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Characteristics and Potential of *Nyamplung* (*Calophyllum inophyllum L.)* Seed Oil from Kebumen, Central Java, as a Biodiesel Feedstock

Sri Kurniati[1], Sudjito Soeparman[2], Sudarminto Setyo Yuwono[3], Lukman Hakim[4]
[1]Electrical Engineering Department, Science and Engineering Faculty, University of Nusa Cendana, Kupang, Indonesia
[2]Mechanical Engineering Department, Engineering Faculty, Brawijaya University, Malang, Indonesia
[3]Department of Agricultural Product Technology, Faculty of Agricultural Technology, Brawijaya University, Malang, Indonesia
[4]Department of Chemistry, Engineering of Natural Sciences, Brawijaya University, Malang, Indonesia

Abstract—*Biodiesel is a fuel that is clean, biodegradable, non-toxic and has low emissions. These conditions provide benefits to the environment, where the use of biodiesel has the potential to reduce pollution levels. Calophyllum inophyllum L. or Nyamplung seed is one type of plant that has the potential to be processed into biodiesel. The potential non-edible feedstock for biodiesel is currently being considered carefully for the purpose of continuing biodiesel production while not having a negative impact on the food issue. In this study, the production of biodiesel from Nyamplung oil using electromagnetic-induction has been investigated. The crude Calophyllum inophyllum oil has a free fatty acid value which is above 2%. Therefore, a pre-treatment acid catalyzed esterification process is required to reduce the free fatty acid (FFA) content. It was found that Calophyllum inophyllum oil was at a ratio of 6:1 M (methanol to oil) with a fairly short heating at 65^{0}C for 1.2 minutes in the presence of 2% KOH to obtain a lower acid value and the yield of methyl esters produced 40.31%. The results are shown that the improvement in biodiesel properties by using two stages of esterification method. The main characteristics of fuels such as viscosity, density, and FAME meet American Society for Testing Materials (ASTM) biodiesel standards.*

Keywords—*Crude oil, esterification, transesterification.*

I. INTRODUCTION

Considering the increasing nature of global energy demand, rising oil prices and concerns about the side effects of fossil fuels on renewable environmental resources have attracted major research interest. Economic competitiveness, environmental factors, and technical reliability are important characteristics of green energy resources. Mitigating carbon dioxide and being an identical substitute for petroleum diesel without the need for further modifications to the engine are the two main advantages of biodiesel.

Regarding the use of alternative fuels, some researchers have treated several plants that can be processed into fuel instead of diesel or gasoline. Generally, biodiesel is a liquid fuel that is processed from plants such as jatropha oil (jatropha curcas) [1-8], palm oil [9-12], soybean oil [13-17], and soursop seed [18]. In addition, one of the potential biodiesel plants is Calophyllum inophyllum or *Nyamplung* (in Indonesia) [19-21]. Calophyllum inophyllum L.belongs to the clan of Calophyllum which is spread throughout the world such as, Madagascar, East Africa. In Indonesia, *Nyamplung* is spread from West Sumatra, Riau, Jambi, South Sumatra, Lampung, Java, West Kalimantan, Central Kalimantan, Sulawesi, Maluku, to East Nusa Tenggara and Papua.

The advantage of *Nyamplung* as biofuel is that the seeds have a higher yield than other types of plants (40-60% fence distance, 46- 54% oil palm, and 40-74% coverage), and their use does not compete with food interests [22]. Based on the prospect of development and other uses, *Nyamplung* plants grow and spread evenly naturally in Indonesia, easy regeneration and fruiting throughout the year which shows a high survival power to the environment. In addition, *Nyamplung* seed productivity (20 tons/ha) is higher than fence distance (5 tons/ha), palm oil (6 tons/ha) and other vegetable plants [23]. *Nyamplung* seeds have an oil content of 75% and unsaturated acids 71% [24]. This is obtained by pressing in the form of greenish yellow oil, similar to olive oil, with an aromatic smell and tasteless taste. It usually produces fruit twice a year and produces up to 100 kg and about 18 kg of oil [25].

In this work, the potential of *Nyamplung* seeds obtained from Kebumen in Central Java, Indonesia was analyzed. The main objective is to find out the characteristics and opportunities of *Nyamplung* seeds to be processed into biodiesel. This effort is done for developing the potential of natural resources that exist in this area. Moreover, important fuel properties were appraised and compared with ASTM and Indonesian National Standard (SNI) methods.

II. EXPERIMENTAL

2.1 Materials

Fig. 1 shows the dry seeds of *Calophyllum inophyllum*. *Nyamplung* oil having >17.77% of Free Fatty Acids (FFA), (Fig. 2) was supplied from Kebumen, Central Java, Indonesia.

Fig. 1. Dry seeds

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Fig. 2. *Calophyllum inophyllum* crude oil

2.2 Electromagnetic Induction Irradiation

Nyamplung oil esterification reactions were carried out in the presence of HCL (2 wt.%) at temperatures 60℃ with using molar ratio of methanol-to- oil (20:1, by mole basis). Briefly, the first catalyst is dissolved in methanol and added 5 grams of *nyamplung* Oil in a 100ml beaker glass and placed inside the induction coil.

