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Alcohols and Conventional Fuels as Dual Fuel and its Performance and Emission Characteristics

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Abstract: Dual fuel vehicles are vehicles in which the vehicles can run on two fuels. Such as in internal combustion engines, one fuel is gasoline or diesel and other is some alternate fuel such as alcohol, bio-diesel, etc. Alternate fuels are the fuels of present and future. More and more vehicles are adopting alternate fuel technology. During the early 1970s, many countries realized the shortage of conventional fuels. That was the stage when development of alternate fuel sources were given attention particularly alcohols. However, use of alcohol was not brought into practice owing to its high costs. The recent developments in the technology though has revived the interest in the use of alcohols as a fuel. Methanol and ethanol blends have been used in both SI and CI engines. There has been a significant decrease in emissions and fuel economy has improved. Since, alcohols blends are economical and are showing a positive result in the engine performance, more and more countries are adopting this technology and working towards a cleaner environment.

Keywords: Dual fuels, alternate fuels, shortage of conventional fuels, methanol and ethanol blends, emissions, engine performance, cleaner environment

1. INTRODUCTION

There has been a prolific increase in the number of automobiles in India. It is estimated that the current motor vehicle population is around 80 million. India's transport sector plays an important role in its development. But, along with development it also contributes in India's environmental degradation. Combustion of fossil fuels like petrol and diesel have led to the widespread release of harmful gases such as CO, HC, NO_x, SPM (Suspended Particulate Matter). The release of these gases has had a detrimental effect on the environment. Hence, there is a need to find a cleaner fuel, that can function in both SI and CI engines. Alcohol is a suitable replacement for conventional fuels. Methanol and Ethanol are the most applicable alcohol fuels. Methanol has been used as a fuel in the US vehicles as early as the mid- 1960s. Ethanol has a higher octane rating. Currently it is used in the US as a ethanol-gasoline blend known as gasohol. Gasohol contains 10% ethanol. The drawback of alcohols being its lower energy content. Which means, to travel the same distance, we would need 1.5 - 2 times more alcohol compared to gasoline.

2. METHANOL

Methanol contains one carbon atom per molecule. It is toxic colorless and tasteless in nature. It is very hard to identify leaks since it has very faint odour. It can be produced from a wide variety of renewable sources such as wood, paper. It is hence known as 'wood alcohol'.

A. Properties

- Formula: CH_3OH
- Molecular weight: 32.04
- Carbon: 37.5%
- Hydrogen: 12.6%
- Oxygen: 49.9%
- Density(kg/L): 0.796
- Specific gravity: 0.796
- Freezing point: -97.5 ºC
- Boiling point: 65 ºC
- Vapor Pressure(kPa): 32
- Specific heat(kJ/kg-k): 2.5
- Viscosity(mPa-s): 0.59
- Water solubility: 100%
- Latent heat of vaporization(kJ/kg): 1178
- Lower heating value(1000 kJ/L): 15.8
- Flash point: 11 ºC
- Auto-ignition temperature: 464 ºC
- Stoichiometric air-fuel ratio: 6.45
- Flame speed rate(m/s): 2 – 4
- Flame visibility: Invisible
- Octane number: 108.7
- Cetane number: -

B. Production

Now-a-days, it is produced from natural gas. Methanol can be produced from syngas. Syngas is produced when methane reacts with steam at 1 to 2 MPa and temperature around 850 ºC. Nickel is used as a catalyst. This is an endothermic reaction.

$CH_4 + H_2O \rightarrow CO + 3H_2$

The Carbon monoxide and hydrogen produced in the last step reacts with another catalyst such as mixtures of copper, zinc oxide and alumina. The entire reaction is carried out at 250 ºC and pressures of 5 to 10 MPa is maintained to form methanol.

$CO + 2H_2 \rightarrow CH_3OH$

There are several other methods for producing methanol such as:

- Methane oxidation with a homogenous catalyst in sulphuric acid.
- Methane bromination followed by hydrolysis
- Direct oxidation of methane.
- Photochemical conversion of methane.

3. ETHANOL

Ethanol has two carbon atoms per each molecule. It is a clean burning, high octane fuel. The flame is invisible. Ethanol can be obtained from a wide variety of sources such as corn, sugarcanes and few other crops. Hence, it also known as 'bio ethanol'.

