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^oC, 50^oC dan 60^oC 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^oC 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
^{o}C	-	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).

Figure 2.1: Palm Oil trees planted in Malaysia

Palm oil is edible oil that used for biodiesel production. There are two types of palm oil; crude palm oil (CPO) that derived from the red fruits of the oil palm and crude palm kernel oil (CPKO) that derived from the fruit's nut. Although both oils originate from the same fruit, palm oil is chemically and nutritionally different from PKO. Table 2.5 shows the present and forecasted production of palm oil for the year 2000-2020 in MnT for Malaysia and Indonesia. In terms of the world market, both Malaysia and Indonesia account for 90% of the palm oil world export trade and will likely remain the key players in the palm oil sector (Sumathi *et al*., 2008).

Table 2.5: Present and forecasted production of palm oil for the year 2000-2020 in MnT for Malaysia and Indonesia (Sumathi *et al*., 2008)

Year	Malaysia	Indonesia	World total
1996-2000	9022 (50.3%)	5445 (30.4%)	17,932
2001-2005	11,066 (47.0%)	8327 (35.4%)	23,530
2006-2010	12,700 (43.4%)	11,400 (39.0%)	29,210
2011-2015	14,100 (40.2%)	14,800 (42.2%)	35,064
2016-2020	15,400 (37.7%)	18,000 (44.1%)	40,800

2.3 Properties of palm oil biodiesel and comparison with diesel fuel

The properties of palm oil are very important because it will influence the performance and emissions of diesel engines. However, the properties of biodiesel depend very much on the nature of its raw material as well as the technology or process used for its production. Among the properties are sulfur content, cetane number and flash point. Higher cetane number of palm oil compared to diesel fuel contributes to easy cold starting and low idle noise. Flash point of palm oil biodiesel is higher than diesel fuel offers easily of handling and much safer because it is less combustible. Moreover, lack of sulfur content contributes to lower particulate emissions of diesel engines. Table 2.6 shows the fatty acid composition of palm oil while Table 2.7 shows the details of palm oil biodiesel and comparison with diesel fuel.

Table 2.6: Fatty acid composition of palm oil (Lam & Lee, 2011)

Fatty acid	**Composition (%)**
Lauric (12:0)	0.1
Myristic (C14:0)	1.0
Palmitic (C16:0)	42.8
Stearic (C18:0)	4.5
Oleic (C18:0)	40.5
Linolic (C18:1)	10.1
Others	1
Total	100

Table 2.7: Comparison of fuel properties of Malaysian diesel, palm oil biodiesel (normal and winter grade) (Lam & Lee, 2011; Lim & Teong, 2010)

Property	**Unit**	**Diesel**	**Palm oil biodiesel**	
			Normal grade	**Winter grade**
Ester content	% mass	-	98.5	98.0-99.5
Free glycerol	% mass	-	<0.02	<0.02
Total glycerol	% mass	-	<0.25	<0.025
Density at 15°C	kg/L	0.853	0.878	0.87-0.89
Viscosity at 40°C	cSt	4	4.4	4.0-5.0
Flash point	°C	98	182	150-200
Cloud point	°C	-	15.2	-18 to 0
Pour point	°C	15	15	-21 to 0
Cold filter plugging point	°C	-	15	-18 to 3
Sulfur content	% mass	0.1	<0.001	<0.001
Carbon residue	% mass	0.14	0.02	0.02-0.03
Cetane index		53	58.3	53.0-59.0
Acid value	mgKOH/g	-	0.08	<0.3
Copper strip corrosion	3 h at 50°C	-	1a	1a
Gross heat of combustion	kJ/kg	45800	40135	39160

2.4 The effects of palm oil biodiesel on engine performance and emissions

Throughout the years, lots of researchers have studied and investigated the effects of palm oil biodiesel on engine performance and emissions. The research conducted including the use of neat palm oil biodiesel and its blends at various percentages. The main findings of past studies of palm oil biodiesel were recorded and summarized in Table 2.8.

Table 2.8: Literatures on the effects of palm oil biodiesel on engine performance and emissions

No	Author	Fuel employed	Main Findings
1	(Deepanraj *et al*., 2011)	B10, B20, B30, B40, B50	The BTE of all blended fuels were lower than DF and increased with the increasing load. However, lower blends of biodiesel increased the BTE. The SFC values were observed higher than that of DF. Overall of HC and CO produced from biodiesel was found lower than DF. Moreover, the NO_x formation was recorded higher than DF and the values increased with the increment of biodiesel volume. It was because of higher temperature of combustion and presence of fuel oxygen with biodiesel blends.
2	(Kinoshita *et al*., 2006)	B100	The BTE recorded was nearly identical to DF while BSFC was higher than that of DF. HC, smoke and NO_x were lower that of DF.
3	(Kalam *et al*., 2005)	B20, B35, B100	Brake power produced from B100 was lower compared to DF and the values getting closer to DF brake power as the volume of palm oil decreased. SFC was higher at B100 and followed by B35 and B20 when compared to DF. Moreover, emissions of CO and HC were found lower than that of DF. For CO_2 emission, B20 and B35 were lower than DF while B100 was higher than DF. Lastly, NO_x emission was higher compared to DF.
4	(Sharon *et al*., 2012)	B25, B50, B75, B100	The performance results showed that BTE for all blended fuels and B100 were lower compared to that of DF while BSFC were higher than DF. This was due to the lower calorific value of biodiesel and its blends compared to DF. The emission of CO was lower than DF. For HC and smoke, B25 showed higher than DF while B50, B75 and B100 produced lower than DF. CO_2 and NO_x emissions were higher than DF because of the complete combustion, higher temperature of

