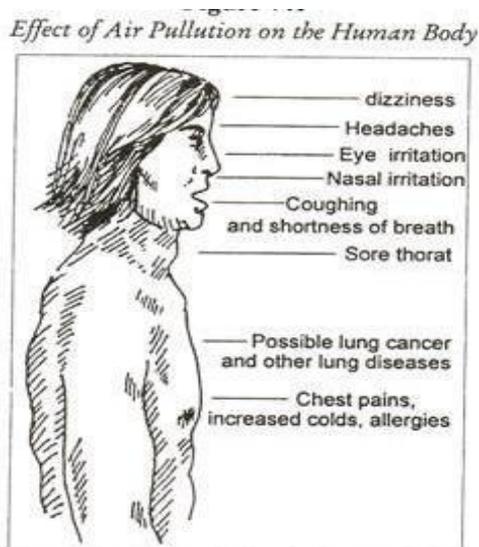


Fig.6 Effect of Air Pollution on the Human Body

Carbon monoxide often affects the oxygen carrying capacity of blood. Nitric oxide is reported to be a pulmonary irritant and its excess concentration may cause pulmonary haemorrhage.

Hydrogen sulfide is also toxic. Lead emitted from automobile exhausts is a cumulative poison and is dangerous particularly to children and may cause brain damage.

The particulate pollutants such as asbestos, silica, carbon, beryllium, lead, etc., are capable of exerting a noxious (fibrotic) local action in the interstitial areas of the lungs. Radioactive elements are also harmful to man and other living organisms. As described earlier, smog has a killer effect, which is also the result of air pollution. The death toll by smog varies from few persons to thousands.

In December 1952, about 4,000 persons died in London due to smog. Similar cases have been reported from London itself in 1956, 1957 and 1962 in which the death toll was between 700 and 1,000 persons. In other countries also smog deaths have been

reported. In fact, the growing air pollution has now become a health hazard for man.

2. Effects on Animals and Plants:

The impact of air pollution on animals is more or less similar to that on man. Chronic poisoning results from the ingestion of forage contaminated with atmospheric pollutants. Among the metallic contaminants, arsenic, lead and molybdenum are important. Fluoride is another pollutant, which causes fluorosis among animals.

A number of livestock have been poisoned by fluorides and arsenic in North America. Bone lesions in animals due to excessive fluorides have also been reported.

Air pollution has caused widespread damage to trees, fruits, vegetables, flowers and in general, vegetation as a whole. The total annual cost of plant damage caused by air pollution in USA alone has been estimated to be in the range of 1 to 2 billion dollars. The most dramatic early instances of plant damage were seen in the total destruction of vegetation by sulfur dioxide in the areas surrounding smelters.

When the absorption of sulfur dioxide exceeds a particular level, the cells become inactive and are killed, resulting in tissue collapse and drying of leaves. Cotton, wheat, barley and apple are more sensitive to this pollutant.

Fluorides are responsible for various types of injuries to plants. The leaves of apple, apricot, fig, peach and prune are more susceptible to air borne fluorides. Fluorides seem to interfere with the photosynthesis and respiration of plants. Smog also causes injury to plants. Similar impact of ozone can be seen in the lesions to plants. Chlorine, ammonia, hydrogen sulfide, etc., are also harmful to vegetation.

3. Effects on Atmosphere:

Some of the effects of air pollution on atmospheric conditions, such as effect on ozone layer, greenhouse effect, etc., have already been discussed. There is an increase in the carbon dioxide concentration in the air due to increased combustion of fossil fuels. Carbon dioxide absorbs heat strongly and the radiative cooling effect of the earth is thus decreased.

The rising of temperatures and ozone holes are some of the problems which have attracted the attention of the scientists all over the world. These problems are not related to any region or a country but are the global problems and their impact on world climate may be hazardous to the whole world.

The local weather conditions are highly susceptible to air pollution. Its impact on temperature, humidity, rainfall and clouds is apparent. The 'smog dom' on large urban centres is the result of air pollution. Due to air pollution, visibility also reduces.

4. Other Effects:

Air pollution can also cause damage to property and materials. The smoke, grit, dust and oxides of sulphur have harmful effects on structures.

In 1972, when an oil refinery at Mathura was opened, its impact on Taj Mahal became a major issue. Sulfur dioxide is the most damaging of gaseous pollutants. Aluminum alloys, copper and copper alloys, iron and steel are corroded when exposed to contaminated air.

Hydrogen sulfide reacts with lead paints to form lead sulfide thereby producing a brown to black discolouration. The damage caused by air pollution to structures is not serious but from an aesthetic point of view, it is not desirable.

Ozone Holes

Ozone depletion occurs when chlorofluorocarbons (CFCs)—formerly found in aerosol spray cans and refrigerants—are released into the atmosphere. These gases, through several chemical reactions, cause the ozone molecules to break down, reducing ozone's ultraviolet (UV) radiation- absorbing capacity.

ozone

Ozone is simply a molecule consisting of 3 oxygen atoms, which reacts strongly with other molecules. Ozone is created in the stratosphere when high energy uv radiation causes an O₂ molecule to split. The free oxygen atoms collide and react with other O₂ molecules to form O₃.

Production is highest where the solar uv is the greatest eg near the tropics, but once created, the ozone is then circulated towards the poles by the atmosphere. The amount of ozone in the stratosphere can vary with location, season and even day to day climatic conditions.

The process of ozone creation is what makes the O₃ in the atmosphere very effective at shielding the Earth from harmful uv radiation, which can cause many biological problems, such as skin cancer. However, due to its high reactivity, the uv found in the troposphere at ground level can also be dangerous as a toxic pollutant which is harmful to plants and lung tissue, and is a major cause of smog.

The discovery of the annual depletion of ozone above the Antarctic was first announced in a paper by Joe Farman, Brian Gardiner and Jonathan Shanklin which appeared in Nature in May 1985. Later, NASA scientists re-analyzed their satellite data and found that the whole of the Antarctic was affected.

All living cells, whether microbes, plants or animals, contain a complex molecule called DNA which carries the genetic code. This is the set of instructions which describes the structure and biochemistry of an organism. Unfortunately, DNA readily

absorbs high-energy UV-B radiation and becomes damaged so that the instructions cannot be read properly. If the amount of UV-B entering the cell increases (as during the ozone hole), the risk of damage also increases and may result in malfunction or death of the organism. Some Antarctic organisms such as algae, lichens and mosses also contain a pigment called chlorophyll. This absorbs visible light as the energy source of photosynthesis for making organic compounds. Chlorophyll also absorbs UV-B light so that the system becomes bleached and non-functional. Even enzymes and other proteins are damaged by this high-energy radiation. Living organisms therefore have to protect themselves from UV-B. Humans can cover their skin with artificial sunscreens, but natural protection systems have also evolved. Many microbes, plants and other animals synthesize protective pigments. Our skin cells synthesize brown melanin to protect against sunburn (which is caused by UV-B radiation), and so do Antarctic lichens on rocks near the edge of the polar ice-cap. A variety of sunscreen pigments are produced by Antarctic organisms on land, in freshwater and in the sea. That is why exposed, snow-free rocks are often covered with bright orange and yellow lichens. Some lichens and microbes even live inside translucent rocks to shelter from high radiation levels and desiccating winds!

The Greenhouse Effect (producing global warming) and ozone depletion are two separate problems, however there are links between them. Warming at the earth's surface is caused by certain gases in the atmosphere which can trap energy from the sun. An increase in the amount of these gases produces an increase in the surface temperature. The largest increase is in carbon dioxide from burning coal, oil, gas and forests, but other gases such as methane (from cattle and rice fields) play a part. A link with ozone depletion is that CFCs are gases which also contribute to greenhouse warming.

A further link is that although the Greenhouse Effect warms the surface, it allows the higher atmosphere, where ozone is present, to cool. This means that more stratospheric clouds may form and so make the ozone hole worse.

Even if the problem of ozone depletion is solved, global warming will still remain. It will cause a rise in sea-level and change the regions where crops can be grown. The issue will be harder to tackle than ozone depletion, but is one which concerns everyone on our planet.

The only way to mend the ozone hole is to stop releasing CFCs and other ozone depleting gases into the atmosphere. The restrictions of the Montreal Protocol and its extensions are helping to do this.

Greenhouse Effect

The Sun powers Earth's climate, radiating energy at very short wavelengths, predominately in the visible or near-visible (e.g., ultraviolet) part of the spectrum. Roughly one-third of the solar Energy that reaches the top of Earth's atmosphere is reflected directly back to space. The remaining two-thirds is absorbed by the surface and, to a lesser extent, by the atmosphere. To balance the absorbed incoming energy, the Earth must, on average, radiate the same amount of energy back to space. Because the Earth is much colder than the Sun, it radiates at much longer wavelengths, primarily in the infrared part of the spectrum (see Figure 1). Much of this thermal radiation emitted by the land and ocean is absorbed by the atmosphere, including clouds, and reradiated back to Earth. This is called the greenhouse effect. The glass walls in a greenhouse reduce airflow and increase the temperature of the air inside. Analogously, but through a different physical process, the Earth's greenhouse effect warms the surface of the planet.

Without the natural greenhouse effect, the average temperature at Earth's surface would be below the freezing point of water. Thus,

Earth's natural greenhouse effect makes life as we know it possible. However, human activities, primarily the burning of fossil fuels and clearing of forests, have greatly intensified the natural greenhouse effect, causing global warming. The two most abundant gases in the atmosphere, nitrogen (comprising 78% of the dry atmosphere) and oxygen (comprising 21%), exert almost no greenhouse effect. Instead, the greenhouse effect comes from molecules that are more complex and much less common. Water vapour is the most important greenhouse gas, and carbon dioxide (CO₂) is the second-most important one. Methane, nitrous oxide, ozone and several other gases present in the atmosphere in small amounts also contribute to the greenhouse effect. In the humid equatorial regions, where there is so much water vapour in the air that the greenhouse effect is very large, adding a small additional amount of CO₂ or water vapour has only a small direct impact on downward infrared radiation. However, in the cold, dry polar regions, the effect of a small increase in CO₂ or water vapour is much greater.

The same is true for the cold, dry upper atmosphere where a small increase in water vapour has a greater influence on the greenhouse effect than the same change in water vapour would have near the surface. Several components of the climate system, notably the oceans and living things, affect atmospheric concentrations of greenhouse gases. A prime example of this is plants taking CO₂ out of the atmosphere and converting it (and water) into carbohydrates via photosynthesis. In the industrial era, human activities have added greenhouse gases to the atmosphere, primarily through the burning of fossil fuels and clearing of forests. Adding more of a greenhouse gas, such as CO₂, to the atmosphere intensifies the greenhouse effect, thus warming Earth's climate. The amount of warming depends on various feedback mechanisms. For example, as the atmosphere warms due to rising levels of greenhouse gases, its concentration of water vapour increases, further intensifying the greenhouse effect. This in turn causes more warming, which causes an additional increase in water vapour, in a self-reinforcing cycle.

This water vapour feedback may be strong enough to approximately double

the increase in the greenhouse effect due to the added CO₂ alone. Additional important feedback mechanisms involve clouds. Clouds are effective at absorbing infrared radiation and therefore exert a large greenhouse effect, thus warming the Earth. Clouds are also effective at reflecting away incoming solar radiation, thus cooling the Earth. A change in almost any aspect of clouds, such as their type, location, water content, cloud altitude, particle size and shape, or lifetimes, affects the degree to which clouds warm or cool the Earth. Some changes amplify warming while others diminish it. Much research is in progress to better understand how clouds change in response to climate warming, and how these changes affect climate through various feedback mechanisms.

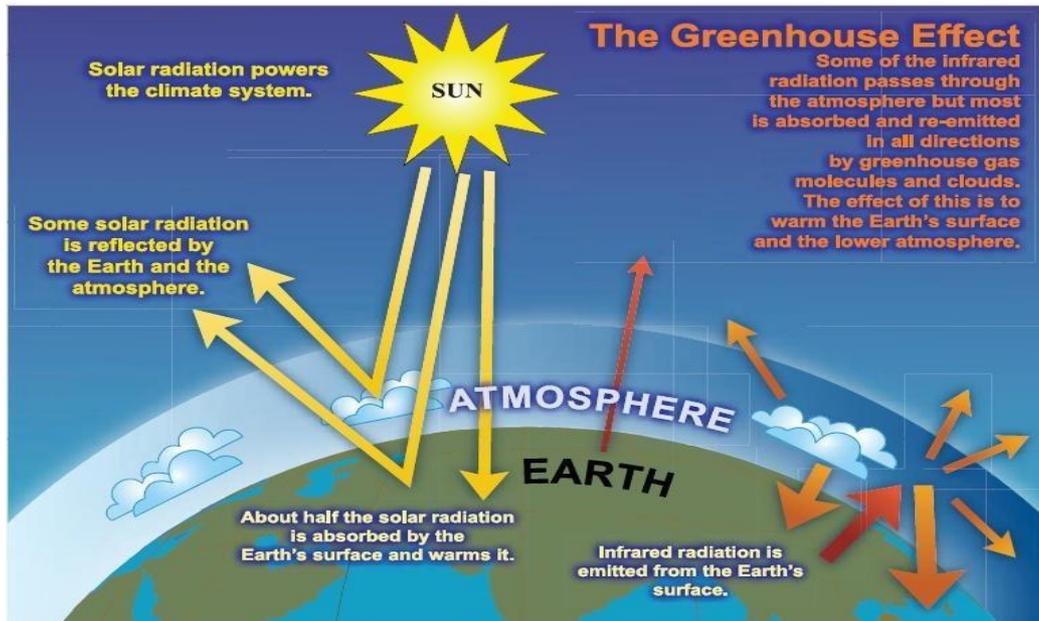


Fig.7 Greenhouse Effect

Climate Change

The climate of the Earth is always changing. In the past it has altered as a result of natural causes. Nowadays, however, the term climate change is generally used when referring to changes in our climate which have been identified since the early part of the twentieth century. The changes we've seen over recent years and those which are predicted over the next 100 years are thought by many to be largely as a result of human behaviour rather than due to natural changes in the atmosphere.

The greenhouse effect is very important when we talk about climate change as it relates to the gases which keep the Earth warm. Although the greenhouse effect is a naturally occurring phenomenon, it is believed that the effect could be intensified by human activity and the emission of gases into the atmosphere. It is the extra greenhouse gases which humans have released which are thought to pose the strongest threat.

The Greenhouse Gases

Almost the Earth's entire atmosphere (99%) is made up of nitrogen (about 78%) and oxygen (about 21%). While both of these gases play important roles in the vast number of processes that support life on Earth, they play almost no direct role in regulating the climate. This is carried out by some of the trace gases in the remaining 1% of the atmosphere which occur in relatively small amounts:

Water vapour Carbon dioxide (produced by burning fossil fuel) Methane (a byproduct of agriculture) Nitrogen Oxides (from car exhausts) Ozone CFCs (chlorofluorocarbons from aerosol and refrigerators)

Although the proportion of the trace gases in the atmosphere appears relatively small, they can still have a big impact on climate change.

Extreme Weather

- Increasing temperatures means the World is likely to see less frosty days and cold spells, but we are expected to experience an increase in heat waves and hot spells
- Greater risk of drought in continental areas
- Increase in extreme precipitation events
- Hurricanes likely to be more intense in some parts of the World due to more rainfall and more intense winds
- An intensification of the Asian summer monsoon is expected
- There will be regional variation in temperature changes; increases will be higher overland and in the northern hemisphere
- However the temperature increase over the North Atlantic will be small

Therefore, even if we stopped CO₂ emissions immediately, the effects of what we've already done would still influence our weather for years to come.

However, carbon dioxide emissions are not going to stop and with that in mind, some change is certainly expected - the level of change depends on the amount of greenhouse gases we continue to use, which in turn is related to population growth, the use of new technologies and how much energy we use.

The European Commission has set a target adopted by all industrialised countries of cutting greenhouse gas emissions to an average of 30% below 1990 levels by 2020.

This is the magnitude of reduction which is required, the Commission believes, to have a 50/50 chance of limiting the global temperature increase to 2°C above pre-industrial levels.

By reducing the number of greenhouse gases even marginally, the rate of change should be less and therefore there will be less impact on our planet and our lives. A gradual change to our climate is easier to adapt as well - we should have more time to prepare our houses and other buildings for changes to the weather, wildlife should have more time to migrate, and the changes to our agricultural practices should be less sudden.

Most commentators say it isn't too late to address climate change and that we need to all work together to do our bit to reduce emissions and the damage we are currently doing to our local environment. We are already seeing change and will continue to do so, but if the scientific models are on the right lines, our climate will be a very different place in the next ten to twenty years to what it is now.

Global Warming Scientists say the temperature of the earth could rise by 3°C over the next 50 years. This may cause drought in some parts of the world, and floods in others, as ice at the North and South Poles begins to melt and sea level rise.

It's normal for temperatures to sometimes be cooler for many hundreds of years, and then sometimes to be warmer. But this time, humans have caused the increase, with carbon from cars and factories.

Global warming is caused by the greenhouse effect. Normally, heat from the sun warms the earth and then escapes back into space. But carbon dioxide and other gases in the atmosphere trap the sun's heat, and this is slowly making the earth warmer.

The ozone layer is a layer of gas high above the surface of the earth that helps to protect it from the sun's ultraviolet radiation, which can damage our skins and cause cancer. Scientists have discovered holes in the ozone layer, caused by substances called chlorofluorocarbons. CFCs are used in refrigerators, aerosol cans and in the manufacture of some plastic products. Some companies now make aerosols that do not contain CFCs, and these are often marked -ozone- friendly. Tropical rainforests are being burnt and cut down because people need more land for agriculture, more hard wood for furniture and firewood. Cutting down the rainforests is dangerous for many reasons.

We need the oxygen that comes from rainforests. The forests absorb carbon dioxide in the process called photosynthesis. Without trees carbon dioxide levels will increase.

Rainforests are the homes of many insects, plants, and animals that we need for medicine and other reasons. Many plants and animals will become extinct.

They can help catch water and give it back to the earth in the form of clouds, which

bring us water. The roots of trees and plants in the rainforest keep water and soil in place. Without the rainforest, there are many problems like floods and mudslides.

Do you believe that some types of extreme weather may be caused by global warming? Extreme weather (downpours/ heavy rains, monsoons, tornadoes, hurricanes, droughts) is a part of nature but I think /don't think it is connected with environmental problems.

The greenhouse effect is the temperature rise that the earth experiences. This happens because of certain gases that get energy from the sun. Without the greenhouse effect, the earth would be too cold, not warm enough for people to live. The greenhouse effect begins with the sun and the energy it radiates to the earth. The earth and the atmosphere absorb some of this energy, but the rest is radiated back into space. Naturally occurring gases in the atmosphere trap some of this energy and reflect it back, warming the earth. Scientist believes that extra gases we release into the air intensify the greenhouse effect. Evidence that scientist have is the result of some of the warmest years in recorded history.

Global warming is the increase in the average temperature of the earth's surface. The increase in greenhouse gases, fossil fuel burning, and deforestation contributes to global warming. The average temperatures have climbed about 1.4° around the world since 1880. The rate of the warming is decreasing. The IPCC (International Panel on Climate Control) reports that 11 of the past 12 years are among the dozen warmest since 1850.

Global Warming-Contributing Factors

One of the biggest contributors to global warming is the methane from cow toots and feces. The methane from the cow comes from the methanotropic bacteria in its stomach. That bacteria help the cows digest grass, their main diet. The methane is produced from carbon in the grass. Also, another contributor to global warming is combustion of fossil fuels in cars, factories, and electricity production. The release of carbon dioxide and other gases into the atmosphere has climbed. Methane and carbon dioxide have hit their highest levels in the last 400 years.

Global Warming: Local Effects

Human activity causing changes in the environment is known as global warming. Scientist reports that 1998 was the warmest year in measured history, with 2005 coming in second place.

Readings taken from the ice wars show that the greenhouse gases carbon dioxide and methane have reached their highest levels in the past 420,000 years. Arctic sea ice is melting, and has declined in the last 30 years. In the last century, the earth's

temperature has raised about 1.2-1.4 degrees Fahrenheit. . Researchers report that temperature will increase 10 degrees Fahrenheit by the end of the century. Hurricanes will become more frequent because of the warm weather. Rising sea levels can flood coastal areas. Severe droughts can become more common in dry areas, and species unable to adapt to the changing areas, would have to face extinction.

Prevention Strategy

To help, you can save energy around the house by unplugging appliances you are not using, and changing regular bulbs to fluorescent light bulbs. You can drive fewer hours in your car each day and instead walk to near places that you can. Also, believe it or not, taking a shower instead of a bath can help save more water! If you recycle cans, bottles, cardboard, and paper materials that will save a lot of room in landfills. If you carry water around with you, refill it in a metal canteen so that we don't have to use and make more plastic bottles. When you use the tap, be sure not to leave it running. When washing your clothes, it's better to hang them on an outside line to dry. This will save more energy using a dryer. To keep from running to the store all the time, you can grow fruits and vegetables, and go to the store for produce and other groceries. Another thing that can help stop global warming that we all love is flying the airplane. If you and your family took local trips, that could save a lot of oil, a popularly used nonrenewable source. If you plant trees that can majorly help the earth. Most trees now are getting cut down for paper so if we plant more it may come close to evening out.

Origins of Contaminants

Indoor contamination has different origins: the occupants themselves; inadequate materials or materials with technical defects used in the construction of the building; the work performed within; excessive or improper use of normal products (pesticides, disinfectants, products used for cleaning and polishing); combustion gases (from smoking, kitchens, cafeterias and laboratories); and cross-contamination coming from other poorly ventilated zones which then diffuses towards neighbouring areas and affects them. It should be borne in mind that substances emitted in indoor air have much less opportunity of being diluted than those emitted in outdoor air, given the difference in the volumes of air available. As regards biological contamination, its origin is most frequently due to the presence of stagnant water, materials impregnated with water, exhausts and so on, and to defective maintenance of humidifiers and refrigeration towers.

