Influence of Fuel Temperature on a Diesel Engine Performance Operating with Biodiesel Blended

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Abstract

This paper is presented to study the effect of temperature using 5 % biodiesel blended on diesel engine performance. The one-dimensional numerical analysis of GT-Power software is used to simulate the commercial four cylinder diesel engine. The standard fuel data base of GT-Power does not contain any biodiesel. Therefore, the authors have measured typical physical properties of the fuel before it can be installed into the GT-Power data base. The diesel engine is simulated to study the characteristic of engine performance when the engine is operating with fuel blend as an alternative fuel. The simulations are conducted at full load condition where the temperature are varies from 300K to 500K. The simulation results show that the brake power and brake torque reduced maximum of 1.39 % and 1.13 % respectively for the engine operating with fuel blend at different temperatures. It was shown that the insignificant different is due to the small gap between energy content values. The decrease in the lower heating value caused an increase in the brake specific fuel consumption thus reduces the brake thermal efficiency of engine performance at full load.

Keywords: *Biodiesel blended fuel, Fuel temperature, Diesel engine*

1. Introduction

Global warming and green house effects nowadays give the high impact to environmental problem. Due to the environmental policies to reduce carbon dioxide emission, taking of biodiesel as an alternative and renewable source to replace fossil diesel becomes increasingly important. Palm oil has been reported to be the most interesting option instead of consideration various oil sources to be the feedstock to biodiesel production plants [1]. Each fuel can be identified through their properties. The more properties that we can identify, the more better we know that fuels. Biodiesel is the general word for all types of fatty acid methyl esters (FAMEs) made from different raw materials that used as fuels. It is produced from transesterification process of vegetables oils or animal fats with the addition of methanol [2]. The transesterification process is a probable method for biodiesel production. This process is the reaction of chemical occur between triglycerides and alcohol in the presence of alkaline liquid catalyst, usually sodium or potassium methoxide. The formation of biodiesel and glycerol produce by the reaction of alcohol and fatty acids [3]. Physically and chemically, all vegetable oils can be used to produce biodiesel fuels [4]. Commonly, the liquid has a similar composition and characteristic such as cetane number, energy content, phase changes and viscosity compare to petroleum-derived diesel. So it can be used in any CI diesel engine without any modification when it is blended together with petroleum-derived diesel. Biodiesel has proposed to become one of the most familiar biofuels in the world compared to petroleum-derived diesel because some of its distinct benefits such as lower greenhouse gases emissions, higher lubricity and cetane ignition rating [2].

Malaysia and Indonesia are the biggest and second biggest producers of palm oil respectively, thus produce 85 % of world's palm oil [5]. The domestic palm-oil production, progressively grow to give the root of the biofuel industry for a future decade. Production is predictable to raise a rate at about 10 percent annually, reaching 1.1 billion litres by 2017. In Southeast Asia (SE Asia) biodiesel production is drastically growing due to its high potentiality and yield factor of palm [5]. Another beneficial point for growing of this plant is the factor of tropical climate and cheap man power of this region [6]. By the target market of EU, the industry will be predominantly export oriented [7]. The vegetable oils are enabling to use in common diesel engine without operational problem with several methods reducing their high viscosity. There were including blending with petrol-diesel, pyrolisis, micro emulsification (co solvent blending), and transesterification [8]. In the early phases of starting biodiesel projects, it can be observed that simple process technologies and basic purification do not accomplish the necessary high quality needed for the modern diesel engine [9]. This paper highlights the new data of biodiesel in GT-Power that are not available in any other analysis of engine performance instead of commonly used the diesel fuel. The objective of this paper is to study the effect of temperature of biodiesel 5 % blended fuel as an alternative fuel with the diesel engine specification. There is a significant difference between the properties of biodiesel fuel and diesel fuel. The relevant properties of diesel and biodiesel fuels are listed in Table 1. The performance terms including brake power, brake torque, brake specific fuel consumption, brake mean effective pressure, volumetric efficiency and brake efficiency has been investigated in this research.

