1. INTRODUCTION

1.1 Project Background

The ever rising cost of fossil fuels has brought the attention of the world back to the fact that the stock of fossil fuels diminishing throughout the world and demand for energy based comforts and mobility is increasing and making mankind even more dependent on it. Therefore it becomes imperative to search for alternative fuels to cater to our needs and to optimally utilize the existing sources of energy. Moreover Environmental issues regarding emissions from conventional fuels such as gasoline and diesel are of serious concern. The emissions from conventional fuel driven vehicles are in the form of hydrocarbons (HC), carbon dioxide (CO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and particulate matter (PM) and other harmful gases which not only have an adverse impact on the human body but also destroy the environment by causing the greenhouse effect, acid rain and global warming.

The transportation sector accounts for a large part of conventional fuel consumption in the world in the form of diesel and gasoline as well as significantly contributes to environmental pollution. Therefore there is an increased focus on finding alternatives for the conventional fuels used for automobile engine propulsion. Many alternative fuels such as natural gas, liquefied petroleum gas (LPG), ethanol blends, hydrogen etc. are being considered to replace conventional fuels in order to reduce the harmful emissions from being released to the atmosphere. These alternative fuels, many of which have been deployed to some or the other extent, have a potential of substantially reducing environmental pollution and helping reduce the usage of conventional fuels.

But developing technology for automobile engines that facilitates usage of alternative fuels is fraught with numerous constraints. The technology that will fulfill all legislative requirements and will be economically viable will emerge as the optimal solution and that may be an engine running on a conventional or on an alternative fuel or on both. In general the alternatives to conventional fuels will need to fulfill numerous criteria such as – Technical Feasibility and Acceptance, Economical Viability, Vehicle Safety Criterion, Compliance of Pollution Norms and Standards etc.; if they are going to be used widely for transportation.

Based on these criteria, several alternate fuels have been considered from time to time as viable and economical substitutes for conventional fuels such as gasoline and diesel. Lately they have gained importance as clean fuels. Amongst these - Natural gas (CNG/LNG), propane (LPG), DME, Ethanol, bio-diesel, hydrogen, methanol etc have been employed to some extent by various cities to reduce pollution levels.

In the Indian context CNG and LPG are two such fuels which have been used as alternatives to conventional fuels in some Major Cities. These fuels have not only helped in reducing air pollution levels in these cities but also have reduced their dependence on conventional fuels. These fuels have emerged as a cost effective alternatives to both gasoline and diesel. The constraining factors in India remain building the requisite infrastructure for large scale implementation of these fuels and Safety Aspects which are of utmost importance while handling these fuels. In this project, the performance and emission characteristics of a multi cylinder automotive gasoline driven engine is compared vis-à-vis the same engine driven by CNG and LPG.

2. LITERATURE REVIEW

SPARK IGNITION ENGINES: AN OVERVIEW

The Spark Ignition Engine is an Internal Combustion Engine that converts chemical energy into useful mechanical energy by burning fuel. Chemical energy is released when the fuel mixture is ignited by the spark in the combustion chamber. The gas produced in this reaction rapidly expands forcing the piston down the cylinder on the power. Combustion in four stroke spark ignition engines is a complex cyclic process consisting of air intake, fuel injection, compression, spark ignition, combustion, expansion, and finally gas exhaust phases where burnt fuel power is transmitted through the piston to the crankshaft.

The basic components for a combustion cycle in a four stroke engine are combustion chamber (cylinder), piston, intake port and outlet or exhaust port. The pistons reciprocate inside the cylinder, exhaust and intake ports open and close during various stages of the cycle. The movement of the piston up or down the cylinder makes up one stroke of the four stroke cycle (Otto cycle). The linear motion is then converted to rotary motion by the crankshaft. The crankshaft is shaped to balance the pistons which are fired in a particular order to reduce the vibration (typically for a 4-cylinder engine, 1-2-4-3 or 1-3-4-2). The flywheel then helps smoothen out the linear movement of the pistons.

Fig.1 on the next page depicts the basic constructional details of S I Engine.

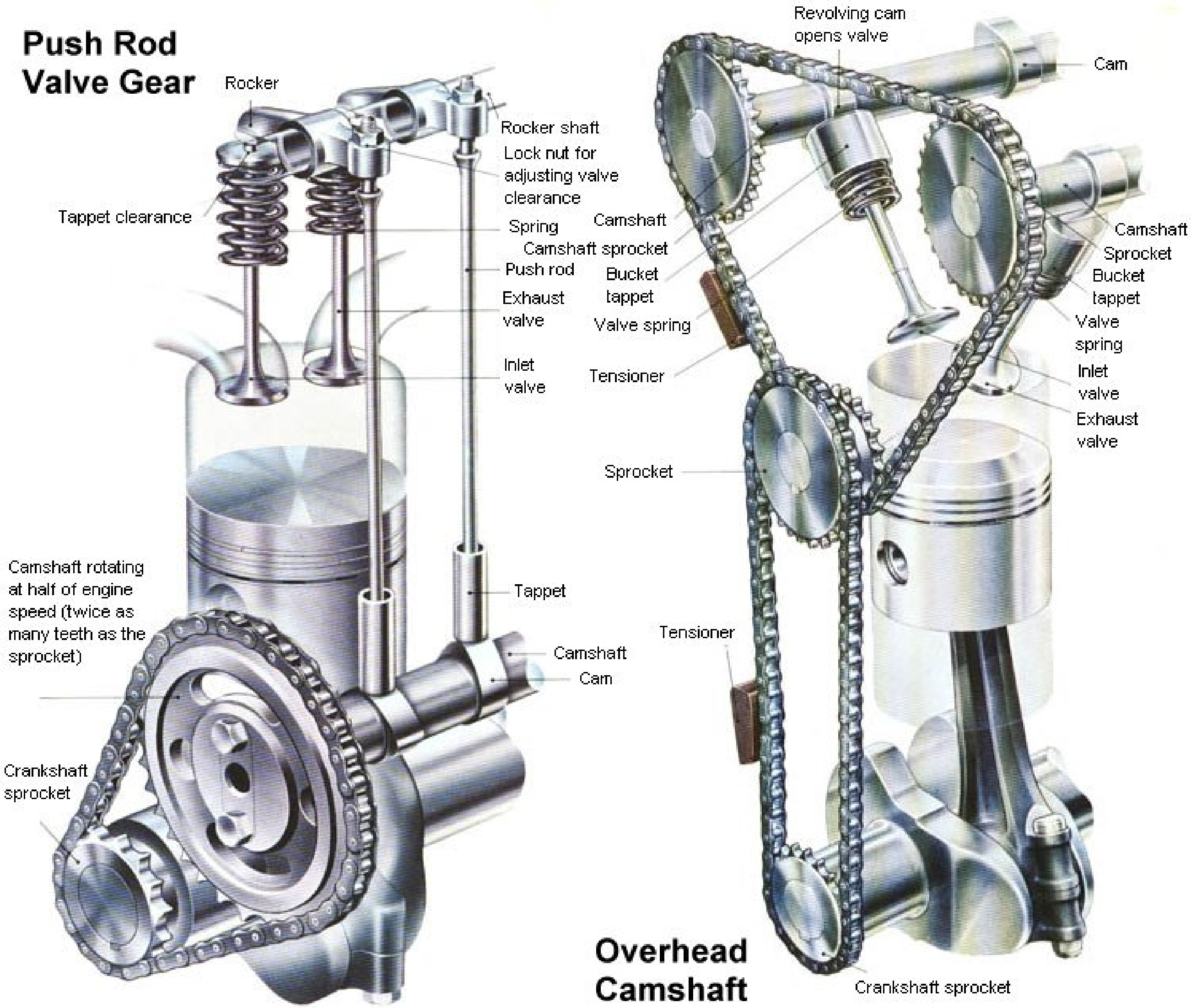

FIG1. CONSTRUCTIONAL DETAILS OF AN S SI ENGINE (1)

2.1 THE OTTO CYCLE

An SI Engine primarily works on the OTTO Cycle. Each movement of the cylinder up or down the cylinder is one stroke of the four stroke combustion cycle or Otto cycle. Most modern internal combustion engines use the four stroke cycle. Named after Nikolaus Otto (1832-1891), the Otto cycle used as an ideal approximation for the spark-ignition engine. The Otto cycle is a set of processes used by spark ignition internal combustion engines (2-stroke or 4-stroke cycles). These engines a) ingest a mixture of fuel and air, b) compress it, c) cause it to react, thus effectively adding heat through converting chemical energy into thermal energy, d) expand the combustion products, and then e) eject the combustion products and replace them with a new charge of fuel and air. The different processes are shown in the figure.

1. Intake stroke, gasoline vapor and air drawn into engine ($5 \rightarrow 1$).
2. Compression stroke, **P, T** increase ($1 \rightarrow 2$).
3. Combustion (spark), short time, essentially constant volume ($2 \rightarrow 3$). Model: heat absorbed from a series of reservoirs at temperatures $\mathbf{T_2}$ to $\mathbf{T_3}$
4. Power stroke: expansion ($3 \rightarrow 4$).
5. Valve exhaust: valve opens, gas escapes.
6. ($4 \rightarrow 1$) Model: rejection of heat to series of reservoirs at temperatures $\mathbf{T_4}$ to $\mathbf{T_1}$.
7. Exhaust stroke, piston pushes remaining combustion products out of chamber ($1 \rightarrow 5$).

We model the processes as all acting on a fixed mass of air contained in a piston-cylinder arrangement, as shown in Figure.

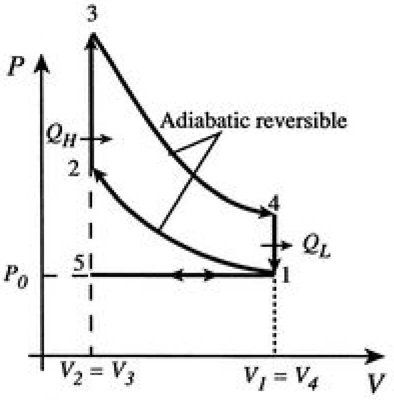

Figure 2: The ideal Otto cycle

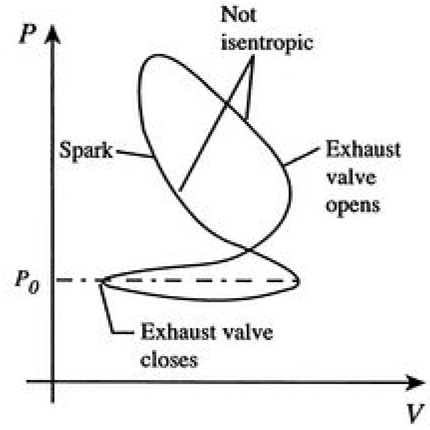

Figure 3: Actual Otto cycle

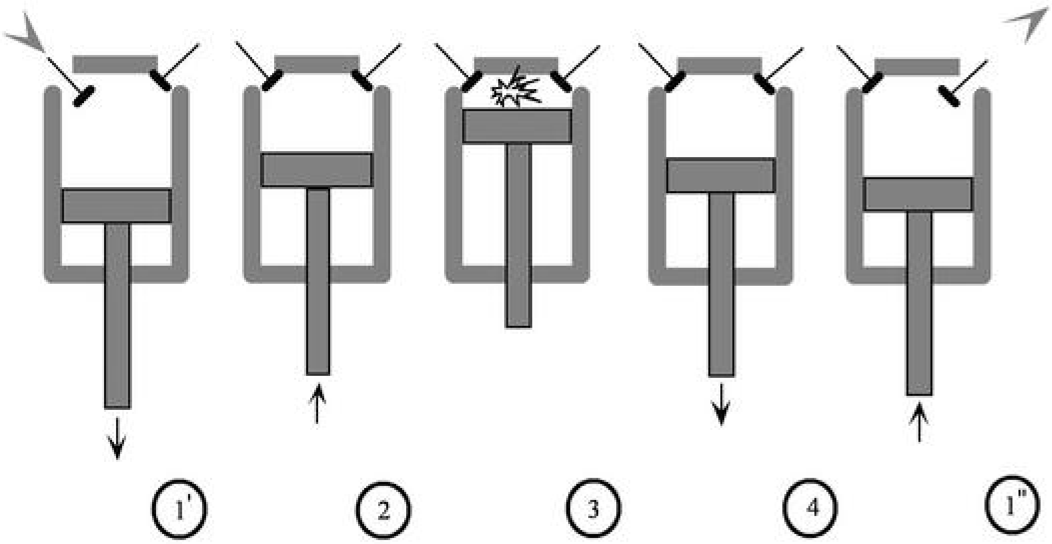

Figure 4: Piston and valves in a four-stroke internal combustion engine

The actual cycle does not have the sharp transitions between the different processes that the ideal cycle has, and might be as sketched in Figure

Efficiency of an ideal Otto cycle

The starting point is the general expression for the thermal efficiency of a cycle:

$$\eta = \frac{\text{work}}{\text{heat input}} = \frac{Q_H + Q_L}{Q_H} = 1 + \frac{Q_L}{Q_H}.$$

The convention, as previously, is that heat exchange is positive if heat is flowing into the system or engine, so Q_L is negative. The heat absorbed occurs during combustion when the spark occurs, roughly at constant volume. The heat absorbed can be related to the temperature change from state 2 to state 3 as:

$$\begin{aligned} Q_H &= Q_{23} = \Delta U_{23} \qquad (W_{23} = 0) \\ &= \int_{T_2}^{T_3} C_v dT = C_v(T_3 - T_2). \end{aligned}$$

The heat rejected is given by (for a perfect gas with constant specific heats)

$$Q_L = Q_{41} = \Delta U_{41} = C_v(T_1 - T_4).$$

Substituting the expressions for the heat absorbed and rejected in the expression for thermal efficiency yields

$$\eta = 1 - \frac{T_4 - T_1}{T_3 - T_2}.$$

We can simplify the above expression using the fact that the processes from 1 to 2 and from 3 to 4 are isentropic:

$$T_4 V_1^{\gamma-1} = T_3 V_2^{\gamma-1}, \qquad T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

$$(T_4 - T_1) V_1^{\gamma-1} = (T_3 - T_2) V_2^{\gamma-1}$$

$$\frac{T_4 - T_1}{T_3 - T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}.$$

The quantity **V_1/V_2 = r** is called the compression ratio. In terms of compression ratio, the efficiency of an ideal Otto cycle is:

$$\eta_{\mathrm{Otto}} = 1 - \frac{1}{(V_1/V_2)^{\gamma-1}} = 1 - \frac{1}{r^{\gamma-1}}.$$

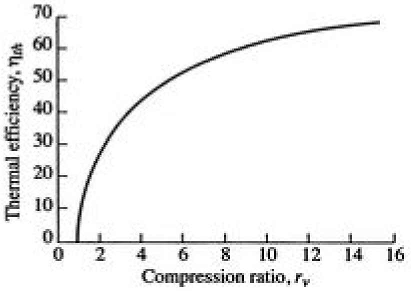

Figure 5: Ideal Otto cycle thermal efficiency

The ideal Otto cycle efficiency is shown as a function of the compression ratio (2)

2.2 Working of a SI Engine

The working of a four stroke SI Engine is depicted and explained as follows:

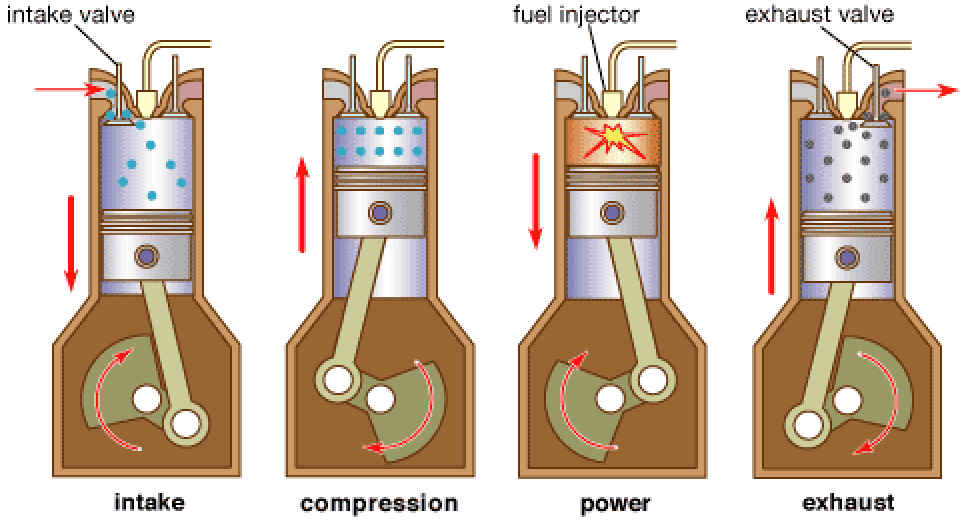

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FIG.6 Working of a Four Stroke S I Engine

(Source: Encyclopedia Britannica)

Intake Stroke:

The intake stroke of the combustion cycle is when the piston travels down the cylinder with the intake port/ports open. A mixture of air and explosive fuel are drawn into the cylinder, the proportions of which are called the air-fuel ratio. Both the air-fuel ratio and the quality of the mixture (dispersion, droplet size etc.) is important for an efficient combustion process. There are two methods of mixing air and fuel in a combustion engine, using a carburetor or fuel injection system.

