VOL. 11, NO. 24, DECEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences


www.arpnjournals.com

RESPONSE SURFACE METHODOLOGY OPTIMIZATION OF PALM RUBBER SEED COMBINED OIL BASED BIODIESEL AND IDI DIESEL ENGINE PERFORMANCE AND EMISSION

Ibrahim Khalil Adam[1], A. Rashid A. Aziz[1] and Suzana Yusuf[2]
[1]Centre for Automotive Research and Electric Mobility, Mechanical Engineering Department Universiti Teknologi Petronas, Seri Iskandar, Perak, Malaysia
[2]Center of Biofuel and Biochemical Research, Biomass Processing Laboratory, Chemical Engineering Department, Universiti Teknologi Petronas, Seri Iskandar, Perak, Malaysia
E-Mail: Ibrahim_g02238@utp.edu.my

ABSTRACT

Emission from diesel engine has been considered as major air pollution sources. The blending of feedstocks is motivated by property enhancement and cost reduction. In this study rubber seed/palm oil mixture at equal blend ratio was used to produce biodiesel. Parametric effect on trans esterification were studied using response surface methodology (RSM). Maximum yield was determined. Methyl ester at optimized condition was produced. Thermo physical properties were studied. Methyl ester effect on the emissions and performance of unmodified indirect injection diesel engine (IDI) at full load was examined. The results show that blends torque and brake mean effective pressure (BMEP) were 1.1% and 1% lower. Compared to diesel fuel, power and brake thermal efficiency (BTE) were 1.1% and 1.3 % lower, but brake specific fuel consumption (BSFC) was 1.4% higher. The CO was reduced 2% while CO2, NOx and exhaust temperature increased on averages of 1%, 1.2% and 1.1% respectively.

Keywords: rubber seed oil, palm oil, response surface methodology, performance and emissions.

INTRODUCTION

The use of clean fuel such as biodiesel has both environmental and economic advantages. The environmental advantage is reduced emissions, whereas economic benefit stems from locally availability of raw material and improve energy security. Currently most of biodiesel production comes from edible sources such as soybean, palm and sunflower oils. However due to price fluctuation, land limitation, contrary to the current social movement and energy policies, it's industrial expansion has been limited [1]. Although the biodiesel production from these sources inevitable for their availability and large production levels, reducing their amounts using no edible sources will relieve them for other uses. Blending edible/non-edible oils is a solution that will give big contribution towards the advancement of the industry. In addition, Jatropha-palm oil, Jatropha- soapnut and Mahua-simarouba oil blends had been investigated [2-6] and observed to be a good potential sources for biodiesel production. In Malaysia there are 1,229,940 hectares of rubber plantation according to association of Natural Rubber Producing Countries and the projected annual production estimated to be 1.2 million metric ton per year [7]. The trees yield in an average of 800 seed (1.3kg) twice a year depending on crop density and soil fertility. The kernel has an average oil of 30-40 wt. % and can be used for biodiesel synthesis. The detailed literature of rubber seed oil based biodiesel production process is available in [8-12]. Usta *et al.* [13] tested oil blend of waste sunflower/hazelnut soapstock in indirect injection diesel engine. It is reported that compared to diesel fuel blends torque and power were higher. Optimum blend was 17.5% methyl ester addition to diesel. Emissions of CO, CO_2 and exhaust temperature were higher. NOx was higher at full load and reduced at partial loads. Raheman *et al. [*5] investigated biodiesel effect obtained from mahua-simarouba oil mixture on a single cylinder diesel engine emissions and performance. They reported higher BSFC and NOx. BTE, CO and total hydrocarbon (THC) were lower compared to diesel fuel. Haas *et al.* [14] investigated soybean soap stock biodiesel in a diesel engine. It is observed that CO, THC and particle matter (PM) were reduced. From a literature view, there is a major lack exists regarding the production optimization, engine emissions and performance of oil blends based biodiesel such as rubber seed/palm oil. Therefore, in this paper, rubber seed/palm oil mixture at equal blend ratio was studied. The response surface methodology (RSM), in Design Expert 8.0 software was utilized to investigate parametric effect on the transesterification process. The experimental design used was Central Composition Design (CCD). Methyl ester at optimized condition was produced using two-step (acid esterification and transesterification) process in hydrodynamic cavitation reaction. Thermo physical properties and IDI diesel engine emissions and performance at full load was investigated. To the authors knowledge this paper is pioneering the testing of unmodified indirect diesel engine using biodiesel based oil blend of rubber seed/palm at full load.

