International Journal of Electrical and Electronic Engineering & Telecommunications Vol. 8, No. 2, March 2019

Performance Analysis of a Diesel-Engine Generator Using Ethyl Ester Synthesized from Anhydrous Ethanol and NaOH

Mattana Santasnachok[1], Ekkachai Sutheerasak[2], Wirogana Ruengphrathuengsuka[1], and Charoen Chinwanitcharoen[1]
[1] Department of Chemical Engineering, Burapha University, Chonburi, Thailand
[2] Department of Mechanical Engineering, Burapha University, Chonburi, Thailand
Email: {mattana; ekkachai; wirogana}@eng.buu.ac.th; charoen@buu.ac.th

Abstract—**Energy is essential for the economic growth in developing countries. The demand for domestic energy consumption in Thailand derives the use of ethyl ester as an alternative fuel because it is synthesized from the transesterification of agricultural products. The main objectives of this research is to investigate the fuel properties and the small diesel-engine performance using the produced ethyl ester from palm oil. The small diesel-engine was a single-cylinder, four-stroke, and direct-injection system, connected with 2.5 kW AC generator. The ethyl ester was produced from palm oil reacted with anhydrous ethanol (99.9%), and NaOH catalyst. The produced ethyl ester had 99.95% yield, 12°C cloud point, 174.3°C flash point, 873 kg/m^3 fuel density, 4.75 mm^2/sec fuel viscosity, and 39.87 MJ/kg fuel heating value. Result of the fuel injection pressure test showed that it is increased with increasing ethyl ester in blending with diesel oil. For the engine performance testing at various speeds and full electrical load showed that the use of diesel oil mixed with ethyl ester from 10 to 50% and pure ethyl ester led to the decrease of electrical power and thermal efficiency and the increase of specific fuel consumption and exhaust gas temperature.**

Index Terms—**ethyl ester, diesel oil, fuel properties, engine performance**

I. INTRODUCTION

Ester is known as one of alternative fuels made from vegetable oil, alcohol (ethanol or methanol) through transesterification reaction using acid or alkali. Ester production is constantly researched especially ester production from methanol because methanol is readily available material and such ester can be easily purified. However, methanol is produced from the petroleum refining and expensive. On the other hand, ethanol is derived from the fermentation of agricultural crops and less toxic than methanol. Therefore, the production of ester from ethanol is interesting nowadays. In Thailand, ester is mainly synthesized from palm oil because the tree is a year-round economic crop and the amount of oil per production area is more than other plants such as soybeans, sunflower, rapeseed, etc. [1]-[3].

References [4] and [5] synthesized palm oil ethyl ester (POEE) from water-free ethanol and different ratios of ethanol to palm oil with potassium hydroxide (KOH) catalyst and obtained 95.8 to 96.5% POEE while [6] found that KCH_3O catalyst was better than NaOH. Reference [7] produced POEE and compared the performance with diesel oil in the direct injection diesel engine between 1,300-2,500 rpm. Such POEE showed 9.38% lower engine power due to 10.72% lower heating value, 3.52% higher density, and higher viscosity than the diesel fuel. Researchers [8]-[10] examined the performance and emissions of direct injection diesel engines, of particular was one and four cylinders, using ethyl ester synthesized from water-free ethanol fractions on non-edible vegetable oil. The results showed that the Brake specific fuel consumption (BSFC) value was higher and thermal efficiency was lower than diesel while emissions of carbon monoxide (CO), hydrocarbon (HC), and black smoke decreased but the amount of carbon dioxide (CO_2) and nitric oxide (NO) increased to compare with diesel fuel. Recently, researchers in Thailand [11], [12] investigated the POEE properties and the performance and emission characteristics of a direct injection diesel engine, four-cylinder and four-stroke, connected with the manual gear box, 5 gears, into a pick-up automobile. The results indicated that such POEE had 99.87% ethyl ester, 36.87 MJ/kg heating valve and 870 kg/m^3 density. The performance test at engine speed 2,500 rpm and constant load showed the decrease of brake power 17.63%, brake thermal efficiency 28.38% and the increase of BSFC 60.37%, exhaust gas temperature 25.78 % compared to diesel fuel. With respect to emissions, black smoke reduction 35.29% but NO increase 44.28% were observed with the use of POEE.

