Journal of Mechanical Engineering and Sciences (JMES)
ISSN (Print): 2289-4659; e-ISSN: 2231-8380; Volume 2, pp. 226-236, June 2012

DOI: http://dx.doi.org/10.15282/jmes.2.2012.10.0021

INFLUENCE OF FUEL TEMPERATURE ON DIESEL ENGINE PERFORMANCE OPERATING WITH BIODIESEL BLEND

Rafidah Rahim, Rizalman Mamat, Mohd Yusof Taib and Abdul Adam Abdullah

Faculty of Mechanical Engineering,
Universiti Malaysia Pahang,
26600 Pekan, Pahang, Malaysia
Email: rizalman@ump.edu.my

ABSTRACT

This paper presents the study of the effect of temperature on diesel engine performance using a 5% biodiesel blend. A one-dimensional numerical analysis is used to simulate the four-cylinder diesel engine. The diesel engine simulation is used to study the characteristics of engine performance when the engine is operating with a fuel blend as an alternative fuel. The simulations are conducted at full load conditions where the temperature varies from 300 to 500 K. The results show that the maximum brake power and brake torque reduction was 1.39% and 1.13%, respectively for an engine operating with a fuel blend. It is shown that the insignificant different due to the small gap between energy content values. A decrease in the lower heating value caused an increase in the brake specific fuel consumption and thus, a reduction in the brake thermal efficiency of the engine performance at full load.

Keywords: Biodiesel blended fuel, Fuel temperature, Diesel engine

INTRODUCTION

Global warming and greenhouse effects are evidence of the high impact of environmental problems. Due to environmental policies to reduce carbon dioxide emissions, the use of biodiesel as an alternative, renewable source to replace fossil diesel is becoming increasingly important. Palm oil has been reported to be the most interesting option in the consideration of various oil sources to be the feedstock to biodiesel production plants (Sani, 2009a). All fuels have properties that we can use to identify them. The fuel, we need to identify the more properties. Biodiesel is the general word encompassing all types of fatty acid methyl esters (FAMEs) made from different raw materials that are used as fuels. It is produced by the transesterification process of vegetables oils or animal fats with the addition of methanol (Lim & Teong, 2010). The transesterification process is a probable method for biodiesel production. This process is the chemical reaction that occurs between triglycerides and alcohol in the presence of an alkaline liquid catalyst, usually sodium or potassium methoxide. The formation of biodiesel and glycerol is the result of the reaction of alcohol and fatty acids (Mamat, 2009). Physically and chemically, any vegetable oil could be used to produce biodiesel fuels (Abdullah, Salamatinia, Mootabadi, & Bhatia, 2009). Commonly, the liquid has a similar composition and characteristic, such as cetane number, energy content, phase change and viscosity compared with petroleum-derived diesel. Therefore, when blended together with petroleum-derived diesel it can be used in any compression ignition (CI) diesel engine without any modification. Biodiesel is suggested to become one of the most widespread biofuels in the world compared with petroleum-derived diesel because of its distinct benefits, such as lower emissions of greenhouse gases, higher lubricity and cetane ignition rating (Lim & Teong, 2010).

Malaysia and Indonesia are the biggest and second biggest producers of palm oil respectively, producing 85% of the world's palm oil (Jayed, Masjuki, Saidur, Kalam, & Jahirul, 2009). Domestic palm-oil production, is expected to grow progressively to give root to the biofuel industry for future decades. Production is predicted to rise at a rate of about 10% annually, reaching 1.1 billion litres by 2017. In Southeast Asia (SE Asia) biodiesel production is growing enormously because of its high potential and yield factor (Jayed et al., 2009). Another benefit of growing this plant is the factor of the tropical climate and cheap labour costs in this region (Tan, Lee, Mohamed, & Bhatia, 2009). The industry will be predominantly export oriented with the EU as the main target market (Wiebe, Croppenstedt, Raney, Skoet, & Zurek, 2008). It is possible to use vegetable oils in common diesel engines without any operational problems because there are several methods for reducing their high viscosity; these include blending with petrol-diesel, pyrolysis, micro-emulsification (co-solvent blending) and transesterification (Knothe, Gerpen, & Krahl, 2005; Sundar Raj & Sendilvelan, 2010). 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 modern diesel engines (Korbitza, Friedricha, Wagingerb, & Worgetterc, 2003). This paper highlights new data of biodiesel in GT-Power that are not available in any other analysis of engine performance. The objective of this paper is to study the effect of the temperature of biodiesel 5% blended fuel as an alternative fuel in a 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 of: brake power, brake torque, brake specific fuel consumption, brake mean effective pressure, volumetric efficiency and brake efficiency have been investigated in this research.