MATERIALS AND METHODS

Material such as crude palm oil and rubber seed oil were purchased from Felcra Chemicals (M) and Kinetics chemicals (M) Sdn. Bhd. respectively, while the chemical and reagents were from Sigma Aldrich Malaysia. Diesel fuel was obtained from a local fuel station.

Rubber seed/ palm oils analysis

Rubber seed/Palm oil mixture at equal blend ratio (vol. %) was characterized. The parameters such as acid value, iodine value, free fatty acid percentage, density, viscosity, calorific value, nitrogen and sulphur content were investigated following AOCS method [15]. The results of oil analysis are presented in Table-1.

Table-1. Rubber seed/ palm oil blend analysis.

Properties	Run1	Run2	Average
Acid value (mgKOH/g oil)	32.4	34.5	33.4
Iodine value (mg/I2/g oil)	95.9	94.3	95.1
Free fatty acid (%)	12.3	11.9	12
Density (kg/m3)	914.7	914.6	914.6
Viscosity (cSt)	43.6	44.1	43.8
Calorific value (J/g)	38155	38210	38182
Sulfur (wt %)	0.554	0.552	0.55
Nitrogen (wt %)	0.404	0.42	0.41

Based transesterification study

Transesterification is a chemical conversion in which the triglycerides is converted to fatty acid alkyl ester. Rubber seed/palm oil blend acid value of 33.4 mg KOH/g oil was reduced to 1.42 mg KOH/g oil in acid esterification process. Oil after acid esterification process was used for transesterification process. Three-neck round bottom flask of 250 ml attached with condenser to avoid alcohol losses was used. Input factors and theirs ranges were, (-1) low level, (+1) high level and on the axial direction were (-2) low level and (+2) high level as presented in Table-2. The required temperature, mixing time (mechanical stirrer) and amount of methanol and catalyst (potassium hydroxide) followed the experimental plan as shown in Table-3. After the specified time the reaction process was stopped and the product was left for separation gravitationally. Two layers such as methyl ester upper and glycerol lower were formed after 12 h. The deionized warm water was used to wash the methyl ester to remove impurities. Finally, the produced biodiesel was stored for properties study. Transesterification optimized condition of 97% conversion yield, were reaction temperature and time of 64 °C and 2.5 h, catalyst amount of 1.3 and methanol to oil ratio of 6:1.

Table-2. Process parameter for transesterification.

Process parameters	-2	-1	0	+1	+2
Alcohol to oil molar ratio	4.64	6	8	10	11.36
Catalyst amount (wt. %)	0.66	1	1.5	2	2.3
Reaction temperature (°C)	38	45	55	65	72
Reaction time (hr)	0.32	1	2	3	3.68

Table-3. Transesterification design plan, experimental and predicated response FAME yield.

Exp. run	Alcohol to oil ratio	Catalyst amount (wt. %)	Reaction temperature (°C)	Reaction time (hr)	Response FAME yield	Predicted FAME yield
1	6	1.00	45	1.00	92	90.88
2	8	2.34	55	2.00	71	72.19
3	6	1.00	65	1.00	97	95.37
4	8	1.50	55	2.00	83	84.17
5	10	2.00	45	1.00	85	84.38
6	8	1.50	55	0.32	72	73.39
7	6	2.00	65	3.00	90	88.37
8	8	1.50	55	3.68	80	81.59
9	10	1.00	65	3.00	70	68.37
10	6	2.00	45	3.00	53	51.88
11	11.36	1.50	55	2.00	88	89.91
12	8	1.50	55	2.00	83	84.17
13	10	2.00	65	1.00	84	82.57
14	4.64	1.50	55	2.00	92	93.99
15	10	1.00	45	3.00	79	78.58
16	8	0.66	55	2.00	70	71.59
17	8	1.50	55	2.00	90	84.17
18	8	1.50	38	2.00	77	77.60
19	8	1.50	55	2.00	84	84.17
20	8	1.50	55	2.00	85	84.17
21	8	1.50	72	2.00	87	89.79