Finally, contamination coming from outside must also be considered. As regards human activity, three main sources may be mentioned: combustion in stationary sources (power stations); combustion in moving sources (vehicles); and industrial processes. The five main contaminants emitted by these sources are carbon monoxide, oxides of sulphur, oxides of nitrogen, volatile organic compounds (including

hydrocarbons), polycyclic aromatic hydrocarbons and particles. Internal combustion in vehicles is the principal source of carbon monoxide and hydrocarbons and is an important source of oxides of nitrogen. Combustion in stationary sources is the main origin of oxides of sulphur. Industrial processes and stationary sources of combustion generate

more than half of the particles emitted into the air by human activity, and industrial processes can be a source of volatile organic compounds. There are also contaminants generated naturally that are propelled through the air, such as particles of volcanic dust, soil and sea salt, and spores and micro-organisms. The composition of outdoor air varies from place to place, depending both on the presence and the nature of the sources of contamination in the vicinity and on the direction of the prevailing wind. If there are no sources generating contaminants, the concentration of certain contaminants that will typically be found in clean outdoor air are as follows: carbon dioxide, 320 ppm; ozone, 0.02 ppm; carbon monoxide, 0.12 ppm; nitric oxide, 0.003 ppm; and nitrogen dioxide, 0.001 ppm. However, urban air always contains much higher concentrations of these contaminants.

Apart from the presence of the contaminants originating from outside, it sometimes happens that contaminated air from the building itself is expelled to the exterior and then returns inside again through the intakes of the air-conditioning system. Another possible way by which contaminants may enter from the exterior is by infiltration through the foundations of the building (e.g., radon, fuel vapours, sewer effluvia, fertilizers, insecticides and disinfectants). It has been shown that when the concentration of a contaminant in the outdoor air increases, its concentration in the air inside the building also increases, although more slowly (a corresponding relationship obtains when the concentration decreases); it is therefore said that buildings exert a shielding effect against external contaminants. However, the indoor environment is not, of course, an exact reflection of the conditions outside.

Contaminants present in indoor air are diluted in the outdoor air that enters the building and they accompany it when it leaves. When the concentration of a contaminant is less in the outdoor air than the indoor air, the interchange of indoor and outdoor air will result in a reduction in the concentration of the contaminant in the air inside the building. If a contaminant originates from outside and not inside, this interchange will result in a rise in its indoor concentration, as mentioned above.

Models for the balance of amounts of contaminants in indoor air are based on the calculation of their accumulation, in units of mass versus time, from the difference between the quantity that enters plus what is generated indoors, and what leaves with the air plus what is eliminated by other means. If appropriate values are available for each of the factors in the equation, the indoor concentration can be estimated for a wide range of conditions. Use of this technique makes possible the comparison of different alternatives for controlling an indoor contamination problem.

Buildings with low interchange rates with outdoor air are classified as sealed or energy-efficient. They are energy-efficient because less cold air enters in winter, reducing the energy required to heat the air to the ambient temperature, thus cutting the cost of heating. When the weather is hot, less energy is also used to cool the air. If the building does not have this property, it is ventilated through open doors and windows by a process of natural ventilation. Although they may be closed, differences of pressure, resulting both from the wind and from the thermal gradient existing between the interior and the exterior, force the air to enter through crevices and cracks, window and door joints, chimneys and other apertures, giving rise to what is called ventilation by infiltration.

The ventilation of a building is measured in renewals per hour. One renewal per hour means that a volume of air equal to the volume of the building enters from outside every hour; in the same way, an equal volume of indoor air is expelled to the exterior every hour. If there is no forced ventilation (with a ventilator) this value is difficult to determine, although it is considered to vary between 0.2 and 2.0 renewals per hour. If the other parameters are assumed to be unchanged, the concentration of contaminants generated indoors will be less in buildings with high renewal values, although a high renewal value is not a complete guarantee of indoor air quality. Except in areas with marked atmospheric pollution, buildings that are more open will have a lower concentration of contaminants in the indoor air than those constructed in a more closed manner. However, buildings that are more open are less energy-efficient. The conflict between energy efficiency and air quality is of great importance.

Much action undertaken to reduce energy costs affects indoor air quality to a greater or lesser extent. In addition to reducing the speed with which the air circulates within the building, efforts to increase the insulation and waterproofing of the building involve the installation of materials that may be sources of indoor contamination. Other action, such as supplementing old and frequently inefficient central heating systems with secondary sources that heat or consume the indoor air can also raise contaminant levels in indoor air.

Contaminants whose presence in indoor air is most frequently mentioned, apart from those coming from outside, include metals, asbestos and other fibrous materials, formaldehyde, ozone, pesticides and organic compounds in general, radon, house dust and biological aerosols. Together with these, a wide variety of types of microorganisms can be found, such as fungi, bacteria, viruses and protozoa. Of these, the saprophytic fungi and bacteria are relatively well known, probably because a technology is available for measuring them in air. The same is not true of agents such as viruses, rickettsia, chlamydia's, protozoa and many pathogenic fungi and bacteria, for the demonstration and counting of which no methodology is as yet available. Among the infectious agents, special mention should be made of: *Legionella pneumophila*, *Mycobacterium avium*, viruses, *Coxiella burnetii* and *Histoplasma*

capsulatum; and among the allergens: Cladosporium, Penicillium and Cytophaga.

NATURE AND SOURCES OF INDOOR CHEMICAL CONTAMINANTS

Characteristic Chemical Pollutants

Chemical contaminants of the indoor air can occur as gases and vapours (inorganic and organic) and particulates. Their presence in the indoor environment is the result of entry into the building from the outdoor environment or their generation within the building. The relative importance of these indoor and outdoor origins differs for different pollutants and may vary over time.

The major chemical pollutants commonly found in the indoor air are the following:

1. Carbon dioxide (CO₂), which is a metabolic product and often used as an indicator of the general level of air pollution related to the presence of humans indoors
2. Carbon monoxide (CO), nitrogen oxides (NO_x) and sulphur dioxide (SO₂), which are inorganic combustion gases formed predominantly during the combustion of fuels and ozone (O₃), which is a product of photochemical reactions in polluted atmospheres but may also be released by some indoor sources
3. Organic compounds that originate from a variety of indoor sources and outdoors. Hundreds of organic chemicals occur in indoor air although most are present at very low concentrations.

Identifies four groups of organic compounds: (1) very volatile organic compounds (VVOC); (2) volatile (VOC); (3) semi-volatile (SVOC); and (4) organic compounds associated with particulate matter (POM). Particle-phase organics are dissolved in or adsorbed on particulate matter. They may occur in both the vapour and particle phase depending on their volatility. For example, polyaromatic hydrocarbons (PAHs) consisting of two fused benzene rings (e.g., naphthalene) are found principally in the vapour phase and those consisting of five rings (e.g., benz(a)pyrene) are found predominantly in the particle phase.

An important characteristic of indoor air contaminants is that their concentrations vary both spatially and temporally to a greater extent than is common outdoors. This is due to the large variety of sources, the intermittent operation of some of the sources and the various sinks present.

Concentrations of contaminants that arise principally from combustion sources are subject to very large temporal variation and are intermittent. Episodic releases of volatile organic compounds due to human activities such as painting also lead to large variations in emission with time. Other emissions, such as formaldehyde release from wood-based products may vary with temperature and humidity fluctuations in the

building, but the emission is continuous. The emission of organic chemicals from other materials may be less dependent upon temperature and humidity conditions but their concentrations in indoor air will be greatly influenced by ventilation conditions.

Spatial variations within a room tend to be less pronounced than temporal variations. Within a building there may be large differences in the case of localized sources, for example, photocopiers in a central office, gas cookers in the restaurant kitchen and tobacco smoking restricted to a designated area.

Sources within the Building

Elevated levels of pollutants generated by combustion, particularly nitrogen dioxide and carbon monoxide in indoor spaces, usually result from unvented, improperly vented or poorly maintained combustion appliances and the smoking of tobacco products. Unvented kerosene and gas space heaters emit significant quantities of CO, CO₂, NO_x, SO₂, particulates and formaldehyde. Gas cooking stoves and ovens also release these products directly into the indoor air. Under normal operating conditions, vented gas-fired forced air heaters and water heaters should not release combustion products into the indoor air. However flue gas spillage and backdrafting can occur with faulty appliances when the room is depressurized by competing exhaust systems and under certain meteorological conditions.

Environmental tobacco smoke

Indoor air contamination from tobacco smoke results from sidestream and exhaled mainstream smoke usually referred to as environmental tobacco smoke (ETS). Several thousand different constituents have been identified in tobacco smoke and the total quantities of individual components vary depending upon the type of cigarette and the conditions of smoke generation. The main chemicals associated with ETS are nicotine, nitrosamines, PAHs, CO, CO₂, NO_x, acrolein, formaldehyde and hydrogen cyanide.

Building materials and furnishings

The materials which have received greatest attention as sources of indoor air pollution have been wood-based boards containing urea formaldehyde (UF) resin and UF cavity wall insulation (UFFI). Emission of formaldehyde from these products results in elevated levels of formaldehyde in buildings and this has been associated with many complaints of poor indoor air quality in developed countries, particularly during the late 1970s and early 1980s. Table

44.2 gives examples of materials that release formaldehyde in buildings. These show that the highest emission rates may be associated with the wood-based products and UFFI which are products often used extensively in buildings. Particleboard is

manufactured from fine (about 1 mm) wood particles which are mixed with UF resins (6 to 8 weight%) and pressed into wood panels. It is widely used for flooring, wall panelling, shelving and components of cabinets and furniture. The plies of hardwood are bonded with UF resin and are commonly used for decorative wall panelling and components of furniture. Medium-density fibreboard (MDF) contains finer wood particles than those used in particleboard and these are also bound with UF resin. MDF is most often used for furniture. The primary source of formaldehyde in all these products is the residual formaldehyde trapped in the resin as a result of its presence in excess needed for the reaction with urea during the manufacture of the resin. Release is therefore highest when the product is new, and declines at a rate dependent upon product thickness, initial emission strength, and presence of other formaldehyde sources, local climate and occupant behavior. The initial decline rate of emissions may be 50% over the first eight to nine months, followed by a much slower rate of decline. Secondary emission can occur due to hydrolysis of the UF resin and hence emission rates increase during periods of elevated temperature and humidity. Considerable efforts by manufacturers have led to the development of lower-emitting materials by use of lower ratios (i.e. closer to 1:1) of urea to formaldehyde for resin production and the use of formaldehyde scavengers. Regulation and consumer demand have resulted in widespread use of these products in some countries.

II. POLLUTANT FORMATION IN SI ENGINES

CHEMISTRY OF SI ENGINE COMBUSTION:

In a Spark ignition engine, a perfectly mixed air fuel mixture enters the engine during suction stroke. The charge is compressed well and at the end of end of compression stroke, the charge is ignited by means of spark from spark plug. The air fuel mixture is delivered to engine by means of carburetor.

The quantity and quality of charge entering the engine is controlled according to the engine speed and load conditions.

GASOLINE ENGINE EMISSIONS

The emissions from gasoline powered automobiles are mainly

1. Unburned Hydro Carbons
2. Carbon monoxide
3. Oxides of nitrogen
4. Oxides of sulphur and
5. Particulates including smoke

Pollutant formation in Gasoline engine:

1. Hydrocarbons:

Hydrocarbon exhaust emission may arise from three sources as

- a. Wall quenching
- b. Incomplete combustion of charge
- c. Exhaust scavenging in 2-stroke engines

In an automotive type 4-stroke cycle engine, wall quenching is the predominant source of exhaust hydrocarbon under most operating conditions.

a. Wall quenching:

The quenching of flame near the combustion chamber walls is known as wall quenching. This is a combustion phenomenon which arises when the flame tries to propagate in the vicinity of a wall. Normally the effect of the wall is a slowing down or stopping of the reaction.

Because of the cooling, there is a cold zone next to the cooled combustion chamber walls. This region is called the quench zone. Because of the low temperature, the fuel-air mixture fails to burn and remains unburned.

Due to this, the exhaust gas shows a marked variation in HC emission. The first gas that exits is from near the valve and is relatively cool. Due to this it is rich in HC. The next

part of gas that comes is from the hot combustion chamber and hence a low HC concentration. The last part of the gas that exits is scrapped off the cool cylinder wall and is relatively cool. Therefore it is also rich in HC emission.

b. Incomplete combustion:

Under operating conditions, where mixtures are extremely rich or lean, or exhaust gas dilution is excessive, incomplete flame propagation occurs during combustion and results in incomplete combustion of the charge.

Normally, the carburettor supplies air fuel mixture in the combustible range. Thus incomplete combustion usually results from high exhaust gas dilution arising from high vacuum operation such as idle or deceleration.

However, during transient operation, especially during warm up and deceleration it is possible that sometimes too rich or too lean mixture enters the combustion chamber resulting in very high HC emission.

Factors which promote incomplete flame propagation and misfire include:

- a. Poor condition of the ignition system, including spark plug
- b. Low charge temperature
- c. Poor charge homogeneity
- d. Too rich or lean mixture in the cylinder
- e. Large exhaust residual quantity
- f. Poor distribution of residuals with cylinder

Carburetion and mixture preparation, evaporation and mixing in the intake manifold, atomization at the intake valve and swirl and turbulence in the combustion chamber are some factors which influence gaseous mixture ration and degree of charge homogeneity including residual mixing.

The engine and intake system temperature resulting from prior operation of the engine affect charge temperature and can also affect fuel distribution.

Valve overlap, engine speed, spark timing, compression ratio, intake and exhaust system back pressure affect the amount and composition of exhaust residual. Fuel volatility of the fuel is also one of the main reasons.

c. Scavenging:

In 2-stroke engine a third source of HC emission results from scavenging of the cylinder with fuel air mixture. Due to scavenging part of the air fuel mixture blows through

the cylinder directly into exhaust port and escapes combustion process completely. HC emission from a 2-Stroke petrol engine is comparatively higher than 4- Stroke petrol engine.

2. Carbon monoxide:

Carbon monoxide remains in the exhaust if the oxidation of CO to CO₂ is not complete. This is because carbon monoxide is an intermediate product in the combustion process. Generally this is due to lack of sufficient oxygen. The emission levels of CO from gasoline engine are highly dependent on A/F ratio.

The amount of CO released reduces as the mixture is made leaner. The reason that the CO concentration does not drop to zero when the mixture is chemically correct and leaner arises from a combination of cycle to cycle and cylinder to cylinder mal distribution and slow CO reaction kinetics. Better carburetion and fuel distribution are key to low CO emission in addition to operating the engine at increased air-fuel ratio.

3. Oxides of Nitrogen:

Nitric oxide is formed within the combustion chamber at the peak combustion temperature and persists during expansion and exhaust in non-equilibrium amount. Upon exposure to additional oxygen in the atmosphere, nitrogen dioxide (NO₂) and other oxides may be formed.

It should be noted that although many oxides of nitrogen may be also formed in low concentrations like, Nitrogen trioxide (N₂O₃), Nitrogen pent oxide (N₂O₅) etc., they are unstable compounds and may decompose spontaneously at ambient condition to nitrogen dioxide.

A study of the equilibrium formation of the different nitrogen oxides showed that NO is the only compound having appreciable importance with respect to engine combustion. In engine terminology an unknown mixture of nitrogen oxides usually NO and NO₂ is known as NO_x. It is expected that higher temperature and availability of oxygen would promote the formation of oxides of nitrogen.

Mechanism of NO formation:

The nitric oxide formation during the combustion process is the result of group of elementary reaction involving the nitrogen and oxygen molecules. Different mechanism proposed are discussed below.

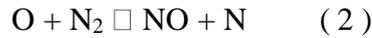
a. Simple reaction between N₂ and O₂



This mechanism proposed by Eyzat and Guibet predicts NO concentrations much

lower than those measured in I.C. engines. According to this mechanism, the formation process is too slow for NO to reach equilibrium at peak temperatures and pressures in the cylinders.

b. Zeldovich Chain Reaction mechanism:



The chain reactions are initiated by the equation (2) by the atomic oxygen, formed in equation (1) from the dissociation of oxygen molecules at the high temperatures reached in the combustion process. Oxygen atoms react with nitrogen molecules and produce NO and nitrogen atoms. In the equation (3) the nitrogen atoms react with oxygen molecule to form nitric oxide and atomic oxygen.

According to this mechanism nitrogen atoms do not start the chain reaction because their equilibrium concentration during the combustion process is relatively low compared to that of atomic oxygen. Experiments have shown that equilibrium concentrations of both oxygen atoms and nitric oxide molecules increase with temperature and with leaning of mixtures. It has also been observed that NO formed at the maximum cycle temperature does not decompose even during the expansion stroke when the gas temperature decreases.

In general it can be expected that higher temperature would promote the formation of NO by speeding the formation reactions. Ample O₂ supplies would also increase the formation of NO. The NO levels would be low in fuel rich operations, i.e. A/F 15, since there is little O₂ left to react with N₂ after the hydrocarbons had reacted.

The maximum NO levels are formed with AFR about 10 percent above stoichiometric. More air than this reduces the peak temperature, since excess air must be heated from energy released during combustion and the NO concentration falls off even with additional oxygen.

Measurements taken on NO concentrations at the exhaust valve indicate that the concentration rises to a peak and then falls as the combustion gases exhaust from the cylinder. This is consistent with the idea that NO is formed in the bulk gases. The first gas exhausted is that near the exhaust valve followed by the bulk gases. The last gases out should be those from near the cylinder wall and should exhibit lower temperatures and lower NO concentration.

4. Particulate matter and Partial Oxidation Products:

Organic and inorganic compounds of higher molecular weights and lead compounds resulting from the use of TEL are exhausted in the form of very small size particles of the

order of 0.02 to 0.06 microns. About 75% of the lead burned in the engine is exhausted into the atmosphere in this form and rest is deposited on engine parts.

Some traces of products of partial oxidation are also present in the exhaust gas of which formaldehyde and acetaldehyde are important. Other constituents are phenolic acids, ketones, ethers etc., These are essentially products of incomplete combustion of the fuel.

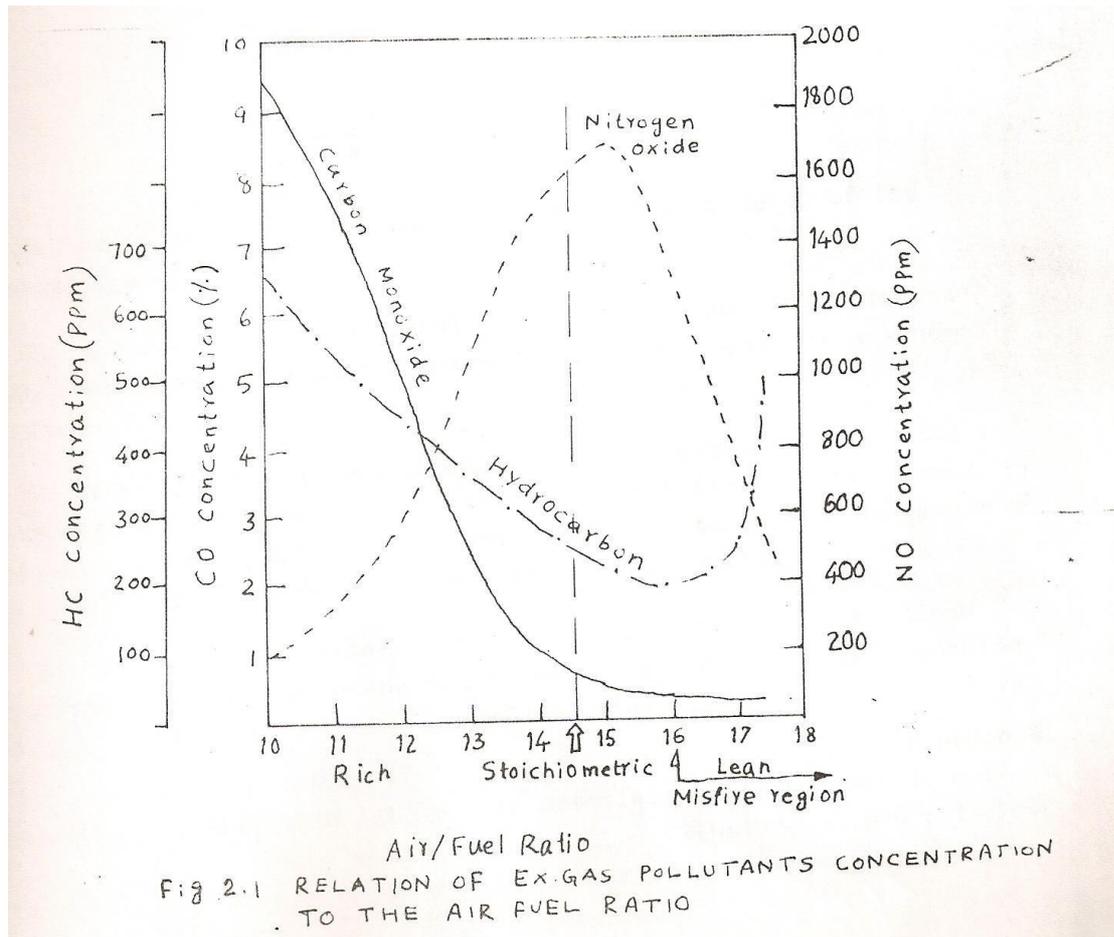


Fig.1 Relation of Exhaust gas Pollutants Concentration to the Air Fuel Ratio

Flame Quenching:

The phenomenon of flame quenching at the engine walls and the resulting unburned layer of combustible mixture play a significant role in the overall problem of air pollution.

It has long been understood that a flame will not propagate through a narrow passage. It has been found that the walls comprising the narrow passage quench the flame by acting as a sink for energy. The minimum distance between two plates through which a flame will propagate is defined as the quenching distance. The quenching distance is found to be a function of pressure, temperature and reactant composition.

When a flame is quenched by a single wall as would be the case in the combustion chamber of a S.I engine, the distance of the closest approach of the flame to the wall is smaller than the quenching distance. This distance is called the dead space. In general, the dead space has been assumed to range from 0.33 to 1.0 of the quenching distance.

Friedman and Johnson, Green and Agnes, Gottenbery and others have made significant work on this area. The following points are drawn from their experiments.

1. Essentially the expression for quenching distance is of the form

$$q_d = \frac{1}{P^\alpha T^\beta}$$

Where the values of α and β depends on the stoichiometry of the combustible mixture.

2. Lean mixtures have significantly large quenching distance than stoichiometry or rich mixture at any given pressure.

3. There exist a direct linear relationship between the total exhausted hydrocarbon and surface to volume ratio, a direct linear relationship between the representatives measured quench distance and the quantity of unburned hydrocarbons in the combustion products.

