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A Review on Performance and Exhaust Emission Measurements of Methanol Fuel Blend in SI Engines

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Abstract

Global warming is mostly caused by the extensive use of conventional fuels, which release harmful gases into the atmosphere. It is therefore vital to develop renewable and sustainable fuels to fulfil worldwide energy demands while minimising environmental harm. Among the alternative fuels that have shown to be a viable fuel is Methanol (M). Emissions are decreased and performance significantly improves when M and its blends are utilised in Internal Combustion Engines (ICE). This article reviews and discusses M properties, its production process and varying M blends that affect performance and emissions from exhaust gases. The current paper focuses on Brake Power (BP), Brake Torque (BT), Vol Eff (Volumetric Efficiency), Brake Specific Fuel Consumption (BSFC) and BTHE and their impact on exhaust pollutants including Carbon Dioxide (CO2), Hydrocarbon (HC), Oxide of Nitrogen (NOx), and Carbon Monoxide (CO) which are currently a major concern. The pros and cons of using M as fuel for Spark Ignition (SI) engines are also covered in this article. Increased methanol fuel contains a blend that leads to improvements in the Vol. Eff, Cylinder Gas Pressure (CGP) and HRR. The percentage ratio of methanol fuel in a blend increases the Compression Ratio (CR) needed for ignition to occur.

Keywords: *Blends, Compression Ratio, Emissions, Methanol, Performance, SI Engines*

1.0 Introduction

The importance of energy and security has increased due to the current rise in global warming as well as the depletion of fossil fuels. Energy sources play an important role in each country's social and economic growth. Rising crude oil costs provide a challenge for emerging countries to meet energy demands[1]. Natural Gas (NG), diesel and gasoline are examples of fossil fuel-derived fuels that are not sustainable. These are believed to possess a limited reserve. Furthermore, the production and consumption of these fuels generate emissions into the atmosphere that lead to environmental issues like air pollution, acid rain and Greenhouse Gas Emissions (GHG). In addition, rising energy use hurts the economies of nations that import fossil fuels. To minimise dependence on oil, prevent an oil crisis with minimum harmful adverse effects and protect the environment, research into alternative fuels with their compatibility for use in IC engines has become significant. Because of this, studies into the most cost-

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effective and environmentally friendly ways to generate the required power in IC engines for various operational conditions and structures have increased[2]. M is a simple alcoholic ingredient that can be used to replace conventional fossil fuels for improved performance as well as lower emissions. Despite significant research on the compatibility of alcoholic blends with diesel and gasoline, not much is known about the use of a Gasoline-Methanol (GM) blend as an engine fuel. Studies on the effects of GM blends on engine performance, exhaust emissions and noise levels promote their usage as an alternative fuel[3]. One of the top five chemicals produced worldwide is M, commonly referred to as CH_3OH. M is a typical oxygenated hydrocarbon and is traditionally utilised in large-scale production of medicines, glues, pigments, television screens, silicone-based products, as well as wood-based goods. Approximately twenty million metric tons of M are generated yearly as fuel or as a component of fuel mixtures and this amount is rising annually.

Methanol has been utilised for energy-related purposes over the last few years[4]. Using a blending of alternative fuels and regular gasoline can help reduce vehicle pollutants and the quantity of crude oil/ petroleum imported. Methanol is a widely accessible alternative fuel that is a viable source of energy with the potential substitute for conventional fossil fuels. Methanol can be utilised as a fuel in today's ICE with little or no modification[5].

A significant category of biofuels is alcohol. With their similar properties to gasoline fuel and their low cost, ethanol (E) and methanol (M) have the most potential for application in the transportation industry among all alcohols. Alcohols burn more efficiently and produce fewer emissions than pure gasoline because their chemical structure contains more oxygen (O_2) with Octane Number (ON) and higher Latent Heat of Vaporisation (LHV)[6].