			combustion and higher oxygen content in the fuels.
5	(Khalid *et al*., 2012)	B5, B10, B15	The brake power and fuel consumption of biodiesel and its blends fuels were comparable to DF and there were not much different than DF. Moreover, flywheel torque was lower than DF while torque was higher for all biodiesel and its blends. The emissions of CO, CO_2 and HC were lower compared to DF and O_2 was higher than DF. Smoke emission was higher at low load and it became lower at higher load compared to DF.
6	(Vedaraman *et al*., 2011)	B20, B30, B40, B100	The results showed that BTE was lower than DF and it was decreases with increase in blend ratio meanwhile BSFC was higher than DF and it was increases as blend ratio increase. For emissions, HC and CO depicted the same trend that it was lower compared to that of DF. The CO_2 and NO_x emissions were higher than DF.
7	(Almeida *et al*., 2002)	B100	B100 resulted in slightly higher of SFC compared to DF (almost 10% higher at low load). Moreover, CO obtained was higher than that of DF while O_2 and CO_2 were almost the same to DF. HC emission of was higher at partial load and lower at higher load compared to DF and NO_x was lower than DF.

DF – Diesel Fuel
BCSFC – Brake Specific Fuel Consumption
SFC – Specific Fuel Consumption
BTE – Brake Thermal Efficiency
O_2 – Oxygen
CO – Carbon Monoxide
CO_2 – Carbon Dioxide
HC – Hydrocarbon
NO_x – Oxides of Nitrogen
B – Palm Oil Biodiesel
Bxx – xx indicated the amount of Palm Oil Biodiesel in the blend

The results of previous studies showed that palm oil biodiesel can be used straight away in operating diesel engines without or little modifications. However, generally most of the researchers reported that the BTE of palm oil biodiesel and its blends were lower than that of diesel fuel while the BSFC was higher for palm oil and its blends compared to diesel fuel. The NO_x emission was recorded higher than diesel fuel for both palm oil and its blends and the HC and CO emissions were recorded lower than that diesel fuel. Table 2.9 shows the statistics of effects of pure biodiesel on engine performance and emissions.

Table 2.9 : Statistics of effects of pure biodiesel on engine performance and emissions (Xue *et al*., 2011)

	Total number of references	Increase		Similar		Decrease	
		Number	%	Number	%	Number	%
Power performance	27	2	7.4	6	22.2	19	70.4
Economy performance	62	54	87.1	2	3.2	6	9.7
PM emissions	73	7	9.6	2	2.7	64	87.7
NO_x emissions	69	45	65.2	4	5.8	20	29.0
CO emissions	66	7	10.6	2	3.0	57	84.4
HC emissions	57	3	5.3	3	5.3	51	89.5
CO_2 emissions	13	6	46.2	2	15.4	5	38.5
Aromatic compounds	13	-	-	2	15.4	11	84.6
Carbonyl compounds	10	8	80.0	-	-	2	20.0

2.5 The changes of fuel inlet temperature and its effects

Temperature is a physical parameter that measures the condition of certain matter either hot or cold. In this study, the fuel will be preheat up to certain temperature and the increasing of fuel temperature may affects on the few fuel properties especially viscosity. Viscosity will gradually decrease as the temperature increase and it will influence the fuel-air mixing due to the changes of spray evaporation and consequently influence the combustion, performance and emissions of diesel engine. Lots of researchers have reported that use of vegetable oils or its blends (higher viscosity) without preheat effects on fuel droplet formation, poor atomization, vaporization and air fuel mixing process (Hazar & Aydin, 2010; Karabektas *et al*., 2008; Pugazhvadivu & Jeyachandran, 2005). These effects cause important engine failures such as fuel filter clogging, piston ring sticking, injector choking, carbon formation deposits and rapid deterioration of lubricating oil (Bari *et al*., 2002; Kalam & Masjuki, 2005; Karabektas *et al*., 2008; Pugazhvadivu & Jeyachandran, 2005). Other than that, it also leads to high smoke, HC and CO emissions (Hazar & Aydin, 2010). Moreover, increasing fuel temperature or heating also will ease the problem of injection process because it results in a decrease of the arithmetic diameter of the fuel droplets due to the effect of surface tension and viscosity changes with temperature (Mamat *et al.*, 2009). Thus, it gives better spray formation and combustion process.

2.6 Performance of preheated biodiesel

The performance parameters of preheat biodiesel had been reviewed such as BTE, BSFC and brake power. The parameters were evaluated and compared to the neat diesel fuel.

