PERFORMANCE TEST OF *CALOPHYLLUM INOPHYLLUM* BIODIESEL ON A SMALL MONO-CYLINDER 5 kVA DIESEL GENERATOR

PENGUJIAN KINERJA BIODIESEL DARI CALOPHYLLUM INOPHYLLUM PADA MESIN DIESEL GENERATOR MONO-SILINDER 5 KVA

Riesta Anggarani, Cahyo S. Wibowo, and **Maymuchar**
"LEMIGAS" R & D Centre for Oil and Gas Technology
Jl. Ciledug Raya, Kav. 109, Cipulir, Kebayoran Lama, P.O. Box 1089/JKT, Jakarta Selatan 12230 INDONESIA
Tromol Pos: 6022/KBYB-Jakarta 12120, Telephone: 62-21-7394422, Faxsimile: 62-21-7246150
E-mail: riesta@lemigas.esdm.go.id, E-mail: cahyow@lemigas.esdm.go.id, E-mail: maymucharm@lemigas.esdm.go.id

First Registered on June 12nd 2013; Received after Corection on July 1st 2013
Publication Approval on : August 31st 2013

ABSTRAK

Kebutuhan bahan bakar diesel untuk masyarakat di daerah pedesaan pada saat ini semakin meningkat. Belum meratanya jangkauan jaringan listrik dan kelangkaan bahan bakar diesel mendorong masyarakat untuk menemukan sumber energi alternatif. Salah satu sumber energi alternatif yang berpotensi adalah *Calophyllum inophyllum* atau tanaman nyamplung, yang tumbuh di daerah dataran rendah dan pesisir pantai. Penelitian yang kami lakukan menggunakan biodiesel yang diperoleh dari minyak nyamplung sebagai bahan bakar generator diesel berkapasitas 5 kVA, dalam bentuk biodiesel murni, campuran 50% minyak diesel (solar) – biodiesel nyamplung, serta minyak solar sebagai bahan bakar acuan. Uji kinerja menggunakan generator diesel dilakukan untuk memperoleh data waktu *start* dingin dan *start* panas, konsumsi bahan bakar, dan emisi gas buang. Hasil pengujian memperlihatkan kenaikan waktu *start* dingin dan *start* panas pada bahan bakar biodiesel nyamplung dibanding dengan bahan bakar acuan. Konsumsi bahan bakar campuran 50% solar – biodiesel nyamplung meningkat sebesar 10.8% dan bahan bakar biodiesel nyamplung 100% meningkat sebesar 16.8%. Analisis emisi gas buang memperlihatkan penurunan emisi gas CO_2 pada bahan bakar biodiesel nyamplung dan campurannya, sementara emisi gas CO dan HC mengalami peningkatan. Emisi gas NO_x dan opasitas gas buang meningkat pada penggunaan biodiesel nyamplung dan campurannya.

Kata kunci: Nyamplung (*Calophyllum inophyllum*), biodiesel, uji kinerja, konsumsi bahan bakar, uji emisi.

ABSTRACT

Demand of diesel fuel for villagers in rural area of Indonesia is getting higher recently. Electricity and diesel fuel shortage are forcing them to find alternative energy sources for their activities. One of the promising energy sources is Calophyllum inophyllum, which commonly grow in low-land and coastal region. In present work, methyl ester obtained from Calophyllum inophyllum were used on a 5 kVA diesel generator, pure and in 50% blend with commercial diesel fuel which also used pure as reference. A performance test cycle for each fuel was conducted with the aim of taking data of cold and warm start up time, fuel consumption, and exhaust gas emission. In the analysis of cold and warm start up time test result, it revealed that 50% blended of diesel fuel and Calophyllum inophyllum increases both cold and warm start up time when compared to pure diesel fuel and the time got higher for pure Calophyllum inophyllum biodiesel. In the result of fuel consumption, 50% blended fuel increases fuel consumption for 10.8% whereas pure biodiesel increases 16.8% fuel consumption. Analysis on the exhaust gas emission resulted that the use of Calophyllum inophyllum biodiesel and its blend decrease the CO_2 *emission while CO and HC emission increases. The* NO_x *emission and the opacity of exhaust gas increase for biodiesel blend, similar results were also obtained for pure biodiesel.*