Table 1. Vapour fuel properties of diesel and biodiesel.

Vapour 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 (Zheng, 2009); **refer from experiment testing

MODEL DEVELOPMENT

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 a four-cylinder, four-stroke direct-injection (DI) diesel engine in a one-dimensional simulation is presented in this paper. Figure 1 shows the complete model of the diesel engine. The environment pressure is at standard atmospheric pressure (1 bar) and the environment temperature 298 K. Initial fluid composition is assumed to be fresh air, neglecting the existence of NO, NO_2 and CO concentrations. The second part of the model includes the engine cylinders supported by the fuel injection system, intake system and exhaust system. There are several components in the power train of a diesel engine. The components of the power train are the injector, cylinder and engine. The powertrain component for the diesel engine is shown just for one cylinder; the other three cylinders share the same configuration.

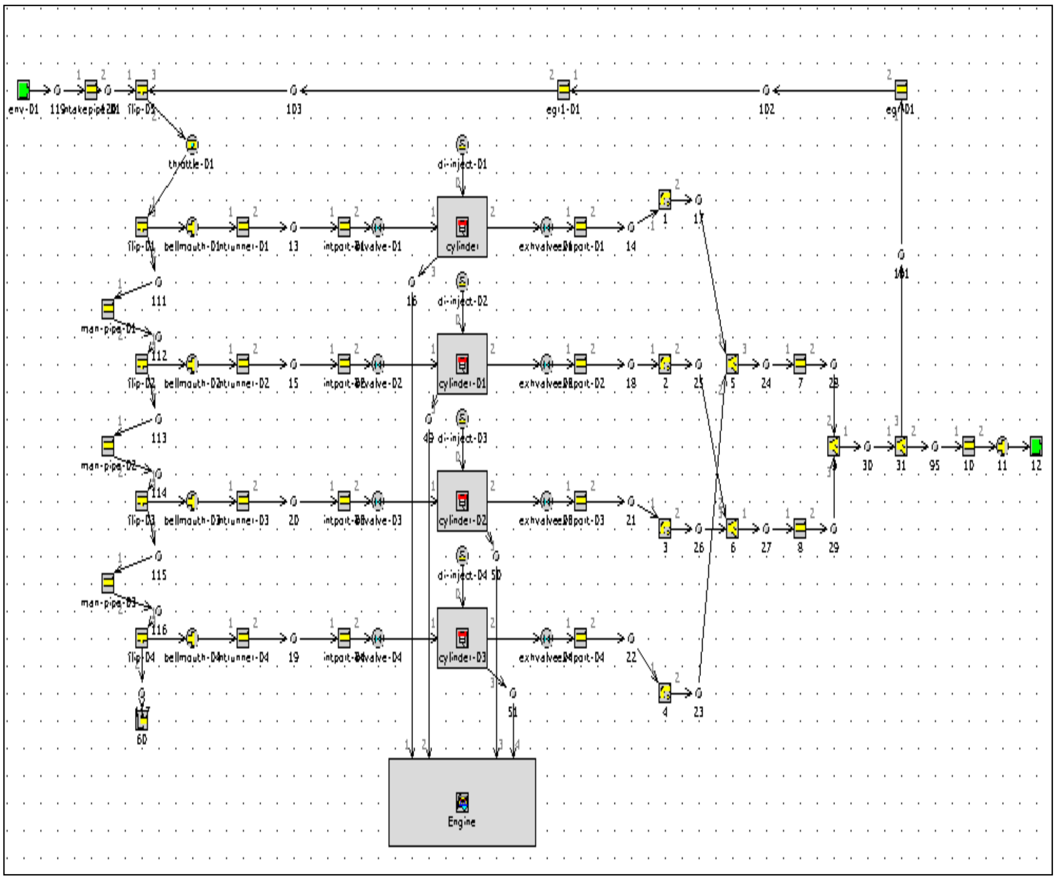

Figure 1. Computational model of the engine.

The 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 is defined by the crank angle with the intake valve closed. The crank angle was considered for the beginning of each cylinder’s cycle, because 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. The dimensions