2.0 Methanol Fuel Used for Spark Ignition (SI) Engines

Since the turn of the 20th century, M has been used in automotive technology. It can also be used as fuel in fuel cells and CI engines. Flexible fuel vehicles have made it possible to employ a range of methanol and gasoline mixtures, from M85 to 100% gasoline[7]. Currently, M is a feasible alternative fuel for IC engines because of its low smoke exhaust emissions and ability to create fuel that is carbon dioxide neutral. M is often referred to as one of the best fuels for ICE in the future due to its versatility in high compression. DI SI engines have the potential to replace diesel in some vocational applications like high CR and intake port injection SI engines. It is a good choice for compact, turbocharged, high-powered density, DI stoichiometric engines because of increased vapourisation heat and much-improved resistance to knocking, M has higher fuel conversion efficiency than gasoline. The investigation of exhaust emissions as well as combustion. Understanding the processes of M fuels and blends is the main scientific engineering technological challenge for the development of M engines[8].

2.1 Methanol Production

Methyl Alcohol consumption is currently estimated to be 92 million tonnes per year worldwide. (Figure 1) and production has increased by almost 1433% since 1975. To make M, a variety of carbon-containing feedstocks

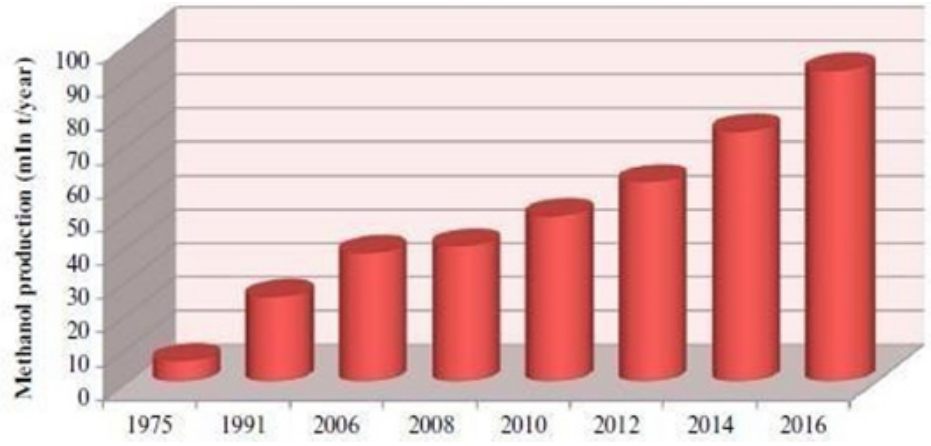


Figure 1. Methanol production indicated in million tones year from 1975 to 2016[8].

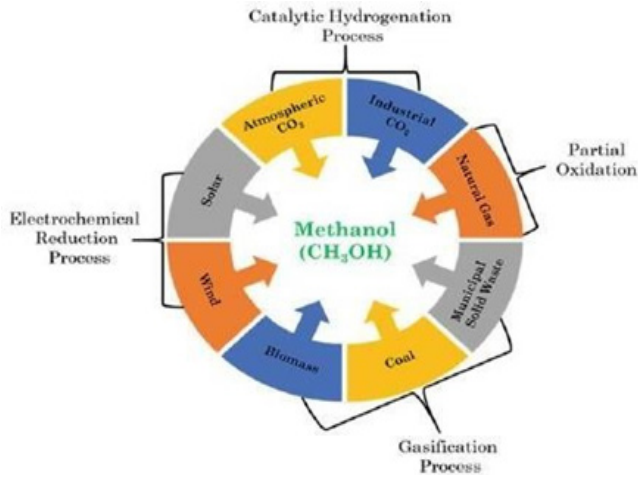


Figure 2. Production of methanol from various sources[1].

can be utilised, including CO_2 fossil fuels, biomass and NG.

Nowadays, NG accounts for about 90% of the M produced. The relatively simple process approach to making the most simple alcohol includes the following three basic techniques. **1.** Synthetic gas generation **2.** Producing crude methanol from syngas **3.** Distillation is used to purify the reactor effluent[8]. Alternative energy sources like wind, solar, etc. can be used to make M through the proper electrochemical reduction of CO_2. Furthermore, it is directly manufactured through the catalytic hydrogenation of CO_2 and partial oxidation of methane.

China is a global leader in the production and application of methanol, particularly in the transportation industry. About 70% of the methanol produced overall comes from coal[1].

