EFFECTS OF BIODIESEL FUEL TEMPERATURE ON PERFORMANCE AND EMISSIONS OF A COMPRESSION IGNITION (CI) ENGINE

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ABSTRACT

Diesel engines are still widely needed and applicable to light duty passenger car and heavy duty vehicles. In recent years, limited supply of fossil fuel makes alternative sources of fuel especially biodiesel receiving a lot of attention in the automotive industry. However, in using biodiesel as fuel had created poor fuel-air mixing that generally will produce lower performance and higher emissions than diesel fuel. This is associated with the fuel properties especially viscosity that higher compared to diesel fuel. The aim of this present research was to investigate the effects of preheated biodiesel based crude palm oil (B5, B10 and B15) at 40^{o}C, 50^{o}C and 60^{o}C on performance and emissions of diesel engine at three different load conditions, which are 0% load, 50% load and 100% load. A four-cylinder four strokes cycle, water cooled, direct injection engine was used for the experiments. The results showed that the maximum performance produced was at 0% load condition with the 60^{o}C of heating temperature by B10 where the torque, flywheel torque and brake power increased by 11.55%, 11.42% and 4.16% respectively compared to diesel fuel. While for the emissions, the preheat temperature results on the decrement of CO emission for all load conditions and the maximum reduction recorded was 41.2%. However, the increment of fuel temperature promotes to the higher NO_x emissions produced and the maximum increment recorded was 51.7%.

ABSTRAK

Enjin diesel masih banyak diperlukan dan digunakan bagi kenderaan ringan dan kenderaan berat. Beberapa tahun kebelakangan ini, bekalan bahan api fosil yang terhad membuatkan sumber-sumber alternatif bahan api terutamanya biodiesel menerima banyak perhatian di dalam industri automotif. Walaubagaimanapun, penggunaan biodiesel sebagai bahan bakar telah menyebabkan campuran bahan api-minyak yang tidak berkuliti yang akan menghasilkan prestasi yang rendah dan gas ekzos yang tinggi berbanding minyak diesel. Ini adalah berkaitan dengan sifat minyak terutamanya kelikatan yang mana ianya lebih likat berbanding dengan minyak diesel. Tujuan kajian ini dijalankan adalah untuk mengenalpasti kesan pemanasan biodiesel berasaskan minyak sawit (B5, B10 dan B15) pada 40^{o}C, 50^{o}C dan 60^{o}C terhadap prestasi dan gas ekzos enjin diesel pada tiga beban yang berbeza, iaitu beban 0%, beban 50% dan beban 100%. Sebuah enjin empat silinder, empat lejang dan sejukan air telah digunakan bagi eksperimen ini. Hasil kajian mendapati bahawa prestasi maksimum yang telah dihasilkan adalah pada beban 0% dengan suhu pemanasan 60^{o}C oleh B10 yang mana daya kilas, daya kilas roda tenaga dan kuasa brek meningkat sebanyak 11.55%, 11.42% dan 4.16% berbanding dengan minyak diesel. Manakala bagi gas ekzos, pemanasan suhu minyak menyebabkan susutan pelepasan CO untuk semua beban dan pengurangan maksimum yang direkodkan adalah sebanyak 41.2%. Walau bagaimanapun, kenaikan suhu pemanasan bahan api mengakibatkan lebih banyak pelepasan NO_x dihasilkan dan peningkatan maksimum yang direkodkan adalah sebanyak 51.7%.

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LIST OF SYMBOLS AND ABBREVIATIONS

B	-	Palm oil biodiesel
B5	-	5% blending ratio
B10	-	10% blending ratio
B15	-	15% blending ratio
BMEP	-	Brake mean effective pressure
BSEC	-	Brake specific energy consumption
BSFC	-	Brake specific fuel consumption
BTE	-	Brake thermal efficiency
^oC	-	Degree celsius
cc	-	Cubic centimeter
CI	-	Compress ignition
cm	-	Centimeter
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
cP	-	Centipoise
CPKO	-	Crude palm kernel oil
CPO	-	Crude palm oil
D	-	Diesel
DF	-	Diesel fuel
DI	-	Direct injection

