

A Review on the Ignition Characteristics of Dimethyl Ether in Diesel Engines

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Abstract – This review study was gathered from the results of various papers performed on the use of dimethyl ether as a fuel or fuel additive in diesel engines. Several methods are applied for the reduction of the polluting emissions emitted from diesel engines. The first method for the reducing of hazardous emissions is improved the combustion by the modification of engine design and fuel injection system, but this is expensive and time consuming process. The second method is the using of various exhaust gas devices i.e. catalytic converters and diesel particulate filters. However, it is determined that the use of these devices affects diesel engine performance conversely. The last method to reduce the polluting emissions and also improve the diesel engine performance is the using of renewable alternative fuels or various fuel additives. Among the various alternative fuels, dimethyl ether (DME) is the pioneer by reason of its attractive fuel properties such as high cetane number and oxygen content. On the other hand, the physical and chemical properties of the used fuel play the important role on the injection, ignition and combustion characteristics of internal combustion engines (ICEs). Moreover, outputs of ICEs i.e. performance, fuel consumption and emissions are affected extensively from the ignition, injection and combustion characteristics. Therefore, it is essential that the results of studies performed on dimethyl ether are evaluated together to support future researches and practice applications. Especially, this review study investigates the effects of using DME on the ignition characteristics.

Keywords – Diesel Engine, Fuel Additives, Dimethyl Ether, Ignition Characteristics, Exhaust Emissions

I. INTRODUCTION

Diesel engines are main power sources owing to their better performance, efficiency and durability, higher fuel economy and lower polluting emissions of hydrocarbons (HCs), carbon monoxide (CO) and carbon dioxide (CO₂) than gasoline engines [1]. However, existing diesel engines emit higher levels of particulate matter (PM) and nitrogen oxides (NO_x) than those of gasoline engines. Therefore, many researchers have tried to develop low-pollution diesel engines and progressive studies have been conducted on alternative fuels which may produce clean diesel engine emissions [2]. Among the variety of alternatives, dimethyl ether (DME) is the most hopeful from the standpoint of energy security, because it can be industrially produced from the coal, natural gas and many kinds of biomass [3]. However, the fuel properties of DME

such as lower viscosity, lubricity, combustion enthalpy and boiling point need the modifications of the engine internal structures and components. The technology with pure DME as an alternative fuel for compression ignition (CI) namely diesel engine is still under development period. However, DME can be used as a blend with diesel fuel and the other fuels [4] Therefore, it is very important that the results of studies performed on the using of DME are assessed collectively to support the future investigations and practice applications. This review study especially concentrates the ignition characteristics of DME in diesel engines.

II. EFFECTS OF DME ON IGNITION CHARACTERISTICS

The properties of DME and diesel fuel are shown in Table 1. It is seen that the properties of DME are quite different from those of diesel fuel. DME has

high vapor pressure and low boiling temperature, which is a gas fuel at room temperature and atmospheric pressure. Its handling characteristics are very similar to liquefied petroleum gas (LPG), a widely fuel used in spark ignition (SI) engines. The heat value of DME is significantly lower than conventional diesel fuel. Therefore, the fuel supply and injection system, and the combustion system of the engine should be redesigned or modified [5].

Table 1. The main properties of DME and diesel fuel [6]

Property	DME	Diesel
Chemical formula	CH ₃ -O-CH ₃	C _x H _y
Molecular weight, g	46.07	170
Boiling point, °C	-24.9	180–360
Liquid density, kg/lt	668	840
Liquid viscosity, cP	0.15	4.4–5.4
Lower heating value, kJ/kg	28430	42500
Ignition temperature, °C	235	250
Cetane number	55–60	40–55
Stoichiometric air/fuel ratio	9	14.6
Modulus of elasticity, N/m ²	6.37x10 ⁸	1.486x10 ⁹
Mass fraction of carbon	52.2	86
Mass fraction of hydrogen	13	14
Mass fraction of oxygen	34.8	0