In a carbureted engine, during the intake stroke of the piston a vacuum is created in the inlet manifold. With a multi cylinder engine the vacuum is almost constant. The carburetor is located at the top of the manifold and air is drawn through it by the vacuum created in the manifold. The carburetor has a small fuel chamber supplied from the fuel tank by a pump, fuel passes through the carburetor to small fuel jets positioned in the air flow. The flow of air past the jets creates a pressure difference causing the fuel to be drawn out. The fuel vaporizes in the air flow and passes through the manifold and into cylinders on their intake stroke. The diagram below shows the basic operation of a fixed jet carburetor.

Electronic fuel injection systems spray fuel at high pressure either directly into the combustion chamber or into the intake port of the cylinder during the intake stroke. Using fuel injection enables improved control over the air-fuel mixture and reduces the power required to draw fuel from the jets. The diagram below shows a typical electronic fuel injection system.

Compression Stroke:

The compression stroke is the upwards movement of the piston in the cylinder with the valves closed following the intake stroke. This upwards motion compresses the fuel air mixture inside the combustion chamber raising the pressure. The difference between the initial volume of the cylinder and the final volume at the top of the compression stroke is known as the compression ratio. Typically this is approximately 9:1 in spark ignition engines and 15:1 for diesel engines. The compression ratio is particularly important in compression fired engines such as diesel engines. The fuel-air mix and compression ratio is critical to avoid pre-ignition which is the abnormal ignition of fuel in the combustion chamber before the combustion stroke. In diesel engines the fuel is injected under high pressure towards the top of the compression stroke. The distribution of fuel before combustion is also of interest because it affects the efficiency of combustion.

Combustion Stroke:

Spark plugs are used to generate the spark which ignites the compressed fuel and air mixture in the spark ignition engine. To generate the spark a high voltage of around

20, 000 Volts is applied. Low voltage current is fed through the primary winding of an inductor coil generating a magnetic field. The high voltage is generated when the low voltage supply is interrupted and the magnetic field breaks down generating a high voltage in the secondary winding which has a much larger number of coils. The low voltage supply to the coil is controlled by the distributor which also controls the spark plug that the high voltage surge is sent to. The distributor timing is critical and usually is timed mechanically from the engine. The diagram below shows the typical set-up of an ignition system for a spark ignition engine.

Compression ignition engines such as the diesel engine do not use spark plugs to ignite the fuel-air mix. When the piston reaches the top of the compression stroke the temperature and pressure in the combustion chamber is sufficient to ignite the mixture. Controlled ignition in both spark ignition and diesel engines is essential for efficient combustion and avoid uncontrolled combustion effects such as pre-ignition, auto-ignition and engine knock.

Exhaust Stroke:

Exhaust gases are pushed out of the cylinder by the upwards motion of the piston following the ignition stroke. The exhaust gases are passed into the exhaust manifold and channeled into the exhaust pipe where they are released into the atmosphere. The exhaust system may contain a smoke box to trap the larger soot particles; it may also be fitted with a catalytic converter which removes some of the harmful components from the exhaust gases. On newer cars some of the exhaust gases are recycled back into the inlet system (typically at the manifold or air filter), this is known as exhaust gas re-circulation EGR.

The efficiency of the combustion process and the design of the engine determine the exhaust constituents. Typically exhaust gases contain oxygen, nitrogen, water vapor, carbon dioxide, carbon monoxide, hydrogen, nitrous oxides, particulates and unburned hydrocarbons. The diagram below shows the effects of the air-fuel ratio on exhaust constituents in a typical engine. $_{(3)}$

2.3 Engine Performance Parameters

Engine performance is a major concern in this research project alongside the main aim of analyzing the reduction in the emission of nitrogen oxides using liquefied petroleum gas in spark ignition engine. Some indicators of engine performance such as input power, brake power, specific fuel consumption and engine efficiency are calculated to compare the engine performance between gasoline and LPG.

2.3.1 Input Power:

The input power of an engine refers to the maximum energy that can be put into the engine, and is given by:

$$IP = Q_{HV} \times \dot{m}_f$$

Where:

IP = Input power (kW)

Q_{HV} = Lower calorific value of fuel (MJ/kg)

m_f = Mass flow rate of fuel (kg/s)

Q_{HV} (Gasoline) = 44.5 MJ/kg

Q_{HV} (LPG) = 50 MJ/kg

2.3.2 Brake Power:

Brake power refers to the power delivered by the engine. During internal combustion, chemical energy from the fuel is converted to generate heat to do work. However, the heat generated cannot be fully converted to work, and some of that are lost to the exhaust flow and to the surroundings by heat transfer. Indicated power (IP), which is used to push the piston to do the work, is used to subtract the friction power to obtain the brake power of an engine. Greater power can be generated by increasing displacement and speed.

Brake power is given by

$$BP = IP - FP$$

$$BP = 2\pi NT/60*10^3$$

Where:

BP = Brake power (kW)

$\Pi = 3.142$

N = Engine speed (rpm)

T= Torque (N.m)

Torque is usually used as a measure of an engine's ability to do useful work, and it has the unit of Nm or lbs-ft. Apart from that, torque also refers to the measure of the work done per unit rotation (radians) of crank. The magnitude of the torque acting on a body is equal to the product of the force acting on the body and the distance from its point of application to the axis around which the body is free to rotate. It should be noted that only the force component that lies on the rotation plane and perpendicular to the radius from the axis of rotation to the point of application contributes to the value of torque. Torque is given by:

$$T = 60P/2\Pi N$$

Where:

T= Torque (Nm)

P=Power Developed by the Engine (W)

$\Pi = 3.142$

N = Engine speed (rpm)

In this research project, the brake power generated is converted to electrical power (EP), which is used to supply electricity to light the electric bulbs. Therefore, the brake power is measured as follows:

$$BP=EP=V*I*PF$$

BP = Brake power (kW)
EP = Electric power (kW)
N = Engine speed (rpm)
V = Voltage (V)
I= Current (A)
PF= Power Factor

2.3.3 Specific Fuel Consumption (sfc):

Specific fuel consumption measures the amount of fuel needed to provide a given power to an engine for a given period. It is an important parameter to compare gasoline and LPG in terms of economic aspect. Sfc is largely dependent on engine design, for example, a typical gasoline engine has a sfc of about 0.3 kg/kWh. However, sfc is inversely related with engine efficiency - a lower value of sfc shows better engine performance. The sfc is defined as:

$$sfc = \frac{m_f}{P}$$

Where:
sfc = Specific fuel consumption (kg/kWh)
m_f= Mass flow rate of fuel (kg/h)
P = Power output (kW)

And Brake specific fuel consumption (bsfc) is given by:

$$bsfc = \frac{\dot{m}_f}{BP}$$

Where:

bsfc = Brake specific fuel consumption (kg/kWh)
m_f= Mass flow rate of fuel (kg/h)
BP=Brake Power (kW)

There are several factors which affect the value of bsfc. For instance, higher compression ratio delivers a greater bsfc as it extracts more power from the fuel. On the other hand, the value of bsfc will decrease if the combustion occurs with a fuel with equivalence ratio near to unity (Φ = 1). Bsfc will be of greater value at high speed as the friction losses are increased. (3)

2.3.4 Engine Efficiency:

Engine efficiency is defined as the ratio of the effective or useful output to the total input in an engine. It also accounts for the fraction of fuel that burns during combustion. For any engine:
Power Generated = Wshaft+Wacc+Qexhaust+Qloss

Where:
Wshaft = brake Power to run engine accessories
Qexhaust = Energy lost in the exhaust flow
Qloss = other energy lost to the surroundings by Heat transfer

For one engine cycle in a single cylinder, the fuel conversion efficiency η_f is given by:

$$\eta_f = \frac{W_c}{m_f Q_{HV}}$$

$$\frac{P}{\dot{m}_f Q_{HV}}$$

and it can be presented in the form of:

$$\eta_f = \frac{3.6}{(sfc)Q_{HV}}$$

Where:

η_f = Engine efficiency

P = Output power produced per cycle (kW)

m_f = Mass flow rate of fuel per cycle (kg/s)

Q_{HV} = Lower calorific value of fuel (MJ/kg)

2.4 SI ENGINE EMISSIONS

Vehicular Emissions typically constitute a number of gases in which CO is major constituent, accounting for almost more than 75% of exhaust gases. Other exhaust constituents are NO_x, VOCs, CO_2, and Particulates etc. In a Spark Ignition engines, flame, initiated at a fixed point within the cylinder (the spark plug), propagates through the in-cylinder charge. Although, under ideal circumstances, the in-cylinder charge will be a homogeneous mixture of fuel and air this is not always the case. Therefore, the flame front will often 'see' significant variations in AFR. Moreover as the products of rich combustion differ from those of lean combustion and also that combustion is an extremely complex multi-step process. Thus, there are chemical reactions that occur both before and after passing of the flame. Typically, the rate of these reactions is highly temperature dependent. Flame temperature is a strong function of AFR; accordingly, local AFR has a significant influence on the composition of the engine out exhaust.

For the ideal combustion of a hydrocarbon fuel there are only carbon dioxide and water vapor in the exhaust. However, in a real application the exhaust gas contains a number of other less desirable pollutant species. Concern over the negative environmental and health effects of these noxious cocktail of gases has prompted the introduction of strict emissions legislation all over the world. (4)

At present, regulated emissions standards apply to the following:

- Total Hydrocarbons (THC)
- Non Methane Hydrocarbons (NMHC)
- Carbon Monoxide
- Oxides of Nitrogen (NOx)
- Particulate Matter (PM)

Some of these emissions are discussed in more detail; in particular, the source of these emissions within an SI engine, their potential impact, and methods for their control.

2.4.1 Oxides of Nitrogen (NO_x)

NOx is the collective term for nitric oxide (NO) and nitrogen dioxide (NO_2) which are extremely toxic gases for humans.

Formation of NOx

Basically, NOx, as the name implies, are generated from reaction between nitrogen and oxygen under high temperature and pressure conditions during the combustion process in an engine cylinder. Normally it takes place at the pre combustion, combustion and post-flame regions where sufficient concentrations of oxygen and nitrogen are present. The formation of NOx depends enormously on the temperature as the rate of dissociation of nitrogen is directly proportional to the temperature increase. (5) Therefore, the higher the combustion reaction temperature, the more NOx will be produced. The chemical reactions of nitrogen and oxygen are as follows (Zeldovich Mechanism):

$N+O_2 = NO+O$

$O+N_2 = NO+N$

$OH+N = NO+H$

There are three different mechanisms of formation of NOx:-

(i) Thermal NOx

It is formed by the stabilization of atmospheric nitrogen in oxidizing atmospheres at a high flame temperature exceeding 1573K or 1300 °C. Thermal NOx is generally produced during the combustion of both gases and fuel oils. The following chemical reactions were classified as an atom shuttle reaction:-

$N_2+O=NO+N$

$N+O_2=NO+O$

When the combustion is under fuel-lean conditions (with less air) and there is a rise in temperature, this will lead to an increase of NOx emissions due to increased oxygen radicals forming in the combustion process. However, when the combustion is under fuel-rich condition (with excess air) the oxidation reaction will involve the OH and H radicals.

$N+OH=NO+H$

$H + N_2=N_2H$

$N_2H+O=NO +NH$

High activation energies are required for the dissociation of oxygen molecules and the disengagement of the triple bond of nitrogen. This phenomenon causes the formation of thermal NOx to be largely dependent on the temperature, the degree of air to fuel mixing, the oxygen and nitrogen in the flame and duration of reaction occurred.

(ii) Fuel NOx

It is formed by the reaction of coal-bound nitrogen compounds with oxygen at temperature exceeding 1123K or 850 °C. The formation of fuel NOx is mainly dependent on the availability of oxygen and the combustion method. Under low

oxygen conditions, hydrogen cyanide (HCN) reacts with oxygen atoms to form oxycyanogen and amine intermediates and NO is formed as the oxidization product.
On the other hand, under excess oxygen conditions, the formation of N_2 is more favorable as the result of additional hydrogenated amine species and the chemical reactions between amine intermediates, hydrocarbon radicals and NO are as follows [5]

$NH_2 + NO = N_2 + H_2O$
$CH + NO = HCN + O$

(iii) Prompt NOx

It is formed by the stabilization of atmospheric nitrogen in reducing atmospheres by the particles of hydrocarbon under fuel-rich conditions. Prompt NOx is of great significance under the condition of very fuel-rich flames and nonessential to be compared with the influence of thermal and fuel NOx.

Concentration of NOx

The concentration of NOx found in the emission of engines is dependent on the combustion temperature, the length of combustion time and the concentration of the nitrogen and oxygen in the engine. The measurement unit of NOx is generally in parts per million (PPM) due to the dilution of NOx percentage with the excess air level in the flue gases. NOx value tends to peak at an air-fuel ratio of approximately 1.1 times stoichiometric with the condition of excess oxygen present.

Effects of NOx towards the Environment

The environmental problems caused by NOx are now worldwide issues due to the seriousness of ozone reactivity and the amount of formation of smog.

NOx combines with water vapor in clouds to produce acid rain which pollutes clean water sources and corrodes metals used in our daily life. Acid rain also harms the growth of organisms in the lake and disturbs the balance of the ecosystem both on land and at sea. Apart from that, acidified soil is the also the result of acid rain and it causes damage to the root system of trees, disabling the nutrient absorption process and disrupting the natural process of photosynthesis. When NOx react chemically with other atmospheric gaseous compounds such as "volatile organic compounds" (VOCs) under the sunlight, it will form smog. Smog is forefront to our environmental concerns as it reduces the visibility of surroundings and poses a health hazard to humans which includes irritation of eyes, respiratory and cardiovascular problems such as asthma and headaches.

Greenhouse effect is a global-warming phenomenon when heat energy from the sunlight is trapped by gases such as NO_x. This increases the average temperature of our planet and acts as a great threat to the life of crops, humans and the environment. The increased temperature will speed up the melting rate of the icebergs in north and south poles and there will be an increased risk of flooding in lower-terrain countries.