A. Properties

- Formula: C_2H_5OH
- Molecular weight: 46.07
- Carbon: 52.2%
- Hydrogen: 13.1%
- Oxygen: 34.7%
- Density(kg/L): 0.79
- Specific gravity: 0.794
- Freezing point: -114 ºC
- Boiling point: 78 ºC
- Vapor Pressure(kPa): 15.9
- Specific heat(kJ/kg-k): 2.4
- Viscosity(mPa-s): 1.19
- Water solubility: 100%
- Latent heat of vaporization(kJ/kg): 923
- Lower heating value(1000 kJ/L): 21.1
- Flash point: 13 ºC
- Auto-ignition temperature: 423 ºC
- Stoichiometric air-fuel ratio: 9
- Flame visibility: Invisible
- Octane number: 108.6
- Cetane number: -

B. Production

The process of making ethanol has been around since man has been on this earth. In recent years, though, it has been considerably refined and upgraded with the improvement in technology.

Sources:

Ethanol can be produced from many raw materials, that is a rich source of carbohydrates, sugar, starch or cellulose. Some of the most common raw materials used are:

- Molasses
- Beet
- Cane or grain sugar
- Grains lke corn, wheat, potato
- Ethanol can be produced by fermentation of carbohydrates:

$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

The most commonly employed industrial process is '**dry milling process**'. The various steps involved are milling, liquefaction, saccharification, fermentation, distillation, dehydration, denaturing.

1. Milling:

The feedstock is powdered in the first step.

2. Liquefaction:

The powdered feedstock is mixed with water and Alpha-amylase and this mixture is passed through cookers where starch is liquefied. It is heated to a temperature of 120 ºC to 150 ºC and then it is held at a temperature of 95 ºC until it liquefies.

3. Saccharification:

In this step liquid starch is converted to fermentable Sugars (dextrose) using a secondary enzyme, glucoamylase.

4. Fermentation:

Yeast is added to ferment the sugars to ethanol and carbon dioxide.

5. Distillation:

The fermented mash contains 10% ethanol which is then distilled in a multi column distillation system, where the solids and water is removed to give 96% ethanol.

6. Dehydration:

In this step, the remaining water from the ethanol is removed and the final product is called 'anhydrous ethanol'.

7. Denaturing:

Ethanol that is to be used as a fuel must be denatured i.e. made unfit for human consumption. This can be achieved by adding 2% to 5% gasoline in the ethanol.

4. MATERIAL COMPATIBILITY

Methanol is more aggressive than ethanol and has a very corroding effect on aluminium. More attention is required on the fuel handling components of methanol vehicles such as fuel cap, fuel lines, fuel pump, fuel tank, and elastomers such as o-rings.

Alcohols contain water and carboxylic acid which can corrode metal components. Metals such as magnesium, zinc casting, brass and copper are not compatible with alcohols. Whereas, metals such as carbon steel, stainless steel and bronze are compatible. Most commonly used elastomers that work well with alcohols are buna-N, viton, fluorosilicones, neoprene and natural rubber.

TABLE I: MODIFICATIONS IN FORD TAURUS FFV

Item Changed	Description
Spark Plug	Has a colder heat range and the wire electrode is wider for better heat transfer
Engine	Internal engine changes for "alcohol fuel compatibility"
Fuel Injectors	Higher fuel flow capacity, modified spray nozzle design and material changes for "alcohol fuel compatibility"
Engine Oil	Specifically designed for engines operated with methanol and ethanol fuels
Fuel Rail	Material changes are made for "alcohol fuel compatibility"
Fuel Pressure Regulator	Material changes are made for "alcohol fuel compatibility"
Engine Block Heater	Use to assist in cold start below -12 deg C
PCM processor	Calibration is utilized to optimize engine function for alcohol fuel operation
Wiring Harness	Wiring changes have been made to connect with the fuel sensor
Fuel Sensor	Determines the percentage of methanol in the fuel for methanol FFVs or percentage ethanol for ethanol FFVs
Fuel Supply and Return Lines	Material changes are made for "alcohol fuel compatibility"
Fuel Pump Assembly/Fuel Sending Unit	Fuel pump specifically designed for alcohol fuels. Stainless steel parts are used.
Vapor Control Valve	Control vapor flow to charcoal filter
Filler Tube	Improved coating is applied and anti-siphon screens installed
Fuel Filter	Material changes are made for "alcohol fuel compatibility"
Charcoal Canister Tray	Protective enclosure
Evaporative Emission System	Charcoal canister system enlarged and modified for additional alcohol fuel vapor capacity and higher vapor flow
Vapor (Rollover) Valves	Helps to increase fuel capacity and vapor flow. Material changes are made for "alcohol fuel compatibility"
Fuel Tank	A specially coated steel fuel tank is used for "alcohol fuel compatibility"