2.2 Properties of Methanol Fuel

Table 1 indicates that the Calorific Values (CV) of M and gasoline are significantly lower, resulting in significant variations in their stoichiometric A/F ratios. As a result, a lot more fuel is required for a given volume of air. When

Table 1. Fuel properties[9]

Properties	Methanol	Gasoline
Composition (C, H, O) (mass%)	37.5,12.5,50	86,14,0
Chemical Formula	CH_3OH	C_8H_{15}
Boiling Point (^{0}C)	64.5	25–215
Heat of evaporation (kJ/kg)	920.7	223.2
Density (kg/m3)	796	760
Oxygen Content/ Mass%	49.9	0.0
Stoichiometric A/F Ratio	6.4	14.6
Saturation pressure at 38 ^{0}C (kPa)	31.69	31
Lower heating value (MJ/kg)	20.1	43.5
Water Solubility (ml/100 ml H2O)	Fully miscible	<0.1
Flashpoint (^{0}C)	11.1	-45 to -38
Toxicity of vapour	Toxic in only Large doses	Moderate Irritant
Auto-ignition Temperature (^{0}C)	470	420

combined, these two facts also demonstrate that the fuel's cooling impact on the intake charge is significantly more than that of gasoline since the fuel's latent temperatures are higher. Due to the reduction in charge temperatures at full load, the engine produces more torque and power and has higher volumetric efficiency.

2.3 Advantages and Disadvantages of Methanol Fuel[4]

Advantages

- Easy to handle as a liquid.
- Safer to store than gasoline due to its lower flammability limit.
- Compatible with ethanol and gasoline.
- Biodegradable.
- Availability of widely shipped chemicals.

Disadvantages

- Compatibility of materials.
- Less safe to store than diesel due to lower flash point.
- Limited diesel miscibility.
- Confined range compared to gasoline or diesel due to low energy density.
- Fuel injectors with low lubricity.

3.0 Effects on Engine

Performance

3.1 Torque

The impact of methanol blends on engine torque at full load speeds is seen in Figure 3. For all engine speeds, it is evident that blends have less torque than gasoline. The maximum torques for all fuels were found to be reached around 2500rpm when the torque curves were examined. Maximum torque values for M10, M20, M30 and M40 are 10, 16, 23 and 30 % less than those for gasoline fuel. As methanol has a lower heating value than gasoline, it releases less energy through combustion and transfers less work during expansion stroke.

During the inlet stroke, the engine consumed the same amount of fuel blends which resulted in a drop in fuel blend energy in the engine cylinder[14]. The main reason for the BP rising to 2500rpm and falling to 3500 rpm in the engine is the variable valve timing mechanism[11]. Methanol consumption causes a 19 per cent increase in BT for a change in CR from 6:1 to 10:1[12].

3.2 Brake Power

Figure 4 shows the impact of methanol blends on brake power at maximum speeds. It is obvious that at all engine speeds, blends have less power than gasoline. M10, M20, M30, and M40 have optimal power that is 12, 16, 30 and 42% less than that of gasoline[14]. As the methanol content of the blended gasoline (M10, M20 and M30) increased

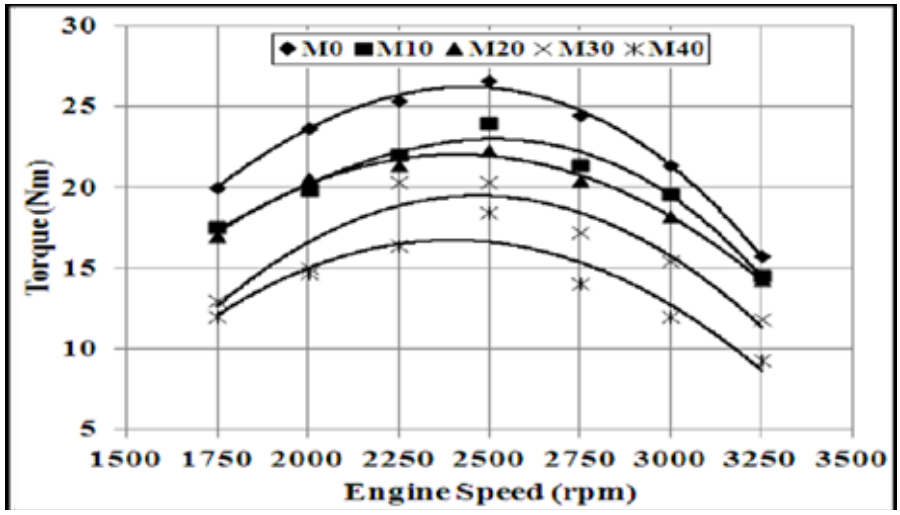


Figure 3. The impact of gasoline-methanol blends on torque[14].

the engine brake power improved marginally. For blends with higher methanol percentages, the increase in IMEF can be attributed to the brake power. Because methanol evaporates at an elevated temperature compared to gasoline, the air-fuel charge cools more quickly and becomes denser.

