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EFFECT OF AMBIENT TEMPERATURE ON DIESEL-ENGINE COMBUSTION CHARACTERISTICs OPERATING WITH ALCOHOL FUEL

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ABSTRACT

Biofuel is an alternative fuel source for diesel engines. Nowadays, biofuel attracts more interest due to the depletion of mineral petroleum resources. The aim of this paper is to study the effect of ambient temperature on the combustion and performance of a diesel engine when using ethanol and methanol as fuels. The one-dimensional numerical analysis uses the GT-Power software program to simulate a commercial four-cylinder diesel engine. The diesel engine was simulated in order to study the characteristics of engine combustion when the engine is operating with ethanol and methanol as alternative fuels. The simulations were conducted under the full-load condition for an engine operating with diesel, ethanol, and methanol. Ambient temperatures used for each test were 30, 40, and 50 °C. The results show that the in-cylinder pressure for ethanol is higher than that of methanol and diesel at different ambient temperatures, while methanol was found to yield a higher rate of heat release compared to ethanol and diesel. However, changes in ambient temperature in the inlet pipe do not affect the rate of heat release when using any fuel. It can be concluded that biofuels are excellent fuel alternatives to replace diesel in the future.

Keyword: Ambient temperature; diesel engine; ethanol, methanol; in-cylinder pressure.

INTRODUCTION

The internal combustion engine is a machine that converts the chemical energy in a fuel into mechanical work. In combustion engines, the chemical energy of the fuel is converted to thermal energy through combustion with the help of oxygen [1]. A strong release of thermal energy will result in the piston being pushed down and the crank rotated at a speed proportional to the kinetic energy received. Two types of internal combustion engine are very popular at present: gasoline and diesel engines [2-6]. Typically, a diesel engine is good for moving heavy machinery in rough conditions. Many studies have found that diesel engines are more efficient than gasoline engines in terms of thermal efficiency [1, 7-10]. Diesel engines are also more economical as well as more durable. However, today's increased use of petroleum fuels has resulted in the depletion of natural resources. Consequently, surveys into alternative fuel sources have been undertaken by many researchers. Biofuels, such as ethanol and methanol, are produced from biomass materials. Usually this fuel will be blended with petroleum fuels, namely with diesel and gasoline [11]. However, biofuels themselves can be used on their own. Biofuels can be described as cleaner burning fuels because they produce fewer air pollutants; the generation of pollutants allows diesel engines to achieve higher complete combustion [12]. Biofuel can serve as an alcohol-based fuel additive that provides oxygen which helps diesel engines to achieve more complete combustion. Indirectly, it will improve performance while reducing emissions such as particulate matter, hydrocarbon and carbon monoxide [13-17].

In modern engine research and studies, using hardware experiments alone would be very expensive and time-consuming, and many cause-and-effect relationships implicit in the test results are often hard to interpret. On the other hand, modelling and simulation approaches, although less precise in predicting the outcome of a specific test, could effectively isolate one variable at a time so enabling parametric studies to be conducted [18-20]. Therefore, simulation could identify cause–effect relationships more clearly, and a validated model could be a very useful tool in the study of new types of engines or engines running with new types of fuels. Since a clear understanding does not yet exist of the effect of using biofuel in a diesel engine, a simulation study of a biofuel engine is necessary, together with experimental study. Therefore, this study aims to measure the variations in diesel-engine performance as a function of the biofuel used. In this paper, one-dimensional simulation analyses in GT-Power were used to simulate four-cylinder diesel engines which are available in the Universiti Malaysia Pahang laboratory. This analysis involves combustion performance and engine performance. Operation of the engine is set at a speed of 2000 rpm and full load in order to readily examine the experimental fuels used.

SIMULATION SETUP

GT-Power is based on one-dimensional modelling, representing the flow and heat transfer in pipes and other components of an engine system. In addition, many other specialized models can be applied for many kinds of system analysis [21-23]. It is known that power is work per unit of time. The torque of an engine is the ability to use the power generated. In the experiment, the torque was measured by a dynamometer. The crankshaft is connected to the engine dynamometer and brake power can be measured by the load applied to it. Figure 1 presents computational model of a four-cylinder, direct-injection, compression-ignition engine.