Test fuel and properties study

The preparation of fuels and properties study were carried out at Universiti Teknologi Petronas. Three samples such as fossil diesel fuel, B10 (10% biodiesel and 90% diesel, and B20 (20% biodiesel and 80% diesel) vol. % were investigated. The blends were mechanically stirred for 15 minutes at 2500 rpm. The properties of the fuels were studied following ASTM and EN standard method. Anton Paar (model DMA 4500M) was used to measure the density following ASTM D 5002 standard method. Anton Paar, Lovis (model 2000 M/ME) was used to study the viscosity. Cloud point and pour point temperature were obtained by CPP 5G's analyzer based ASTM D 2500 and ASTM D 97 test methods respectively. FPP 5G's and 873-CH-9101 Metrohm analyzer were used to measure the cold filter plugging point and oxidation stability following ASTM D 6371 and EN 14112 standard. Octane number was analyzed using SHATOX SX-100K) with RS-232 interface connector following ASTM D-613 standard method. The surface tension was measured using rame hart model 260. The properties of the methyl ester and blends are presented in Table-4.

Engine testing

Unmodified multi cylinder indirect injection diesel engine, model XLD 418D was used for presence investigation. The experimental setup and engine specification are shown in Figure-1 and Table-5. The engine and the dynamometer were controlled using control panel (ECU) equipped with sensors, logging and data acquisition device. The experiments were started with engine warm up for about 30 minutes using diesel fuel and the test was conducted in a full and partial loads at variable speed of 1000 to 4500 rpm. The engine was flushed with fossil diesel after every fuel change and running for 20 minutes to insure full exhaustion of pervious sample. The experiments were repeated two time to insure stable reading of torque, engine oil and cooling water inlet and outlet temperatures and fuel mass flow. The emissions such as NOx, CO, O_2, exhaust gas temperature and CO_2 were measured using Mur Vario Plus Industrial exhaust gas analyser 944008 model. Exhaust gas analyser was calibrated at each fuel changed. The repeated measured data for each blend were averaged prior used for analysis and discussions.

Table-4. Methyl ester and blends properties.

Property	B0	B10	B20	Diesel
Density (kg/m3) at 25°C	874	829.5	834.9	825
Viscosity at 40°C (mm2/s)	4.8	3.4	3.6	3.21
Calorific value (MJ/kg)	38	42.4	41.9	43.2
Cetane Number	52	47.9	48.3	47
Oxidation stability (h)	8.92	92.4	83.3	103.6
Flash Point (°C)	151	79.8	86.9	72.4
Cloud Point (°C)	5	-13.5	-12.1	-17
Pour point(°C)	-1	-28.1	-24.2	-32
Clod Filter Plugging Point (°C)	0	-	-	-
Surface tension (Nm)	29.3	27.5	27.6	27.1
Carbon (% w/w)	75.4	85.5	84.3	86.6
Hydrogen (% w/w)	11.4	13.07	12.5	13.2
Nitrogen (% w/w)	0.07	0.015	0.02	0.01
Sulfur	0.00	0.144	0.13	0.16
Oxygen (%)	12.8	2.5	3.36	0.0

Table-5. Engine specification.

Engine	Diesel engine
Model	XLD 418D
Type	Four stroke, 44 kW at 4800 rpm
Cylinder number	4 in line OHC, water cooling
Combustion	IDI, natural aspirated
Bore × stroke	82.5×82 mm
Displacement	1753 cc
Compression ratio	21.5:1