A better power output is attained as a result. Compared to M50, gasoline gives more BP at all engine speeds[15]. Methanol blend fuels are more efficient because, compared to gasoline, they have a higher laminar flame speed, which helps to complete combustion before heat escapes from the cylinder[6].

3.3 Specific Fuel Consumption

A larger amount of methanol in the fuel blends was related to increased BSFC. The SFC rises as the proportion of methanol in the blend increases because it has a lower latent heating value than gasoline. Since blends have a lower Heating Value (HV) than base gasoline (M0), at the same operating conditions, more blends are needed to provide equal power. The addition of methanol results in average increases in the SFC of 3%, 10%, 14%, and 30% at 2500 rpm for M10, M20, M30, and M40, respectively, as indicated in Figure 5. When the maximum torque values are attained, the specific fuel consumptions are minimum for all fuels at a speed of roughly 2500 rpm. The SFC

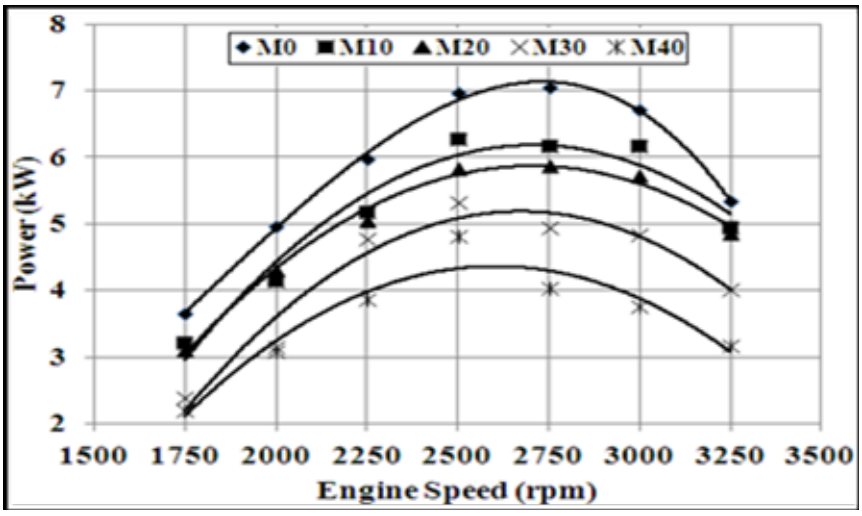


Figure 4. The impact of gasoline-methanol blends on brake power[14].

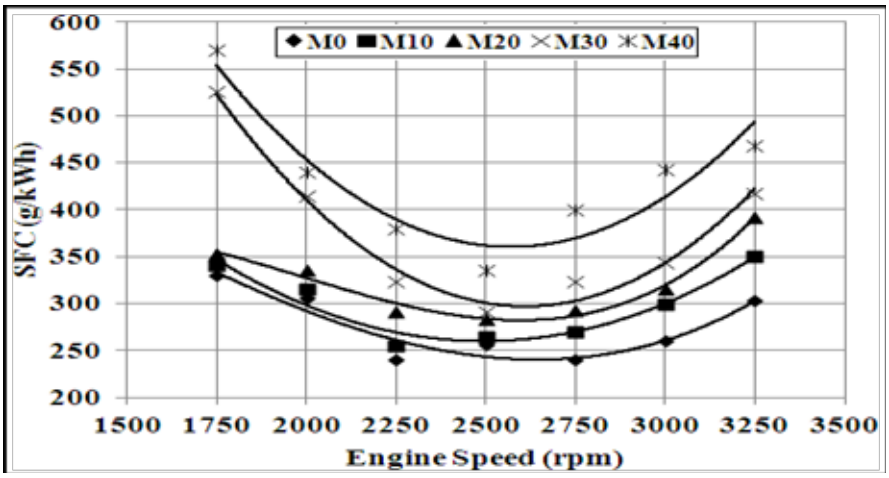


Figure 5. The impact of gasoline-methanol blends on SFC[14].