Agrawal & Agrawal (2007) studied the performance of a four stroke single cylinder diesel engine fuelled by preheated Jatropha oil as fuel. They reported that the BSFC of preheated Jatropha oil was higher than that of diesel fuel but lower that unheated Jatropha oil at medium load as per depicted in the Figure 2.2. Moreover, the thermal efficiency of preheated Jatropha oil was lower that diesel fuel but slightly higher than unheated Jatropha oil as shown in Figure 2.2. The reason for this behavior may be improved fuel atomization because of reduced fuel viscosity.

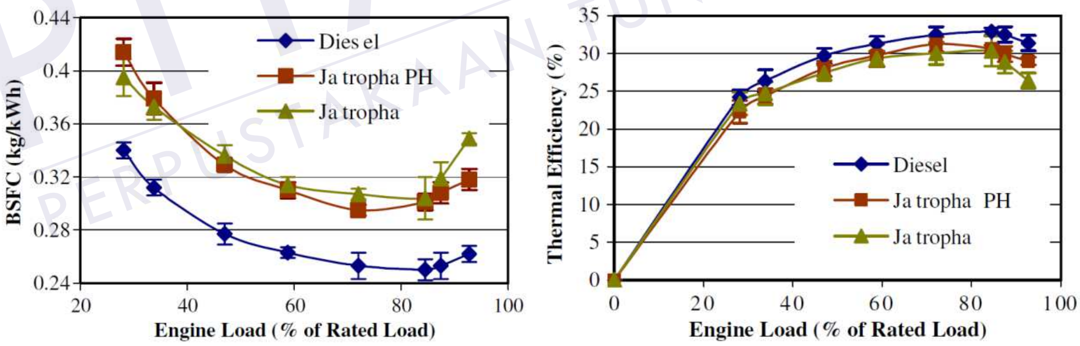

Figure 2.2: Engine performance parameters of Jatropha oil (heated and unheated conditions) (Agarwal & Agarwal, 2007)

The use of preheated rapseed oil biodiesel at two different fuel blends: O20 (20% rapeseed oil – 80% diesel fuel) and O50 (20% rapeseed oil – 80% diesel fuel) was investigated by Hazar & Hydin (2010). They found that preheated biodiesel has increased the brake torque from its normal condition but the value remained lower when compared with that diesel fuel as per depicted in Figure 2.3. Meanwhile, the power variation of diesel fuel is higher than those of O20 and O50 for all engine operations either with preheat or not because diesel fuel has higher calorific value. The increment of rapeseed oil in the blends remained lower compared to diesel fuel because the viscosity of the blend is reducing with preheating led to the higher leakages in the pump and injector resulting in lower power outputs. The BSFC was increased with the increasing rapeseed oil in the blends compared with diesel fuel.

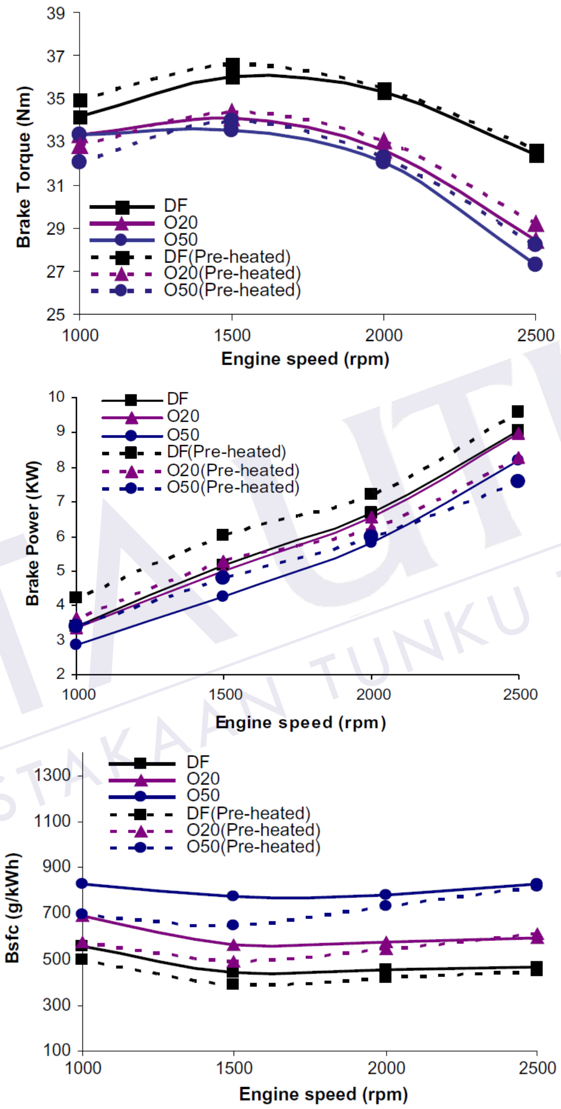

Figure 2.3: Performance parameters of rapeseed oil biodiesel (Hazar & Aydin, 2010)

Karabektas *et al.* (2008) analyzed the preheated cottonseed methyl ester performance on a diesel engine and concluded that the brake power of the heated fuel was lower than that of diesel fuel due to an excessive leakage through the fuel pump and injectors. However, thermal efficiency was higher compared to diesel fuel and they reported it was attributed to the preheating process that gives better combustion characteristics of biodiesel because of decreased viscosity and improved volatility. Pugazhvadivu & Jeyachandran (2005) investigated the performance of a diesel engine using preheated waste frying oil as fuel. They reported that brake specific energy consumption for preheated waste frying oil was higher than diesel fuel and the value was increased with decreasing fuel temperature ranging from 135^{o}C to 30^{o}C. They also concluded that thermal efficiency was lower compared to diesel fuel.

