THE PERFORMANCE AND EMISSIONS ANALYSIS OF A MULTI CYLINDER SI ENGINE WITH VARIOUS BLENDS OF ETHANOL-GASOLINE

A major thesis submitted in partial fulfillment
of the requirements for the award of the degree of

Master of Engineering
In
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By

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Under the able guidance of
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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this project report entitled, "**THE PERFORMANCE AND EMISSIONS ANALYSIS OF A MULTI CYLINDER SI ENGINE WITH VARIOUS BLENDS OF ETHANOL-GASOLINE**" submitted as major project towards the fulfillment of the requirements for the award of the degree of Master of Engineering with specialization in Thermal Engineering, D.C.E. Delhi, is an authentic record of my own work carried out under the supervision of **Prof. Amit Pal,** Mechanical Engineering Department, at Delhi College of Engineering, Delhi.

The matter embodied in this dissertation report has not been submitted by me for the award of any other degree.

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of knowledge.

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ABSTRACT

As energy crunch loom large. Fossil fuel stocks are falling. Oil price have broken the $140 barrier par gallon. Many countries are switching to bio-fuels. The EU has decided to use 5.75 % bio fuels like ethanol for motor cars by 2010. China plans to use 10%bio-fuels by 2010. The US already produces about 10 million tones Ethanol. Interestingly, Henry Ford, the father of modern automobile was an ardent advocate of ethanol as a fuel for motor cars. He was a great believer in recycling. Presently we are using 5% ethanol blend with petrol which can be increased to 10%.Brazil is already using 10% ethanol blended with petrol in motor cars which can be increased to 100% ethanol dedicated vehicle. Researchers have shown that the use of high ethanol fuels can results in up to a 66 % reduction of hydrocarbon emissions. Hydrocarbon typically represents 80 % of total vehicle emission. Current vehicle are capable of using E 10, a blend of 90 % gasoline and 10% ethanol. The production and research on ethanol compatible vehicles has increased in recent years with a focus on six years of importance: the engine, engine control system, cold starting strategy, emission control, compatible materials and safety. This major project report is concentrated on high energy content of different ethanol-gasoline blends E5, E7.5, E10 E12.5, E15, and an effort to cover all the other important areas of concern.

Conventional fuel such as gasoline and diesel are causing serious environmental issues due to their high amount of pollutants. Therefore, in this project blending of ethanol in gasoline is analyzed in order to reduce harmful emission to a safer level.

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1. INTRODUCTION

1.1 Project Background

With the stock of fossil fuels diminishing throughout the world and demand for energy based comforts and mobility ever increasing, time is ripe that we strike a balance between energy security and energy usage. Moreover having uplifted to such a sphere of engineering excellence, reverting back to the ages of the bull carts will prove next to impossible thereby compelling us to search for a basket of alternative fuels to derive energy to cater to our needs. Several sources of energy, especially for driving the automotives are being developed and tested. Judicious utilization of this basket of energy is the call of the hour for a nation to see itself through the tough days ahead.

Today's engine development is heavily controlled by increasingly stringent emission legislation, leading to rapid developments. The EEV (Enhanced Environmental Friendly Vehicles) standard is coming into force for polluted cities, creating an extra incentive for the development of extra clean vehicle technology. The future of gaseous/alternative fuels depends on the maximum limit of polluting emissions allowed, the technology available and the cost of concepts developed. Promising developments are taking place in the area of the conventional prime mover, the S.I. engine.

Environmental issues regarding the emission of conventional fuels such as gasoline and diesel are of serious concern worldwide. The standard emission from conventional fuel vehicles are hydrocarbon (HC), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x) and particulate matter (PM). These emissions are harmful gases which can have adverse impact on human body and destroy the environment by playing an important role in formation of the greenhouse effect, acid rain and global warming. Therefore, alternative fuels such as Ethanol (alcohol), natural gas, liquefied petroleum gas (LPG), are being considered to replace the role of conventional fuels in order to reduce these harmful emissions from being released to the atmosphere. These alternative fuels may possibly contribute to a significant reduction in emission in most, vehicles operating worldwide**.**

At the end of the day the concept that fulfils all legislative requirements and can be sold at the lowest price will be the winner and that may be an engine running on a conventional or on an alternative fuel or most likely on both.

The alternatives to petroleum-based fuels must meet the following criteria, if they are going to be used widely for transportation.

- Technically acceptable
- Economically competitive
- Environmentally acceptable
- Safe & easily available

Based on the above criteria, several alternate fuels have been considered from time to time all over the world as low cost substitutes for gasoline and diesel. Lately they have gained importance as clean fuels. The prominent among these are Ethanol, biodiesel, electric fuel,, hydrogen, methanol, natural gas (CNG/LNG), propane (LPG), DME, P-series and solar fuels**.**

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. In this era of credit trading and with new data there is always a lot to do to integrate these air quality areas with respect to ethanol. For example, ethanol currently is the only compound that can be blended with gasoline to help reduce global warming; yet there is no program in place to offer any credit in this area.

2. LITERATURE REVIEW

SI ENGINE EMISSIONS

When considering the exhaust emissions from Spark Ignition engines, it is important to recall that we are dealing with premixed combustion. A 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. As you know, the products of rich combustion differ from those of lean combustion. Recall 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 as shown in figure.

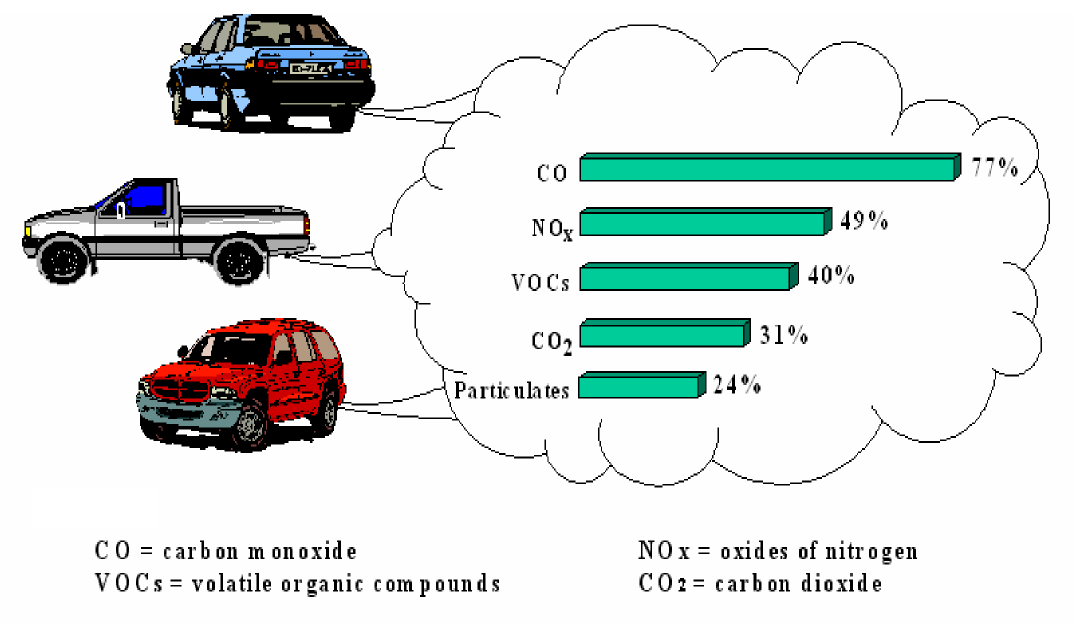


Figure-1: Composition of exhaust gases

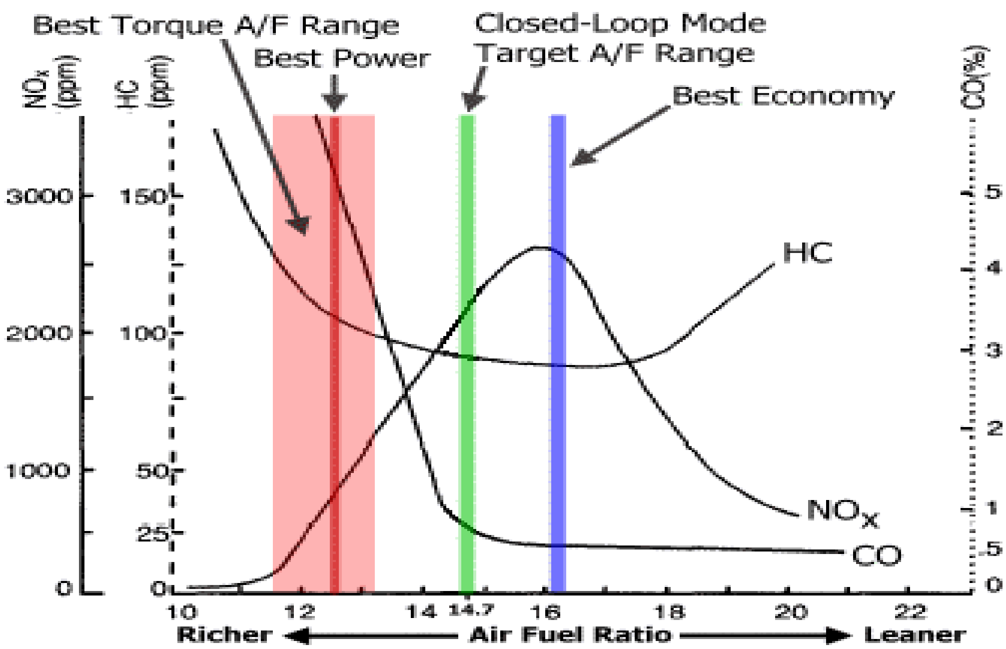


Figure-2: Variation of NO, CO and HC emissions with fuel-air ratio

For the ideal combustion of a hydrocarbon fuel we would have only carbon dioxide and water vapor in the exhaust. However, as we know, 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. [3]

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)

Let us now consider some of these emissions in more detail; in particular, we will consider the source of these emissions within an SI engine, their potential impact, and methods for their control.

2.1 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.

<u>Formation of NOx</u>

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) <u>Thermal NOx</u>

It is formed by the stabilization of atmospheric nitrogen in oxidizing atmospheres at a high flame temperature exceeding 1573K or 1300 ℃. 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 ℃. The formatio n 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]

<u>Factors Affecting NOx Emissions</u>

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]

2.2 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).

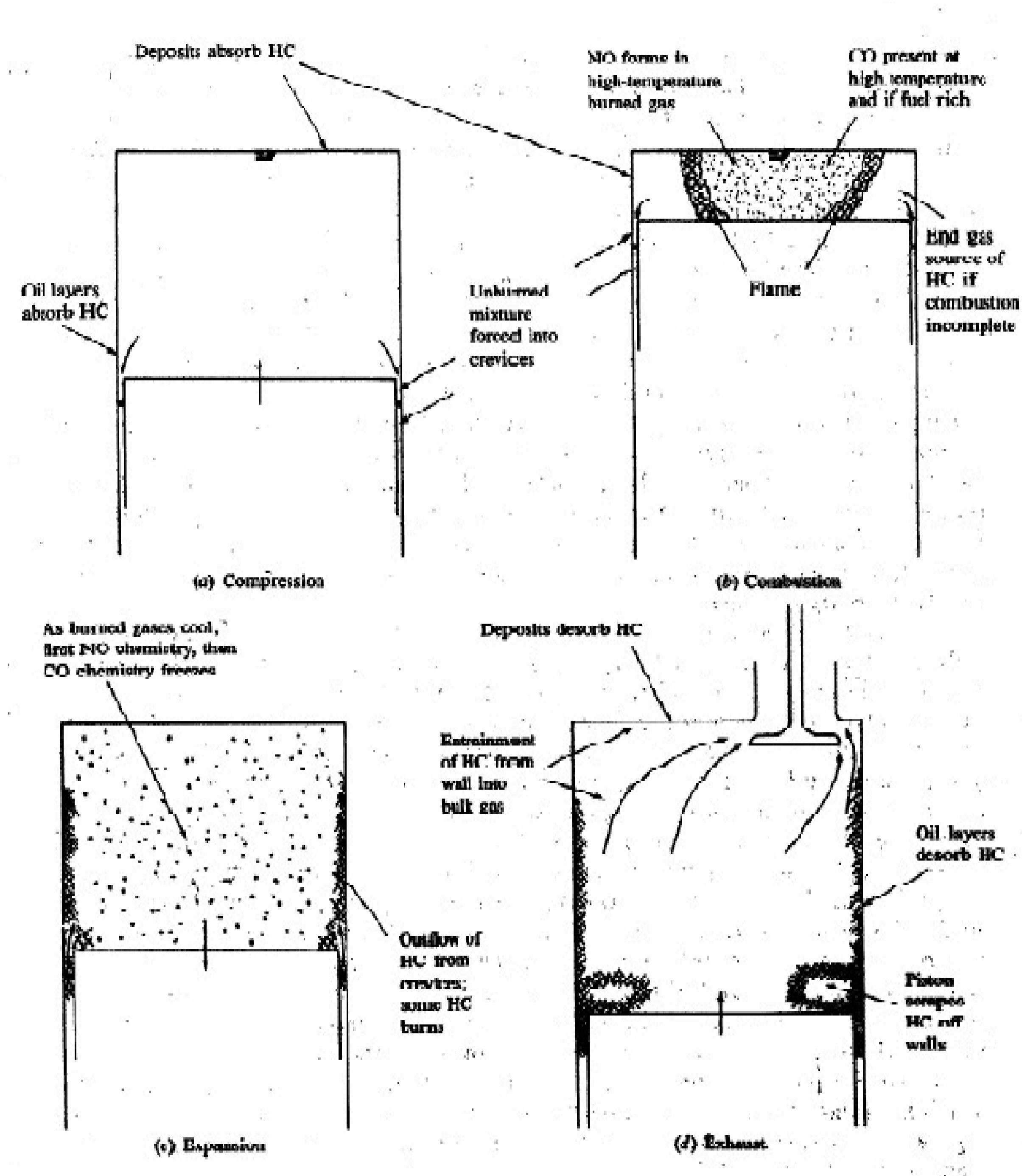


Figure-3: Formation Mechanisms of Major Pollutant Species in SI Engines

2.3 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]

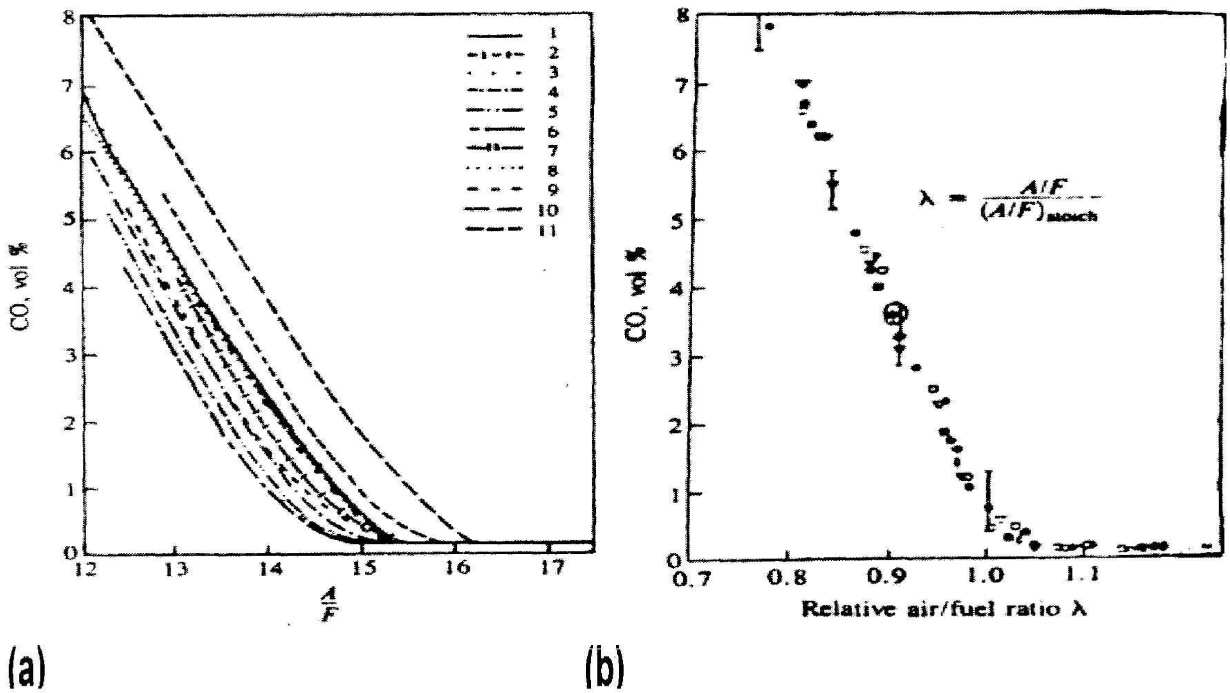


Figure-4: Variation of SI engine CO emissions with various fuels (a) with air/fuel ratio; (b) with relative air/fuel ratio (λ)

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

RH----› R----› RO_2----› RCHO----› RCO----› 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 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]

2.5 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 . [3]

2.6 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. [3]

3. EMISSION CONTROL STRATEGIES FOR S.I. ENGINES

3.1 Alternative Fuel:-

In this project we mainly emphasizing on using Ethanol as an alternative fuel so we will discuss about it in details in section-5, here we are discussing in brief about various alternative fuels also.