Keywords: *Calophyllum inophyllum, biodiesel, performance test, fuel consumption, emission test.*

I. INTRODUCTION

For some time now we have been living in environmental dilemmas which challenge human creativity and capacity to venture sustainable solutions to protect the life on our planet and our existence upon it. Among them are the needs to protect fresh water and agricultural lands for food production, to combat greenhouse effect and to produce energy from non-fossil sources[1]. The increasing depletion of non-renewable energy and the progress of diverse energy strategy have drawn unprecedented attention to bioenergy. Many countries such as Brazil, USA and China have already made considerable progress on the use of bioenergy. There are some critical considerations related to develop bioenergy, one of them is food security problem. We could take a look for China as an example. With the development of bioenergy such as ethanol, biodiesel and alike, food security problem causes a serious concern in China[2]. As the prices rise for petrifaction energy such as fuel ethanol using corn as raw material is stimulated to develop rapidly, leading to an increase in China's corn price. How about Indonesia? There is no comprehensive study yet concerning on the effect of bioenergy development on food security in Indonesia, but we may predict the same condition can occurs regarding the source used for bioenergy in Indonesia are mainly coming from food supply such as sugar cane for ethanol and palm oil for biodiesel.

Avoiding such condition as food versus energy, we need to establish multi-variety energy development strategy, find appropriate ways to develop bioenergy, and keep sustainable development of resources and environment. Diversification of bioenergy sources being one of the solutions. Focusing research on the non-edible sources for biodiesel feedstock can be used as main strategy to hurdle of food versus energy phenomena. Currently we focus on the work to study the potentiality of *Calophyllum inophyllum* (known as Nyamplung in Bahasa) biodiesel to be used as diesel fuel, either in pure biodiesel form or blended with conventional diesel fuel. Together with *Jatropha curcas,* these two plants are getting more attention as non-edible sources for biodiesel feedstock[3].

Calophyllum inophyllum is a large evergreen, natives from East Africa, southern coastal India to Indonesia and Australia. In Indonesia, *Calophyllum inophyllum* are culativated in almost all coastal region, spreading out from National Park of Alas Purwo, National Park of Kepulauan Seribu, Baluran, Ujungkulon, Pangandaran, southern coastal of Java Island, coastal of Papua Island, coastal of North Maluku, and west coastal of Sumatera Island[4]. The highest oil content is extracted from the dried nut's kernel. The extracted oil then converted to Fatty Acid Methyl Esther (FAME) generally known as biodiesel through transesterification reaction, for further discussion we may called it *Calophyllum Inophyllum Methyl Esther* (CIME).

Figure 1
***Calophyllum inophyllum* tree with the fruit**
Source: www.cthar.hawaii.edu

A.K. Hegde and K.V.S Rao[5] studied engine performance in terms of Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTE), and emission characteristic of a 4-stroke single cylinder compression ignition (CI) engine fuelled by pure diesel fuel and various concentration of CIME blended with diesel fuel. They also add a package of additive to improve engine performance. They found that BTE decreased with the increasing concentration of CIME, but additives could improve BTE value of blended CIME better than using conventional diesel fuel. The BSFC increased with the increasing concentration of CIME, but additives could improve the BSFC value. As the addition of more additives concentration, the NO_x emission marginally increased. For all loads, it is observed that the exhaust gas temperature increased with the increasing concentration of CIME.

