Engine Emissions and Their Control: Review

Mr. Shete Yogesh Shreekrushna

Lecturer, Mechanical Engineering Department, SIET (Poly.), Paniv, Maharashtra, India

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Abstract - *Each combustion process is a source of various emissions. During combustion, are formed not only carbon dioxide and water, but still a lot of other products of combustion and incomplete combustion. The emissions exhausted in to the surrounding pollute the atmosphere and causes various problems such as global warming, acid rain, smog, odors, respiratory and other health hazards. Knowledge of the mechanisms and the pathways of formation allow the use of so-called primary methods of reducing emissions and thereby reduce emissions to the atmosphere. In this paper we are going to focus on the basic mechanisms of pollutant formation in continuous-flow combustors internal combustion engines and gas cleaning systems. We are also going to have a glance at various pollutants and their effects on environment as well as on human. The main pollutants contributed by I.C. engines are CO, NO_X unburned hydro-carbons (HC) and other particulate emissions. Other sources such as Electric power stations industrial and domestic fuel consumers also add pollution like NO_X, SO_2 and particulate matters. In addition to this, all fuel burning systems emit CO2 in large quantities and this is more concerned with the Green House Effect which is going to decide the health of earth. Lot of efforts are made to reduce the air pollution from petrol and diesel engines and regulations for emission limits are also imposed in USA and in a few cities of India. An extensive analysis of energy usage and pollution shows that alternative power systems are still a long way behind the conventional ones.*

***Key Words*: Fuel Compositions, Pollutants, Formation of Pollutants, Affect of Pollutants, Parameter, Control, Catalytic Converter, EGR, Emission reduction.**

Abbreviations:

NO_x – Oxides of Nitrogen
CO – Carbon Monoxide
HC – Hydrocarbons
EGR- Exhaust Gas Recirculation
PCV – Positive Crankcase Ventilation

1. INTRODUCTION

Undesirable emissions in internal combustion engines are of major concern because of their negative impact on air quality, human health, and global warming. Therefore, there is a concerted effort by most governments to control them. Undesirable emissions include unburned hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM). "Emissions" is a collective term that is used to describe the undesired gases and particles which are released into the air or emitted by various sources. The U.S. Environmental Protection Agency (EPA) is primarily concerned with emissions that are or can be harmful to the public at large. EPA considers carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM), and sulphur dioxide (SO2) as the pollutants of primary concern, called the Criteria Pollutants. These pollutants originate from the following four types of sources. 1. Point sources, which include facilities such as factories and electric power plants. 2. Mobile sources, which include cars and trucks but also lawn mowers, airplanes, and anything else that moves and releases pollutants into the air. 3. Biogenic sources, which include trees and vegetation, gas seeps, and microbial activity. 4. Area sources, which consist of smaller stationary sources such as dry cleaners and degreasing operations.

1.1 Emission & Pollutants Formation in SI Engine

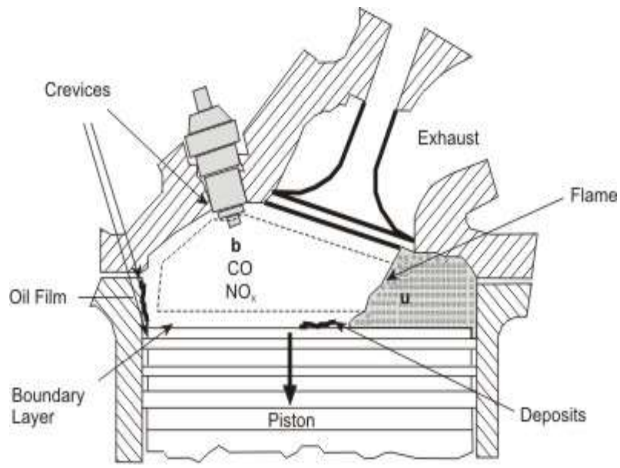

Fig -1: Schematic representation of progress of combustion in SI engine & pollutant formation.

In IC engine, power is generated by converting chemical energy of fuel into the mechanical work. During this conversion process, the fuel gets burnt to achieve heat energy. After burning of fuel, the process of throwing remaining or burnt gasses out of the cylinder is called as Emission. This emission consists various harmful contents in its composition. NOx and CO are formed in the burned gases in the cylinder. Unburned HC emissions originate when fuel escapes combustion due to several processes such as flame quenching in narrow passages present in the combustion chamber and incomplete oxidation of fuel that is trapped or absorbed in oil film or deposits.