Next, ozone depletion is also related to the excessive emission of NO_x. Nitrogen oxides formed will allow more penetration of harmful ultraviolet solar radiation to the earth and lead to skin irritation for humans. The reaction mechanisms are listed below:-

$NO + O_3 = NO_2 + O_2$
$NO_2 + O = NO + O_2$

Ozone (O_3) is destroyed in the first reaction to form nitrogen dioxide (NO_x), and then the nitric oxide (NO) is regenerated in the second reaction to repeat the ozone depletion step. These processes will continue and will stop only when the whole ozone layer is consumed. (6)

Factors Affecting NOx Emissions

There are several factors which affect the formation of NOx in the engine and they are listed below:

(i) The air-fuel ratio (λ) plays a major role in determining the amount of emission of NOx as oxides of nitrogen are formed by the reaction of nitrogen in the fuel with oxygen in the combustion air. When the air to fuel ratio is greater than one which indicates that the combustion is in the lean condition, the fuel mixture has considerably less amount of fuel and excess amount of air. Engines designed for lean burning can achieve higher compression ratios and hence produce better performance. However, it will generate high amount of NOx due to the excess oxygen present in the air.

(ii) Combustion temperature is also one of the primary factors that influence the formation of NOx. The formation of NOx is directly proportional to the peak combustion temperature, with higher temperatures producing higher NOx emissions from the exhaust.

(iii) The amount of nitrogen in the fuel determines the level of NOx emissions as fuels containing more nitrogen compounds result in higher levels of NOx emissions. Choices of fuel type alter the formation of both the theoretical flame temperature reached and rate of radioactive heat transfer.

(iv)The firing and quenching rates also influence the rate of NOx formation where a high firing rate is associated with the higher peak temperatures and thus increases the NOx emission. On the other hand, a high rate of thermal quenching results in lower peak temperatures and contributes to the reduction of NOx emission.

(v) Engine parameters such as load and speed of engine also influence the NOx emissions from the exhaust. When the engine is running under lean conditions, it emits less NOx. However the nitric oxide (NO) emissions will consequently increase as the engine load increases. The effect of load becomes less significant when the engine is running close to stoichiometric air to fuel ratio. On the other hand, engine speed may increase or decrease the NO emissions as higher engine speed increases the burned gas mass fraction and thus offsets the peak temperature, depending on the exact engine conditions. (5)

2.4.2 Unburned Hydrocarbons (UHC) Emissions

Total hydrocarbon (THC) is used to measure the level of formation of unburnt hydrocarbons caused by incomplete combustion in the engine. The hydrocarbons emitted may be inert such as methane gas or reactive to the environment by playing a major role in the formation of smog. The types hydrocarbons emitted from the exhaust greatly depend on the type and composition of fuel used. Fuels with a greater concentration of aromatics and olefins compounds will result in a higher percentage of reactive hydrocarbons. [3]

Formation of HC Emissions

HC emissions rise rapidly as the mixture becomes substantially richer than stoichiometric. When combustion quality deteriorates, e.g., with very lean mixtures HC emissions can rise rapidly due to incomplete combustion or misfire in a fraction of the engine's operating cycles.

The possible HC emission formation mechanisms for spark-ignition engines (where fuel-air mixture is essentially premixed) have been proposed (6)

1. Crevice flows: - The crevice mechanism where crevices in the combustion chamber are filled with a mixture of fuel and air. This mixture remains unburned after flame passage since the flame cannot propagate into the crevices. When the exhaust valve opens and the pressure drops in the combustion chamber the fuel in crevices is driven out in hot bulk gasses and are being partly oxidized. The UHC emissions from SI engines will normally increase with increasing compression ratio.

2. Flame quenching: - As the flame approaches the combustion walls it is extinguished (due to heat transfer to walls) thus, leaving a layer of unburned fuel-air mixture adjacent to the wall.

3. Absorption/desorption in oil films: - Hydrocarbons can be absorbed into the oil film on the cylinder bore during compression. These hydrocarbons are released again during expansion and often escape oxidation as a result. Absorption/desorption from in-cylinder deposits may also be considered as a reason for the UHC.

4. Incomplete combustion: - Incomplete combustion in a fraction of the engine's operating cycle (either partial burning or complete misfire), occurring when combustion quality is poor (e.g. during engine transients when A/F, EGR, and spark timing may not be adequately controlled).

2.4.3 CO Emissions

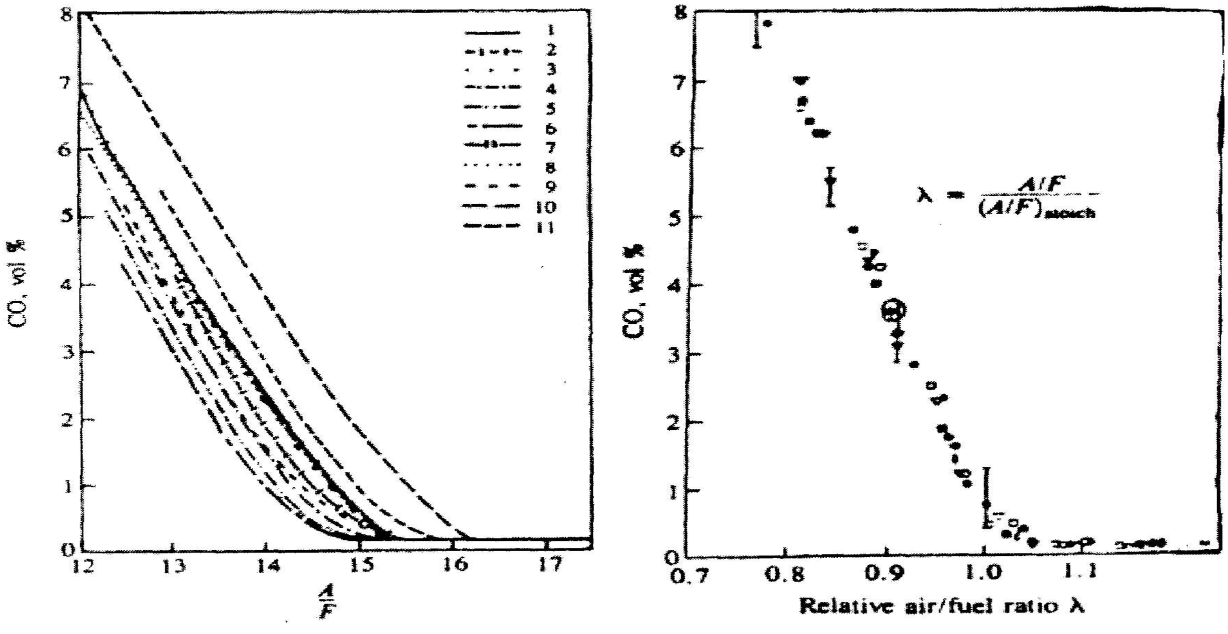
Carbon monoxide (CO) is a colorless, odorless, flammable and highly poisonous gas which is less dense than air. Inhalation of carbon monoxide can be fatal to humans since a small concentration as little as 0.1% will cause toxicities in the blood due to its high affinity to oxygen carrying hemoglobin. Exposure levels must be kept below 30 ppm to ensure safety. Apart from that, carbon monoxide also helps in the formation of greenhouse gases and global warming by encouraging the formation of NO_x.

Formation of CO

Carbon monoxide forms in internal combustion engines as a result of incomplete combustion when a carbon based fuel undergoes combustion with insufficient air. The carbon fuel is not oxidized completely to form carbon dioxide and water. This effect is obvious in cold weathers or when an engine is first started since more fuel is needed.

Carbon monoxide emission from internal combustion engines depend primarily on the fuel/air equivalence ratio (λ). Figure7 (a) shows the variation of CO emission for eleven fuels with different hydrocarbon contents and a single curve may be used to represent the data when using the relative air/fuel or equivalence ratio as represented in Figure7 (b).

Both the graphs clearly show that the amount of CO emitted increases with decreasing air to fuel ratio. Spark ignition gasoline engines which normally run on a stoichiometric mixture at normal loads and fuel-rich mixtures at full load shows significant CO emissions. On the other hand, diesel engines which run on a lean mixture only emit a very small amount of CO which can be ignored. Additional CO may be produced in lean-running engines through the flame-fuel interaction with cylinder walls, oil films and deposits. Direct injection diesel engines also emit more CO than indirect-injection engines. However, the CO gas emission increases with increasing engine power output for both engines. (7)



(a) **(b)**

Figure-7: Variation of SI engine CO emissions with various fuels (a) with air/fuel ratio; (b) with relative air/fuel ratio (λ)

CO formation is one of the principle reaction steps in the hydrocarbon combustion mechanism, which may be summarized by

$RH \text{----›} R \text{----›} RO_2 \text{----›} RCHO \text{----›} RCO \text{----›} CO$

Where 'R' stands for the hydrocarbon radical.

The CO formed from hydrocarbon radicals can be oxidized to form carbon dioxide in an oxidation reaction, in an equilibrium condition:

$$CO + OH = CO_2 + H$$

The emission of CO is a kinetically-controlled reaction since the measured emission level is higher than equilibrium condition for the exhaust. Three-body radical recombination reactions such as:

$$H+H+M=H_2+M \quad H+OH+M=H_2O+M \quad H+O_2+M=H_2O+M$$

Above reaction is found to be rate-controlling reactions for emission of CO gas.

Reduction of carbon monoxide in internal combustion engines can be achieved by improving the efficiency of combustion process or utilization of oxidation catalysts to oxidize carbon monoxide to carbon dioxide. Engine modifications such as improved cylinder head design, controlled air intake and electronic fuel injection can help to maintain a lean air/fuel mixture which is favorable.

2.4.4 PM Emissions from SI Engines

Although the emission of particulate matter is usually associated with the diesel engine, there is increasing evidence to suggest that PM emissions from SI engines pose a significant threat to health. In particular, PM emissions pose a significant problem for Stratified Charge Direct Injection Gasoline engines. In order to understand the reasons for this concern, we must first consider the formation and composition of PM.

PM Formation in SI Engines

- Particulates are principally SOOT which has absorbed other organic compounds i.e. hydrocarbon compounds.

- Soot is describes as a carbonaceous material not just carbon
- PM is formed in fuel-rich regions of flames (both pre-mixed and diffusion flames)

With respect to the Direct-Injection Spark-Ignition (DISI) engine, particularly in stratified charge mode, it is extremely difficult to achieve good charge homogeneity. Accordingly, there are proportionally a larger number of fuel-rich regions within the cylinder of a DISI engine, which provide potential sites for PM formation, than is the case for a similar Port-Fuel-Injected (PFI) engine. The literature suggests that PM emissions from DISI engines are an order of magnitude greater than an equivalent PFI engine.

Harmful Effects of PM Emissions

There is an increasing body of evidence to suggest that aerodynamic size is a significant factor determining the health effect of particulate emissions from engines. The adverse health effects of very small (nano) particles are thought to be particularly severe. Sub-micron particles remain airborne for a substantially greater time than do larger particles. Nano particles are easily ingested and absorbed into the bloodstream etc.

Spark-Ignition engines are prone to produce sub-micron PM prompting authorities to consider moving from existing mass based PM emissions regulations to size-based regulations for future standards. (5)

2.4.5 Carbon Dioxides

Carbon dioxide is considered as the major greenhouse gas and it can cause death by suffocation if inhaled in large amounts. CO_2 has the tendency to absorb heat radiation of the sun, thus creating a thermal radiation shield which reduces the amount of thermal radiation energy allowed to escape from the earth. As a result of this, the temperature of earth rises and accelerates the melting rate of polar ice caps and expansion of oceans into low lying areas .To reduce the emission of CO_2 efficiently, engine with higher thermal efficiency that are able to operate at the lowest level of excess air are used . (4)

2.4.6 Sulphur Dioxide (SO_2)

Sulfur dioxide (SO_2) belongs to the family of sulfur oxide gases (SOx). These gases dissolve easily in water and are produced when sulfur or fuels containing sulfur are oxidized:

$$S + O_2 = SO_2$$

SO_2 dissolves in water vapors to form acid, and interacts with other gases and particles in the air to form sulfates and other products that can be harmful to the people and environment. Moreover, oxidation of SO_2 will further produce SO_3 in the atmosphere under the influence of sunlight:-

$$2SO_2 + O_2 = 2SO_3$$

Some of the SO_3 will also be introduced directly from the combustion processes alongside SO_2. SO_3 will react rapidly with moisture from the atmosphere to form sulphuric acid, which is the main element in acid rain:-

$$SO_3 + H_2O = H_2SO_4$$

It had been proven that even with sophisticated combustion techniques; there had been no significant improvement of reduction in the emission of sulphur dioxide. Therefore the best way to solve this problem is the selection of low sulphur content fuels such as Ethanol, LPG, and CNG etc. (4)

3. EMISSION CONTROL STRATEGIES FOR S.I. ENGINES

3.1 After Exhaust Treatment Devices

Catalytic converters are used on both spark ignition and compression ignition engines. For spark ignition engines, the most commonly used catalytic converter is the three-way converter which converts the three main pollutants of concern — CO, HC, and NO_x— to less-toxic substances. The control of NO_x involves a *reduction* process that releases oxygen and the control of CO and HC involves an *oxidation* process that consumes oxygen. Therefore, a 3-way converter contains two catalyst-coated stages: The first catalyst stage encountered by the exhaust is for reduction of NOx, which produces oxygen employed by the second stage to oxidize CO and HC. 3-way converters work most efficiently with exhaust from engines operated on a stoichiometric air-fuel mixture. Generally, such engines are equipped with closed-loop feedback fuel mixture control employing one or more oxygen (lambda) sensors. While a 3-way catalyst can be used in an open-loop system, NO_x reduction efficiency is low. Since NO_x emissions are now regulated throughout the world, open-loop fuel systems are obsolete in many jurisdictions. Closed-loop maintenance of the stoichiometric air-fuel ratio is most often attained by means of an engine management system with computer-controlled fuel injection, though early in the deployment of 3-way converters, carburetors equipped for feedback mixture control were used during the transition to fuel injection. Within a narrow ratio band surrounding stoichiometry, conversion of all three pollutants is very complete, sometimes approaching 100%. However, outside of that band, conversion efficiency falls off very rapidly. Two-way (or oxidation) converters act only to control CO and HC, and have therefore been abandoned on conventional spark ignition engines in most jurisdictions due to an inability to control NO_x.

A three-way catalyst reduces emissions of CO (carbon monoxide), HC (hydrocarbons) and NO_x (nitrogen oxides) simultaneously when the oxygen level of the exhaust gas stream is below 1.0%, though performance is best at below 0.5% O_2. Unwanted reactions, such as the formation of H_2S (hydrogen sulfide) and NH_3 (ammonia), can occur in the three-way catalyst. Formation of each can be limited by modifications to the wash-coat and precious metals used. It is, however, difficult to eliminate these side products entirely.

For example, when control of H_2S (hydrogen sulfide) emissions is desired, nickel or manganese is added to the wash-coat - both substances act to block the adsorption of sulfur by the wash-coat. H_2S is formed when the wash-coat has adsorbed sulfur during a low temperature part of the operating cycle, which is then released during the high temperature part of the cycle and the sulfur combines with HC. For "lean burn" spark ignition engines (e.g. compressed natural gas, or compressed natural gas with diesel fuel pilot injection), an oxidation catalyst is used in the same manner as in a compression ignition engine.