of bore, stroke and connecting rod correspond to a real engine and have been defined in this general engine panel. Data in the engine cylinder geometry are: bore, stroke, wrist pin to crank offset, compression ratio, TDC clearance height and connecting rod length. The input of the engine crank train consists of the number and configuration of the cylinders and engine type. The exhaust system has a few components, size and different data. The system was started from the exhaust valve till environment. The details of the engine parameters used in this model are described in Table 2. Figure 2 shows the component configuration for the four cylinders. The components in this system require a few data to complete the data form before running the model.

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

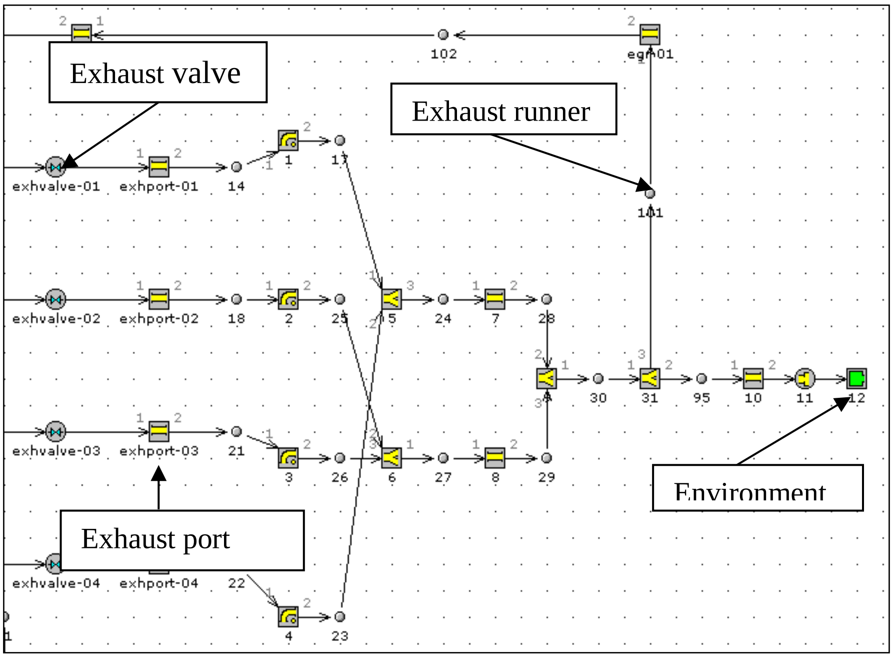

Figure 2. Exhaust system components.

Engine Performance Parameters

Some basic parameters commonly used to characterise engine operation are investigated. These include: the mechanical output parameters of work, torque and power; the input requirements of air, fuel kand combustion; efficiencies; and emission measurement of engine exhaust (Heywood, 1988; Pulkrabek, 2004).

Volumetric Efficiency: This 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):

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

where ρ_a = the inlet air density.