D.K. Bora *et al.*[6] conducted research on the usage of equal volume mixture of Karanja (*Pongamiapinnata*) methyl esther, Polanga (*Calophyllum inophyllum*) methyl esther, and Jatropha

(*Jatropha curcas*) methyl esther to be blended with diesel fuel in various concentrations. The engine used for the research is a Kirloskar single cylinder, 4 stroke, air cooled direct injection diesel engine. They concluded that performance characteristic of engine with mixed biodiesel operation are comparable to those with neat diesel operation. Major pollutants (CO, smoke, NO_x) showed marked reduction over the entire range of experiments.

From previous research, it is clear that the CIME is very potential to be used as diesel fuel alternatives. Since Indonesia is rich of coastal regions harvesting *Calophyllum inophyllum* in all season, moreover CIME as biodiesel fuel has not been applied so far in this country, study focusing the optimization of CIME as diesel fuel substitution is greatly required. The effect of using pure diesel fuel, 50% blend of diesel fuel – CIME, and pure CIME in term of engine performance and emission characteristic on a 5 KvA diesel generator engine is described in this paper. This type of diesel generator engine is widely used in rural area for multi purposes and suitable for

Table 1
Test engine specification

Engine name	Yanmar
Type	TF 85 MR DI
Cylinder	1
Stroke	4
Volume Capacity	493 cc
Max. power (DK/ppm)	8.5 / 2200
Working power (DK/ppm)	7,5 / 2200
Injection type	Direct Injection
Cooler	Water

Table 2
Physical and Chemical Characteristics of CIME (refer to SNI 04 7182-2006 standard)

No.	Parameters	Unit	Test Method	Limits	CIME test result
1.	Specific Gravity @40^0 C	Kg/m^3	ASTM D1298	850-890	880.6
2.	Kinematic Viscosity @40^0C	cSt	ASTM D445	2.3 – 6.0	5.72
3.	Cetane number	-	ASTM D613	Min. 51	71.9
4.	Flash point	^{0}C	ASTM D93	Min. 100	151
5.	Cloud point	^{0}C	ASTM D2500	Max. 18	38
6.	Copper strip corrosion	-	ASTM D130	Max. no 3	1b
7.	Carbon residue - origin sample - 10% distillate volume	% mass	ASTM D4530	- Max. 0.05 - Max. 0.03	0.04
8.	Water and sediment	% vol.	ASTM D1796	Max. 0.05	0
9.	Distillation temperature at 90% dist.volume	^{0}C	ASTM D1160	Max. 360	340
10.	Sulfated ash	% mass	ASTM D874	Max. 0.02	0.026
12.	Sulphur	mg/kg	ASTM D1266	Max. 100	16
13.	Phospor	mg/kg	ASTM D1091	Max. 10	0.223
14.	Acid number	mg KOH/gr	AOCS Cd 3d-63	Max. 0.8	0.76
15.	Total glycerol	% mass	AOCS Ca 14-56	Max. 0.24	0.22
16.	Esther Alkyl content	% mass	SNI04 7182	Min. 96.5	96.99
17.	Iodium number	% mass	AOCS Cd1-25	Max. 116	85

applying the concept of energy self-supplied village (Desa Mandiri Energi).

II. MATERIALS AND METHOD

The tested fuels are conventional diesel fuel (cetane number 48 grade), 50% blend of diesel fuel – CIME, and 100% CIME. CIME is supplied by Research and Development Center for Forest Crop (Puslitbang Hutan Tanaman). The test engine specification is listed in Table 1. The physical and chemical characteristics of CIME used in this paper are listed in Tabel 2.

A cycle referred to Figure 3 was conducted for each test period. The test engine is warmed up to 15 minutes before each cycle. At full speed condition, all data of fuel consumption (lt/hour), hot and cold start up time (sec.), and emission characteristics in terms of CO_2, CO, HC, NO_x and opacity were taken.