A test conducted on three sample metals such as brass, aluminium alloy and stainless steel was conducted by immersing these samples in E10 and E20 fuels at 45 ºC. The mass loss/gain data was recorded periodically at the end of 3rd, 4th, 5th, 6th and till 12th week and the corrosion rate was recorded for each metal. The study has revealed that all three metals are compatible with E10 and E20 fuels. This study has given a significant information regarding the use of metals for the fuel system.

5. ENGINE MODIFICATIONS

Alcohols have high octane number. This allows the compression ratio to be between 11:1 to 13:1. Due to their low energy content when compared to gasoline and diesel, we need the carburetor to be modified by introducing two float chambers for alcohol and gasoline respectively. Alcohols do not vaporize easily, so this affects cold starting. An electrical heating element can be placed around fuel tank, carburetor or inlet manifold. Alcohols burn slowly, hence, ignition timing needs to be advanced, enabling the slow burning alcohol to develop more pressure and power in the cylinder.

To use ethanol as a fuel in SI engine, the orifice diameter of the main jet should be increased. For proper functioning of engine at idle state, the orifice diameter should be increased. A vacuum controlled valve is used to increase the fuel flow rate when the accelerator pedal is depressed. 25% increase in accelerator pump is sufficient for higher fuel flow capacity for increasing the power. The inlet valve diameter is to be increased to allow more fuel to enter the combustion chamber.

Use of ethanol blends in conventional gasoline vehicles is restricted to a low mixture as ethanol is corrosive and degrade materials of engine and fuel system. Engine has to be adjusted to a higher compression ratio to take advantage of ehanol's high oxygen content, thus allowing an improvement in fuel economy and reduction in emissions. It may be necessary to change fuel filters often because ethanol blends deposit solid particles on it. Nickel plating of fuel lines to prevent corrosion caused by ethanol blends. Higher fuel flow rate injectors are required to compensate for oxygenate qualities of ethanol.

For CI engines, since both methanol and ethanol have high self ignition temperature, high compression ratio of about 25:1 to 27:1 is required. This would make the engine extremely heavy and expensive. The better method is to utilize them in dual fuel operation. In the dual fuel operation, alcohol is injected or carbureted into the inducted air. Due to the high self ignition temperature of alcohols, there would be no ignition with the usual diesel compression ratio of 16:1 to 18:1. A little before the end of compression stroke, a small quantity of diesel oil is injected into the combustion chamber through a normal diesel pump and spray nozzles. The diesel readily ignites and initiates the combustion of the alcohol-air mixture. However, this design calls for two complete and separate fuel systems with fuel tanks, fuel pumps, injection pump and injectors.

Some other methods of using alcohols in CI engines are:

- Alcohol-diesel fuel solutions
- Alcohol-diesel emulsions
- Alcohol fumigation
- Surface ignition of alcohols
- Spark ignition of alcohols
- Alcohol containing ignition improving additives

6. COMBUSTION OF ALCOHOLS

A. Methanol

Methanol has many desirable combustion characteristics. It has a high octane number indicating anti-knock performance. High latent heat of vaporization allowing a denser fuel-air charge. It has excellent lean burn properties. These properties make it more suitable foe SI operation. The flames produced during combustion are invisible. Because of its high flammability, it is also used as an additive in gasoline. Methanol atomizes quickly when compared to gasoline, hence, a better vaporization rate is obtained. The combustion of methanol in the presence of oxygen gives carbon dioxide and water.