Table 1. Vapor Fuel Properties of Diesel and Biodiesel

Vapor Fuel Properties	Diesel	Biodiesel
Carbon Atom per Molecule	13.5	18.82*
Hydrogen Atom per Molecule	23.6	34.39*
Oxygen Atom per Molecule	0	2*
Nitrogen Atom per Molecule	0	0*
Density (kg/m^3)	830	852**
Lower Heating Value (J/kg)	4.32×10^7	4.61×10^7**
Critical Temperature (K)	569.4	785.87
Critical Pressure (bar)	24.6	12.07
Min. Valid Temperature (K)	200	100
Max. Valid Temperature (K)	1200	1200
Min. Valid Pressure (bar)	0.01	0.01
Max. Valid Pressure (bar)	2000	300

*refer from [10]

**refer from experiment testing

2. Model Setup

In general, a one dimensional (1D) simulation of an engine model consists of the intake system, powertrain model, exhaust system, engine cylinders and valve train. The development of the four cylinders and four-stroke direct-injection (DI) diesel engine in one-dimensional simulation presented in this paper.

First step of building engine model in GT-Power is modeling the intake system. For the selected diesel engine, the intake system has a few components, size and different data. The system was started from the environment till the intake valve. The intake system components in the GT-POWER model were environment, int runner, int port, and int valve.

Figure 1 shows the complete model of the diesel engine and the circle shows the intake system components. The other three cylinders have the same intake system configuration. The components in this system require a few data to complete the data form before running the model.

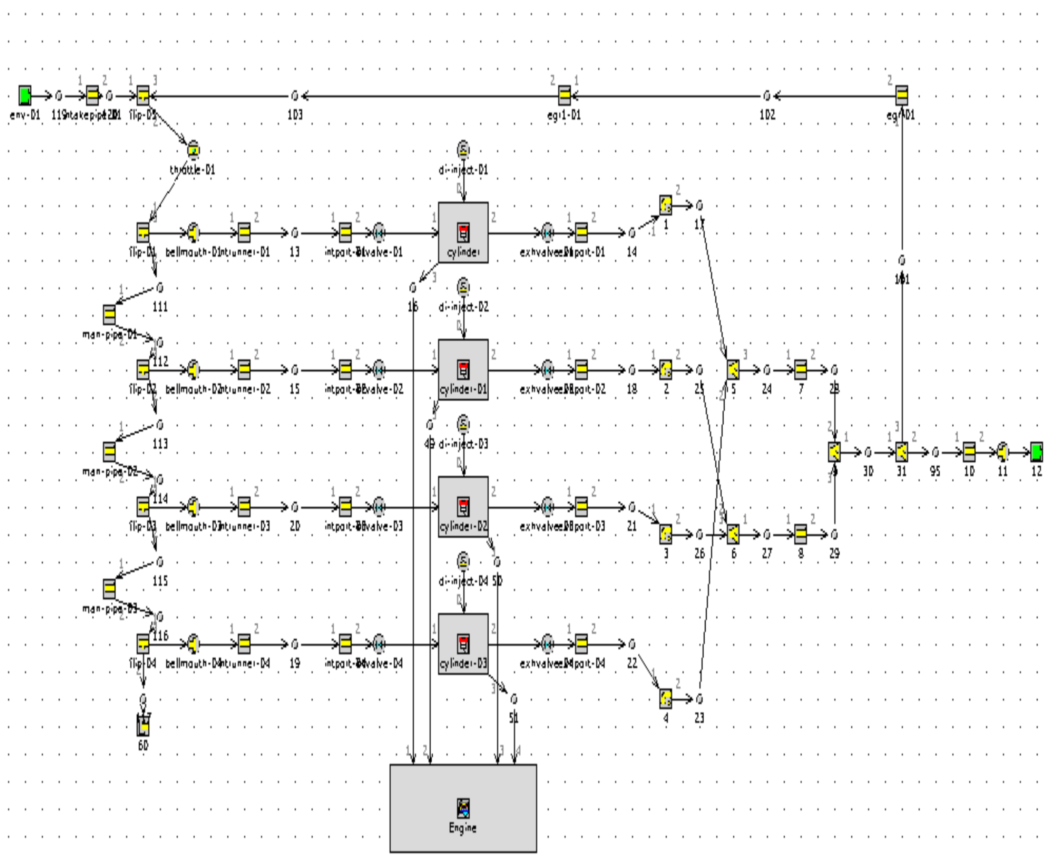

Figure 1. Complete Model of the Engine

Data in environment panel is pressure, temperature, pressure flag and composition. For this study, the environment pressure is at standard atmospheric pressure which is 1 bar. The same goes for environment temperature, which is assumed to be 298 K. Initial fluid compositions is assumed to be fresh air and by neglecting the existing of NO, NO2 and CO concentration.