4. The quenching distance of copper, mica, glass and platinum surfaces were the same and hence, they concluded that the quenching effect was independent of the surface material.

5. As the temperature of the wall increases, the flame can propagate closer to it. If high temperature materials could be used to make the cylinder walls in an engine capable of withstanding 800 °C to 1200 °C temperature, the quench layer thickness can be reduced to bring down the concentration of hydrocarbons.

Daniel proposed that the unburned hydrocarbons that are exhausted during the cruise and acceleration modes are due to the quenching of flames by the walls of the combustion chamber piston.

He measured the thickness of the dark zone between the flame and the combustion chamber wall in a single cylinder engine that was fitted with a single quartz head. The dark zone or dead space was measured by taking stroboscopic picture of successive cycle through the quartz cylinder head, and he showed that the quantity of fuel trapped in the dead space was sufficient to account for the unburned hydrocarbons emitted from the engine. He also reported that the thickness of the dark zone was a function of temperature and pressure as referred by Friedman and Johnson.

Tabaczynski proposed that there are four separate quench regions in the cylinder of a S.I engine. As shown in fig 3.1, these four quench layers may be expected to be exhausted from the cylinder at different times during the exhaust stroke. Regions 1 and 2 shown in the figure are the head and side wall quench layers respectively. Region 3 represents the piston face quench layer and region 4 corresponds to the quench volume between the

cylinder wall, piston crown and first compression ring.

It has been proposed that the head quench layer and part of the side wall quench layer nearest the exhaust valve leave the cylinder when the exhaust valve opens. Due to the low flow velocities near the piston face, the piston face quench layer will probably not leave the cylinder at any time during the stroke. During the expansion stroke, the hydrocarbons from the crevice between the piston crown and the first compression ring are laid along the cylinder wall.

As the piston begins its upward stroke, it has been shown that a vortex is formed which scrapes up the hydrocarbons along the wall and forces them to be exhausted near the end of the exhaust stroke.

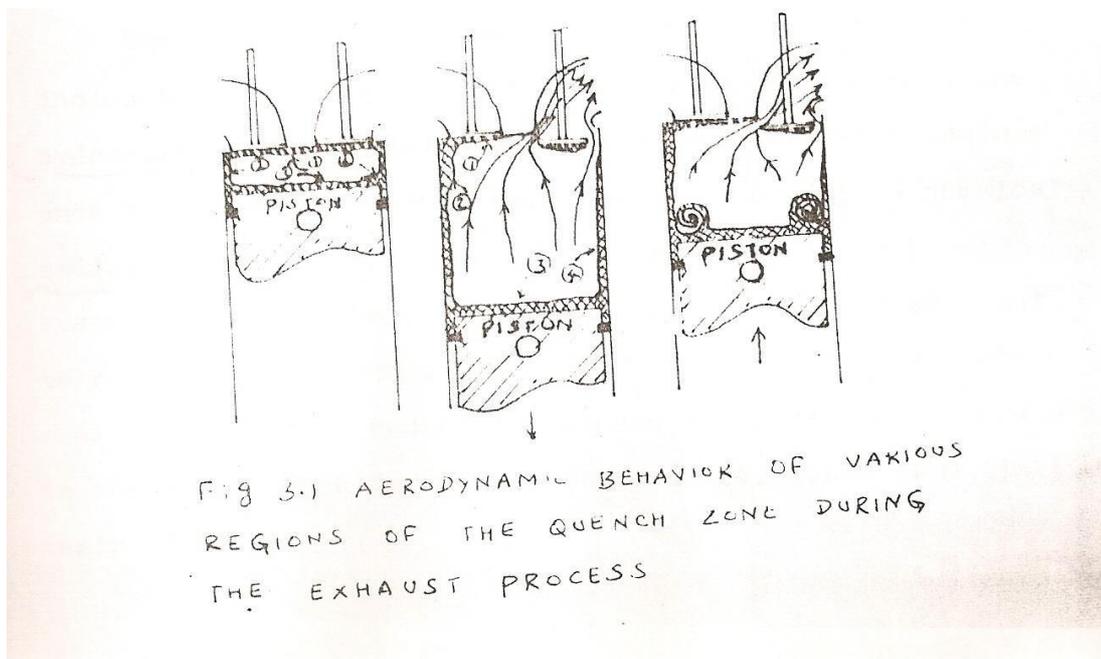


Fig.2 Aerodynamic Behavior

EFFECT OF DESIGN AND OPERATING VARIABLES ON GASOLINE ENGINE EXHAUST EMISSIONS

The exhaust emission of hydrocarbons, carbon monoxide and nitric oxide can be minimized by the control of several inter related engine design and operating parameter. Fuel preparation, distribution and composition are also factors. In this section the effects on emissions of factors which the engineer has under his control when designing and tailoring his engine for minimum exhaust emissions are discussed. The factors include:

- Air fuel ratio
- Load or power level
- Speed

- Spark timing
- Exhaust back pressure
- Valve overlap
- Intake manifold pressure
- Combustion chamber deposit build up
- Surface temperature
- Surface to volume ratio
- Combustion chamber design
- Displacement per cylinder
- Compression ratio
- Stroke to bore ratio

In the following discussions, the hydrocarbons and CO emissions are treated together; because once they are formed they both can be reduced by chemical oxidation process in either the cylinder or the exhaust system. On the other hand nitric oxide, once formed must be reduced by a chemical reduction process.

In the first case for HC and CO reduction, excess O₂ is required where as in the second case for NO reduction a deficiency of O₂ is desirable.

EFFECTS ON UNBURNED HYDROCARBONS AND CARBON MONOXIDE

1. AIR – FUEL RATIO:

a. Hydrocarbon emission:

Hydrocarbon emissions are high at rich air fuel ratios and decrease as the mixture is leaned up to about 17:1. When operation leaner than 17 or 18:1 is attempted, emissions increases because of incomplete flame propagation and the engine begin to misfire.

The basic factor contributing to the shape of the curve for HC emissions are the effect of mixture ratio on quench layer thickness and on fuel concentration within that quench layer, and the effect of mixture ratio on the availability of excess oxygen in the exhaust to complete the combustion and on the exhaust system temperature. When the temperature is over 650 °C and with oxygen available appreciable exhaust after reaction does occur.

b. CO emission:

CO emissions are high at rich air fuel ratios and decreases as the mixture is leaned.

On the richer side, a change of only 1/3 air fuel ratio leads to a change of 1.0% in exhaust CO. The reason that the CO concentration does not drop to zero when the mixture is chemically correct and leaner arises from a combination of cycle to cycle and cylinder to cylinder mal distribution and slow CO kinetics.

2. POWER OUTPUT:

a. Hydrocarbon emission:

Hydrocarbon concentration does not change as load is increased while speed and mixture ratio are held constant and spark is adjusted to MBT. This result is to be viewed as arising from effects of several factors some of which tend to reduce HC while others tend to increase them, apparently counter balancing one another.

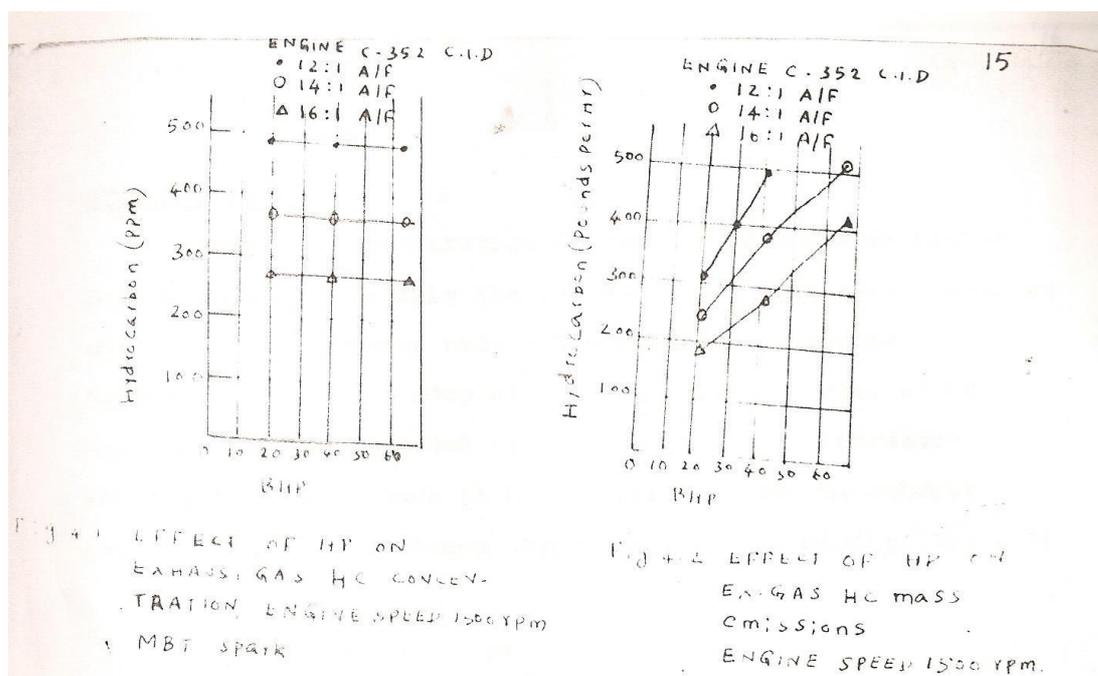


Fig.3 Effect of Exhaust Gas on BHP

A factor which increases the HC formation as load increases is the reduced time within the exhaust system. The residence time of the exhaust gas in the very hot section of the exhaust system is very important for increased exhaust after-reaction.

Factors tending to reduce HC concentration include decreased quench thickness and increased exhaust temperature. Quench layer thickness decreases inversely as pressure increases and the mean cylinder pressure increases linearly with increase in load. Increased temperature with increasing load tends to increase exhaust after-reaction.

However, an almost linear increase in HC mass emissions is observed as load is increased. A light car with low power is better than a large car on mass emission basis.

b. CO emission:

At a fixed air- fuel ratio there is no effect of power output on CO emission concentration. However, as in the case of HC emissions, CO emission on mass basis will increase directly with increasing output, giving advantage for a small light and efficient car.

3. ENGINE SPEED:

a. Hydrocarbon emission:

HC emission is considerably reduced at higher engine speeds. This is because with increase in engine speed, the combustion process within the cylinder is increased by increasing turbulent mixing and eddy diffusion. In addition, increased exhaust port turbulences at higher speeds promotes exhaust system oxidation reactions through better mixing.

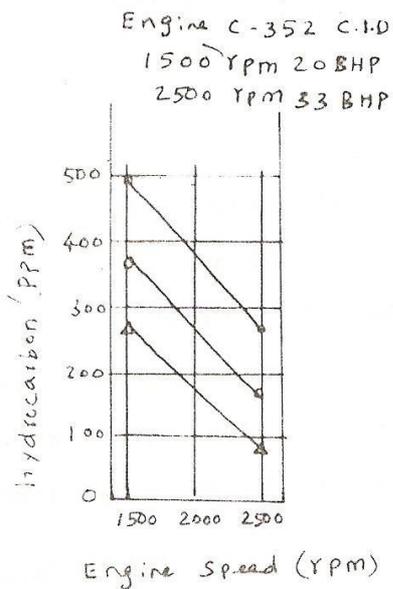


Fig 4.3
EFFECT OF ENGINE
SPEED ON EXHAUST
GAS HYDROCARBON
CONCENTRATIONS AT
12:1, 14:1 and 16:1
A/F ratios

Fig.4 Effect of Engine Speed on Exhaust Gas

b. CO emission:

Speed has no effect on CO concentration. This is because oxidation of CO in the exhaust is kinetically limited rather than mixing limited at normal exhaust temperatures.

4. SPARK TIMING:

a. HC emission:

HC emission has huge impact on spark timing. As the timing is retarded, the HC emissions are reduced. This is because, the exhaust gas temperature increases which promotes CO and HC oxidation. This advantage is gained by compromising the fuel economy.

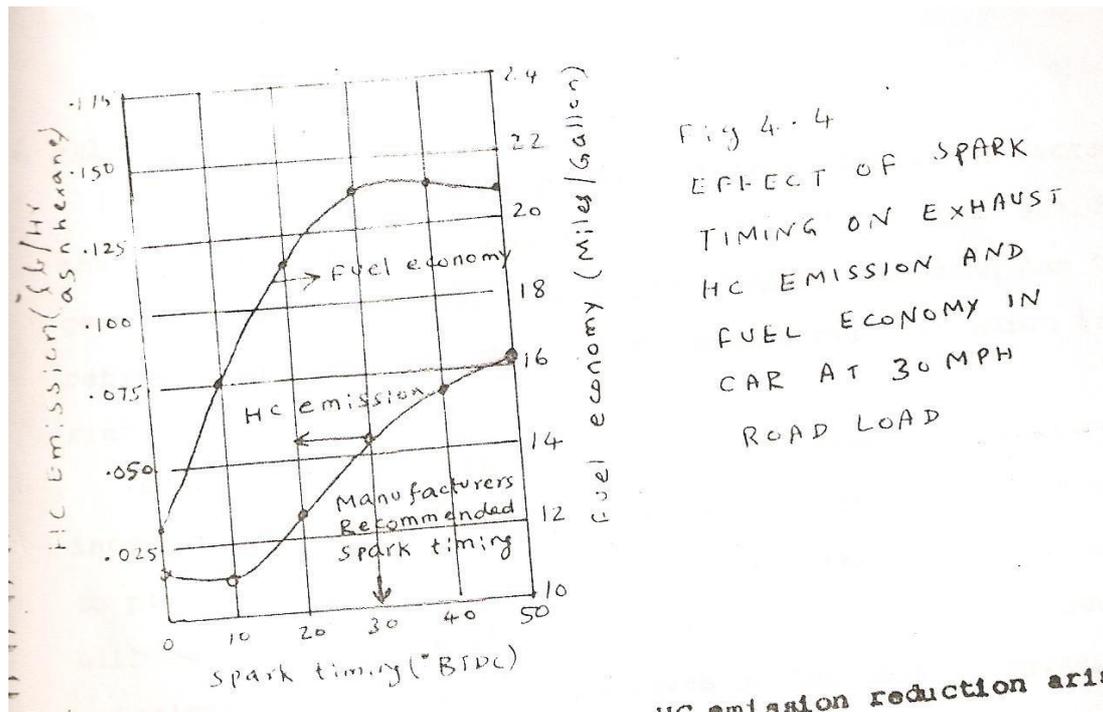


Fig.5 Effect of Spark Timing

b. CO emission:

Spark timing has very little effect on CO concentration. But at very high retarded timing, the CO emission increases. This is due to lack of time, to complete oxidation of CO.

5. EXHAUST BACK PRESSURE:

a. HC emission:

Increasing exhaust back pressure increases the amount of residual exhaust gas left in the cylinder at the end of the exhaust. If this increase in dilution does not affect the combustion process adversely, the HC emissions would be marginally reduced. The reduction arises from leaving the tail end of the exhaust, which is rich in HC, in the cylinder. This tail will be subsequently burned in the next cycle. If the back pressure is increased more and more, HC emission would rise sharply because of the effect of excessive dilution on combustion.

On the other hand, increased dilution at idle increases HC emission concentration. At idle, dilution is already quite high and combustion is marginal and the engine cannot tolerate much more exhaust dilution.

6. VALVE OVERLAP:

a. HC emission:

Increasing valve overlap has an effect similar to increasing the back pressure. The charge is further diluted with residual gases. A slight 2 overlap provided minimizes emission due to re burning of exhaust tail gas which is rich in HC.

Combustion deteriorates with lean mixture as residual is increased. If the mixture ratio is richened to provide stable idle and off-idle performance, then HC advantage will be lost and CO will be increased.

In general, minimum HC emissions are obtained with moderate or low back pressure with minimum overlap.

b. CO emission:

There is no effect of overlap on CO concentration at a constant mixture ratio. However any increase in richness of the mixture for smooth idle or off idle will increase the CO directly. This is due to lack of insufficient supply of oxygen for complete oxidation of CO.

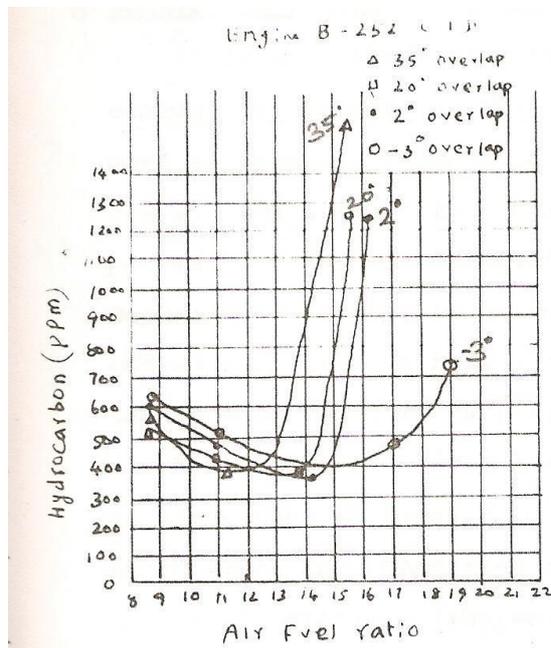


Fig 4.5

EFFECT OF A/F RATIO ON EXHAUST GAS HYDROCARBON CONCENTRATIONS AT IDLE FOR VALVE OVERLAP SETTINGS OF 36 deg, 20 deg (standard) 2 deg and -3 deg.

Fig.6 Effect of Air Fuel Ratio on Exhaust gas

7. INTAKE MANIFOLD PRESSURE:

a. HC emission:

The intake manifold pressure variation reflects the variation in power output of an engine. Between 22cm and 60cm of Hg manifold pressure, the A/F ratio is lean which minimizes HC and CO emissions. Above 60cm of Hg, the engine power increases and the carburettor switch to rich mode. The rich mixture increases HC and CO emissions. This

holds good only in case of carbureted engine. At light loads and low manifold pressure, additional HC emissions results from wall quenching accompanying rich mixtures delivered from the carburetor and incomplete combustion at manifold pressures below 15cm of Hg.

8. COMBUSTION CHAMBER DEPOSITS:

a. HC emission:

It is well known that in a normal engine the major source of combustion chamber deposit is TEL, a fuel additive used to suppress combustion knock. The deposits act to increase the surface area of the chamber because of their irregular porous nature. As a result, the mass of quenched HC increases. Deposits act as a sponge to trap raw fuel which remains unburned and adds to exhaust. All these tend to increase the HC emission.

Tests have indicated that removal of deposits, depending on the extent of deposit build up, would reduce about 15% in HC emissions. Addition of fuel additives to reduce deposit build up may be helpful. Ethylene dibromide is commonly added to motor fuel to reduce lead deposits from TEL. Any modification to both fuels and lubricants can indirectly reduce HC emissions through deposit modification.

b. CO emission:

There is no effect of deposit build up on CO emission.

9. SURFACE TEMPERATURE:

a. HC emission:

Combustion chamber surface temperature affects the unburned HC emissions by changing the thickness of combustion chamber quench layer and degree of after burning. Higher the combustion chamber surface temperature, the lower are the HC emissions.

In addition to changing quench distance and after-reaction, changing engine temperature increases fuel evaporation and distribution, and result in a faster reaction and hence reduced HC emission.

b. CO emission:

An increase in surface temperature of chamber increases the rate of oxidation of CO and hence reduces CO emission. Further exhaust after reaction also increases resulting in decrease in CO emission.

10. SURFACE TO VOLUME RATIO:

a. HC emission:

Because hydrocarbon emissions arise primarily from quenching at the combustion chamber wall surface, it is desirable to minimize the surface area of the chamber. The ratio

of surface area to volume of the combustion chamber (S / V) is useful for interpreting the effects of many designs and operating variables on HC concentration. Lowering the S / V ratio reduces HC emission concentration.

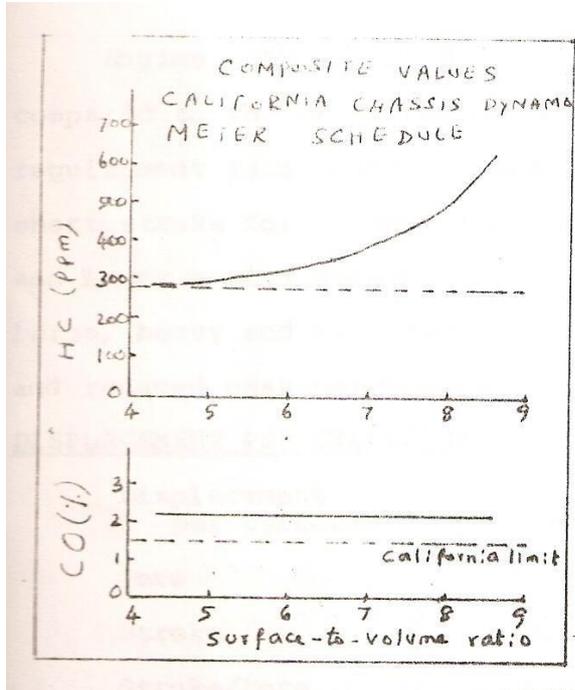


Fig 4.6
 COMPOSITE EXHAUST HC CONCENTRATION, MEASURED, CORRECTED AND WEIGHTED ACCORDING TO CALIFORNIA SCHEDULE, INCREASED WITH INCREASING S/V RATIO. CARBURETTORS WERE TAILORED TO GIVE EQUAL, MIDRANGE A/F RATIOS RESULTING IN EQUAL CO CONCENTRATION

b. CO emission:

CO concentration has no effect on surface to volume ratio.

11. COMBUSTION CHAMBER DESIGN:

One of the most important factors that the emission engineer has under his control is the combustion chamber design. For a given clearance volume, reducing the surface area is an important way of reducing HC emission. Designing a combustion chamber to create better turbulence will reduce both HC and CO emission.

12. STROKE / BORE RATIO:

Another design factor is stroke to bore ratio. Engines with small bore and long stroke have lower S / V ratio. Engines with low surface to volume ratio provide a good emission reduction compared to the engine with higher surface to volume ratio.

Displacement per cyl.	41	41
Bore	4	3.62
Stroke	3.25	4
Stroke/bore	.813	1.105
s/v	8	6.1

The engine with s/v 6.1 should provide good emission result. Unfortunately this requirement is opposed to modern design practice of short stroke for reduced friction, increased power and economy. Long stroke engines tend to be large, heavy and more expensive and they have poor fuel economy and reduced peak power.