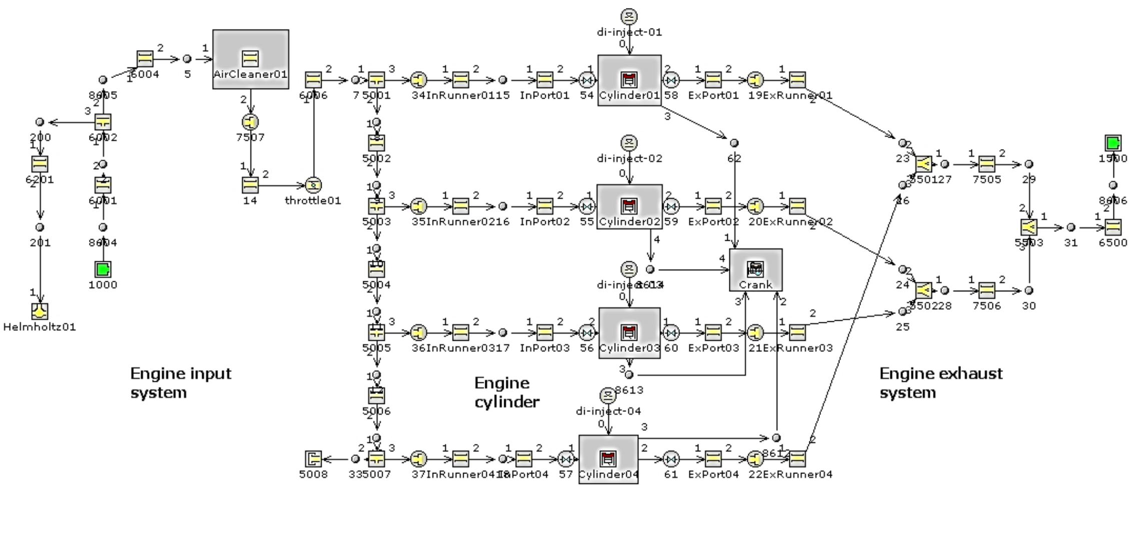

Figure 2. Computational model of a four-cylinder, direct-injection, compression-ignition engine

In this study, the development of a four-stroke, direct-injection (DI) diesel engine via simulation was undertaken. All the data were selected corresponding to the real engine with the specifications outlined in Table 1. This engine is naturally aspirated, water-cooled, and equipped with a GNU vertical rot meter on the engine cooling system. The data were analyzed graphically using GT-Power (GT-Post) version 6.1 and Microsoft Excel. The fuel properties of diesel, ethanol and methanol are given in Table 2. The table shows that methanol has the highest oxygen content, while the heating value and cetane number are low compared to diesel. Ethanol and methanol also have lower boiling points compared to diesel.

Table 1. Specification of the Mitsubishi diesel engine.

Engine parameters	Value
Model	Mitsubishi 4D68
Type	Air-cooled diesel engine
Bore (mm)	82.7
Stroke (mm)	93.0
Displacement (L)	1.998
Number of cylinders	4 in-line
Compression ratio	22.4
Connecting rod length (mm)	150.0
Piston pin offset (mm)	1.0
Ignition system	Direct injection

Table 2: Properties of diesel and biofuel, [24, 25].

Fuel properties	Unit	Diesel	Ethanol	Methanol
Density at 26.85°C	kg/m^3	822.8	789.0	792
Cetane number	-	55	<8	5
Kinematic viscosity at 40°C	mm^2/s	2.6	1.2	0.44
Surface tension at 20°C	N/m	0.023	0.022	0.023
Lower heating value	MJ/kg	42.7	27.7	21.1
Specific heat capacity	J/kg°C	1850	2100	2545
Boiling point	°C	180–360	78	65
Oxygen	%weight	0	34.8	49.9