Recently, many systems have used a pre-catalyst in the system to reduce startup emissions and burn off hydrocarbons from the extra-rich mixture used in a cold engine. Upstream and downstream parts are now often separated in the system to provide an optimum temperature and space for extra oxygen sensors. The converter needs to be placed close enough to the engine to quickly reach operating temperature but far enough away to avoid heat damage.

Many three-way catalytic converters utilize an air injection tube between the first (NO_x reduction) and second (HC and CO oxidation) biscuits of the converter. This tube is fed by either an air pump or by an aspirator. The injected air provides oxygen for the catalyst's oxidizing reaction. These systems also sometimes include an upstream air injector to admit oxygen to the exhaust system before it reaches the catalytic converter. This pre-cleans the extra-rich exhaust from a cold engine, and helps bring the catalytic converter quickly up to operating temperature.

Most newer systems do not employ air injection. Instead, they provide a constantly varying mixture that quickly and continually cycles between lean and rich to keep the first catalyst (NO_x reduction) from becoming oxygen loaded, and to keep the second catalyst (CO oxidization) sufficiently oxygen-saturated. They also utilize several oxygen sensors to monitor the exhaust, at least one before the catalytic converter for each bank of cylinders, and one after the converter. Some systems contain the reduction and oxidation functions separately rather than in a common housing.

A catalytic converter besides its housing has three main components

1. Catalyst
2. Substrate or Support, and
3. Intermediate coat or wash-coat

These converters have binary metals such as platinum and rhodium, which reduces nitrogen oxides along with oxidation of HC and CO. The three way converter operates in two stages; the first converter stage uses rhodium to reduce the NO_x in the exhaust into N_2 and CO_2. In the second stage platinum or palladium acts as into harmless water and CO_2. For supplying the oxidation catalyst to change HC and CO oxygen required in the second stage, air is fed into the exhaust after the first stage. The catalyst allows the oxidation of exhaust gases at a much lower temperature than in combustion chamber. Both reduction and oxidation reactions take place within a single device. (8)

The reduction reactions for the catalyst are as follows-

$$2CO + 2NO \rightarrow 2CO_2 + N_2$$

$$HC + NO \rightarrow CO_2 + H_2O + N_2$$

The oxidation reactions are-

$$2CO + O_2 \rightarrow 2CO_2$$

$$HC + O_2 \rightarrow CO_2 + H_2O$$

where the HC in equations refer to a general hydrocarbon(9)

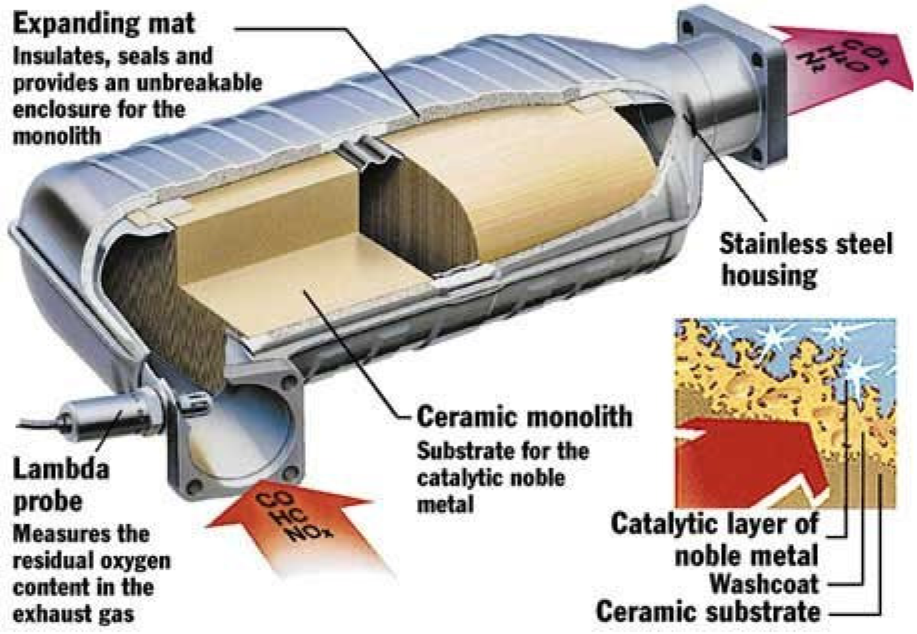


Figure-8: Schematic of a Catalytic Converter

Techniques for Reducing CO & HC Emissions

Both un-burnt CO & HCs emitted from an engine are the products of either incomplete combustion or incomplete oxidation. Accordingly, control strategies for UHC and CO aim to complete the oxidation process; this may be achieved by further combustion or chemical catalysis. (10)

Thermal Afterburning is a process used to control UHC and CO emissions in which air is injected into the exhaust manifold close to the exhaust valves that causes further combustion and oxidation. There are, however, significant disadvantages to thermal afterburning, namely an air pump is required, leading to increased inefficiency and the additional combustion process may result in increased NO_x emissions

Techniques for Reducing NO_x Emissions

Most of NO_x reduction techniques aim at reducing the in-cylinder temperature in some way as NO_x emissions from IC engines is particularly sensitive to combustion temperature. The process involved in controlling exhaust NO_x emissions focused on retarding ignition timing, and/or operating with a leaner mixture (excess air) but in both of these scenarios the combustion efficiency/power output is reduced, which is a major limitation

3.2 Alternative Fuels:-

3.2.1 Liquefied petroleum gas (LPG)

LPG has a simpler molecular structure and its carbon to hydrogen ratio is low resulting in lower emissions. It is a mixture of light hydrocarbons which are gaseous at normal temperatures and pressures, and which liquefy readily at moderate pressures or reduced temperature. It is odorless and therefore for safety reasons, a pungent compound, mercaptan is added in order to make any leaks easily detectable.

High Octane rating of LPG allows compression ratio and thereby efficiency to be increased. High energy content (weight wise) of natural gas results in more efficient vehicle operation. But as LPG is stored in liquid form above atmospheric pressure so it requires more complex storage system than gasoline. Also LPG in gaseous form is heavier than air so it does not disperse in the atmosphere making it prone to catching fire in the presence of a fire source. Moreover LPG is sensitive to gas-liquid phase change at the typical vehicle operating temperature and pressure making it difficult to provide appropriate fuel metering for all operating conditions.

The primary constituents of LPG are-

- Propane (C_3H_8)
- Propylene (C_3H_6)
- Butane (C_4H_{10})

Studies have shown that exhaust and evaporative greenhouse emissions are approximately 15 per cent lower from LPG than from petrol vehicles and moreover it does not need lead or other additives to increase its octane rating.(11)

3.2.2 Compressed Natural Gas (CNG)

Natural gas is abundantly available in nature and has a small and simple molecular structure and its carbon to hydrogen ratio is low resulting in much lower emissions. Natural gas is a mixture of hydrocarbons-mainly methane (CH_4) and is produced either from gas wells or in conjunction with crude oil production. High Octane rating of natural gas allows compression ratio and thereby efficiency to be increased. High energy content (weight wise) of natural gas results in more efficient vehicle operation.

But Natural gas requires large infrastructure for its transportation, distribution and refueling. Moreover as natural gas is compressed to very high pressures approx 200 bar for automotive applications it requires use of heavy and strong storage tanks. Moreover low volumetric efficiency results in power loss and restricts natural gas vehicle (NGV) range.

The main constituent of natural gas is methane, which is a relatively un-reactive hydrocarbon. Natural gas as delivered through the pipeline system also contains hydrocarbons such as ethane and propane; and other gases such as nitrogen, helium, carbon dioxide, hydrogen sulfide, and water vapor. In addition to methane (CH_4), natural gas also contains small percentages of Ethane (C_2H_6), Propane (C_3H_8), Butane (C_4H_{10}), Pentane (C_5H_{12}) etc.

CNG is an excellent fuel for spark ignition engines due to its high Octane Number. Retro fitment of CNG Conversion kits has now become common in vehicles driven by SI Engines. Although when properly operated and maintained, leakage of CNG is minimum, it should be noted that methane is an even more active greenhouse gas than CO_2.

The primary advantage of using CNG is that it substantially reduces particulate emissions, particularly from the new, dedicated CNG engines now available for buses and trucks. These new engines reduce particulate emissions to very low levels and are therefore extremely popular in the city bus fleet sector because of their cleaner image. Many new CNG buses are in operation or on order for several international capital cities.

But storage of CNG is a problem because of its low boiling point. CNG must be stored in high pressure tanks. These cylinders are heavy and they reduce payload and space in smaller vehicles.

3.2.3 Methanol

Methanol (CH_3OH), also known as wood alcohol, is an alcohol fuel and it can be used as an alternative fuel in flexible fuel vehicles that run on M85 (a blend of 85% methanol and 15% gasoline). However, it is not commonly used because automakers are no longer supplying methanol-powered vehicles. Methanol can be used to make methyl tertiary-butyl ether (MTBE), an oxygenate which is blended with gasoline to enhance octane and create cleaner burning fuel. MTBE production and use has declined because it has been found to contaminate ground water. In the future, methanol could possibly be the fuel of choice for providing the hydrogen necessary to power fuel cell vehicles.

As engine fuels, ethanol and methanol have similar chemical and physical characteristics. Methanol is methane with one hydrogen molecule replaced by a hydroxyl radical (OH).

Methanol (CH_3OH) is a clear liquid alcohol that can be produced from natural gas, coal, crude oil and biomass crops such as wood and wood residues as well as directly from catalytic synthesis:

$$CO+2H_2 \rightarrow CH_3OH$$

Methanol is the simplest alcohol. It is a clear, colorless liquid. Combustion of methanol is as follows-

$$2CH_3OH+ 3O_2 \rightarrow 2CO_2 + 4H_2O$$

Currently, pure methanol can be used in purpose-designed engines such as some racing cars, since its very high octane rating allows for the use of very high compression engines producing significantly more power than an equivalent petrol engine.

Pure methanol can be mixed with petrol for use in flexible-fuelled vehicles (FFV) capable of measuring the methanol: petrol ratio being delivered to the engine. This is so that the engine management system can adjust the air: fuel ratio and timing to match the requirements of whatever mixture is being used. The water solubility of methanol poses a problem. Methanol cannot be used in blends with petrol above 5% in normal cars, and then only with co-solvents, because of the fear of phase separation.

Methanol has the potential to reduce greenhouse gas emissions but would need to be produced from biomass to make a possible contribution. Methanol derived from natural gas using current technology offers at best only a small greenhouse gas emission benefit over petrol. Although the emissions of CO, hydrocarbons and nitrogen oxides are lower in methanol-dedicated cars, the exhaust of these vehicles contains more formaldehyde, a known carcinogen. Methanol can also lead to greater unburnt fuel emissions of methanol and methane which, however, are usually more readily degraded than unburnt hydrocarbons. Methane is a major greenhouse gas. Under combustion, methanol produces neither soot particles nor sulphur oxides. It also yields less nitrogen oxides than any other fuel.

Methanol is extremely toxic and therefore hazardous to handle. It is also corrosive requiring modification of a conventional vehicle's fuel system. It has only half the energy content of petrol, which results in greater fuel consumption per unit volume and shorter travelling range -- compensated to some extent by its suitability for use at a higher compression ratio and its ability to deliver more power. (7)

3.2.4 Hydrogen

The simplest and lightest fuel is hydrogen gas (H_2). Hydrogen is in a gaseous state at atmospheric pressure and ambient temperatures. Hydrogen may contain low levels of carbon monoxide and carbon dioxide, depending on the source.

Hydrogen is being explored for use in combustion engines and fuel cell electric vehicles. On a volumetric basis, the energy density of hydrogen is very low under ambient conditions. This presents greater transportation and storage hurdles than for liquid fuels. Storage systems being developed include compressed hydrogen, liquid hydrogen, and physical or chemical bonding between hydrogen and a storage material (for example, metal hydrides).

The ability to create hydrogen from a variety of resources and its clean-burning properties make it a desirable alternative fuel. Although there is no significant transportation distribution system currently for hydrogen transportation use, we can transport and deliver hydrogen for early market penetration using the established hydrogen infrastructure; for significant market penetration, the infrastructure will need further development.

Widespread use of hydrogen as an energy source could help address concerns about energy security, global climate change, and air quality. Fuel cells are an important enabling technology for the hydrogen future and have the potential to revolutionize the way we power our nation, offering cleaner, more efficient alternatives to the combustion of gasoline and other fossil fuels. Hydrogen's main benefits are that it reduces greenhouse gas emissions and improves air quality

There are two common feedstock's for hydrogen production, water and hydrocarbons such as methane.

1. Hydrogen is produced from water by hydrolysis using electricity. The major positive aspect of hydrogen is that there is an almost limitless supply of it in water (if the supply of electricity is limitless), and that it is non-toxic.

2. Hydrogen is produced when hydrocarbons react with steam. While this is a very simple process, it relies upon the earth's finite reserves of hydrocarbons, making hydrogen, in this case, not a true non-fossil alternative. If, however, vegetable oils/plants are used as a source of hydrocarbons, hydrogen becomes a renewable, if expensive, alternative.

Hydrogen is the lightest element in the universe. Under normal conditions, it is a colorless, odorless and tasteless gas. The complete combustion of hydrogen is very clean, provided the peak temperature is limited:

$$2H_2 + O_2 = 2H_2O$$

If it burns at high temperatures, nitrogen in the air is also heated forming nitrogen oxides. However, the temperature can be controlled by introducing water to the hydrogen/air mixture while still obtaining good combustion. It is also possible to cool the combustion by using excess air since hydrogen will burn even in dilute mixtures.

Currently hydrogen is used as a fuel only in space rockets. However, some vehicle manufacturers are developing hydrogen powered engines which may be tested as prototypes in about three years time. The main technical difficulty with hydrogen is storage. In compressed or liquid form, it needs a heavy and expensive tank. Another alternative is to utilize the ability of metal hydrides to absorb hydrogen, and to desorb it when it is needed. Liquefying it is costly in terms of energy use. Safety is a major concern, in use and distribution. Hydrogen is very flammable over a wide range of air: fuel ratios, and it burns rapidly with a high temperature, colorless flame. (7)

3.2.5 Electricity

Electricity can be used as a transportation fuel to power battery electric and fuel cell vehicles. In an electric vehicle (EV), a battery or other energy storage device is used to store the electricity that powers the motor. EV batteries must be replenished by plugging in the vehicle to a power source. Some electric vehicles have onboard chargers; others plug into a charger located outside the vehicle. Both types, however, use electricity that comes from the power grid. Although electricity production may contribute to air pollution, EVs are considered zero-emission vehicles because their motors produce no exhaust or emissions. . EV batteries have a limited storage capacity and their electricity must be replenished by plugging the vehicle into an electrical source. The electricity for recharging the batteries can come from the existing power grid or from distributed renewable sources such as solar or wind energy. Fuel cell vehicles use electricity produced from an electrochemical reaction that takes place when hydrogen and oxygen are combined in the fuel cell stack. The production of electricity using fuel cells takes place without combustion or pollution and leaves only two byproducts, heat and water.

Electricity is unique among the alternative fuels in that mechanical power is derived directly from it, whereas the other alternative fuels release stored chemical energy through combustion to provide mechanical power. Motive power is produced from electricity by an electric motor. Electricity used to power vehicles is commonly provided by batteries, but fuel cells are also being explored. Batteries are energy storage devices, but unlike batteries, fuel cells convert chemical energy to electricity. (11)

Like battery powered vehicles fuel cell vehicles use on-board electric motor. But while drivers must periodically recharge battery powered vehicles with electricity generated elsewhere, fuel-cell vehicles make their own power from on board supply of hydrogen, or a hydrogen-rich fuel such as natural gas, methanol, ethanol or gasoline. This enables drivers to fill up at a service station, rather than recharge the car, making it a more practical solution for today's automobiles. There are six basic types of fuel cells, solid oxide, phosphoric acid, alkaline, molten carbonate, direct methanol and Proton Exchange Membrane (PEM).

