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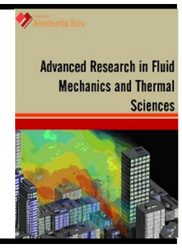

Simulation Study of Combustion Characteristics of Diesel-Ethanol-Palm Oil Methyl Ester Blends in Diesel Engine

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ABSTRACT

Diesel-ethanol-palm methyl ester (PME) blends are believed to be able to improve the combustion characteristics since diesel, ethanol, and PME have different fuel characteristics. This paper is aimed to study the combustion characteristics of pure diesel and diesel-ethanol-PME blends with different compositions through simulation works and to estimate the best fuel composition that can be used in real engine applications. A simulation work was conducted using seven different diesel-ethanol-PME blends for a combustion based on a compression ignition Yanmar TF90 engine parameter by using a CONVERGE CFD software. Seven diesel-ethanol-PME blends (10 vol% to 40 vol%) PME were mixed in ethanol together with 50 vol% diesel fuel operated at 1600 RPM. High PME percentage increased the heat release rate (HRR). However, due to non-uniform chemical energy release from the reaction, the blends of 25 vol% PME with 25 vol% ethanol blends released the highest HRR. A high percentage of ethanol reduced the temperature and increased the heat release. From the cumulative heat release, ignition delay occurred for blends that had more than 15 vol% ethanol. In conclusion, blending ethanol and PME in diesel increased the combustion heat release rate to have better engine efficiency. However, the blend that contained more than 35 vol% ethanol was not suitable to be used in direct injection compressed ignition engine without any modification since the temperature and HRR of the blends is very low.

Keywords:
Palm oil Methyl Ester, Combustion Characteristics, Heat Release Rate, Ignition

1. Introduction

Diesel engine is known as the most powerful engine that is able to provide high efficiency to vehicles, especially for heavy duty vehicles, due to the high energy contents in diesel fuel. However, diesel fuel is also known as the major contributor of greenhouse emission that leads to the development of fuel modification techniques to reduce engine modification cost and the creation of alternative fuels in diesel engine to reduce petroleum energy dependence and reduce

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transportation cost for petroleum [1]. Malaysia is currently moving forward to be recognised as an automotive industry hub country towards energy efficiency vehicles (EEV) since 2014 after introducing the National Automotive Policy (NAP)[2]. With the abilities of producing palm oil as the main agriculture income, the production of biodiesel has been developed by using raw palm oil. This development has also been supported by the Malaysian government by declaring palm oil development as one of the eight entry projects (EEPs) under 12 National Key Economic Areas (NKEAs) to improve the economic growth of Malaysia [3]. This is because the production of biodiesel does not need a complex process known as the transesterification process from the reaction of triglycerides and alcohol with the existence of catalyst [4-5].

Therefore, replacing diesel with new renewable energy such as palm oil methyl ester (PME) is expected to reduce petroleum dependency and reduce harmful emissions [6-7]. However, PME has higher viscosity and density as compared to diesel and this may lead to engine injection system problems such as choking and deposition. Therefore, with the help from alcohol, which is also known as biofuel, ethanol is widely used because it has lower viscosity and density that enables it to reduce injection system problems especially in cold weather. However, adding ethanol in blends at a higher percentage may cause other problems such as corrosion and lower efficiency since ethanol contains a small percentage of water that is easy to evaporate and can corrode the engine parts. Diesel, ethanol, and PME have different thermo-physical properties that influence the combustion behaviour. Table 1 shows the thermo-physical properties of diesel, ethanol, and PME at 40°C [8-10].