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

V_{disp} = displacement volume

N = engine speed

Engine Brake Torque: This is a good indicator of an engine's ability to do work. It is defined as the force acting at a moment distance and has units of N-m. Torque (τ) is related to work by Eq. (2) (Pulkrabek, 2004):

$$2\pi\tau = W_b = (bmep)V_d / n \tag{2}$$

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,

$$\tau = (bmep)V_d / 4\pi \tag{3}$$

Brake Power: Power is defined as the rate of work of the engine. The brake power is expressed as Eq. (4) (Pulkrabek, 2004):

$$\begin{aligned} \dot{W} &= WN/n \\ \dot{W} &= 2\pi N\tau \\ \dot{W} &= (1/2n)(mep)A_p\overline{U}_p \\ \dot{W} &= (mep)A_p\overline{U}_p/4 \end{aligned} \tag{4}$$

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 (Ganesan, 2003). Solving for thermal efficiency as Eq. (5):

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

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:

$$Bmep = w_b / \Delta v;\ bmep = 2\pi n \tau / V_d \tag{6}$$

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

Brake Specific Fuel Consumption: Brake power gives the brake specific fuel consumption, which is expressed as Eq. (7):

$$bsfc = \dot{m}_f / \dot{W}_b \tag{7}$$

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

RESULTS AND DISCUSSION

The engine parameters were analysed to provide a better understanding of the effect of fuel temperature using biodiesel 5% blended fuel on the engine performance. The simulation was analysed at different fuel temperatures, starting at a temperature of 300 K, reaching a maximum of 500 K. The tests were performed by varying the engine speed, starting from 1000 rpm and increasing to 4000 rpm in increments of 500 rpm. The variation in engine performance is assessed through brake power, brake thermal efficiency, brake engine torque, brake mean effective pressure and brake specific fuel consumption. The variation of brake power for different fuel temperatures 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. Higher fuel temperatures tend to produce higher injection pressure (Mamat, Abdullah, Xu, Wyszynski, & Tsolakis, 2009a). The highest injection pressure causes the lowest ignition delay, which results in the increase of brake power. A shorter ignition delay causes the early start of combustion. At low speed, a close resemblance occurred representing a small discrepancy in the output between the different fuel temperatures. The maximum reduction of 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 is also decreased. Some reduction will occur in the engine power if the lower calorific value biodiesel is used in a diesel engine without modification (Can, Çelikten & Usta, 2004). Figure 4 shows the variation of brake thermal efficiency with engine speed. It is a good measure of assessing how efficiently the energy in the fuel was changed to mechanical output (Aziz, Said, & Awang, 2005). They generally show similar trends and closely resemble one another. The brake thermal efficiencies at a temperature of 300 K are lower than at a temperature of 500 K. The lowest temperature caused the energy content to decrease, resulting in the lowest brake thermal efficiency. The efficiency is improved when the fuel temperature is increased (Mamat, Abdullah, Xu, Wyszynski, & Tsolakis, 2009b).