RESULTS AND DISCUSSION

The analysis focuses on the combustion process in order to identify the effects the biofuel has on the in-cylinder pressure and rate of heat release by outlining the influence in the most representative operating modes. Moreover, measured levels of different parameters (ambient temperature and fuel type) were analyzed in order to gain a better understanding of the observed trends. Simulations using GT-Power were undertaken to study the effect of inlet air temperature on performance of the diesel engine. In Figure 2, a P–V diagram comparison between methanol, ethanol, and diesel at 30°C air inlet temperature is illustrated. The results show that methanol has a higher differential pressure compared with that of diesel and ethanol. These differences indicate that methanol has enough thermal energy to provide tremendous pressure in the engine cylinder [26]. This is because, during the top isentropic processes, greater methanol energy is transferred out of the system in the form of work than for diesel and ethanol. These conditions represent the different combustion behaviors of fuels during the combustion period [14]. Therefore, it can be concluded that different fuel properties in the test fuels result in the most different combustion behaviors.

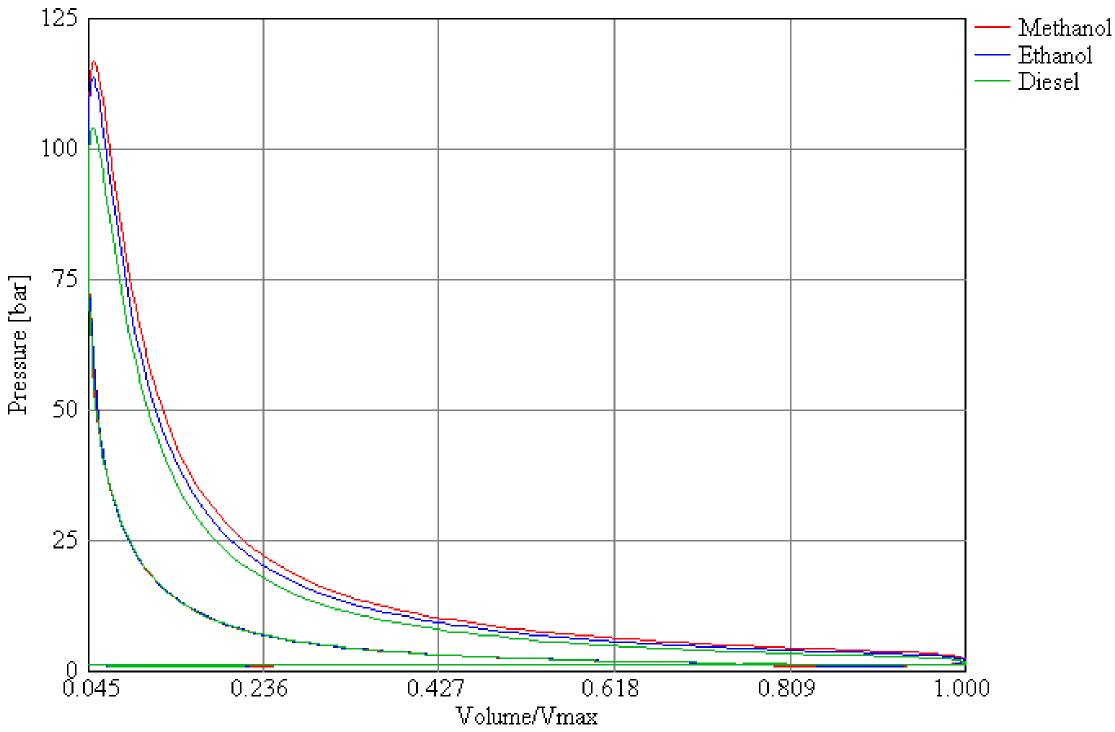

Figure 3. Pressure–volume (P–V) diagram of diesel, methanol and ethanol engines operating at 30°C ambient temperature.

Figure 3 shows the difference in pressure involving diesel, ethanol, and methanol at an ambient temperature of 30°C. Through visual inspection, we find that methanol has the highest peak-pressure point at 120.1 bar. This is followed by ethanol (113.5 bar) and diesel (103.9 bar). This is due to methanol having the highest specific heat value. However, ethanol produces increased pressure the fastest among all the tested fuels after the start of injection at -17°. Significant changes occur in the crank angle between -15° and -10°. At this point in the cycle, the engine is already approaching its maximum compression stroke and the fuel is ready to be injected with fuel/air at the 0° crank angle.