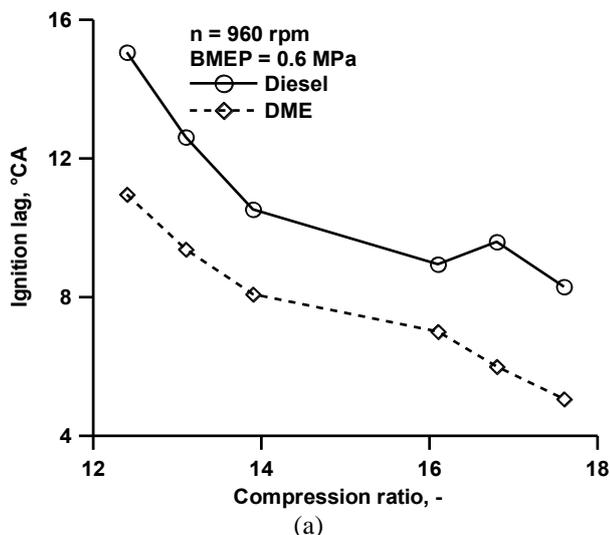


Fig. 1. Variation of ignition lag for DME and diesel fuel [7]

Fig. 1 shows the variation of ignition lag with compression ratio for DME and diesel fuel at the conditions given in Fig. 1. As seen Fig. 1, ignition lag decreases with the increasing of compression ratio. It is declared that this is due to increasing of cylinder gas temperature during the end of the compression period. On the other hand, DME gives the lower ignition lag values than diesel fuel as seen in Fig. 1. It is declared that this is sourced from the lower ignition temperature and higher cetane number of DME as seen in Table 1 [7].

Fig. 2(a) and (b) illustrates the variation of ignition timing and ignition delay for DME and diesel fuel at the conditions given in Fig. 2(a). The ignition timing generally increases when the DME–ethanol (E) blends are used as seen from Fig. 2(a). It is considered that this is sourced from the extremely lower cetane number and higher latent of vaporization of ethanol. These properties of ethanol delay the ignition of the DME–ethanol blends so ignition timing rises. Due to the effects of same fuel properties of ethanol, the ignition delay also increases for the DME–ethanol blends compared to pure DME as seen in Fig. 2(b) [8].

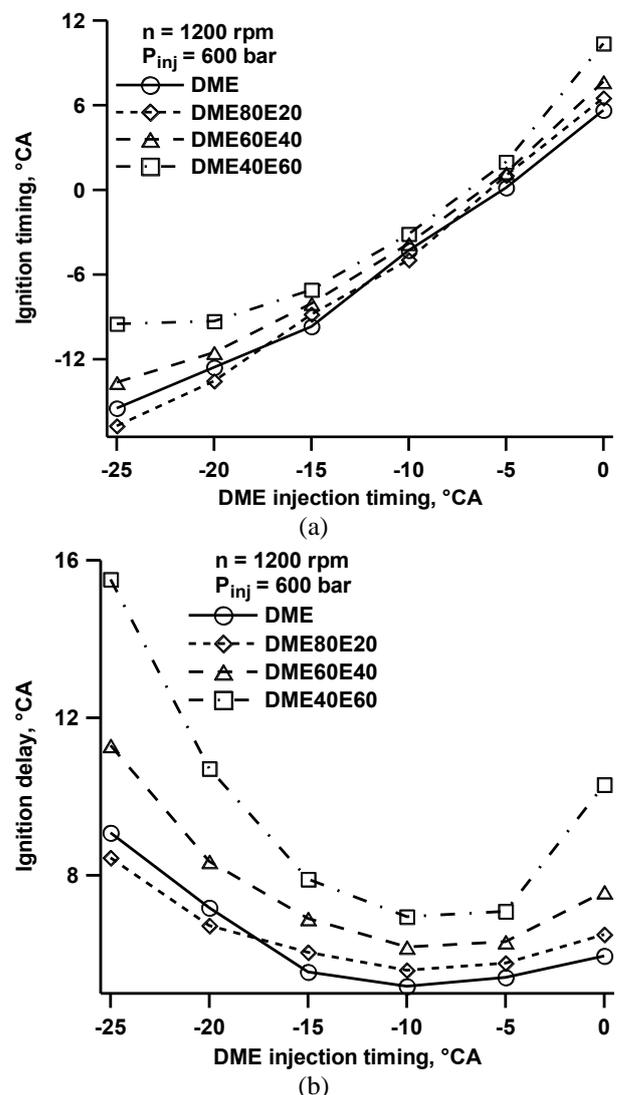


Fig. 2. Variation of a) ignition timing and b) ignition delay for DME and DME–ethanol (E) blends [8]

Fig. 3 indicates the variation of start of ignition with the injection timing for DME–biogas (BG) blends. The start of ignition is defined as a crank angle at 10% of the cumulative heat release.