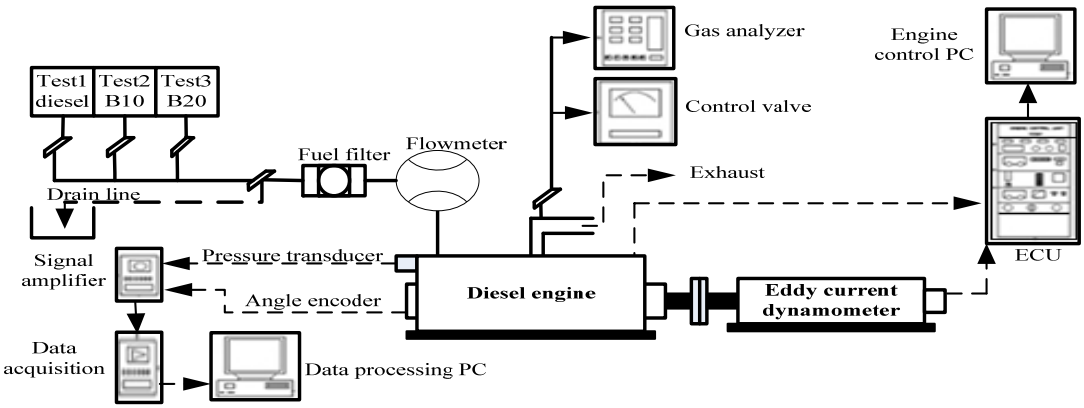


Figure-1. Schematic diagram of engine testing.

RESULTS AND DISCUSSION

Effect of catalyst, oil to alcohol ratio, reaction time and temperature on FAME yield

The parametric effect such as reaction temperature, time, catalyst and oil to alcohol ratio on FAME conversion based transesterification is presented in Figure-2. (a) and (b). It is observed that by increasing alcohol to oil ratio and catalyst the FAME yield decreased. The reason behind is due to saponification reaction resulting in poor product separation and higher glycerol formation. It was observed that the first 25-30 minutes of reaction time was enough to achieve the maximum amount of FAME yield, whereas FAME conversion rate increased as temperature increased and promoted reaction towards product side as presented in Figure-2b.

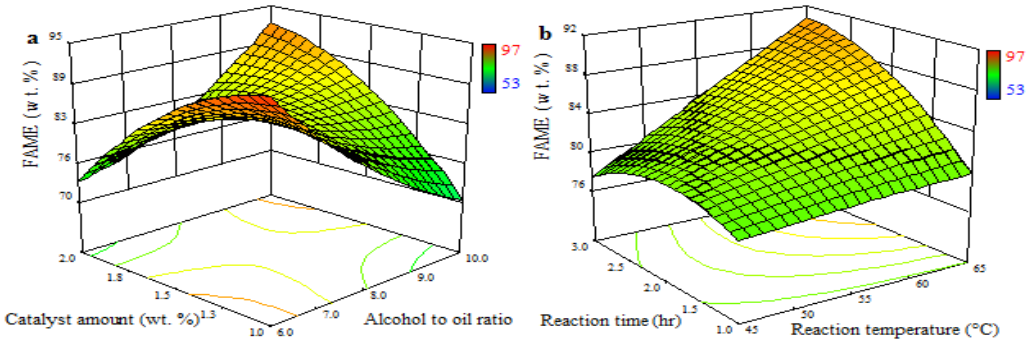


Figure-2. Effect of oil to alcohol ratio and catalyst (a) and reaction temperature and time (b).

ANOVA (Analysis of variance) study based transesterification process

The transesterification output response significance was statistically studied using ANOVA test and presented in Table-6. The model assumed to be significant if P-value is less than 0.05 at 95% confidence level. Data fitting goodness was expressed in terms of determination coefficient (R^2) and goodness of prediction (adjusted-R^2). The influence of oil molar ratio to alcohol, reaction temperature, time and catalyst ratio on FAME conversion was measured using F-value. The higher the F value of the variable, the high its influence as shown in Table 6. In this study B (catalyst) and D (reaction time) are most influencing variables compared to alcohol to oil ratio and reaction temperature as in Figure-3a. Thus the steepest factor is the most influencing compared to others. The trend between the model predicted values versus actual confer the software prediction compared to the experimental, thus the model positively fitted well with the experimental as in Figure-3b. The points are close towards the center linear line. From the regression analysis the response equation was produced in terms of actual and coded terms. The second order coded polynomial equation in terms of most influencing variables on yield is presented in Equation. (1).

$$\text{FAME yiled} = +88.86 - 6.18*B + 5.05*D - 4.61*B^2 - 4.93*D^2 + 9.66*AB - 5.59*AC \quad (1)$$

Table-6. Based transesterification ANOVA analysis.