Table 1
Thermo-physical properties of diesel, ethanol and PME fuels

Properties	Diesel	Ethanol	PME
Molecular formula	NC_7H_{16}	C_2H_5OH	$C_{18}H_{34}O_2$
Viscosity (cSt)	3.49	1.2	4.8
Density (kg/m^3)	834	752	881
Low heating value (MJ/kg)	43.2	36.4	37.8
Cetane number	50	8	56
Oxygen contents (%)	0.3	25	11

A research from Govindan *et al.*, [11] has worked with a simulation to identify the combustion characteristics by using the Ansys-Fluent software on thumba biodiesel (10 vol%–30 vol%) with diesel blends. The study found that the peak pressure for high biodiesel percentage is slightly higher than diesel. However, due to the low heating value of biodiesel, the heat release rate (HRR) of biodiesel blends is slightly lower than diesel. A simulation work is a automation technology to analyse the combustion behaviour of an engine, which allows the analysis to be simple, flexible, and managed at a low cost with high quality results [5]. The addition of ethanol, which has a much lower heating value than biodiesel and diesel, showed that it has influences on the combustion characteristics. A study from How et al. found that the addition of 5 vol% ethanol in 20 vol% biodiesel and diesel through an experimental work gave slightly lower peak pressure and HRR. This indicates that the addition of coconut oil methyl ester and ethanol in diesel reduces heat release and pressure during combustion and slightly reduces thermal efficiency [12]. However, due to the limitation of cost and time, simulation works are more preferable as a new development of PME blends based on the real properties of diesel, ethanol, and PME. In this study, high percentage ethanol and PME were used to develop a new diesel-ethanol-PME blend composition.

This paper is aimed to optimise the best diesel-ethanol-PME blends to be used in the direct injection compression ignition Yanmar TF90 engine and to study its heat release behaviour. This study is a simulation work study based on the direct injection compression ignition Yanmar TF90 engine parameter. Seven different diesel-ethanol-PME blends have been used while maintaining the percentage of diesel at 50 vol% with 10 vol% until 40 vol% ethanol and PME for each blend. The thermo-dynamic property preparation for input data has been mathematically prepared and the heat release behaviour has been studied for the blends by observing the combustion ability for each blend.

2. Methodology

A simulation work was conducted based on a direct injection compression ignition Yanmar TF90 engine parameter and a model for this engine has been used by using a CONVERGE CFD software. Figure 1 and Table 2 show the engine combustion chamber model and the parameter of direct injection compressed ignition Yanmar TF90 engine. In this study, ethanol and PME were set to be mixed before entering the injection nozzle, where 50 vol% diesel was maintained for each blend with different percentages of ethanol and PME, starting from 10 vol% until 40 vol%.