Figure 2
Engine Test Rig

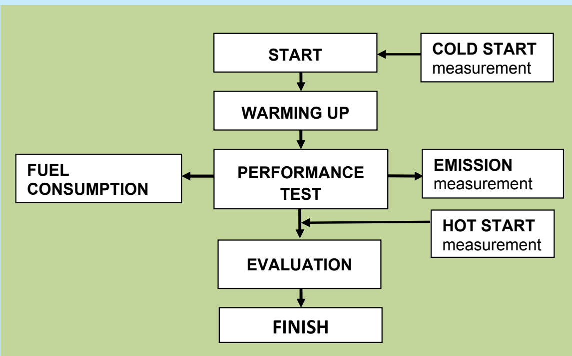

Figure 3
PerformanceTest Flow Diagram

III. RESULTS AND DISCUSSION

Fuel consumption calculation for each fuel was conducted using two methods. First, measuring the time needed (in second) to consume 50 gram fuel. Figure 4 describes the time needed for each tested fuel.

Figure 4 shows that to consume 50 gram for each fuel, the time needed for 100% CIME is the fastest among others. Compared to diesel fuel as reference, CIME was consumed 16.8% faster, whether 50% blend diesel fuel – CIME was consumed 10.8% faster in the matter of time needed. It means that for a specified amount of fuel, as the CIME concentration is higher, the consumption rate getting faster significantly until depletion occurs. Figure 5 depicts the measurement of fuel consumption based on time method, where certain amount fuel (50 gram) consumed and time needed was measured.

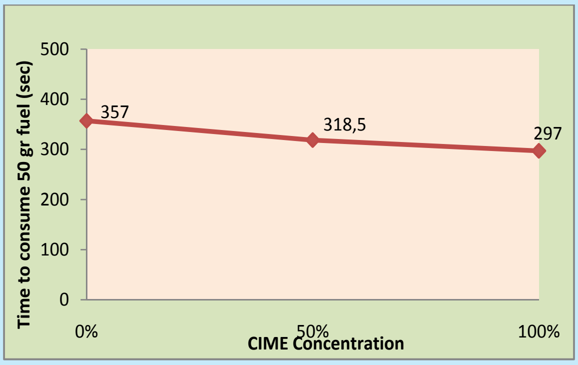

Figure 4
Time-based fuel consumption of tested fuels

Figure 5
Measurement of fuel consumption
time-based method

The second method of fuel consumption measurement was carried out by involving specific gravity of each fuel to calculate amount of the fuel needed to operate test engine in 1 hour period. Figure 6 describes the result of fuel consumption calculation in 1 hour period.

Based on the data of fuel consumption rate of tested fuels described in Figure 6 we conclude that the higher the CIME concentration in the fuel, the higher consumption rate will be obtained. For 1 hour testing period, the 100% CIME fuel is consumed at the rate of approximately 7.7% higher than reference fuel, whereas in the 50% blend fuel is only 6.3% higher than reference.

The high consumption rate of the CIME and its blend fuel may be caused by higher specific gravity of the CIME in comparison with diesel fuel. Table 2 exhibits that specific gravity of CIME is 880.6 kg/m^3. It is higher than the maximum limit of specific gravity of diesel fuel (820 – 870 kg/m^3). This conclusion is in accordance to the study of D.K. Bora *et al*.[6], that evaluates the higher consumption of CIME fuel and its blend, indicating the higher density and so related to lower calorific value of CIME biodiesel than those of diesel fuel.

The result of analysis at cold start time measurement as listed on Table 3 identifies that addition of CIME into diesel fuel increases the time which is required for cold start. The higher the CIME concentration applied, the longer cold starts time needed. This phenomenon is related with the physical and chemical properties of CIME biodiesel, especially Cloud Point. Cloud Point is the temperature at which the fuel shows a haze from the formation of crystals. Cold flow properties of biodiesel such as