Generally engine emissions are classified in to two categories (1) Exhaust Emissions & (2) Non-Exhaust Emissions.

1.1.1 Exhaust Emissions

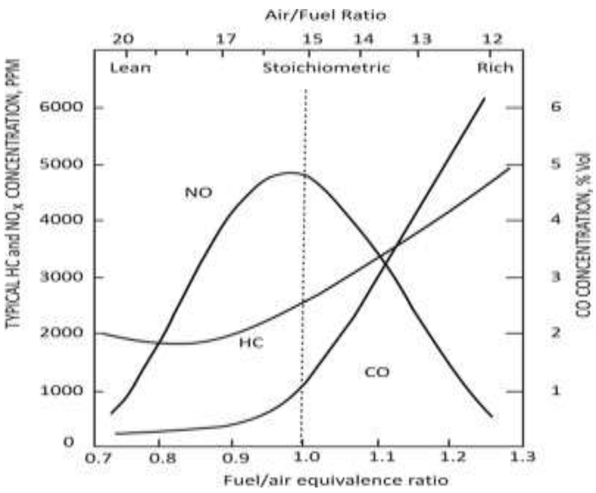

Fig -2: Fuel-Air Equivalence Ratio

Exhaust Emissions have few of the major constituents such as,

1. Unburnt Hydrocarbons (HC)
2. Oxides of Carbon (CO & CO_2)
3. Oxides of Nitrogen (NO & NO_2)
4. Oxides of Sulphur (SO & SO_2)
5. Particulates, Soot & Smoke.

The first four are the common in both SI & CI engines and the last two are mainly from CI engines.

NOx is formed by oxidation of molecular nitrogen. During combustion at high flame temperatures, nitrogen and oxygen molecules in the inducted air breakdown into atomic species which react to form NO. Some NO2 is also formed and NO and NO2 together are called as NOx.

CO results from incomplete oxidation of fuel carbon when insufficient oxygen is available to completely oxidize the fuel. CO rises steeply as the air-fuel (A/F) ratio is decreased below the stoichiometric A/F ratio.

HC originates from the fuel escaping combustion primarily due to flame quenching in crevices and on cold chamber walls, fuel vapor absorption in the oil layer on the cylinder and in combustion chamber deposits, and presence of liquid fuel in the cylinder during cold start. As to be noticed from the figure, Fuel-Air is also one of the most important parameter in exhaust emission. The rich mixture does not have enough Oxygen to react with all the Carbon and hydrogen, and both the HC & CO emissions increases. For Ø<0.8, HC emissions also increases due to poor combustion and misfire. Maximum NO_x emissions occur at slightly lean conditions, where the combustion temperature is high and there is an excess of oxygen to react with the nitrogen.

1.1.2. Modes of Engine Emissions

Table -1: Emissions by SI Engine

Exhaust Emissions	:	Almost all of 100% of NO_x & CO and 60% of HC are emitted through the engine exhaust.
Crankcase Emissions	:	About 20% of HC are emitted via crankcase blow by gases.
Evaporative Emissions	:	Fuel evaporation from the tank, fuel system, carburetor, and permeation through fuel lines.

Table -2: Concentration of emissions by SI Engine

CO	:	0.2 to 5% by Volume
HC	:	300 – 6000 ppmc
NO_X	:	50-2000 ppm

ppmc1= parts per million as methane measured by Flame Ionization Analyzer/Detector (FIA or FID).

CO emissions are high under engine idling and full load operation when engine is operating on fuel rich mixtures. HC emissions are high under idling, during engine warm-up and light load operation, acceleration and deceleration. NOx are maximum under full engine load conditions.