Source	Sum of squares	DF	Mean square	F-value	P-value
Model	1764.66	14	126.05	9.24	**0.0060**
A (Alcohol /oil ratio)	0.98	1	0.98	0.072	0.7976
B (Catalyst)	216.32	1	216.32	15.86	**0.0073**
C (temperature)	1.38	1	1.38	0.10	0.7615
D (time)	144.50	1	144.50	10.59	**0.0174**
A^2	51.71	1	51.71	3.79	0.0994
B^2	317.57	1	317.57	23.28	**0.0029**
C^2	10.66	1	10.66	0.78	0.4107
D^2	362.92	1	362.92	26.61	**0.0021**
AB	309.25	1	309.25	22.67	**0.0031**
AC	250.32	1	250.32	18.35	**0.0052**
AD	12.80	1	12.80	0.94	0.3701
BC	54.34	1	54.34	3.98	0.0929
BD	0.072	1	0.072	0.01	0.9444
CD	52.79	1	52.79	3.87	0.0967
Residual	81.83	6	13.64		
Lack of Fit	80.33	2	40.17	107.11	< **0.0003**
Pure Error	1.50	4	0.38		
$R^2 = 0.96$	R^2 adj =0.85		Ad.precision =10.93		

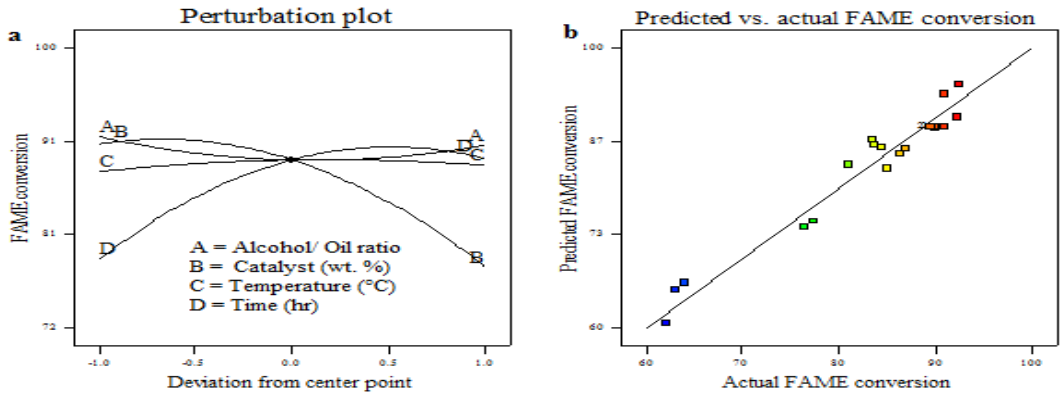
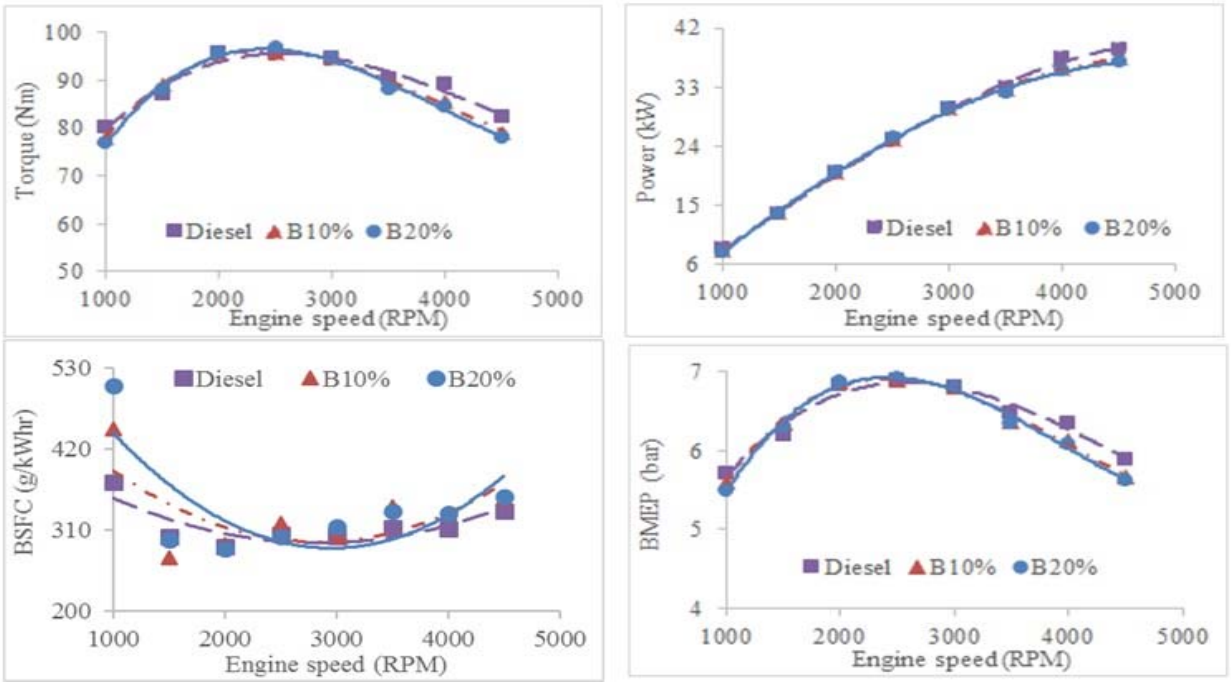