FAME	-	Fatty acid methyl ester
g	-	gram
h	-	hour
HC	-	Hydrocarbon
HP	-	Horsepower
kg	-	kilogram
kJ	-	kilo Joule
kPa	-	kilo Pascal
kW	-	kilowatt
MPa	-	Megapascal
N	-	Ambient temperature condition
Nm	-	Newton meter
NO_x	-	Nitrogen oxides
O_2	-	Oxygen
P	-	Preheat temperature
P40	-	40^oC of preheat temperature
P50	-	50^oC of preheat temperature
P60	-	60^oC of preheat temperature
PKO	-	Palm kernel oil
ppm	-	Parts per million
rpm	-	Revolution per minute
s	-	Second
SFC	-	Specific fuel consumption
SO_2	-	Sulfur dioxide
THC	-	Total hydrocarbons

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CHAPTER 1

INTRODUCTION

1.1 Background of study

In the era of improvement technologies, emission regulations have become more stringent in order to keep and maintain clean and healthy environment. Industrial revolution especially in automotive industry was contributing quite higher number of percentage to the earth pollutions in our daily life that consequently will contribute to global warming effects and acid rain formation. Despite years of improvement on the petroleum fuels and combustion characteristics were attempts, issues regarding emissions still become the main conversation in the automotive industry. Limited supply of world petroleum resources and unpredicted increment on the petroleum price made the situation more critical. Thus, demand on the utilization of biodiesel fuels and its blends as alternative energy sources is urgently required to meet the future legislation.

Research and development of biodiesel fuels and its blends are very important to study and investigate in reducing dependency to diesel fuel. Besides, the implementation of biodiesel fuels is in line with the government policy that focusing on renewable energy. Lower emissions exhausted from biodiesel fuels are very good criteria and many researchers reported that the performance of biodiesel fuels and its blends are comparable with diesel fuel. A few established and developed European countries have started to use biodiesel fuels as primary fuel rather than diesel fuel.

1.2 Problems statement

Biodiesel is an alternative fuel that receiving a lot of attention nowadays due to its availability sources and renewability. Source of biodiesel may be divided into two categories; vegetable oils and animal fats. However, vegetable oils have become the main actor in producing biodiesel such as soybean oil, raw rapeseed oil, waste cooking oil, cottonseed oil, sunflower oil, crude palm oil and many more. The usage of this vegetable oil is due to the great fuel properties such as flash point and acid value that comparable to the diesel fuel. In Malaysia, abundantly sources of crude palm oil have resulted on the large numbers of research and development was conducted. It can be use in diesel engine directly without major modification. However, lack of study is carry out on the preheat biodiesel blends before entering to the combustion chamber.

Most biodiesel fuels have faced a problem where the fuels are not operating effectively in cold weather. It is due to the fuel properties such as viscosity that affected the fuels flow rate and poor fuel atomization during combustion process (Karabektas *et al*., 2008). Moreover, viscosity also may causes carbon deposits build up on injector and valve seat during extended operation of the engine (Yilmaz & Morton, 2011). Table 1.1 simplified the known problems, probable cause and the potential solutions for using straight vegetable oil in diesel engines (Balat & Balat, 2008).

Further studies on the effects of preheat biodiesel blends fuel derived from palm oil on the performance and emissions was conducted. Preheat is one of the effective method to lower the viscosity of biodiesel fuels and its blends. Viscosity of fuels decrease as the temperature increase (Agarwal & Agarwal, 2007; Hazar & Aydin, 2010; Bari *et al*., 2002; Hossain & Davies, 2012).

Table 1.1 : Problems and potential solutions for using straight vegetable oils as diesel engines fuel (Balat & Balat, 2008)