The synthesis of ethyl ester from palm oil for diesel-engines has been studied by several researches. Thus, this research aims to analyze the POEE properties and the performance of a diesel-engine generator, which is the single-cylinder, four-stroke, direct-injection diesel-engine

---

Manuscript received March 5, 2018; revised September 13, 2018; accepted September 13, 2018.

Corresponding author: M. Santasnachok (email: mattana@eng.buu.ac.th)

doi: 10.18178/ijeetc.8.2.108-112

connected with 2.5 kW_e AC generator using a 99.9% non-water-soluble ethyl ester extracted from palm oil and ethanol with sodium hydroxide (NaOH) catalyst.

II. METHODOLOGY

A. Ester Preparation

The POEE was produced by transesterification process using oleic palm oil which consisted of free fatty acid, palmitic acid 40.06%, stearic acid 4.3%, oleic acid 40.72% and linoleic acid 12.08% as the following steps. 1) The oleic palm oil was heated up at 120°C for 30 min to remove free fatty acid and moisture. 2) The mixture of 7 g of NaOH in 217.38 g of water-free ethanol (99.9%) was reacted with the treated palm oil at the mass ratio of 6:1 [1], [5] in a rounded glass agitator at 65°C under 500 rpm for at least 60 min. 3) The ethyl ester (EE) and glycerin would be separated by gravity using a separation funnel as shown in Fig. 1. The separated EE would be more than 95% if the separation took for 3-4 h. 4) The separated EE was purified by adding 10% HCl to remove the dissolved glycerin and, then, was washing by clean water for at least four times to ensure that all fatty acid are removed. 5) The EE was heated up at 120°C for 20 min. to remove water. Hence, the POEE was prepared.


(a) Reaction process (b) Separation between EE and glycerin

Fig. 1. The POEE synthesis.

TABLE I: FUEL PROPERTIES

Items	Physical properties					
	Pour point (°C)	Cloud point (°C)	Flash point (°C)	Fuel density (kg/m^3)	Fuel viscosity (mm^2/sec)	Heating value (MJ/kg)
ASTM	D97	D2500	D93	D1298	D445	D240
D100	-8.0	7.0	45.0	821	2.90	44.36
B10	-0.5	8.0	81.0	839	4.03	42.86
B20	1.0	8.5	84.3	842	4.09	42.40
B30	1.3	9.0	89.2	843	4.17	41.53
B40	1.7	9.5	97.3	847	4.24	40.31
B50	2.2	10.0	110.2	849	4.39	40.90
B100	4.0	12.0	174.3	873	4.75	39.87

The properties of POEE were measured at the biofuel and alternative fuel laboratory, Chemical Engineering Dept., Faculty of Engineering, Burapha University by using Gas Chromatography (GC) to determined EE amount. With 8 GC tests, the POEE yielded the EE between 97.69 to 99.95% which was a good result compared to other researches [1], [5] and was suitable to mixed with diesel fuel for engine performance study [8], [9]. The tested fuels would be diesel fuel (D100), pure POEE (B100), and the blends of B100 with D100 at several volume ratios B100:D100 from 10 to 50% (B10 to B50). Table I showed pertinent tested fuel physics properties measured under various ASTM procedures.

We found that pour point, cloud point and flash point were soared to 4°C, 12°C, and 174.3°C, respectively. Moreover, such blended fuels and B100 compared with diesel fuel indicated that cloud point increased from 1 to 5°C, flash point increased from 36 to 129.3°C, fuel density increased from 2.19 to 6.33%, kinematic viscosity increased from 1.13 to 1.85 mm^2/sec, heating value decreased from 3.38 to 10.12%, respectively, which were consistent with the results reported in [1], [5], and [7].

B. Fuel-injection Pressure Testing

After the property measurements, the fuel-injection pressure of all tested fuels were determined at the Automotive biofuels and combustion engineering research (ABCER) laboratory, Mechanical Engineering Dept., Burapha University as shown in Fig. 2.