1.2 Emission & Pollutants Formation in CI Engine

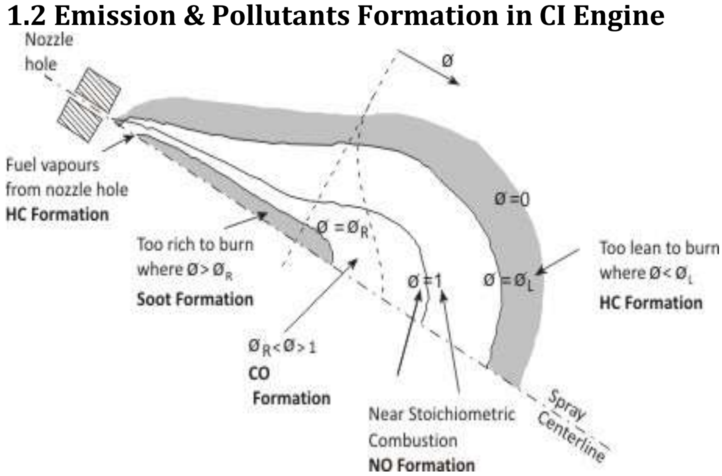

Fig -3: Schematic representation of progress of combustion in CI engine & pollutant formation.

A fully developed diesel spray may be considered to consist of three distinct regions based on the variations in fuel-air equivalence ratio, Ø across the cross section of the spray as seen radially outwards from the centerline of spray.

A fuel rich core where fuel-air equivalence ratio is richer than the rich flammability limits i.e., ($Ø > Ø_R$)

Flammable region in which Ø lies within the rich and lean flammability limits, i.e., ($Ø_R > Ø > Ø_L$)

A Lean Flame-Out Region (LFOR) where Ø is lower than lean flammability limits and extends up to the spray boundary i.e.,($Ø_L$ > Ø > 0)

NO is formed in the high temperature burned gases in the flammable region. Maximum burned gas temperatures result close to stoichiometric air-fuel ratio and these contribute maximum to NO formation.

CO is formed in fuel rich mixtures in the flammable region. Soot forms in fuel-rich spray core where fuel vapors is heated by the hot burned gases. (Ø > $Ø_R$)

Unburned HC and oxygenated hydrocarbons like aldehydes originate in the region where due to excessive dilution with air the mixture is too lean at the spray boundaries. In excessive lean mixtures combustion process either fails to begin or does not reach completion. Towards the end of combustion, fuel in the nozzle sac and orifices gets vaporized, enters the combustion chamber, and contributes to HC emissions.

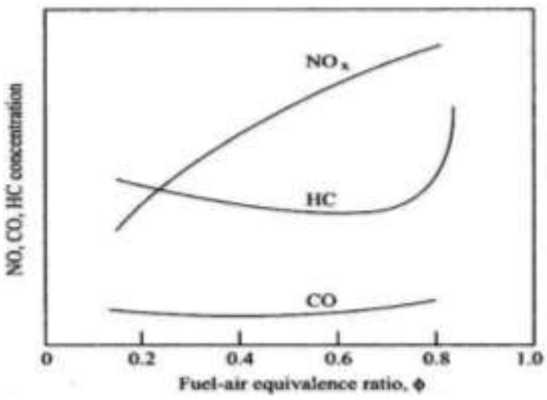

Fig -4: Fuel-Air Equivalence Ratio

Table -3: Emissions by CI Engines

CO	:	0.03 – 0.1 %, v/v
HC	:	20 – 500 ppmc
NO_x	:	100 – 2000 ppm
PM	:	0.02 – 0.2 g/m^3

2. Pollutants

2.1. Hydrocarbon Emissions:

The causes for hydrocarbon emission from SI engine are,

1. Incomplete combustion
2. Crevice volume and flow in crevices
3. Leakage past the exhaust valve
4. Valve overlap
5. Deposits on wall
6. Oil on combustion chamber wall

Older two stroke SI engines and many modern small two stroke engines add HC emissions to the exhaust during scavenging process. The intake air-fuel mixture is used to push exhaust residual out of the open exhaust port called as Scavenging. This can be the major source of HC in the exhaust & is one of the major reasons why there have been no modern two-stroke cycle automobile engines. On the other hand, CI engine operate with an overall fuel-lean equivalence ratio, CI engine have only one fifth the HC emission of SI engine. In general, a CI engine has a combustion efficiency of about 98%. This means that only 2% of the HC fuel being emitted. Some of the total fuel does not evaporate until combustion has stopped. This will increases HC emissions. CI engine also have HC emissions for some of the same reason as SI engine do.