Singh *et al.* (2010) studied the performance of preheated Jatropha oil on medium capacity diesel engine. They found that the BTE for Jatropha oil was lower than diesel fuel throughout the entire operating range. However, when the temperature of preheating fuel increases, BTE also increases close to diesel fuel as per shown in Figure 2.4. The reason why the BTE lowers compared to diesel fuel are lower calorific values due to presence of oxygen in unsaturated hydrocarbon and high viscosity of Jatropha oil. They also reported that brake specific energy consumption is higher than diesel fuel due to high density and low calorific value of fuel.

Canakci *et al.* (2009) tested an indirect injection of four strokes eater cooled diesel engine using preheated crude sunflower oil. Their tests showed that the brake torque decreased by 1.36% while the BSFC increased by almost 5% on average compared to diesel fuel over the speed range at full load condition as per depicted in Figure 2.5. The effects of preheated cottonseed oil methyl ester on performance parameters were conducted by Augustine *et al.* (2012) using 660CC single cylinder diesel engine. They concluded that BSFC is higher than that of diesel engine for all loads tested. This was due to more blended fuel which is used to produce same power as compared to diesel fuel. Moreover, BTE was lower than diesel fuel but increased by the preheated temperature ranging from 40^{o}C up to 80^{o}C, but for 100^{o}C decreases due to vapor locking in the fuel line and hence more fuel consumption is obtained for the same power compared to other mode of operation.

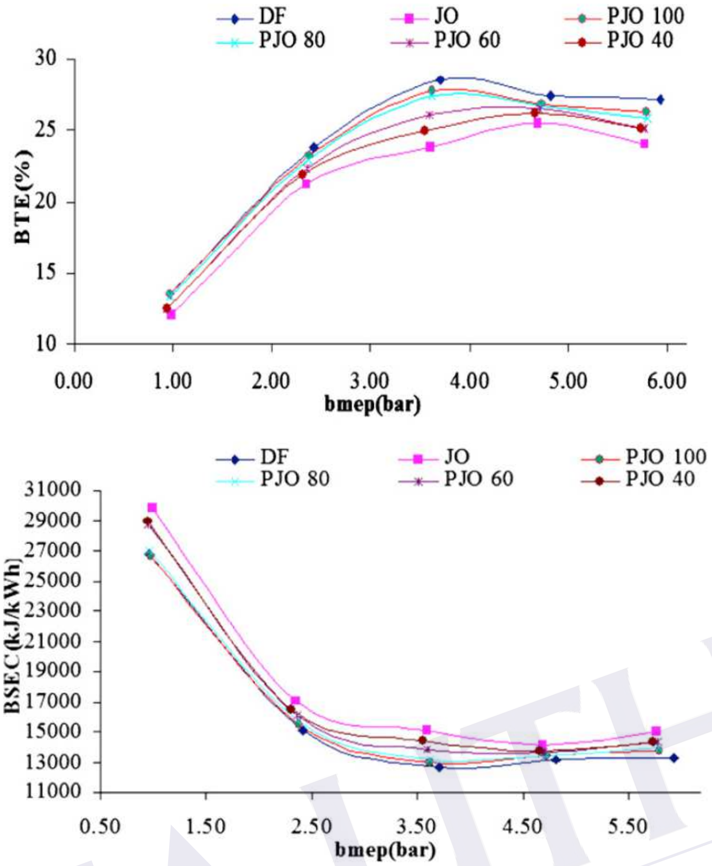

Figure 2.4: Engine performance parameters of Jatropha oil (Singh *et al.*, 2010)

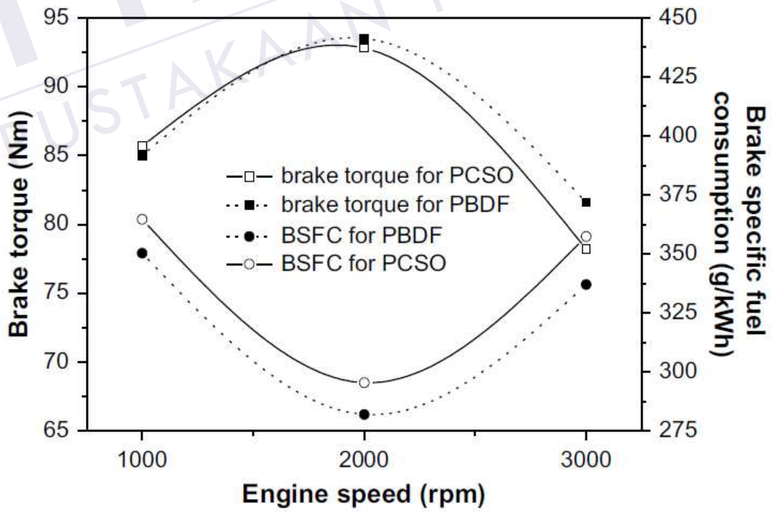

Figure 2.5: The brake torque and BSFC versus engine speed of preheated crude sunflower oil (Canakci *et al.*, 2009)