The second part of the model includes engine cylinder and fuel injection system. It was supported by fuel injection system, intake system and exhaust system. There are several components in the power train of diesel engine. However, the basic for all diesel engines were the same components. The components size and data were recorded and inserted into the GT-POWER form.

The components of the power train are injector, cylinder and engine. Every component in this system panels requires several specifications and details to full the attribute panels and run the model. Powertrain component for the diesel engine only shown for one cylinder, and the rest three cylinders shared the same configuration.

Engine cylinder input panel consists of various attributes such as the start of cycle, cylinder geometry object and initial state name. The start of the cycle was also defined by the crank angle at intake valve close. Crank angle was considered for each cylinder’s cycle begins. This value does not affect the simulation predictions; it only specifies the starting and ending angle within a cycle over which integrated and averaged predictions are measured. This attribute should usually be set to "def" which sets the value equal to the specified value in 'Engine Crank Train' for Start of Cycle (CA at IVC).

The dimensions of bore, stroke and connecting rod which are measured, corresponding to the real engine have been defined in this general engine panel. Others components, size and data are recorded and inserted to the GT-POWER template library input panels. Data in the engine cylinder geometry are bore, stroke, and wrist pin to crank offset, compression ratio, TDC clearance height and connecting rod length.

The input panel for the template of engine crank train consists of the number of cylinders, configuration of the cylinder and engine type. For the selected diesel engine, the exhaust system has a few components, size and different data. The system was started from the exhaust valve till environment. The exhaust system components in the GT-POWER model were environment, exh runner, exh port, and exh valve. Figure 2 showed components configuration for the four cylinders. The components in this system require a few data to complete the data form before running the model.

In GT-POWER, there is no biodiesel fuel data included in fuel properties panel. A gas reference object is commonly described by its C:H:O:N compositions. For incompressible/combustible liquid properties, information about density, vapor fluid object and heat of vaporization are the necessary input to GT-POWER.

Typically every liquid reference object must be associated with a gas reference object so that the properties of the liquid will be known if the fluid evaporates. Then, for the gas/vapor properties of biodiesel need to be determined which consists of molecular weight, lower heating value, and number of atoms per molecule which is carbon, hydrogen, nitrogen and oxygen.

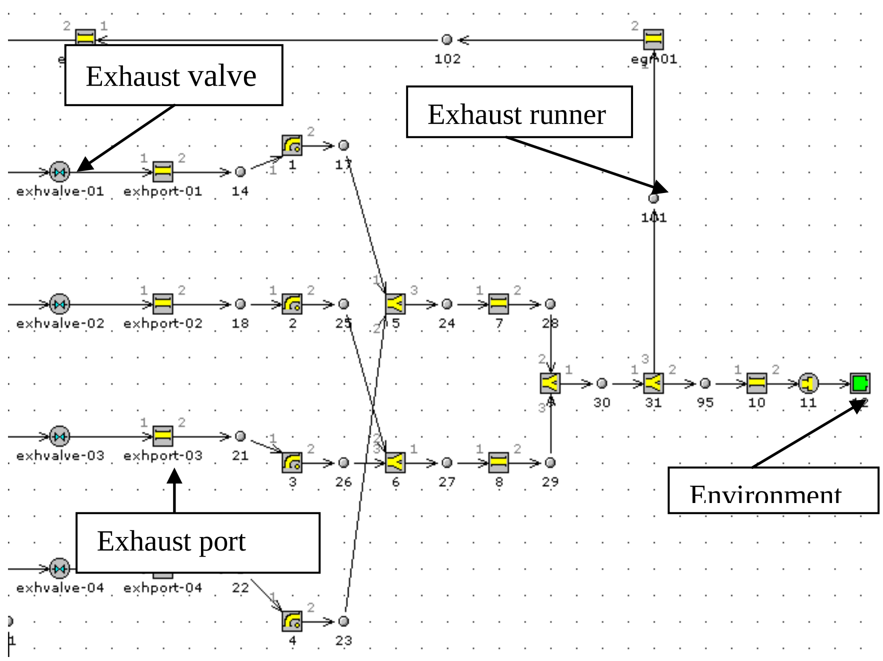

Figure 2. Exhaust System Components

The details of the engine parameters used in this model are described in Table 2 below.