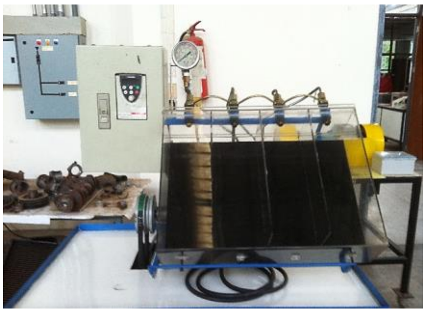

Fig. 2. The manually fuel-injection system model.

It was a manual fuel-injection system connected with the adjustable speed AC motor controlled by an inverter. During the test, the adjustable speed was kept constant at 1,200 rpm while the fuel-injection pressure was recorded from a pressure gage connected with the first injector (on the left hand side). Results of fuel-injection pressures in Fig. 3 showed that B10 to B50 increased the fuel-injection pressure from 0.95 to 8.98% and up to 15.37% for B100. Since density (compressibility) of B10 to B50 and B100 were higher (lower) than that of diesel fuel, therefore, B10 to B50 and B100 led to advanced injection timing and the change of performance and emission characteristics [13].

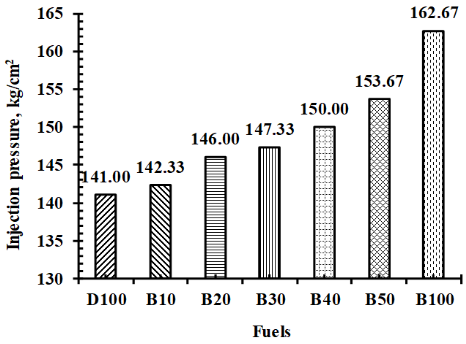

Fig. 3. Fuel-injection pressure of the fuels.

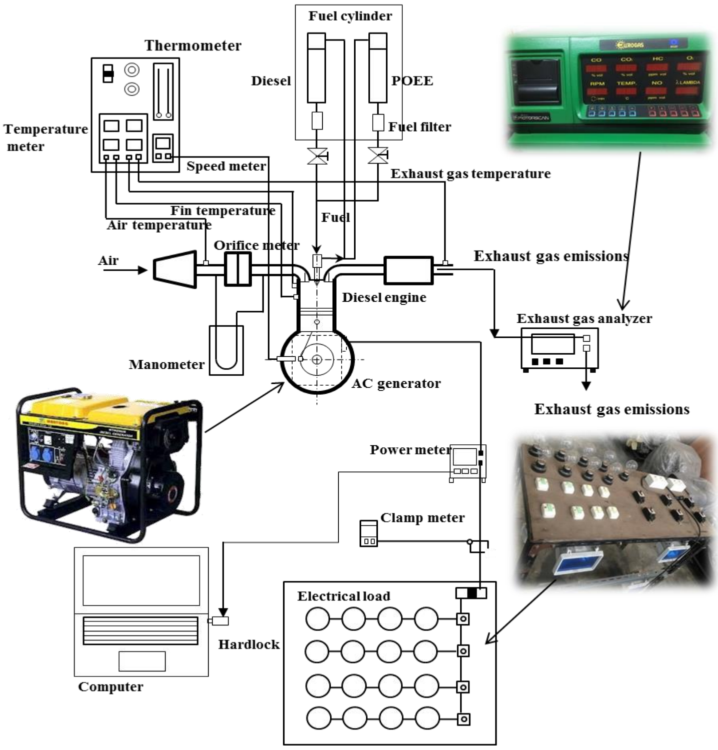

Fig. 4. Schematic of experimental setup.

TABLE II. ENGINE SPECIFICATION

Item	Description
Model	170FS(E)
Engine type	air-cooled, direct injection
Number of cylinder (cyl)	1
Displacement (L)	0.211
Bore x Stroke (mm)	70x55
Compression ratio	20:01
Normal power (kW)/speed (rpm)	3.8 / 3000
Maximum power (kW)/speed (rpm)	4.2 / 3600

C. Experimental Setup of Diesel-engine Testing

The performance and emission characteristics of the studied fuels were investigated at the ABCER laboratory according to the schematic in Fig. 4.