The PEM fuel cell has several advantages for transportation use:

- High power density
- Relatively quick start up
- Compact size
- Low operating temperature
- Low noise levels.

EVs have lower fuel and maintenance costs than gasoline-powered vehicles. The cost of an equivalent amount of fuel for EVs costs less than the price of gasoline. Also, maintenance for EVs is less, EVs have fewer moving parts to service and replace, although the batteries must be replaced every three to six years. (12), (13)

3.3 Hybrid Electric Vehicles

Hybrid electric vehicles (HEVs) combine the benefits of high fuel economy and low emissions with the power, range, and convenience of conventional diesel and gasoline fueling. HEV technologies also have potential to be combined with alternative fuels and fuel cells to provide additional benefits. Future offerings might also include plug-in hybrid electric vehicles. Hybrid Electric Vehicles (HEVs) combine two or more energy conversion technologies (e.g. heat engines, fuel cells, generators, or motors) with one or more energy storage technologies (e.g., fuels, batteries, ultra capacitors, or flywheels). The combination of conventional and electric propulsion systems offers the possibility of greatly reducing emissions and consumptions, while giving consumers both the extended range and convenient refueling they expect from a conventional vehicle. HEVs can either have a parallel or series design. In a parallel design, the energy conversion unit and electric propulsion system are directly to the vehicles wheels. The primary engine is used for highway driving; the electric motor provides added power during hill climbs, acceleration, and other periods of high demands. In a series design, the primary engine is connected to a generator that produces electricity. The electricity charges the batteries and drives an electric that powers the wheels.

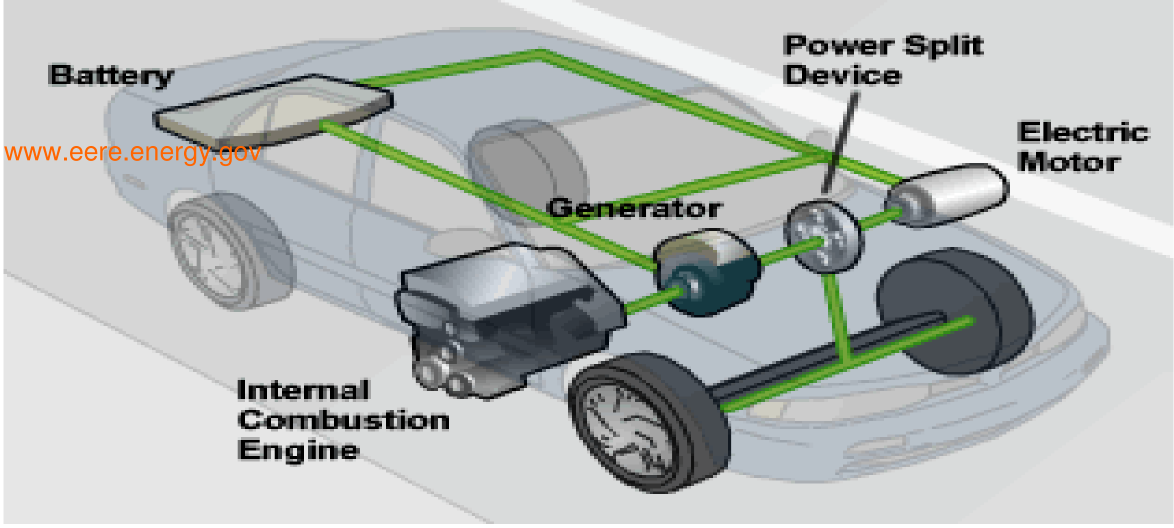


FIG.9 Hybrid electric Vehicle

Advantages of HEVs

The advantages of HEVs are-

- HEVs are two or three times more fuel efficient than conventional vehicles.
- Good emission benefits
- Extended vehicle range.
- Easy and rapid refueling.
- Compensates the shortfall in battery technology.
- Application of regenerative braking helps minimize energy loss.(10)

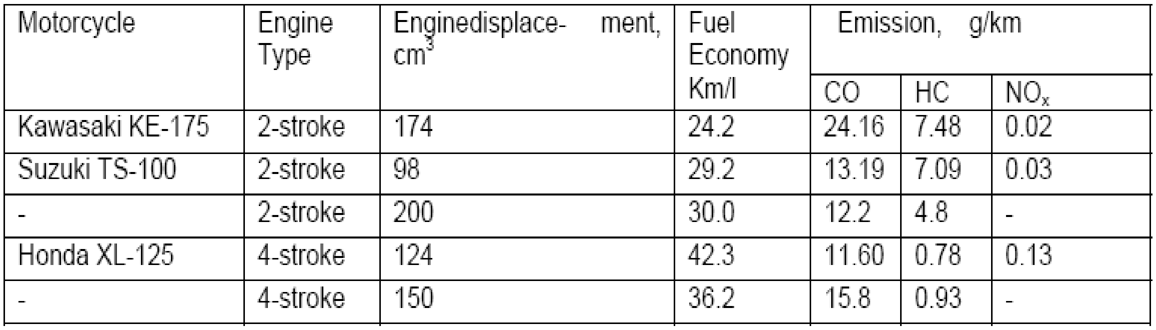
3.4 Advanced Engine Technologies

In addition to using alternative fuels and exhaust gas treatment there are advanced engine technologies which can aid in reducing engine exhaust emissions. Some of them are listed as follows-

3.4.1 Conversion of Two Stroke Engines to Four Stroke Engines

In Delhi, two-wheelers account for about two thirds of the total vehicular population. The big proportion of overall automobile pollution is due to large number of two-wheelers /three wheelers fitted with 2-stroke engines. Because of the inherent drawbacks in the design of 2- stroke engines, 2-wheelers emit about 20-40% of the fuel un-burnt/partially burnt. At present, two-wheelers generate more than 70% of the hydrocarbon emissions and nearly 40% of the CO emissions in Delhi. As these emissions are less visible than SPM, the general public is not aware of the role of 2-wheelers in the deteriorating air quality. To reduce pollution scenario from such vehicles 2-stroke engines need to be replaced by 4-stroke engines. It is one of the alternative technologies for reducing vehicular pollution and aimed to reduce pollutants from exhaust of smaller 2-stroke engine fitted vehicles such as scooters and motorcycles /three wheelers (Table 1). (14) Relative to carbureted 2-stroke engines, the main benefits offered by carbureted 4-stroke engines are:

- Misfire-free operation.
- Reduced fuel consumption and CO_2 emissions,
- Reduced HC emissions.
- Improved drivability



Motorcycle	Engine Type	Enginedisplace- ment, cm^3	Fuel Economy Km/l	Emission, g/km		
				CO	HC	NO_x
Kawasaki KE-175	2-stroke	174	24.2	24.16	7.48	0.02
Suzuki TS-100	2-stroke	98	29.2	13.19	7.09	0.03
-	2-stroke	200	30.0	12.2	4.8	-
Honda XL-125	4-stroke	124	42.3	11.60	0.78	0.13
-	4-stroke	150	36.2	15.8	0.93	-

Table-1:-Two and Four-Stroke Engine Powered Motorcycles (Driving Cycle Test) (Driving Cycle Test)

3.4.2 Exhaust Gas Recirculation

The Exhaust Gas Recirculation (EGR) system's purpose is to reduce NO_x emissions that contribute to air pollution. The first EGR systems were added to engines in 1973, and today most engines have an EGR system.

As long as the EGR system is functioning properly, it should have no noticeable effect on engine performance. But if the EGR system is leaking or inoperative, it can cause driveability problems, including detonation (knocking or pinging when accelerating or under load), a rough idle, stalling, hard starting, elevated NOx emissions and even elevated hydrocarbon (HC) emissions in the exhaust.

Exhaust gas recirculation reduces the formation of NOX by allowing a small amount of exhaust gas to "leak" into the intake manifold. The amount of gas leaked into the intake manifold is only about 6 to 10% of the total, but it's enough to dilute the air/fuel mixture just enough to have a "cooling effect" on combustion temperatures. This keeps combustion temperatures below 1500 degrees C (2800 degrees F) to reduce the reaction between nitrogen and oxygen that forms NO_x.

To re-circulate exhaust back into the intake manifold, a small calibrated "leak" or passageway is created between the intake and exhaust manifolds. Intake vacuum in the intake manifold sucks exhaust back into the engine. But the amount of recirculation has to be closely controlled otherwise it can have the same effect on idle quality, engine performance and driveability as a huge vacuum leak.

Most older EGR systems use a vacuum regulated EGR valve while newer vehicles tend to have an electronic EGR valve to control exhaust gas recirculation. When the engine is idling, the EGR valve is closed and there is no EGR flow into the manifold. The EGR valve remains closed until the engine is warm and is operating under load. As the load increases and combustion temperatures start to rise, the EGR valve opens and starts to leak exhaust back into the intake manifold. This has a quenching effect that lowers combustion temperatures and reduces the formation of NOx.

The common problems associated with EGR are

Pinging (spark knock or detonation) because the EGR system is not working, the exhaust port is plugged up with carbon, or the EGR valve has been disabled.

Rough idle or misfiring because the EGR valve is not closing and is leaking exhaust into the intake manifold.

Hard starting because the EGR valve is not closing and is creating a vacuum leak into the intake manifold.

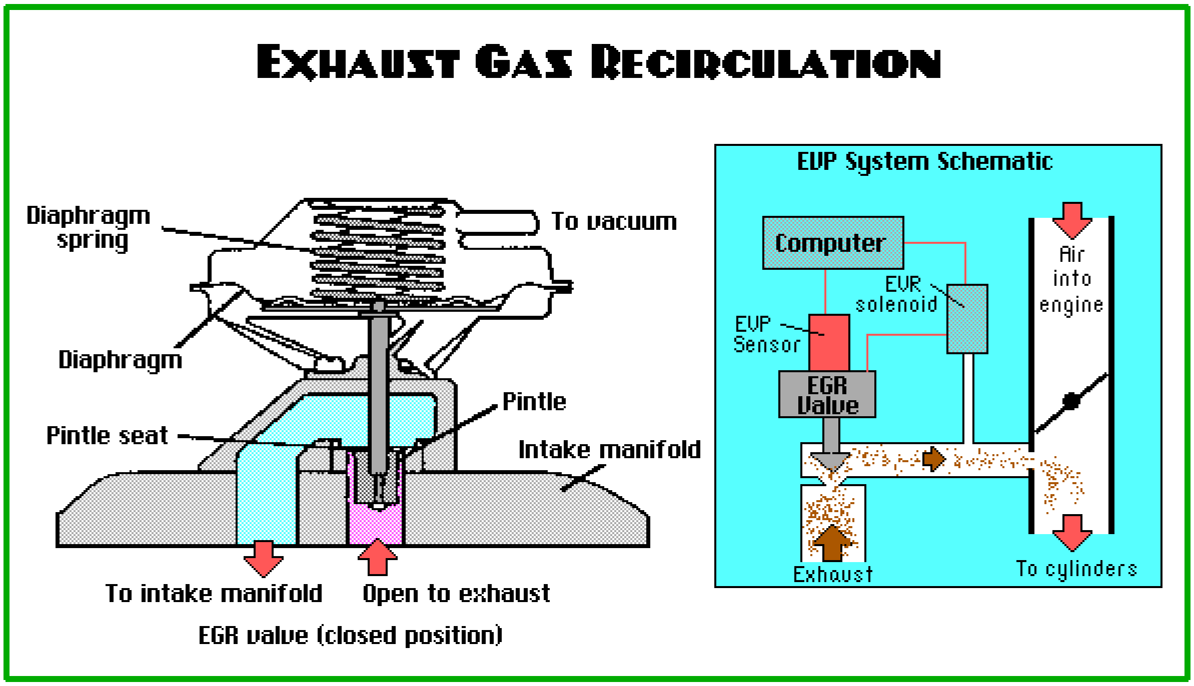


Figure-10: Exhaust Gas Recirculation System

The amount of EGR that a particular combustion chamber design will tolerate depends on combustion characteristics, speed, load and the equivalence ratio. The HC emissions increase with increasing EGR. EGR adversely affects the fuel economy. More maintenance problems are faced due to closing of EGR valves and other flow lines. However the best EGR must have lowest NO_x emissions, which is obtained at stoichiometric mixture either by carburetor or EFI system. The necessity of EGR to be optimum and compatible enough, it must be electronically controlled. (10)

3.4.3 STRATIFIED CHARGE ENGINES

The **stratified charge engine** is a type of internal-combustion engine similar in some ways to the Diesel cycle, but running on normal gasoline. The name refers to the layering of fuel/air mixture, the charge inside the cylinder. It uses a direct-injection system, like the Diesel, with its inherent ability to be run at efficient high compressions. However, like the Otto, it relies on gasoline's ability to mix quickly and cleanly in order to avoid the poor combustion found in older direct injection Diesels.

To do this the fuel injectors are aimed to inject the fuel into only one area of the cylinder, often a small "sub-cylinder" at the top, or periphery, of the main cylinder. This provides a rich charge in that area that ignites easily and burns quickly and smoothly. As the combustion process proceeds, it moves to a very lean area (often only air) where the flame-front cools rapidly and the harmful NO_x has little opportunity to form. The additional oxygen in the lean charge also combines with any CO to form CO_2, which is less harmful. This technology has also been applied to the latest electronically controlled direct injection diesels. The injection system on these engines delivers the fuel in multiple injection bursts to ensure better fuel/air mixing and reduced diesel knock.

The much cleaner combustion in stratified charge petrol engines allows for the elimination of the catalytic converter and allows the engine to be run at leaner mixtures, using less fuel. It has had a similar effect on diesel engine performance.

3.4.4 Positive Crankcase Ventilation

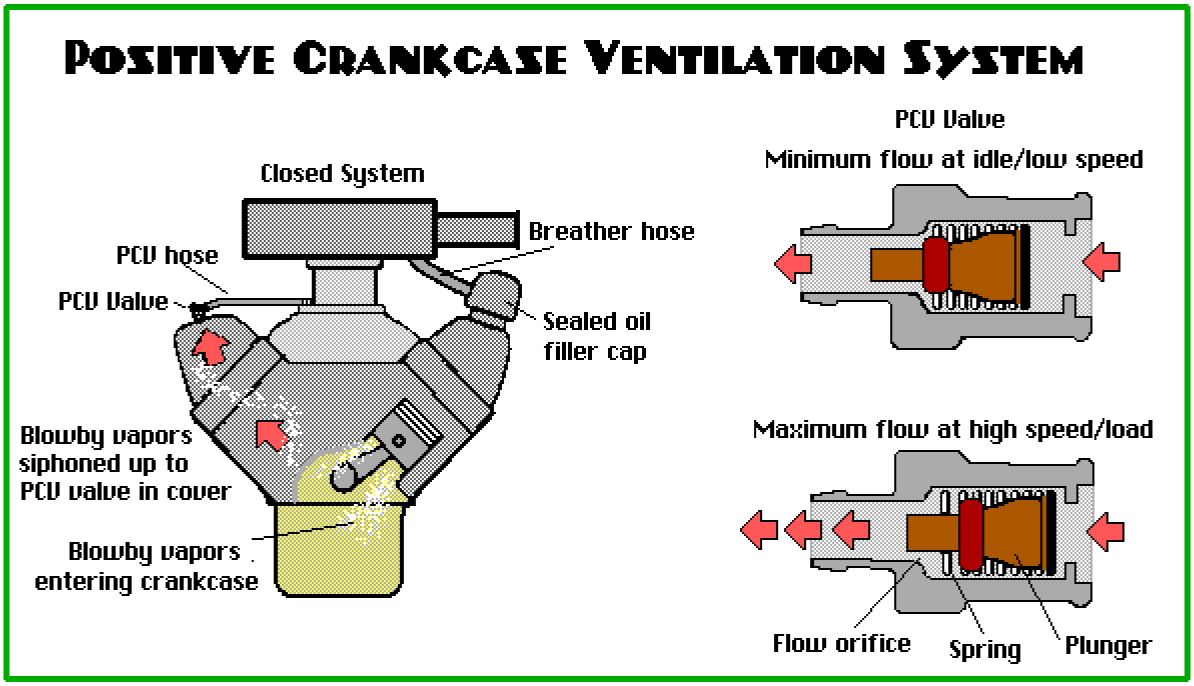


FIG.11: Positive Crankcase Ventilation System

The Positive Crankcase Ventilation (PCV) system reduces blowby emissions from the engine. About 20% of the total hydrocarbon (HC) emissions produced by a vehicle are blowby emissions from gases that get past the piston rings and enter the crankcase. The higher the mileage on the engine and the greater the wear on the piston rings and cylinders, the greater the blowby into the crankcase.