Table 2: Diesel Engine Specifications

Parameter	Value
Bore (mm)	82.7
Stroke (mm)	93
Compression ratio	22.4
Displacement (cc)	500
Number of Cylinder	4
Connecting Rod Length (mm)	150
Piston Pin Offset (mm)	1
Intake Valve Open (°CA)	351
Intake Valve Close	-96
Exhaust Valve Open	125
Exhaust Valve Close	398

In this section, some basic parameters that commonly used to characterize engine operation are investigated. These include the mechanical output parameters of work, torque, and power; the input requirement of air, fuel and combustion; efficiencies; and emission measurement of engine exhaust [11, 12].

***Volumetric Efficiency*:** Volumetric efficiency is used as an overall measure of the effectiveness of a four stroke cycle engine and its intake and exhaust system as an air pumping device. It is calculated as in Eq. (1):

$$\eta_\upsilon = \frac{\dot{m}_a}{\rho_a V_{disp} N/2} \quad (1)$$

Where ρ_a = the inlet air density.

$\dot{m}_a$ = the steady-state flow of air into the engine

V_{disp} = displacement volume

***Engine Brake Torque*:** Torque is a good indicator of an engine's ability to do work. It is defined as force acting at a moment distance and has units of N-m or lbf-ft. Torque (τ) is related to work by [12]:

$$2\pi\tau = W_b = (bmep)V_d / n \quad (2)$$

Where W_b = brake work of one revolution

V_d = displacement volume

n = number of revolutions per cycle

For a four-stroke cycle engine that takes two revolutions per cycle,

$$\tau = (bmep)V_d / 4\pi \quad (3)$$

***Brake Power*:** Power is defined as the rate of work of the engine. If n = number of revolutions per cycle and N = engine speed, then brake power is expressed as Eq. (4) [12]:

$$\dot{W} = WN / n$$
$$\dot{W} = 2\pi N\tau$$
$$\dot{W} = (1/2n)(mep)A_p\overline{U}_p$$
$$\dot{W} = (mep)A_p\overline{U}_p / 4 \qquad (4)$$

Where W = work per cycle
A_p = piston face area of all pistons
$\overline{U}_p$ = average piston speed

Brake Thermal Efficiency: Brake thermal efficiency (η_{bth}) is the ratio of energy in the brake power (bp), to the input fuel energy in appropriate units [13]. Solving for thermal efficiency as per below:

$$\eta_{bth} = \frac{\text{bp}}{\text{Mass of fuels} \times \text{calorific value of fuel}} \qquad (5)$$

***Brake Mean Effective Pressure*:** Mean effective pressure is a good parameter for comparing engines with regard to design or output because it is independent of both engine size and speed. If brake work is used, brake mean effective pressure is obtained:

$$Bmep = w_b / \Delta v$$
$$bmep = 2\pi n\tau / V_d \qquad (6)$$

Where $\Delta v = v_{bdc} - v_{tdc}$

Brake Specific Fuel Consumption: Brake power gives the brake specific fuel consumption:

$$bsfc = \dot{m}_f / \dot{W}_b \qquad (7)$$

where $\dot{m}_f$ = rate of fuel flow into engine

3. Results and Discussion

This chapter discusses the output trend of engine performance from the simulation results. The engine parameters and responses triggered from the GT Power software were recorded and analyzed to provide a better understanding of the engine reaction on the effect of fuel temperature using biodiesel 5 % blended fuel. The simulation was analyzed with different fuel temperature start with temperature 300K reach maximum at 500K. The tests were performed by varying the engine speed starting from 1000rpm until 4000rpm with the increment of 500rpm. The variation of the engine performance that had been discussed comprises of brake power, brake thermal efficiency, brake engine torque, brake mean effective pressure and brake specific fuel consumption. The trend output for fuel temperature gives the reason for their circumstance.