3.1.1 Liquefied petroleum gas (LPG) as an alternate fuel

Production

LPG is often produced from raw natural gas when this is processed into pipeline quality natural gas. LPG is also produced when crude oil is refined.

Chemistry

LPG 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 so, for safety reasons, a pungent compound, mercaptan is added to make any leaks easily detectable.

The main component gases of LPG are-

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

Each gas undergoes a separate reaction during combustion:

Propane: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

Propylene: $2C_3H_6 + 9O_2 \rightarrow 6CO_2 + 6H_2O$

Butane: $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$

Environmental considerations

The use of LPG is widespread, with an estimated 250,000 vehicles running on it in Australia. Of these, around 180,000 are privately owned. Estimates are that exhaust and evaporative greenhouse emissions are approximately 15 per cent lower from LPG than from petrol vehicles. It does not need lead or other additives to boost its octane rating.

Comparisons of the levels of noxious gas emissions from LPG and petrol vehicles are inconclusive, with test results indicating both higher and lower levels of petrol vehicles. Some recent tests suggest that noxious emissions are worse from LPG vehicles. LPG is a non-renewable resource.

Economic considerations

LPG is available Australia-wide through the service station networks. When converted to a gas, LPG expands up to 270 times. This means that the liquid form which is easily achieved is a very efficient way of carrying large amounts of gas. In general economic terms it is unattractive, requiring a subsidy in the form of an excise exemption as an incentive to consumers who must cover the costs of conversion of the vehicle to operate on LPG.[9]

3.1.2 Compressed Natural Gas (CNG) as an alternate fuel

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. Natural gas is consumed in the residential, commercial, industrial, and utility markets.

The interest in natural gas as an alternative fuel stems mainly from its clean burning qualities, its domestic resource base, and its commercial availability to end users. Because of the gaseous nature of this fuel, it must be stored onboard a vehicle in either a compressed gaseous state (CNG) or in a liquefied state (LNG). [8]

Chemical Properties

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.

Production

Natural gas is comprised of a mixture of gases, mainly hydrocarbons, found in geological formations. Methane is the principal component, generally comprising from 87 per cent to 97 per cent by volume of the hydrocarbons depending on the source of the gas.

Chemistry

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})

It can be compressed and used as an automotive fuel.

Its combustion is given by:

$CH_4+2O_2 =CO_2+2H_2O$

Environmental considerations

Because of its high octane number, CNG is an excellent fuel for spark ignition engines. Older cars are not difficult to convert from petrol to CNG. However, as engine management systems become more complicated, conversions are becoming more difficult or involve non-optimal engine operation. As a gas it can pose safety hazards during necessarily frequent refueling operations. Although when properly operated and maintained, leakage of CNG is minimam it should be noted that methane is an even more active greenhouse gas than CO_2.

Emissions from CNG-powered vehicles depend on the quality of the vehicle's conversion. In older cars without catalytic converters, non-methane hydrocarbon, CO and nitrogen oxides in exhausts from CNG-fuelled cars are much less than from petrol-driven vehicles. There is less difference between emissions from petrol and CNG in cars with catalytic converters; in both instances emissions are greatly reduced. CO emissions are the same while nitrogen oxide emissions may be slightly higher from CNG. Overall there appears to be slightly less greenhouse gas emission from CNG vehicles compared to petrol vehicles. Use of CNG 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 expected to rapidly penetrate 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. [8]

<u>Economic considerations</u>

The benefits of CNG are thus greatly reduced, because the compression ratio and engine efficiency of dual-fuelled cars cannot be increased to take advantage of CNG's high octane number. Storage of CNG is also a problem. Because of its low boiling point, natural gas must be stored in high pressure tanks. These are heavy, reducing payload and space in smaller vehicles. A CNG-fuelled car with a 75 litre tank is about 150kg. heavier than a petrol-driven car of the same size. This is not such a problem with large vehicles such as buses. Natural gas is lighter than air, and will dissipate into the atmosphere if leakage occurs. Like LPG, it is usually odorized to make it detectable. It is non-toxic and non-reactive.

The major problems with CNG are that it is uneconomic because the cost of converting cars is high and the short range between refueling is inconvenient.

3.1.3 Methanol as an alternate fuel

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.

Chemical Properties:

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).

Production

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:

$$CO + 2H_2 \rightarrow CH_3OH$$

At present, however, natural gas is by far the most economically and environmentally viable source.

Chemistry

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.

Environmental considerations

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.

Economic considerations

Methanol is a high cost fuel compared with petrol, but relatively cheap compared with other options. 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]

3.1.4 Hydrogen as an alternate fuel

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: -

• Stronger national energy security
• Reduced greenhouse gas emissions
• Improved air quality
• Increased energy efficiency

Production

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.

Chemistry

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.

Environmental considerations

Because hydrogen produced by electrolysis is an indirect user of electricity, which is most often derived from fossil fuel-powered stations, the complete production process may indirectly involve considerable CO_2 emissions. For the total environmental effect of hydrogen to be positive, the electricity used in its production should be generated from renewable sources such as solar, wind or hydro-power.

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]

3.1.5 Electricity as an alternate fuel

Electricity can be used as a transportation fuel to power battery electric and fuel cell vehicles. When used to power electric vehicles or EVs, electricity is stored in an energy storage device such as a battery. 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. [9]

Production

Electricity is produced from power plants throughout the country, transmitted to substations through high voltage transmission systems, stepped down to lower voltages, and carried to homes and businesses through local distribution systems. This electricity is charged and stored in the onboard rechargeable batteries, which power the motor of the vehicles. 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.

Environmental Considerations

Electric vehicles (EVs) do not undergo any combustion process. Mechanical power is directly derived from electricity. There are no tailpipe emissions. Water is the only emission when hydrogen is used as the fuel in fuel cells but the process of commercial hydrogen production to feed the fuel cell is associated with some CO_2 emissions. Emissions that can be attributed to EVs are generated in the electricity production process at the power plant.

Economical Considerations

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. [10], [11]

3.2 After Exhaust Treatment Devices

Catalytic converters are now almost universally used for exhaust emission control in spark ignited engine vehicles. The catalytic converter consists of bed of an active catalytic material housed in a metal casing. The exhaust gas flow is directed over the catalyst bed where the pollutants are converted to harmless gases. The catalytic converter has advantage over the thermal reactor as the high conversion rates of pollutant are obtained at moderately low inlet exhaust gas temperatures, and the engine parameters like compression ratio, spark timing, air fuel ratio etc., can be maintained at the level required for optimum engine combustion and performance.

A catalytic converter besides its housing has three main components

1. Catalyst
2. Substate or Support, and
3. Intermediate coat or washcoat

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. [13]

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

Figure-5: Three way catalytic converter

Hydrocarbons and CO Reduction Techniques

Both unburned hydrocarbons and CO leaving an engine are the products of 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. **[**15]

Historically, initial attempts to control UHC and CO emissions were focused on thermal afterburning in which-

- Air is injected into the exhaust manifold close to the exhaust valves
- Causes further combustion and oxidation

There are, however, significant disadvantages to thermal afterburning, namely:

- An air pump is required, leading to increased inefficiency
- The additional combustion process can lead to increased NOx

NO_x Reduction Techniques

As we learned earlier, NOx emissions from IC engines are particularly sensitive to combustion temperature. Thus, the majority of NOx reduction techniques aim to reduce the in-cylinder temperature in some way.

Initial attempt to control exhaust NO_x emissions were concentrated on:

- retarding ignition timing, and/or
- operating with a leaner mixture (excess air)

In both of these cases combustion efficiency/power output is reduced.

3.3 Advanced Engine Technologies

There are other advance engine technologies which can reduce engine exhaust emissions some of them are as below-

3.3.1 Conversion of Two Stroke Engines in 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)

3.3.2 Exhaust Gas Recirculation

Exhaust gas recirculation (EGR) is the principal technique used to control SI engine NO_x emissions and was introduced in 1973 when the emissions standards for NO_x were first enforced in USA. A fraction of the exhaust gases are recirculated through control valve from the exhaust to the engine intake system. The recirculated exhaust gas is usually mixed with the fresh fuel air mixture just below throttle valve. By recirculating some of the exhaust gas back through the intake manifold to the cylinders, we can lower the combustion temperature. Lowering the combustion temperature lowers the amount of NO_x produced. Consequently, less of it comes out through the tail pipe. EGR principle is shown schematically in Figure. Initially a fixed orifice plate was used for metering the exhaust gas quantity to be recirculated. Later, to meet more stringent standards, spring loaded vacuum controlled and temperature compensated variable flow metering valve were used. It is seen that substantial reduction in NO_x emission are achieved with 10 to 25 % EGR. [14]

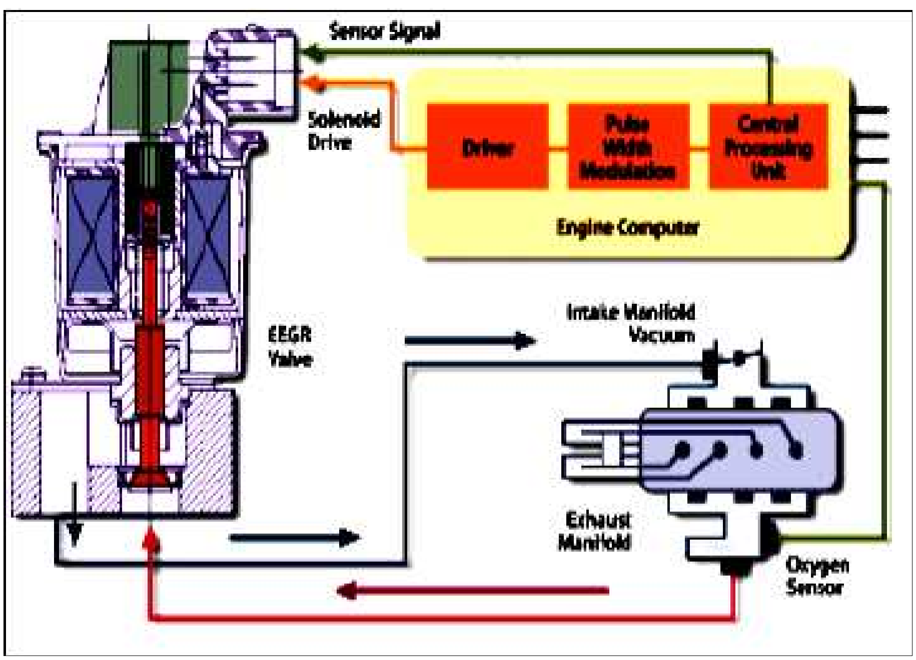


Figure-6: Exhaust Gas Recirculation System

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. [15]

3.4 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.

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.[15]

4. BASICS OF ETHANOL

4.1 Introduction

Ethanol (ethyl alcohol, grain alcohol, EtOH) is a clear, colorless liquid with a characteristic, agreeable odor. In dilute aqueous solution, it has a somewhat sweet flavor, but in more concentrated solutions it has a burning taste. Ethanol (CH_3CH_2OH) is a group of chemical compounds whose molecule contains a hydroxyl group (-OH), bonded to a carbon atom. Ethanol made from cellulosic biomass materials instead of traditional feedstocks (starch crops) is called **bio-ethanol.**

The Clean Air Amendments of 1990 mandated the sale of oxygenated fuels in areas with unhealthy levels of carbon monoxide. Since that time, there has been strong demand for ethanol as an oxygenated blend with gasoline. In the United States each year, more than 1.5 billion gallons are added to gasoline to increase octane and improve the emission quality of gasoline. In some areas ethanol is blended with gasoline to form an E10 blend (10% ethanol and 90% gasoline), but it can be used in higher concentrations such as E85 or in its pure form. [17]

Production:-The production phases in Ethanol production are shown in the following figure.

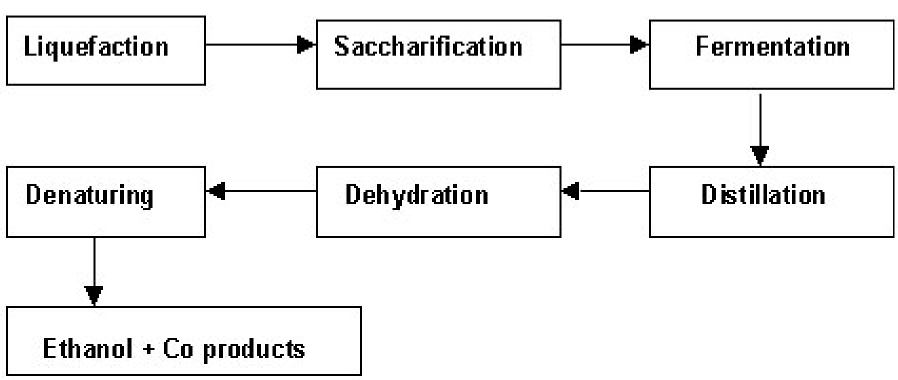


Figure-7: Ethanol Production Process

Fuel ethanol is denatured with small amount (2%-5%) of some product such as gasoline, to make it unfit for human consumption. Two main co products of ethanol production are CO_2 and distillers grain. Many ethanols collect the CO_2, clean it of any residual alcohol, compress it and sell it for use in carbonate beverages or to flash freeze meat.

4.2 Emissions Characteristics

Emission results of a test conducted by National Renewable Energy Laboratory (NREL), USA are given in the following table. The test was conducted on Taurus 1998 model with both E85 and gasoline RF-A (industry average gasoline). Table-3 shows the comparative emissions from ethanol and gasoline fuelled vehicle. [18]

Emissions in g/mi	**AFV-Ethanol**	**Gasoline**
NHMC	**0.10**	**0.10**
CO	**1.48**	**1.13**
NO_X	**0.12**	**0.09**
CO_2	**396.4**	**439.7**

Table-2:- Comparative Emissions (Ethanol vs. Gasoline)

Emissions of total weighted toxics (including benzene, 1-3, butadiene, formaldehyde, and acetaldehyde) for the E85 were 55% lower than that tested on gasoline.

A recent Australian study with E10 gives the following emission results:

- Decreased emissions of CO by 32%.
- Decreased emissions of HC by 12%.
- Decrease in non-regulated toxics like,
  1-3 butadiene decrease by 19%,
  Benzene decrease by 27%,
  Toluene decrease by 30% and
  Xylene decrease by 27%.
- Increase in non-regulated toxics, acetaldehyde increase by 180% and formaldehyde increase by 25%,1% increase in NO_x

Recent Australian life-cycle analysis work has revealed that E10 blends are considered greenhouse neutral. The same study revealed that E10 decreased tail pipe emissions of hydrocarbons and NO_x (25% and 15% respectively), but particulates (PM10) remained unchanged.

Advantages of Ethanol:-

Some of the advantages of Ethanol as an automotive fuel are-

- It reduces our dependence on imported fuels.
- It reduces air pollution.
- Ethanol is renewable.
- Refueling is akin to that of gasoline or diesel.
- Is applicable for both light and heavy-duty vehicles.
- More energy density compared to gasoline with optimized compression ratio.
- Maintenance assistance required is more or less identical to that of fuelled vehicles conventionally.

Disadvantages of Ethanol:

Some of the disadvantages of Ethanol are-

- Demands frequent refueling keeping the volume of the tank unaltered.
- Use of special compatible lubricants required.
- Ethanol, especially E85 requires special replacement parts.

Operation and Performance:

- High energy density compared to gasoline.
- No loss in power, acceleration and payload.
- Special lubricants are required.
- Special parts required.

It is estimated that the US automakers have about 250,000 light-duty E85 vehicles on the road by the year 2010.