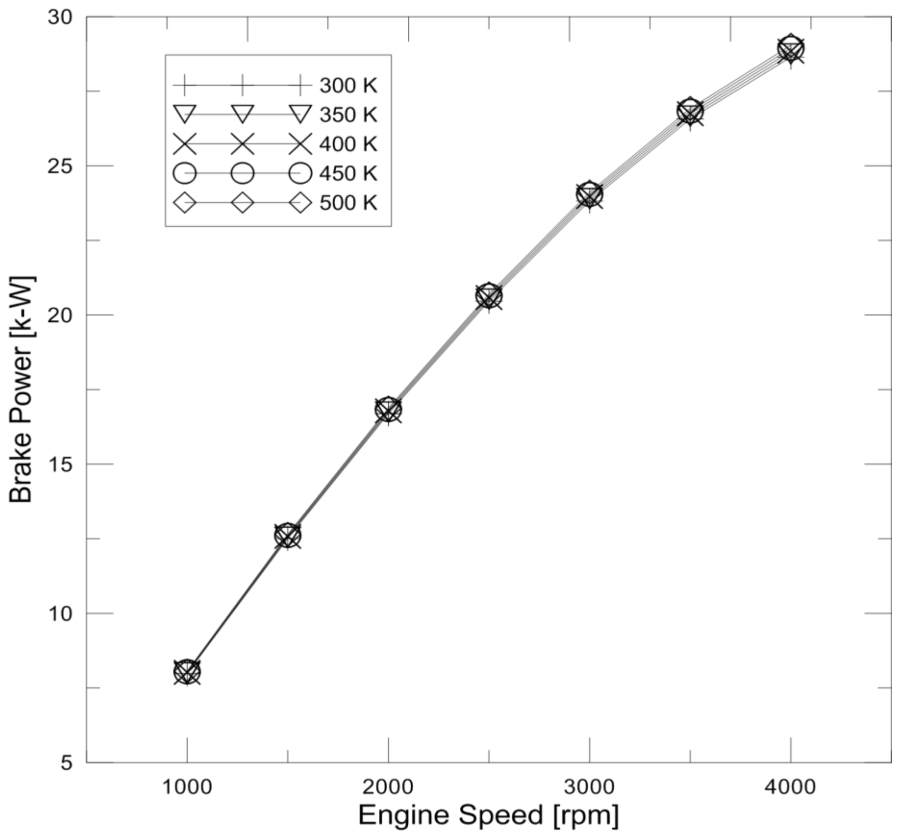

Figure 3. Variation of brake power with engine speed.

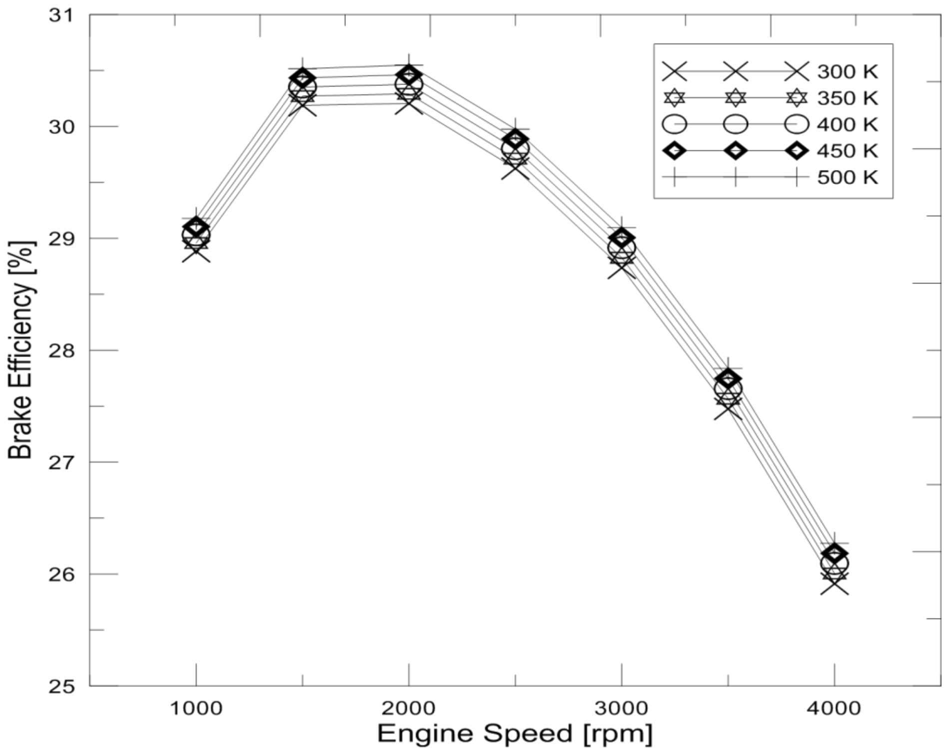

Figure 4. Effect of engine speed variation on brake thermal efficiency.

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 (Abu Zaid, 2004). At low speed, torque increases as the engine speed increases, reaching a maximum and then, as the engine speed increases further, the torque decreases. The torque decreases because the engine is unable to ingest a full charge of air at the higher speed (Abu Zaid, 2004). The higher fuel temperatures tend to produce higher injection pressure (Mamat et al., 2009b). 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 (Mamat et al., 2009b). The maximum recorded reduction of brake engine torque was about 1.13% with an engine speed of 2000 rpm.