Hossain and Davies (2012) investigated the performance an indirect injection multi-cylinder compression ignition operating on preheated Jatropha and kranja oils. The authors reported that BSFC of Jatropha and kanja oils were higher as compared to diesel fuel because the calorific value for both oils was lower than diesel fuel thus more fuel is needed for the same engine output. BTE recorded for both oil were close to diesel fuel at high load but 10% lower than diesel fuel at low load condition as per shown in Figure 2.6. Yilmaz and Morton (2011) studied the performance of three vegetable oils at two different engines; Yanmar and Kubota engines. They found that preheating increases thermal efficiency and vegetable oil shows higher thermal efficiencies than diesel fuel for all of the preheated fuels and both engines. Thermal efficiencies for both engines are shown in Figure 2.7.

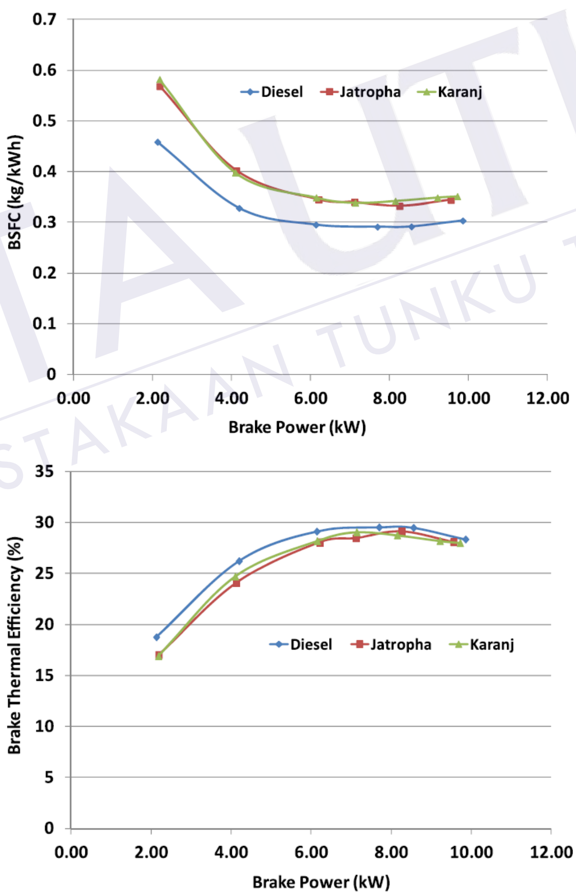

Figure 2.6: BSFC and BTE versus brake power of preheated Jatropha and kranja oils (Hossain & Davies, 2012)