The variation of brake power for different fuel temperature with engine speed is shown in Figure 3. Brake power is generally considered when the power absorption device is attached to the drive-shaft of the engine. The figure illustrates the engine outputs at full load. Reference [14] stated that the higher fuel temperatures tend to produce higher injection pressure. The highest injection pressure causes the lowest ignition delay, thus resulting in the increase of brake power. The shorter ignition delay causes the early start of combustion. A close resemblance occurred at low speed representing small discrepancy in output between the fuel temperatures. The maximum reduction brake power recorded was about 1.39% at the highest speed. It is well known that the heating value of the fuel affects the power of an engine. As the fuel temperature is decreased, the energy level also decreased. Some reduction will occur in the engine power if the lower calorific value of biodiesel used in diesel engine without modification [15].

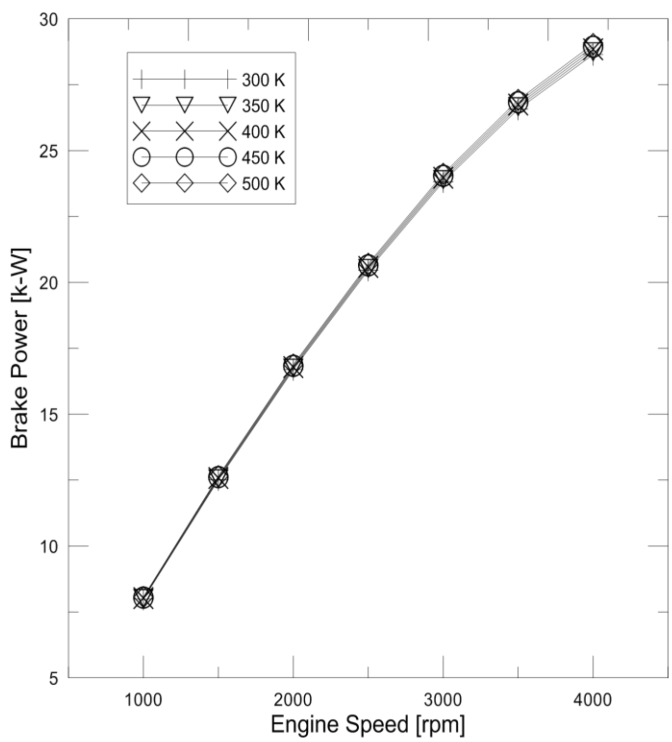

Figure 3. Variation of Brake Power Against with Engine Speed

Figure 4 shows the variation of brake thermal efficiency with engine speed. It is a good measure in assessing how efficiently the energy in the fuel was changed to mechanical output [16]. They generally show similar trends and closely resemble one another. The brake thermal efficiencies at temperature 300K is lower than temperature at 500K. The lowest temperature caused the energy content decreased thus resulting the lowest of brake thermal efficiency. The efficiency is improved when the fuel temperature increases [14].

