Performance and Emission Characteristics of Methanol and Di-Methyl Ether as Spark Ignition Engine Fuel: A Review

Pratibhu Roy1, Ranendra Roy2, Bijan Kumar Mandal3*

Abstract: This paper presents a brief review on the use of methanol and di-methyl ether (DME) in spark ignition engine, their performance and emission characteristics based on the reports of different researchers available in the literature. Methanol can be produced from avail-able fossil raw materials and also from biomass. A very few literature is available on the study of DME as a supplementary fuel to gasoline. Therefore the authors have made an attempt to compile those findings in this paper for further progress. Also the usability of methanol as a supplementary fuel have been complied and represented in graphical man-ner. DME is primarily produced by converting natural gas, organic waste or biomass to synthetic gas in a two-step synthesis process. The review shows that engine power, brake specific fuel consumption, brake thermal efficiency increases or decreases depending upon the operating conditions of the engine and methanol percentage in the methanol-gasoline blends. Similar trend is observed with di-methyl ether. The emissions of CO, CO2 and NOx decrease, but the emissions of hydrocarbon, formaldehyde and unburned methanol increase with methanol addition to gasoline. In case of di-methyl ether addition, CO, CO2 and NOx emissions increase, but hydrocarbon emission decreases. It can be said that methanol and DME addition to gasoline is an effective way for improving the economic and emissions performance of the SI engine.

Keywords: *Methanol, Di-methyl ether, Blends, Spark ignition engine, production, Per-formance, Emission.*

I. Introduction

With the rapid development of the industry and society, the requirement of fossil fuels is growing rapidly. So, there is a great anxiety about the shortage of energy because of finite reserves of fossil fuels or other reasons (such as petroleum crisis and the Persian Gulf War). The use of fossil fuels such as petrol also results in two most serious problems of global warming and environmental pollution. Facing the challenges of limited fossil fuel reserves and stringent environmental constraints, the issue of finding substitutes for fossil fuels has become a major work for researchers studying internal combustion (IC) engines [1]. In the last two decades, the researchers and manufacturers have provided major reduc-tions in the exhaust emission levels of the automobiles due to increasing global concern about the air pollution [2], but the problem has yet not been solved. So, from all aspects it is needed to search for renewable and green alternative fuels for internal combustion en-gines. Alcohol (methanol, ethanol and butanol etc.) show promises to be one of the best alternative fuels for spark ignition (SI) engines. El-Emam and Desoky [3] investigated the performance and emission of SI engines fuelled with pure ethanol and pure methanol and observed that thermal efficiency was increased and also the NOx and the CO emissions were decreased with both methanol and ethanol. Sapre [4] investigated the performance and emission characteristics of methanol-gasoline blends (M30, M50 and M70) in a single cylinder variable compression ratio spark ignition engine and noticed that adding methanol to gasoline and increasing the compression ratio increased the engine power and thermal efficiency and decreased in NOx emissions. Çetinkay a and Çelik [5] studied the effect of pure methanol and methanol-gasoline blends (M30, M50, M75) in a spark ignition engine and observed that specific fuel consumption is increased and CO, HC emissions are de-creased with increase in fraction of methanol in the blend. However, HC emission in-creased when pure methanol was used as fuel. Abu-Zaid et al. [6] reported that the addition of methanol to gasoline increased the octane number, thus engines fuelled with methanol-gasoline blend can operate at higher compression ratios. Arapatsakos et al. [7] experimen-tally investigated the performance of a four-stroke spark ignition engine using methanol-gasoline blends (M10, M20 and M30) and observed that with the increase in methanol percentage specific fuel consumption increased and CO and HC emissions decreased. In another study, Arapatsakos et al. [8] investigated the behaviour of four-stroke spark igni-tion engine using gasoline-methanol blends as fuel and observed that HC emissions de-creased as methanol content in the fuel increased, but HC emissions significantly increased when M100 fuel was used. Some researchers have also added di-methyl ether to gasoline and studied their energetic and environmental performances. In this paper, an attempt has been made by the authors to review the present status of using methanol and dimethyl ether blended with gasoline in spark ignition engine. The properties of methanol and di-methyl ether have also been discussed in the context of SI engine fuels.