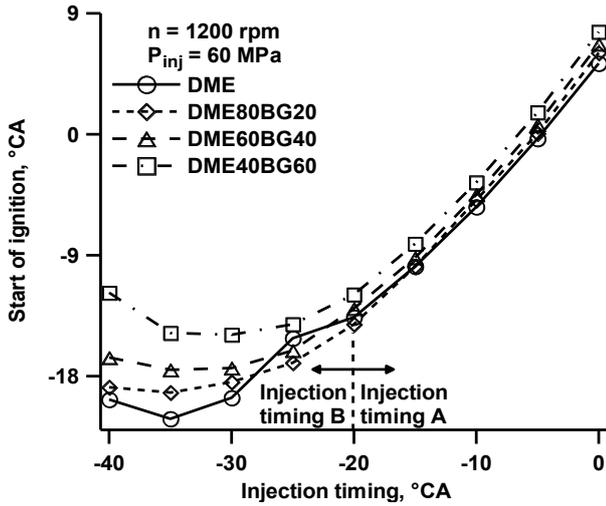


Fig. 3. Variation of start of ignition with injection timing for DME and DME-biogas (BG) blends [9]

As seen in Fig. 3, the injection timing from TDC (top dead center) to 20° BTDC (before top dead center) called “Injection timing A” demonstrates a linear correlation between injection timing and SOI, regardless of the blending ratio of BG. At the same time, there is not much difference in ignition delay among these conditions. In the “Injection timing A” region, the direct injected DME is sufficiently mixed with BG, and the mixture of BG and DME efficiently utilizes the oxygen in the combustion chamber. Therefore, the mixing ratio of BG has a little impact on ignition characteristics, because the “Injection timing A” region has good conditions for ignition and combustion. In other words, the direct injection timing of DME is a more influential parameter affecting ignition characteristics than the mixing ratio of BG in the “Injection timing A” region. On the other hand, the injection timing for before 20° BTDC called “Injection timing B” from 40° BTDC to 20° BTDC does not demonstrate a linear correlation with the injection timing. Furthermore, the effect of mixing ratio on the ignition delay is obvious with the advanced injection timing. In the “Injection timing B” region, the injection timing shows a polynomial curve with the advanced injection timing. In addition, the increase in BG mixing ratio enhance the start of ignition at the same injection timing. This can be explained that the geometry of combustion chamber i.e. the injected DME spray separates into two directions toward the piston bowl and squish after targeting the piston lib (around 25° BTDC) or it entirely flows into the squish and crevice regions when the injection timing advanced before 25° BTDC. Thus, the amount of DME flowing into the

piston bowl decreased as the injection timing advanced. Therefore, a non-linear correlation between ignition timing and injection timing resulted from the distribution of direct injected DME. As well, the retardation of ignition timing due to the increase in mixing ratio of BG resulted from the decrease in DME and the increase in BG with higher auto-ignition temperature over 632 °C [9].