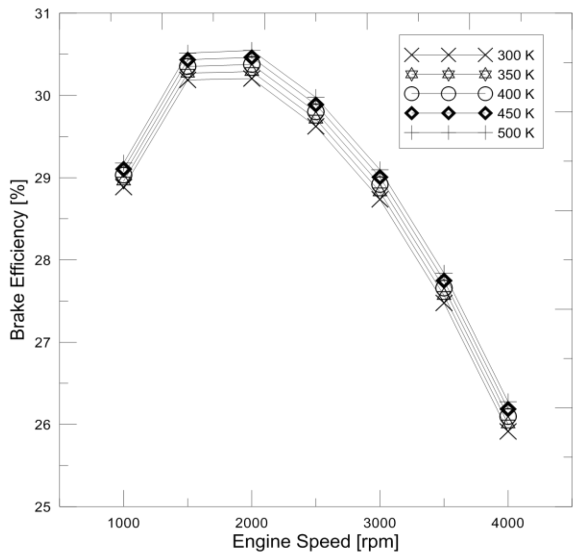

Figure 4. Effect of Engine Speed Variation on Brake Thermal Efficiency

The effect of different fuel temperatures on brake engine torque for various speeds is shown in Figure 5. The torque is a function of engine speed [17]. At low speed, torque increases as the engine speed increase, reaches a maximum and then, as engine speed increase further, torque decreases as shown in Figure 5. The torque decreases because the engine is unable to ingest a full charge of air at the higher speed [17]. Reference [14] stated that the higher fuel temperatures tend to produce higher injection pressure. When the fuel temperature is increased, the fuel density decreases. Therefore, a higher injection pressure is required to gain an equal fuel mass in order to produce the same required brake torque [14]. The maximum reduction brake engine torque recorded was about 1.13 % when engine speed achieved at 2000 rpm.

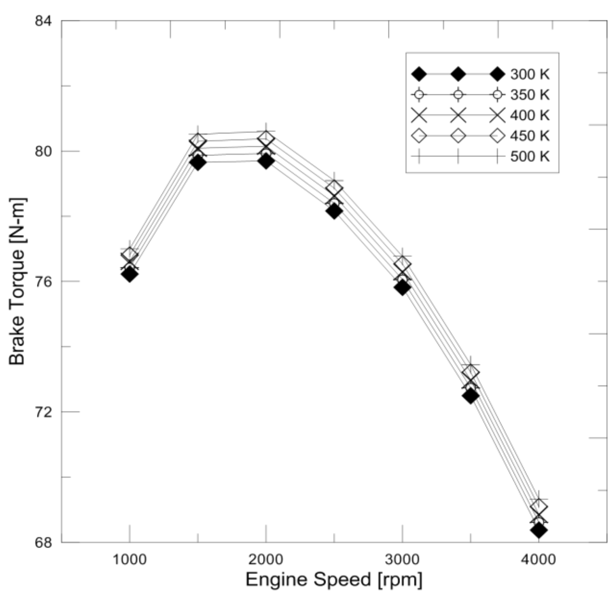

Figure 5. Variation of Brake Engine Torque Against Engine Speed

Brake mean effective pressure is defined as the average mean pressure. When the pistons uniformly imposed from the top to the bottom of each power stroke, the measured brake power output had generated. Figure 6 shows the variation of brake mean effective pressure (BMEP) against engine speed. The mean effective pressure is regularly used to calculate the performance of an internal combustion engine. They generally show the similar trends for each temperature. The maximum reduction of the brake mean effective pressure recorded was about the same with the brake engine torque. Brake thermal, brake torque and BMEP show the similar trends with difference circumstance reasons.