2.2 Carbon Monoxide (CO) Emissions:

Carbon monoxide is a colorless & odorless but a poisonous gas. When there is no enough oxygen to convert all carbon to CO_2, some fuel does not get burned and some carbon ends up as CO.

$$CO + \frac{1}{2}O_2 \rightarrow CO_2 + Heat$$

Typically the exhaust of SI engine will be about 0.2 to 5% of CO. Not only Co considered as an undesirable emission, but it also represent lost of chemical energy. Maximum CO is generated when an engine is runs rich. Rich mixture is required for starting or when accelerating under the load. Poor mixing, local rich regions, and incomplete combustion will also be the source of CO emissions.

2.3 Oxides of Nitrogen (NO_X)

Exhaust gases of an engine can have up to 2000 ppm of oxides of Nitrogen. Most of this will be Nitrogen Oxide (NO) with a small amount of Nitrogen Dioxide (NO_2). NO_X is created mostly from nitrogen in air. Nitrogen can also be found in blends of fuel. All the restrictions are probably occurring during the combustion process and immediately after. These include but are not limited to:

$$O + N_2 \rightarrow NO + N$$
$$N + O_2 \rightarrow NO + O$$
$$N + OH \rightarrow NO + H$$

NO, in turn, can further react to form NO_2 by various means including,

$$NO + H_2O \rightarrow NO_2 + H_2$$
$$NO + O_2 \rightarrow NO_2 + O$$

At low temperatures, atmospheric nitrogen exists as a stable diatomic molecule. Therefore, only very small trace amount of oxides of nitrogen are found. Significant amount of N is generated in the temperature range of 2500-3000K that can exist in an engine. The higher the combustion reaction temperature, the more diatomic nitrogen N_2 will dissociate to monatomic nitrogen N, and more NO_X will be formed. Although maximum flame temperature will occur at a stoichiometric air-fuel ratio. The maximum NO_x is formed at a slightly lean equivalence ratio of about 0.95. The formation of NO_X is also depends on pressure and air-fuel ratio. Combustion duration plays a significant role in NO_X formation within the cylinder.

Photochemical smog is formed by the photo-chemical reaction of automobile exhaust and atmospheric air in the presence of sunlight. NO_2 decomposes into NO and monatomic oxygen:

$$NO_2 + Enenrgy\ from\ Sunlight\ \rightarrow NO + O + Smog$$

Monatomic oxygen is highly reactive and initiates a number of different reactions, one of which is formation of ozone:

$$O + O_2 \rightarrow O_3$$

Ground level Ozone is harmful to lungs and other biological tissue. It is harmful to plants and trees and cause very heavy crop losses each year. Damage is also caused through reaction with rubber, plastics, and other materials. Ozone also results from atmospheric reactions with other engine emissions such as HC, aldehydes and other oxides of nitrogen.

2.4 PARTICULATES

The exhaust of CI engines contains solid carbon soot particles that are generated in the fuel-rich zones within the cylinder during combustion. These are sees as exhaust smoke & cause undesirable odor pollution. Maximum density of particulate emissions occurs when the engine is under load at WOT. At this condition maximum fuel is injected to supply maximum power, resulting in a rich mixture & poor fuel economy. This can be seen in the heavy exhaust smoke emitted when a truck or railroad locomotive accelerates up a hill or from a stop.

Particulates generation can be reduced by engine design & control of operating conditions, but quite often this will create other adverse results. However a longer combustion time means a high cylinder temperature and more NO_X generation. Dilution with EGR lowers NO_X emissions but increases particulates and HC emissions.

2.5 OTHER EMISSIONS

Apart of the major emission like mentioned above, there is other emission that came out of the exhaust. These emission are listed below

1. Aldehydes
2. Sulphur
3. Lead
4. Phosphorus.

3. EMISSION CONTROL METHODS

It is to be noted that combustion process in the four stroke cycle occurs only for about 25 to 50 ms depending upon the operating conditions. After the combustion ends, the constituents in the cylinder gas mixture that have been partially burned continue to react during the expansion stroke, during exhaust blow down and in to the exhaust process.