Figure-3. Based transesterification perturbation plot (a) and prediction vs. actual FAME (b).

Engine performance and emissions at full load

The variations of engine emissions and performance and averages of performance and emissions over speed at full load are presented in Figure-4. Compared to diesel fuel, blends torque, power and BMEP were almost similar at 1000 -3000 rpm, whereas the difference was more dominant as speed increased beyond 3000 rpm. The reason behind this is additional lubricity provided by biodiesel blends and oxygen resulted in complete combustion [16]. The reduction at higher speed is because of engine inability to ingest fuel charge of air and increased frication loses. CO emission of the blends compared to diesel fuel was 2% lower. The CO reduction was because of biodiesel chemically bound oxygen that results in increasing the oxidation rate of CO to CO_2. The increases of CO_2 were observed to be 1% compared to diesel fuel. NOx and exhaust temperature of the blends were 1% and 1.3% higher compared to diesel fuel. Due to higher combustion temperature and higher boiling point constituents This probably because of higher combustion temperature and higher boiling point constituents in biodiesel fuel which are continuously burning at late combustion phase [17, 18]. On average over the speeds ranges, blends torque was 1% lower compared to diesel fuel. BSFC of B10 and B20 were found to be higher and obtained a values of 334 and 342 g/kWhr respectively compared to diesel 316 g/kWhr. The average BTE reduction for the blends compared to diesel was 1.1%. CO emission of the blends on average compared to diesel fuel was 1.4% lower, but the CO_2 was 1% higher. Exhaust temperature and NOx of the blends compared to diesel fuel were increased 1.1% and 1% respectively.