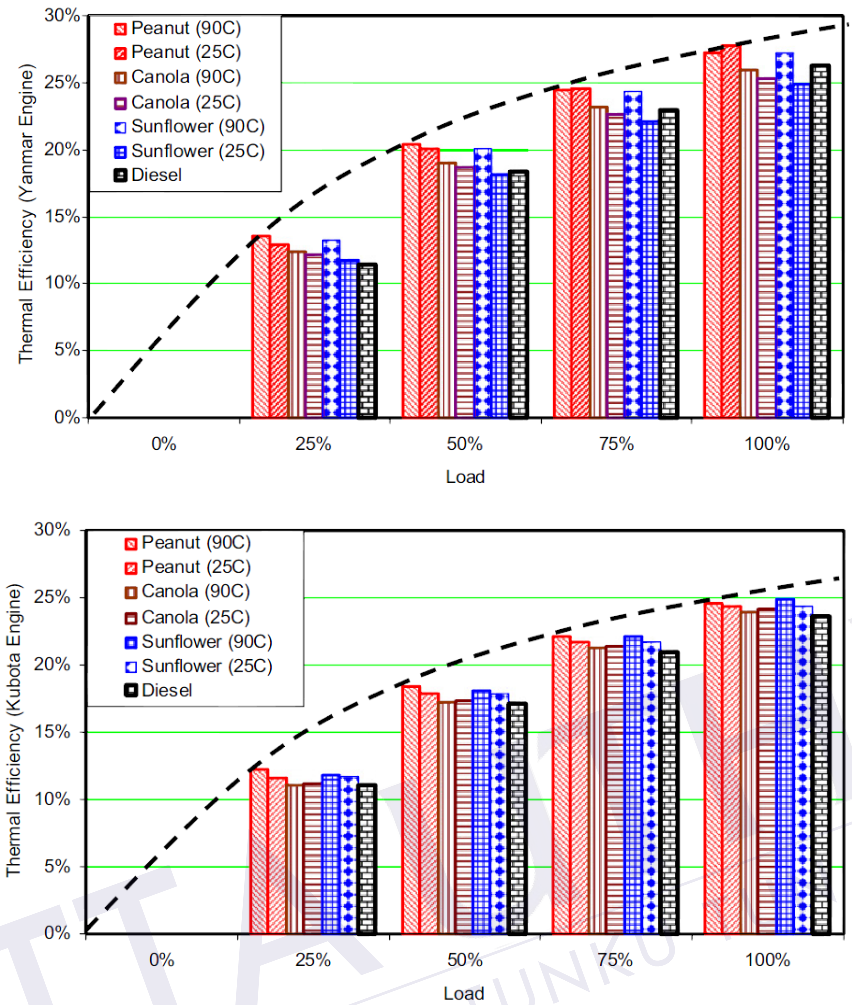

Figure 2.7: Thermal efficiency versus load for preheated peanut, canola and sunflower oils operated on Yanmar and Kubota engines (Yilmaz & Morton, 2011)

Kumar *et al.* (2005) analyzed a four stroke single cylinder compression ignition engine using preheated animal fat. The authors reported that specific fuel consumption was more with neat animal fat at all preheated temperatures tested as compared to diesel fuel as per shows in Figure 2.8. This is due to high viscosity and poor volatility of the animal fat results in poor atomization and mixture formation hence increases the fuel consumption to maintain the power. The potential waste cooking oil biodiesel as an alternative fuel was investigated by Licauco (2009). They tested the fuel on Mazda 4bc2 engine and found that the power produced was lower than diesel fuel due to its lower cetane number and heating value as per shows in Figure 2.9. Meanwhile the BSFC was averagely 19% higher compared to diesel fuel. Lim *et al.* (2002) investigated the use of crude palm oil on Yanmar L60AE-DTM engine and reported that more crude palm oil was consumed to produce the same power. Figure 2.10 shows the BSFC at 400kPa BMEP was about 13% more than diesel fuel and it's was attributed to the lower calorific value of crude palm oil. They also reported that crude palm oil combustion produced higher BTE than diesel fuel combustion.

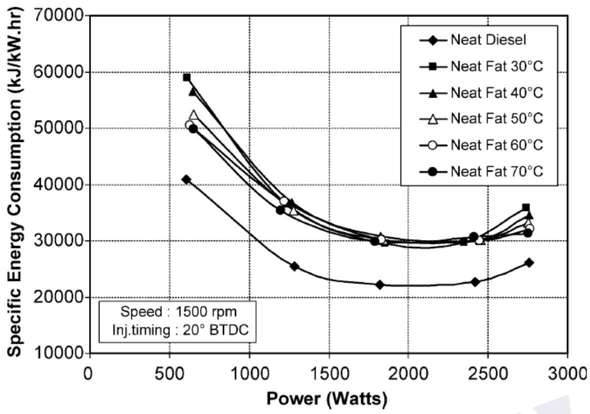

Figure 2.8: Specific fuel consumption versus power of preheated animal fat (Kumar *et al.*, 2005)

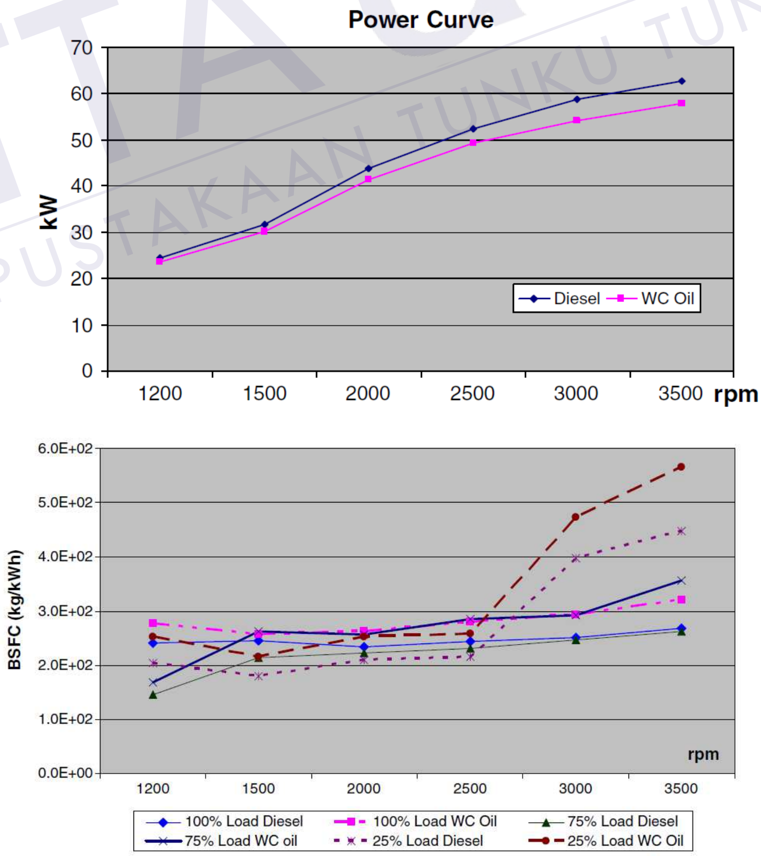

Figure 2.9: Power and BSFC versus rpm of processed waste cooking oil (Licauco, 2009)