4.3 Indian Initiatives on Ethanol

In the year 1980, IIP and IOC, R&D conducted a study with ethanol as the fuel in some 13-passenger cars including army vehicles. The test included city driving, highway driving and hill driving conditions. Some of the findings of this study are:-

- Loss in volumetric fuel economy of 1% and 3.9% with E10 and E20 fuels respectively under city driving conditions and 3.5% and 4.3% under highway driving conditions.
- Improvement in fuel economy in Ambassador and standard cars under hill driving conditions ranged from 4% to 13%.
- Cold starting at ambient temperatures from 0℃ to 30℃ remained unaffected.
- Hot startability and driveability demerits found higher with ethanol blends.
- No compatibility problems observed with metallic and non-metallic components.

Moreover a committee to look into all the aspects of introduction of Ethanol-Gasoline blend as an auto fuel was constituted by the MoP&NG. The committee was heading with the preliminary aim to introduce ethanol blends in the NCR but considering the economics and logistics, the committee could not mandate the introduction sometimes in the year 1999.

Ministry of Petroleum & Natural Gas (MoP&NG) launched three pilot projects in the country. The first project at Mirja was initiated on 15.4.2001, the 2nd at Bareilly on 22.6.2001 and the 3rd was launched at Manmad on 24.6.2001. Other technical and R&D activities are also been carried out in various parts of India.

Based on the experience of the pilot projects, Government of India on 29.11.2001 has taken a decision to introduce petrol blended with 5% ethanol for use in motor vehicles all over the country in a phased manner. In the first phase, the 5% ethanol blended petrol will be introduced in the States of Andhra Pradesh, Gujarat, Haryana, Karnataka, Maharastra, Punjab, Tamil Nadu and Uttar Pradesh. Rest of the States/Union Territories will be taken up in the second phase.

On the other hand, India is also working to blend 10% ethanol in petrol. The pilot projects and R&D initiatives are also lined up to study the feasibility of 10% ethanol-gasoline blend. Amendment in BIS specification to accommodate this 10% blend is being pursued. [19]

4.4 Ethanol's Properties

The Physical properties for the Ethanol are shown in Table-3. Ethanol has many characteristic qualities such as its distinctive intoxicating smell and pink color. [22]

Physical Property	Corresponding Value
Boiling Point	79^oC
Melting Point	-117^oC
Relative density	0.8
Solubility In Water	Miscible
Vapour Pressure,kpa at 20^O C	5.8
Relative Vapour Density	1.6
Flash Point	13^oC
Auto-Ignition Temperature	$363\ ^oC$
Explosive Limit, Vol % in Air	3.3-19

Table-3:- Physical Properties of Ethanol

Vapor Pressure: The vapor pressure of E85 and E10 (gasohol), is a very important characteristic property of this fuel. It determines the cold start behavior of an engine. At low temperatures it is very difficult to create vapor. Alcohol has lower vapor pressure than gasoline. As a result, cold starting with E85 is very difficult as compared with conventional gasohol and gasoline engine. The E10 curve demonstrates that the higher level of gasoline (90%) in this blend produces a much higher vapor pressure at temperatures below 30℉, where cold starting is very difficult. [18]

Calorific Value: In addition to ethanol's poor cold starting characteristics ethanol also has lower energy content than gasoline because of its chemical structure in which alcohol molecules contains fixed oxygen. E85 has 71.6% the energy of E10 as demonstrated in Table-4. This means it will require approximately 28.4% more E85 to produce the same heating value as gasohol. And in comparison to gasoline (43960/26800) =1.64 or approximately 64%more pure alcohol is required. [18]

Octane Number: E85 does offer a higher octane number, which allows for use in higher compression engines. This will increase thermal efficiency of engines and result in a slight decrease in fuel consumption.

Latent heat of vaporization: In comparison with gasoline, ethanol has very high latent heat of vaporization. For pure ethanol it is 2.91 times that of gasoline in a stoichiometric mixture. It result in an air temperature reduction of approximately 4.5℃, thus increasing the volumetric efficiency an d hence the power output.

Ethanol Fuel Mixtures:

Generally, the higher the ethanol component of a gasohol blend, the lower its suitability for standard car engines. Pure ethanol reacts with or dissolves certain rubber and plastic materials and must not be used in unmodified engines. Additionally, pure ethanol has a much higher octane rating (116 AKI, 129 RON) than ordinary gasoline (86/87 AKI, 91/92 RON), requiring changes to the compression ratio or spark timing to obtain maximum benefit. To change a pure-gasoline-fueled car into a pure-ethanol-fueled car, larger carburetor jets (about 30-40% larger by area) are needed. (Methanol requires an even larger increase in area, to roughly 50% larger.) Ethanol engines also need a cold-starting system to ensure sufficient vaporization for temperatures below 13 ℃ (55 ℉) to maximize combustion and minimize uncombusted non vaporized ethanol. On the other hand, if 10 to 30% ethanol is mixed with gasoline, no engine modification is typically needed. Many modern cars can run on these mixtures very reliably. [26]

Beginning with the model year 1999, an increasing number of vehicles in the world are manufactured with engines which can run on any gasoline from 0% ethanol up to 85% ethanol without modification. Many light trucks (a class containing minivans, SUVs and pickup trucks) are designed to be dual fuel or flexible fuel vehicles, since they can automatically detect the type of fuel and change the engine's behavior, principally air-to-fuel ratio and ignition timing to compensate for the different octane levels of the fuel in the engine cylinders. [20]

Characteristic	**E85**	**Gasohol**
Specific Gravity @60℉	0.78	0.73 - 0.76
Boiling Point (BP)	~173	77 - 410
Gross Heat of combustion (BTU/lb)	13935	19468
Net Heating Value (mass) (BTU/lb)	12,665	18,000
Net Heating Value (volume) (BTU/gal)	82,150	112,900
Heat of Vaporization (BTU/lb)	357	200
Vapor Pressure @ 100℉ (psi)	~2.5	8 - 16
Cetane Number	Below 15	Not Applicable
Stoichiometric A/F	9.7	14
Appearance	Pink, Colorless	Colorless to light amber
PRICE ($/gallon)	1.39	0.99-1.05

Table 4:-Characteristics of E85 and Gasohol

4.5 Materials Compatibility with E85

One of the most important issues with using E85 is to use materials unaffected by E85. Two basic materials problems exist with the use of alcohols such as-

1. Swelling and embrittlement of rubber fuel lines and oil-rings

2. Galvanic corrosion

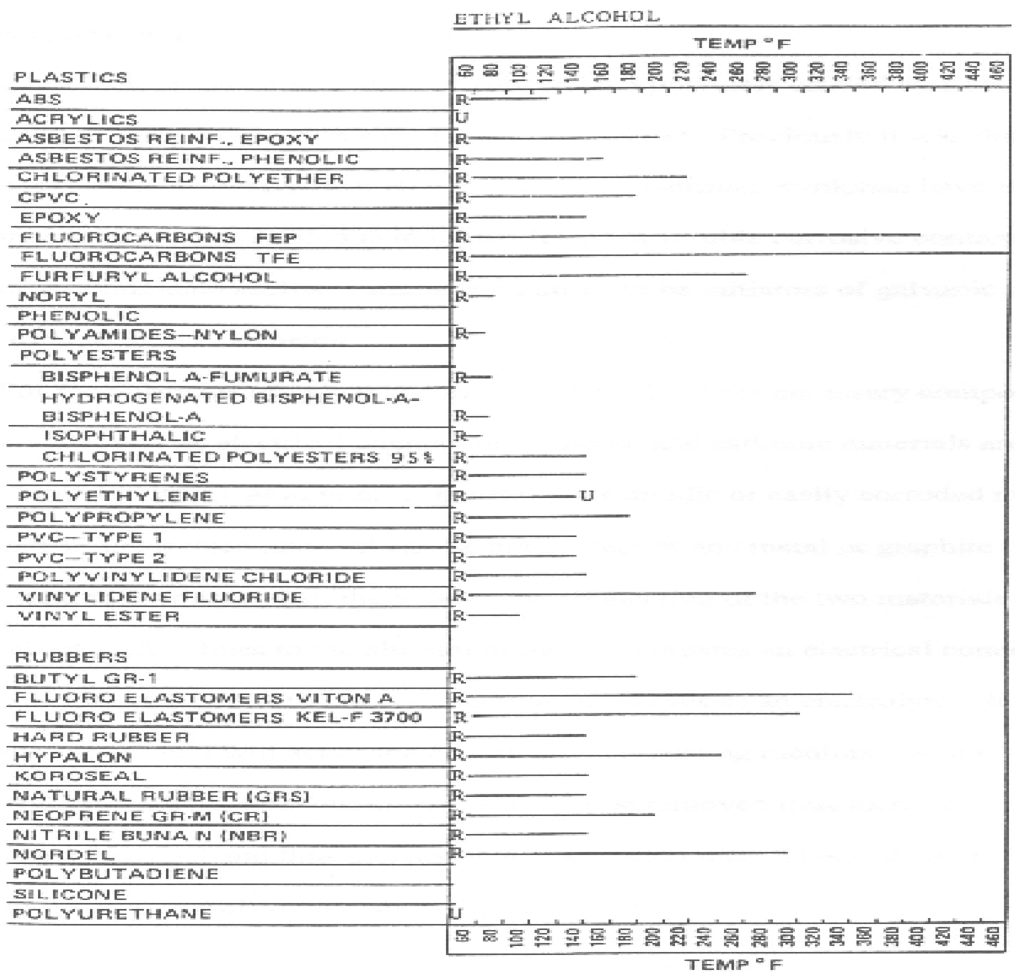
Causes and Solutions to Swelling and Embrittlement to Rubber Components

Swelling of rubbers associated with fuel is simply due to the absorption of fuel into the rubber. Once absorbed into rubber, the oxygen in alcohol fuels will break the rubber's carbon-carbon double bonds in the rubber and embrittle the rubber and cause swelling. The loss of bond strength creates a reduction in strength and results in failure. An additional problem with rubbers in fuel systems is the temporary attachment of hydrocarbons in the rubber to the hydrocarbons of the fuel. As a result, the hydrocarbons in the rubber may add to a fuel's hydrocarbon content, creating increased emissions.

Rubber Replacements

Embrittlement, swelling, and component breakdown can all be solved by the use of compatible materials listed in Table-6. In Table-6 the material resistance to ethyl alcohol is shown as a function of temperature. Vitons (DuPont's trade name) are the most unaffected materials in the presence of ethanol. Vitons are highly fluorinated elastomers, thus the name fluoro-hydrocarbon elastomers. Viton B, Viton GFLT, Viton GF are all acceptable materials to be used in an ethanol vehicle. [28]

Nylon components such as the fuel hoses that connect the main fuel supply to the main stainless steel fuel lines and the in-tank fuel pump reservoir are compatible with E85. Nylons demonstrate resistance to ethanol up to 80^oF. The strainer on the fuel pump is made of Saran, also a compatible material that exhibits no degradation.



R = Resistant, U = Unsatisfactory

Table-5:-Compatibility of Plastics with Ethanol

Fuel pressure regulators that are generally used in gasoline run vehicle are not E85 compatible. The rubber diaphragm used in pressure regulator gets swelled with E85. Rubber used for the fuel fill tube in modern vehicles is generally not acceptable for use with E85. Viton materials must be used to replace the existing tube. The tube must also have a flame arrestor built into its design. [21]

Fuel pump for dedicated ethanol vehicles (E85) must also be replaced. Current production vehicles use in-tank electric fuel pumps that run continuously. The E85 compatible fuel pumps are modified by the use of silicone rubber around the power and ground wires leading into the electric motor. Silicone rubber is used to prevent the E85 from contacting the electrical connections that will result in a concentrated corrosion cell.

Galvanic Corrosion

In addition to the deterioration of rubbers and polymers caused by E85, the deterioration of metal components is also very important. Previously it was thought that methanol was more corrosive than ethanol. Tests by Norman Brinkman have shown E85 to be more corrosive than M85 due to higher levels of soluble corrosive contaminants. Corrosion contaminants such as sulfates are known to be initiators of galvanic corrosion.

Sources of Galvanic Corrosion

For the existence of galvanic corrosion there are three necessary components: an anode, cathode, and an electrical connection. Anodic and Cathodic materials are listed in Table-6. In fuel systems, aluminum is generally the anodic or easily corroded material. The cathode or unaffected material can be brass, steel or any metal or graphite that is more resistant to corrosion than the anode. The connection of the two materials such as the stainless steel fuel lines to the aluminum fuel rails creates an electrical connection. Fuel such as E85 is also electrically conducting and serves as an electrolyte. Initially the sulfates and the ethanol will act as the electrically conducting medium (electrolyte) in the fuel. As the galvanic process continues metal will be removed thus increasing the conductivity of the fuel and thus increasing the corrosion rate.

This is demonstrated by Faraday's Law of Electrolysis shown in following Equation.

$$CR = Ki_{corr} = \frac{f\,EK}{\sum(R_i + G/k)}$$

CR Corrosion rate

f Faraday constant

K Proportionality constant

i_{corr} Electrical current flow through the solution-metal interface

E Voltage between the anode and the cathode

k Electrical conductivity

G Geometrical factor

R_i Interfacial impedances

For alcohol fuels the interfacial impedances are small relative to the G/k ratios. As a result, the interfacial impedance can be eliminated from above Equation to yield following Equation.

$$CR = \frac{f\,EK}{(G/k)}$$

In effect, the corrosion rate is limited by the conductivity of the fuel. When metal components corrode, their addition to the fuel system increase the corrosivity of the fuel. US Department of Energy suggests conductivity of not more than 5 µS/ cm.

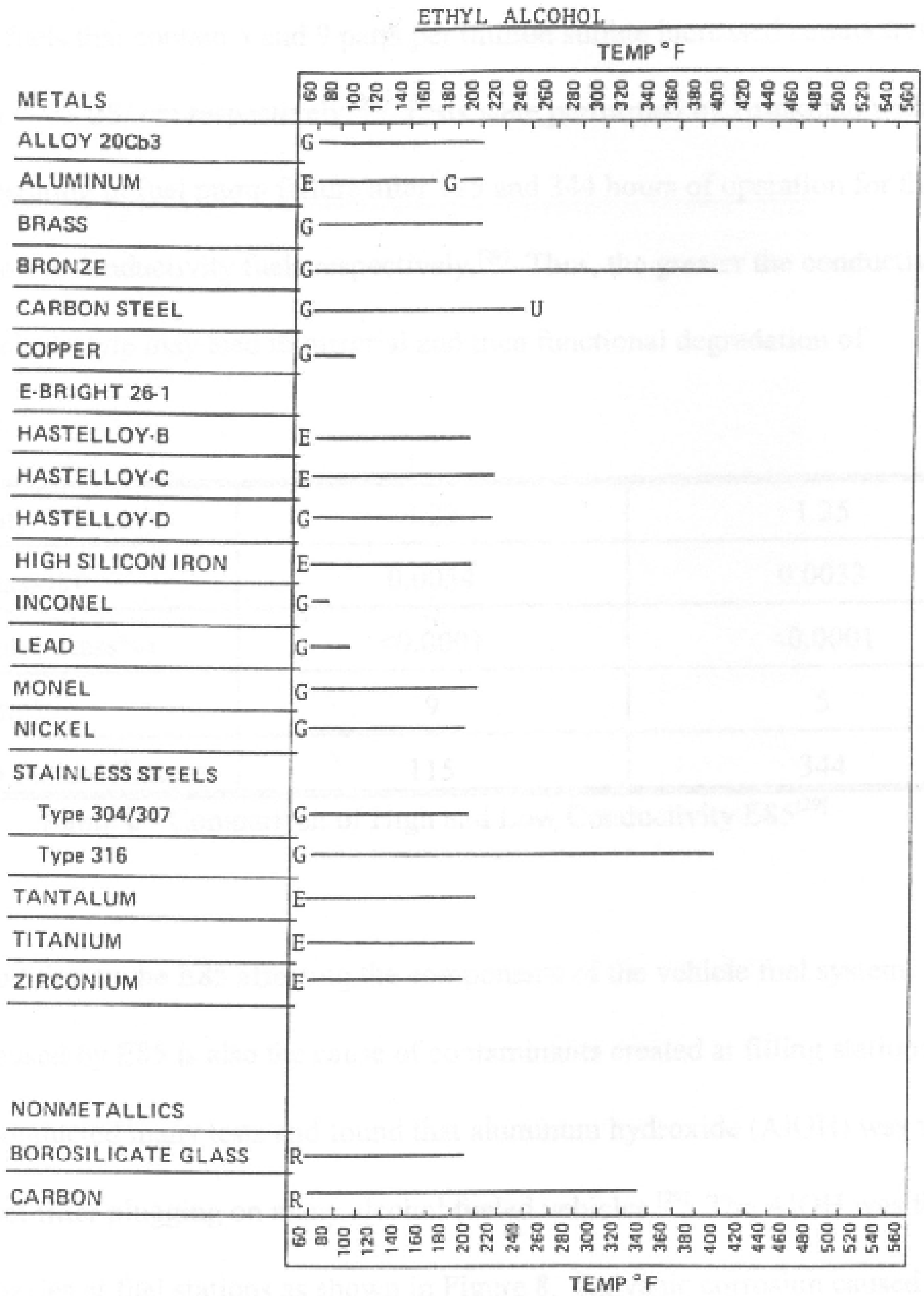


Table-6:-Compatibility of Metals with Ethanol

In addition to the E85 affecting the components of the vehicle fuel system, corrosion caused by E85 is also the cause of contaminants created at filling stations. A study conducted by Brinkman found that aluminum hydroxide (AlOH) is the source of fuel filter plugging on many alcohol fueled vehicles. The AlOH is found to be on the nozzles at fuel stations. Galvanic corrosion causes the formation of AlOH with the aluminum nozzle being the anode, the steel spring as the cathode and the E85 as the electrolyte. The aluminum nozzle also exhibits pitting corrosion from the E85. [20]

Solutions to Galvanic Corrosion

To reduce the galvanic corrosion, dissimilar metals should not be used in contact. To control the galvanic corrosion anodized aluminum and stainless steel components should be used when using alcohols. Fuel lines, tanks, and fuel filters must be made of Stainless steel. Anodization process creates an aluminum oxide layer that prevents further deterioration by isolating the reactive aluminum surface. The fuel rails experienced no deterioration as a result. To protect the fuel rails an inert coating should be applied to the interior and exterior of the fuel rails. E85 properties also must be controlled to insure that sulfates are not originally present in the fuel. [28]

5. 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-8: EXPERIMENTAL SETUP

The main aim of this experiment is to investigate the effects on performance and emissions of blending of ethanol with gasoline fuel in a four cylinder Wagon-R engine.