Figure 4 shows a comparison of the maximum peak-pressure points of each fuel at ambient temperatures of 30°C, 40°C and 50°C. In these graphs, 4 (a), 4 (b) and 4 (c), the higher ambient temperature input and the lower points of peak pressure in the cylinder are displayed. Diesel yielded the highest drop rate of 1.35%, followed by methanol (1.24%) and ethanol (0.58%). The additional oxygen content in high-methanol causes a more complete combustion and causes higher pressure than in the other fuels [26, 27]. This shows that the higher the ambient temperature in the inlet pipe, the better the work rate. Although the pressure drop is small, it is demonstrated that increasing the ambient temperature will result in reduced engine performance.

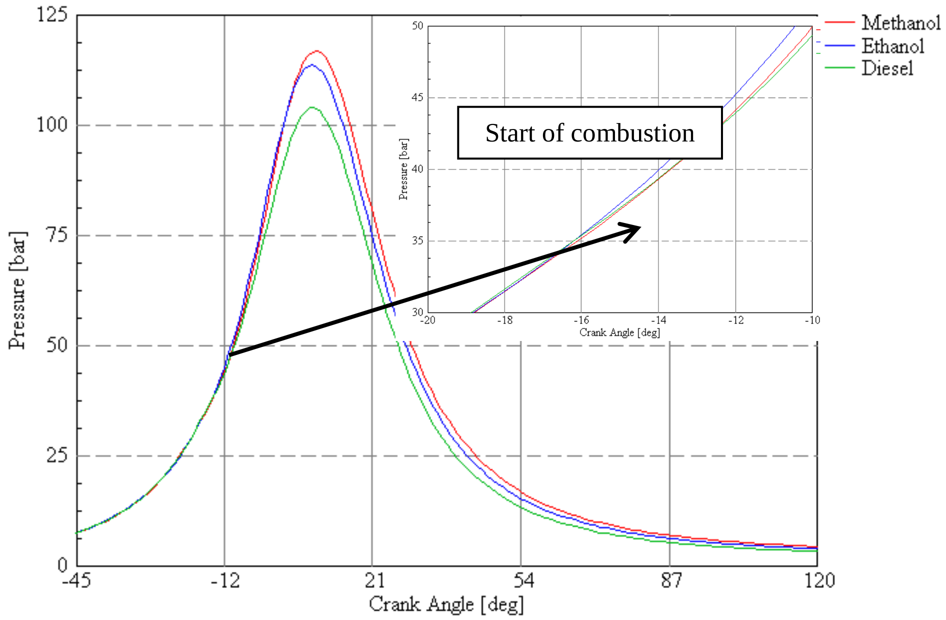

Figure 4. In-cylinder pressure of diesel, methanol and ethanol engines operating at 30°C ambient temperature.