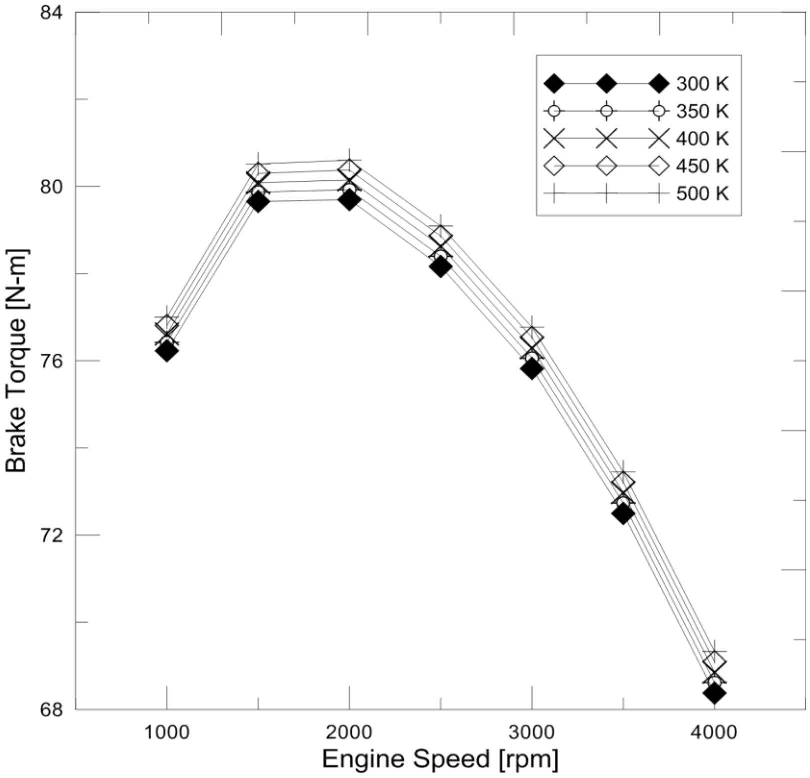

Figure 5. Variation of brake engine torque against engine speed.

Figure 6 shows the variation of brake mean effective pressure (BMEP) against engine speed. The brake mean effective pressure is used to calculate the performance of an internal combustion engine. Similar trends can be seen for each temperature. Brake thermal efficiency, brake torque and BMEP show similar trends under different circumstances. Figure 7 shows the effect of engine speed variation on brake specific fuel consumption (BSFC) for different fuel temperatures. This too, shows similar trends for the different temperatures of the fuels. The minimum BSFC (255.907 g/kW-hr) was obtained from the highest temperature of 500 K, while the maximum BSFC (301.668 g/kW-hr) was obtained from the lowest temperature of 300 K. The higher BSFC is due to the lower energy content of the fuel (Mamat et al., 2009a). As the temperature increases, the energy content also increases, causing the lowest BSFC for a temperature of 500 K compared with the temperature of 300K. (Heywood, 1988) reported that the lowest possible value of specific fuel consumption is obviously the most desirable.