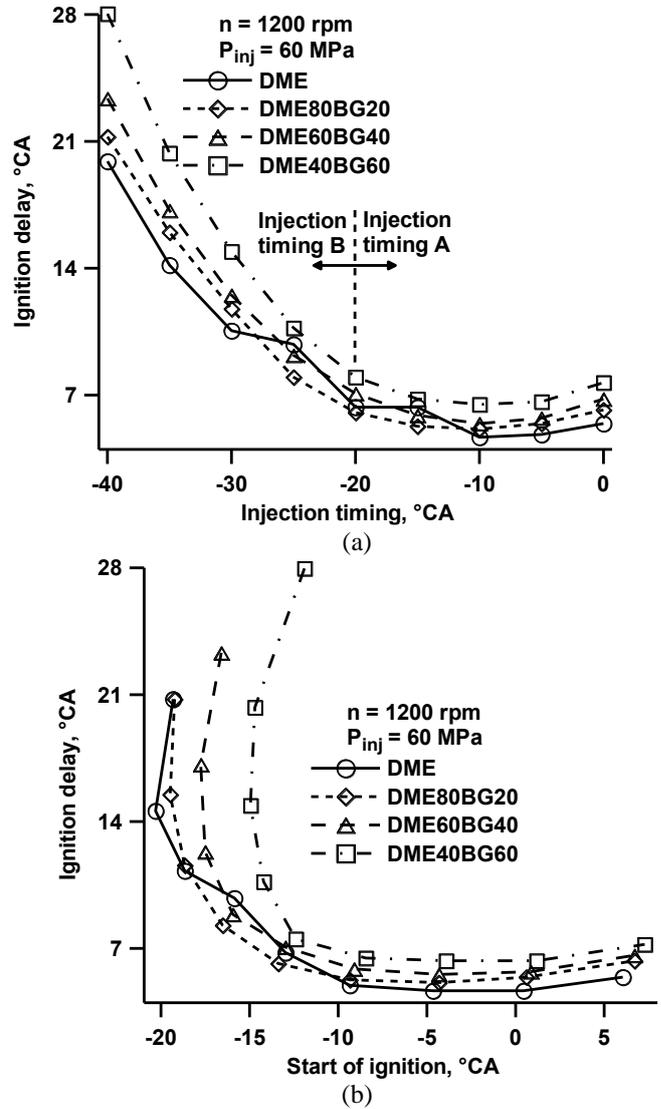


Fig. 4. Variation of ignition delay with a) injection timing and b) start of ignition for DME and DME-biogas (BG) blends [9]

Fig. 4 gives more details the relation between ignition delay and injection timing. Fig. 4(a) depicts the relation between injection timing and the ignition delay and Fig. 4(b) shows the relation between start of ignition and ignition delay for various mixing ratios of BG from 0 to 60. As seen in Fig. 4(a), the retarded injection timing causes an exponential decrease in ignition delay, because the advanced injection timing results in lower pressure and temperature in the combustion cylinder. The

low pressure and temperature conditions make it difficult to ignite. In addition, the difference in ignition delay among test conditions changed from about 7.4 degree at 40° BTDC to about 1 degree at 20° BTDC as the injection timing was retarded. In the “Injection timing A” region, the difference in ignition delay among test conditions was within 1 degree. The increase in mixing ratio of BG caused an increase in ignition delay in the “Injection timing B” region, since the mean cetane number in mixture of DME and BG decrease. On the other hand, Fig. 4(b) depicts the ignition delay characteristics for start of ignition in various mixing ratio conditions of DME and BG. As seen in Fig. 4(b), the ignition delay characteristics are clearly divided into two parts as the standard of the ignition timing around 13° BTDC (corresponding to 20° BTDC in the injection timing). After, 13° BTDC in start of ignition, the ignition delay is almost the same regardless of the mixing ratio. However, in the region before 13° BTDC namely “Injection timing B”, the ignition delay shows very sensitive to changes in start of ignition such that it suddenly changes for very small variations in start of ignition. In addition, as the increased mixing ratio of BG, the timing for the ignition limitation of start of ignition is retarded to TDC [9].

Figs. 5(a) and (b) show the effects of the exhaust gas recirculation (EGR) rate on the ignition delay of DME and DME–bioiesel (BD) blends for engine loads (BMEP) of 0.4 MPa and 0.8 MPa. The ignition delay slightly increases as the EGR rate increases, because the residence time for O₂–fuel interaction increases at a higher EGR rate. The effect of the BD ratio on the ignition delay is complex; BD5 has the shortest ignition delay, while DME has the longest, although the difference is not significant. There are four factors related to the ignition delay as follow. Firstly, the cetane number of BD is slightly lower than that of DME, and the chemical ignition delay is slightly longer than that of DME. Secondly, the higher viscosity, surface tension and distillation range of BD lead to poor atomization performance. Thirdly, the calorific value of BD is more than 40% higher than that of DME, the elasticity modulus is large, and the fuel injection duration is shortened. Finally, although the spray cone angle is smaller with adding DME in BD, the spray penetration distance and spray area increase, and the fuel–O₂ mixing fast. It is considered that the effects of factors 3 and 4 advance the ignition delay more

strongly than those of factors 1 and 2, so the ignition delay of DME is the longest and that of B5 is the shortest. However, it is thought that the effect of factor 2 increases and the ignition delay period becomes longer as the BD ratio increases [10].