13. DISPLACEMENT PER CYLINDER:

For a given displacement, engines with larger cylinders have smaller surface to volume ratio. This result suggests that for an engine of given displacement, hydrocarbon emissions can be reduced by decreasing the number of cylinders and increasing the displacement per cylinder. On the other hand, for a given number of cylinders, increasing the engine displacement reduces s/v ratio and reduces HC.

Displacement per cyl.	41	30.2
Bore	4	3.62
Stroke	3.25	2.94
Stroke/bore	.813	.813
s/v	8	9

14. COMPRESSION RATIO:

A decrease in compression ratio decreases surface to volume ratio. Decrease in compression ratio increases the clearance volume greatly with little increase in surface area. Due to this decrease in surface to volume ratio the HC emission is reduced.

A decrease in compression ratio decreases the HC emission on a second way also. With reduced compression ratio, thermal efficiency is lowered and as a result exhaust gas temperature is increased. This improves exhaust system after-recirculation and lowers the HC emission even more.

DESIGN FOR LOW S/V RATIO

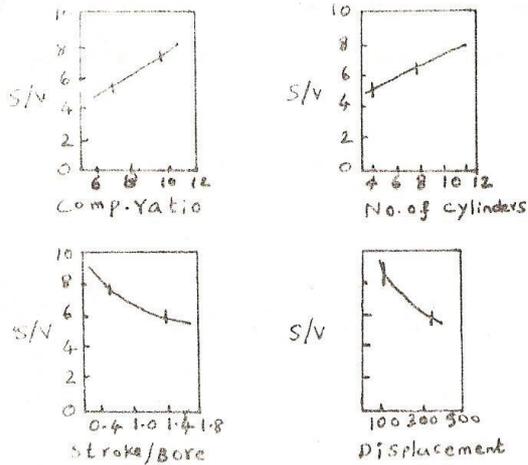


FIG 4.7
 COMPRESSION RATIO, NO OF CYLINDERS,
 AND DISPLACEMENT ALL SHOW THE
 SIZE EFFECT. AS THE INDIVIDUAL
 COMBUSTION CHAMBER GETS
 SMALLER THE S/V RATIO GETS
 LARGER. AS THE STROKE/BORE RATIO
 GETS LARGER (LONGER STROKE
 ENGINES) THE S/V RATIO GETS
 SMALLER. VERTICAL LINES ON
 EACH CURVE MARK THE
 BOUNDARIES OF PRESENT
 PRODUCTION PRACTICE

On the other hand, as engine efficiency is lowered, mass flow is increased for a given horse power level which increases mass emissions.

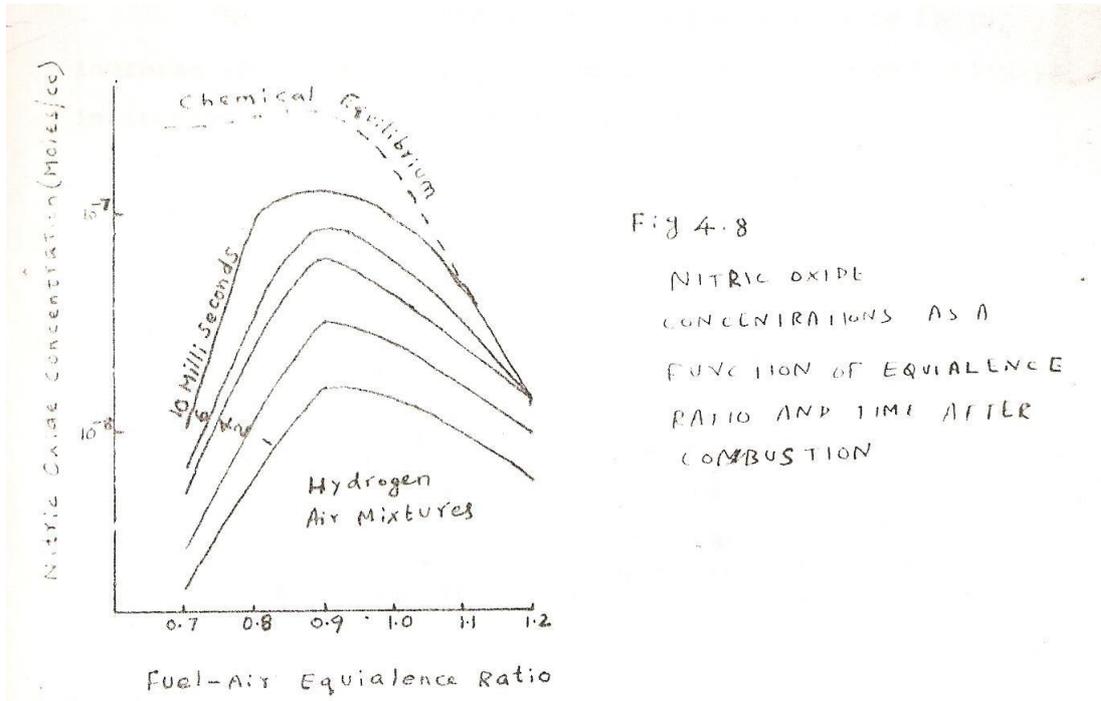
On the other hand with large reduction in compression ratio, the temperature in chamber decreases and it increases both HC and CO emission.

EFFECT OF NITRIC OXIDE:

The concentration of NO in the exhaust gases depends upon the difference between the rate of its formation at the highest temperature in the cycle and the rate of its decomposition as the temperature decreases during the expansion stroke. A study of the decomposition rate of NO indicates that the amount decomposed is negligible because of the short time available during the expansion stroke.

1. EQUIVALENCE RATIO:

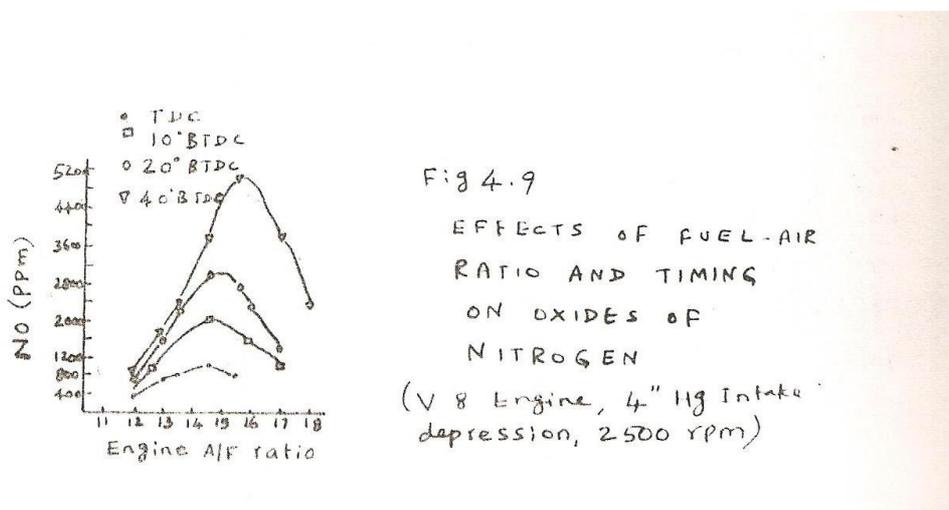
The equivalence ratio affects both the gas temperature and the available oxygen during combustion. Theoretically an increase in the equivalence ratio from 1.0 to 1.1 results in an increase of maximum cycle temperature by about 55C while oxygen concentration is reduced by 50%. At equivalence ratio of 1.1, NO in the exhaust is very low. Maximum NO concentration occurs at an equivalence ratio of 0.8. The maximum cycle temperature with this lean mixture is lower than with a rich mixture but available oxygen concentration is much higher.



With very rich mixtures, low peak combustion temperatures and low oxygen concentration lead to low NO. For mixtures leaner than 15.5:1 there is enough oxygen but the temperature is very less and hence lower the NO formation. Thus NO concentration is very low for very lean as well as very rich mixtures.

2. SPARK TIMING:

An advance in spark timing increases the maximum cycle temperature and therefore results in increased NO concentration.



3. ANIFOLD PRESSURE:

An increase in manifold vacuum decreases load and temperature. As a result the

ignition delay is increased and the flame speed is reduced. Both these factors increase the time of combustion. This reduces the maximum cycle temperature and thus reducing NO concentration in the exhaust.

4. ENGINE SPEED:

An increase in engine speed has little effect on ignition delay. Increase in engine speed results in an increase in flame speed due to turbulence and reduces heat losses per cycle which tends to raise compression and combustion temperature and pressure. If spark timing is held constant, a greater portion of this combustion tends to occur during expansion where temperature and pressure are relatively low.

This is most pronounced for the slowest burning mixture ratio of 19:1. For richer mixtures which burn faster, the effect of reduced heat losses at higher speeds predominates.

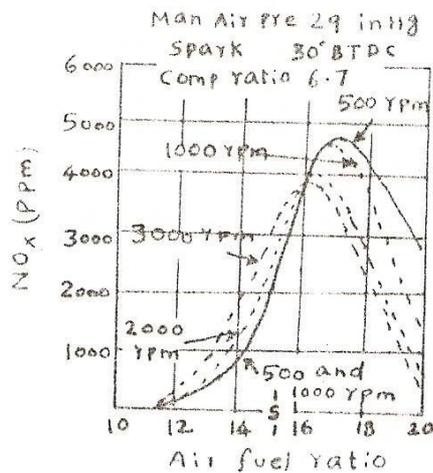


Fig 4.10
Effect of speed
on Exhaust
NO concentration

These are two opposing influences – an increase in the rate of NO formation due to reduced heat losses opposed by a reduction in the rate of NO formation due to late burning. For rich mixtures where combustion and NO formation are rapid, the former predominates. For lean mixtures where combustion and NO formation are slow, the later effect predominates.

5. COOLANT TEMPERATURE AND DESPOSIT:

An increase in the coolant temperature results in a reduction of heat losses to the cylinder walls and an increase in the maximum gas temperature. This results in an increase in NO concentration.

An increase in deposit thickness causes an increase in compression ratio, reduction in heat losses to the coolant and an increase in NO concentration.

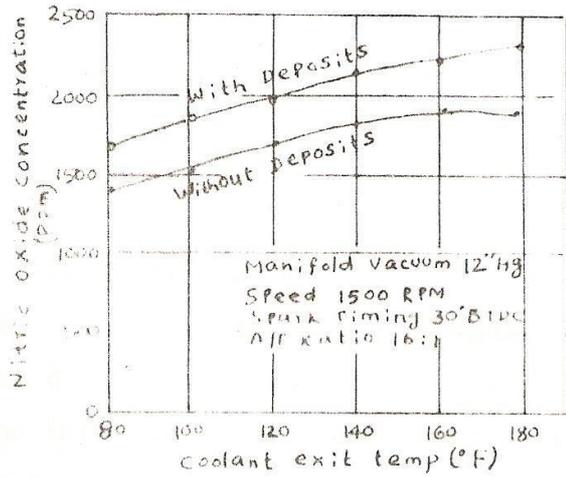


Fig 4.11
EFFECT OF
COOLANT TEMP
ON EXHAUST
NO CONCENTRA
TION, FOR DUPLICATE
RUNS WITH AND
WITHOUT DEPOSITS

6. HUMIDITY:

The reduction in NO formation caused by an increase in mixture humidity is mainly due to the drop in maximum flame temperature. Test on hydrogen-air, and ethylene-air mixture indicates that 1% of water vapour reduces the flame temperature by 20C. This reduces the initial rate of NO production by about 25%.

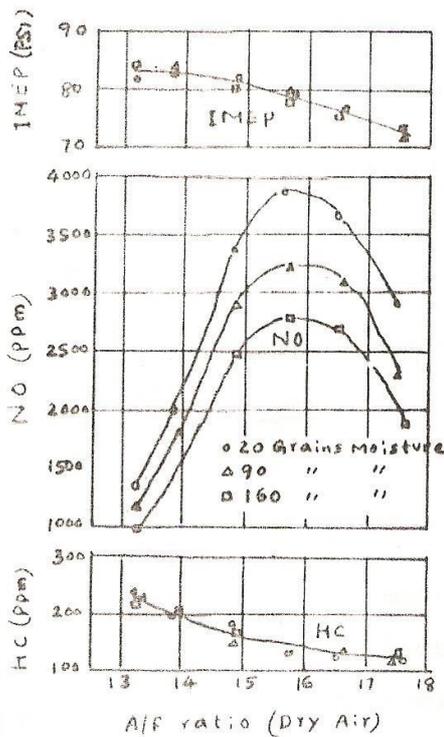


Fig 4.12
EXHAUST EMISSIONS
AND IMEP VERSUS
AIR FUEL RATIO
AT 1600 RPM
12 in Hg intake
vacuum

7. EXHAUST GAS RECIRCULATION:

Recycling of a portion of exhaust gas to inlet charge increases dilution. This reduces peak combustion temperature, since the inert exhaust gas re-circulated will act as a heat sink.

This also reduces the oxygen availability. About 15% recycle will reduce NO_x emission by about 80%. The maximum percentage which can be re circulated is limited by rough engine operation and loss of power.

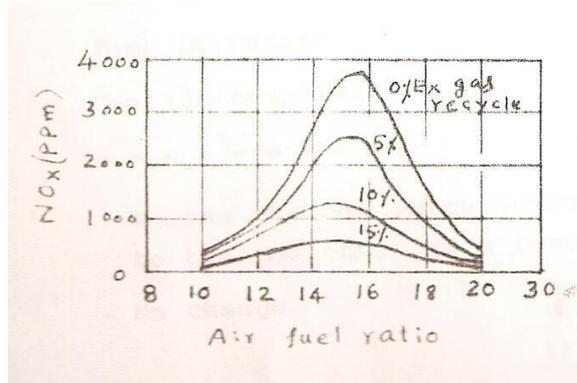


Fig 4-13
EFFECT OF RECYCLING
OF EX-GAS ON
NO_x CONCENTRATION.

8. SURFACE TO VOLUME RATIO:

Engine changes which decrease surface to volume ratio reduce heat loss to the coolant. As a result NO concentration may increase.

EFFECT OF DESIGN AND OPERATING VARIABLES ON EXHAUST EMISSIONS

SL.NO.	VARIABLE INCREASED	HC	CO	NO
1	Load	-	-	Increase
2	Speed	Decrease	-	Increase/Decrease
3	Spark retard	Decrease	-	Decrease
4	Exhaust back pressure	Decrease	-	Decrease
5	Valve overlap	Decrease	-	Decrease
6	Intake manifold pressure	-	-	Increase
7	Combustion chamber deposit	Increases	-	Increases
8	S/V ratio	Increase	-	-
9	Combustion chamber area	Increase	-	-
10	Stroke to bore ratio	Decrease	-	-

11	Displacement per cyl.	Decrease	-	-
12	Compression ratio	Increase	-	Increase
13	Air Injection	Decrease	Decrease	Increase
14	Fuel injection	Decrease	Decrease	Increase
15	Coolant temperature	Decrease	Decrease	Increase

III. POLLUTANT FORMATION IN CI ENGINES

DIESEL ENGIN EXHAUST EMISSIONS:

The pollutants from diesel engines can be categorized into two types:

1. Visible and 2. Invisible. The first one consists of smoke and metallic particulates. Smoke being so conspicuous and odorous is objected to public and also reduces visibility and has smudging character but is not harmful to health.

The second type consists of CO, unburnt hydrocarbons including poly nuclear aromatics, oxides of N₂, SO₂ and partially oxidized organics (aldehydes, ketones etc.,)

Among these pollutants smoke, CO, UBHC and oxides of nitrogen are of most immediate concern.

FORMATION OF POLLUTANTS IN DIESEL ENGINES:

Unlike a gasoline engine, where fuel and air are premixed into a homogenous form before entering the cylinder, in the diesel engine fuel is injected into the compressed air charge inside the cylinder. As the mixing of air and fuel has to take place entirely in the combustion chamber, complete mixing is virtually impossible and infinite variations in air-fuel mixture ratio takes place within the same cylinder. Also as the load requirement is met through variation in the quantity of fuel injected, the overall air fuel ratio varies within wide limits, about 20:1 to 60:1.

A normally rated and well maintained engine emits negligible amount of CO and unburnt hydrocarbons, through considerable amount of oxides of nitrogen and smoke are emitted.

Carbon monoxide:

It is formed during combustion when there is insufficient oxygen to oxidize the fuel fully. Compression ignition engines have long been known to produce low levels of CO because of excess amount of air available for combustion. Theoretically it should not emit any CO as it always operated with large amount of excess air. Nevertheless CO is present in small quantities (0.1 to 0.75%) in the exhausts. This is possible because of the fact that fuel injected in later part of the injection does not find enough oxygen due to local depletion in certain parts of the combustion chamber.

Unburnt Hydrocarbons:

The concentrations of hydrocarbons in diesel exhaust varies for a few parts per million to several thousand parts per millions depending on engine speed and load.

Hydrocarbons in engine exhaust are composed of many individual hydrocarbons in the fuel supplied to the engine as well as number of hydrocarbons partially unburnt produced during the combustion process. In addition some unburnt hydrocarbons may be from lubricating oils. Tests on engine with single component fuels shows that these engines contained hydrocarbons of higher and lower molecular weights, than original fuel as well as molecules with different structures. Aromatic compounds have been observed in exhaust of engines operated on pure paraffins. Poly nuclear aromatics found in exhaust are products of this synthesis.

During the normal operation the relatively cold walls “quench” the fuel air mixture and inhibit combustion leaving a thick skin of unburnt air fuel mixture over the entire envelope of the combustion chamber. The amount of unburnt fuel depends on the thickness of quench zone and the effective combustion chamber area. The thickness of quench zone depends on many variables as combustion temperature, pressure, mixture ratio, turbulence and residual gas dilution. Higher surface to volume ratio of combustion chamber leads to greater fraction of unburnt hydrocarbon from the quench zone.

Partially oxidized hydrocarbons (aldehydes) have been associated with diesel exhaust. They produce objectionable odor and are high when engine idles and under cold starting indicating poor combustion.

OXIDES OF NITROGEN:

This is more significant. The formation of Nitric oxide, the major component of oxides of nitrogen depends on number of operating conditions of diesel engine. The main factors that control this formation are amounts of oxygen available and the peak temperature in the zones with sufficient oxygen and residence times at temperatures above 2000K.

Both open and pre-combustion chamber produce small amount of oxides of nitrogen when air fuel ratio is about 0.01 to maximum near air fuel ratio of about 0.035 ratios. Additional fuel tends to lower air fuel ratio; the charge temperature also reduces which consequently reduces oxides of nitrogen.

Formation of oxides of nitrogen:

Since nitrogen is a high temperature species its formation is influenced by combustion temperature and time available for combustion. Hence NO tends to increase with advanced injection timing. Also NO produced increase with fuel supply. Notable exception is prechamber. In direct injection engines NO reaches maximum value at stoichiometric air fuel ratio, as lean and rich mixtures tend to reduce combustion temperatures. Increase in compression ratio leads to increase in combustion temperature and hence higher NO formation.

Valve overlap has significant effect on NO formation. Higher valve overlap dilutes the incoming air more and more leading to increasing in fuel/air ratio. This in turn reduces combustion temperatures and hence lowers NO formation.

Earlier inlet valve opening before TDC leads to increased dilution of incoming air and hence lower NO.

Extended inlet valve opening up to 20 has no effect on NO formation as it does not vary manifold pressure.

Extended exhaust valve opening before bottom dead centre results in marginal increase in NO due to better scavenging, conversely later exhaust valve opening leads to delayed scavenging and higher dilution.

Exhaust valve closing determine effect of scavenging and pronounced effect on dilution and hence Nitrogen formation.

DIESEL ENGINE SMOKE EMISSION:

Engine exhaust smoke is a visible indicator of the combustion process in the engine. Smoke is due to incomplete combustion. Smoke in diesel engine can be divided into three categories: blue, white and black.

Blue smoke:

It results from the burning of engine lubricating oil that reaches combustion chamber due to worn piston rings, cylinder liners and valve guides.

White or cold smoke:

It is made up of droplets of unburnt or partially burnt fuel droplets and is usually associated with the engine running at less than normal operating temperature after starting, long period of idling, operating under very light load, operating with leaking injectors and water leakage in combustion chamber. This smoke normally fades away as engine is warmed up and brought to normal stage.

Black or hot smoke:

It consists of unburnt carbon particles (0.5 – 1 microns in diameter) and other solid products of combustion. This smoke appears after engine is warmed up and is accelerating or pulling under load.

Formation of smoke in Diesel engines:

The main cause of smoke formation is known to be inadequate mixing of fuel and air. Smoke is formed when the local temperature is high enough to decompose fuel in a region where there is insufficient oxygen to burn the carbon that is formed. The formation of over-rich fuel air mixtures either generally or in localized regions will result in smoke. Large amounts of carbons will be formed during the early stage of combustion. This carbon appears as smoke if there is insufficient air, if there is insufficient mixing or if local temperatures fall below the carbon reaction temperatures (approximately 1000C) before the mixing occurs.

Acceptable performance of diesel engine is critically influenced by exhaust some emissions. Failure of engine to meet smoke legislation requirement prevents sale and particularly for military use, possible visibility by smoke is useful to enemy force. Diesel emissions gives information on effectiveness of combustion, general performance and condition of engine.

FACTORS AFFECTING SMOKE FORMATION:

The smoke intensity in the diesel exhaust is generally affected by many parameters. By controlling them, smoke intensity may be reduced.

1. Injection timing:

Advancing the injection timing in diesel engines with all other parameters kept constant results in longer delay periods, more fuel injected before ignition, higher temperatures in the cycle and earlier ending of the combustion process. The residence time is therefore increased. All these factors have been found to reduce the smoke intensity in the exhaust. However earlier injection results in more combustion noise, higher mechanical and thermal stresses, and high NO concentration.

In a recent study, Khan reported that a very late injection reduces the smoke. The timing after which this reduction occurs is that at which the minimum ignition delay occurs. He suggested that one of the factors that contributes to the reduction in smoke at the

retarded timing is the reduced rate of formation due to decrease in the temperature of the diffusion flames as most of these flames occur during the expansion stroke.

2. Rate of Injection:

Higher initial rates of injection have been found to be effective in reducing the exhaust smoke.