3.1 Catalytic Converters

The most effective after treatment for reducing engine emissions is the catalytic converter found on most automobiles and other modern engines of medium or large size. Catalytic converters are chambers mounted in the flow system through which the exhaust gases pass through. These chambers contain catalytic material which promotes the oxidation of the emission contained in the exhaust flow. Co and HC can be oxidized to Co_2 & H_2O in exhaust systems and thermal converters if the temperature is held at 600-700^{0}C. If the certain catalysts are present, the temperature needed to sustain theses oxidation processes is reduced to 250-300^{0}C, making for much more attractive system. Aluminum oxide is the base ceramic material used for catalytic converter. The catalyst materials most used are platinum, palladium, and rhodium. Palladium and platinum

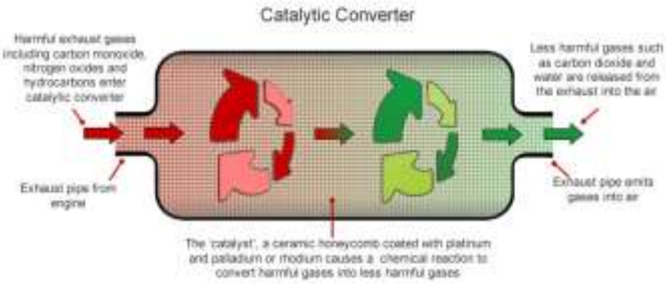

Fig -5: Catalytic Converter

Palladium and platinum promotes the oxidation of Co & HC. Rhodium promotes the reaction NO_X in one or more of the following reactions:

$$NO + CO \rightarrow \frac{1}{2}N_2 + CO_2$$

$$2NO + 5CO + 3H_2O \rightarrow 2NH_3 + 5CO_2$$

$$2NO + CO \rightarrow N_2O + CO_2$$

$$NO + H_2 \rightarrow \frac{1}{2}N_2 + H_2O$$

$$2NO + 5H_2 \rightarrow 2NH_3 + 2H_2O$$

$$CO + H_2 \rightarrow CO_2 + H_2$$

Also often used is cerium oxide, which promotes the so called water gas drift. This reduces CO by using water vapor as an oxidant instead of O_2, which is very important when the engine is running rich. The efficiency of a catalytic converter is very much dependent on temperature. When converter in good working order is operating at a fully warmed temperature of 400^0C or above, it will remove 98-99% of CO, 95% NO_X, more than 95% of HC from exhaust flow emissions.

It is important that a catalytic converter be operated hot to be efficient, but not hotter. Engine malfunctions can cause poor efficiency and overheating of converters. A turbocharger lowers the exhaust temperature by removing energy, and this can make a catalytic converter less efficient. Sulphur offers unique problem for catalytic converter. Some catalysts promote the conversion of SO_2 to SO_3, which eventually gets converted to sulphuric acid. Catalytic converters are not efficient when they are very cold. When an engine is started after not being operated for several hours, it takes several minutes for the converter to reach an efficient operating temperature. The temperature at which a converter becomes 50% efficient is defined as the light-off temperature, and is in the range of $250\text{-}300^0C$. A large percentage of automobile travel is for short distance where the catalytic converter never reaches efficient operating temperature and therefore emission is high. Unfortunately, most short trips occur in cities where high emissions are more harmful. Further, all engines use a rich mixture when starting. Otherwise cold start ups pose a major problem. It is estimated that cold start-ups are the source of 70-90% of all HC emissions.

3.2 Reducing Emissions by Chemical Methods

Development work has been done on large stationery engines using cyanuric acid to reduce NO_X emissions. Cyanuric acid is a low-cost solid material that sublimes in the exhaust flow. The gas dissociates, producing isocyanides that reacts with NO_X to form N_2, H_2O & CO_2. Operating temperature is about 500^0C. Up to 95% NO_X reduction can be achieved with the no loss of engine performance. At present this system is not practical for automobile engines because of its size, weight and its complexity. H_2S emissions occur under rich operating conditions. Chemical systems are being developed that trap & store H_2S when an engine operates rich & then convert this to SO_2 when operation is lean and excess oxygen exists.

$$H_2S + O_2 \rightarrow SO_2 + O_2$$

3.3 Ammonia Injection System

Some large marine engines & stationery engines reduce NO_X emissions with an injection system that sprays NH_3 into the exhaust flow. In the presence of a catalyst, the following reaction will occurs,

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

$$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O$$

Ammonia injection systems are not practical in automobiles or on other small engines.