Table II presented the specification of diesel-engine used in this experiment. The AC generator 2.5±5 kW_e was directly coupled into the engine using electric lamps to increase the electrical load. The output electrical power from an electrical load was analyzed using a power meter richtmass RP-96EN through the clamp IMARI-CT100/1A. The data was recorded from richtmass RS485 using USB data converter and hardlock for RP series connected with a computer. The calibration was made for power-meter parameters with a clamp meter. A fuel cylinder was used to record the fuel flow rate for calculating the fuel consumption rate later on.

D. Experimental Procedure

In reference to the standard of engine testing for performance and emission characteristics of diesel-engine, the engine was firstly warmed up about 15-20 min using D100, the room and coolant temperature was set at 30±2 °C and 85±5 °C, respectively, and all experiments were recorded in the period of 50 to 100 hours [14]. During constant engine operation, engine speed was adjusted from 1,800 to 2,800±50 rpm with full electrical load. Various tested fuels were used (B10 to B50 and B100) using the condition of engine testing similar to D100. All parameters from engine testing were calculated to analyze the results of the tested fuels on the engine performance.

III. RESULTS AND DISCUSSION

Results from the diesel-engine testing by using B100 and B10 to B50 in comparison with D100 were described below.

A. Electrical Power

The output electrical power (Pele) using B10 to B50 and B100 compared with D100 by adjusting the engine speed from 1,800 to 2,800±50 rpm at full load were shown in Fig. 5 on left axis. Electrical power increased in overall with the increase in engine speed but the use of B10 to B50 and B100 resulted in the lower of electrical power.

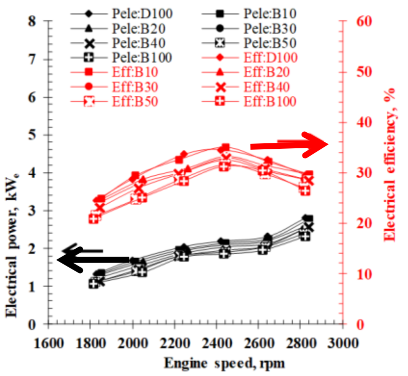

Fig. 5. Electrical power and efficiency with engine speeds.

Considering the engine speed at 2,400 rpm, the use of B10 to B50 and B100 resulted in the decrease of electrical power from 2.04 to 13.09% and 15.54% in comparison with D100, respectively. These results were consistent with the previous research work [9] because the heating value was lower than D100.

B. Electrical Efficiency

Fig. 5 on right axis showed the variation between the electrical efficiency (Eff) with engine speeds. In overall, the efficiency increased with the increase of engine speed, reached the peak at 2,400 rpm, and dropped at furthermore speeds. The electrical efficiency using B10 to B50 and B100 also decreased in line with the overall trend and the decrease was even more profound with the higher ethyl ester content.

At the peak electrical efficiency (2,400 rpm), B10 to B50 and B100 produced 2.94 to 14.88% and 15.89% lower electrical efficiency compared to D100, respectively. These results were consistent with previous works [9, 15] since ethyl ester had higher density and lower heating value than D100. In addition, ethyl ester molecules had more oxygen that enhances the combustion reaction so that the start of combustion was happened slightly earlier to reduce the ignition delay period. Further to this, the work in expansion stroke also decreased that led to the reduction of work net into a cylinder [11], [12].

C. Specific Fuel Consumption (SFC)

Left axis on Fig. 6 showed the variation between SFC with engine speeds that SFC decreased with the increase of engine speed. The SFC using B10 to B50 and B100 also decreased in line with the overall trend but the higher ethyl ester composition gave the higher SFC.

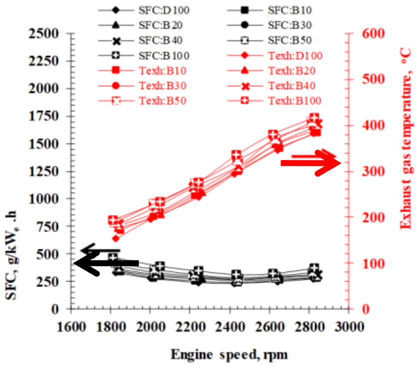

Fig. 6. SFC and exhaust gas temperature with engine speeds.