Problem	Probable cause	Potential solution
Short Term		
1. **Cold weather starting**	High viscosity, low cetane and low flash point of vegetables oils.	Pre-heat fuel prior to injection. Chemically alter fuel to an ester.
2. **Engine knocking**	Very low cetane of some oils. Improper injection timing.	Adjust injection timing. Use higher compression engines. Pre-heat fuel prior to injection. Chemically alter fuel to an ester.
Long Term		
3. **Coking of injectors on piston and head of engine and carbon deposits on piston and head of engine**	High viscosity of vegetables oil, incomplete combustion of fuel. Poor combustion at partial load with vegetable oils.	Heat fuel prior to injection. Switch engine to diesel fuel when operating at part load. Chemically alter the vegetable oil to an ester.
4. **Excessive engine wear**	High viscosity of vegetables oil, incomplete combustion of fuel. Poor combustion at partial load with vegetable oils. Possibly free fatty acids in vegetable oil. Dilution of engine lubricating oil due to blow-by of vegetable oil.	Heat fuel prior to injection. Switch engine to diesel fuel when operating at part load. Chemically alter the vegetable oil to an ester. Increase motor oil changes. Motor oil additives to inhibit oxidation.
5. **Failure of engine lubricating oil due to polymerization**	Collection of polyunsaturated vegetable oil blow-by in crankcase to the point where polymerization occurs.	Heat fuel prior to injection. Switch engine to diesel fuel when operating at part load. Chemically alter the vegetable oil to an ester. Increase motor oil changes. Motor oil additives to inhibit oxidation.

1.3 Objectives

The objectives of this research are;

i. To conduct biodiesel blending process at various ratio.

ii. To investigate the effect of various biodiesel fuel temperature and blending ratio on performance and emissions of CI engine.

iii. To make recommendation of the biodiesel fuel temperature and blending ratio that strongly affects the vehicles performance and exhaust emissions according to the load condition.

1.4 Scopes

The scopes of study are:

i. Determine the fuel properties of B5, B10 and B15 biodiesel blending ratio at 40^{o}C, 50^{o}C and 60^{o}C.
ii. Set up and conduct the experiment of performance and emissions of Mitsubishi Pajero (4D56) CI engine at various rpm (1500 rpm, 2000 rpm, 2500 rpm and 3000 rpm) and load conditions (0 %, 50 % and 100 %).
iii. Study the comparison of CI engines performance operating by preheated biodiesel fuel and normal diesel fuel.

1.5 Significant of study

This study is based on the analysis of the crude palm oil (CPO) biodiesel at three types of blending ratio as per stated below:

i. B5 (5% palm oil biodiesel, 95% diesel)
ii. B10 (10% palm oil biodiesel, 90% diesel)
iii. B15 (15% palm oil biodiesel, 85% diesel)

Moreover, the blended fuels were heated up to three different temperatures that were 40^{o}C, 50^{o}C and 60^{o}C. The influences of preheat fuel properties on performance and emissions were obtained and further analyzed in order to understand the relation between temperature, fuel properties and combustion characteristics. The results are very important for future study and development as a reference to establish a new alternative energy that produced lower effects to our earth and further reduce dependence on fossil fuels.

CHAPTER 2

LITERATURE REVIEW

2.1 Biodiesel fuels

Biodiesel is known as a non-petroleum diesel, a mixture of mono-alkyl esters of long chain fatty acid (FAME) and it is an alternative fuel that made from vegetable oils and animal fats. It is a renewable energy, more cleanly than petroleum fuel and large availability sources (Mekhilef *et al.*, 2011; Abdullah *et al.*, 2009). The concern about biodiesel is quickly increased since the petroleum crises in 1970s that cause rapidly increasing in market prices. Growing concern of the environment and the effect of greenhouse gases also had revived more and more interests in the use of vegetable oils as a substitute of petroleum fuel (Abdullah *et al.*, 2009; Balat & Balat, 2008).

Biodiesel is produced by transesterification reaction of vegetable oil with low molecular weight alcohol, such as ethanol or methanol (Mekhilef *et al.*, 2011). The properties of biodiesel generally has higher density, viscosity, cloud point, cetane number, lower volatility and heating value compared to diesel fuel that affecting on the engine performance and emissions. However, neat biodiesel or its blends may be used in the existing diesel engines with little or no modification to the engine (Benjumea & Agudelo, 2008; Haseeb *et al.*, 2010).

Normally, the blended biodiesel with diesel fuel is referred as Bxx, where xx indicated the amount of biodiesel in the blend. For example, B15 blend means 15% biodiesel mixed with 75% diesel fuel in the volume percentage. Table 2.1 shows a few biodiesel blends and their effect on the engine performance and emissions while Table 2.2 depicts the emissions reduction factors on biodiesel.