Before PCV was invented, blowby vapors were simply vented to the atmosphere through a "road draft tube" that ran from a vent hole in a valve cover or valley cover down toward the ground.

In 1961, the first PCV systems appeared on California cars. The PCV system used intake vacuum to siphon blowby vapors back into the intake manifold. This allowed the HC to be re-burned and eliminated blowby vapors as a source of pollution.

The system proved to be so effective that "open" PCV systems were added to most cars nationwide in 1963. An open PCV system draws air in through a mesh filter inside the oil filler cap or a breather on a valve cover. The flow of fresh air through the crankcase helped pull moisture out of the oil to extended oil life and reduce sludge. The only drawback to these early open PCV systems was that blowby vapors could still backup at high engine speed and loads, and escape into the atmosphere through the oil filler cap or valve cover breather.

In 1968, "closed" PCV systems were added to most cars. The breather inlet was relocated inside the air cleaner housing so if pressure backed up it would overflow into the air cleaner and be sucked down the carburetor. No vapors would escape into the atmosphere. The major component in the PCV system is the PCV valve, a simple spring-loaded valve with a sliding pintle inside. The pintle is tapered like a bullet so it will increase or decrease airflow depending on its position inside the valve housing. The movement of the pintle up and down changes the orifice opening to regulate the volume of air passing through the PCV valve.

The PCV valve is typically located in a valve cover or the intake valley, and usually fits into a rubber grommet. The location of the valve allows it to pull vapors from inside the engine without sucking oil from the crankcase (baffles inside the valve cover or valley cover deflect and help separate droplets of oil from the blowby vapors).

A hose connects the top of the PCV valve to a vacuum port on the throttle body, carburetor or intake manifold. This allows the vapors to be siphoned directly into the engine without gumming up the throttle body or carburetor.

Because the PCV system pulls air and blowby gases into the intake manifold, it has the same effect on the air/fuel mixture as a vacuum leak. This is compensated for by the calibration of the carburetor or fuel injection system.

Consequently, the PCV system has no net effect on fuel economy, emissions or engine performance -- provided everything is working correctly.

4. BASICS OF CNG

4.1 Introduction

Natural gas was first used as fuel in China during AD221-263.The gas was obtained from shallow wells near seepages and was distributed locally through piping made of hollowed-out bamboos. Since then, there are no records on the usage of natural gas until the early 17th century in Northern Italy, where it was used as a fuel to provide lighting and heating (Tiratsoo 1979, p.8). As the time moves on, the usage of natural gas spread to North America, Canada, New Zealand and Europe. The usage was limited to domestic and industry heating.

When the world turned into the 20th century, the usage of natural gas expanded to most part of Western Europe and USA. Exploration for the natural gas source was more active after the post-war years. It became a commercial item in the form of liquefied natural gas (Tiratsoo 1979, p.8) for exports and imports. The gas fields or the natural gas resources are mainly found in Asia and Middle East countries. These include Malaysia, Brunei, Algeria, Libya, Saudi Arabia, Kuwait and Iran. By 1980s, these countries became the main exporters of natural gas.

Natural gas consists mostly of methane and is drawn from gas wells or in conjunction with crude oil production. Compressed natural gas (CNG) vehicles store natural gas in high-pressure fuel cylinders at 3,000 to 3,600 pounds per square inch. Since natural gas is colorless, odorless and tasteless, an odorant is normally added to CNG for safety reasons. Liquefied natural gas (LNG) vehicles store natural gas as a cryogenic liquid.

CNG as an alternative automotive fuel is gaining wide acceptance all over the world and especially in India where in Delhi it has helped in significantly reducing the pollution levels.

4.2 CNG Properties

Physically, natural gas is colorless, tasteless, relatively non-toxic (Yusaf et al. 1996a, p.19) and not a volatile organic compound (VOC). It exists in our environment at normal temperature and pressure, which gave it its name. To use natural gas as fuel in vehicles, it has to be compressed at a high pressure of about 18- 20MPa at normal temperature in vessels before it can be supplied to the engine's combustion chamber. Generally, natural gas is lighter than air with a vapor density of 0.68 relative to air. Therefore, if leaking happens, it will not cause explosion but instead it will disperse to the atmosphere.

Natural gas has a high auto-ignition temperature compared to gasoline or diesel, which is the lowest temperature for it to ignite through heat alone and without any spark or flame (*Clean Air Program - Assessment of the Safety, Health, Environmental and System Risks of Alternative Fuel* 2 April 2004). Higher ignition temperature means that natural gas is more difficult to ignite. This can significant reduce the fire hazard, and constitute anti-knocking ability especially when it is compressed in a very high pressure in the combustion chamber. This property is certainly useful for the design of a dual-fuel engine. The ignition temperature for natural gas is about 900 K.

The table below depicts the properties of Natural Gas**.**

PROPERTIES	NATURAL GAS
Boiling Point (K @1 Atm)	147
Density (kg/cum)	128
Auto Ignition Temperature (K)	900
Flash Point (K)	124
Octane Number	130
Flammability Limits Range	5.0-15
Net Energy Content (MJ/Kg)	49.5
Combustion Energy (KJ/cum)	24.6
Vapourisation Energy (MJ/cum)	215-276

Table 2: Properties of Natural Gas

Other physical properties such as the flammability limits range, octane rating, Wobbe Index and flash point also play an important role in the analysis of compression ratio and combustion efficiency of the engine.

The flammability limit range is the concentration of natural gas in air to cause an explosion. This is between the lower explosive limit (LEL) of 5% to the upper explosive limit (UEL) of 15%. If the concentration of natural gas is more or less than this range, an explosion would not occur. This will certainly reduce the risk of explosion of CNG in air due to leaking because natural gas can only burn in air when the concentration of CNG is high. For natural gas, the octane number is approximately 130 as shown in Table. This is much higher than gasoline with an octane number of 96. This property is important as it determines the time needed for the natural gas and air to mix homogeneously in the combustion chamber to minimize knocking or detonation. (16)

4.3 Benefits and Limitations of CNG

4.3.1Benefits:

Environmental: CNG vehicles produce far less of all regulated pollutants that comparable gasoline or diesel vehicles, including NO_x and particulate matter. In addition, CNG vehicles produce far less unregulated air toxics and greenhouse gases.

Operating Cost: Natural gas is cheaper "at the pump" than gasoline and diesel fuel. Prices vary around the country. Vehicle operating costs are reduced by as much as 70% by using CNG instead of Gasoline.

Distribution Efficiency/Safety: India has a huge natural gas transmission and distribution network. This is the safest and most efficient energy distribution system.

Flexibility: CNG vehicles can be (and are being) produced as dedicated and bi-fuel versions. Dedicated vehicles are most appropriate where vehicles tend to operate in an area where natural gas fueling is available. Bi-fuel vehicles have both natural gas and gasoline storage tanks on board, and can operate on either fuel at the flip of a switch. Bi-fuel vehicles are most appropriate where the driver may need to travel to areas not currently served by natural gas stations.

Transition to Hydrogen: Since hydrogen is a gas, hydrogen-powered vehicles will require changes in a number of areas, including building codes and standards, mechanic/ inspector/user training. NGVs require many of the same changes. Therefore, a growing NGV market today is smoothing the path for a hydrogen vehicle market tomorrow.

4.3.2Limitations

Fueling: There are only around 400 natural gas fueling stations in India (compared to 190,000 gasoline stations). In addition, each station costs significantly more than for a comparable gasoline/diesel dispenser and storage tank system.

Vehicle Cost: Primarily because of (1) low production volumes and (2) the greater cost of fuel storage tanks, NGVs cost more than comparable gasoline or diesel models.
Driving Range: Compared to a volumetric gallon of gasoline or diesel fuel, there is less energy in an energy gallon equivalent of

natural gas (both CNG and LNG). Therefore, the driving range of vehicles operating on natural gas is less.

Other: On-board natural gas fuel tanks are larger than comparable gasoline or diesel fuel tanks. Therefore, in some vehicles, cargo space is considerably reduced.

4.4 Indian Initiatives on CNG

CNG is being used as an alternative transportation fuel in major cities such as New Delhi, Mumbai, and Ahmedabad etc. To combat rising air pollution levels , the Supreme Court of India took over the responsibility and issued on July 28, 1998 a time frame for measures to be taken. The order was directed towards the government of the national capital region (NCR), which includes Delhi. With respect to the scope of the Info Pool the following orders were of interest:

- Replacement of all pre-1990 autos and taxis with new vehicles using clean fuels by March 31, 2000
- Financial incentives for replacement of all post-1990 autos and taxis with new vehicles on clean fuels by March 31, 2001
- No buses more than eight years old to ply except on CNG or other clean fuels, by March 31, 2000
- Entire city bus fleet (DTC and private) to be steadily converted to single fuel mode on CNG by March 31, 2001
- New interstate bus terminals (ISBT) to be built at entry points in the north and southwest to avoid pollution due to entry of inter-state buses by March 31, 2000
- Gas Authority of India Ltd. to expand its CNG dispensing capacity from nine stations to 80 by March 31, 2001

- Two independent fuel testing labs to be established by June 1, 1999
- Automatic inspection and maintenance (I&M) facilities to be set up for commercial vehicles in the first phase, immediately.
- Comprehensive I&M programs to be started by transport department and private sector by March 31, 2001.

The order to move the entire bus fleet to CNG bus by March 31, 2001, was not achieved; therefore, the Supreme Court gave a conditional extension until September 30, 2001. Thereafter the entire public transport fleet in Delhi was converted to CNG. This has helped in considerably reducing air pollution levels in Delhi. Similar CNG distribution networks have been operational in Mumbai, Ahmedabad etc. but unlike Delhi none of these cities has its entire public transport system working on CNG.

5. BASICS OF LPG

5.1 Introduction

The composition of LPG depends on its source: whether it is extracted from natural gas or produced during the refining of petroleum. LPG is primarily propane, although it may contain significant amounts of ethane and butane as well. Data from the California Air Resources Board (CARB) indicate that the propane content of LPG delivered to CARB over a seven-year period (1982-1989) varied from -63% to 96% [JoWO]. Other sources place the range of propane in LPG **from** 50%-100% [KW83]. Further data from the CARB analysis indicated that the ethane content of the fuel was -15% in the early 1980s, but only **4%** later in the late 1980s. Commercially, there are four grades of LPG [RBWSO]:

Commercial propane, which is predominantly propane and/or propylene

Commercial butane, which is predominantly butanes and/or butylenes

Commercial butane-propane (B-P) mixtures, which are mixtures of butanes, butylenes, propane, and propylene

HD-5 propane, which has not less than 90% liquid volume propane and not more than 5% liquid volume propylene.

According to Russell et al. [RBWSO], only **HD-5** propane is suitable **as** a fuel for spark ignition engines. However, analysis of LPG composition over time [Joh90] indicates that the 90% propane standard for **HD-5** may only be met 60% of the time, and may occasionally drop substantially below (propane content = 63%) the **HD-5** standard. Certainly, more information is needed about the "quality" or composition of LPG at end-use fueling stations. Several oil companies (Conoco, Phillips) appear to be making efforts to produce standardized LPG fuels, which will probably be tightly regulated **HD-5** type fuels.

In theory, LPG composition for automotive use is governed by American Society for Testing and Materials (ASTM) standard 1835. This standard specifies that the fuel must consist mainly of propane, with no more than **5%** propylene and 2.5% of butanes or heavier HC. Other countries allow more butane in LPG, which ranges from a C,/C, ratio of 90/10 in the United Kingdom, through *50/50* in other parts of Europe, to 20/80 in Italy [OC90]. Other restrictions are normally specified to limit: Residual matter to no more than 5% upon evaporation, to prevent clogging of regulators and metering systems Corrosion characteristics, to protect copper and brass fittings Water content, to prevent corrosion and line freezing.

The limitation on propylene is primarily due to its low knock resistance (low octane number Excess propylene concentration could lead to preignition and engine damage. Propylene is normally only found in LPG produced from oil refining. LPG extracted from natural gas does not normally contain propylene. A second concern with propylene is its photochemical reactivity, which is higher than that of propane. This could be an important issue in ozone non-attainment areas. (17)

5.2 LPG PROPERTIES

The table depicts properties of LPG:

CHARCTERISTICS	LPG
Boiling point (^oC)	**-44**
Molecular weight (kg/Kmol)	**44.1**
Density at 15 ◦C kg/l	**0.507**
Research Octane Number	**100**
Stoichiometric air fuel ratio (kg/kg)	**15.6**
Flame speed (m/s)	**48**
Upper Flammability limits in air (% vol)	**74.5**
Lower Flammability limits in air (% vol)	**4.1**
Lower calorific value (kJ/kg)	**46.365**

Table 3: Properties of LPG

5.3 Benefits and Limitations of LPG

5.3.1 Benefits

Cost of fuel: It is considerably cheaper to run a vehicle on LPG rather than on Gasoline. In the times of ever increasing prices of gasoline, running one's vehicle on LPG gives enormous savings.

Description	Maruti		Premier	
	LPG	MS	LPG	MS
Mileage,km/litre	16	18	10	12
Conversion Cost,Rs	20000	-	20000	-
Fuel Prices, Rs. / litre	26.57	48.38	26.57	48.38
Cost Per Km, Rs.	1.65	2.68	2.65	4.03
Savings, Rs. / Km	1.03	-	1.39	-
Break even at Kms	20000	-	14388	-

Cleaner emissions: Using LPG as an automotive fuel results in a reduction in emissions as compared to Gasoline**.** LPG produces significantly less carbon monoxide, hydrocarbons and oxides of nitrogen emissions as well as a smaller percentage of carbon dioxide emissions than petrol. LPG also emits 90% less particulates, in weight, than diesel engines. The exhaust emissions of vehicles running of Auto LPG emit

- 75 % less CO
- 85 % less Hydrocarbons
- 40 % less NO

- 87 % less Ozone depletion as compared to vehicles running on petrol. (18)

Better for engine oil: LPG users do not need to replace their vehicles as often. The average gas powered engine will last longer than a petrol engine.

5.3.2 Limitations

Initial cost: The cost of legal conversion (including approved conversion kit, CCOE approved LPG fuel tanks, piping, fitment charges and RTO endorsement) is approx. Rs.15000/- to Rs.25000/- depending on type of vehicle.