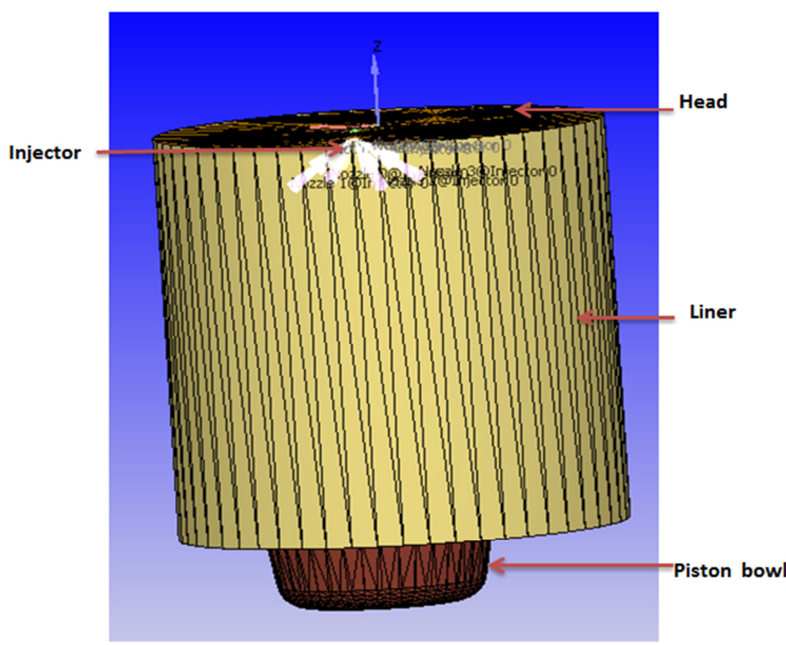

Fig. 1. Direct injection compressed ignition Yanmar TF90 engine model

While conducting a simulation for blended fuel case, some basic information needs to be provided including fuel thermo-physical properties, chemical kinetic reaction, and gas data. All the properties of PME fuel were theoretically estimated from a mathematical model, meanwhile the properties for diesel and ethanol were provided by the software library [13]. Before the estimation was calculated, all the fuel density, viscosity, and calorific values of each blend have been experimentally conducted and used as the initial values for simulation setup [14]. The chemical kinetic reaction for blends was obtained from Lawrence Livermore National Library (LLNL). Combustion, injection, and turbulence models were set up for each blend. The heat release rate (HRR) data was obtained and fuel ignitability was investigated.

Table 2
Engine and injection system specification [15]

Engine specification	
Bore x stroke (m)	0.085 x 0.087
Connecting rod length (m)	0.13
Bowl diameter (m)	0.0463
Bowl depth (m)	0.016
Compression ratio	18
Engine speed	1600
Injector specification	
Number of nozzle	4
Nozzle diameter (m)	0.0022
Injection pressure (MPa)	19.613
Back pressure (MPa)	6
Flow rate coefficient	0.6088
Injection duration (°CA)	16
Start of injection (°CA BTDC)	-18
Injected mass (mg/cycle)	19
Injection cone angle (°)	10

3. Results and discussion

3.1 Heat Release Rate (HRR)

Figure 2 shows the heat release rate (HRR) for different diesel-ethanol-PME blends operated at 1600 RPM engine speed and its comparison with the diesel fuel combustion. The results found that blending ethanol and PME influenced the heat release rate of the blends. However, the graph shows that the addition of ethanol more than 40 vol% tends to have lower HRR than diesel. The heat release rate recorded was too low since the fuel was found to be unable to burn. This is because the temperature in the cylinder was not high enough to ignite the fuel due to the high auto-ignition temperature of ethanol. The graph also shows that the addition of high PME contents increased heat release during combustion. However, the addition of ethanol in the blends slightly reduced the heat release rate due to the low heating value of the blends. Due to the different properties of PME and ethanol, a high percentage of PME will not necessarily have higher HRR. At this condition, other factors such as chemical energy rate distribution may change the heat release. The peaks that occur in the HRR profile indicate that the fuel has experienced premixed and mixed controlled combustions. From the graph, the blend that produced the highest HRR is E25B25, followed by E20B30, E30B20, E15B35, E10B40, E35B15, diesel, and E40B10 blends. This non-uniform change of HRR data occurred probably due to a few factors such as the mixture of fuel with air that could easily vaporise and produce a non-uniform air fuel ratio (AFR) composition distribution during the expansion. Besides, the effect of heat transfer to the wall that is related to the chemical energy rate influenced the non-uniform heat release rate, while the crevice area in the cylinder led to the obtainability of inaccurate data [16]. E40B10 was found to have lower HRR than diesel. This is due to the reason that the blend was not able to ignite and this condition proved that E40B10 is not suitable to be used in a normal diesel engine and it may give lower thermal efficiency to the engine.