Table 2.1: Biodiesel blends its effect on engine performance and emissions (Combs, 2008)

Name	Blend	Properties and effect on engine performance and emissions
B5	5% biodiesel 95% diesel fuel	Very similar to diesel fuel; generally accepted by all engines manufacturer. Reduces air pollution from unburned hydrocarbons, carbon monoxide and particulate matter, and emits lower levels of carbon dioxide than diesel fuel. Approved for use in Texas.
B10	10% biodiesel 95% diesel fuel	Reduces air pollution and emits lower levels of greenhouse gases than diesel fuel.
B20	90% diesel fuel 95% diesel fuel	May cause a slight (1% to 2%) decrease in engine power and fuel economy. Lowers unburned hydrocarbons by 21%, carbon monoxide by 11% and particulate matter by 10%. Previously thought to cause a less than 2%v increase in NO_x emissions, although broader, more recent studies indicate no increase on average. Approved to use in Texas with additives.
B100	5% biodiesel 95% diesel fuel	May cause a 5% to 10% decrease in engine power and fuel economy.

Table 2.2: Emission reduction factors (Lozada *et al*., 2010)

Emissions	B100
Total hydrocarbons (THC)	-67%
Carbon Monoxide (CO)	-48%
Particulate matter	-47%
Nitrous oxide (NO_x)	+10%
Carbon dioxide (CO_2)	-100%
Sulfur dioxide (SO_2)	-100%

2.1.1 Advantages of biodiesel

Among the advantages of biodiesel to the consumers are:

(i) It is sustainable renewable fuel and may be produced domestically, thus lower dependence on crude oil (Abdullah *et al*., 2009)

(ii) It has higher flash point than conventional diesel fuel results on safer handling (Abdullah *et al*., 2009)

(iii) It is environmental friendly and lower harmful emissions (Abdullah *et al*., 2009)

(iv) It is favorable energy balance, biodegradable and non-toxic and any spill over will be easier and cheaper to clean up (Abdullah *et al*., 2009; Mekhilef *et al*., 2011)

(v) It does not contains any sulfur, aromatic hydrocarbons and metal crude residues; these properties contribute to improve the combustion efficiency and emission profile (Gomma, 2010)

(vi) It contains high oxygen amount 10 to 12% by weight which can significantly contribute to complete combustion (Gomma, 2010)

(vii) It can be directly use as fuel without any modifications as biodiesel is compatible with existing diesel engines (Lam & Lee, 2011; Lim & Teong, 2010; Kannan *et al*., 2011; Xue *et al*., 2011)

2.1.2 Disadvantages of biodiesel

Among the disadvantages of biodiesel to the consumers are:

(i) It has higher viscosity that results on poor fuel atomization and incomplete combustion (Yilmaz & Morton, 2011)

(ii) It produce lower engine performance compared to diesel fuel

(iii) Fuel consumption of an engine becomes higher because it is needed to compensate the loss of heating value of biodiesel compared to diesel fuel (Xue *et al*., 2011)

(iv) It may cause dilution and polymerization of engine sump oil, as a result it requiring more frequent oil changes (Rakopoulos *et al*., 2006)

(v) It has higher pour point, lower calorific value and lower volatility (Rakopoulos *et al*., 2006)

(vi) It has lower oxidation stability, hygroscopic, and as solvents, it will cause corrosion of components, attacking some plastic materials used for seals, hoses, paints and coatings (Rakopoulos *et al*., 2006)

(vii) It has higher oxygen content compared to diesel fuel and it provides relatively high NOx emissions during combustion process

(viii) It has higher cold filter plugging point temperature than diesel fuel, hence it will crystallize into a gel when used in its pure form (Gomma, 2010)

(ix) Fuel filter need to replace few time during the initial stages of biodiesel use due to its strong solvent that will scrubs out all the tars, varnishes and gum left by diesel fuel in the fuel system (Gomma, 2010)

2.1.3 Biodiesel standard

In Malaysia, two major biodiesel standards that are most referred are European Standard for Biodiesel (EN 14214) and Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels (ASTM D6751) as per shown in Table 2.3 and 2.4 respectively.