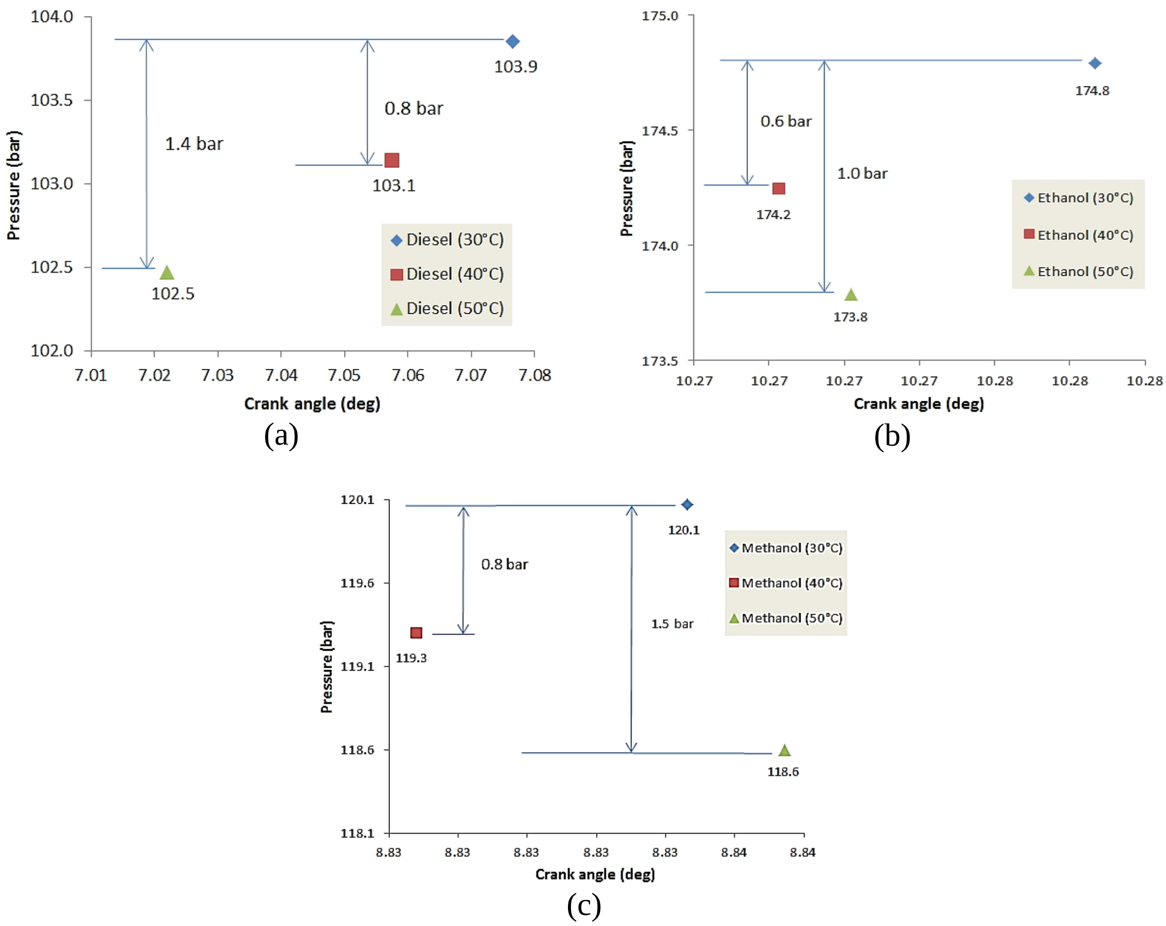

Figure 5. Comparing the peak dispersion of (a) diesel, (b) ethanol and (c) methanol in-cylinder pressure at ambient temperatures of 30°C, 40°C and 50°C, respectively.

In Figure 5, a comparison between the peak difference of in-cylinder pressure for diesel, ethanol, and methanol for ambient temperatures of 30°C, 40°C and 50°C are shown. Based on these observations, in-cylinder pressure produces the lowest peak point at the highest ambient temperature. Thus, combustion of methanol at an ambient temperature of 30°C produces the highest pressure of 120.1 bar. The lowest point is the peak pressure combustion of diesel at a temperature of 50°C. Ethanol also has a consistent peak point of combustion pressure between those of diesel and ethanol. The combustion of ethanol at an ambient temperature of 30°C will produce the most outstanding in-cylinder pressure in the engine. In contrast, the burning of diesel at an ambient temperature of 50°C will produce the weakest in-cylinder pressure in the engine.