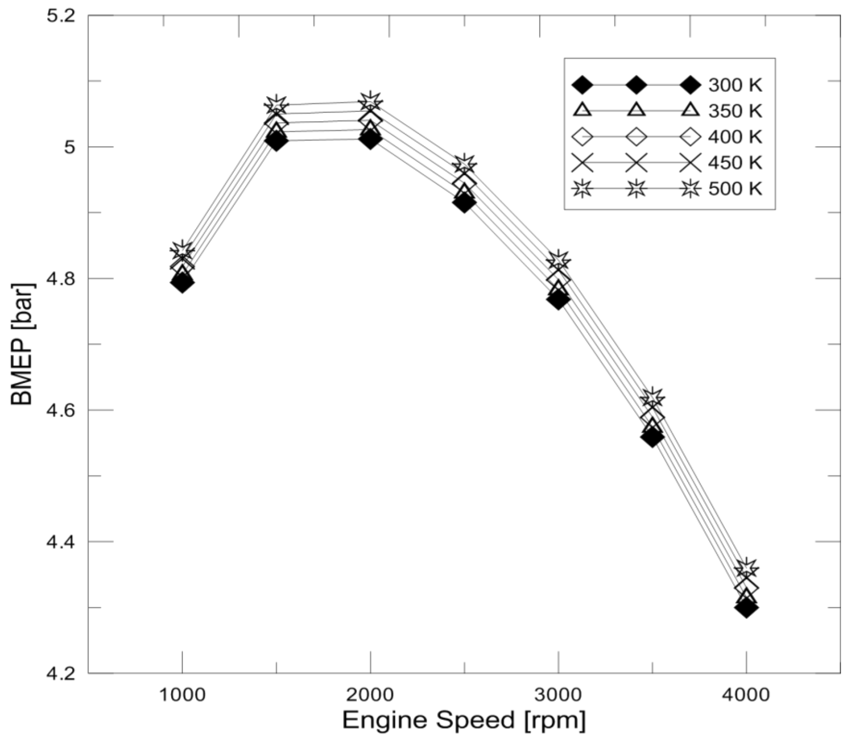

Figure 6. Variations of brake mean effective pressure against engine speed.

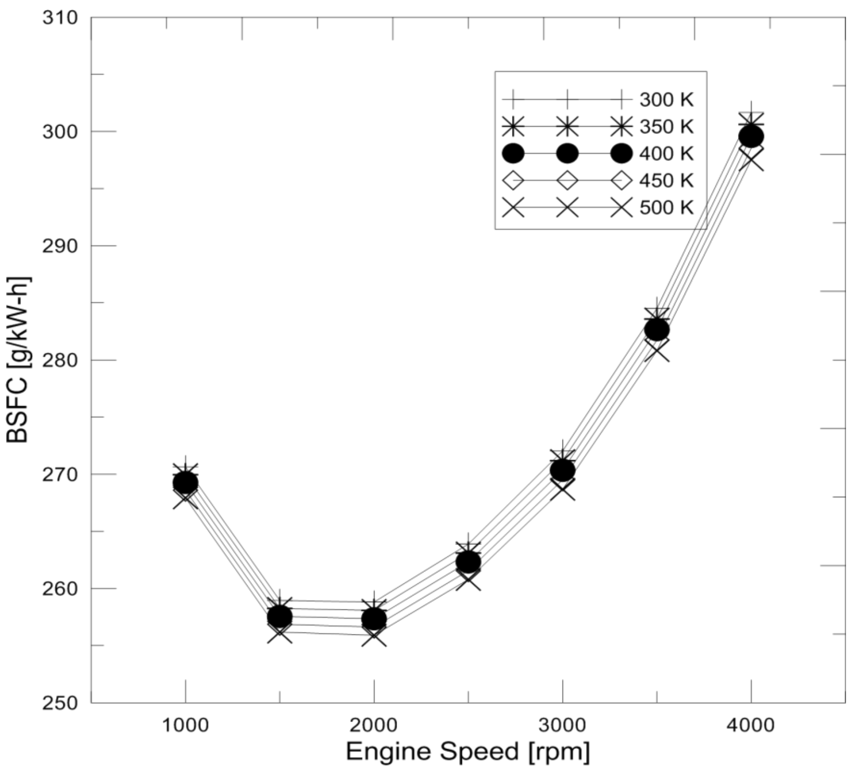

Figure 7. Effect of engine speed variation on brake specific fuel consumption.

CONCLUSIONS

The effect of fuel temperature and variation of engine speed on the engine performance of a four-cylinder diesel engine has been investigated. The conclusions can be summarised as follows:

- The highest fuel temperature causes the highest injection pressure, resulting in a shorter ignition delay.
- The shorter ignition delay attributed to the early start of combustion, leading to a higher in-cylinder pressure.
- The increase of fuel temperature represents higher energy content, resulting in lower BSFC, as is obviously desired.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the University Malaysia Pahang for the financial support under University Grant (No. RDU100333) and Graduate Research Scheme.