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

B. Ethanol

Ethanol is volatile, flammable, colourless liquid that has a strong characteristic odour. It burns with a smokeless blue flame that is not always visible. It contains a hydroxyl group which gives it its physical properties. This hydroxyl group also makes it more viscous and less volatile than less polar organic compounds of similar molecular weight. Mixtures of ethanol and water that contain more than 50% of ethanol are flammable. The combustion of ethanol in presence of oxygen gives carbon dioxide and water.
$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$

Combustion of ethanol in IC engine yields large amounts of formaldehyde which is carcinogenic in nature and also yields related species such as formalin, acetaldehyde, etc. This leads to photochemical reaction that causes the formation of more ground level ozone.

7. BLEND PROPERTIES

Methanol and ethanol are blended with gasoline or diesel and then used as a fuel in IC engines. Alcohols blends are currently being used in countries like Brazil, USA, etc. While Brazil uses E25 (25% ethanol) for all its light duty vehicles, USA uses E10 (10% ethanol) for its vehicles.

Ethanol has more water absorbing properties. As a result of this, phase separation between ethanol and gasoline might occur leading to failure of fuel lines due to clogging. Thus, Ethanol blends should have lower ethanol content with respect to gasoline to avoid phase separation. The fuel economy declines with higher water content. In theory, ethanol has 34% less energy content than gasoline. Hence, it will affect the mileage of the vehicle. We will require 34% more ethanol when compared to gasoline to cover the same distance per gallon.

Here are some standard alcohol blends and properties as shown below in the table:

TABLE II: ALCOHOL BLEND CHARACTERISCTICS

Property item	Test fuel							Test method
	Gasoline	E10	E20	E30	M10	M20	M30	
Heat of combustion (MJ/kg)	44.133	42.447	40.672	38.673	41.615	38.233	36.247	ASTM D340
Reid vapour pressure (kPa)	35.00	59.53	54.61	53.31	57.43	66.58	68.74	ASTM D323
Research octane number	84.8	88.3	93.4	98.9	88.2	94.4	98.4	ASTM D2699
Density at 15.5°C (kg/l)	0.7678	0.7760	0.7782	0.7794	0.7692	0.7707	0.7734	ASTM D1298

The American Society for Testing and Materials (ASTM) has set a standard D4806-98 for denatured duel ethanol blending with gasoline. The principle requirements for ethanol are as follows:

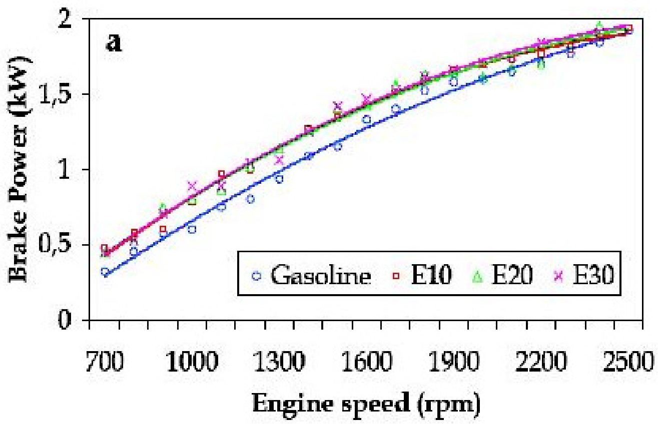
- Ethanol content should be a minimum of 92.1% by volume.
- Methanol content should not be more than 0.5% by volume.
- Water content should be a maximum of 1% by volume.
- Solvent washed gum should be maximum of 5mg per 100 ml.
- Chloride ions should be a maximum of 40g per liter.
- Acetic acid content should be a maximum of 70 ppm.
- Copper content should be a maximum of 40g per liter.
- Appearance should be visibly free from suspended contaminants.
- Denaturant should be a minimum of 1.6% and a maximum of 4.76% by volume.

India has adopted IS 15464:2004 for the use of anhydrous ethanol as automotive fuel. This was adopted by the Bureau of Indian Standards.