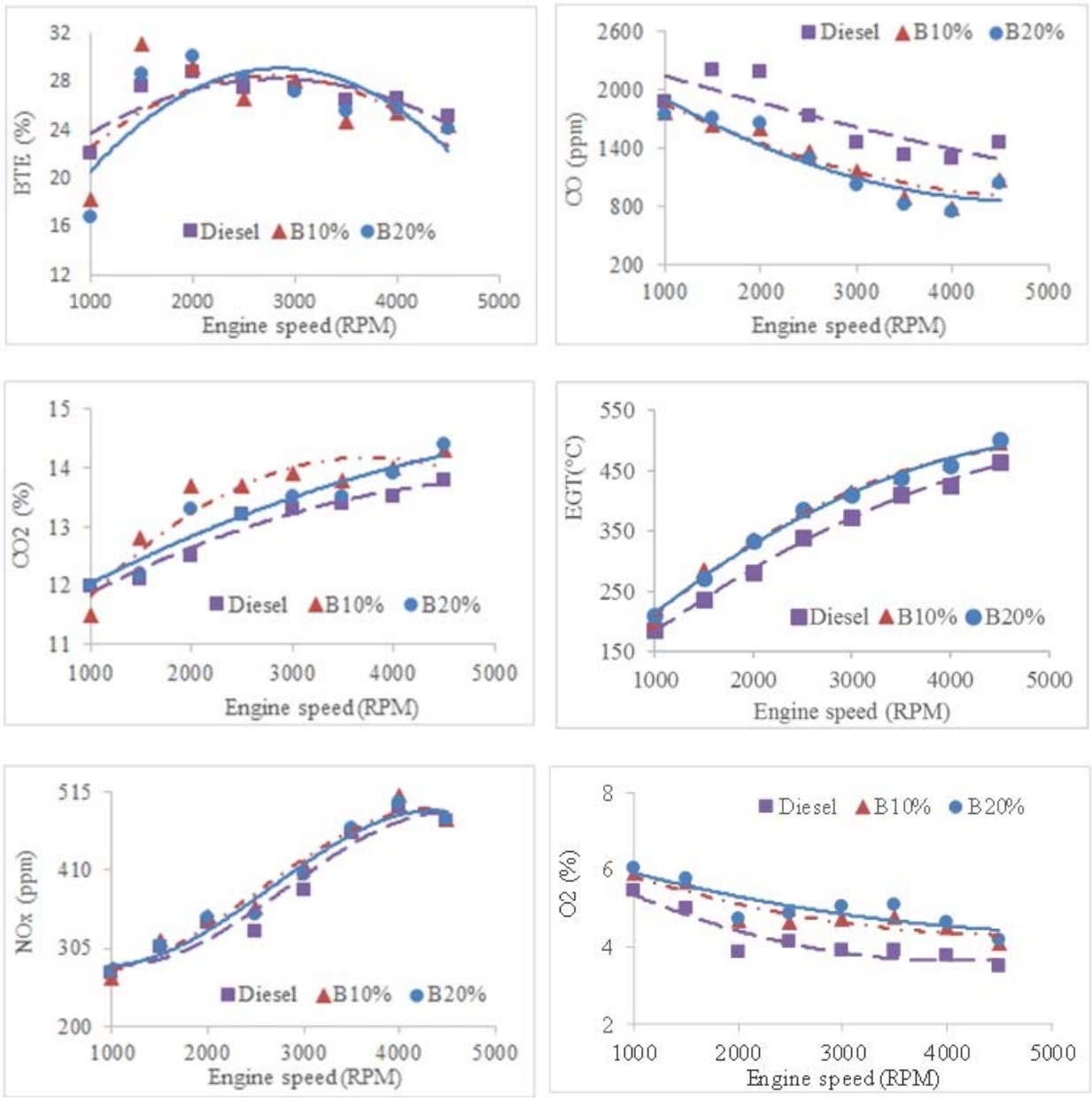


Figure-4. Variation of engine performance and emissions vs. speed at full load.

CONCLUSIONS

In this study parametric effect on rubber seed/palm oil biodiesel synthesis were studied using response surface methodology method. Optimum condition of higher yield was determined and biodiesel at optimized condition was produced. Methyl ester was characterized and found to be in good agreement with ASTM and EN standard. In addition, the effect of obtained methyl ester blended diesel on the emissions and performance of IDI engine were investigated. The following conclusions are obtained.

The catalyst (B) and reaction time (D) were found to be the most influencing variables compared to alcohol to oil ratio (A) and reaction temperature(C).

On an averages blends BSFC was 1.4% higher, while brake thermal efficiency was either similar or less than diesel fuel. CO emission of the blends was up to 1.5% lower but CO_2 was 1% higher compared to diesel fuel. Exhaust temperature and NOx of the blends compared to diesel fuel was 1.1% and 1% higher compared to diesel fuel.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Universiti Teknologi Petronas for the funding in conducting this research work.