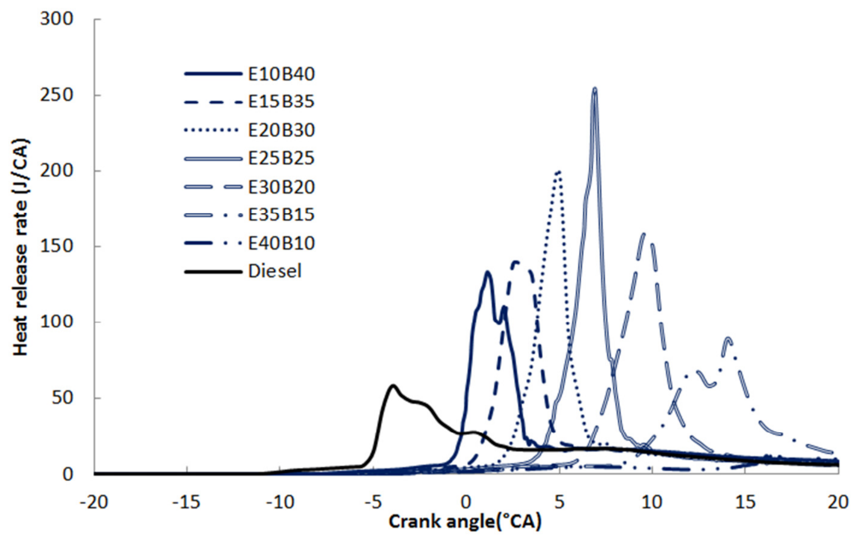

Fig. 2. In-cylinder pressure and HRR profile for different diesel-ethanol-PME blends operated at 1600 RPM

Since the E40B10 blend was found to be unable to ignite, Fig. 3 Shows the temperature profile of all fuel blends and diesel operated at 1600 RPM. The graph shows that the ignition of E25B25 has increased the temperature in the cylinder with the highest value of 1426 K. High PME contents in the blends increased the cetane number of the blends and increased the temperature. The addition of ethanol in the blends slightly reduced the temperature due to the low heating value of ethanol. Due to the non-uniform AFR during the expansion, the in-cylinder temperature also has the same pattern as the heat release rate. E40B10 is acknowledged as a blend that is unable to ignite. As observed from the temperature profile, E40B10 has a very low temperature at around 845 K. This temperature is not high enough to burn the fuel since the auto-ignition temperature for this blend should reach 875.65 K [17]. This condition has caused the blend that contained 40 vol% of ethanol to release a very small energy and is unable to be ignited under a very low temperature and pressure. However, there is no significant relation for the temperature and HRR to rise with the increased ethanol or PME because during the expansion, more fuels are burnt, and as the combustion duration is longer, more fuels are burnt [18]. Besides, another factor that leads to the various results of temperature for diesel-ethanol-PME blends is due to the PME's high viscosity, which caused improper fuel distribution since the fuel encountered improper atomisation and incomplete combustion. The addition of ethanol already changed this fuel property, which as a result, led to better atomisation and slightly increased the temperature and heat release rate. Additionally, a study from Paul et al. found that the combustion of diesel-ethanol-PME blends at various loads provided another reason to the non-uniform increase of the heat release rate during combustion [19].

3.2 Cumulative Heat Release

Figure 4 shows the cumulative heat transfer for all diesel-ethanol-PME blends and diesel fuel operated at 1600 RPM. The figure shows that higher PME percentage blends have a tendency to burn earlier and release more energy. However, since E10B40 still contained 10 vol% of ethanol, the energy released for this blend was slightly later than diesel. However, the higher cumulative heat release of diesel-ethanol-PME blends as compared to diesel shows that blended fuel has a faster burning rate that diesel. The figure also shows that the higher percentage of ethanol in the blends reduced the heat release due to the lower heating value of ethanol. However, the blends that contained lower than 30 vol% ethanol have higher cumulative heat release. Meanwhile, the other blends such as E35B15 and E40B10 have lower cumulative heat release due to the ignitibility limit of ethanol as a result of the low cetane number. Nevertheless, the energy release difference for diesel-ethanol-PME blends is very small and indicates that the energy release by the blends has no significant difference. Besides, Fig. 4 indicates that the cumulative heat release of diesel and blended fuels reached its maximum value at 18.0 °CA ATDC. This maximum value shows that the combustion has taken place around 50 % and burned half of the fuel mass fraction [20]. This shows that the higher percentage of ethanol has a smaller combustion percentage and leads to incomplete combustion.