8. PERFORMANCE CHARACTERISTICS

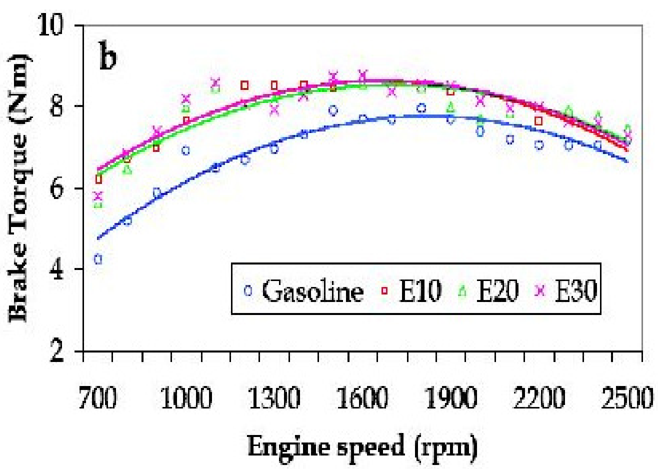
A. Ethanol

Brake power vs Engine speed



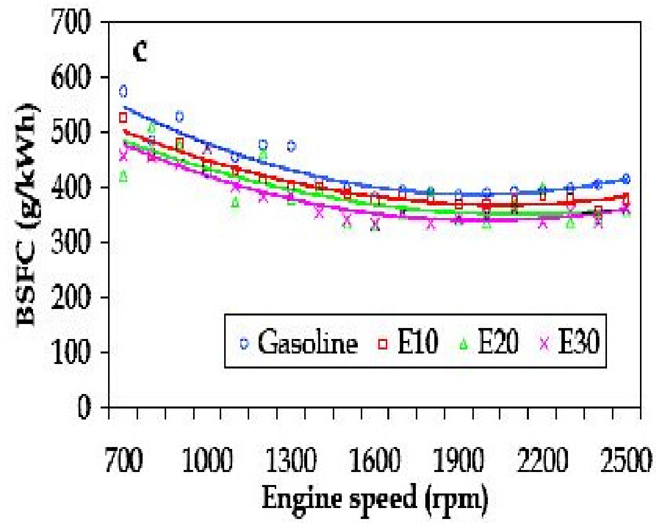
The above graph indicates the influence of ethanol gasoline blended fuels on engine power. When the ethanol content was slightly increased in the blend, the engine brake power slightly increased for all engine speeds. With an increase in the ethanol percentage, the density of the blend increased and the volumetric efficiency increased, increasing the brake power.

Brake torque vs Engine speed



The above graph indicates the influence of ethanol gasoline blended fuels on engine torque. The increase in ethanol content increases the torque slightly. The brake torque of gasoline was lower than E10 and E30, especially due to the addition of ethanol the anti-knock characteristics improved allowing advanced ignition timing which resulted in a higher combustion pressure and thus higher torque.

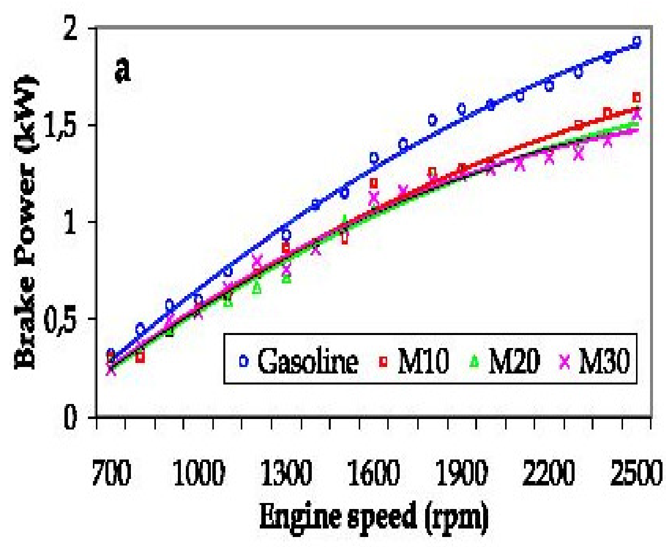
Brake Specfic Fuel Consumption(BSFC) vs Engine speed



BSFC is defined as the ratio of the rate of fuel consumption and brake power. BSFC decreases as the ethanol content increases. As the engine speed increases, the BSFC decreases. This is due to the increase in brake thermal efficiency.