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

6. 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 various blends of ethanol-gasoline. In this project i have made five different blends of ethanol and gasoline i.e. E5, E7.5, E10, E12.5, E15 and run the engine on gasoline and these five blends, 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. In this era of credit trading and with new data there is always a lot to do to integrate these air quality areas with respect to ethanol. For example, ethanol currently is the only compound that can be blended with gasoline to help reduce global warming; yet there is no program in place to offer any credit in this area.

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 these blends are given below-

6.1 Gasoline:-

Q_{LHV}= 44.5 MJ/Kg

Load(Kg)	Power (watt)	η_{th}	BSFC (Kg/KWh)	CO (%)	HC (ppm)	NO_x (ppm)
0	0	-	-	1.8	103	184
2	675.76	12.60	.4953	1.2	82	221
4	1351.52	16.82	.37098	.87	75	374
6	2019.53	19.84	.3145	.40	69	744
8	2684.08	25.18	.2478	.28	64	1421
10	3344.32	30.6	.2037	.16	45	1663

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

6.1 Performance and emissions Curves For Gasoline

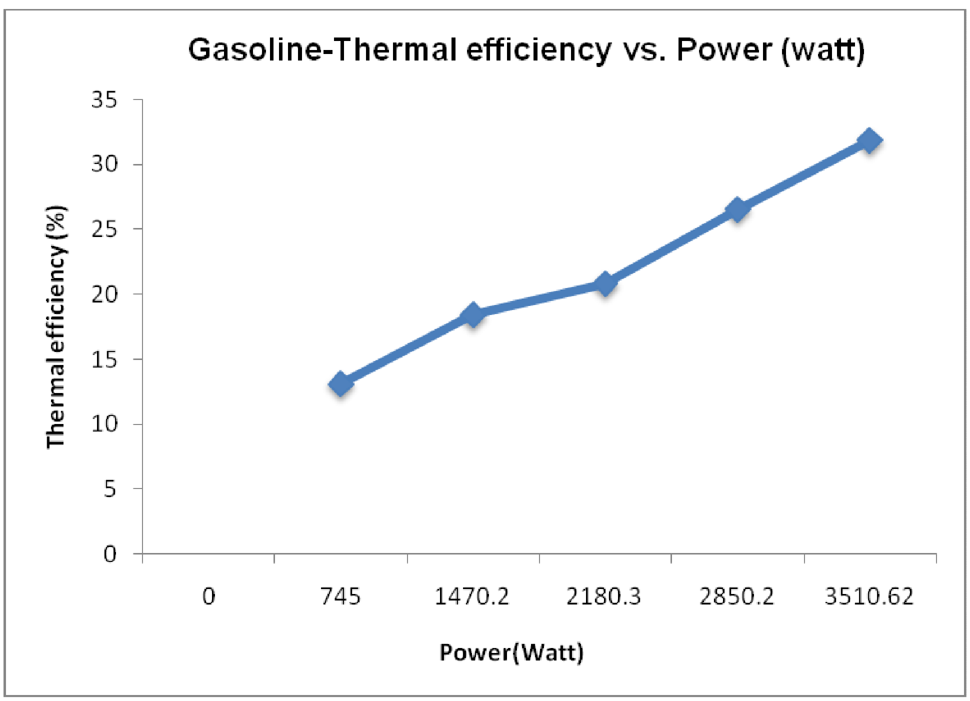


Figure-9: Curve b/w Thermal efficiency vs. Power (watt) (Gasoline)

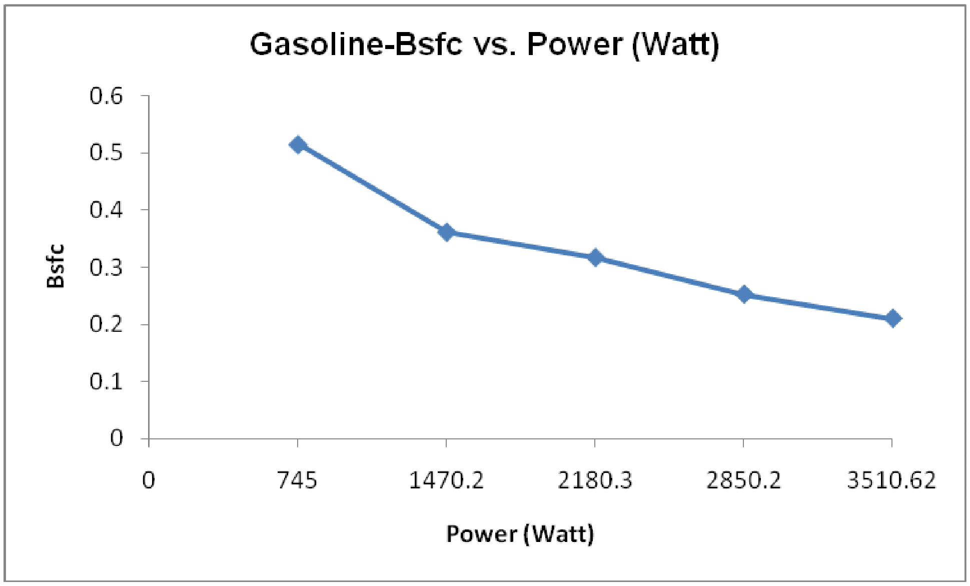


Figure-10: Curve b/w Bsfc vs. Power (Watt) (Gasoline)

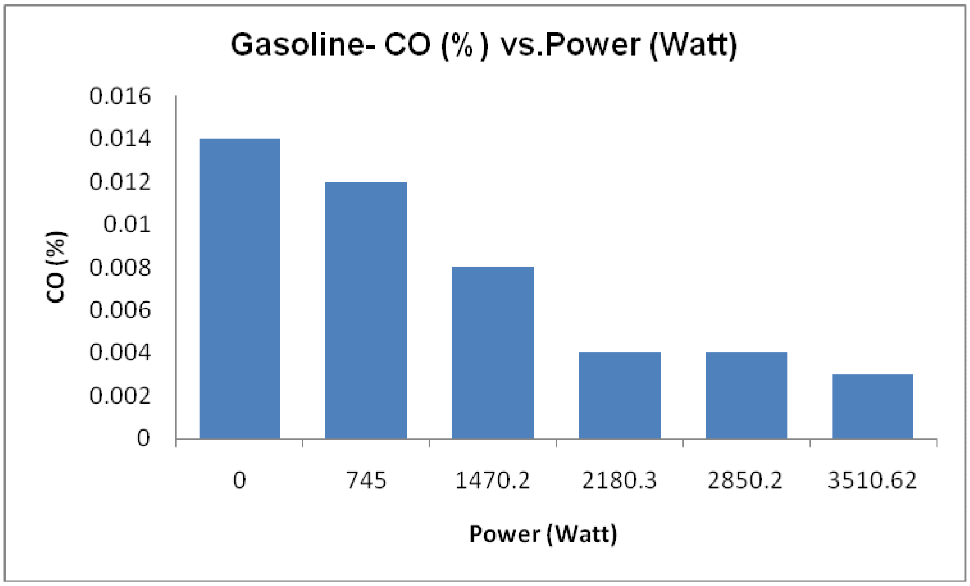


Figure-11: Curve b/w CO (%) vs. Power (Watt) (Gasoline)

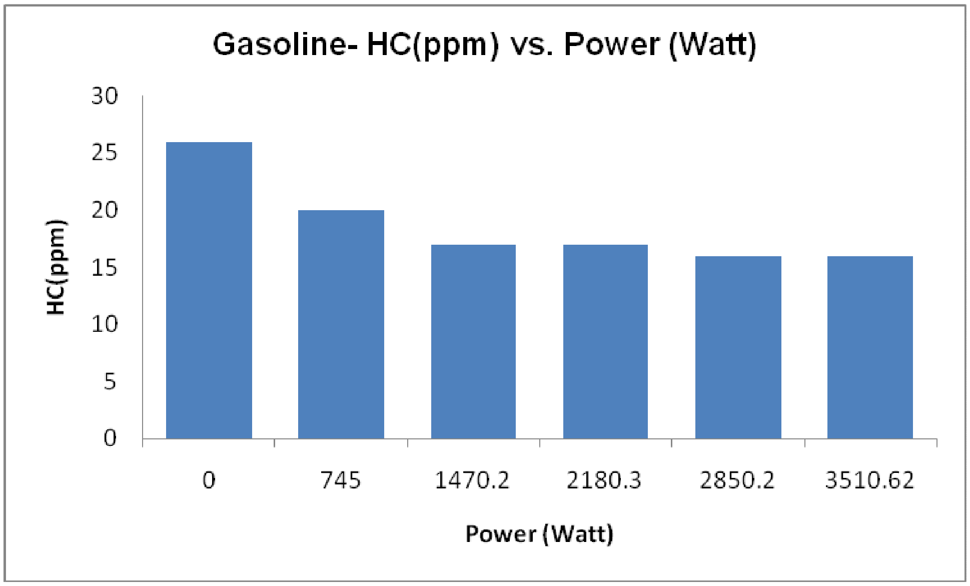


Figure-12: Curve b/w HC (ppm) vs. Power (Watt) (Gasoline)

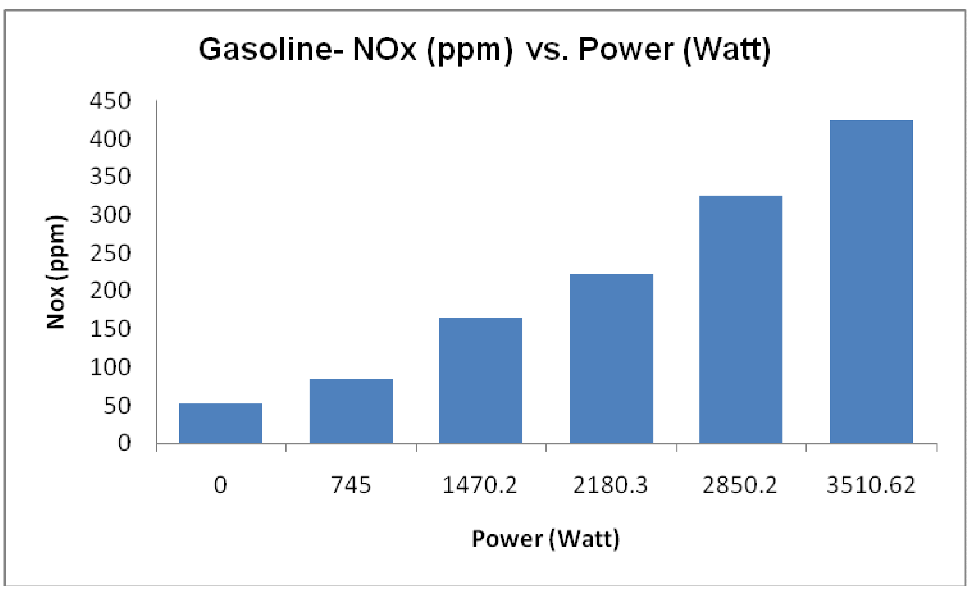


Figure-13: Curve b/w NO_X (ppm) vs. Power (Watt) (Gasoline)

6.2 E-5 (95%gasoine+ 5% ethanol):-

Q_{LHV}= 43.6455 MJ/Kg

Load(Kg)	Power (watt)	η_{th}	BSFC (Kg/KWh)	CO (%)	HC (ppm)	NO_x (ppm)
0	0	-	-	1.20	98	125
2	680.3	12.7	.5492	.98	75	185
4	1355.50	16.85	.3810	.50	68	300
6	2025.53	19.95	.3225	.22	62	700
8	2695.08	25.2	.2525	.20	60	1300
10	3360.8	31.0	.2080	.12	42	1350

Table-8: Variation in various parameters with the Power for E-5

6.2 Performance and emissions Curves For E-5

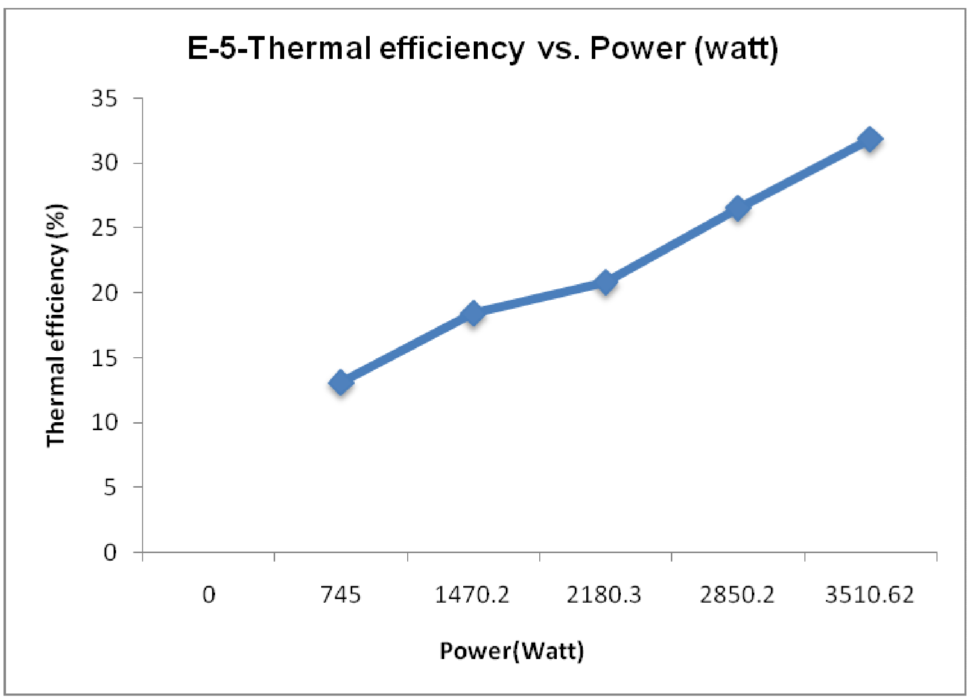


Figure-14: Curve b/w Thermal efficiency vs. power (watt) (E-5)