II. Properties of methanol and di-methyl ether

Properties of any fuel depend fully on its chemical compositions which determine the per-formance and emission characteristics of the engine. Compared with other alternatives, methanol and di-methyl ether (DME) are suitable alternative fuels for spark ignition (SI) engines. Methanol is similar to traditional gasoline as a liquid fuel in respect to the storage, transportation, distribution and applications. It can be produced from widely available fos-sil raw materials in-

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cluding coal, natural gas and bio-substances [9].When used in SI en-gines, as methanol has a high octane number, high latent heat of vaporization and high oxygen content (around 50% by mass), it will result in a good antiknock performance, dense fuel–air charge and excellent lean com-bustion . Although methanol is a good alterna-tive fuel for IC engines, the low vapour pressure and high latent heat of vaporization of methanol cause cold start difficulties at low ambient and in-cylinder temperatures. Higher laminar flame propagation speed of methanol makes combustion process faster and thus improves engine thermal efficiency. DME can be produced from a variety of feed-stocks such as natural gas, coal, crude oil, residual oil, waste products and biomass. The high cetane number and low boiling point of DME symbolize the short ignition delay, low auto-ignition temperature and almost instantaneous vaporization when DME is injected into the cylinder. Moreover, as DME is non-toxic and environmentally benign, whatever at low or high mole fractions (percent by volume) in air, it hardly has any odor and causes negative health effects. The DME has a low carbon-to-hydrogen ratio (C: H), a high oxygen content (around 35% by mass) and no C–C bonds in its molecu lar structure. The thermo-physical properties of methanol, di-methyl ether compared to the gasoline are taken from the work of Semelsberger et al. [10] and listed in Table 1.

Properties	Methanol	Di-methyl ether	Gasoline
Formula	CH_3OH	CH_3OCH_3	C_7H_{16}
Molecular weight (g mol^{-1})	32.04	46.07	100.2
Density (g cm^{-3})	0.792	0.661	0.737
Octane number	111	-	>90
Cetane number	-	55-60	-
Normal boiling point (ºC)	64	−24.9	38-204
Auto ignition temperature (^{0}C)	465	235	228-470
Latent Heat of Vaporization (kJ/kg)	1103	467	305
LHV (kJ g^{-1})	19.99	28.62	43.47
Carbon Content (wt. %)	37.5	52.2	85.5
Sulfur content (ppm)	0	0	~ 200

Iii. Production of methanol and di-methyl ether

The global production of methanol is about 40 million ton per year, most of which is pro-duced from natural gas. To-day, the high price of oil and natural gas has spurred new inter-est in alternative feed-stocks for the production of methanol. The major sources of metha-nol are coal and heavy petroleum fractions. But nowadays, due to the fossil fuel nature of coal and petroleum products, methanol is be-ing produced from biomass in a sustainable way. The pro-duction of methanol from biomass consist the following processes:

- Gasification of the biomass to produce synthesis gas
- Gas upgrading (gas clean-up, CO-shift and CO-removal); to meet the requirements of the methanol synthesis.
- Methanol synthesis and purification to meet the output specifications.

The conversion of hydrogen and carbon oxides to methanol is described by the follow-ing reactions:

$CO + 2H_2 = CH_3OH$, (ΔH_{298K} = 90.7 kJ/mol)

$CO_2 + 3H_2 = CH_3OH + H_2O$, ($\Delta H_{298K}$ = 40.9 kJ/mol)

$CO_2 + H_2 = CO + H_2O$, (ΔH_{298K} = 49.8 kJ/mol)

DME is primarily produced by converting natural gas, or-ganic waste or biomass to synthe-sis gas (syngas). The syn-gas is then converted into DME via a two-step synthesis, first to methanol in the presence of catalyst (usually copper-based), and then by subsequent methanol dehydration in the presence of a different catalyst (for example, silica-alumina) into DME. The following reactions occur in the presence of catalyst like silica-alumina for the conversion [10]:

$2H_2 + CO \rightarrow CH_3OH$

$2CH_3OH \rightarrow CH_3\text{-}O\text{-}CH_3 + H_2O$

$CO + H_2O \rightarrow CO_2 + H_2$

IV. Performance characteristics of methanol

The purpose of this paper is to review the present status of methanol and di-methyl ether as fuel in SI engine. The per-formance and emission are the two most important charac-teristics of any engine that should be investigated using the targeted fuels. The targeted fuels for this study are the dif-ferent fuel blends of methanol and di-methyl ether with gasoline. Per-formance parameters like specific fuel con-sumption, thermal efficiency, power output and torque which have been evaluated by different researchers after experimental studies are reported in this section. Li et al. [11] experimentally investigated the effects of injection and ignition timings on performance and emissions from a sin-gle-cylinder, four stroke spark-ignition spark ignition en-gine and observed that at 1600 rpm (full load) and optimal injection and ignition timings, methanol engine can obtain shorter ignition delay, maxi-mum in-cylinder pressure,

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maximum heat release rate and higher thermal efficiency com-pared to the case of non-optimized injection and ignition timings which can lead to an im-provement of brake specific fuel consumption. Çelik et al. [12] studied the effect of pure methanol over a gasoline engine at different compression ratios and reported that at higher compression ratio with methanol, the torque output, cylinder pressure, power output, spe-cific fuel consumption and brake thermal efficiency is higher (due to higher octane number of methanol) than those of gasoline at lower compression ratio. At lower compression ra-tio, the performance characteristics with methanol are better than conventional gasoline. Eyidogan et al. [13] experimentally investigated the performance and combustion charac-teristics of a spark ignition (SI) engine using methanol-gasoline fuel blends and observed that due to the lower energy content and more oxygen rate of methanol, combustion effi-ciency and brake specific fuel consumption are increased than gasoline. The brake thermal efficiency increases and exhausts gas temperature decreases than gasoline because of the high latent heat of vaporization of methanol. Ozsezen and Canakci [14] experimentally investigated the performance and emission characteristics of methanol-gasoline blends and demonstrated that the peak wheel power and fuel consumption slightly increased when the vehicle was fuelled with methanol-gasoline blends. Generally, the methanol-gasoline blends at all vehicle speeds provided slightly higher combustion efficiency relative to pure gasoline. The best combustion efficiency was obtained with the use of M5 at 40 kmh-1 and 80 kmh-1 vehicle speeds. Abu-Zaid et al. [15] investigated the effect of methanol addition on the performance of a spark ignition engine and observed that addition of methanol to gasoline increases the octane number to operate the engine at higher compression ratios. The best engine performance for maximum power output, brake mean effective pressure (BMEP), minimum brake specific fuel consumption and thermal efficiency occurs when M15 blend (methanol 15% and gasoline 85%) is used.

The experimental study by Çelik et al. [12] is grap hically represented in figures 1-2. The effect of both fuels and compression ratios on engine torque is shown in figure 1. By increasing compression ratio from 6:1 to 10:1, about 14% increase in torque is obtained without the occurrence of knock when methanol is used. From the plot of specific fuel consumption (SFC) vs. speed at various compression ratios (Figure 2), it is observed that SFC values for methanol are higher than those of gasoline at all the compression ratios (CRs) as the heating value of methanol is nearly half of that of gasoline. And the lowest SFC value is obtained at 2500 rpm. At the compression ratio (6:1), SFC is about 90% higher for methanol than that of gasoline.

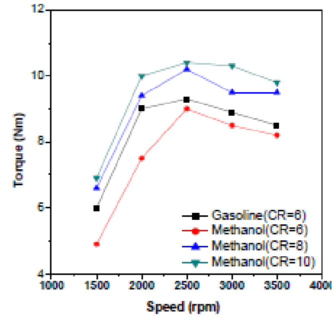

Fig. 1. Variation of torque with speed for different gasoline-methanol blends at different compression ratios. [12]

In another experimental investigation, Shenghua et al. [16] have seen that the brake ther-mal efficiency is improved with the increase in methanol content in the blend and becomes maximum for M20 (29% at engine speed 3500 rpm). This is due to the fact that the lami-nar flame speed of methanol is higher than those of most of the hydrocarbon fuels and the heat of vaporization of methanol is 3 times higher than that of gasoline which helps in complete combustion and reduces the heat losses. The variation of brake thermal effi-ciency with engine speed is represented in figure 3 from the work of Shenghua et al. [16].