increases at both low and high speeds, as shown in Figure 5. This occurs because the engine produces little power at low speeds and a large amount of friction power at high speeds, which causes the power to increase more slowly than the fuel consumption, thereby raising the SFC[14]. M10 and M15 are demonstrated to have significantly lower BSFC values at all engine loads as compared to other fuels at all ignition timings. Low fuel consumption is a result of complete combustion being ensured by oxygen molecules attached to the fuel[13].

3.4 Brake Thermal Efficiency[1]

A typical engine working at all ignition timings has a lower Thermal Efficiency (THE) than the gasoline-methanol blends between M5 and M15. Additionally, it was noted that the Brake Thermal Efficiency (BTHE) rose as the blend percentage enhanced. The ignition advance causes a rise in combustion rate and mixture M5 has a higher BTHE at 30 ignition timing than other blends. The faster combustion rate is assumed to be owing to the fuel's molecular oxygen, which has a heating value identical to regular gasoline for M5. In some blends, the HV of fuel reduces as the amount of methanol (M) increases, but the rate of combustion is significantly higher than regular gasoline, leading to better BTHE[13].

3.5 Volumetric Efficiency

When operating at high engine speed the engine has to inhale the air charge quickly, which reduces the volumetric efficiency of all fuel blends. As demonstrated in Figure 6, the volumetric efficiency rose as the proportion of the methanol ratio increased. Methanol's LHV is higher than that of gasoline. Before fuel is burned, its liquid molecules must be evaporated, which is known as the LHV. The air cools and becomes denser when heat from the atmosphere is absorbed. This increases the amount of air mass that can enter the cylinder during the inlet stroke. Consequently,

There was a rise in volumetric efficiency[14]. Volumetric efficiency rises as the methanol percentage increases because more air is introduced into the engine cylinder[11].

4.0 Effects on Engine Exhaust Emissions

When methanol is used, engine emissions of hydrocarbons and carbon monoxide as well as NOx are reduced. Moreover, the methanol blends have a toxicity content as; based on reports, their emissions are significantly cleaner than those of conventional fuels. The detailed literature analysis shows the different methanol fuel blends affect various exhaust emissions characteristics[18].

4.1 Carbon Monoxide Emission

Figure 7 shows the change in CO emission for all fuels based on the ongoing testing. When the methanol ratio and engine speed increased, the CO emissions dropped. Compared to methanol, gasoline has approximately twice as much carbon in it. During combustion,

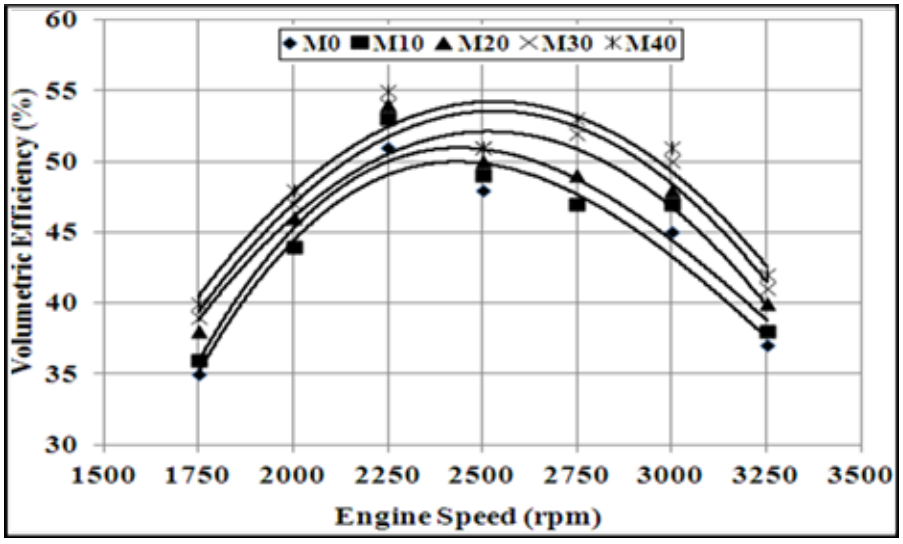


Figure 6. The impact of gasoline-methanol blends on volumetric efficiency[14].