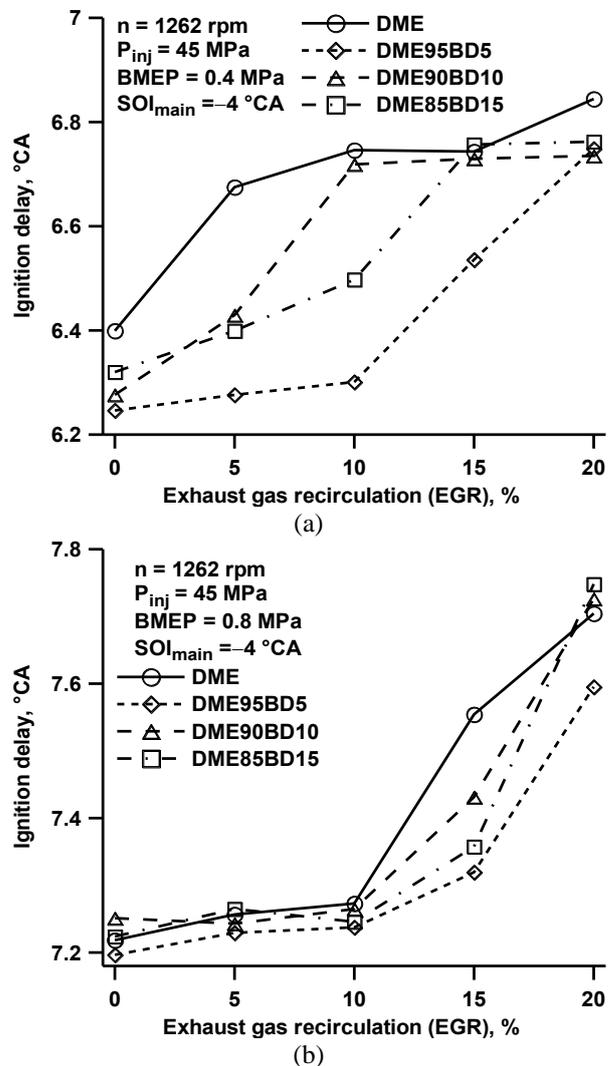


Fig. 5. Variation of ignition delay with exhaust gas recirculation a) BMEP of 0.4 MPa and b) BMEP of 0.8 MPa for DME and DME–bioiesel (BD) blends [10]

Fig. 6 indicates the variation of injected fuel quantity with main combustion duration for DME without and with post injection conditions. The main combustion duration is proportional to the fuel quantity of the main injection, and get longer with decreasing of main fuel quantity as seen in Fig. 6. The lengthened combustion duration means that combustion was slower than with single injection, which decreased the maximum cylinder gas temperature. The post combustion phase was primarily affected by post injection timing, and the subsequent difference was appreciable. The cylinder gas temperature decreased considerably with volume expansion during the expansion period.

Thus, temperature at post injection decreased and ignition delay and combustion duration of post injection increased [11].