3.4 Exhaust Gas Recirculation

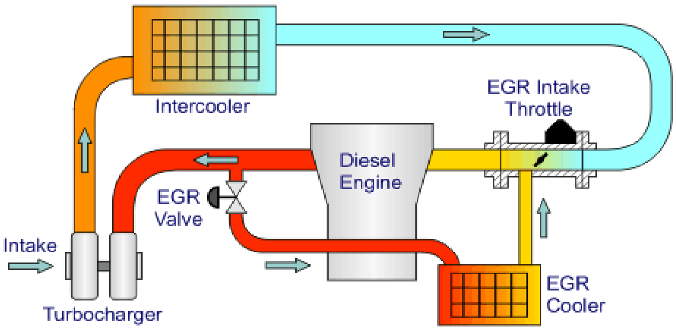

Fig – 6: Components of EGR

The most effective way to reducing NO_X emissions is to hold combustion chamber temperature down. Although practical, this is a very unfortunate method in that it also reduces the thermal efficiency of the engine. EGR is done by ducting some of the exhaust flow back in to the intake system, usually immediately after the throttle. The amount of flow can be as high as 30% of the total intake. EGR combines with the exhaust residual left in the cylinder from the previous cycle to effectively reduce the maximum combustion temperature. The flow rate of EGR is controlled by the engine management system. EGR is defined as a mass percent of the total intake flow,

$$EGR = \frac{\dot{m}EGR}{\dot{m}_{cyl}} \times 100$$

Where cyl = total mass flow into the cylinder.

Not only does EGR reduce the maximum temperature in the combustion chamber, but it also lowers the overall combustion efficiency. Increase in EGR results in some cycle partial burns & in the extreme, total misfires. Thus, by using EGR to reduce NO_X emissions, a costly price of increased HC emissions & lower thermal efficiency must be paid.

3.5 Non Exhaust Emissions

Apart from exhaust emissions there are three other sources in an automobile which emit emissions. They are,

- Fuel Tank
- Carburetor
- Crankcase

The fourth source is tail pipe exhaust emissions. The evaporative losses are the direct losses of raw gasoline from the engine fuel system; the blowby gases are the vapors & gases leaking into the crankcase from the combustion chamber & the pollutants from the exhaust pipe are due to incomplete combustion.

3.6 Evaporative Loss Control Device (ELCD)

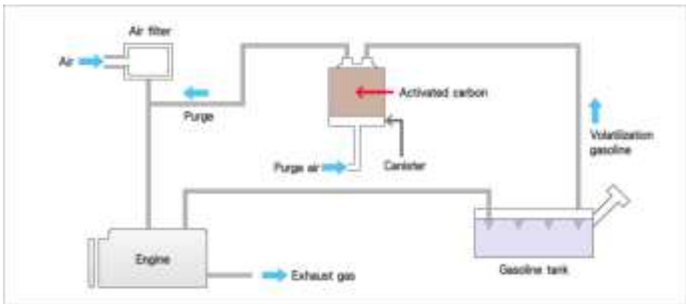

Fig – 7: ELCD

This device aims at controlling all evaporative emissions by capturing the vapors & recalculating them at appropriate time. The device consists of absorbent chamber, the pressure balance valve, and the purge control valve. The absorbent chamber which consists of charcoal bed or foamed polyurethane holds the hydrocarbon vapor before they can escape to atmosphere. The carburetor bowl & the fuel tank, main source of HC emissions, are directly connected to the absorbent chamber when engine is turned off. As already mentioned, hot soak is the condition when a warmed up car is stopped & its engine turned off. This result in some boiling in the carburetor bowl & significant amount of HC loss occurs. The ELCD completely controls all types of evaporative losses. However, the tolerance of the carburetor for supplying fuel-air ratio reduces to about 3% only. This requires very accurate metering control.

In modern evaporative control system, the fuel tank is fitted to the vapor-liquid separator which is in the form of chamber on fuel tank. Vapor from the fuel tank goes to the top of the separator where the liquid gasoline is separated & sent back to the fuel tank through the fuel return pipe. A vent valve is provided for the carburetor for the flow of fuel vapor. This vent is connected by a tube to canister. The canister absorbs the fuel vapors & stores them. HC are left in the canister due to the process of adsorption, & air leaves from the canister in the atmosphere. The fresh air purges the gasoline vapors from the canister. Purging is the process by which the gasoline vapors are removed from the charcoal particles inside the canister. The air carries HC through the purge control solenoid valve to the engine induction system. The purge controlled solenoid valve is controlled by Electronic Control Module of the Computer Command Control system in modern automobiles.