3. Injection nozzle:

The size of the nozzle holes and the ratio of the hole length to its diameter have an effect on smoke concentration. A larger hole diameter results in less atomization and increased smoke. An increase in the length/diameter ratio beyond a certain limit also results in increased smoke.

4. Maintenance:

The engine condition plays a very important role in deciding the smoke levels. The maintenance affects the injection characteristics and the quantity of lubricating oil which passes across the piston rings and thus a profound effect on smoke generation tendency of the engine. Good maintenance is a must for lower smoke levels.

5. Fuel:

Higher cetane number fuels have a tendency to produce more smoke. It is believed to be due to lower stability of these fuels. For a given cetane number less smoke is produced with more volatile fuels.

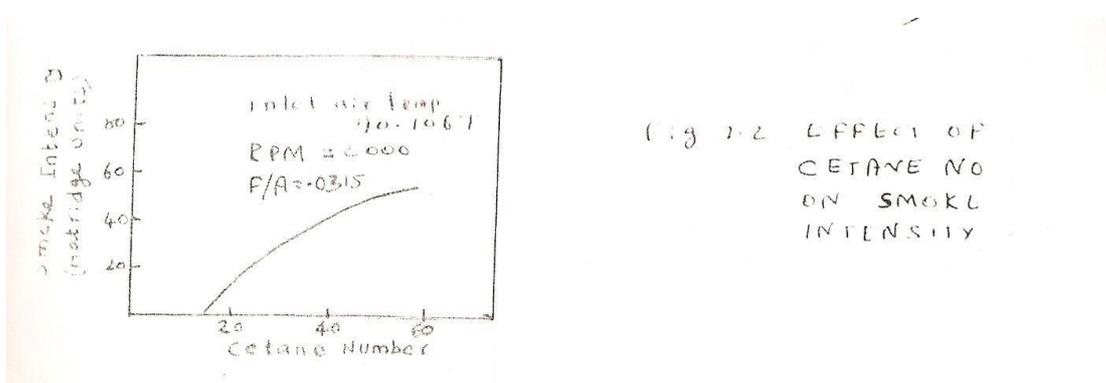


FIG: 1 Effect of Cetane Number on Smoke Intensity

6. Load:

A rich fuel-air mixture results in higher smoke because the amount of oxygen available is less. Hence any over loading of the engine will result in a very black smoke.

The smoke level rises from no load to full load. During the first part, the smoke level is more or less constant as there is always excess air present. However in the higher load range there is an abrupt rise in smoke level due to less available oxygen.

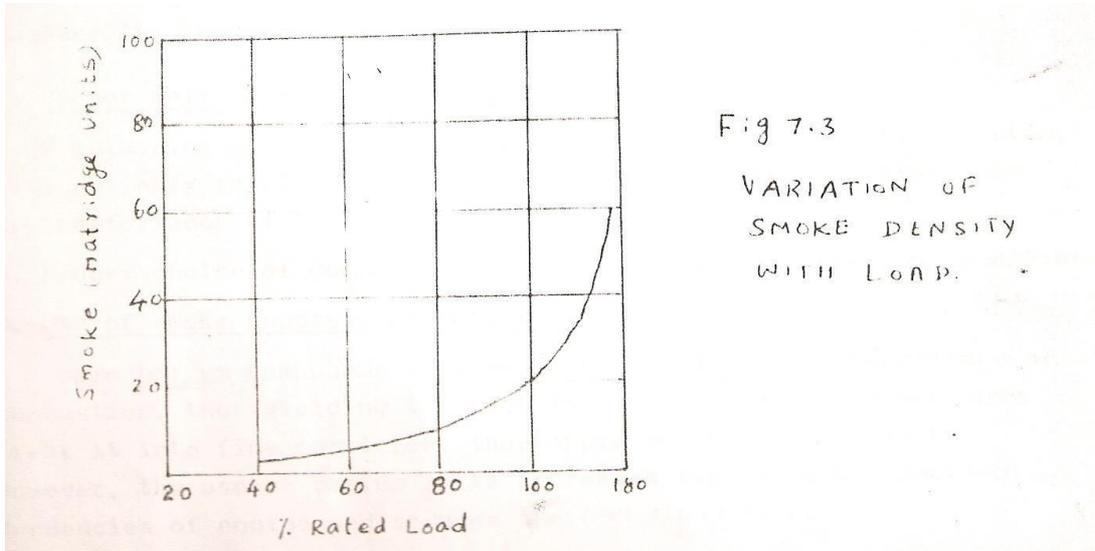


Fig.2 Variation of Smoke Density with Load

7. Engine type and speed:

Naturally aspirated engines have higher smoke levels at higher loads than turbo charged engines, because the later have sufficient oxygen even at full loads. The smoke is worse at low as well as at high speeds. This follows the volumetric efficiency curve of the engine in some measure as it drops at the extremes of speed.

8. Fuel air ratio:

The smoke increases with richening the mixture. The increase in smoke occurs even with as much as 25% excess air in cylinder, cleanly indicating that the diesel engine has a mixing problem.

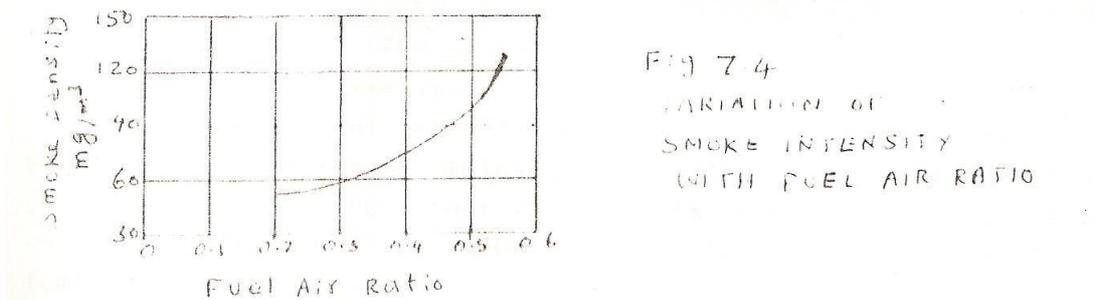


Fig. 3 Variation of Smoke Density with Fuel Air Ratio

CONTROL OF DIESEL ENGINE SMOKE:

Smoke can be reduced by some of the following methods:

1. Derating:

Derating is nothing but making the engine to run at lower loads. At lower loads more excess air is present in the combustion chamber and hence the smoke developed is less as already discussed. However, this means a loss of output.

2. Proper maintenance of the engine:

Maintaining the engine properly, especially the injection system, will not only result in reducing smoke but also keep the performance of the engine at its best.

3. Proper choice of combustion chamber design and operating conditions:

A proper choice of combustion chamber design results in better mixing of fuel and air in the chamber and hence reduces the smoke level to a considerable level.

4. Use of smoke suppression additives:

Some barium compounds if used in fuel reduce the temperature of combustion, thus avoiding the soot formation. Even if formed they break it into fine particles, thus appreciably reducing smoke. However, the use of barium salts increases the deposit formation tendencies of engine and reduces the fuel filter life.

5. Adopting fumigation technique:

This method consists of introducing a small amount of fuel into the intake manifold. This starts precombustion reactions before and during the compression stroke resulting in reduced chemical delay, because the intermediate products such as peroxides and aldehydes react more rapidly with oxygen than original hydrocarbons. The shortening of delay period curbs thermal cracking which is responsible for soot formation.

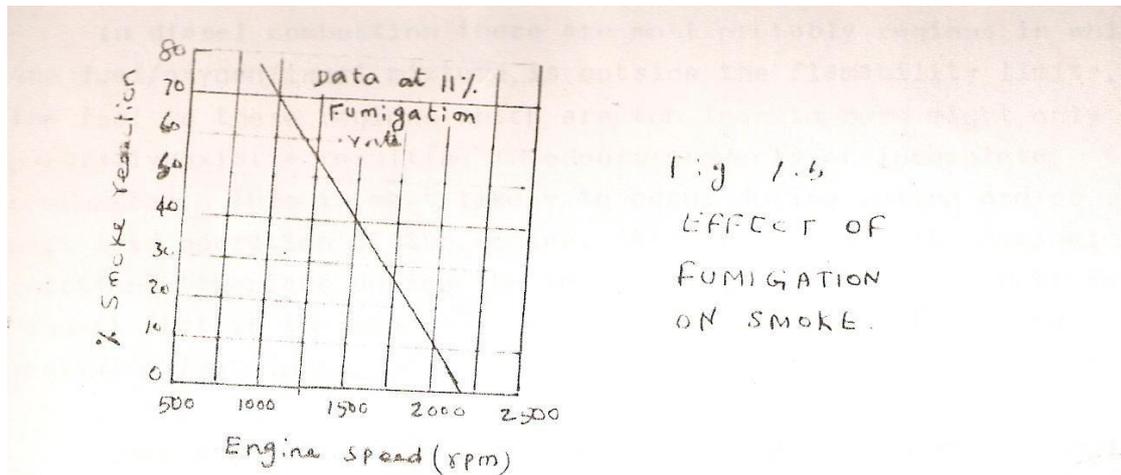


Fig.4 Effect of Fumigation on Smoke

Fumigation rate of about 15% gives best smoke improvement. However this improvement varies greatly with engine speed. At low engine speeds 50 to 80% smoke reduction is obtained. This decrease as speed increases until a speed at which there is no effect of fumigation.

DIESEL ODOUR:

Ever since the first diesel engine was developed, the odor from its exhaust has been recognized as undesirable. Determination of the cause of this odor has been difficult because of the complexity of the heterogeneous combustion process and the lack of chemical instruments available. In practice the human nose plays a significant role in odor measurement.

The members of the aldehydes family are supposed to be responsible for the pungent odors of diesel exhaust. Though the amount of aldehydes is small being less than 30ppm, the concentration as low as 1ppm are irritating the human eyes and nose.

Mechanism of odour production:

Some experimental results indicate that the products of partial oxidation are the main cause of odor in diesel exhaust. This partial oxidation may be because of either very lean mixture or due to quenching effect.

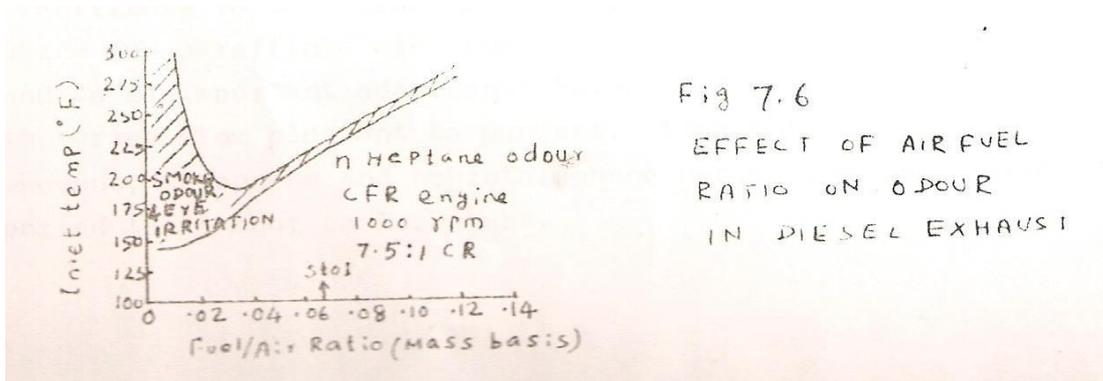


Fig.5 Effect of Air Fuel Ratio on odor in Diesel Exhaust

In diesel combustion there are most probably regions in which the fuel/oxygen/inert mixture is outside the flammability limits. The fuel in these regions which are too lean to burn might only partially oxidize resulting in odors. This is most likely to occur during idling and or part load operation of the engine. Also the fact that chemical reactions take place during the second stage of diesel combustion suggest that if the reactions are quenched during this period, partial oxidation products will result in odour in the diesel exhaust.

Barns concluded in his research that diesel odor resulted from partial oxidation reaction in the fuel lean regions which are almost inevitably formed in heterogeneous combustion. Graph shows the relative odor producing capabilities of different air fuel regions. The data shown in graph were obtained using CFR engine and varying air- fuel ratios and the inlet air temperatures.

Odor relevant compounds:

Until recently very little was known about the compound or compounds that contribute to the odorous qualities of diesel exhaust. Rounds and Pearsall correlate odor with the aldehydes in diesel exhaust gas. However Vogh says that aldehydes are not significant contributors to the overall odor problem. Vogh also says that neither SO₂ nor particulate contribute significantly to diesel odor emissions.

Research work at the Illinois Institute of Technology, Research Institute (IITRI) has contributed significantly to the development of a better understanding of the chemical nature of the odor contributors in diesel exhaust. Based on the IITRI work, various high molecular weight cyclic and aromatic hydrocarbons including naphthalene, tetralin and cyclo paraffins some with olefinic and or paraffinic side chains were reported as major contributors to the burnt odor note of the exhaust.

Various non aromatic hydrocarbons with more than one double or triple bond were also reported to contribute to the burnt odor note. Furan aldehydes, aromatic benzene and

paraffinic aldehydes from ethanol to n-octanol were found to be important odor contributors and have individual odors that varied from pleasant to pungent. Some heterocyclic sulfur compounds, thiophene and benzothiophene derivatives were also reported to be odor contributors.

FACTORS AFFECTING ODOR PRODUCTION:

1. Fuel air ratio:

The fact that very lean mixtures result in odorous diesel exhaust has already been discussed.

2. Engine operation mode:

It has been found that the mode of operation of the engine significantly affects the exhaust odor. Maximum odor occurs while accelerating from idle and minimum odor results when the engine is running at medium speed and or at part loads.

Effect of engine operating mode on odor production (4-stroke normally aspirated medium speed diesel engine)

Engine operation mode	Odor intensity (Turk number)
Idle	3.6
Acceleration	4.1
Part load	3.0
Full load	3.5

3. Engine type:

The odor intensity does not vary with the engine type as can be seen from the table. The odor intensity from all the engines is more or less the same.

Engine type	Odor intensity (Turk number)
Two stroke	3.5
Four stroke normally aspirated (medium speed)	3.3
Four stroke normally aspirated (high speed)	3.5

Four stroke – Turbo charged	3.4
-----------------------------	-----

4. Fuel composition:

It is really surprising to find that the composition of the fuel has no effect on exhaust odor intensity. The changes in fuel composition result in different second stage combustion time in diesel combustion and it is expected that this will affect the degree of oxidation if quenching is taking place. However the results contradict this expectation.

5. Odor suppressant additives:

It has been claimed from time to time, by different manufactures of odor suppressant additive compounds that they reduce the odor. However small and rather insignificant effects upon the odor has been found in comparison of exhausts from treated and untreated fuels. No predictable and reliable correspondence between the additives and odor is found.

Odor Measurement Techniques:

Effective chemical or physical methods for the measurement of odor have not been developed, and therefore the human nose plays a significant role in all odor studies. In practice odor is measured by a specially selected, specially trained human panel.

When the nose is subjected to an odor, the physiological response to the odor can be classified by either intensity or intensity and quality. The Turk kit contains a number of different standard odors that are classified as a) burnt/smoky b) oily c) pungent/acid and d) aldehydic/aromatic. It has been generally accepted as a standard for rating the intensity and quality of an unknown odorous sample.

Odor-detection methods that have been developed todate may be placed in two general categories. The first category includes methods that only rate the over all odor intensity, while the second group is employed to classify odors by quality and intensity. The threshold dilution technique and natural dilution technique that are described below fall into the first category.

The threshold dilution technique consists of presenting raw diesel exhaust synthetically diluted with variable quantities of odor free air to a panel of “Sniffers” person who smells. A series of diluted samples, both above and below the threshold dilution ratio, are presented to members of the panel and the individual panel members are

asked to determine whether or not any odor is detectable. The odor intensity is assumed to be proportional to the dilution ratio at which the odor is just detectable to the panel.

The natural dilution technique was developed in order to determine whether diesel powered vehicles could meet the motor vehicle exhaust odor on standards set by the state of California. During the course of these tests, a panel is seated at varying distance from a vehicle. Both the vehicle and the panel are located inside a large municipal hanger, in order to minimize the effects due to winds and the panelists are asked to determine whether or not they can detect any odor from the vehicle. Their responses are utilized to evaluate threshold response distances.

Variations of the direct method have been used to rate the quality and intensity of diesel odor and hence they fall into the second category of odor detection methods. When applying this method, the exhaust from the diesel engine is usually diluted with odor free air at the engine exhaust pipe and the resulting mixture of gases which consists of raw diesel exhaust mixed with odor free air in ratios ranging from 1 to 200 flows dynamically through a presentation system to the panelists. The panelists who have been previously trained to evaluate both quality and intensity as determined by the Turk kit are asked to record their response to test gases as a function of dilution ratio and experimental parameters.

IV. CONTROL OF EMISSIONS FROM SI AND CI ENGINES

Design changes:

The effects of engine design and operating variables on exhaust emission were discussed in a detailed manner already. Based on the discussions made already the engine design modifications approaches to control the pollutants are discussed below.

1. NO_x is decreased by

A. Decreasing the combustion chamber temperature

The combustion chamber temperature can be decreased by

1. Decreasing compression ratio
2. Retarding spark timing
3. Decreasing charge temperature
4. Decreasing engine speed
5. Decreasing inlet charge pressure
6. Exhaust gas recirculation
7. Increasing humidity
8. Water injection
9. Operating the engine with very lean or very rich air fuel ratio
10. Decreasing the coolant temperature
11. Decreasing the deposits
12. Increasing S/V ratio

B. By decreasing oxygen available in the flame front

The amount of oxygen available in the chamber can be controlled by

1. Rich mixture
2. Stratified charge engine
3. Divided combustion chamber

2. Hydrocarbon emission can be decreased by

1. Decreasing the compression ratio
2. Retarding the spark
3. Increasing charge temperature
4. Increasing coolant temperature
5. Insulating exhaust manifold
6. Increasing engine speed

7. Lean mixture
8. Adding oxygen in the exhaust
9. Decreasing S/V ratio
10. Increasing turbulence
11. Decreasing the deposits
12. Increasing exhaust manifold volume
13. Increasing exhaust back pressure

3. CO can be decreased by

1. Lean air fuel ratio
2. Adding oxygen in the exhaust
3. Increasing coolant temperature.

EXHAUST GAS RECIRCULATION:

In exhaust gas recirculation a portion of the exhaust gas is recirculated to the cylinder intake charge. This reduces the peak combustion temperature, since the inert gas serves as a heat sink. This also reduces the quantity of oxygen available for combustion.

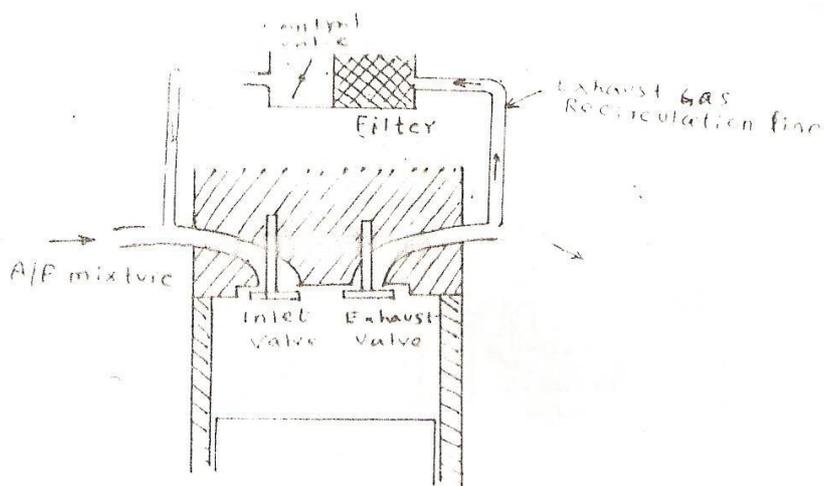


Fig B.11 EXHAUST GAS RECIRCULATION SYSTEM

The exhaust gas for recirculation is passed through the control valve for regulation of the rate and inducted down to the intake port. The recycle rate control valve is connected to the throttle shaft by means of appropriated linkage and the amount of valve opening is regulated by throttle position. The link is designed so that recycled exhaust is normally shut off during idle to prevent rough engine operation. This is also shut off during full throttle, acceleration to prevent loss of power when maximum performance is needed.

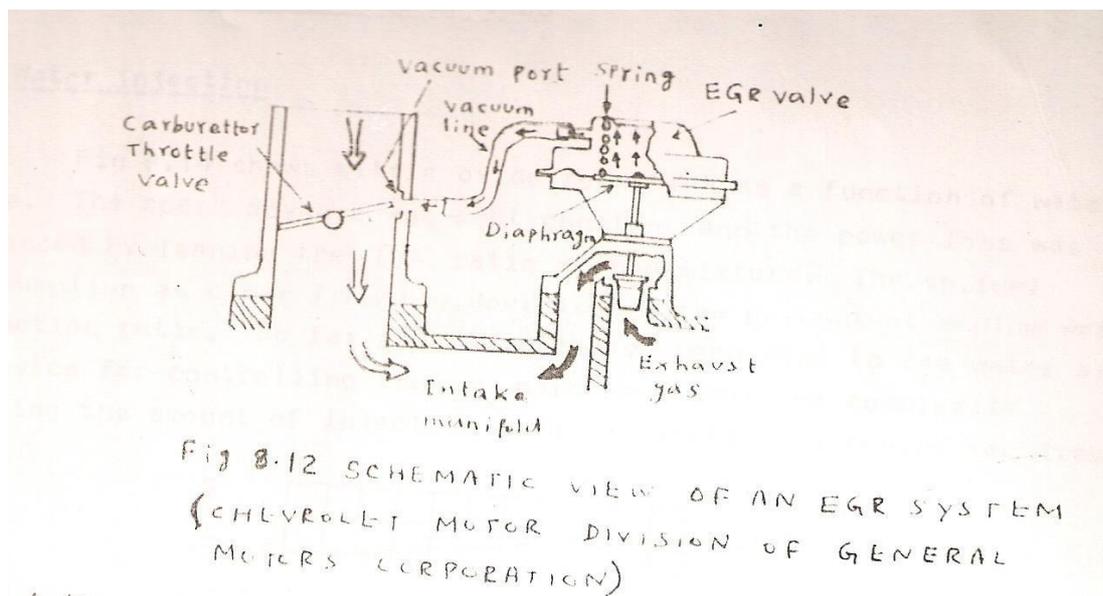
The NO_x concentration will vary with the amount of recycling of gas at various air fuel ratios. About 15% recycle will reduce NO_x emission by about 80%. The maximum

percentage which can be circulated is limited by rough engine operation and loss of power.