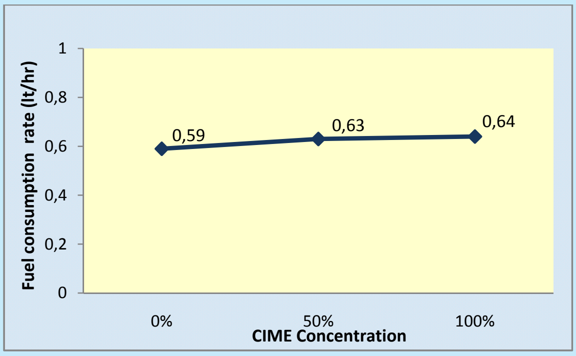

Figure 6
Fuel consumption rate of tested fuels

Table 3
Cold start time measurement

Fuel	Cold Start (sec.)				Effect (%)
	1st test	2nd test	3rd test	Average	
Diesel Fuel (reference)	1,1	1	0,9	1,0	-
50% diesel – 50% CIME	1,2	1,1	1,1	1,1	13,3
100 % CIME	1,1	1,3	1,1	1,2	16,7

Table 4
Hot start time measurement

Fuel	Hot Start (sec.)				Effect (%)
	1st test	2nd test	3rd test	Average	
Diesel Fuel (reference)	0.7	0.9	0.8	0.8	-
50% diesel – 50% CIME	1	1.1	1.2	1.1	37.5
100% CIME	1.1	1.2	1.1	1.15	43.7

Table 5
Emission characteristic of tested Fuels (CO_2, CO and HC)

Fuel	Emission Components					
	CO_2 (ppm)	effect (%)	CO (ppm)	effect (%)	HC (ppm)	effect (%)
Diesel Fuel	1.54	-	0.04	-	17	-
50% Diesel – 50% CIME	1.45	-5.86	0.05	25	18.5	8.82
100% CIME	1.37	-10.75	0.06	37.5	24.5	44.12

Table 6
Emission characteristic of tested fuels (NO_x and Opacity)

Fuel	*Emission Components*			
	NO_x	effect (%)	Opacity	effect (%)
Diesel fuel (reference)	81	-	6,2	-
50% diesel fuel – 50% CIME	101	24.69	6.65	7.26
100% CIME	108.5	33.95	8.0	29.03

Cloud Point, Cold Filter Plugging Point, and Pour Point are fully affected by fatty acid composition of biodiesel[7]. In the country where cold season existthis parameter is very crucial. As showing in Table 2, the Cloud Point of CIME used in this research is 38^0 C. This value is much higher than the maximum limit of biodiesel specification. The high Cloud Point value of CIME describes the crystal formation start at around 38^0C, almost the same with the temperature of nozzle injector where the fuel will be distributed in combustion chamber. It means that there is possibility that the crystal formation already started so the fuel is not evenly distributed by the nozzle injector inside combustion chamber. This phenomenon causes delay on the cold start time.

Similar with the result of cold start time measurement, increasing time needed for hot start occurs coincide with the increasing concentration of CIME, as showed in Table 4. In spite of in hot start testing the cloud point has noeffect significantly; however the FAME content in the fuel causes the longer time of the hot start. Nevertheless the increasing of time needed both for cold start and hot start is not too significant. The highest difference is only 1.15 second.

The results of emission measurements are listed in Table 5. This table exhibits that the emission of carbon dioxide (CO_2) decreases as the concentration of CIME getting higher. Carbon dioxide (CO_2) is a product of fundamental combustion reaction, so with this result we may conclude that using biodiesel affecting the fundamental combustion reaction. In the contrary with the result of CO_2 emission, increasing of CIME concentration causes effects in improving the emission of CO and unburned Hydrocarbon (HC). The higher emission of CO and HC can be described as follows: Increasing concentration of CIME causes in increasing the viscosity of the blended fuel. The higher viscosity causes smaller amount of fuel to be injected. As a result leaner mixture in combustion chamber is created. The calorific value of biodiesel is lower than diesel fuel so it may lower the cylinder gas temperature. The combined effect of leaner mixture and the lower gas temperature results in incomplete combustion of a significant portion of the blend leading to higher HC and CO emissions[8].