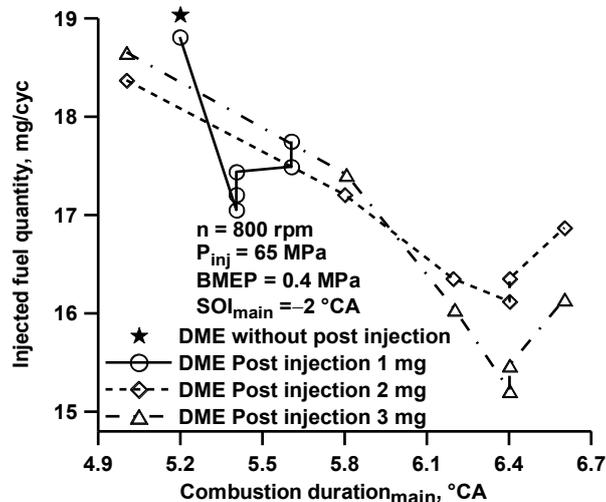
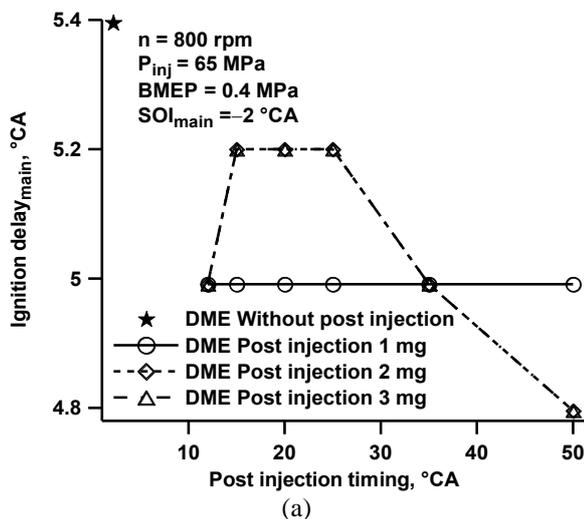
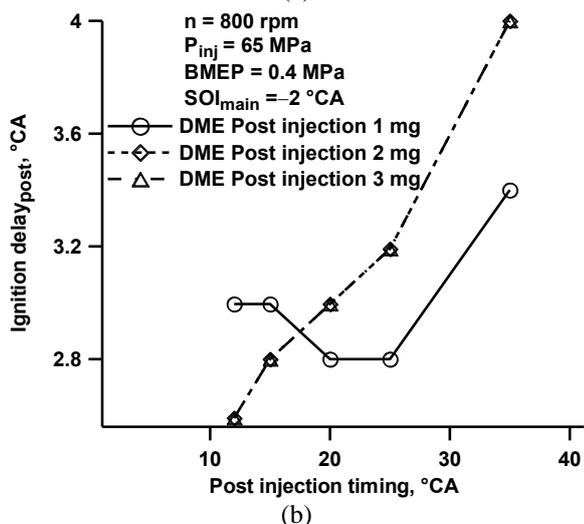


Fig. 6. Variation of injected fuel quantity with main combustion duration for DME [11]



(a)



(b)

Fig. 7. Variation of a) main ignition delay and b) post ignition delay with post injection timing of DME [11]

Fig. 7(a) and (b) indicates the variation of main and post ignition delay with post injection timing for

DME. As seen in Fig. 7(a), main ignition delay remains stable for 1 mg post injection while it increases before and then decreases for post injection of 2 mg and 3 mg with the increase of post injection timing. It is determined that the ignition delay for the main injection is similar to the delay of single injection. It is declared that ignition delay is affected by charge temperature change due to the combustion chamber wall and residual gas temperatures. Post combustion can increase the charge temperature, but this increase was unnoticeable because the post injection quantity was small. As seen in Fig. 7(b), post ignition delay increases with the increase of post injected fuel. It can be evaluated that the ignition lasts longer naturally with the increasing amount of injected fuel. On the other hand, post ignition delay decreases before and then increases for post injection of 1 mg while it increases for post injection of 2 mg and 3 mg with the increase of post injection timing. It is thought that post ignition delay lasts longer with the increase of post injection timing due to the decreasing temperature in the cylinder [11].

III. CONCLUSION

The main conclusions of this review study can be summarized as follow.

- It is determined that ignition lag decreases with the increasing of compression ratio for DME and diesel fuel. It is also declared that DME gives the lower ignition lag values than diesel fuel.
- It is determined that DME–ethanol blends give the higher ignition timing and ignition delay values than that of pure DME.
- It is determined that DME–biogas blends give the higher start of ignition and ignition delay values than that of pure DME.
- It is determined that DME–biodiesel blends give the lower ignition delay values than that of pure DME.
- It is determined that main injected fuel quantity and ignition delay decrease with post (split) injection of DME compared to single injection. It is determined that main ignition delay remains stable for 1 mg post injection of DME while it increases before and then decreases for post injection of 2 mg and 3 mg of DME with the increase of post injection timing. It is also determined that post ignition delay decreases before and then increases for post injection of 1 mg while it increases for post injection of 2 mg

and 3 mg with the increase of post injection timing.

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