The above figure shows a vacuum controlled EGR valve used to control the recycle rate. A special passage connects the exhaust manifold with the intake manifold. This passage is opened or closed by a vacuum controlled EGR valve. The upper part of the valve is sealed. It is connected by a vacuum line to a vacuum port in the Carburetor. When there is no vacuum the port, there is no vacuum applied to the diaphragm in the EGR valve. Therefore, the spring holds the valve closed. No exhaust gas recirculates. This is the situation during engine idling when little NO_x is formed.

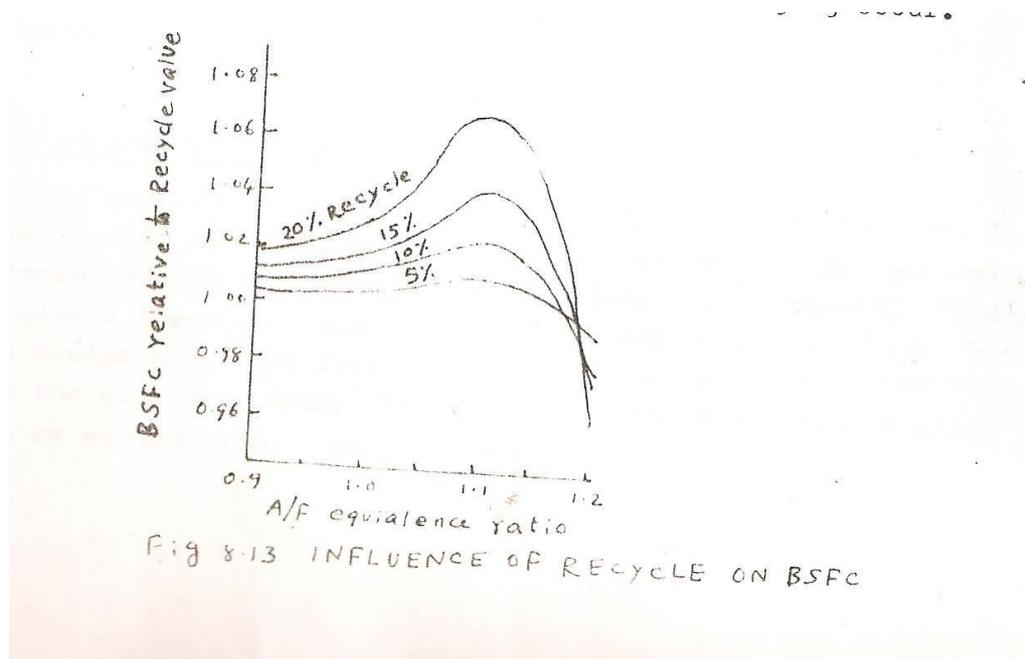
As the throttle valve opens it passes the vacuum port in the Carburetor. This allows intake manifold vacuum to operate the EGR valve. Then vacuum raises the diaphragm, which lifts the attached valve off its seat. Now exhaust gas flows into the intake manifold. There the exhaust gas mixes with the air fuel mixture and enter the engine cylinders.

At wide open throttle, there is little vacuum in the intake manifold. This produces a denser mixture which burns cooler during the combustion process. Therefore at wide open throttle there is less need for exhaust gas recirculation. Due to low vacuum, the EGR valve is nearly closed.



A thermal vacuum switch on many cars prevents exhaust gas recirculation until the engine temperature reaches about 100 F Or 37.8C. The thermal vacuum switch is also called a coolant temperature override switch (CTO switch). It is mounted in a cooling system water jacket, so it senses coolant temperature. If this temperature is below 100F, the switch remains closed. This prevents the vacuum from reaching the EGR valve, so the exhaust gas does not recirculate. Cold engine performance immediately after starting is improved. After the engine warms up it can tolerate exhaust gas recirculation. Then the CTO valve opens. Now vacuum can get to the EGR valve, so that exhaust gas can recirculate.

EGR invariably results in drop in power, increased fuel consumption and rough combustion. In addition excessive intake system deposit buildup and increased oil sludging occur.



Fumigation technique:

This method consists of introducing a small amount of fuel into the intake manifold. This starts precombustion reactions before and during the compression stroke resulting in reduced chemical delay, because the intermediate products such as peroxides and aldehydes react more rapidly with oxygen than original hydrocarbons. The shortening of delay period curbs thermal cracking which is responsible for soot formation.

Fumigation rate of about 15% gives best smoke improvement. However this improvement varies greatly with engine speed. At low engine speeds 50 to 80% smoke reduction is obtained. This decrease as speed increases until a speed at which there is no effect of fumigation.

CRANKCASE EMISSION AND CONTROL

During the compression and combustion strokes, highly corrosive blowby gases are forced past the piston rings into the crankcase. The amount of blowby entering the crankcase generally increases with engine speed. The amount of blowby also depends on other conditions including piston, ring and cylinder wear. The actual amount of wear may be small, perhaps only a few thousandths of an inch. But almost any wear is enough to weaken the sealing effect of the rings and permit blowby to increase. Blowby gases contain burned

and unburned fuel, carbon and water vapour from the combustion chamber. When

the engine is cold, some of the water vapour of the blowby condenses on the cylinder walls and crankcase. It forms into droplets and runs down into the oil pan. Gasoline vapour also condenses on cold engine parts and drips down into the oil pan. This gasoline dilutes and thins the oil, reducing its lubricating ability.

The churning action of the rotating crank shaft can whip the water and engine oil into thick, gummy substance called sludge. The acid compounds from the blowby can get into the sludge and cause corrosion and faster wear of engine parts. Sludge can also clog oil passages and prevent normal engine lubrication, thereby leading to early engine failure.

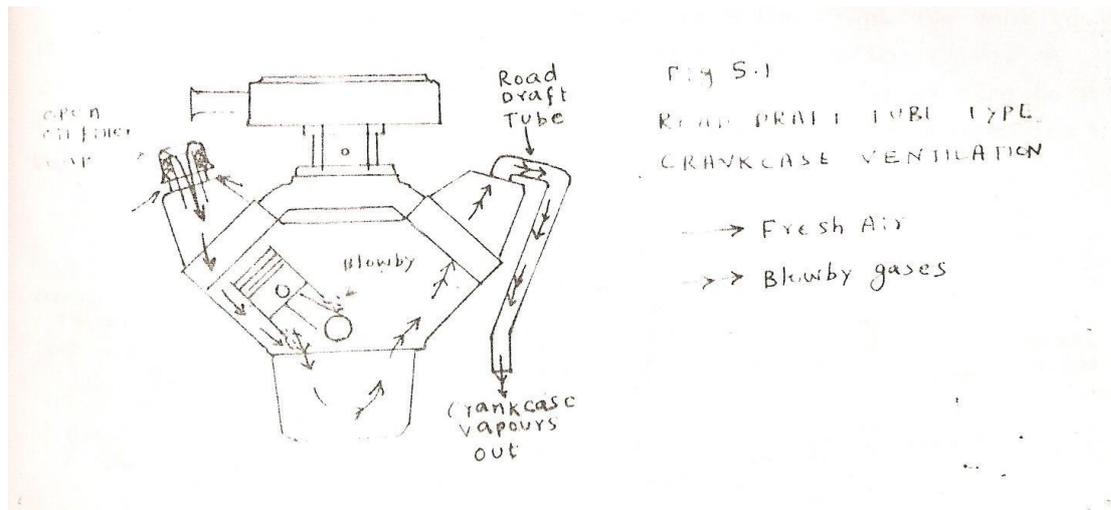
Blowby causes pressure in the crankcase. If this pressure is allowed to build up, engine oil is forced past the oil seals and gaskets and out of the engine. To help to control the effect of blowby, there must be a way to relieve the crankcase pressure caused by blowby gases.

CRANKCASE VENTILATION

To avoid the above said problems, the unburned and partly burned gasoline and the combustion gases and water vapour must be cleared out of the crankcase by providing crankcase ventilation systems.

In early engines, the crankcase ventilation system was very simple. It provided crankcase breathing by passing fresh air through the crankcase. On almost all American made automobile engines built prior to 1961, the fresh air entered through an air inlet at the top front of the engine. The fresh air is mixed with the blowby fumes and other vapours in the crankcase. These vapours were routed out of the crankcase through a large hollow tube called the road draft tube, which discharged under the car into the atmosphere.

The fresh air inlet was usually the crankcase breather cap. On most engines it also served as the cap for the crankcase oil filler tube. The cap was open, or vented with holes on both sides to let fresh air to pass through. The cap was filled with oil soaked steel wool or similar material to serve as an air filter. The filter prevented dust particle in the air from getting into the crankcase oil and causing engine wear.



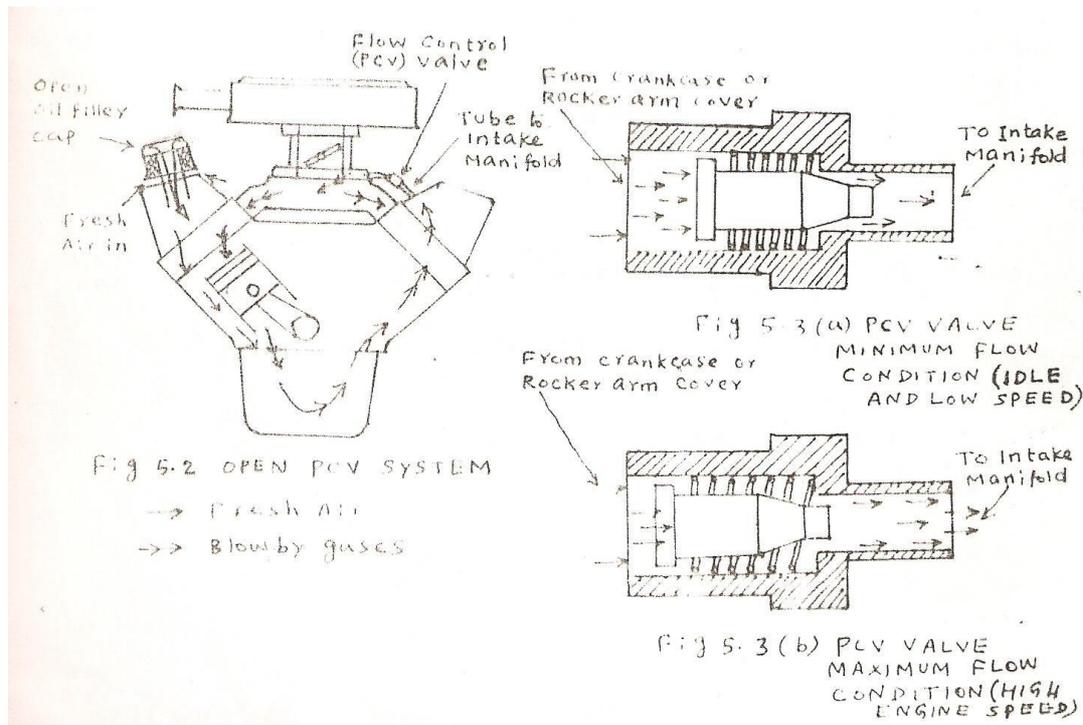
ROAD DRAFT TUBE EMISSIONS:

The road draft tube system worked well to keep the crankcase free of fumes and pressure build up. However it discharged all the crankcase pollutants into the atmosphere. This discharge through the road draft tube represented about 20% of the total HC emissions from an automobile. Therefore controlling blow by was the first step in eliminating atmospheric pollution from the automobile.

OPEN PCV SYSTEM:

An early system that partially controlled crankcase emission was installed on cars built for sale in California beginning in 1961. The system was called open positive crankcase ventilation system.

In this system a tube is connected between a crank case vent and the intake manifold. While the engine is running, intake manifold vacuum is used to pull vapour from the crankcase through the tube into the intake manifold. Fresh ventilating air is drawn into the crankcase through an open oil filler cap. In the intake manifold, the crankcase vapours are mixed with the incoming air-fuel mixture and sent to the cylinders for burning.



For the engine to operate properly under all conditions of speed and load, a flow control valve is required. Without a flow control valve, excessive ventilation air passes from the crankcase into the intake manifold during idling and low speed. This upsets the engine air fuel ratio and results in poor idling with frequent stalling.

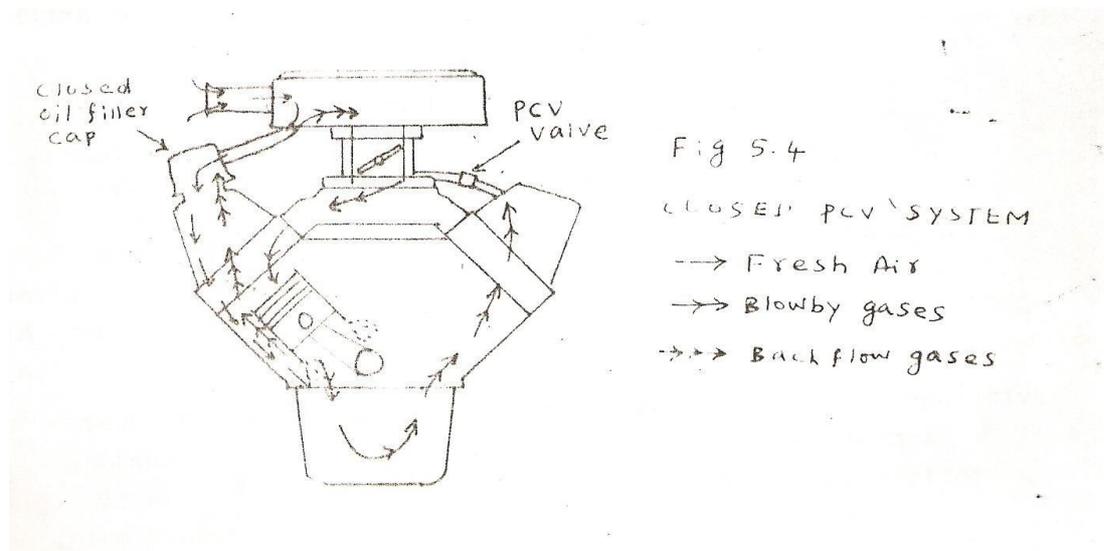
The PCV valve is installed in a tube from the crankcase vent to the intake manifold. The PCV valve is a variable orifice valve. A variable orifice is a hole that acts as a valve by changing the size to vary the flow rate through it. This valve is also called a metering valve, a modulator valve and a regulator valve.

A typical PCV valve consists of a coil spring, a valve and a two piece outer body which is usually crimped together. At idle or low speed, high intake manifold vacuum tends to pull the valve closed or into its minimum flow condition. As the valve tries to close it compresses the valve spring. The smaller opening now allows a much smaller volume of blow by gas to pass through. At high engine speeds, the compressed spring overcomes the pull of the vacuum on the valve. The spring begins to force the valve open towards the maximum flow condition. As the valve moves open, the flow capacity increases. This is to handle the greater volume of blowby that results from an increase in engine load and speed.

CLOSED PCV:

The crankcase emission control system described above is not completely effective in controlling crankcase emissions. In open type system, blowby in excess of the PCV valve flow rate escapes to the atmosphere through the open oil filler cap. To overcome this problem, a closed positive crankcase ventilation system was developed. All cars manufactured in California in 1963 and later used a closed type of positive crankcase ventilation system.

The blowby gases are turned to the engine cylinder through the intake manifold and under appropriate conditions, through the Carburetor air cleaner. The PCV valve described earlier is generally used as the flow control valve. A closed oil filler cap is used. Other possible outlets for blow by gases, such as dipstick tube are sealed.



All cars are now being equipped with such closed PCV system wherever there are air pollution regulations. These systems have completely eliminated the crankcase as a source of atmospheric contamination and no additional control in future is required in this direction.

EVAPORATIVE EMISSIONS AND CONTROL

Hydrocarbon evaporative emissions from a vehicle arise from two sources as evaporation of fuel in the carburetor float bowl (5-10 percent) of fuel in the fuel tank (about 5 percent).

CARBURETOR EVAPORATIVE LOSSES:

Carburetor hydrocarbon vapour losses arise from distillation of fuel from the float bowl. Carburetor fuel temperature often reaches 55°C during warm weather engine operation and may rise up to 80°C during a hot soak. Hot soak is a condition when a running car is stopped and its engine turned off. During the soak a significant fraction of the fuel will boil off and a large portion of the loss finds its way into the atmosphere. There is a considerable rise in fuel system temperature following shut down after a hard run.

The basic factors governing the mass of fuel distilled from Carburetor during a hot soak period are

- maximum fuel bowl temperature
- amount of fuel in the bowl
- amount of after-fill and
- distillation curve of the fuel

Tests have indicated that a less volatile fuel would reduce the evaporative losses considerably. A fuel with 20% distilled at 72 °C would give 22% less losses as compared to a fuel which distilled 25% at 72 °C .

The Carburetor bowl volume has a significant effect on evaporative losses. Increase in the volume of the bowl increases the losses linearly. If an insulated spacer is placed between the Carburetor and the inlet manifold, almost 50% reduction can be observed.

Filling of the Carburetor (after- fill) to the original liquid level is similar to an increase in the bowl volume and the distillation losses would increase by about 15%.

FUEL TANK EVAPORATIVE LOSSES:

Fuel tank losses occur by displacement of vapour during filling of petrol tank, or by vaporization of fuel in the tank, forcing the vapour through a breather vent to the atmosphere. When the temperature is low, the fuel tank breathes in air. When the temperature goes high it breathes out air, loaded with petrol vapours. Fuel tank losses occur because the tank temperature is increased during the vehicle operation which causes an increase in the vapour pressure and thermal expansion of tank vapour.

The mechanism of tank loss is as follows: When a partially filled fuel tank is open to atmosphere, the partial pressure of vapour phase hydrocarbons and vapour pressure of the liquid phase are equal and they are in equilibrium. If the temperature of the liquid is increased, say by engine operation, the vapour pressure of the liquid will increase and it

will vaporize in an attempt to restore equilibrium. As additional liquid vaporize the total pressure of the tank increases and since the tank is open to atmosphere, the vapour will flow out of the tank. This outflow to the vapour will increase if in addition to liquid temperature rise, the vapour temperature is also increased.

The evaporation from the tank is affected by a large number of variables of which the ambient and fuel tank temperature, the mode of vehicle operation, the amount of fuel in the tank and the capacity, design and location of the fuel tank with reference to exhaust system and the flow pattern of the heated air underneath the vehicle.

Less the tank fill, greater is the evaporative loss. The effect of the tank fill and the temperature are shown in the table. This reflects the difference in the tank vapour space. Also when a car is parked in a hot location, the evaporation of gasoline in the tank accelerates and so the evaporation loss is greater.

EFFECT OF FUEL TANK FILL ON EVAPORATIVE LOSS:

Tank fill	Ambient temperature C	Temp. rise during test in °C	Loss during operations %
¼	19	7	5.7
½	16	4	1.2
¾	18	2	0.1
Full	22	3	0.0

The operational modes substantially affect the evaporation loss. When the tank temperature rises, the loss increases. The fuel composition also affects the tank losses. About 75% of the HC losses from the tank are C4 and C5 hydrocarbons.

Design factors that affect the evaporative losses include the peak tank temperature, the area of the liquid vapour surface, and the amount of agitation. It is obvious that nay design change which reduces the peak tank temperature will reduce the tank loss. Such modifications include tank insulation, lower surface to volume ratio of tank, better tank orientation or location for reduced heat pick up from solar radiation or other heat sources such as the exhaust system.

The surface area for evaporation and tank agitation are factor which influence the speed with which equilibrium is achieved. Baffles in the tank can reduce losses by maintaining concentration gradients.

EVAPORATIVE EMISSION CONTROL DEVICES:

Evaporative emission control devices are designed to virtually eliminate the hydrocarbon vapours emitted by the Carburetor and fuel tank during both running and hot soak. During running, fuel tank vapours are inducted and burned in the engine. Carburetor losses are vented to intake system. Vehicles without evaporative controls are estimated to lose 30 g/day of HC from fuel tank filling and breathing. Another 40 g/day is lost by evaporation from the Carburetor (hot soak loss) when the vehicle is parked after being operated. ON this basis, evaporative losses are estimated to be 23% of total HC emissions.

The device as shown in the figure consists of an absorbent chamber, the pressure balance valve and the purge control valve. The absorbent chamber which consists of a charcoal bed or foamed poly- urethane holds the hydrocarbon vapour before they can escape to atmosphere. The Carburetor bowl and the fuel tank are directly connected to the absorbent chamber.

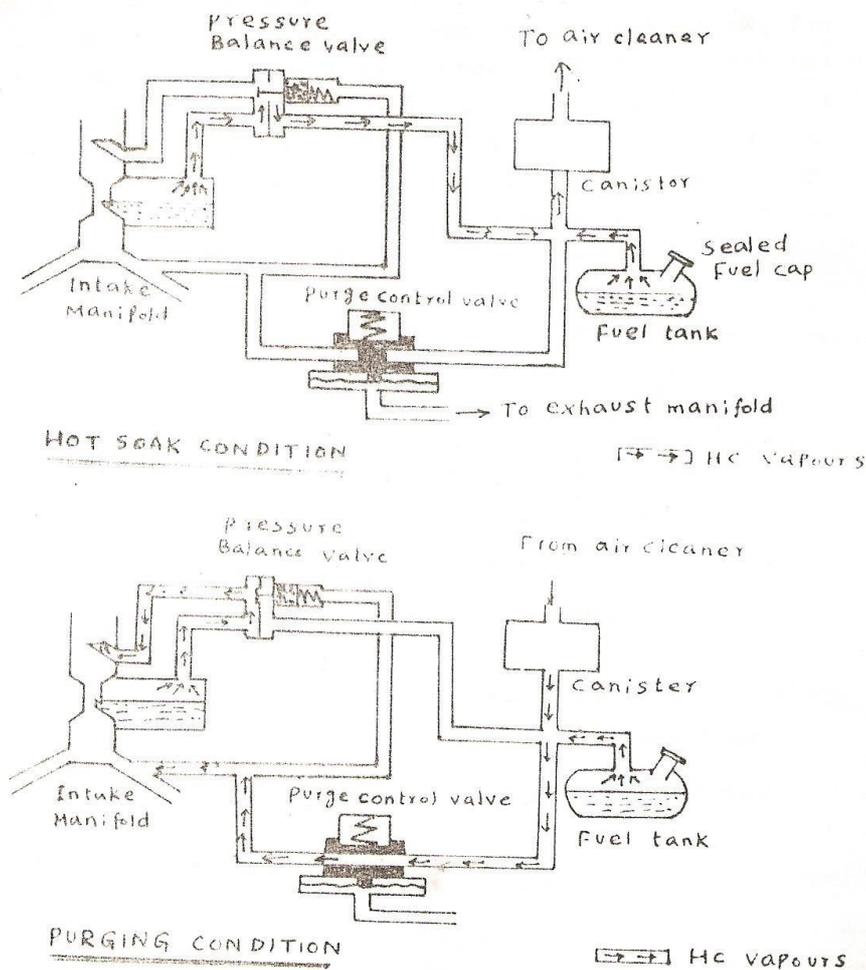


Fig 6.1 FUEL SYSTEM EVAPORATIVE LOSS CONTROL DEVICE

During hot soaks, vapours from the fuel tank are routed to a storage device. Carburetor vapours may be vented to the storage system or retained internally in the Carburetor or induction system volume. A schematic diagram of this arrangement is shown in the figure.