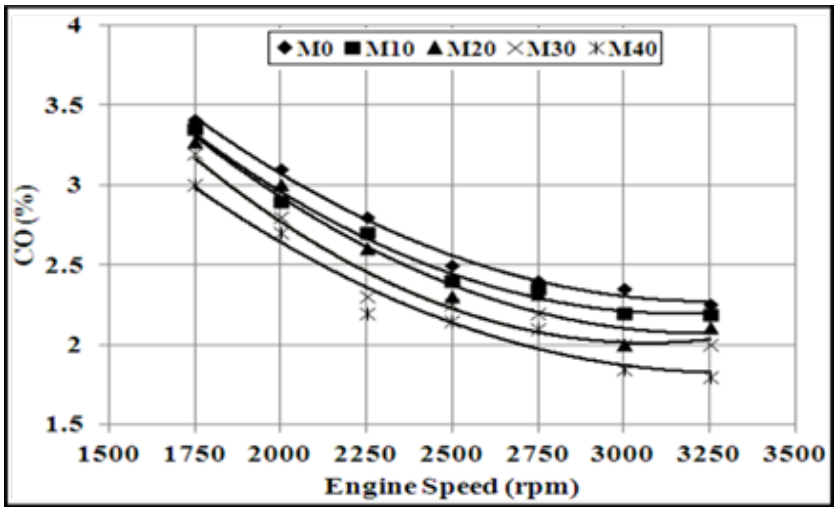


Figure 7. The impact of gasoline-methanol blends on the CO emission[14].

carbon directly transforms into CO. As a result, as the methanol percentage in the blends increased, the carbon monoxide emissions reduced. Additionally, the air in the engine cools as an outcome of the enhanced heat from the methanol vaporisation, increasing air density and allowing for a higher intake stroke. More complete combustion results in a leaner fuel combination, which might reduce CO emissions. The methanol's oxygen presence makes the reaction more thorough. As a result, the blends burn more completely and release less CO when the proportion of methanol in the blends rises[14]. The air-fuel ratio primarily determines CO emissions. Methanol reduces CO emissions because it enriches the air with oxygen[12]. The CO concentration falls as the methanol percentage rises. This can be understood by the methanol's enrichment of the oxygen, in which a higher proportion of oxygen will promote the engine exhaust process's subsequent oxidation of CO[11].

4.2 Hydrocarbon

Hydrocarbon emissions are the main reason for incomplete combustion that arises from a lack of air or oxygen in the cylinder. It is evident that for all fuels, the HC emission reduced as speed increased. This occurs as a result of the

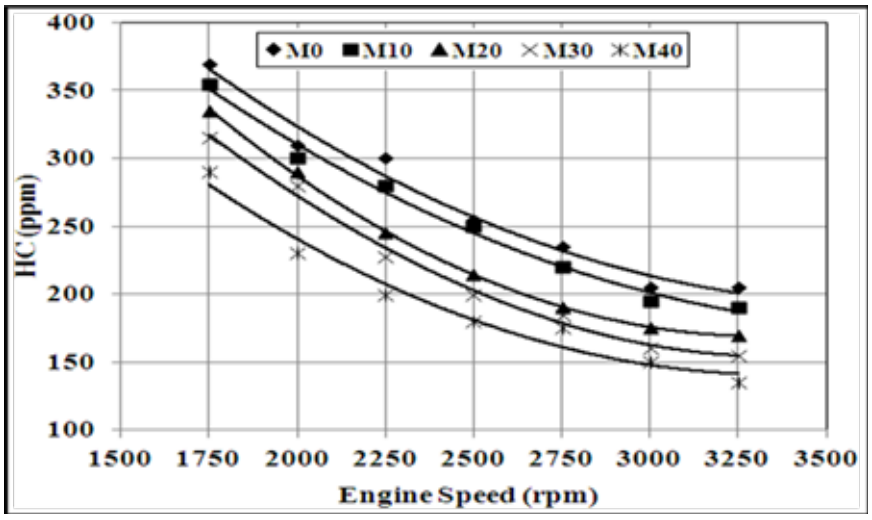


Figure 8. The impact of gasoline-methanol blends on the HC emission[14].