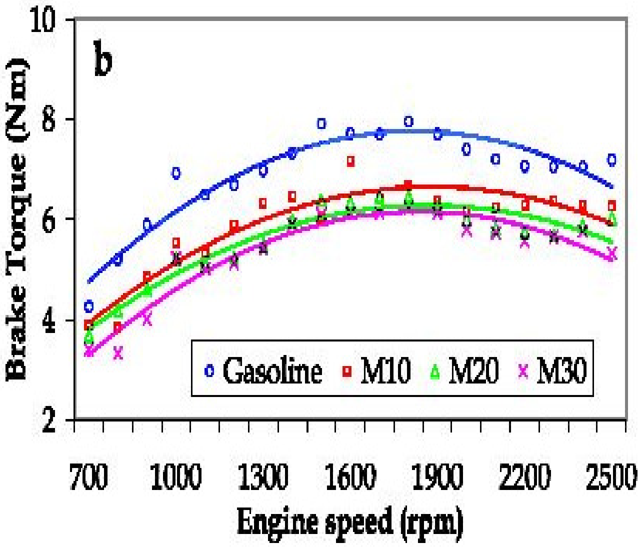
B. Methanol

Brake power vs Engine speed



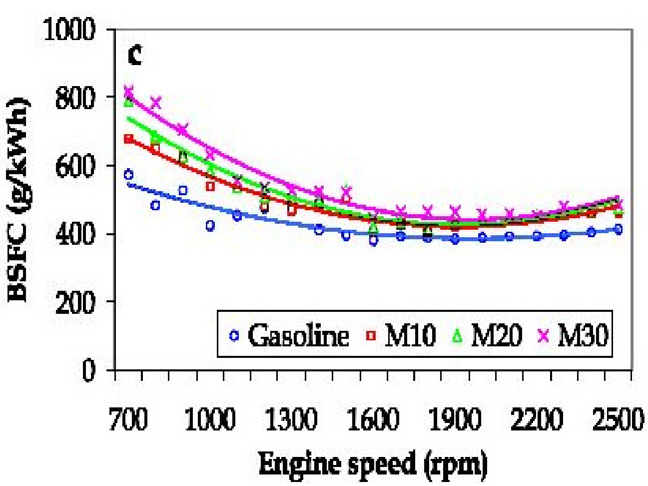
The above graph indicates the influence of methanol gasoline blended fuels on engine power. When the methanol content was slightly increased in the blend, the engine brake power slightly decreased for all engine speeds. The brake power of gasoline is higher than all those methanol blends M10 - M30, especially for high engine speeds at about 2500 rpm. This may be attributed to the slow burning of methanol.

Brake torque vs Engine speed



The above graph indicates the influence of methanol gasoline blended fuels on engine torque. The increase in methanol content decreases the torque slightly. This can be attributed to the leaning effect that reduces the equivalence ratio to a lower value.

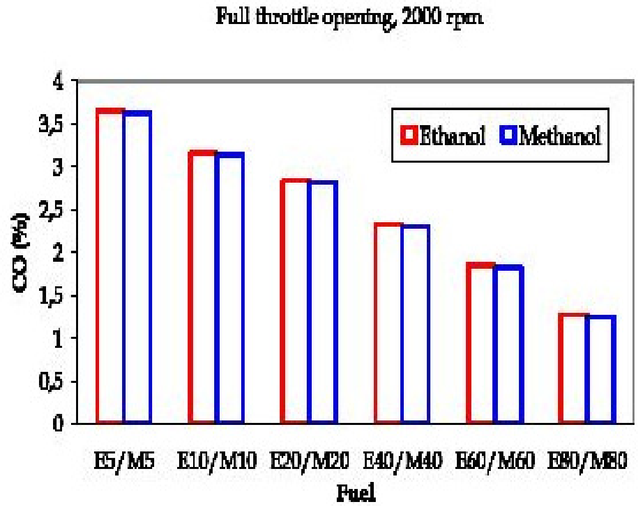
Brake Specfic Fuel Consumption (BSFC) vs Engine speed



BSFC is defined as the ratio of the rate of fuel consumption and brake power. The energy content of the blend decreases with increase in methanol content. This causes the Brake power to reduce ultimately resulting in increase in BSFC. As the engine speed increases, the BSFC decreases.