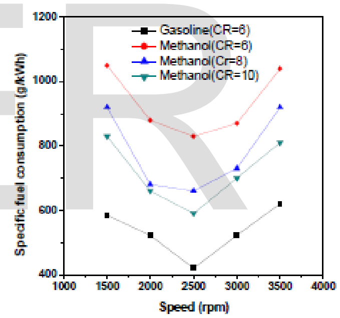

Fig. 2. Variation of specific fuel consumption with speed for different gasoline-methanol blends at different compression ratios. [12]

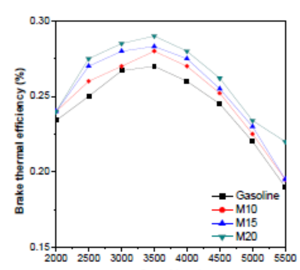

Fig. 3. Variation of brake thermal efficiency with engine speed for different gasoline-methanol blends. [16]

V. Emission characteristics of methanol

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Most of the emissions from the engines are carcigenous and harmful for environment as well as human health. Only four most important emissions considered under this study are CO, unburned hydrocarbon (UHC), NOx and CO2. The effect of methanol addition to pet-rol/gasoline on the pollutants emissions is briefly discussed in the following section. Shen-ghua et al. [16] investigated the performance and emission characteristics of a spark igni-tion engine using methanol-gasoline fuel blends. They observed an improvement in the engine cold start and also the reduction in CO and HC emissions significantly due to more oxygen content of the blended fuels. As nitrogen oxides (NOx) emission is more with al-cohol blended fuels, a three-way catalytic converter (TWC) was also been used for the treatment of the exhaust from the engine. The use of TWC reduces the NOx emissions and further improves HC and CO emissions. The non-regulated emissions like unburned methanol and formaldehyde increase with the fraction of methanol. On the other hand, from the study of the emission characteristics of methanol-gasoline blends made by Ozsezen and Canakci [14], it is reported that increase in CO emission and decrease in HC emission occur using methanol-gasoline blends. They also reported that CO2 emission increases with methanol addition to the gasoline fuel. Minimum CO2 emission was obtained when M5 blend is used. From the exhaust emissions results by Liao et al. [17], it is reported that HC emissions during the rich combustion increases with increase in methanol into gasoline at relatively low temperature due to enhanced evaporation of the blended fuel.

The emission data from the experimental study conducted by Çelik et al. [12] is repro-duced in figures 4-7. They reported that CO, NOx, CO2 emissions are decreased with methanol at higher compression ratio compared to gasoline. Only the HC emission is higher at any compression ratio compared to gasoline. For all compression ratios and all fuels, increasing the engine speed decreases CO emission (Figure 4) and it is lower for methanol than that with gasoline. By increasing compression ratio from 6:1 to 10:1, CO emission decreases by almost 16%. From the graphs of CO2 emission vs speed as shown in figure 5, it is observed that at all the compression ratios with methanol; CO2 is lower than that with gasoline as alcohols have both lower carbon-hydrogen ratio and carbon con-tent than gasoline. By increasing compression ratio from 6:1 to 10:1, a 13% increase in CO2 was obtained when methanol was used.