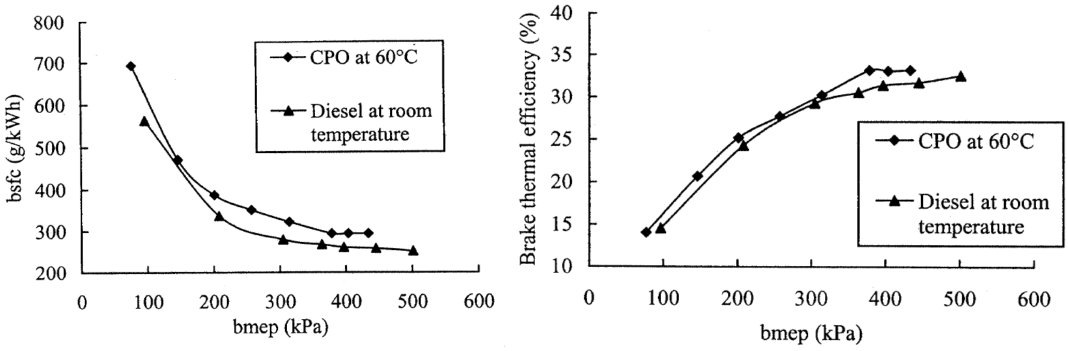

Figure 2.10: BSCF and brake thermal efficiency versus BMEP of crude palm oil (Lim *et al.*, 2002)

2.7 Emissions of preheated biodiesel

Emissions from combustion of biodiesel and its blends generally similar to combustion of diesel fuel such as CO_2, CO, NO_x, smoke, unburned HC and sulphur oxides. A review has been made about preheat biodiesel emissions.

Agrawal & Agrawal (2007) conducted an experiment of preheated Jatropha oil in a direct injection compression ignition engine. They observed that heating the oil result in lower smoke opacity compared to unheated oil but it is still higher than diesel fuel. CO_2 emission shows marginal increase compared to diesel fuel but lower than unheated Jatropha oil. They also observed that CO emission has similar trend to the CO_2 emission. This possibly attributed to poor spray atomization and non-uniform mixture formation. Meanwhile, HC emission was lower at half load and tends to increase at higher load for all fuels. Figure 2.11 illustrates the emissions produced. Hazar & Aydin (2010) reported reduction in smoke and CO emissions with the induction of preheat fuel before combustion. This trend may be due to the higher viscosity and poor volatility which causes poor spray characteristics, forming locally rich air-fuel mixture during combustion process. The NO_x emission increases with the increase in fuel inlet temperature. The increase in NO_x with preheating emission was attributed to the increase in combustion gas temperature. Figure 2.12 show the effects of preheating raw rapeseed oil and its blends on emissions parameters.

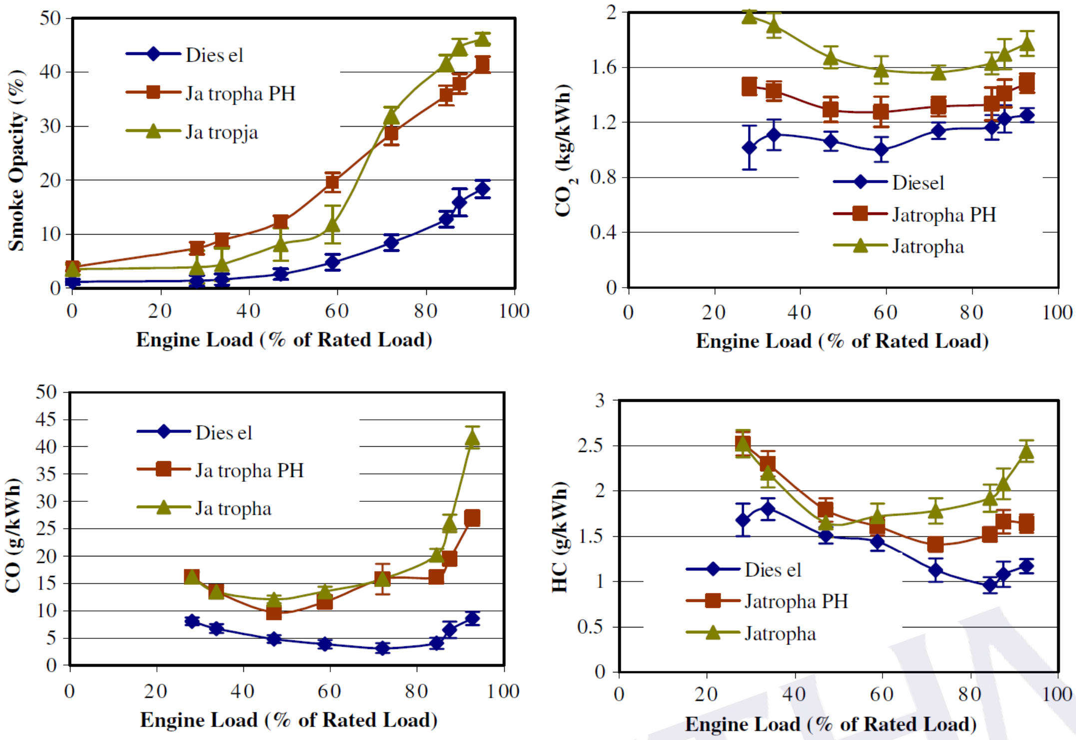

Figure 2.11: Emissions parameters of Jatropha oil (heated and unheated conditions) (Agarwal & Agarwal, 2007)