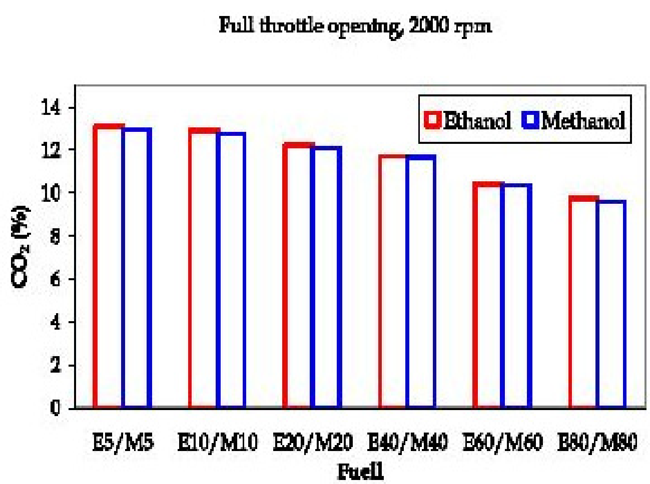
9. EMISSION CHARACTERISTICS OF ALCOHOL-GASOLINE BLENDS

Carbon monoxide (CO):



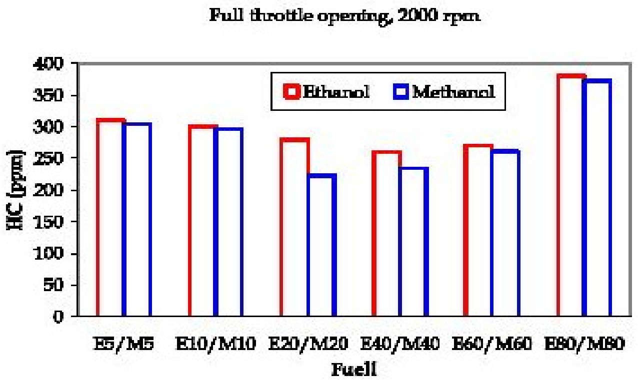
CO is a toxic gas. It is produced as a result of incomplete combustion of gasoline. When methanol or ethanol is blended with gasoline, the amount of CO emission is reduced. This reduction in CO emissions can be attributed to the presence of oxygen in alcohols. You can see from the graph that as the percentage of alcohol in an alcohol-gasoline blend is increased, CO emissions are reduced.

Carbon dioxide (CO_2):



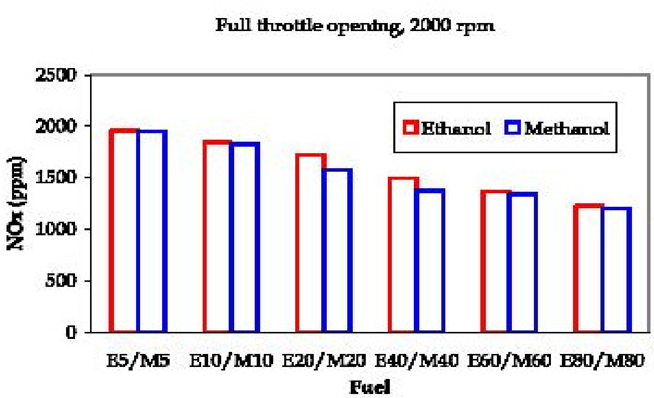
From the above graph, the CO_2 are lower for higher percentage of alcohol in alcohol-gasoline blends. Since, methanol and ethanol have less number of carbon atoms, the amount of CO_2 released will be less compared to the combustion of pure gasoline.

Hydrocarbon (HC):



The HC emission results indicate that methanol and ethanol can be regarded as partially oxidized hydrocarbon when added to the blended fuel. Therefore, HC emissions reduce slightly when the percentage of ethanol/methanol in the blend is increased. But, the graph indicates an increase in HC emissions for E80/M80 blends. This may be attributed to the higher latent heat of vaporization of ethanol/methanol. The cylinder temperature reduces and this results in partial burning of the fuel. Therefore, HC emissions increases and engine power may slightly decrease for E80/M80 fuel.