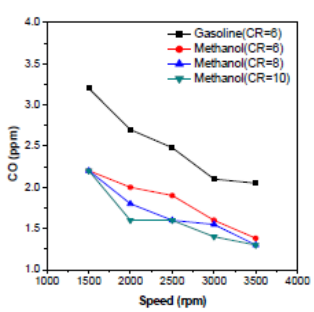

Fig. 4. Variation of CO emission with speed for different gasoline-methanol blends at different compression ratios. [12]

The effect of methanol addition to gasoline on HC emission at various compression ratios has been shown in figure 6. It is reported that HC emission is higher for methanol than that with gasoline at all the compression ratios of 6, 8 and 10 considered in their study. Also, HC emission increases by about 12% with increasing the compression ratio from 6:1 to 10:1 for methanol. This is because as the compression ratios increase the combustion chamber surface/volume ratio increases also and the flame cools in the places near to sur face and misfire occurs thereby increasing HC emission. The effect of both fuels on com-pression ratios and NOx emission (figure 7) shows that at all the compression ratios with methanol, NOx is lower than that with gasoline and NOx emission increases by about 16% with increasing the compression ratio from 6:1 to 10:1 due to the increase in combustion temperature.

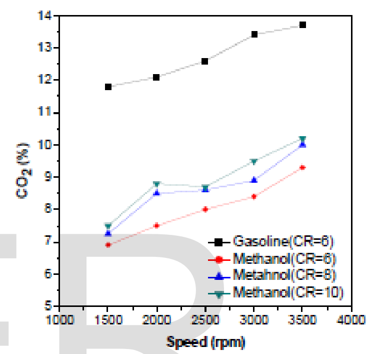

Fig. 5. Variation of CO2 emission with speed for different gasoline-methanol blends at different compression ratios. [12]

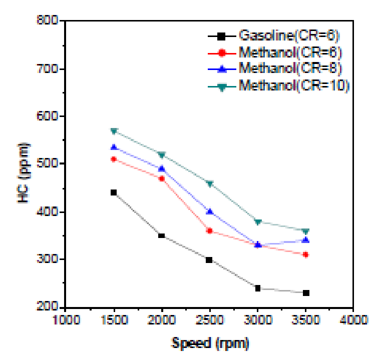

Fig. 6. Variation of HC emission with speed for different gasoline-methanol blends at different compression ratios. [12]

VI. Performance and emission of di-methyl ether

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Liang et al. [18] investigated the combustion and emission performance of Di-methyl ether (DME) enriched gasoline fuels in a spark ignition engine and observed that indicated thermal efficiency increased and flame development and propagation durations were shortened with the increase of DME enrichment level at idle condition. However, CO and NOx emission increases with the addition of DME. Ji et al. [1] carried out an experiment at idle and stoichiometric conditions to investigate the effect of DME addition on the idle performance of a spark-ignited (SI) ethanol engine. They noticed that the fuel energy flow rate drops with the increase of DME fraction in the fuel. This is due to the low volume energy density of the gaseous DME and indicated thermal efficiency increases. The en-richment of DME also enhances the peak in-cylinder temperature and shortens both the flame development period and propagation duration. Whereas, HC emissions are de-creased with the increasing fraction of DME addition and NOx emissions were slightly increased.

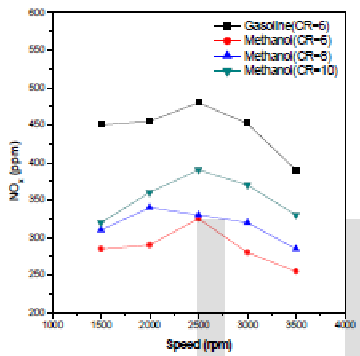

Fig. 7. Variation of NOx with speed for different gasoline-methanol blends at different compression ratios. [12]

VII. Conclusion

The present study investigates the usability of methanol and di-methyl ether as fuels for a spark ignition engine by analyzing the experimental results available in the literature. From this study, it can be concluded that the blends of methanol and gasoline containing low fraction of methanol can be used in SI engines without any engine modifications. Gasoline blended with both methanol and di-methyl ether slightly lower the engine power and torque, while increase engine brake thermal efficiency. Moreover, CO, CO2 and NOx emissions decrease and HC emission increases with the increase in methanol content in gasoline-methanol blends. However, increase of methanol increases the formaldehyde emissions and unburnt methanol emission. But, the emission behaviour using DME-gasoline blends shows reverse result than methanol blends. So, it can be concluded that methanol and DME addition to gasoline is an effective way for improving the economic and emissions performance of the SI engine and also helpful for realizing the stable opera-tion, especially at idle conditions.

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