combustion temperature inside the engine chamber rising with increased speed. Additionally, when engine speed increases, there is more turbulence in the combustion chamber. As a result, there is a decrease in HC emissions and fast combustion. Furthermore, it is anticipated that lower exhaust temperatures characterising oxygenated blends will lead to reduced hydrocarbon emissions than gasoline. The HC emission was decreased as the methanol percentage in the blends increased because the oxygenated mixture contained adequate Oxygen for full combustion[14]. As the amount of methanol (M) increases, it is shown that the level of HC drops. The cause for the reduction in HC concentration means that hydrocarbon pollutant falls as the relative A/F ratio rises[11].

4.3 Carbon Dioxide Emission

Despite being non-toxic, carbon dioxide increases the greenhouse effect. Methanol produces less CO_2 than gasoline at all CRs. There is about 37% less CO_2 when methanol is used at the same CR (6/1) than gasoline. Because alcohols are lower in C content and C/H ratio than gasoline in engines that use alcohol, carbon dioxide is low methanol (M) emits around 30% less CO_2 at a CR of 10/1 than pure gasoline fuel, which has a CR of 6/1. Using methanol, the CO_2 increased by 13% when CR was raised from 6/1 to 10/1. With an increase in CR, both CO_2 levels and combustion efficiency improve. Low BTHE and insufficient air and fuel mixing time after the optimal range led to a decrease in CO_2 emissions at higher engine speeds. Previous research reveals higher CO_2 exhaust gas emissions when methanol is blended with gasoline fuel[12,19].

4.4 Oxides of Nitrogen Emission

When compared to pure gasoline, all CRs that use methanol fuel produce less NOx. In comparison to gasoline, methanol (M) releases around 35% fewer nitrogen oxides at the same CR (6/1). When compared to gasoline with a CR of 6/1, methanol with a CR of 10/1 emits nearly 22% less NOx. Compared to gasoline fuel, methanol has a higher heat of vaporization the rate of combustion also decreases when the blend's temperatures drop toward the end of the intake stroke. Engine NOx emissions consequently decrease when CR increases from 6/1 to 10/1, and NOx for methanol rises by about 16%. Nitrogen oxide levels are increased as the CR improves because it raises the temperature at which combustion occurs[12]. It has been noted that as CR increased, NOx emission rose at all speeds[20].

5.0 Conclusion

This article reviews the impacts of methanol on spark ignition engine performance, combustion, and exhaust emissions. Methanol is added to gasoline to improve combustion, smoother operation, decrease duration, and reduce exhaust pollutants. The conclusions drawn from the above studies are listed below:

1. Methanol use as fuel only indicates increased influence over crude oil pricing and the dominance of oil-producing countries in the global market. Self-sufficient methanol consumption is a significant advancement because oil imports have generally been the main driver of the world exchange of currencies.
2. The efficiency of gasoline engines is significantly affected by the methanol fuel's octane rating.
3. The quantity of gasoline crude oil imported can be reduced by at least 15% as 15% methanol is blended with the gasoline. Furthermore, this would result in a 20% reduction in GHG related to Particulate Matter (PM), NO_X, and Sulphur Oxides (SOx) enhancing the quality of air in urban areas.
4. When an engine was operating on a methanol-gasoline mixture, it was found that although BSFC declined, performance parameters like BT, BP, BTE, and volumetric efficiency (Vol. Eff) increased.
5. The impact of operating temperatures on all of the spark ignition engine's parameters was not studied. Variations in atmospheric temperature, particularly in a country like India, have a direct impact on the engine's heat transfer rate, thus more research is needed.
6. As the percentage ratio of methanol (M) rises, thus rise the NO_X levels. When the combustion process approaches stoichiometric flame temperature grows, resulting in higher NO_X emissions.
7. The increase in methanol percentage results in lower CO and HC emissions. This is because methanol (M) has more oxygen molecules, which causes it to burn more effectively.

8. A rise in methanol content leads to a rise in CO_2 emissions. Due to better burning, the quantity of carbon dioxide has increased.

6.0 References

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