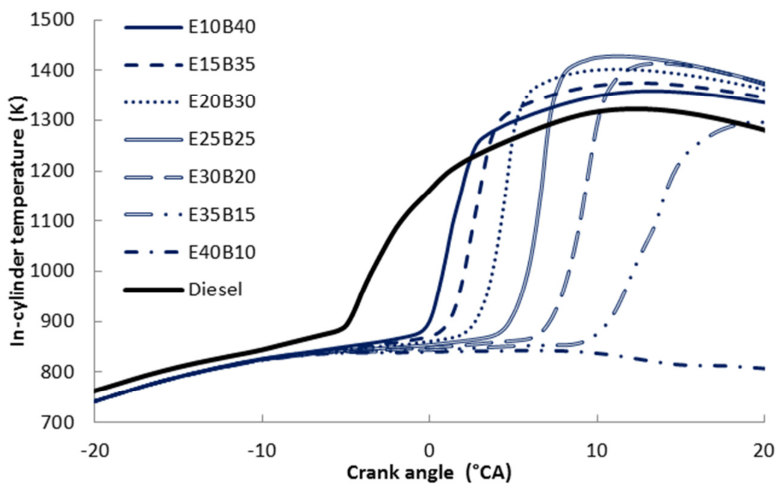

Fig. 3. Temperature profile of diesel and diesel-ethanol-PME blends operated at 1600 RPM

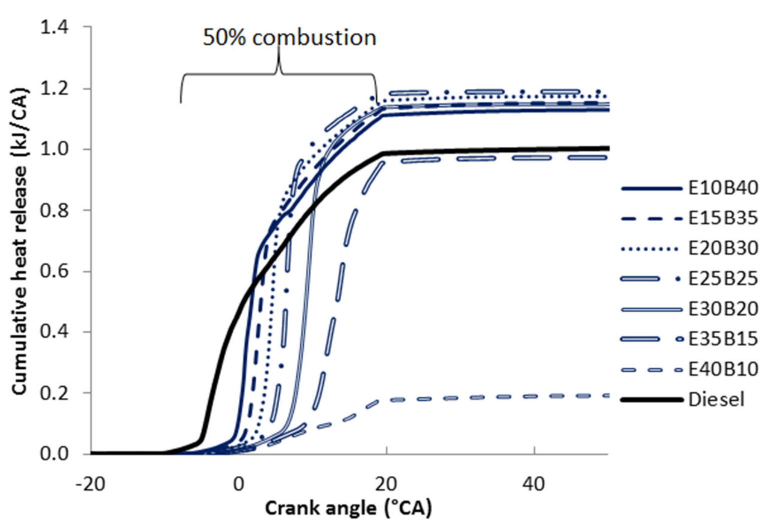

Fig. 4. Cumulative heat transfer for diesel and diesel-ethanol-PME blends operated at 1600 RPM

4. Conclusions

This study has found that blending diesel with ethanol and PME can improve the combustion characteristics by increasing the heat release rate during combustion and improving the ignition quality. Blending (15 vol% to 40 vol%) PME with (10 vol% to 35 vol%) ethanol in 50 vol% diesel has slightly increased the heat release rate. However, in the simulation study, the chemical energy release from the chemical reaction influenced the temperature in the cylinder that led to a non-uniform heat release rate. Besides, this study has found that E25B25 has the highest heat release rate, followed by other blends that are slightly higher than diesel. The blends that contained more than 35 vol% ethanol slightly reduced the heat release rate as analysed from the cumulative heat release. The ignition delay of the blends with higher PME percentage is shorter than the other blends but slightly longer than diesel fuel, which shows that blends with 15 vol% of PME and above released more energy for better engine efficiency. Meanwhile, the blends that contained less than 15 vol% of PME were unable to ignite since they released very low heat energy due to ethanol energy contents. Therefore, the direct injection compressed ignition Yanmar TF90 engine is only capable to work with 15 vol% of PME and above to avoid any engine modification.

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