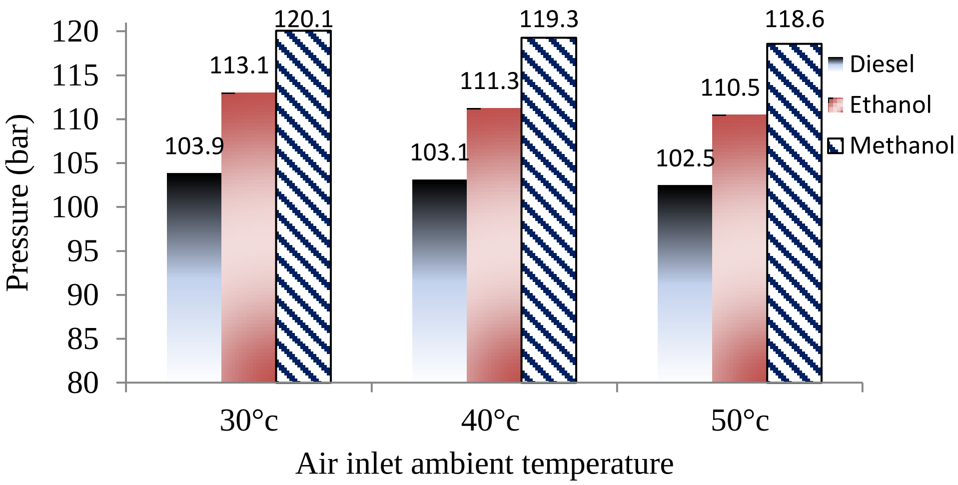

Figure 6. Comparing the peak dispersion of diesel, ethanol and methanol in-cylinder pressure between ambient temperatures of 30°C, 40°C and 50°C.

Figure 6 shows the heat-release rate of diesel, ethanol, and methanol at a 30°C ambient temperature. Graphically, the heat-release rate for diesel is very high at a crank angle of 11.8°. Ethanol can yield higher pressure in the combustion chamber, as previously mentioned, but has a peak heat-release rate that is lower than diesel by 26.9%. Methanol yielded a peak heat-release rate of 30.9%, lower than those of diesel and ethanol. As shown, methanol has two peaks that are of almost the same magnitude at crank angles of 6.7° and 9.5° after top dead center (ATDC). This was due to heat release earlier than in other fuels from 17.6° before top dead center (BTDC). Despite having a low-pressure discharge rate, diesel has a better combustion rate. However, the high heat-release rate will result in the formation of NOx much more readily due to the high temperature in the cylinder [1, 28, 29]. Although diesel has a high peak heat-release rate value, it does not mean the total heat release of diesel is also high. Figure 7 shows that the heat-release rate of methanol is higher and faster than the other two fuels. At the crank angle of 0°, the heat-release rate of methanol reaches almost 22% compared to diesel which is less than 10%. However, although diesel is comparatively slow and hot at crank angles near zero because of the slow rate of heat release, it becomes considerable at a 13° crank angle and is equal to methanol at a 27° crank angle. The diesel showed fast ignition due to the high cetane number [12]. A rapid heat-release rate is indicative of the increased effectiveness of the combustion process in internal combustion engines [30]. In this case, it may be concluded that heat-release analysis, though based on a simplified approach if compared with more enhanced engine-analysis techniques, is a useful way of explaining experimental or simulation results as it helps to clarify the trends in the main engine parameters