REFERENCES

[1] Wendy, N, Pei Qin, Hon Loong, L, Yusup, S 2013.Supply network synthesis on rubber seed oil utilisation as potential biofuel feedstock. Energy 55: 82-88.

[2] Sarin, R, Sharma, M, Sinharay, S, Malhotra, RK 2007.Jatropha – Palm biodiesel blends : An optimum mix for Asia. Fuel 86: 1365-1371.

[3] Amit, S, Arora, R, Singh, NP, Sarin, R, Malhotra, RK, Kundu, K 2009.Effect of blends of Palm-Jatropha-Pongamia biodiesels on cloud point and pour point. Energy 34: 2016-2021.

[4] Amit, S, Arora, R, Singh, NP, Sarin, R, Malhotra, RK 2010.Blends of biodiesels synthesized from non-edible and edible oils: Influence on the OS (oxidation stability). Energy 35(8): 3449-3453.

[5] Jena, RH, Jadav, PC, Snehal, S 2013.Performance of a diesel engine with blends of biodiesel (from a mixture of oils) and high-speed diesel. International Journal of Energy and Environmental Engineering 4(1): 1-1.

[6] Yi, CH, Han, CT, Hong, CJ 2012.An optimum biodiesel combination: Jatropha and soapnut oil biodiesel blends. Fuel 92(1): 377-380.

[7] Eka, HD, Tajul, AY, Wan, N, W. A. 2010.Potential use of Malaysian rubber (Hevea brasiliensis) seed as food, feed and biofue. International Food Research Journal 17: 527-534.

[8] Ramadhas, AS, Jayaraj, S, Muraleedharan, C 2005.Biodiesel production from high FFA rubber seed oil. Fuel 84: 335-340.

[9] Yang, R, Su, M, Zhang, J, Jin, F, Zha, C,Li, M *et al*. 2011.Biodiesel production from rubber seed oil using poly (sodium acrylate) supporting NaOH as a water-resistant catalyst. Bioresource Technology 102: 2665-2671.

[10] Ahmad, J, Yusup, S,Bokhari, A, Mohammad Kamil, R 2014.Study of fuel properties of rubber seed oil based biodiesel. Energy Conversion and Management 78: 266–275.

[11] Morshed, M, Ferdous, K, Khan R., M, Mazumder, MSI, Islam, MA, Uddin, MT 2011.Rubber seed oil as a potential source for biodiesel production in Bangladesh. Fuel 90: 2981–2986.

[12] Ramadhas, AS, Jayaraj, S, Muraleedharan, C 2005.Characterization and effect of using rubber seed oil as fuel in the compression ignition engines. Renewable Energy 30: 795-803.

[13] Usta, N, Ozturk, E, Can, O, Conkur, ES, Nas, S, Con, AH *et al*. 2005.Combustion of biodiesel fuel produced from hazelnut soapstock/waste sunflower oil mixture in a Diesel engine. Energy Conversion and Management 46(5): 741-755.

[14] Haas, MJ, Scott, KM, Alleman, T, L., McCormick, RL 2001.Engine Performance of Biodiesel Fuel Prepared from Soybean Soapstock: A High Quality Renewable Fuel Produced from a Waste Feedstock. Energy & Fuels 15: 1207-1212.

[15] Firestone, D 1998.Offical methods and recommended practices of the AOCS. American Oil Chemists Society

[16] M.A. Kalam, M. Husnawan, Masjuki, HH 2003.Exhaust emission and combustion evaluation of coconut oil-powered indirect injection diesel engine. Renewable Energy 28: 2405–2415.

[17] Muralidharan, K, Vasudevan, D 2011.Performance , emission and combustion characteristics of a variable compression ratio engine using methyl esters of waste cooking oil and diesel blends. Applied Energy 88(11): 3959-3968.

[18] Ashrafur, R, S. M. ,Hassan, M, H. ,Kalam, MA, Abedin, MJ, Sanjid, A, Sajjad, H 2013.Production of palm and Calophyllum inophyllum based biodiesel and investigation of blend performance and exhaust emission in an unmodified diesel engine at high idling conditions. Energy Conversion and Management 76: 362-367.