Table 2.3: European Standard for Biodiesel (EN 14214)

Property	Unit	Limits		Test Method
		min	max	
FAME content	% (m/m)	96.5	-	EN14103
Density at 15 °C	kg/m^3	860	900	EN ISO 3675 EN ISO 12185
Viscosity at 40 °C	mm^2/s	3.5	5.0	EN ISO 3104
Flash point	°C	101	-	EN ISO 2719 EN ISO 3679
Sulfur content	mg/kg	-	10.0	EN ISO 20846 EN ISO 20884
Carbon residue (on 10 % distillation residue)	% (m/m)	-	0.3	EN ISO 10370
Cetane number	-	51.0	-	EN ISO 5165
Sulfated ash content	% (m/m)	-	0.02	ISO 3987
Water content	mg/kg	-	500	EN ISO 12937
Total contamination	mg/kg	-	24	EN 12662
Copper strip corrosion (3 h at 50 °C)	rating	class 1		EN ISO 2160
Oxidation stability, 110 °C	hours	6.0	-	prEN 15751 EN 14112
Acid value	mg KOH/g	-	0.5	EN 14104
Iodine value	g iodine/100 g	-	120	EN 14111
Linolenic acid methyl ester	% (m/m)	-	12.0	EN 14103
Polyunsaturated (≥ 4 double bonds) methyl esters	% (m/m)	-	1	
Methanol content	% (m/m)	-	0.2	EN 14110
Monoglyceride content	% (m/m)	-	0.8	EN 14105
Diglyceride content	% (m/m)	-	0.2	EN 14105
Triglyceride content	% (m/m)	-	0.2	EN 14105
Free glycerol	% (m/m)	-	0.02	EN 14105 EN 14106
Total glycerol	% (m/m)	-	0.25	EN 14105
Group I metals (Na+K)	mg/kg	-	5.0	EN 14108 EN 14109 EN 14538
Group II metals (Ca+Mg)	mg/kg		5.0	EN 14538
Phosphorus content	mg/kg	-	4.0	EN 14107

Table 2.4: Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels (ASTM D6751)

Property	Unit	Grade S15	Grade S500	Test Method
		Limits	Limits	
Calcium and Magnesium, combined	ppm (µg/g)	5 max	5 max	EN 14538
Flash point (closed cup)	°C	93 min	93 min	ASTM D93
Water and sediment	% volume	0.050 max	0.050 max	ASTM D2709
Kinematic viscosity, 40°C	mm^2/s	1.9-6.0	1.9-6.0	ASTM D445
Sulfated ash	% mass	0.020 max	0.020 max	ASTM D874
Sulfur	% mass (ppm)	0.0015 max (15)	0.05 max (500)	ASTM D5453
Copper strip corrosion		No. 3 max	No. 3 max	ASTM D130
Cetane number		47 min	47 min	ASTM D613
Cloud point	°C	Report*	Report*	ASTM D2500
Carbon residue	% mass	0.050 max	0.050 max	ASTM D4530
Acid number	mg KOH/g	0.50 max	0.50 max	ASTM D664
Cold soak filterability	seconds	360 max	360 max	ASTM D7501
Free glycerin	% mass	0.020 max	0.020 max	ASTM D6584
Total glycerin	% mass	0.240 max	0.240 max	ASTM D6584
Phosphorus content	% mass	0.001 max	0.001 max	ASTM D4951
Distillation temperature, Atmospheric equivalent temperature, 90 % recovered	°C	360 max	360 max	ASTM D1160
Sodium and Potassium, combined	ppm (µg/g)	5 max	5 max	EN 14538
Oxidation stability	hours	3 minimum	3 minimum	EN 15751

Note: * The cloud point of biodiesel is generally higher than petroleum based diesel fuel and should be taken into consideration when blending.

2.2 Palm oil

The oil palm tree in Malaysia was originated from West Africa. The development of oil palm as a plantation crop started in 1917 at Tennamaran Estate, Selangor (Hai, 2002). The oil palm is a tropical palm tree; hence it can be cultivated easily in Malaysia. The scientific name of oil palm tree is *Elaeis Guineensis* (Sumathi *et al.*, 2008).

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