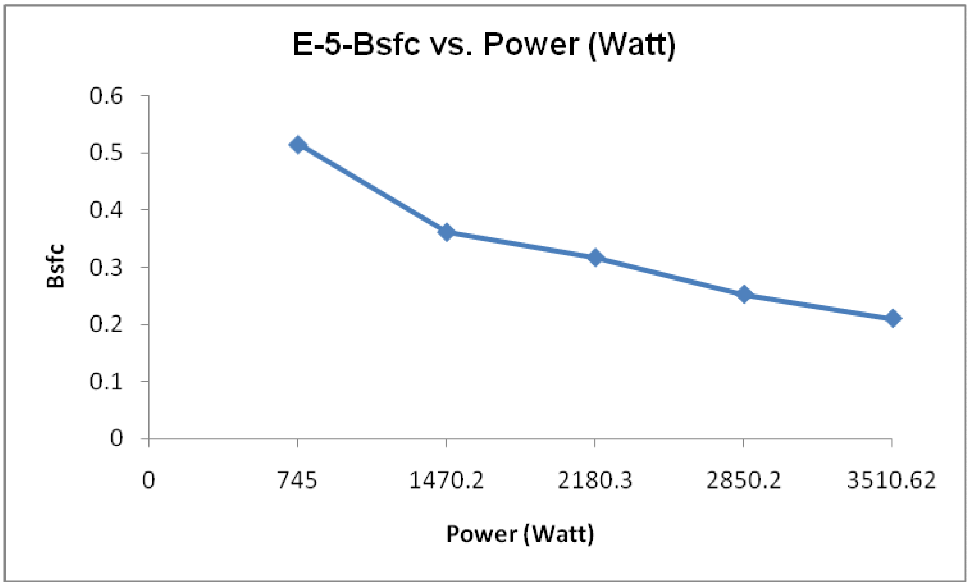


Figure-15: Curve b/w Bsfc vs. Power (Watt) (E-5)

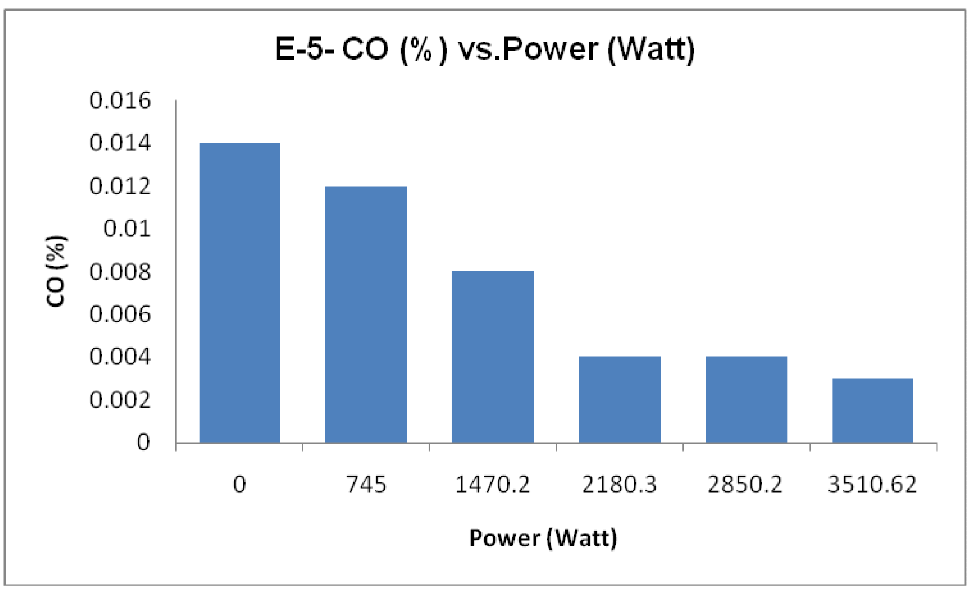


Figure-16: Curve b/w CO (%) vs. Power (Watt) (E-5)

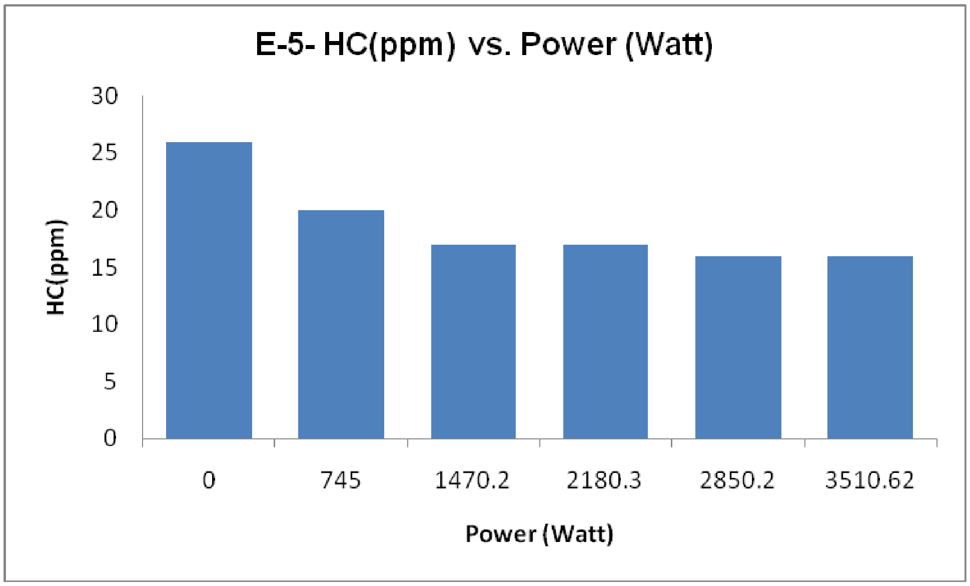


Figure-17: Curve b/w HC (PPM) vs. Power (Watt) (E-5)

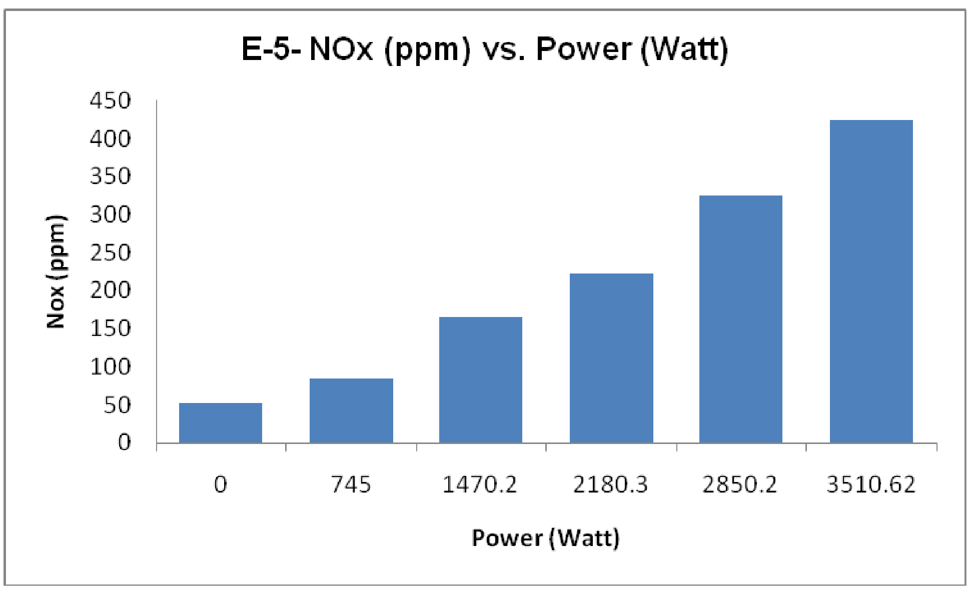


Figure-18: Curve b/w NO_X (ppm) vs. Power (Watt) (E-5)

6.3 E-7.5 (92.5%gasoline+ 7.5% ethanol):-

Q_{LHV}= 43.2182 MJ/Kg

Load(Kg)	Power (watt)	η_{th}	BSFC (Kg/KWh)	CO (%)	HC (ppm)	NO_x (ppm)
0	0	-	-	1.21	96	122
2	681.47	12.7	.5590	.96	72	182
4	1359.50	16.9	.3812	.48	66	296
6	2030.60	19.99	.3226	.21	61	680
8	2698.80	25.2	.2540	.19	58	1260
10	33627.8	31.0	.2090	.10	40	1300

Table-9: Variation in various parameters with the Power for E-7.5

6.3 Performance and emissions Curves For E-7.5

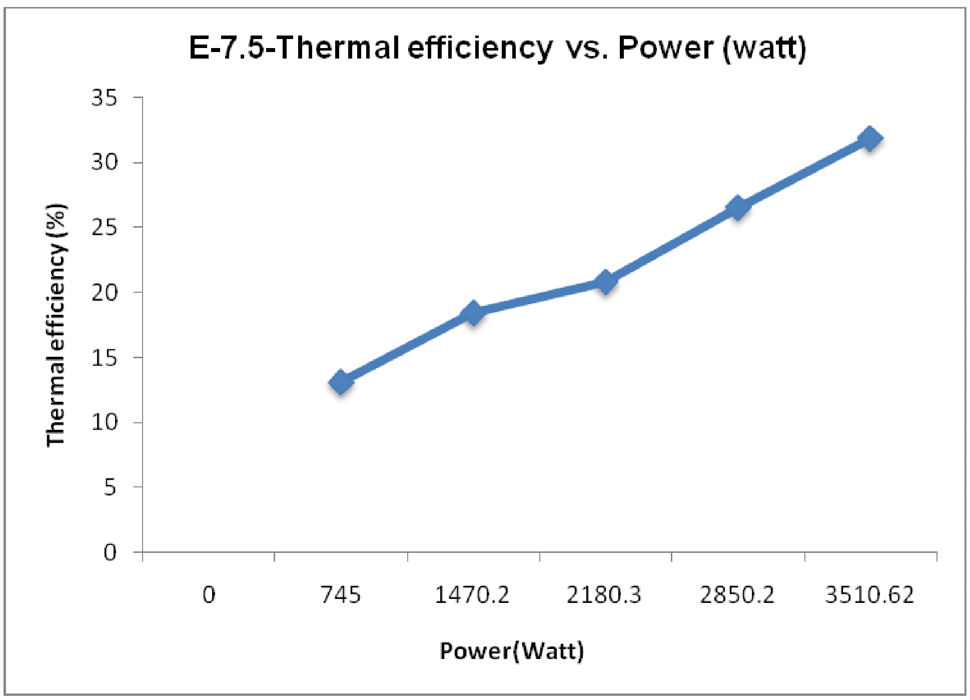


Figure-19: Curve b/w Thermal efficiency vs. Power (Watt) (E-7.5)

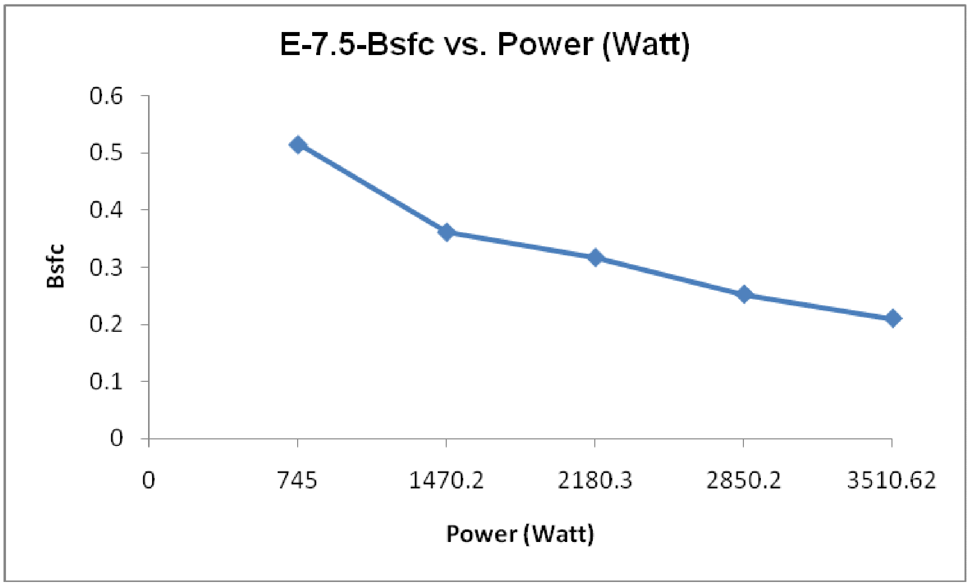


Figure-20: Curve b/w Bsfc vs. Power (Watt) (E-7.5)

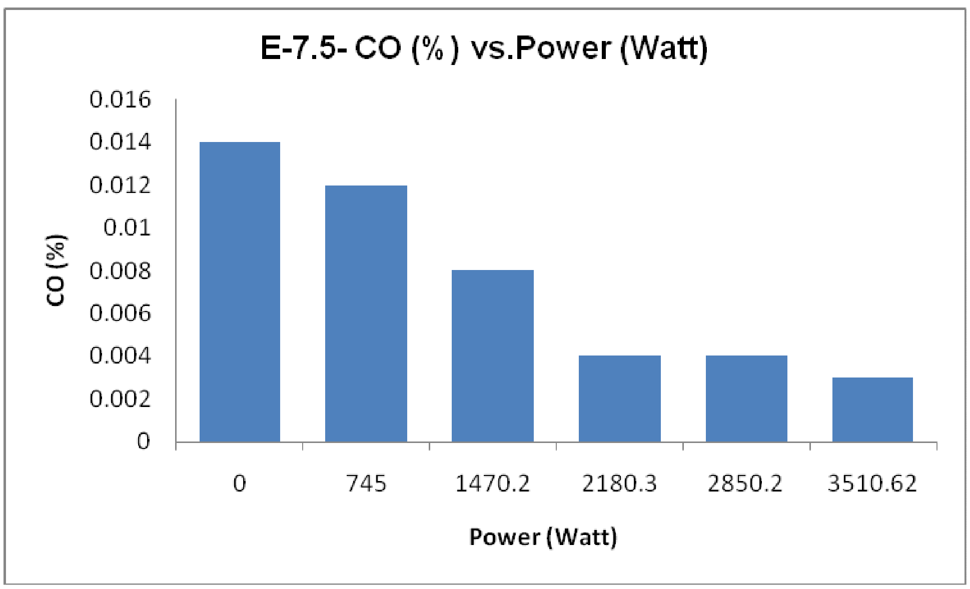


Figure-21: Curve b/w CO (%) vs. Power (Watt) (E-7.5)

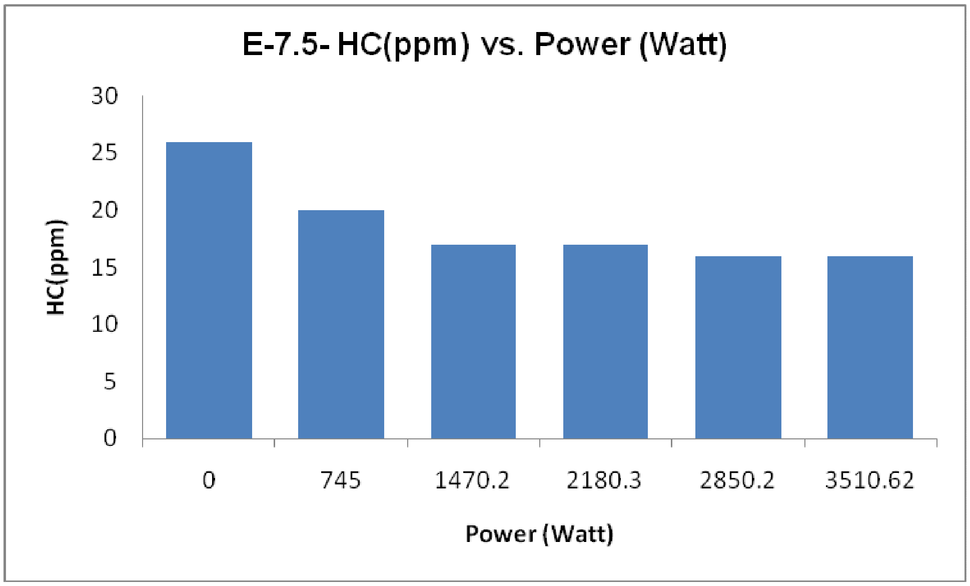


Figure-22: Curve b/w HC (ppm) vs. Power (Watt) (E-7.5)