Lack of filing stations: Till date, 128 ALDS have been set up in Metros / Major Cities in India. Another 15 ALDSs have been mechanically completed & are likely to be commissioned within two months. But compared to CNG, of which there are more than 160 Stations in Delhi itself, there is a great shortfall of LPG filling facilities.

Tank space: Converting a gasoline driven vehicle to LPG reduces the space in the vehicle. The tank may be located in the boot, reducing space for luggage and possibly meaning the loss of the spare wheel.

Safety Considerations: Its vapor flammability limits in air are wider than those of petrol, which makes LPG ignite more easily.

5.4 Indian Initiatives on LPG

With effect from April 24, 2000, the use of Auto LPG as an automotive fuel was made legal in India, albeit within the prescribed safety terms and conditions. However, use of domestic LPG cylinders in automobiles is illegal. With rising automotive fuel prices at the global level, customers are increasingly opting for economical and eco-friendly fuel alternatives, one of which is Auto LPG. Auto

LPG has less impact on greenhouse emissions than any other fossil fuel when measured through the total fuel cycle. The higher energy content in this fuel results in a 10% reduction of CO2 emission compared to other fuels and substantially reduces air pollution caused by vehicular emissions. With a switchover to Auto LPG–driven cars, customers can save about 30% on their fuel bills.

Parameter	Auto LPG	CNG
Fuel Quality	Stable Quality, since produced in Refineries under controlled conditions.	Varying composition since it is supplied direct from the wells without any processing.
Delivery Pressure	10 bar	200 bar
Refueling Time	Like MS, 3 to 4 minutes, liquid handling.	High refueling time of 5 to 10 minutes, depending on the differential pressure, gaseous handling.
Engine Performance	Better than Petrol under high speed and heavy load conditions.	Due to impurities, adverse engine performance under high speed and heavy load conditions.
Availability	Can be made available in any part of the Country by installing Storage facility.	Available only on select cities where pipeline has been laid.
Cost of Dispensing infrastructure	40 lakhs at an existing Retail Outlet	150 lakhs at an existing Retail Outlet.
Cost of conversion of vehicle	Rs.15000/- to Rs.25000/-	Rs.35000/- to Rs.40000/- (for 3 /4 wheelers). Rs.300000/- for buses.

Table 6: Comparison of CNG and LPG

6. EXPERIMENTAL SETUP

Description

The setup consists of four cylinder, four stroke, Petrol (MPFI) engine connected to eddy current type dynamometer for loading. It is provided with necessary instruments for measurements of combustion pressure and crank-angle. These signals are interfaced to computer through engine indicator for Pθ−PV diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The set up has stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rota meters are provided for cooling water and calorimeter water flow measurement.

FIGURE-12: EXPERIMENTAL SETUP

The main aim of this experiment is to investigate the effects on performance and emissions with Gasoline, CNG and LPG in a four cylinder Wagon-R engine.

A CNG Conversion Kit and a LPG Conversion kit were installed on the engine with an arrangement for changeover from one fuel to another.

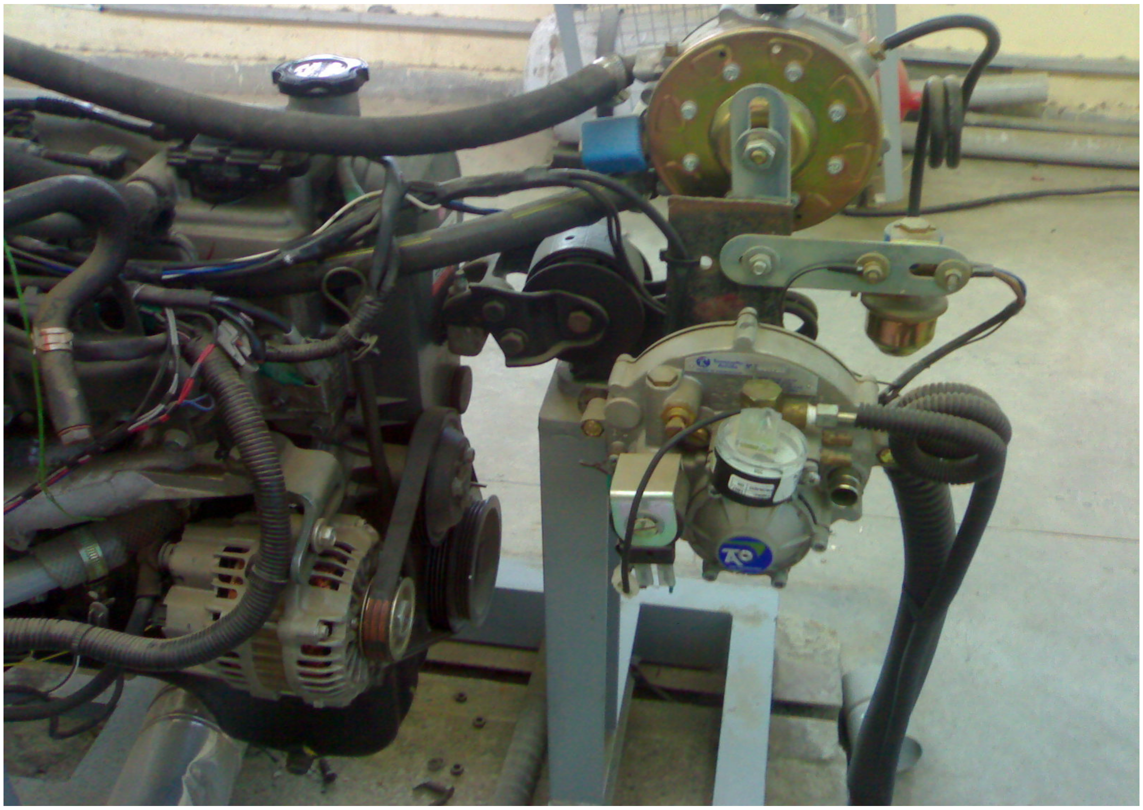


FIG-13. : CNG and LPG Conversion Kits mounted on the Test Rig

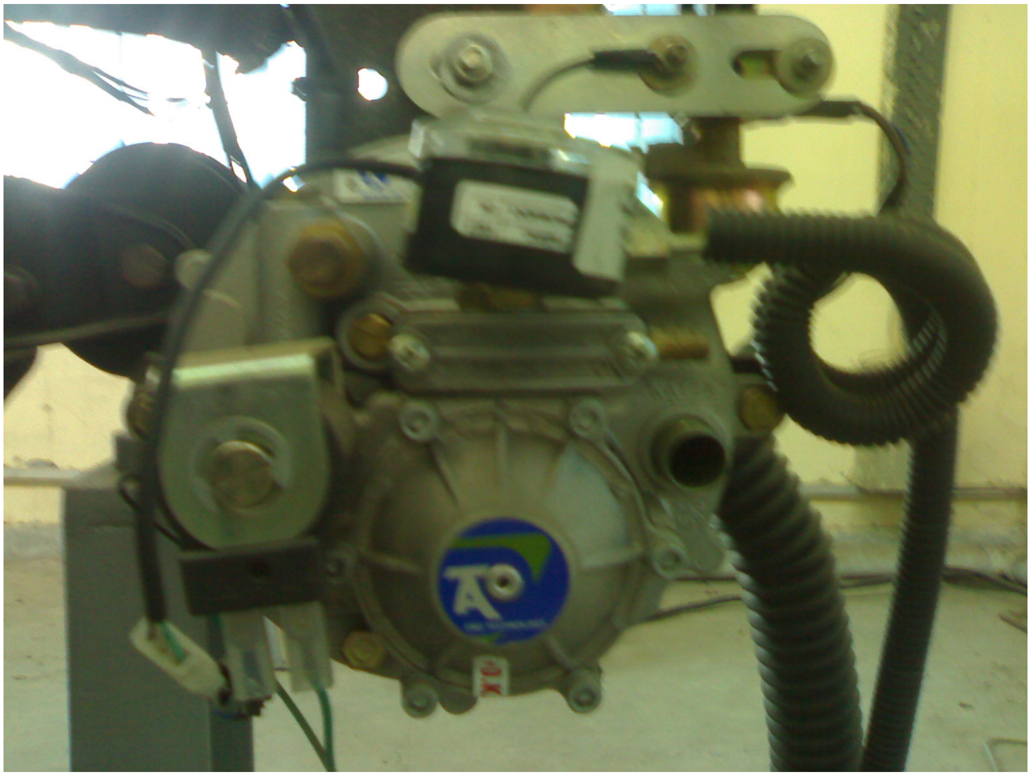


FIG-14. : CNG CONVERSION KIT

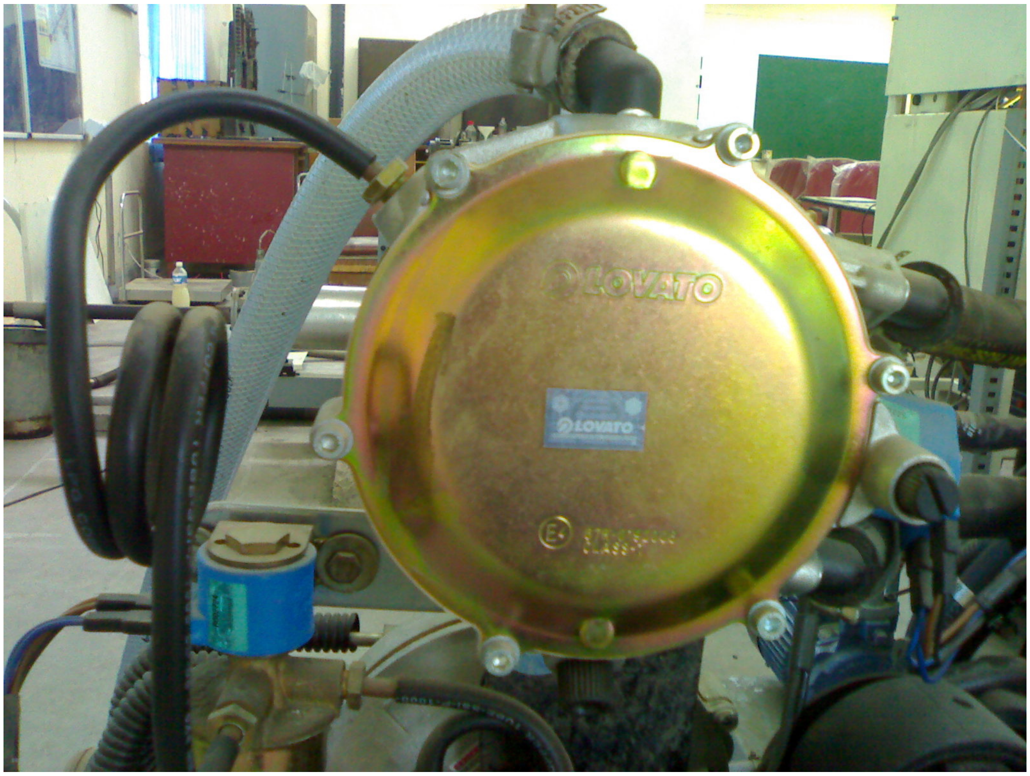


FIG-15. : LPG CONVERSION KIT

ENGINE TEST SETUP SPECIFICATIONS

Engine	Make- Maruti, Model Wagon-R MPFI, Type 4 Cylinder, 4 Stroke, Petrol (MPFI), water cooled, Power 44.5kw at 6000 rpm, Torque 59 NM at 2500rpm, stroke 61mm, Bore 72mm, 1100 CC, CR 9.4:1
Dynamometer	Type eddy current, water cooled, with loading unit, Make- Saj test plant Pvt. Ltd., Model AG80
Propeller shaft	With universal joints, Make Hindustan Hardy Spicer,
Air box	M S fabricated with orifice meter and manometer (Orifice dia 40 mm)
Fuel tank	Capacity 15 lit with glass fuel metering column
Calorimeter	Type Pipe in pipe, 25-250 LPH
Rotameter	Make Eureka Model PG 5, Range 25-250 lph, Connection ¾” BSP vertical, screwed, packing Neoprene
Rotameter	Make Eureka, Model PG 9, Range 100-1000 lph, Connection 1” BSP vertical, screwed, packing Neoprene
Piezo sensor	Make PCB Piezotronics, Model HSM111A22, Range 5000 psi, Diaphragm stainless steel type & Hermetic Sealed
Crank angle sensor	Make Kubler-Germany Model 8.3700.1321.0360 Dia: 37mm Shaft Size: Size 6mmxLength 12.5mm, Supply Voltage 5-30V DC, Output Push Pull (AA,BB,OO), PPR: 360, Outlet cable type

	axial with flange 37 mm to 58 mm
Load indicator	Make Selectron, model PIC 152–B2, 85 to 270VAC, Retransmission output 4-20 mA
Battery	Make Exide, Model MHD 350 06687, 12 V DC
Engine indicator	Input Piezo sensor, crank angle sensor, No. of Channels 2, Communication RS232
Digital milivoltmeter	Range 0-200mV, panel mounted
Temperature sensor	Make Radix Type K, Ungrounded, Sheath Dia.6mmX110mmL, SS316, Connection 1/4"BSP (M) Adjustable compression fitting
Fuel measuring unit	Make Apex, Glass, Model: FF0.090
Temperature Transmitter	Make Wika, model T19.10.3K0-4NK-Z, Input Thermocouple (type K), output 4-20mA, supply 24VDC, Calibration: 0-1200deg.C
Load indicator	Digital, Range 0-50 Kg, Supply 230VAC
Load sensor	Make Sensotronics Sanmar Ltd., Model 60001, Type S beam, Universal, Capacity 0-50 kg
Fuel flow transmitter	DP transmitter, Range 0-500 mm WC
Air flow transmitter	Pressure transmitter, Range (-) 250 mm WC
CNG Conversion Kit	Make: Tomasetto Achilles
LPG Conversion Kit	Make: LOVATO

7. OBSERVATIONS OF THE PERFORMANCE EVAUATION TEST

In this project work my main aim is to analyze the performance and emissions analysis of a multi cylinder SI engine with Gasoline, CNG and LPG at different load conditions.

Ethanol in gasoline can favorably impact mobile source emissions in five main air quality areas: these areas are fine particulate matter (PM), carbon monoxide, toxics, ozone, and global warming.

Here in this performance evaluation test we are showing different curves b/w load (watt) vs. Thermal efficiency, Bsfc, CO, HC, NO_x. The various performance and emissions curves for Gasoline, CNG and LPG are given in the following pages.