3.7 Blowby Control

The blowby is the phenomenon of leakage past the piston rings from the cylinder to the crankcase. The blowby HC emission are about 20% of the total HC emissions from the engine. This is increased up to 35% when rings are worn.

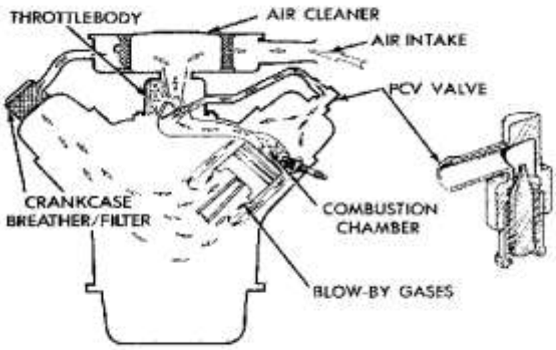

Fig- 8: Positive Crankcase Ventilation (Open System)

The blowby is the phenomenon of leakage past the piston rings from the cylinder to the crankcase. The blowby HC emission are about 20% of the total HC emissions from the engine. This is increased up to 35% when rings are worn. The basic principle of all types of blowby control is recirculation of the vapor back to the intake air cleaner. There are large number of systems are used such as positive crankcase ventilation.

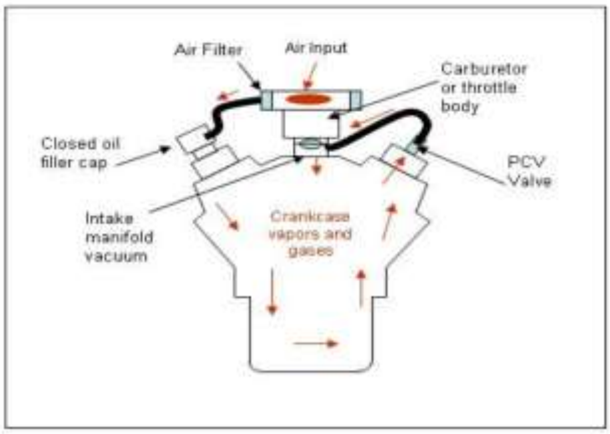

Fig- 9: Positive Crankcase Ventilation (Closed System)

Open type of PCV has leading from crankcase cover through a flow control valve & into the intake manifold, usually, through an opening just below the carburetor. To provide proper ventilation of the interior of the engine, fresh air is usually drawn in through a rocker arm cover opposite that containing the PCV system. In closed PCV system if the PCV valve is plugged the blowby is rerouted through the tube to the air cleaner & subsequently into the air horn of the carburetor. There is no possible escape of blowby into the atmosphere, even with 100% PCV valve plugging. Again, with the PCV valve plugged, fresh air ventilation cannot take place. The closed system, however, requires the engine to digest all blowby developed regardless of the mechanical condition of the PCV system. The design of the valve is such that at high speed & power, that is, at low manifold vacuum the valve opens and allows a free flow of blowby gases to the intake system. This is consistent with high quantity of blowby gas which has to be transferred to carburetor at high speed. In the closed ventilation system a provision is made for the blowby gases to escape to atmosphere in case of the metering valve failure.

4. CONCLUSION

This paper provides information about the formation of pollutants and their effect on other aspects. Generally the emissions which are most poisonous a hazardous for human health are required to reduce. The various methods are developed for the same purpose. Higher percentage of Oxides of Nitrogen is most common type of pollutant occurs in large scale. Then an oxide of carbon and unburnt hydrocarbons takes place. The various devices such as Particulate trap, catalytic converters, thermal converters, EGR, and evaporative emission control systems are used to overcome these issues. Also we had a glance at modern emission reduction techniques such as charcoal canister. Few of the devices used for emission reductions are affects the overall efficiency of the engine and also affects the performance characteristics. Sometimes device used for reduce one emission may rise in another emission.

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BIOGRAPHIES

Mr. Shete Yogesh Shreekrushna
"Lecturer, Mechanical Engineering Department, SIET (Poly.), Paniv, Maharashtra."