Upon restart, filtered air is drawn through the stored vapours and the mixture is metered into the intake system and burned in the engine. In this manner the storage device is purged (removed off the retained vapour). The operations of the purge control valve are controlled by the exhaust back pressure.

The storage system consists of a canister containing activated charcoal located in the engine compartment. Activated charcoal has an affinity for HC and on a recycle basis can store 30-35 grams of fuel per 100 grams of charcoal without breakthrough. Typically 700-800 grams of charcoal are used in a vehicle system.

One problem with any storage system is the possibility of liquid fuel entering the storage device. Ball check valves or vapour liquid separators assure that only fuel vapours reach the storage device. In addition, a dead volume in the tank allow for thermal expansions of a full fuel tank. About 10% of the tank volume is partially walled off from the remainder of the tank. When the tank is filled, this volume remains nearly empty. After a period of time, the fuel fills the additional volume thereby leaving room for expansion in the rest of the tank. Otherwise expansion could force the liquid fuel into the charcoal canister or the crankcase.

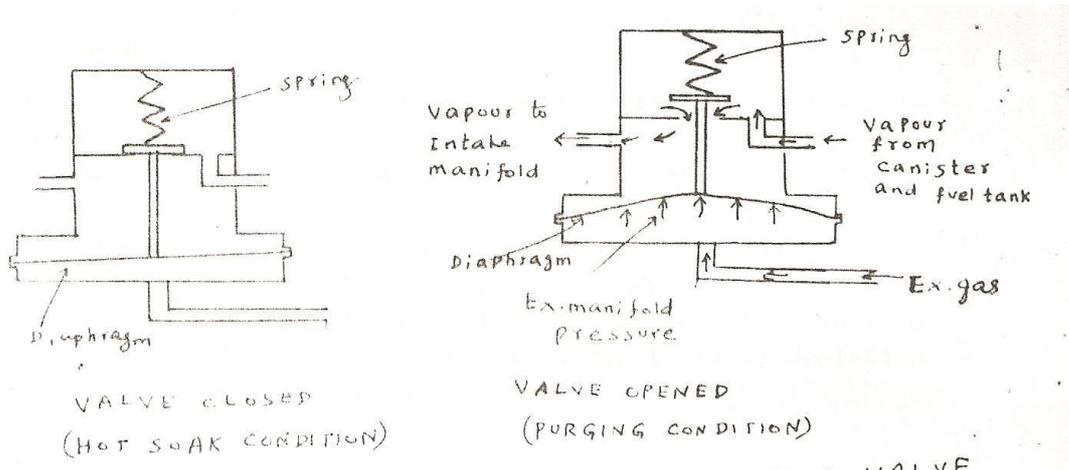


Fig 6.2 OPERATION OF PURGE CONTROL VALVE

THERMAL REACTORS:

Thermal reactor is a chamber in the exhaust system designed to provide sufficient residence time to allow appreciable homogeneous oxidation of HC and CO to occur. In order to improve CO conversion efficiency, the exhaust temperature is increased by retarding spark timing. This however results in fuel economy loss.

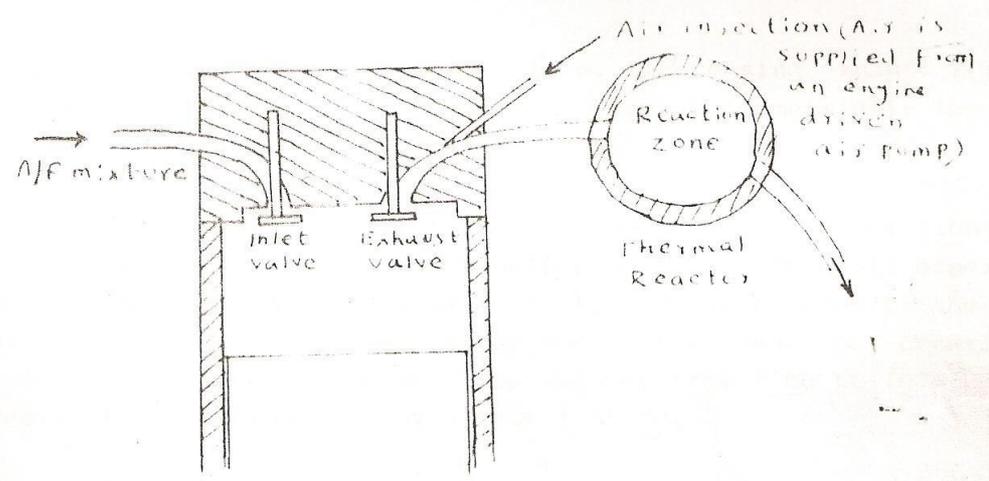


Fig 8.1 THERMAL REACTOR SYSTEM

The air is supplied from an engine driven pump through a tube to a place very near to the exhaust valve. To achieve a high degree of exhaust system oxidation of HC and CO, a high exhaust temperature coupled with sufficient oxygen and residence time to complete the combustion is needed. Oxides of nitrogen are not reduced. In fact, they may be

increased if sufficiently high exhaust temperature results from the combustion of CO and HC with the added air or if the injected air enters the cylinder during the overlap period, thereby leaning the mixture in the cylinder.

Warren has derived the following equation for the concentration of hydrocarbons leaving the exhaust system.

$$C_o = C_i * \exp \frac{K_r O_2 P^2 V}{K_3 T^2 W}$$

Where,

C_o = Concentration of HC leaving the thermal reactor

C_i = Concentration of HC leaving cylinders and entering the thermal reactor

K_r = Specific reaction rate $\text{ft}^3/\text{lbm} - \text{mole}/\text{sec}$

K_3 = constant

O_2 = oxygen concentration in exhaust gases. Volume percent

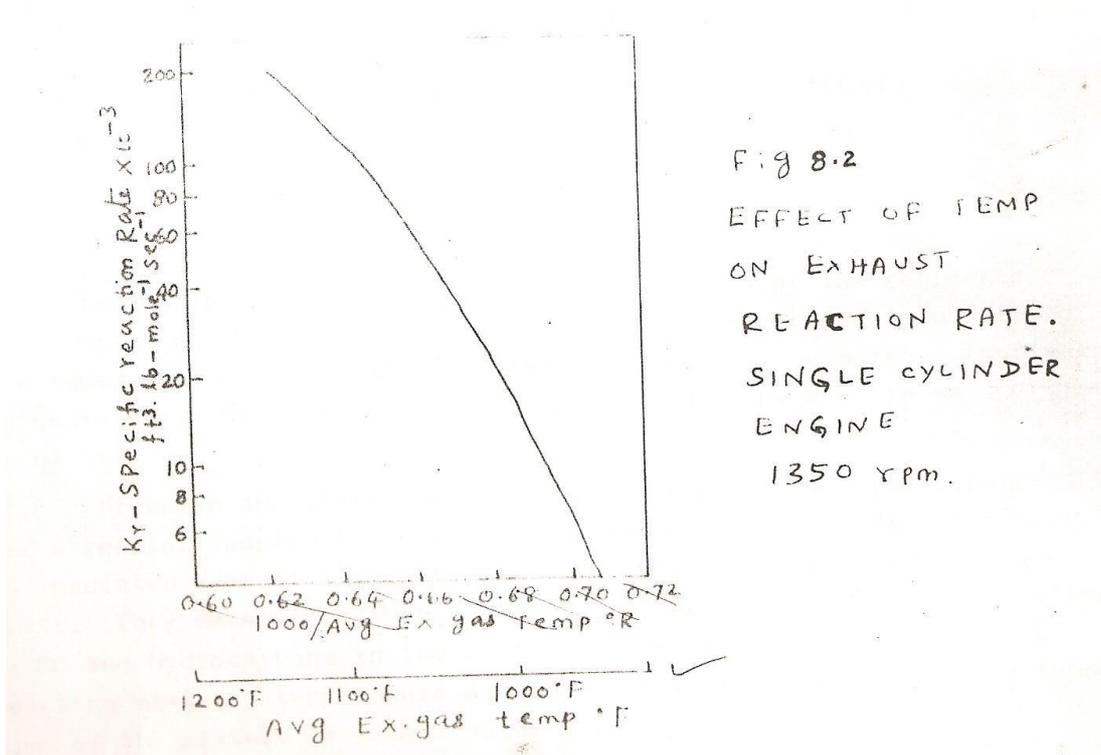
P = exhaust pressure (Psi)

V = thermal reactor volume available for reaction Cu.ft

T = Absolute temperature C

W = Mass flow rate of air (lb/sec)

Note the importance of pressure term. Increasing exhaust system back pressure promote after reaction. However commercially, the possible back pressure increase is small.



The graph shows the effect of temperature on specific reaction rate K_r , calculated from the above equation by Warren from his experimental data. The nearness of his curve to a straight line suggests the equation is a good approximation for the overall reactions occurring. Note that a decrease in exhaust temperatures from 1100°C to 1000°F decrease the reaction rate by a factor of 10.

The graph shows the effect of temperature and reactor volume on exhaust hydrocarbon concentration at an oxygen input concentration of 3%. Reactor volume may be viewed as the volume of the exhaust system which is insulated and at the high temperature needed for reaction.

Note that if the exhaust temperature were 1400°F, only twice the conventional system volume is required for virtually complete elimination of the hydrocarbons. On the other hand, if the temperature were only 1200°F, eight times the volume would achieve only a 76% reduction. A pair of conventional exhaust manifolds has about 0.09 ft³ of volume.

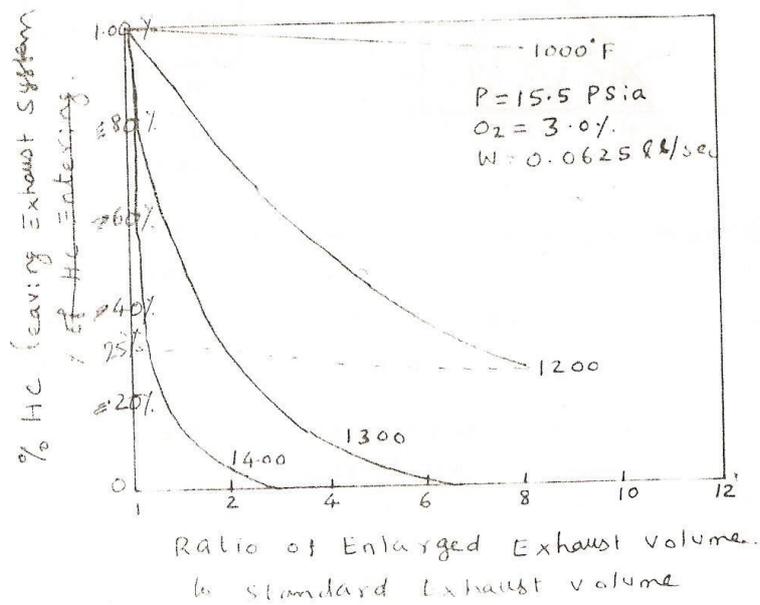


Fig 8.3 CALCULATED EFFECT OF VOLUME AND TEMPERATURE ON EXHAUST REACTION

Increasing the exhaust system volume increases the residence time during which reactions can occur. This is a benefit, providing the added surface area does not result in excessive cooling. Thus when large volume exhaust manifolds are to be used, they must be well insulated.

Brownson and Stebar have studied thermal reactor performance for a reactor coupled to a single cylinder CFR engine. In their work an insulated exhaust mixing tank of 150 cubic inch was used for some tests. They determined that the basic factors governing the combustion of CO and hydrocarbons in the exhaust system are composition of the reacting mixture, temperature and pressure of the mixture, and residence time of the mixture or time available for reaction.

The graph shows the hydrocarbon and CO emissions as a function of air-fuel ratio and injected air flow rate. The emission concentration results were corrected for the added air. Injected air flow rate is indicated as a percentage of the engine air volume flow rate. An insulated 150 cubic inch exhaust mixing tank was used.

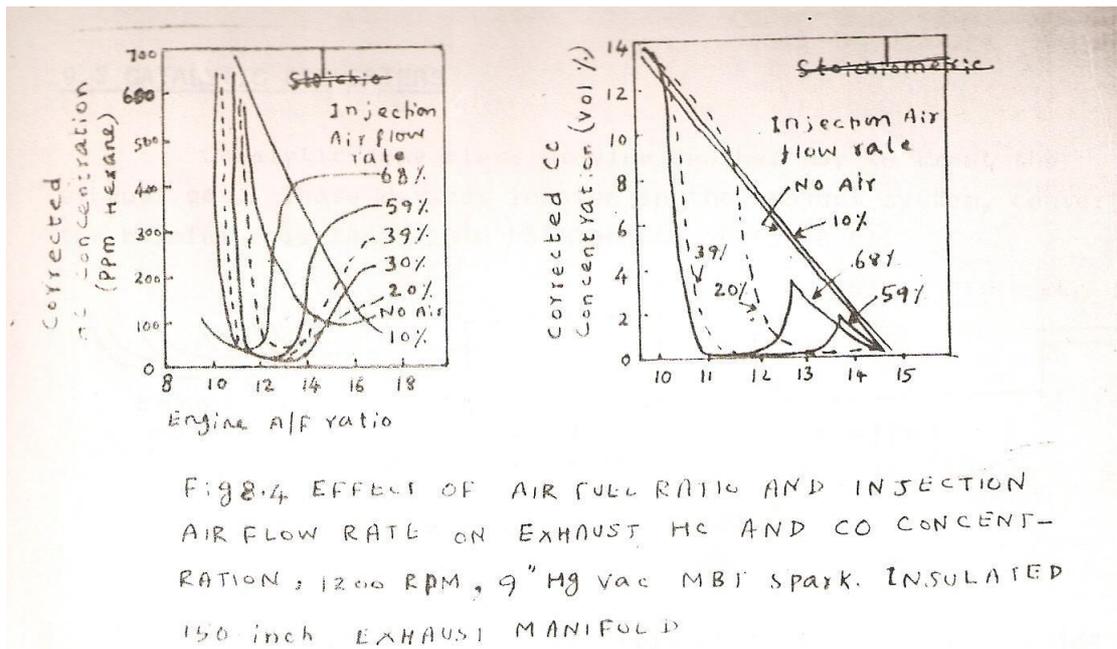
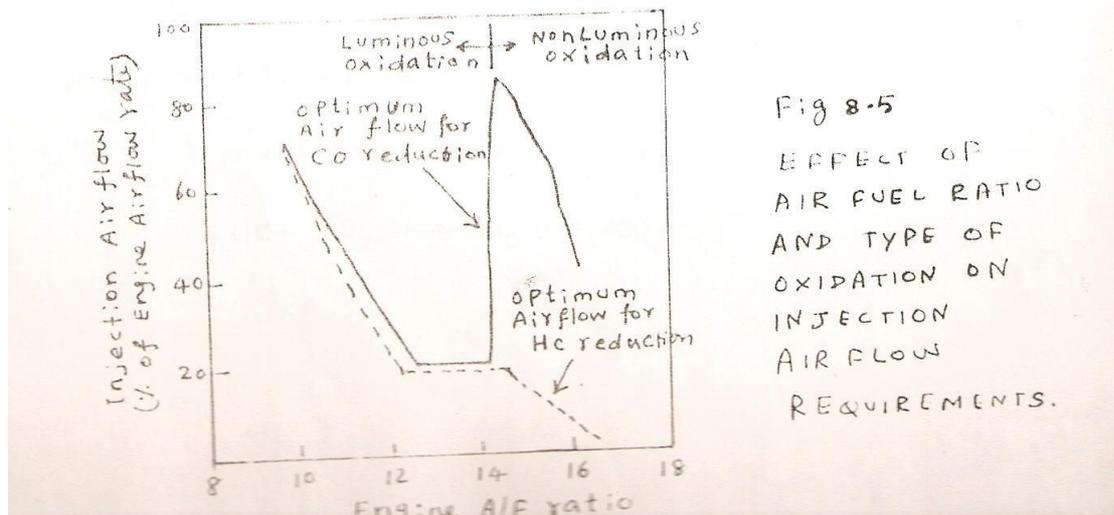


Fig 8.4 EFFECT OF AIR FUEL RATIO AND INJECTION AIR FLOW RATE ON EXHAUST HC AND CO CONCENTRATION: 1200 RPM, 9" Hg Vac MBI Spark. INSULATED 150 inch EXHAUST MANIFOLD

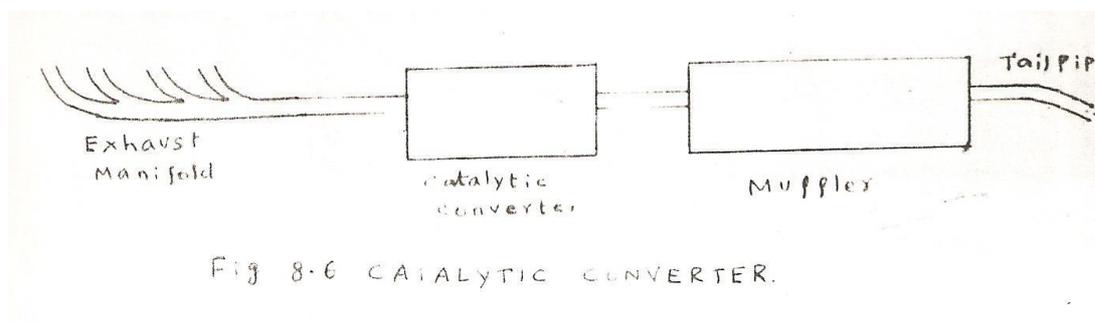
The minimum HC concentrations occurred at rich mixtures. When too much air was injected, especially at lean mixtures, excessive cooling of the exhaust increased HC concentrations above those with no air. Thus the normal oxidation process was apparently inhibited by this cooling. A small increase in CO occurred slightly richer than stoichiometric. At stoichiometric mixtures and leaner, CO was very low. Best results occurred for rich mixtures with air injection at 20-30% of inlet air flow. The air-fuel ratio for best emission reduction was 13.5:1. Normally engine operation at such a rich mixture would reduce fuel economy by 10%.

At each air-fuel ratio there exists one minimum air injection rate that provides maximum emission reduction. Minimum air flow is desired in order to reduce pump power requirement, size and cost. Graph shows the optimum air injection rate for both HC and CO emissions.



CATALYTIC CONVERTERS:

Catalytic converters provide another way to treat the exhaust gas. These devices located in the exhaust system, convert the harmful pollutants into harmless gases.



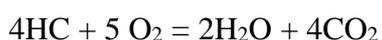
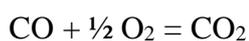
In contrast to thermal reactors efficient catalytic oxidation catalysts can control CO and HC emissions almost completely at temperature equivalent to normal exhaust gas temperatures. Thus the fuel economy loss necessary to increase the exhaust temperature is avoided.

Inside the catalytic converter the exhaust gases pass over a large surface area coated with a catalyst. A catalyst is a material that causes a chemical reaction without actually becoming a part of the reaction process.

Catalytic reaction of NO can be represented as follows:



HC / CO oxidation is represented by



The figure shows a single bed catalytic converter. The exhaust gas and air are passed through a bed of platinum coated pellets or honeycomb core. HC and CO react with the oxygen in the air. Harmless water and carbon dioxide are formed. The catalyst platinum act on the exhaust gas in two ways, converting HC and CO to carbon dioxide and water. So it is called a two way catalyst.

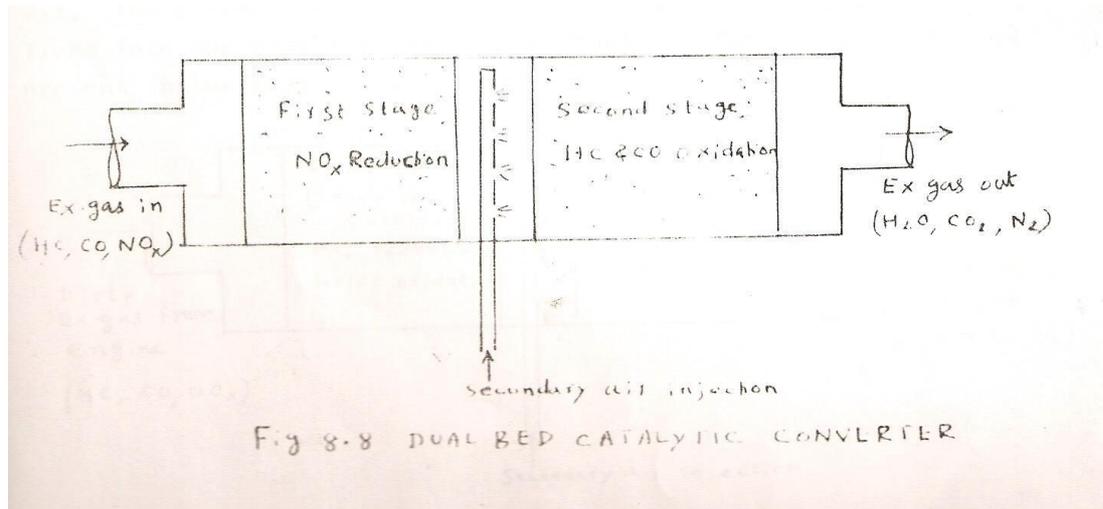


Figure show a dual bed catalytic converter. The exhaust gas first passes through the upper bed. The upper bed contains a reducing catalyst (example rhodium). NOx is reduced to nitrogen and oxygen in the upper bed. Then secondary air is mixed with the exhaust gas. The mixture of exhaust gas and secondary air flows to the lower bed. The lower bed contains an oxidizing catalyst (example platinum). HC and CO are oxidized to water vapour and carbon dioxide in the lower bed. Here the catalyst rhodium is a one way catalyst since it acts o NOx only. Platinum is a two way catalyst since it acts on HC and CO.