Considering at 2,400 rpm, the use of B10 to B50 resulted in the increase of SFC from 2.09 to 20.54% while B100 resulted in the increase of SFC 33.30% in comparison with D100 respectively. These results are consistent with the previous research works [8-10] that led to the increase of fuel consumption rate.

D. Exhaust Gas Temperature

Fig. 6 on right axis showed the variation between exhaust gas temperatures with engine speeds. Exhaust gas temperature increased with the increase of engine speed. The exhaust gas temperature using B10 to B50 and B100 also increased in line with the overall trend and the increase was even more profound with the higher ethyl ester content. Considering at 2,400 rpm, the use of B10 to B50 and B100 resulted in the increase of exhaust gas temperature from 4.93 to 19.06% and 14.36% in comparison with D100 respectively. These results were consistent with ref. [15] that led to continuous burning in the exhaust stroke.

IV. CONCLUSIONS

The performance, combustion and emission characteristics of palm oil ethyl ester have been experimentally investigated using a single cylinder, small diesel-engine. The effect of B100 blend ratio and engine speed on the engine performance and emissions are investigated. The following major conclusions can be drawn. 1) B100 has ethyl ester from 97.69 to 99.95% and the value of pour point, cloud point, flash point, density, and viscosity are higher than those of D100; except the heating value which is lower. 2) The more fractions of ethyl ester in the blended fuel is not only shorten the ignition delay period, but also increased fuel-injection pressure, specific fuel consumption, and exhaust gas temperature. 3) The blended fuel with higher ethyl ester content, also, leads to the decrease of electrical power and thermal efficiency.

This investigation generates more several interested research activities. More physical properties of ethyl ester related to the combustion such as distillation temperature, cetane number, surface tension, etc. The comparison of engine performance and emission characteristics between palm oil ethyl ester and palm oil methyl ester as well as the engine wear. The ultimate challenge is to determine the feasible solution of ethyl ester utilization that proves economically in the current circumstances and conserves the environment.

ACKNOWLEDGMENT

The authors wish to thank A. Intayoong, B. Mahaman and C. Punsri for collected experimental data. The financial support from the Faculty of Engineering, Burapha University, Thailand (Grant No. 10/2551, 6/2559 and 036/2561) is gratefully acknowledged.

REFERENCES

[1] N. Patchana and M. Santikunaporn, "Biodiesel production by transesterification of palm oil with ethanol," presented at the 1st Confer. Grad. Stu. Net. Thai, Thailand, 2012.

[2] G. Anastopoulos, Y. Zannikou, S. Stournas, and S. Kalligeros, "Transesterification of vegetable oils with ethanol and characterization of the key fuel properties of ethyl esters," *Energy*, vol. 2, pp. 362-376, June 2009.

[3] A. Demirbas, "Comparison of transesterification methods for production of biodiesel from vegetable oil and fat," *Ener. Con. Manag.*, vol. 49, pp. 125-130, June 2007.

[4] O. J. Alamu, M. A. Waheed, and S. O. Jekayinfa, "Effect of ethanol-palm kernel oil ratio on alkalicatalyzed biodiesel yield," *Fuel*, vol. 87, pp. 1529-1533, Sept. 2007.

[5] K. Noipin and S. Kumar, "Optimization of ethyl ester production from palm oil," *Petroleum and Coal*, vol. 56, no. 3, pp. 249-258, Jan. 2014.

[6] G. Mendow, N. S. Veizaga, B. S. Sanchez, and C. A. Querini, “Biodiesel production by two-stage transesterification with ethanol,” *Bio. Tech.*, vol. 102, pp. 10407-10413, Aug. 2011.

[7] O. J. Alamu, E. A. Adeleke, N. O. Adekunle, and S. O. Ismaila, “Power and torque characteristics of diesel-engine fuelled by palm-kernel oil biodiesel,” *Leo. Jour. Sci.*, vol. 14, pp. 66-73, June 2009.

[8] P. Verma and M. P. Sharma, “Performance and emission characteristics of biodiesel oil diesel-engines,” *Inter. Jour. Renew. Ener. Res.*, vol. 5, no. 1, pp. 245-250, Feb. 2015.