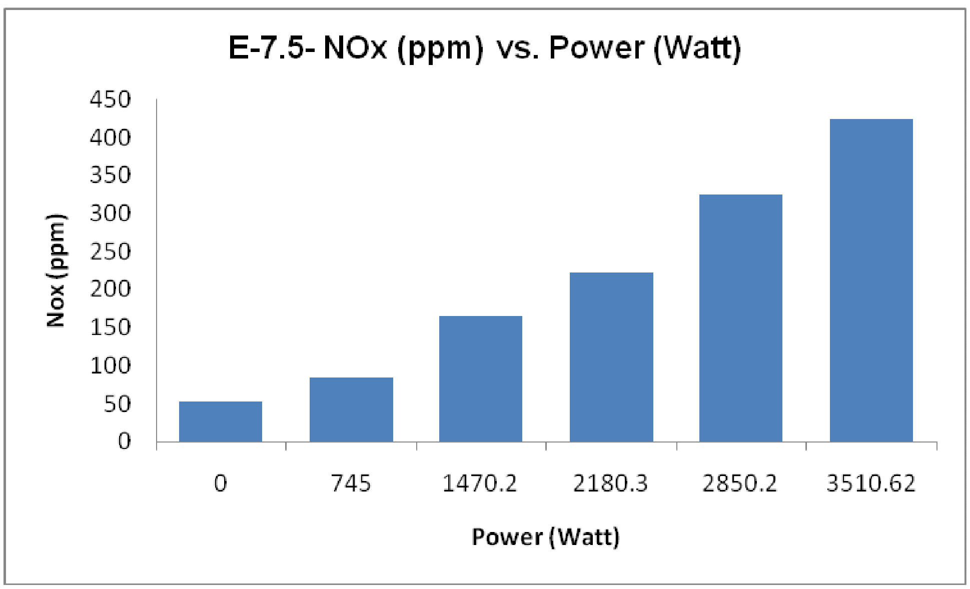


Figure-23: Curve b/w NO_X (ppm) vs. Power (Watt) (E-7.5)

6.4 E-10 (90%gasoline+ 10% ethanol):-

Q_{LHV}= 43.79 MJ/Kg

Load(Kg)	Power (watt)	η_{th}	BSFC (Kg/KWh)	CO (%)	HC (ppm)	NO_x (ppm)
0	0	-	-	.812	75	80
2	776.24	13.4	.484	.669	68	160
4	1509.36	18.5	.3496	.357	65	261
6	2251.11	21.0	.3109	.220	58	638
8	2932.48	26.6	.2440	.173	52	794
10	3622.47	32.5	.1993	.09	32	1203

Table-10: Variation in various parameters with the Power for E-10

6.4 Performance and emissions Curves For E-10

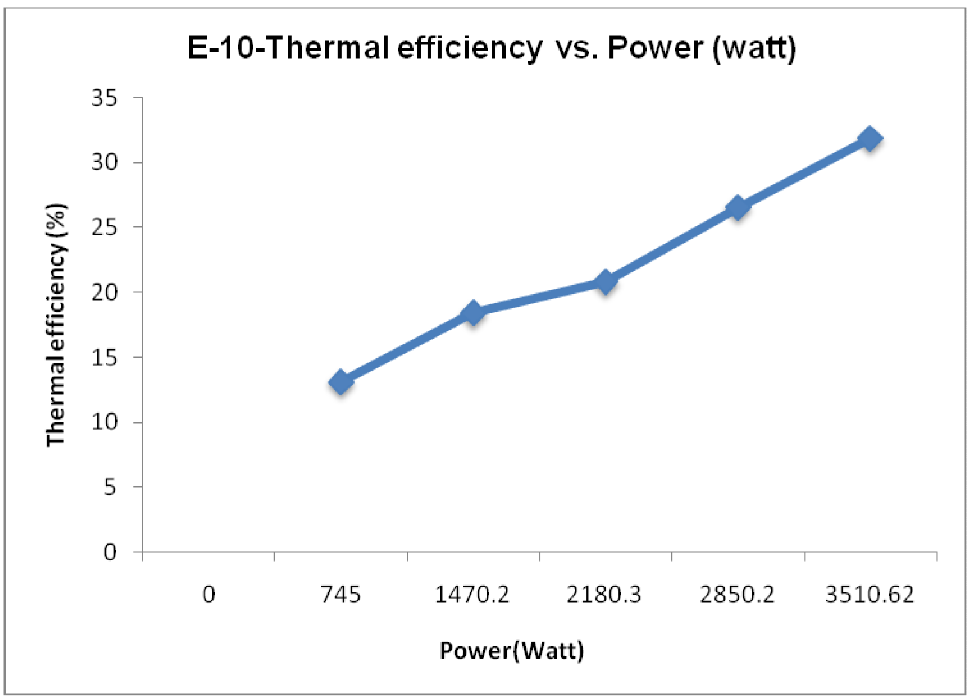


Figure-24: Curve b/w Thermal efficiency vs. Power (Watt) (E-10)

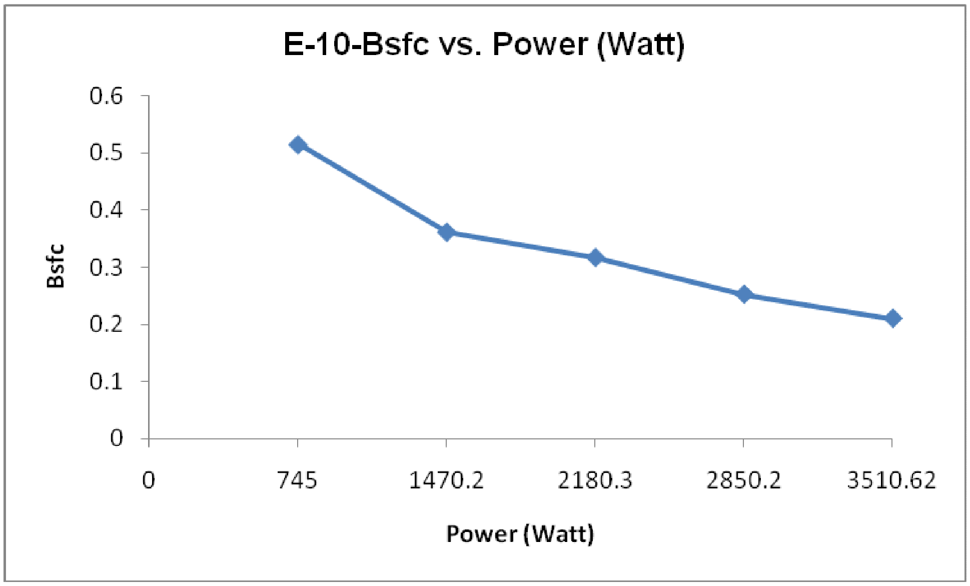


Figure-25: Curve b/w Bsfc vs. Power (Watt) (E-10)

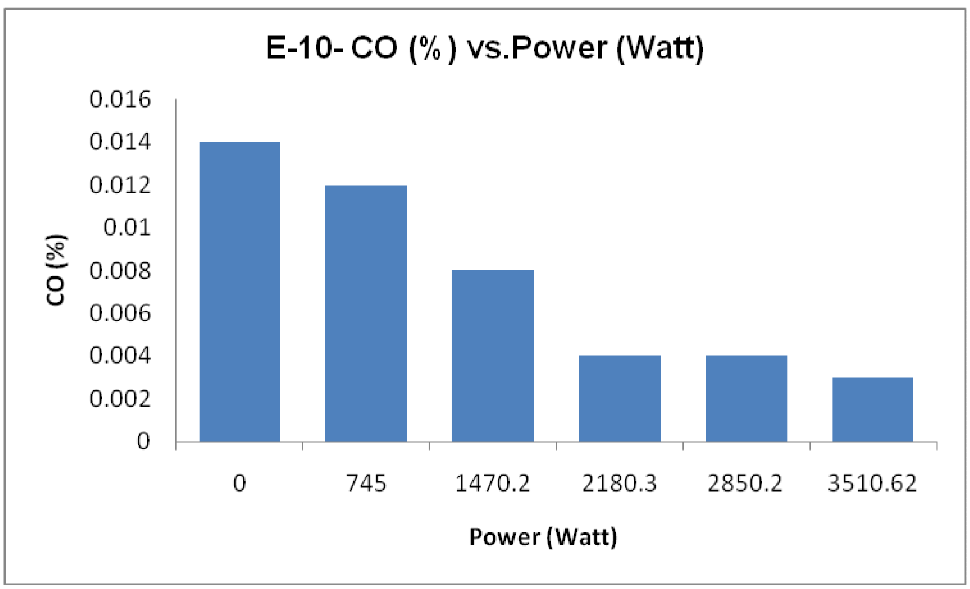


Figure-26: Curve b/w CO (%) vs. Power (Watt) (E-10)

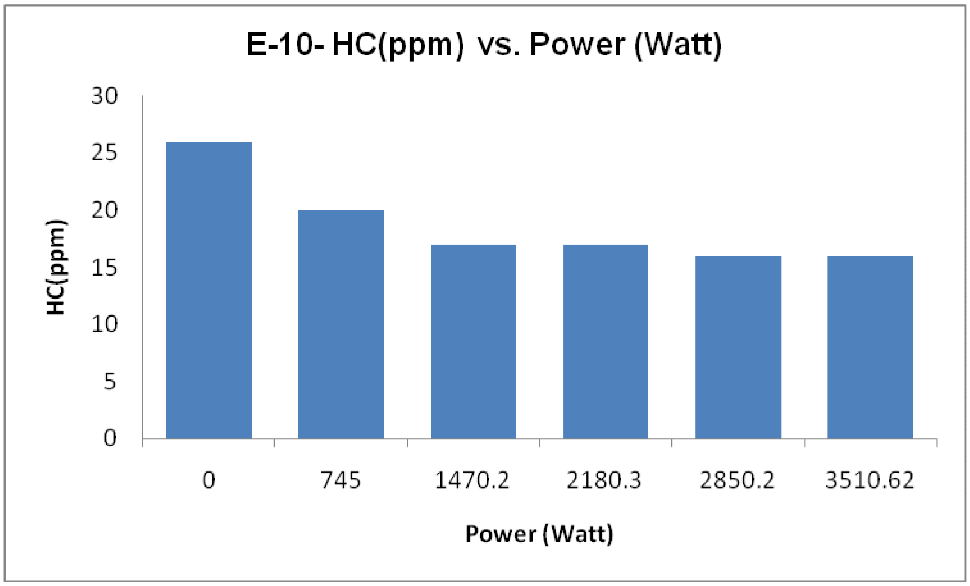


Figure-27: Curve b/w HC (ppm) vs. Power (Watt) (E-10)

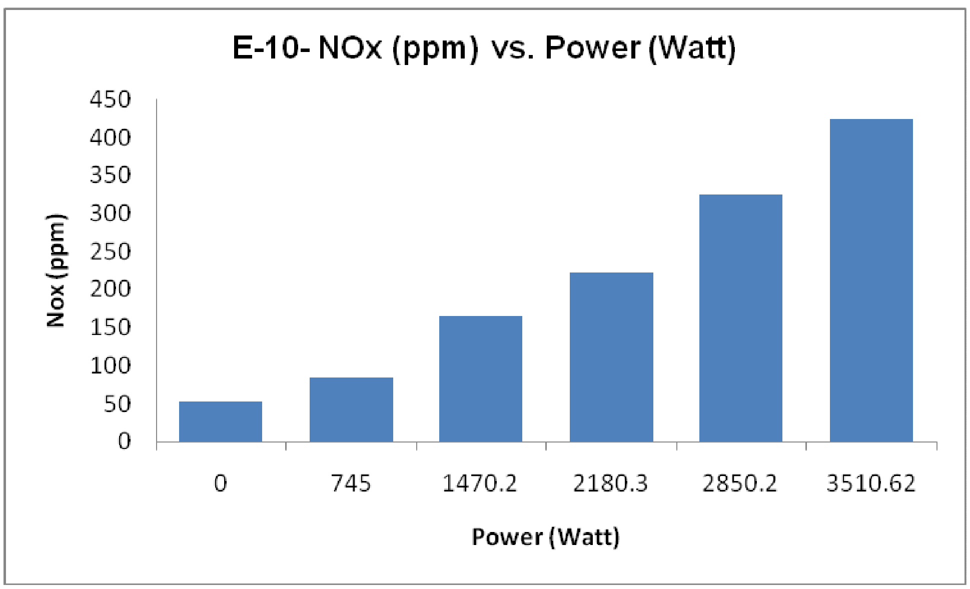


Figure-28: Curve b/w NOX (ppm) vs. Power (Watt) (E-10)

6.5 E-12.5 (87.5%gasoline+ 12.5% ethanol):-

Q_{LHV}= 42.3637 MJ/Kg

Load(Kg)	Power (watt)	η_{th}	BSFC (Kg/KWh)	CO (%)	HC (ppm)	NO_x (ppm)
0	0	-	-	.410	56	75
2	860.50	14.55	.4600	.310	45	148
4	1662.0	19.90	.3320	.210	30	256
6	2470.30	22.6	.2930	.112	26	548
8	3120.62	28.0	.2320	.090	22	685
10	3800.50	34.8	.1970	.07	20	1150

Table-11: Variation in various parameters with the Power for E-12.5

6.5 Performance and emissions Curves For E-12.5

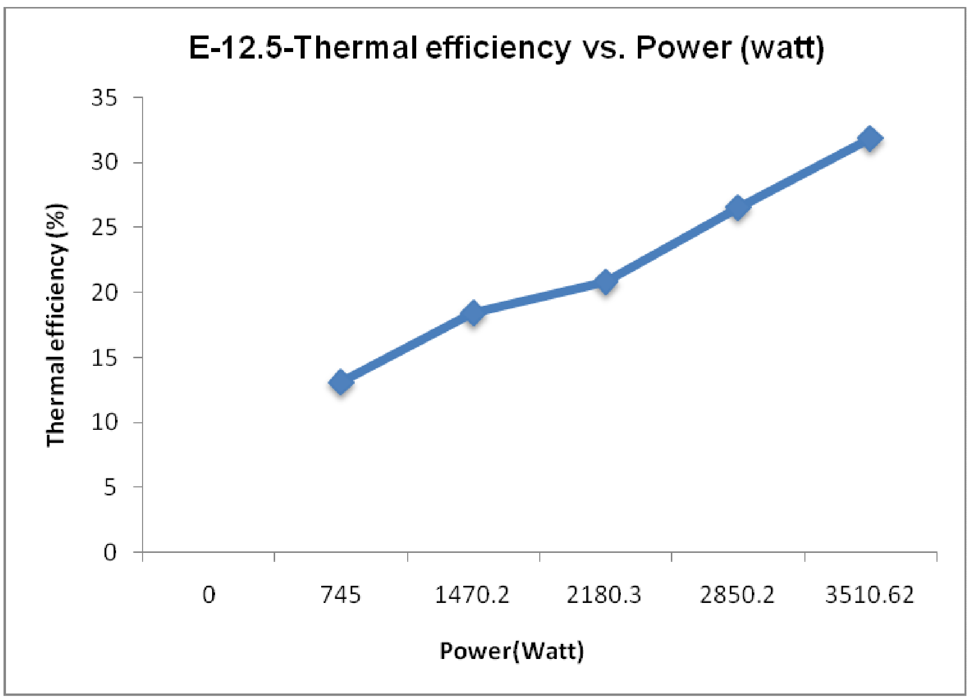


Figure-29: Curve b/w Thermal efficiency vs. Power (Watt) (E-12.5)

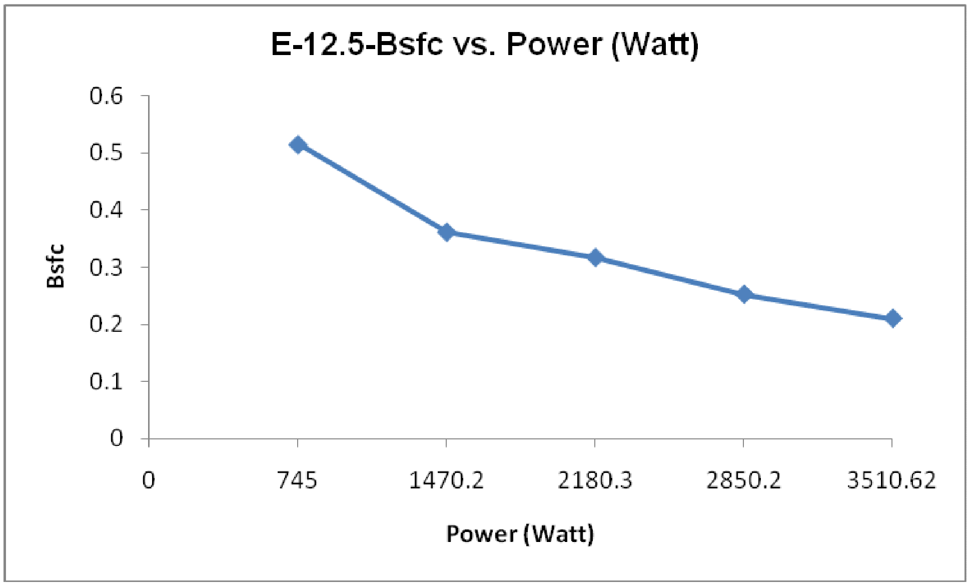


Figure-30: Curve b/w Bsfc vs. Power (Watt) (E-12.5)