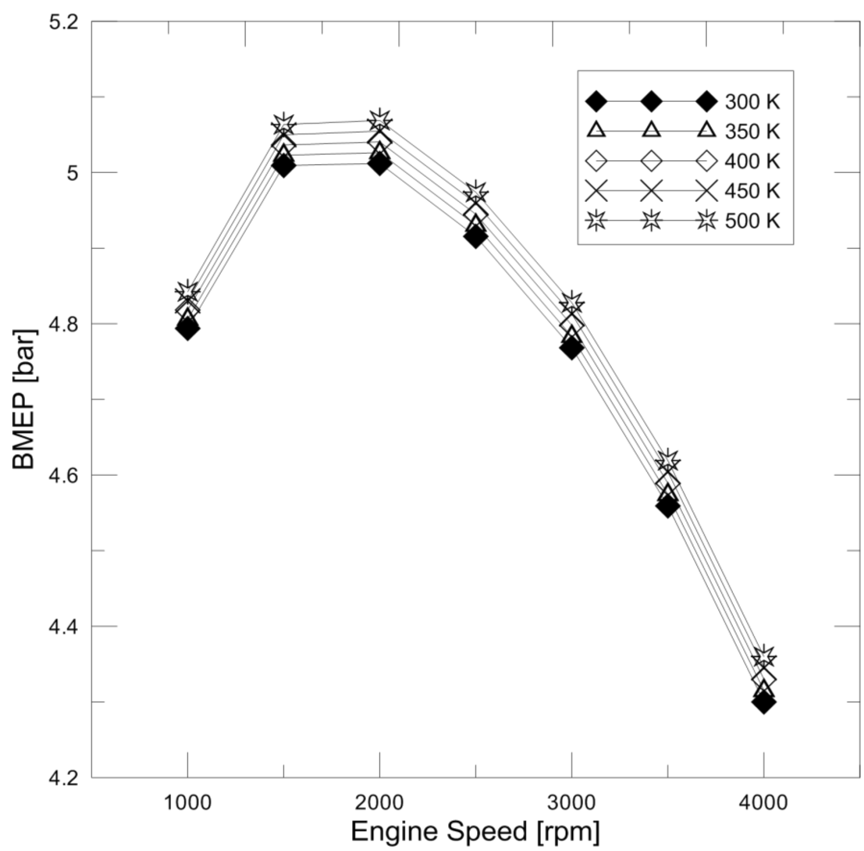

Figure 6. Variations of Brake Mean Effective Pressure Against Engine Speed

Figure 7 shows the effect of engine speed variation on brake specific fuel consumption (BSFC) for different fuel temperature. They generally show similar trends for the difference of fuels. The minimum BSFC (255.907 g/kW-hr) obtained from highest temperature at 500K while the maximum BSFC (301.668 g/kW-hr) obtained from lowest temperature at 300K. The higher BSFC is due to lower energy content of the fuel [18]. As the temperature increase, the energy content also increased thus caused the lowest BSFC for temperature at 500K compare to temperature at 300K. [11] reported that the lowest value of specific fuel consumption obviously desirable.

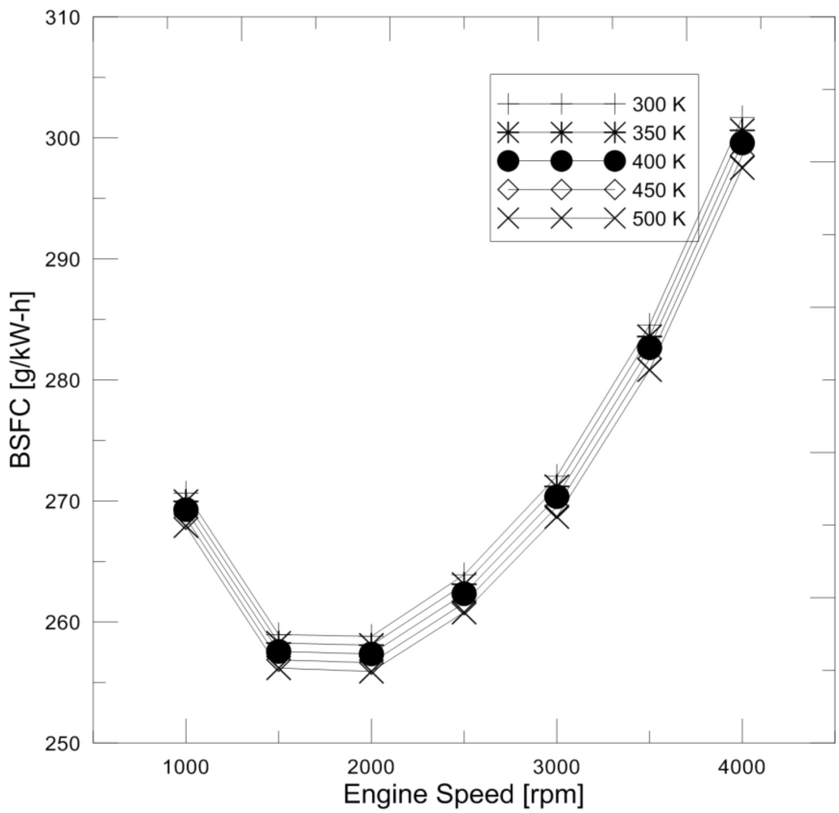

Figure 7. Effect of Engine Speed Variation on Brake Specific Fuel Consumption

4. Conclusion

The effect of fuel temperatures on variation engine speed and their impact on the engine performance of a four cylinder diesel engine has been investigated. The conclusions can be summarized as follows:

- The highest fuel temperature causes the highest injection pressure thus resulting in shorter ignition delay.
- The shorter ignition delay attributed to the early start of combustion thus leads to the higher in-cylinder pressure.
- The increasing of fuel temperature representing the highest energy content thus resulted in lower BSFC as obviously desired.

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