Nitrous oxide (NO_X):



NO_X are usually formed when the temperature within the combustion chamber is very high. Since, ethanol/methanol have higher latent heat of vaporization, the temperatures in the cylinder are maintained at a lower temperature. Hence, NO_X are reduced.

10. VEHICLES RUNNING ON METHANOL

Many automakers around the world have developed FFV's that run on methanol. An alcohol fuel sensor is used to monitor the fuel mixture and signal the ECU to adjust fuel flow and timing. Lager fuel injectors were used to compensate the lower energy content of methanol. methanol is corrosive and will attack metals and elastomers. There was a need to employ a metal that could withstand the corrosive action of methanol. Therefore, stainless steel was employed. Some of the FFV's that came into production were Ford Taurus FFV (1993-1998), Chrysler Dodge spirit/Plymouth acclaim (1993-1994), Chrysler Concorde/Intrepid (1994-1995) and the General Motors Lumina (1991-1993). These were the largest selling vehicles in the market. By the end of 1996, Ford Taurus was the only methanol powered vehicle available in the market. China has adopted methanol-gasoline blended fuel (M10) as the transportation fuel for their transit buses, FFV's and dedicated methanol fueled vehicles.

Lotus Exige 270E:

Back in 2008, Lotus unveiled a prototype named 'Exige 270E' that could run on gasoline, bio ethanol(E85) and methanol. Considering a car to run on three fuels is a challenging task, but, lotus had done it successfully and developed a car that could develop a power of 270 bhp. Lotus had come with a concept of using synthetic methanol in place of bio ethanol. Methanol can be prepared synthetically from CO_2 extracted from the atmosphere. Since, we get CO_2 from the tailpipe emissions, it can be used for the production of synthetic methanol. This makes the fuel environmentally neutral. Synthetic methanol can be prepared by combining hydrogen with CO_2 extracted from the atmosphere to produce liquid methanol.

Ford focus launched in 2012 is powered by a 2 liter DOHC four cylinder inline engine with twin-independent variable camshaft timing (Ti-VCT) gasoline direct injection which has E85 flex fuel capability.

Citroen C4 launched in the year 2007

Methanol for fuel cells:

Methanol being a stable carrier of hydrogen can be used as a fuel for fuel cells. Hydrogen is extracted from methanol and this can be used in fuel cells. In November 2000, Diamler-Chrysler introduced the 'necar-5' which ran on fuel cell powered by methanol. The necar-5 features a methanol reformer that serves as a on-board chemical plant. This reformer converts methanol to hydrogen gas.

Ethanol vehicle have been used widely in the U.S. Ethanol-gasoline blends are used in FFV's, which operate on a combination of ethanol and gasoline by automatically sensing the percentage of alcohol in the fuel tank and adjusting the engine parameters accordingly. The U.S postal service made the largest purchase of FFV's by a federal government agency, agreeing to buy nearly 23750 vehicles vehicles powered with up to 85% ethanol (E85). Scania, a Swedish company has developed buses that are powered by ethanol, and these have been operating in Stockholm. These buses feature the company's third generation ethanol engines with technology to cut carbon-dioxide emissions by up to 90% compared to conventional diesel engines. Scania's new ethanol engines meet Euro5 emissions standards. Their technology is based on exhaust gas recirculation system.

11. ALCOHOLS SCENARIO INDIA

The Indian Ethanol Program started during the World War II due to the shortage of petrol. The Oil Shock of the mid-70s saw a revival of the interest in ethanol. Successful trials in 1979, the Indian Oil Corporation and Indian Institute of Petroleum on 15 cars found ethanol(10% and 20% blends) is suitable for blending in gasoline. Finally, in April 2001, three successful projects using E5 were conducted. Ethanol was mixed at oil depots and supplied to nearly 300 petrol pumps. In 2002, notifications for mandatory blending of 5% ethanol in gasoline in nine states and four union territories were released. However, due to various reasons ethanol has not been fully adopted completely in the country. It is evident that alcohol fuels is the alternate fuel for a developing country like India.

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