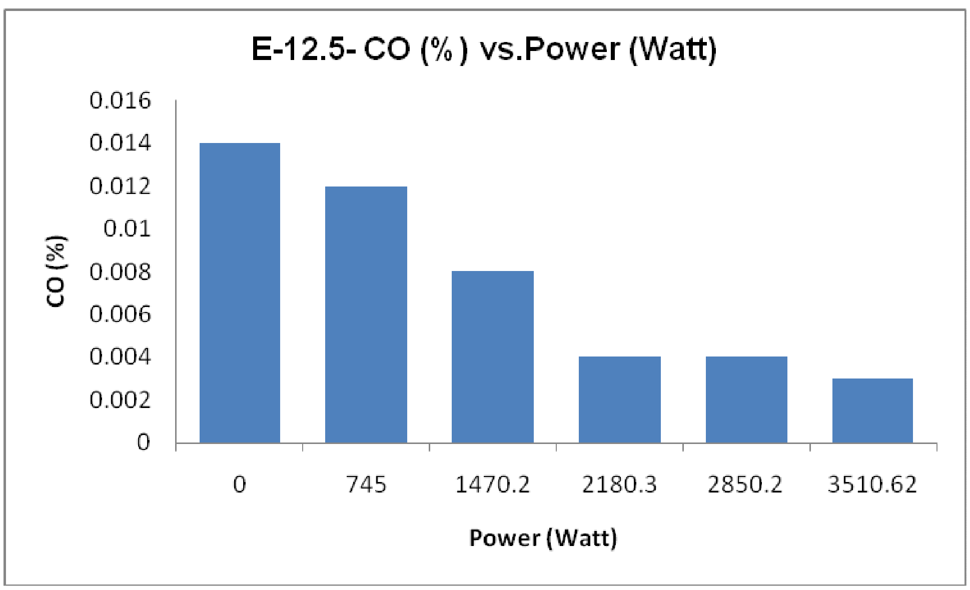


Figure-31: Curve b/w CO (%) vs. Power (Watt) (E-12.5)

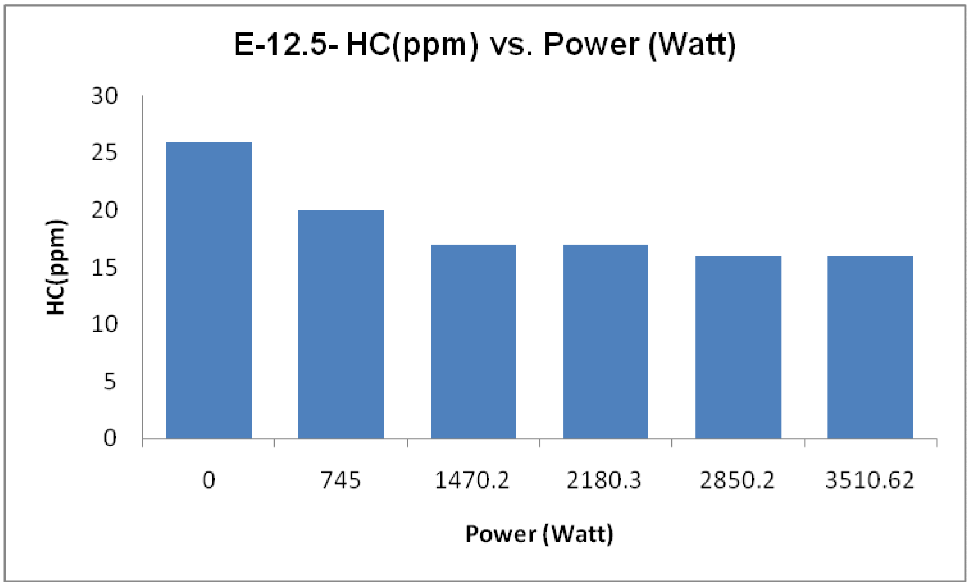


Figure-32: Curve b/w HC (PPM) vs. Power (Watt) (E-12.5)

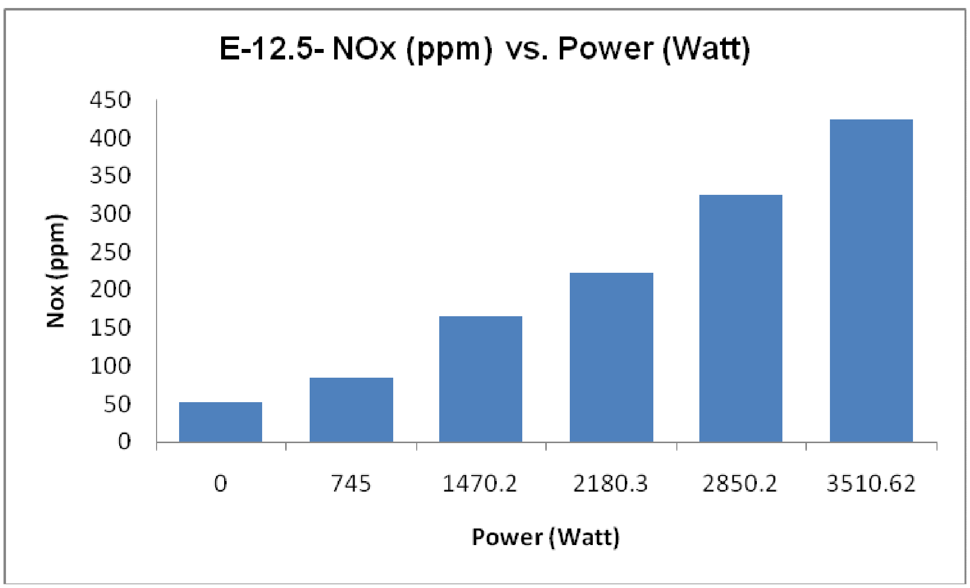


Figure-33: Curve b/w NO_X (ppm) vs. Power (Watt) (E-12.5)

6.6 E-15 (85.0%gasoline+ 15 % ethanol):-

Q_{LHV}= 41.9365 MJ/Kg

Load(Kg)	Power (watt)	η_{th}	BSFC (Kg/KWh)	CO (%)	HC (ppm)	NO_x (ppm)
0	0	-	-	.014	26	53
2	745.0	13.10	.5154	.012	20	85
4	1470.20	18.40	.3615	.008	17	165
6	2180.30	20.82	.3170	.004	17	223
8	2850.20	26.55	.2525	.004	16	325
10	3510.62	31.85	.2100	.003	16	425

Table-12: Variation in various parameters with the Power for E-15

6.6 Performance and emissions Curves For E-15

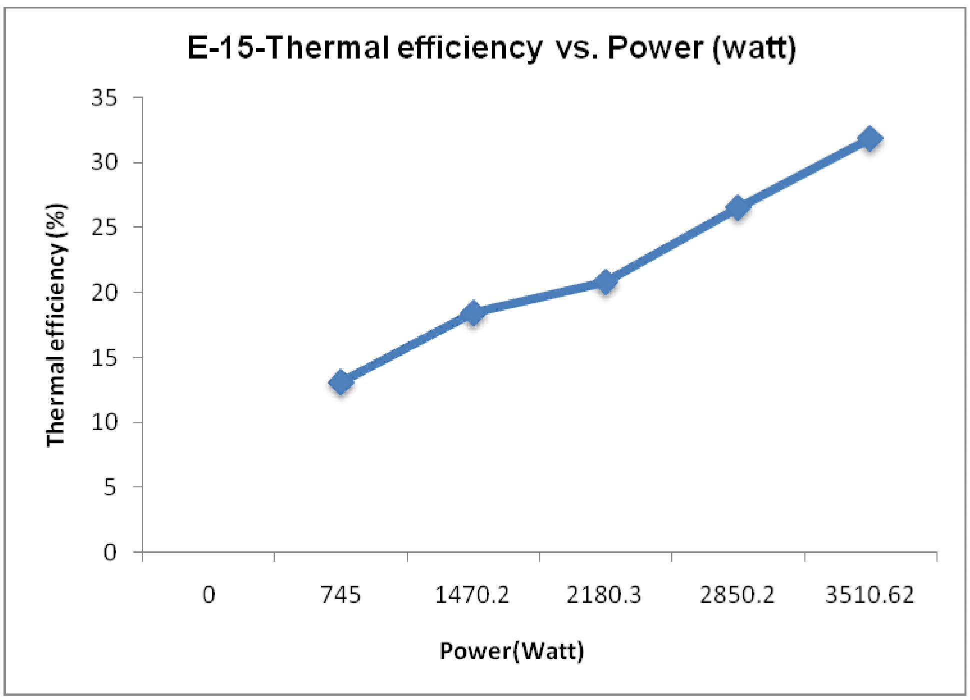


Figure-34: Curve b/w Thermal efficiency vs. Power (Watt) (E-15)

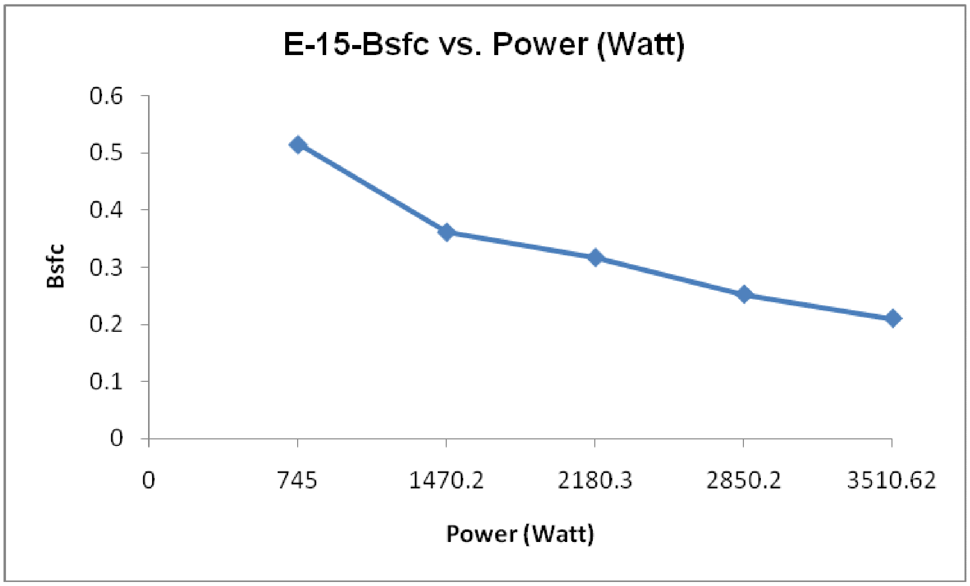


Figure-35: Curve b/w Bsfc vs. Power (Watt) (E-15)

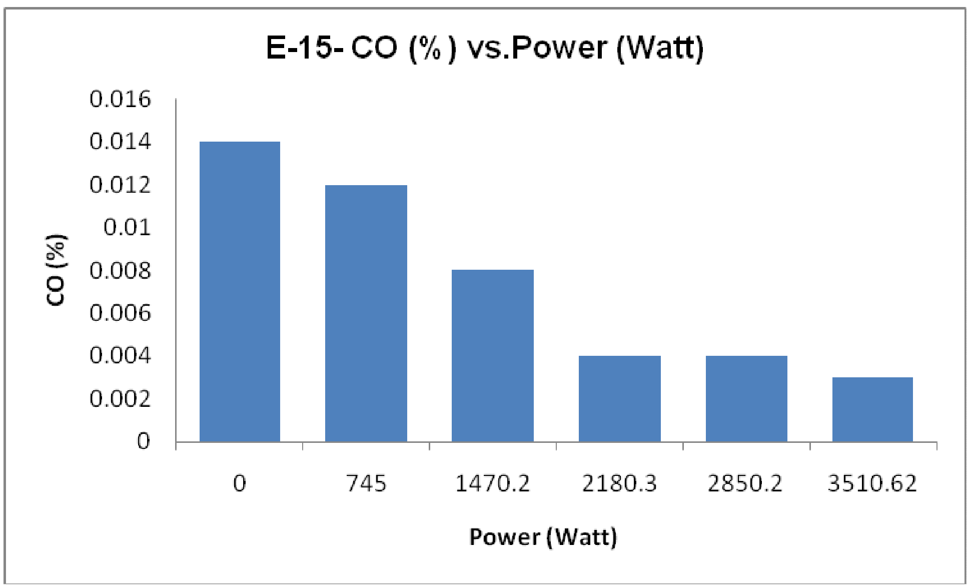


Figure-36: Curve b/w CO (%) vs. Power (Watt) (E-15)

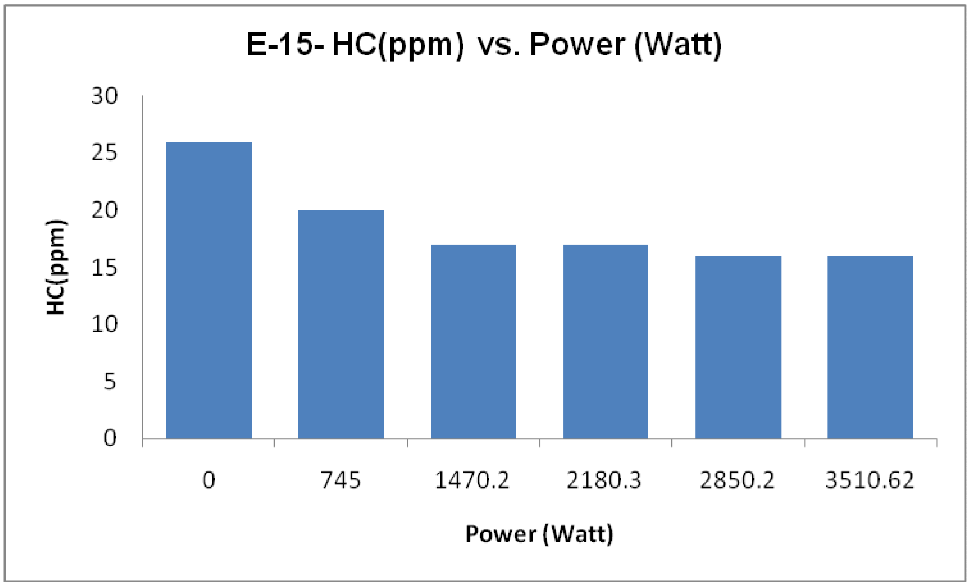


Figure-37: Curve b/w HC (ppm) vs. Power (Watt) (E-15)

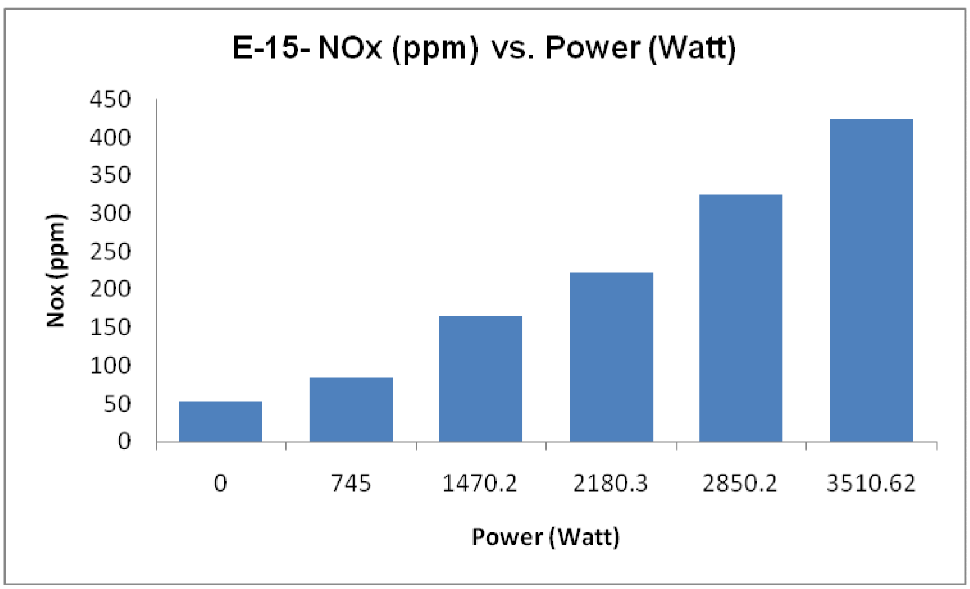


Figure-38: Curve b/w NO_X (ppm) vs. Power (Watt) (E-15)

7. RESULTS AND DISCUSSION

1. Thermal efficiency:-

On comparing the gasoline with ethanol fuel blends we find that the thermal efficiency of ethanol is better than that of gasoline because of following reason:-
1. Higher octane rating of the gaseous fuel allows higher compression ratio in comparison to pure gasoline mode.
2. Since ethanol enters in a gaseous state it allows more proper mixing of fuel and air. Proper mixing means proper combustion and less fuel goes unborn into exhaust, giving more thermal efficiency.