[9] B. Baiju, M. K. Naik, and L. M. Das, “A comparative evaluation of compression ignition engine characteristics using methyl and ethyl esters of karanja oil,” *Renew. Ener.*, vol. 34, pp. 1616-1621, Dec. 2008.

[10] R. Kumar, A. K. Dixit, and R. K. Sharma, “Properties and use of jatropha curcas ethyl ester and diesel oil blends in variable compression ignition engine,” *Jour. Sci. Indus. Res.*, vol. 74, pp. 343-347, June 2015.

[11] M. Santasnachok, E. Sutheerasak, and C. Chinwanitcharoen, “The use of bio-diesel oil produced from anhydrous ethanol in an automobile,” presents at the 5th Asi. Confer. Inno. Ener. Envir. Chem./Eng., Yokohama, Japan, 2016.

[12] E. Sutheerasak and C. Chinwanitcharoen, “Experimental investigations of a diesel engine fuel with ethyl ester from anhydrous ethanol and KCH_3O,” presented at the 1st Maejo. Eng. Inter. Confer. Renew. Ener., Thailand, 2017.

[13] S. Chockalingam and S. S. Chowdry, “Experimental investigation of cardanol ethyl ester as an alternative fuel for diesel engine,” *Jour. Chem. Pharma. Sci.*, vol. 10, no. 2, pp. 212-216, Feb. 2017.

[14] A. J. Martyr and M. A. Plint, *A Textbook of Engine Testing Theory and Practice*, Butterworth-Heinemann: Oxford, 2007, pp. 180-182.

[15] H. Akay and H. Aydoğan, “The effects of camelina ethyl ester on the performance of diesel engine and combustion characteristics,” *Inter. Jour. Auto. Engin. Techn.*, vol. 6, no. 2, pp. 95-103, August 2017.

M. Santasnachok graduated in Chemical Engineering from Burapha University in 2007, Master of Science in Chemical Engineering from De La Sale University in 2009, and Doctoral Engineering from Tokyo Institute of Technology in 2015. She has years of research and teaching experiences at Chemical Engineering Department, Faculty of Engineering at Burapha University in particular fields of environmental catalysis and utilization of waste materials.

E. Sutheerasak is an Assistant Professor of Mechanical Engineering Department, Faculty of Engineering at Burapha University. He studies the researches about the use of ethanol, biodiesel and biomass for internal combustion engines besides teaching experience of more than 16 years at undergraduate level. Sutheerasak has large number of research papers in journals and conference proceedings to his credit. His areas of interest include for internal combustion engine characteristics, such as performance, combustion and emissions, renewable energies and gasifiers. He has been undertaking various administrative work of the college at different positions since year 2002. He is also member and life member of the Institution of Engineers (Thailand) and Thai Society of Mechanical Engineers, respectively.

W. Ruengphrathuengsuka received his Ph.D. (Chemical Engineering) from Texas A&M University, USA, since 1992. He is an Assistant Professor of Chemical Engineering Department, Faculty of Engineering, Burapha University, Thailand. His current research interests are in the areas of multi-phase equilibrium and transport in associated with interfacial science and renewable or alternative energy materials. He is a senior member of the Institution of Engineers (Thailand), an associated member of the council of Engineers (Thailand) and a life-time member of the Thai Institute of Chemical Engineering and Applied Chemistry.

C. Chinwanitcharoen received his B.S. in Industrial Chemistry from Srinakharinwirot University (Bangkok, Thailand) in 1996 and his Ph.D. from Kanazawa University, Japan, in 2005 under the supervision of Prof. Toshiro Yamada, working on eco-based polyurethane shape memory polymer. He is now a lecturer at Faculty of Engineering Burapha University in Chonburi, Thailand. He has honorably received “King Bhumibol” Scholarship from H.R.H. Princess Maha Chakri Sirindhorn. He was awarded the academic outstanding from “Prof. Tab Nilanithi Foundation” as the best graduate in industrial chemistry of this year. He also received best poster presentation award and outstanding paper from Japan Society of Polymer Processing and Asian Pacific Confederation of Chemical Engineering, respectively. His current research interests are in field of oleochemistry, biodiesel, and waterborne polyurethane dispersions.