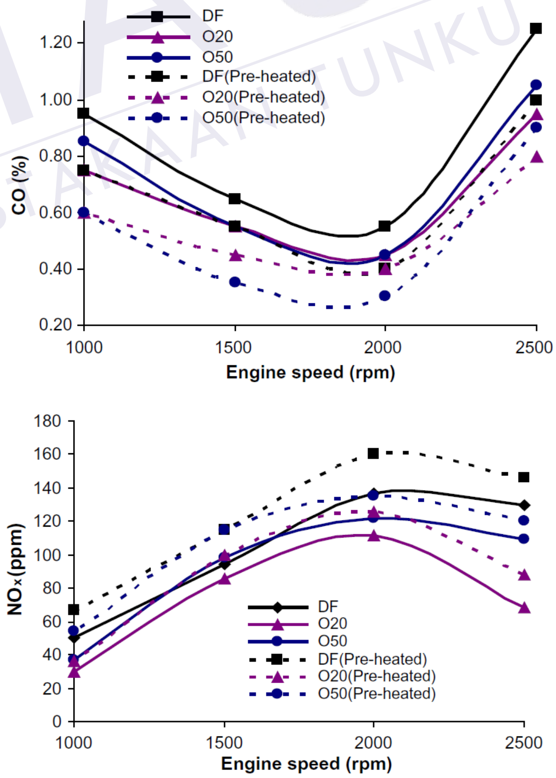

Figure 2.12: Effects of preheating raw rapeseed oil and its blends on emissions parameters (Hazar & Aydin, 2010)

Karabektas *et al.* (2008) observed that CO emissions lower in comparison to diesel fuel while running the diesel engine using cottonseed oil methyl ester. Preheating of biodiesel decreases the viscosity and improves the oxidation of biodiesel in the cylinder. The NO_x emission was higher than diesel fuel and the authors found that the maximum increase was obtained in the case of preheating temperature was 90^{o}C. Pugazhvadivu & Jeyachandran (2005) stated that NO_x emission of waste frying oil was lower compared to diesel fuel and its keep increasing close to diesel fuel with the increase of temperature. The increase in NO_x was due to the increase in the combustion gas temperature with an increase in fuel inlet temperature. The CO and smoke emissions show the same trend where the emissions were higher than that of diesel and the values tend to decrease to diesel fuel emissions when the heating temperature increase. The decrease was due to the improvement in spray characteristics and better air-fuel mixing. The crude palm oil emissions were tested by Bari *et al.* (2002) and observed that the CO and NO were higher than those for diesel fuel by average values of 9.2% and 29.3% respectively, throughout the load range as per depicted in the Figure 2.13.

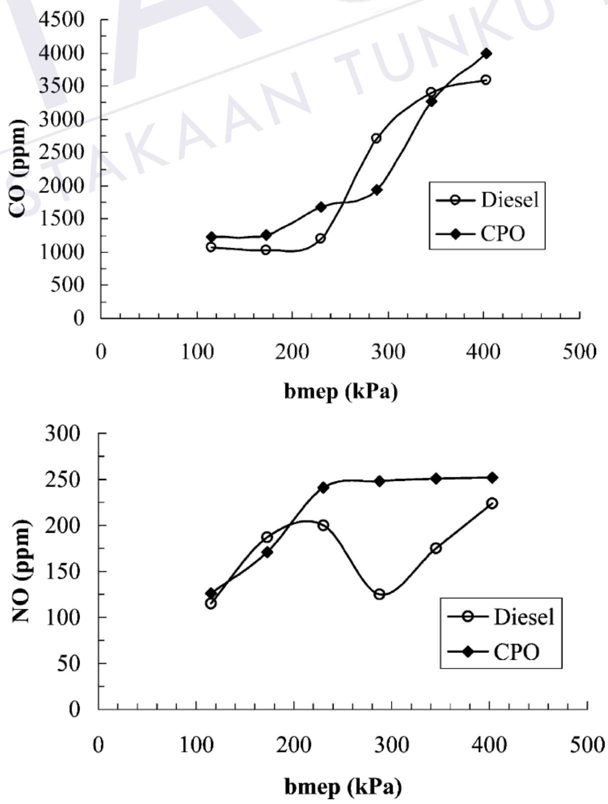

Figure 2.13: CO and NO emissions of preheated crude palm oil (Bari *et al.*, 2002)

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