REFERENCES

Abdullah, A. Z., Salamatinia, B., Mootabadi, H., & Bhatia, S. (2009). Current status and policies on biodiesel industry in Malaysia as the world's leading producer of palm oil. *Energy Policy*, 37(12), 5440-5448.

Abu Zaid, M. (2004). Performance of single cylinder, direct injection Diesel engine using water fuel emulsions. *Energy Conversion & Management*, 45(5), 697-705.

Aziz, A. A., Said, M. F., & Awang, M. A. (2005). Performance of palm oil-based biodiesel fuels in a single cylinder direct injection engine. *Palm Oil Developments*, 42, 15-27.

Can, Ö., Çelikten, I., & Usta, N. (2004). Effects of ethanol addition on performance and emissions of a turbocharged indirect injection Diesel engine running at different injection pressures. *Energy Conversion and Management*, 45(15-16), 2429-2440.

Ganesan, V. (2003). *Internal combustion engines* (Second ed.). New Delhi: Tata Mc Graw Hill Company Limited.

Heywood, J. B. (1988). *Internal combustion engine fundamentals*. New York: McGraw-Hill.

Jayed, M. H., Masjuki, H. H., Saidur, R., Kalam, M. A., & Jahirul, M. I. (2009). Environmental aspects and challenges of oilseed produced biodiesel in Southeast Asia. *Renewable and Sustainable Energy Reviews*, 13, 2452-2462.

Knothe, G., Gerpen, J. V., & Krahl, J. (2005). T*he Biodiesel Handbook*. USA: AOCS Publishing.

Korbitza, W., Friedricha, S., Wagingerb, E., & Worgetterc, M. (2003). *Worldwide review on biodiesel production*. IEA Bioenergy Task.

Lim, S., & Teong, L. K. (2010). Recent trends, opportunities and challenges of biodiesel in Malaysia: An overview. *Renewable and Sustainable Energy Reviews*, 14, 938-954.

Mamat, R. (2009). P*erformance and emission characteristics of an automotive diesel engine using biodiesel fuel with the influence of air intake variables*. PhD Thesis. The University of Birmingham, UK.

Mamat, R., Abdullah, N. R., Xu, H., Wyszynski, M. L., & Tsolakis, A. (2009a). Effect of air intake pressure drop on performance and emissions of a diesel engine operating with biodiesel and ultra low sulphur diesel (ULSD). *Proceedings of International Conference on Renewable Energies and Power Quality*, pp. 1-8.

Mamat, R., Abdullah, N. R., Xu, H., Wyszynski, M. L., & Tsolakis, A. (2009b). Effect of fuel temperature on performance and emissions of a common rail diesel engine operating with rapeseed methyl ester (RME). *SAE International, Paper Number: 2009-01-1896*.

Pulkrabek, W. W. (2004). *Engineering fundamentals of the internal combustion engine*. Second ed., Pearson-Prentice Hall.

Sani, A. R. (2009a). Sektor pengangkutan Jepun digesa guna biodiesel sawit. Retrived from http://www.bharian.com.my/Current_News/BH/Saturday/BeritaSawit.

Sundar Raj, C., & Sendilvelan, S. (2010). Effect of oxygenated hydrocarbon additives on exhaust emission of a diesel engine. *International Journal of Automotive and Mechanical Engineering*, 2, 144-156.

Tan, K., Lee, K., Mohamed, A., & Bhatia, S. (2009). Palm oil: addressing issues and towards sustainable development. *Renewable and Sustainable Energy Reviews*, 13(2), 420-427.

Wiebe, K. A., Croppenstedt, T., Raney, J., Skoet, & Zurek, M. (2008). *The State of Food and Agriculture*. Rome: FAO Publications.

Zheng, J. (2009). *Use of an engine cycle simulation to study a biodiesel fueled engine.* PhD Thesis. Shanghai Jiaotong University, Texas, USA.