A three way catalyst is a mixture of platinum and rhodium. It acts on all three of the regulated pollutants (HC, CO and NOx) but only when the air- fuel ratio is precisely controlled. If the engine is operated with the ideal or stoichiometric air-fuel ratio of 14.7:1. The three way catalyst is very effective. It strips oxygen away from the NOx to form harmless water, carbon dioxide and nitrogen. However the air- fuel ratio must be precisely controlled, otherwise the three way catalyst does not work.

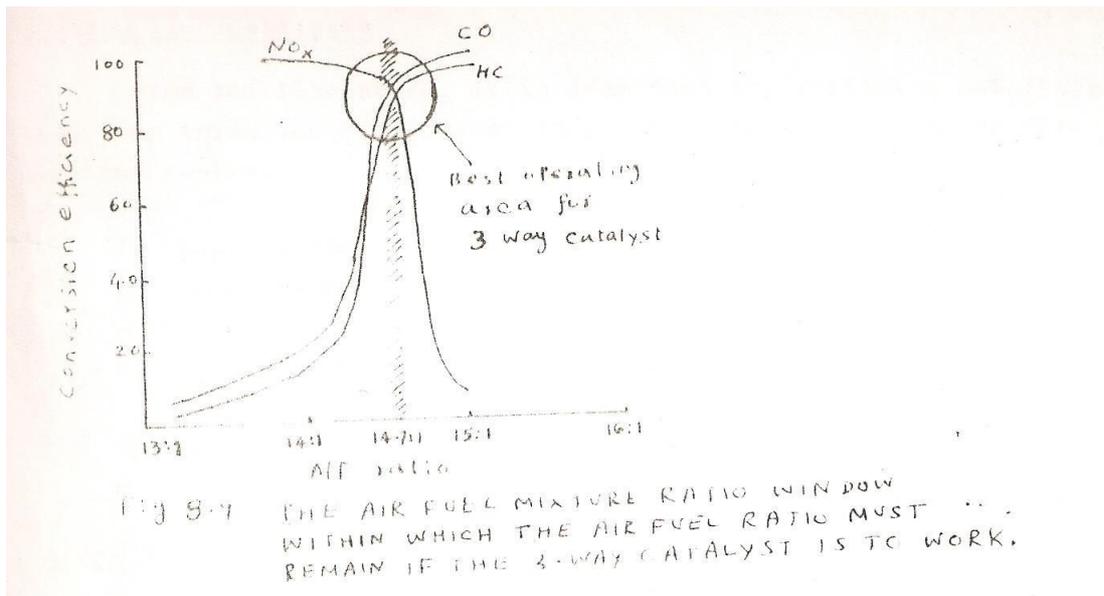
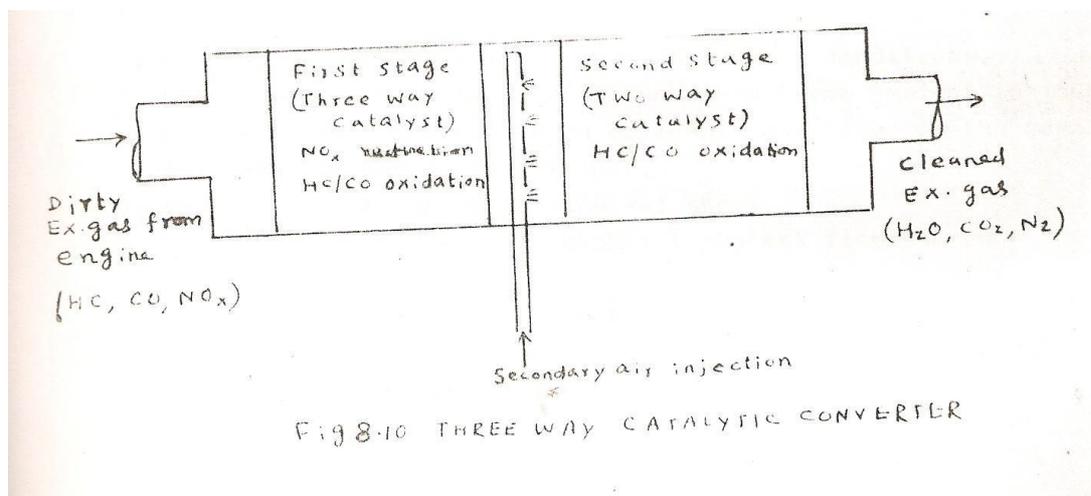


Figure shows a three way catalytic converter. The front section(in the direction of gas flow) handles NO_x and partly handles HC and CO. The partly treated exhaust gas is mixed with secondary air. The mixture of partly treated exhaust gas and secondary air flows into the rear section of the chamber. The two way catalyst present in the rear section takes care of HC and CO.



Generally catalysts are classified as:

1. Supported catalysts based on
 - a. Noble metals
 - b. Transition metals
2. Unsupported metallic alloys

NO-Reduction Catalysts:

From the literature, it is seen that the following materials have been tried successfully as reduction catalysts in the vehicle emission control

1. Copper oxide-chromia
2. Copper oxide – Vanadia
3. Iron oxide – Chromia
4. Nickel oxide pelleted on monolithic ceramic and metallic supports
5. Monel metal
6. Rare earth oxides

HC/CO oxidation catalysts:

1. Noble metal catalysts such as activated carbon, palladium or platinum
2. Transition metal oxide catalysts such as copper, cobalt, nickel and iron chromate as well as vanadium or manganese promoted versions of these metals.
3. Copper chromite-alumina and platinum oxide –alumina catalysts were developed with sufficient activity, stability and mechanical strength.

The catalysts chosen for vehicle emission control should satisfy the following:

1. High conversion efficiency under transient conditions
2. Effective for wide range of temperature (for ambient to 1600 F)
3. Must withstand the poisoning action of additives in the gasoline that are emitted in the exhaust
4. Must be able to withstand thermal shock
5. Be attrition resistant to highly turbulent flows through the converter
6. Vehicle operation for 50,000 miles
7. Convert into harmless products
8. Cheap and readily available.

Converter Design:

Converter volume is fixed, based on the space velocity and exhaust flow rate

Space velocity = gas flow rate in cm^3/hr / converter volume in cm^3

The reciprocal of this expression is the residence time. As the exhaust flow rate varies under different modes of vehicle operation, an average gas flow rate of $0.85\text{m}^3/\text{min}$ and a space velocity of $15000/\text{hr}$ are normally selected for the preliminary design of the converter. This will give a converter volume of $3,540\text{ cm}^3$ in each stage.

Draw backs of the catalytic converter system:

1. Generally catalysts are active only at relatively high temperature. Emissions during warm-up cannot be catalysed and this period has particularly heavy emissions.
2. Catalysts operate over a wide but not unlimited temperature range. A temperature control is required to avoid burnout temperature at high speeds and loads.
3. Catalysts are poisoned by exhaust constituents in particular lead compounds. Hence conversion efficiency decreases with use.
4. The catalytic bed offers considerable back pressure which increases with use.
5. Catalytic converters are expensive.

Importance of unleaded Petrol:

Vehicles equipped with catalytic converters must use only un- leaded gasoline. If the gasoline contains lead, the lead will coat the catalyst and the converter will stop working.

OTHER EMISSION CONTROL DEVICES:

1. Water injection:

In this a small amount of water is injected into the combustion chamber. Due to this the peak combustion temperature is reduced and thus NO_x emission is reduced.

Graph shows nitric oxide reduction as a function of water rate. The spark advance was kept constant and the power loss was balanced by leaning the A/F ratio of the mixture. The specific fuel consumption as clear from the graph, decreases a few percent at medium water injection ratio. So far no attempts have been done to use water as a device for controlling the NO_x, perhaps because of complexity varying the amount of injection rate in relation to engine requirements.

2. Direct air Injection:

In this compressed air is introduced into the combustion chamber in addition to air fuel charge from the Carburetor. This gives better combustion and hence reduced hydrocarbon and CO emission. This will also give tremendous power boost with some saving in fuel. But extra equipment in the form of air compressor and air valves will raise the cost very much. Also, exhaust gas recirculation will still be needed to curb NO_x emissions.

3. Ammonia Injection:

In this ammonia is injected into the exhaust gas. Ammonia reacts with NO_x in exhaust and forms nitrogen and water. Thus NO_x emission is reduced.

As a fuel, ammonia does not hold much promise, but if used as an exhaust additive it can give excellent control for NO_x emission. Ammonia and nitric oxide interact to form nitrogen and water. Ford motor company has been doing investigations with injecting Ammonia-water in the exhaust manifold, downstream from the port.

For an effective utilization of Ammonia injection, the exhaust gas temperature has to be kept within strict limits and the injecting device has to be put sufficiently down to bring the gas temperature to 165°C. This also demands a very close tolerance in air- fuel ratio supplied by the Carburetor. The present Carburetors are incapable of this and it might be necessary to adopt electronic injection system to keep it.

4. Electronic Injection:

It is possible to develop an electronic injection system with sensors for air temperature, manifold pressure and speed which will precisely regulate the fuel supply giving only such air fuel ratio that will give no hydrocarbon or CO emissions.

Since the injection can be affected in individual intake ports, the problem of fuel distribution among various cylinders will automatically be avoided.

The emissions on deceleration can be completely removed by shutting off the fuel supply when the throttle is closed. But this system will still not be able to control the HC emission. Combination of electronic injection and ammonia as an exhaust additive has an attractive future.

V. MEASUREMENT TECHNIQUES EMISSION STANDARDS AND TEST PROCEDURE

VEHICLE EMISSION STANDARDS:

Federal exhaust emission test procedures for light duty vehicles under 6000 lb GVW covering the period 1972 to 1975 assess hydrocarbon, carbon monoxide and nitric oxide emissions in terms of mass of emission emitted over a 7.5 mile chassis dynamometer driving cycle. Results are expressed as grams of pollutant emitted per mile.

There are two procedures in using the same test equipment which assess vehicle emissions. One, which is termed as CVS-1 (constant volume sampling), employs a single bag to collect a representative portion of the exhaust for subsequent analysis. This single bag system applied to testing of 1972, 1973 and 1974 vehicles. Based on this test, emission standards for vehicles have been set at

Hydrocarbons	3.4 g/mile (1972 to 1974)
Carbon monoxide	3.9 g/mile (1972 to 1974)
Oxide of nitrogen	3.0 g/mile (1973 to 1974)

The second test procedure, termed CVS-3 uses three sampling bags and is designed to give a reduced and more realistic weighing to cold start portion of the test. This three bag system applies to testing of 1975 to 1976 vehicles. Exhaust emission standards based on this test are

Hydrocarbons	0.41 g/mile (1975 to 1976)
Carbon monoxide	3.4 g/mile (1975 to 1976)
Oxide of nitrogen	3.0 g/mile (1975)

One of the latest U.S standards (1982) for passenger cars and equivalents are

Hydrocarbons	0.41 g/mile
Carbon monoxide	3.4 g/mile
Oxide of nitrogen	1.5 g/mile

These are measured by following a prescribed test procedure.

Driving Cycle:

The driving cycle for both CVS-1 and CVS-3 cycles is identical. It involves various accelerations, decelerations and cruise modes of operation. The car is started after soaking for 12 hours in a 60-80 F ambient. A trace of the driving cycle is shown in figure. Miles per hour versus time in seconds are plotted on the scale. Top speed is 56.7 mph. Shown for

comparison is the FTP or California test cycle. For many advanced fast warm-up emission control systems, the end of the cold portion on the CVS test is the second idle at 125 seconds. This occurs at 0.68 miles. In the CVS tests, emissions are measured during cranking, start-up and for five seconds after ignition is turned off following the last deceleration. Consequently high emissions from excessive cranking are included. Details of operation for manual transmission vehicles as well as restart procedures and permissible test tolerance are included in the Federal Registers.

CVS-1 system:

The CVS-1 system, sometimes termed variable dilution sampling, is designed to measure the true mass of emissions. The system is shown in figure. A large positive displacement pump draws a constant volume flow of gas through the system. The exhaust of the vehicle is mixed with filtered room air and the mixture is then drawn through the pump. Sufficient air is used to dilute the exhaust in order to avoid vapour condensation, which could dissolve some pollutants and reduce measured values. Excessive dilution on the other hand, results in very low concentration with attendant measurement problems. A pump with capacity of 30-350 cfm provides sufficient dilution for most vehicles.

Before the exhaust-air mixture enters the pump, its temperature is controlled to within $\pm 10^\circ\text{F}$ by the heat exchanger. Thus constant density is maintained in the sampling system and pump. A fraction of the diluted exhaust stream is drawn off by a pump P2 and ejected into an initially evacuated plastic bag. Preferably, the bag should be opaque and manufactured of Teflon or Teldar. A single bag is used for the entire test sample in the CVS-1 system.

Because of high dilution, ambient traces of HC, CO or NO_x can significantly increase concentrations in the sample bag. A charcoal filter is employed for leveling ambient HC measurement. To correct for ambient contamination a bag of dilution air is taken simultaneously with the filling of the exhaust bag.

HC, CO and NO_x measurements are made on a wet basis using FID, NDIR and chemiluminescent detectors respectively. Instruments must be constructed to accurately measure the relatively low concentrations of diluted exhaust.

Bags should be analyzed as quickly as possible preferably within ten minutes after the test because reactions such as those between NO, NO₂ and HC can occur within the bag quite quickly and change the test results.

CVS-3 SYSTEM:

The CVS-3 system is identical to the CVS-1 system except that three exhaust sample bags are used. The normal test is run from a cold start just like the CVS-1 test. After deceleration ends at 505 seconds, the diluted exhaust flow is switched from the transient bag to the stabilized bag and revolution counter number 1 is switched off and number 2 is activated. The transient bag is analyzed immediately. The rest of the test is completed in the normal fashion and the stabilized bag analyzed. However in the CVS-3 test ten minutes after the test ends the cycle is begun and again run until the end of deceleration at 505 seconds. This second run is termed the hot start run. A fresh bag collects what is termed the hot transient sample. It is assumed that the second half of the hot start run is the same as the second half of the cold start run and is not repeated. In all, three exhaust sample bags are filled. An ambient air sample bag is also filled simultaneously.

STANDARDS IN INDIA:

The Bureau of Indian Standards (BIS) is one of the pioneering organizations to initiate work on air pollution control in India. At present only the standards for the emission of carbon monoxide are being suggested by BIS given in IS:9057-1986. These are based on the size of the vehicle and to be measured under idling conditions. The CO emission values are 5.5 percent for 2 or 3 wheeler vehicles with engine displacement of 75cc or less, 4.5 percent for higher sizes and 3.5 percent for four wheeled vehicles.

IS: 8118-1976 Smoke Emission Levels for Diesel vehicles prescribes the smoke limit for diesel engine as 75 Hatridge units or 5.2 Bosch units at full load and 60-70 percent rated speed or 65 Hatridge units under free acceleration conditions.

EMISSION MEASURING INSTRUMENTS:

Terms of expressions:

In emission measurement, volume concentrations of the several components are characteristically expressed in the following terms

1. Carbon dioxide and carbon monoxide are expressed as percent of the sample volume.
2. Nitric oxide and nitrogen dioxide are expressed as volume parts of NO or NO₂ per million parts of the sample (ppm). The total of NO and NO₂ is designated as NO_x.
3. Hydrocarbon is expressed as i. Parts of hydrocarbon per million parts of the sample or ii. Parts of carbon per million parts of the sample (ppmc). The latter term is defined as the volume concentration of hydrocarbon in the sample multiplied by the average number of carbon atoms per molecule of that hydrocarbon. Thus 1ppm propane (C₃H₈) is

the equivalent of 3ppm C hydrocarbon. In the early days of emission measurement hydrocarbon emissions were measured in terms of the carbon equivalent of hexane or ppm hexane. Thus in early usage ppm values were often assumed to be ppm hexane even though not designated as hexane, this usage is ambiguous and should be avoided.

Flame Ionisation Detector (FID):

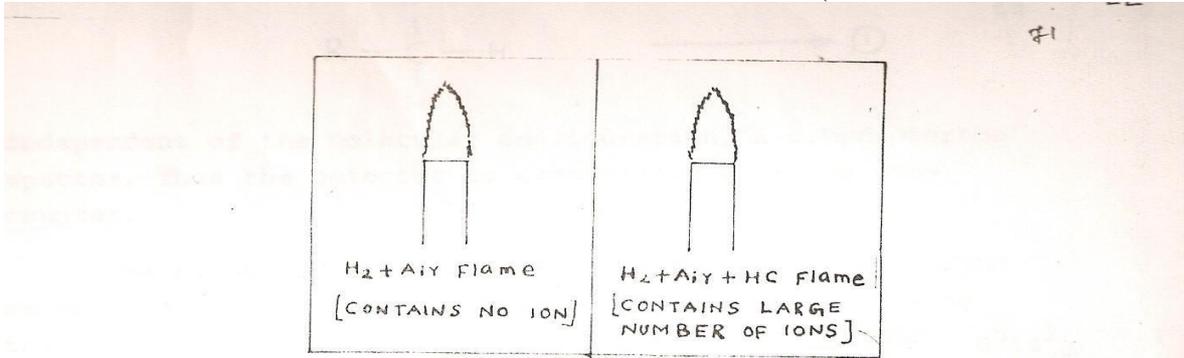


Fig 1. EFFECT OF HYDROCARBON COMPOUNDS IN SAMPLE IN IONISATION OF HYDROGEN-AIR FLAME

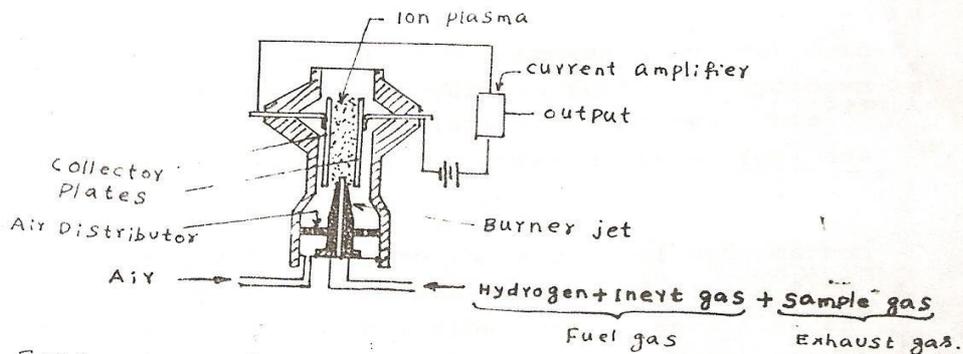


Fig 2. FLAME IONISATION DETECTOR

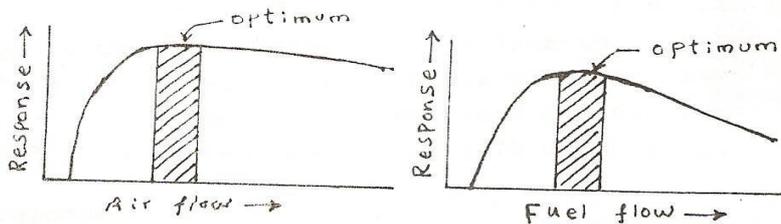


Fig 3. RESPONSE OF FID to air rate and to fuel rate.

The unburned hydrocarbons in the exhaust consist of about 200 different compounds, each with different composition and different number of carbon and hydrogen atoms. It is impossible to detect each of these hydrocarbons separately. The over all concentration of the unburned hydrocarbons may be found by measuring the equivalent concentration of n- hexane (C₆H₁₄). An accurate method of measuring the unburned hydrocarbon emissions is to use the Flame Ionisation Detector (FID).

The working principle of FID is as follows: A hydrogen-air flame contains a negligible amount of ions but if few hydrocarbon molecules are introduced into the flame

a larger number of ions are produced. The ion yield is proportional to the amount of hydrocarbon introduced into the flame.

The basic elements of a Flame Ionisation Detector are as shown in the figure, a burner and ion collector assembly. In practice, a sample of gas is mixed with hydrogen in

the burner assembly and the mixture burned in a diffusion flame. Ions that are produced in the flame move to the negatively polarized collector under the influence of an electrical potential applied between the collector plates. At the negative collector, the ions receive, via a current network, electrons that are collected from the flame zone at the positive collector. Thus a small current proportional to the amount of hydrocarbon entering the flame flows between the collector plates. This small current is amplified using a high impedance direct current amplifier, the output of which becomes an indication of hydrocarbon present.

The detector responds to carbon that is linked with hydrogen as in equation 1 and the response is largely independent of the molecular configuration, i.e hydrocarbon species. Thus the detector is essentially a carbon atom counter.

The output of the FID depends on the number of carbon atoms passing through the flame in a unit time. Doubling the flow velocity would also double the output. Hexane (C_6H_{14}) would give double the output of propane (C_3H_8). Therefore FID output is usually referred to a standard hydrocarbon usually as PPM of normal hexane.

Characteristics of the FID are improved with most burned designs if instead of using pure hydrogen fuel, the hydrogen is mixed with inert gas to decrease flame temperature. This mixture of hydrogen and inert gas is referred to as fuel gas or fuel.

The FID responds directly to the amount of hydrocarbon entering the flame. Therefore close control of sample flow is required. In general, the sample flow rate is specified at the minimum amount that will give the required sensitivity in any given instrument. Fuel and air flow rates also influence the response characteristics of the detector. Response typically first rises and then fall with increased fuel rate, as shown in the figure. Typical volume rates of instrument gases are sample 3-5 ml/min and fuel gas mixture 75ml/min and air 200ml/min.

Presence of CO, CO₂, NO_x, water and nitrogen in the exhaust have no effect on the FID reading.

FID analyzer is rapid, continuous and accurate method of measuring HC in the exhaust gas concentrations as low as 1ppb can be measured.

NON-DISPERSIVE INFRA-RED ANALYSER:

In this NDIR analyses the CO exhaust gas species being measured is used to detect itself. This is done by selective absorption.