Another parameter measured in emission testing are NO_x and opacity of the exhaust smoke. Table 6 listed the result of NO_x and opacity for each tested fuel.

Table 6 indicates that both NO_x emission and opacity of the exhaust gas increase with increasing concentration of CIME. Increases in NO_x emissions have often been attributed to the oxygen content of the fuel molecule[9], either through the thermal or via the prompt mechanism.

IV. CONCLUSIONS

The current study demonstrates that using CIME in a small monocylinder generator set increases fuel consumption as the CIME concentration increases. Pure CIME fuel consumption is 16.8% higher than conventional diesel fuel whereas 50% blend of CIME-diesel fuel is 10.8% higher. The cold start time and hot start time increases as the CIME concentration increases. The difference range is 0.8-1.2 second; it means that the increasing time of the hot and cold start time is not too significant.

Emission of CO_2 decreases with increasing the concentration of CIME, whereas both of CO and HC emission increases with the higher CIME concentration. Emission of $NO_x$and the opacity of exhaust gas increases with increasing of CIME concentration.

Generally the performance of the CIME used for small monocylinder generator set engine is fairly good. We suggest optimizing the CIME concentration within the blend so we can get better emission result and minimizing fuel consumption rate.

REFERENCES

1. [5]**Avinash K. Hegde** and **K.V. Sreenivas Rao.** Performance and emission study of 4S CI engine using *Calophyllum inophyllum* with additives. *International Journal on Theoretical and Applied Research on Mechanical Engineering.* Vol.1. Issue 1. 2012. pp 1-4.
2. [6]**Dilip Kumar Bora, L.M. Das, M.K**. **Gajendra Babu.** Performance of a mixed biodiesel fueled engine. *Journal of Scientific and Industrial Research.* Vol. 67. 2008. pp 73-76.
3. [2]**Fangwei Wu, Deyuan Zhang, Jinghua Zhang**. Will the development of bioenergy in China create a food security problem? Modeling with fuel ethanol as an example. *Renewable Energy*. vol.47. 2012. pp 127-134.
4. [3]**H.C. Ong, T.M.I. Mahlia, H.H. Masjuki, R.S. Norhasyima.** Comparison of Palm oil, *Jatropha curcas* and *Calophyllum inophyllum* for biodiesel : A Review. *Renewable and Sustainable Energy Reviews.* Vol.15. Issue 8. 2011. pp 3501-3515.
5. [4]**Head of R&D Center of Forest Plants**. Prospect of *Calophyllum inophyllum* development for biofuel application by establishment of Energy-Independent Village (Desa Mandiri Energi). Presented in Coordination Meeting of Regional II for Planning and Development of Forest Plants-based Bioenergy. Purwokerto. 13th of November 2009.
6. [8]**K. Anand, R.P. Sharma, Pramod S. Mehta.** Experimental investigations on combustion, performance and emission characteristics of neat karanji biodiesel and its methanol blend in diesel engine. *Biomass and Bioenergy.* Vol. 35. Issue 1. 2011. pp 533-541.
7. [7]**K. Rajagopal, Ch. Bindu, R.B.N. Prasad**, **Adeel Ahmad**. Cloud Point of Biodiesel and Blends. *Journal of Chemical, Biological and Physical Sciences.* Vol.2. No.4. 2012. pp 1998-2003.
8. [1]**M.A.R.Rodrigues, J.DeRuyck, P.R.Diaz, V.K.Verma, S. Bram**. An LCA based indicator for evaluation of alternative energy routes. *Applied Energy*. Vol. 88. issue 3.2011. pp 630-635.
9. [9]**M. Lapuerta, O. Armas, R. Ballesteros, J. Fernandez.** Diesel emissions from biofuels derived from Spanish potential vegetable oil. *Fuel.* Vol. 84. Issue 6. 2005. pp 773-780.