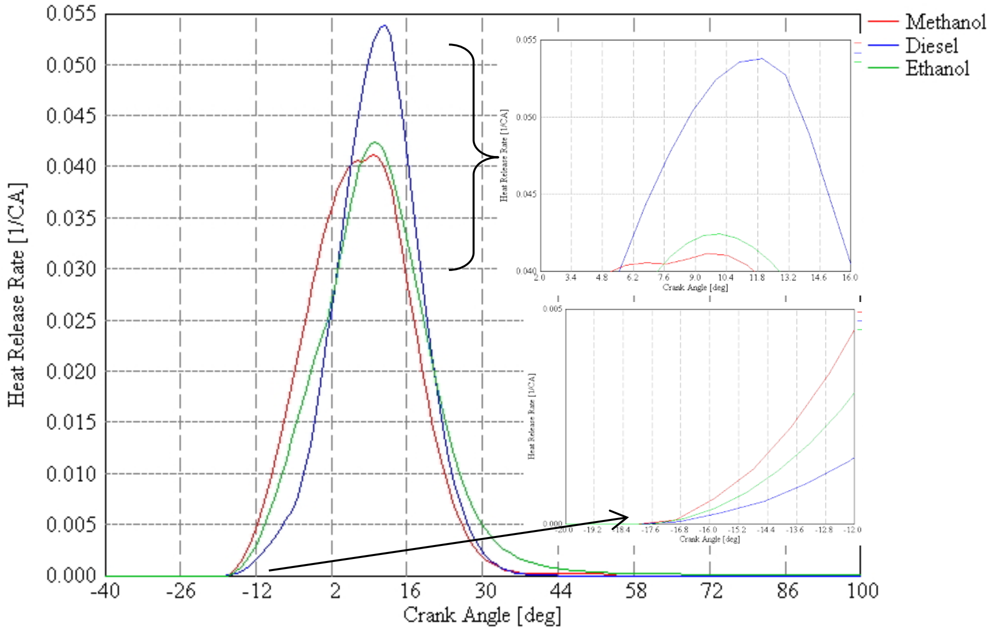

Figure 7. Rate of heat released of diesel, methanol and ethanol in engines operating at 30°C ambient temperature.

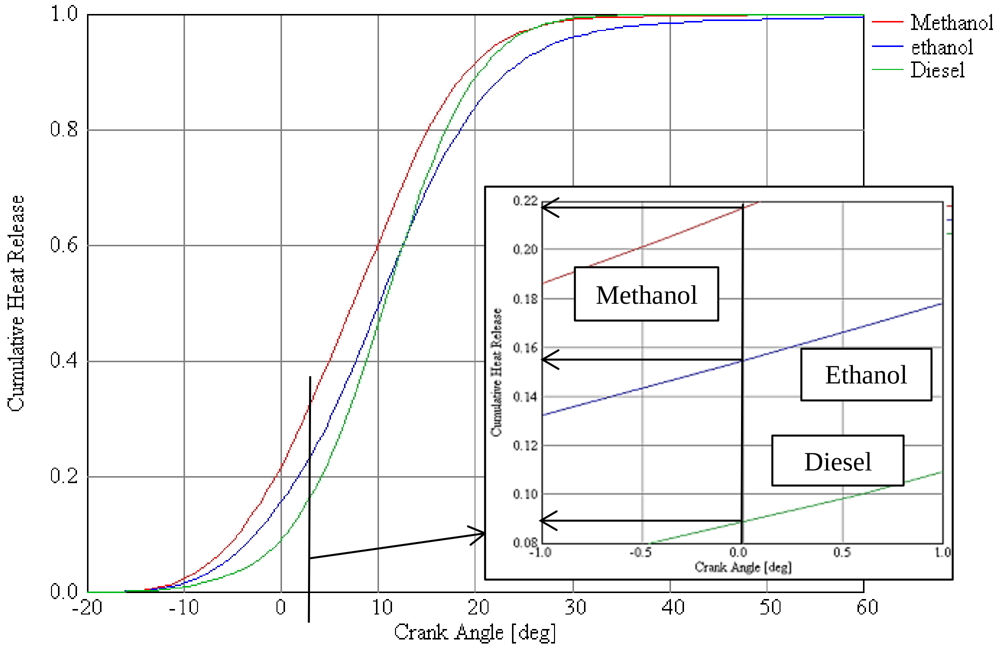

Figure 8. Cumulative rates of the heat release of diesel, methanol and ethanol in engines operating at 30°C ambient temperature.

CONCLUSIONS

Generally, alcohol fuel has a significant effect on the combustion characteristics of diesel engines. The main results of this investigation show that:

1. Ethanol produces the highest pressure of 174.8 bar at an ambient temperature of 30°C. Diesel produced the lowest peak-pressure combustion at a temperature of 50°C.
2. The pressure in the cylinder decreased with the increase in inlet air temperature in all simulation results used in the present work. The decrease in in-cylinder pressure will produce weak engine performance.
3. The heat-release rate for diesel is the highest at a crank angle of 11.8° in comparison to the other fuels. Methanol has two peaks at almost the same value, at crank angles 6.7° and 9.5° ATDC.
4. Methanol is the best fuel in terms of the heat-release rate in the combustion chamber.

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