7.1 Observation Tables

Table-7: Variation in various parameters with the Power for Gasoline

Power (kW)	η_{th}	BSFC (Kg/KWh)	CO (%)	HC (ppm)	NO_x (ppm)
4.5	13.6	0.37	4	500	200
14	16.9	0.35	2.5	450	300
26	23.6	0.34	2.1	340	500
32	27.4	0.32	1.1	275	610
34	32.2	0.30	0.75	240	770
37	29.6	0.41	0.45	205	850

Table-8: Variation in various parameters with the Power for CNG

Power (kW)	η_{th}	BSFC (Kg/KWh)	CO (%)	HC (ppm)	NO_x (ppm)
4.5	14.1	0.30	2.5	400	200
14	18.0	0.29	1.35	355	300
26	24.1	0.27	1.2	220	445
32	27.2	0.25	1.05	185	615
34	31.7	0.28	0.78	160	760
37	29.9	0.30	0.47	100	840

Table-9: Variation in various parameters with the Power for LPG

Power (kW)	η_{th}	BSFC (Kg/KWh)	CO (%)	HC (ppm)	NO_x (ppm)
4.5	14.2	0.32	2.8	420	209
14	18.2	0.31	1.6	400	305
26	18.6	0.31	1.4	250	450
32	26.9	0.33	1.1	200	619
34	31.5	0.31	0.7	175	780
37	29.1	0.29	0.4	140	880

7.2 Comparative Performance and Emissions Curves

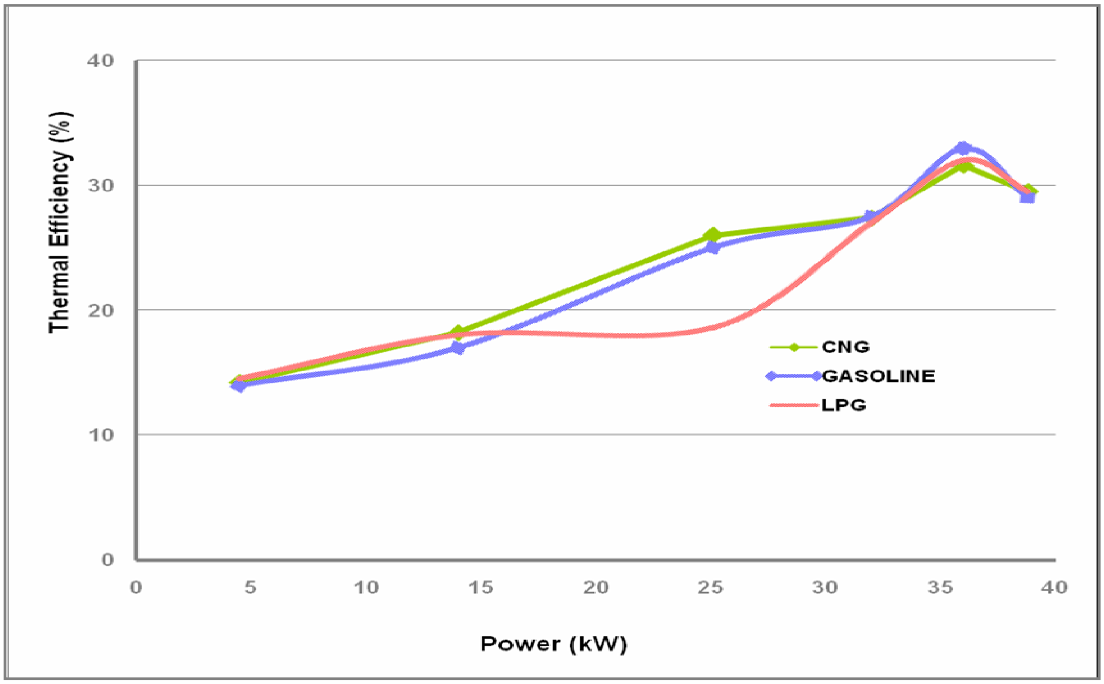


Figure-17: Curve b/w Thermal efficiency vs. Power (kW)

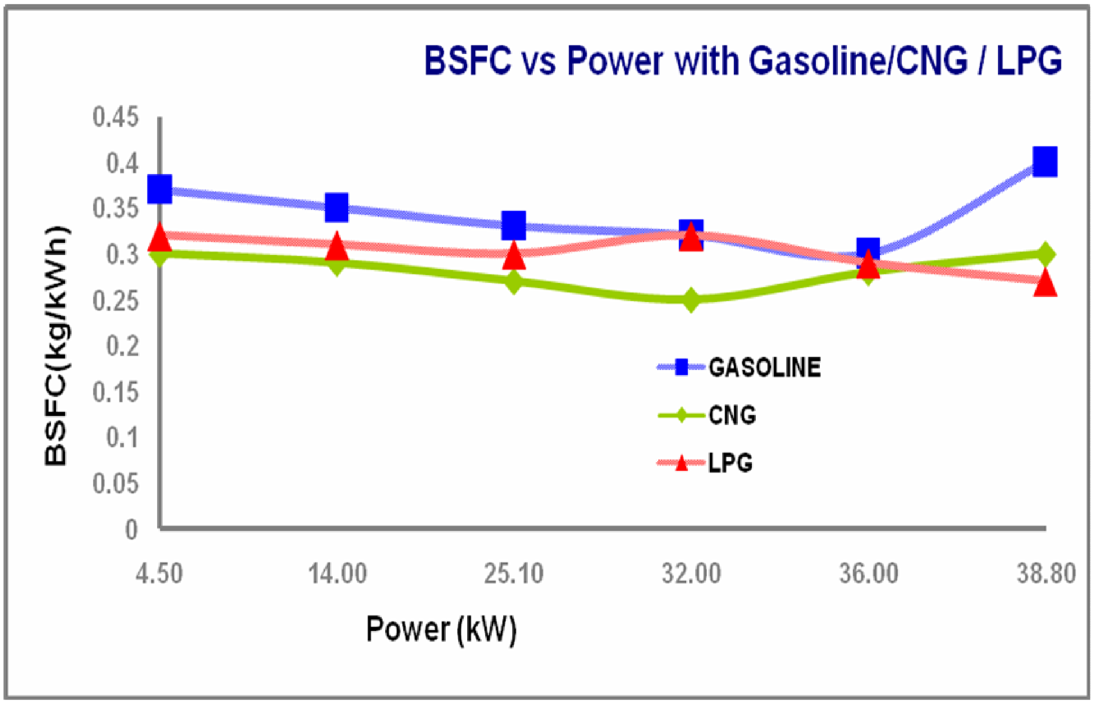


Figure-18: Curve b/w Bsfc vs. Power (Watt) (Gasoline)

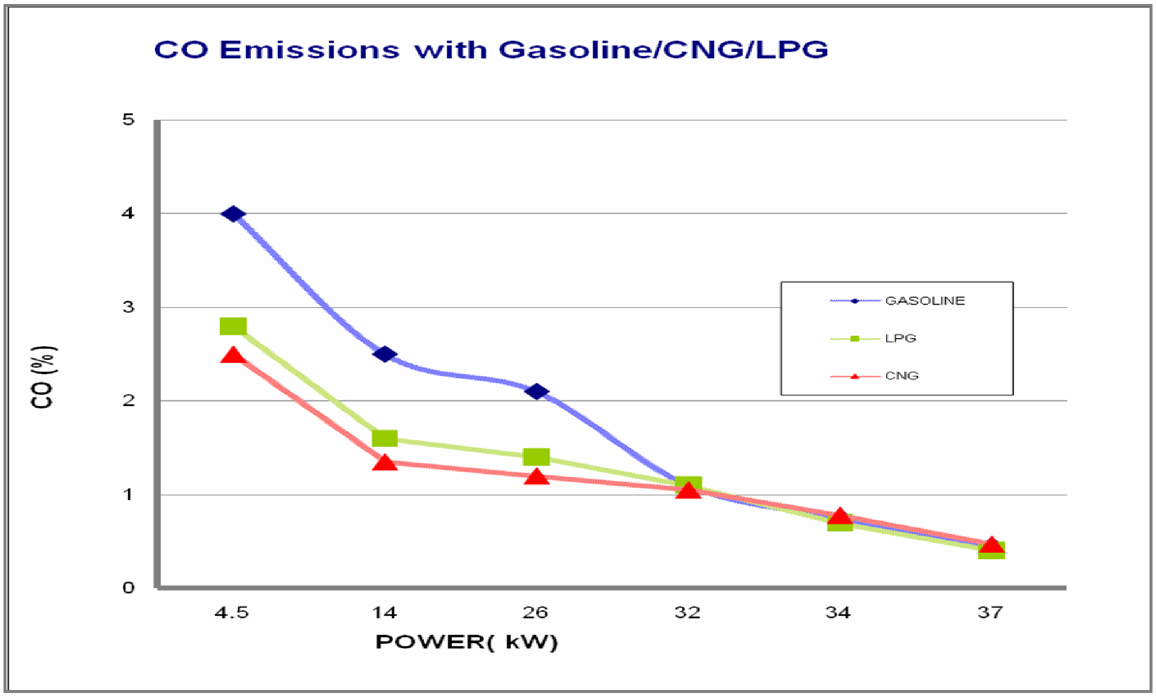


Figure-19: Curve b/w CO (%) vs. Power (kW) for Gasoline, CNG & LPG

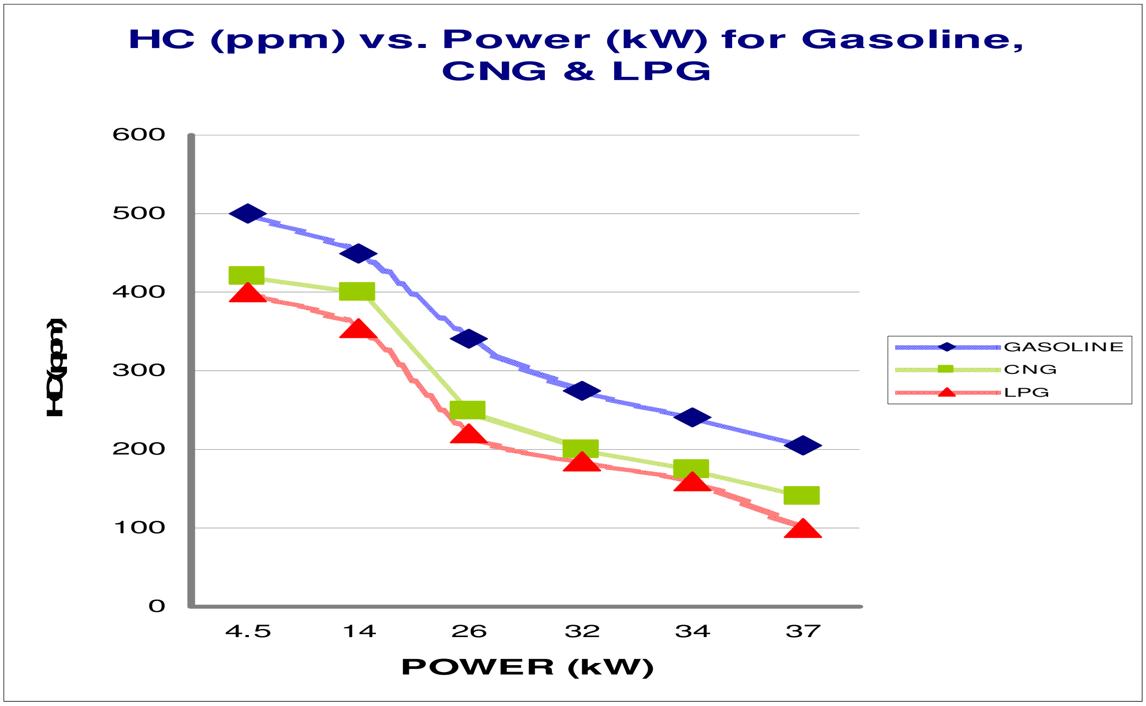


Figure-20: Curve b/w HC (ppm) vs. Power (kW) for Gasoline, CNG & LPG

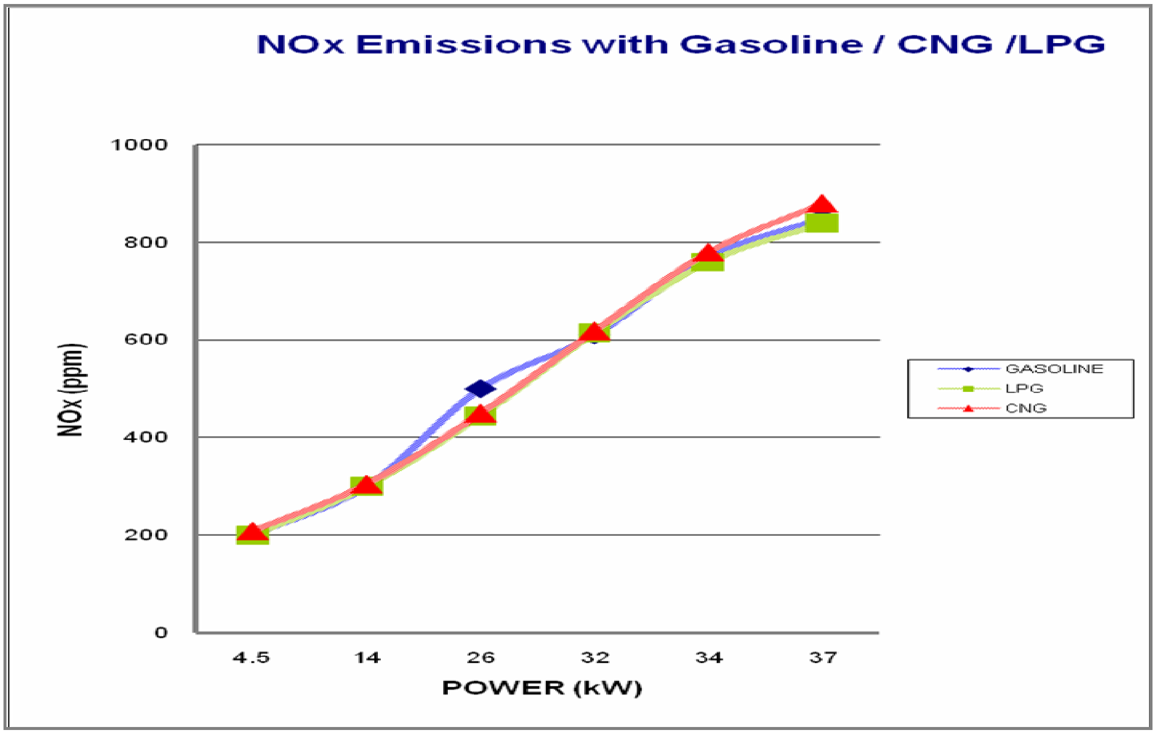


Figure-21: Curve b/w NO_X (ppm) vs. Power (kW) for Gasoline, CNG & LPG

CONCLUSION

The benefits of CNG and LPG as alternate automotive fuels may not be realized by simply using them in an unmodified petrol engine. As the test results indicate, the energy content of CNG and LPG is the most limiting factor in acceptance for fuel economy and performance reasons. Optimum performance is achieved by using gasoline but alternate fuels ie. LPG and CNG aid in emissions reduction in terms of CO and HC emissions but still in terms of NO_x emissions no considerable difference is noticed.

- The results of Thermal Efficiency vs. Power show that gasoline gives the most optimum thermal efficiency, especially at higher power, closely followed by CNG and LPG. Therefore for engines designed to run on gasoline, LPG and CNG can be close substitutes but cannot achieve the same level of thermal efficiency across the power range. As the test rig engine ie. Wagon –R, 4 cylinder, in line engine was basically a gasoline engine, thermal efficiency showed the above mentioned trend.
- Considering the trend of BSFC vs. Power for the three fuels it is observed that CNG gives the lowest BSFC vis-à-vis Gasoline and LPG even when used to run an engine designed for gasoline, although it increases somewhat at very high power. This observation reinforces the fact that optimum BSFC is achieved by using CNG even in an unmodified gasoline engine.

- Use of CNG and LPG in Gasoline engines reduces the CO emissions vis-à-vis gasoline but at higher loads this drop in emissions is not realized.
- Drop in HC emissions is consistent throughout the power range in case of CNG and LPG as compared to gasoline.
- There is no considerable difference w.r.t NO_x emission when the engine was run on gasoline, CNG and LPG. Therefore the gains of low NO_x emissions cannot be achieved by using the alternate fuels in an engine designed for gasoline.

FUTURE SCOPE OF WORK

The recommended future scope of work can be performing the experiments with a Variable Compression Ratio Engine. As the Octane number of CNG and LPG is much higher than gasoline, therefore higher compression ratios can be employed to achieve higher thermal efficiencies and lower BSFC. This would lead to an optimization of performance of SI engines when driven with these alternate fuels such as CNG and LPG.

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