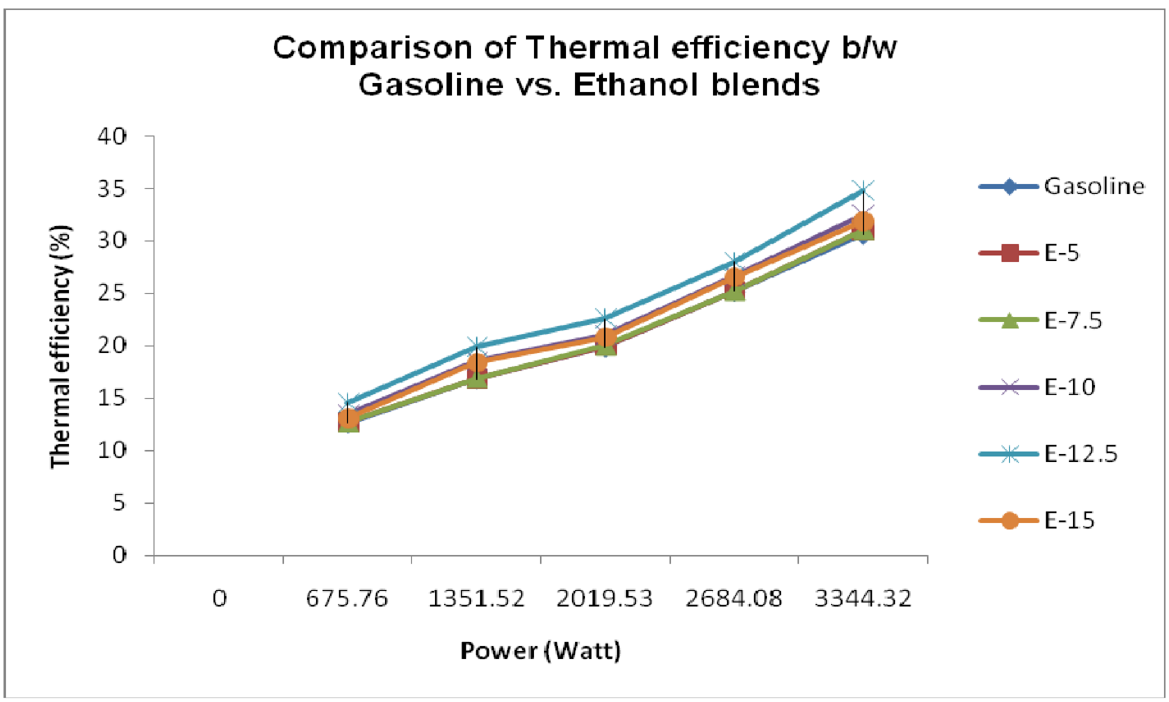


Figure-39: Variation of thermal efficiency with power at various ethanol blends.

2. Brake specific fuel consumption (Bsfc) :-

Variation of Bsfc with the power is shown in the graph. Though the Bsfc continuously decreases with the power, ethanol volume is more thus in the induction stroke less quantity of ethanol is drawn.

- At full power, increase in ethanol flow rate reduces the Bsfc.
- At partial power, increase in ethanol leads to decrease in Bsfc.
- At particular ethanol flow rate, increase in the applied power decreases Bsfc of engine.

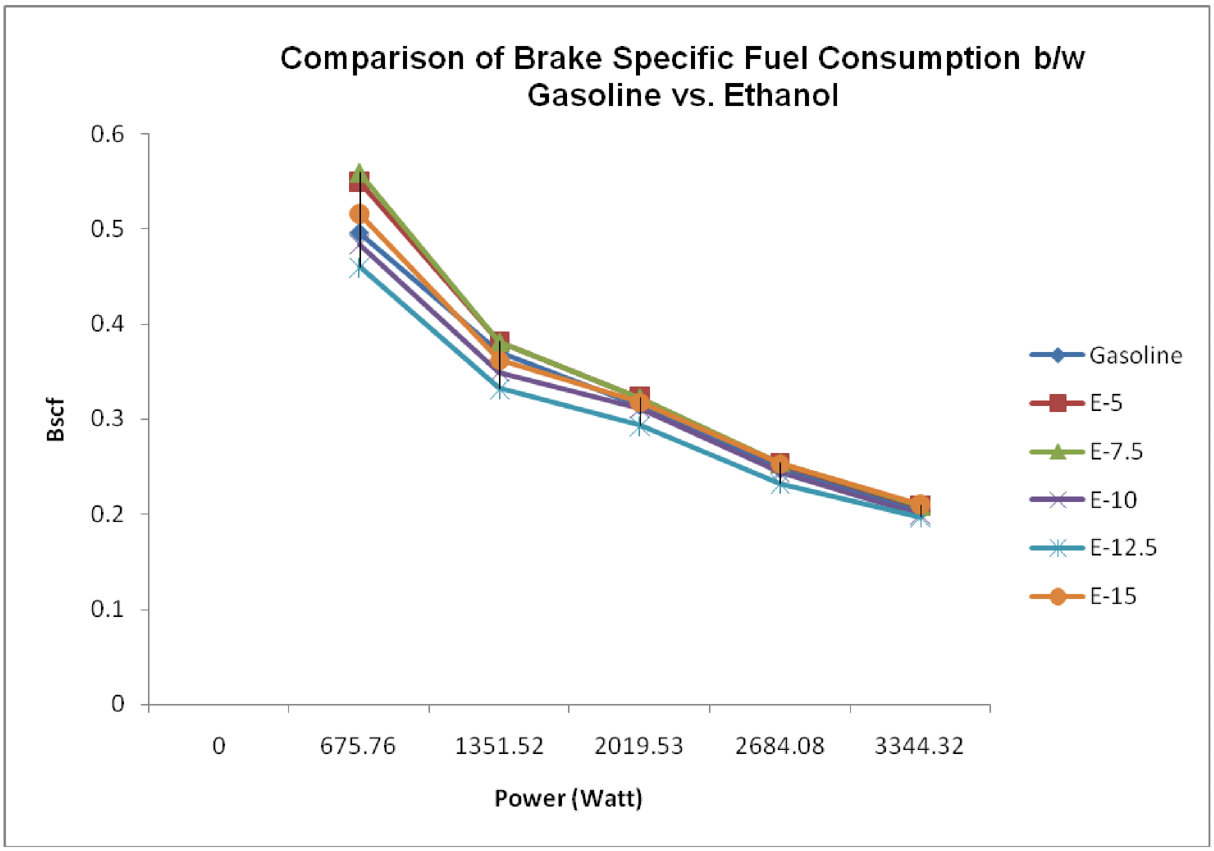


Figure-40: Variation of Bsfc with power at various ethanol blends.

Emissions characteristics:-

1. CO Emissions

Figure shows the emission of CO for gasoline and ethanol blends and it is found that CO emission of ethanol fuel system is less.

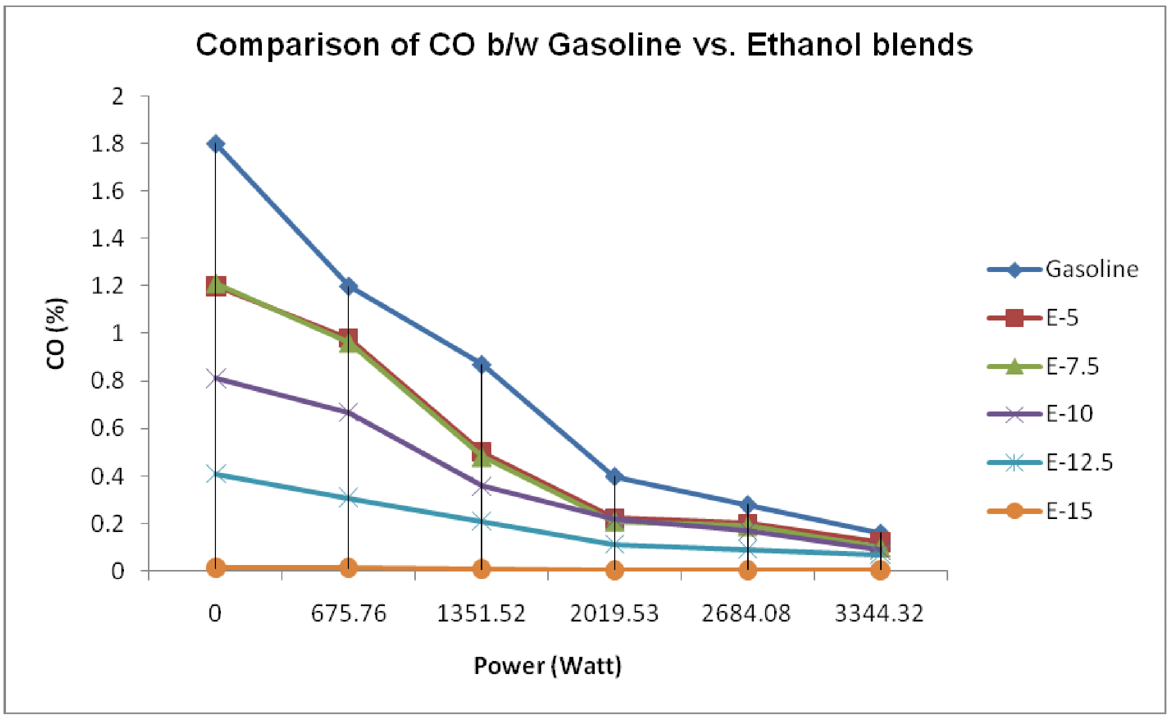


Figure-41: Variation of CO emissions with power at various ethanol blends.

2. Hydrocaorbons

Unborn hydrocarbon emissions are the result of incomplete combustion. The pattern of the hydrocarbons emissions is closely related to many design and operating variables. Total hydrocarbon emissions decreases with increase in power and it is less for ethanol blends as shown in the graph.

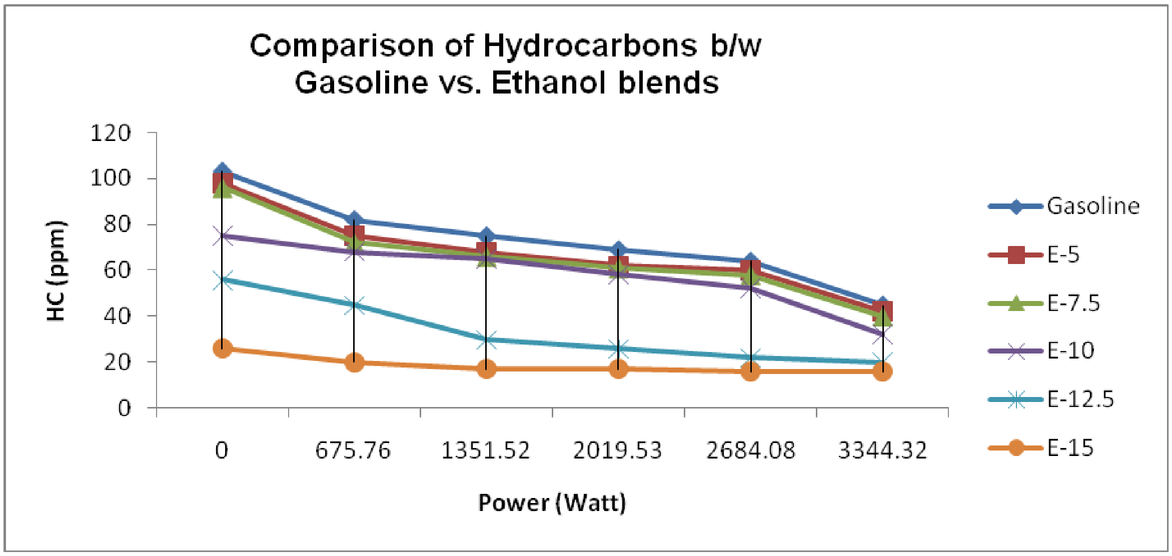


Figure-42: Variation of HC emissions with power at various ethanol blends.

3. Nitrogen Oxides (NOx)

High peak temperature and availability of oxygen are two main reasons for the formation of NO_X. In S.I. engine the flame velocity of ethanol is less, which leads to decrease in NO_x.Our result shows that the NO_x for ethanol blends are less than that of gasoline.

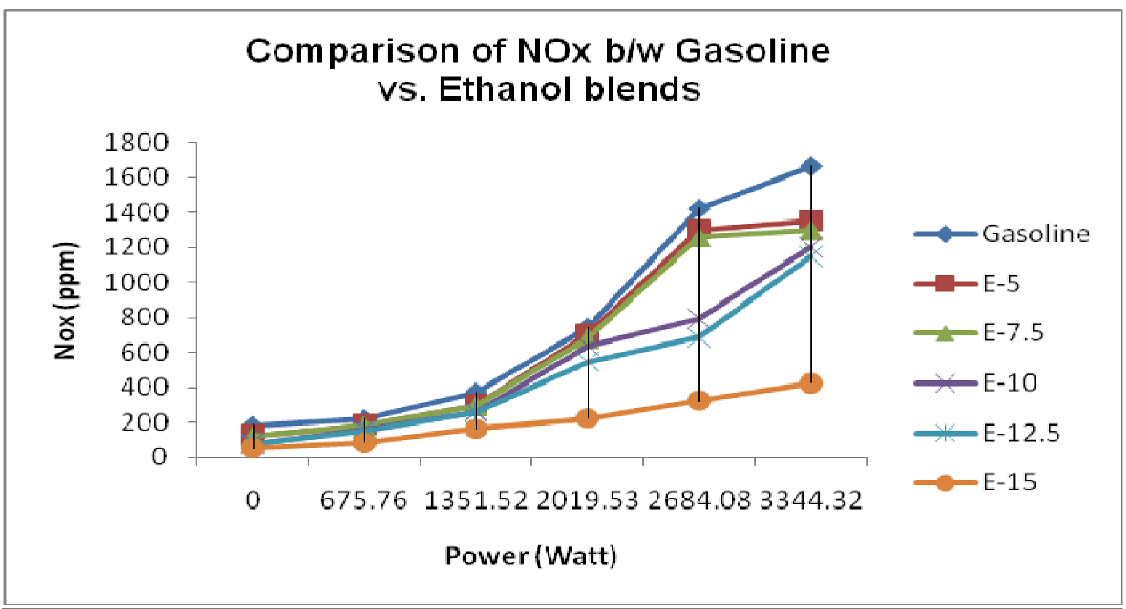


Figure-43: Variation of HC emissions with power at various ethanol blends.

CONCLUSION

Unlike most fuel additives and blend stocks, the benefits of ethanol-in-petrol may not be realized by simply adding ethanol to the petrol for use in an unmodified petrol engine. A multitude of pitfalls exist with the use of ethanol in petrol solutions, fortunately, these pitfalls can be overcome with low or no incremental cost.

- The energy content of ethanol will be its most limiting factor in acceptance for fuel economy and performance reasons.
- Cold start and emission technologies are the most important technologies to develop as related with ethanol usage. Systems such as heating grids and hydrocarbon traps have proven to be effective solutions to both areas of interest.
- Performance is greatly limited by the NO_X emissions created by high compression ratios. Adequate performance can be achieved but cannot be adequately utilized if emissions equipment is not utilized. If emissions can be controlled compression ratios of 11.0 to 12.0 should be used in dedicated ethanol vehicles.
- Gasohol vehicles modified for dedicated E85 usage must have full emissions modifications to reap the benefits of using a clean air fuel.
- Do not overlook safety issues involved with ethanol as they are different than those for E10.

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