Fig. 3. The esterification process using electromagnetic induction

The beaker glass is filled with a mixture of methanol, *nyamplung* oil, HCL, and some iron metal elements are added. The method of processing biodiesel with electromagnetic induction radiation as shown in Fig. 3. The HCL catalyst samples were collected at the same experimental time interval (i.e. 1.2 minutes). The methanol was then evaporated and the product is transferred to a 100 mL separating funnel for the purification step. Products washed with hot distilled water (>80^{0}C) to remove the remaining acid in the product, continue until the washing water shows pH ～ 7.

2.3 Analysis

The acid value (AV) of the oil sample was measured using a titration method reported previously [26, 27]. The FFA conversion reaction was the calculated based on the difference of acid value of feedstock and the product after the reaction completed [Eq. 1].

$$FFA\ conversion\ (\%) = \frac{AV_1 - AV_2}{AV_1}\ x\ 100 \quad (1)$$

where AV_1 is the initial acid value, and AV_2 is the acid value after the esterification reaction.

III. RESULT AND DISCUSSION

3.1. Properties of Nyamplung Oil

Table 1 shows the characteristics of *Nyamplung* seed oil. The oil extracted from *Nyamplung* seeds reaches a yield of 69.11%, indicating the high oil content of *Nyamplung* seeds and the next potential as an oil source. The value of free fatty acid (FFA) from *Nyamplung* seed oil was 17.77%, indicating a high FFA content. Two fatty acid methyl esters were identified in the *Nyamplung* biodiesel, among which methyl linoleate (3.85%), and methyl palmitoleate (13.92%) were present in the highest amounts. The biodiesel production process must be refined to maximize the value of materials and minimize costs [28-30]. To maximize the yield of biodiesel from oils with high FFA levels, esterification must be done to reduce the level of FFA before transesterification [31-33]. Therefore, a two-stage acid catalyzed esterification process followed by alkali-transesterification was chosen for the synthesis of biodiesel from *Nyamplung* seed oil in this study.

TABLE 1. Composition of *Calophyllum inophyllum* crude oil

No.	Parameter test	Result
1	Methyl Butyrate	<0.1
2	Methyl Hexanoate	<0.1
3	Methyo Octanoate	<0.1
4	Methyl Decanoate	<0.1
5	Methyl Undecanoate	<0.1
6	Methyl Laurate	<0.1
7	Methyl Tridecanoate	<0.1
8	Methyl Tetradecanoate	<0.1
9	Myristoleit Acid Methyl Ester	<0.1
10	Methyl Pentadecanoate	<0.1
11	Cis-10-Pentadecenoit Acid Methyl Ester	<0.1
12	Methyl Palmiate	<0.1
13	Methyl Palmitoleate	13.92
14	Methyl Heptadecanoate	<0.1
15	Cis-10-Heptadecanoate Acid Methyl Ester	<0.1
16	Methyl Octadecanoate	<0.1
17	Trans-9-Elaidic Acid Methyl Ester	<0.1
18	Cis-9-Oleic Methyl Ester	69.11
19	Lenolelaidic Acid Methyl Ester	<0.1

No.	Parameter test	Result
20	Methyl Leloneate	3.85
21	Methyl Aracehidate	<0.1
22	Gamma-Lenolenic Acid Methyl Ester	<0.1
23	Methyl Cis-11 eicocenoate	<0.1
24	Methyl Lenolenate	<0.1
25	Methyl Heneicosanoate	<0.1
26	Cis-11-14-eicosedienoic Acid Methyl Ester	<0.1
27	Methyl Docosanoate	<0.1
28	Cis-8-11-14-eicosedienoic Acid Methyl Ester	<0.1
29	Methyl Ecurate	<0.1
30	Cis-11-14-17-eicosedienoic Acid Methyl Ester	<0.1
31	Methyl Tricosanoate	<0.1
32	Methyl Cis-5-8-11-14-eicosedienoic	<0.1
33	Cis-13-16-Docosadienoic Acid Methyl Ester	<0.1
34	Methyl Lignocerate	<0.1
35	Methyl Cis-5-8-11-14-17- Eicosapentaenoate	<0.1
36	Methyl Nervonate	<0.1
37	Cis-4-7-10-13-16-Docosahexaenoate	<0.1

3.2 Free Fatty Acid (FFA) Testing

The esterification process aims to reduce the levels of free fatty acids in *Nyamplung* oil to reach below 2% with a molar ratio of 1:20 (oil to methanol). In this stage, the catalyst in the form of HCL is added as much as 2% mass of oil by dissolving it into methanol until it is completely mixed. The beaker glass is closed at the top to prevent oxidation with the surrounding air as long as the measurement of the volume and mass of the oil is refined oil by 300ml. Table 4 shows the results of esterification reactions carried out twice to get FFA values below 2%.

TABLE 2. Composition of *Calophyllum inophyllum* crude oil

Temperature	Esterification I		Esterification I	
	Time (Min)	**FFA (%)**	**Time (Min)**	**FFA (%)**
60^0C	15	9.2	5	0.7

3.3 Methyl Ester Analysis

The analysis of provided *Nyamplung* oil has been done by using gas chromatography - mass spectrometer detector（GC-MS. In this case GCMS testing was conducted at the Laboratory of the State University of Malang. Fig. 4 showed the GC chromatogram of *Nyamplung* feedstock.

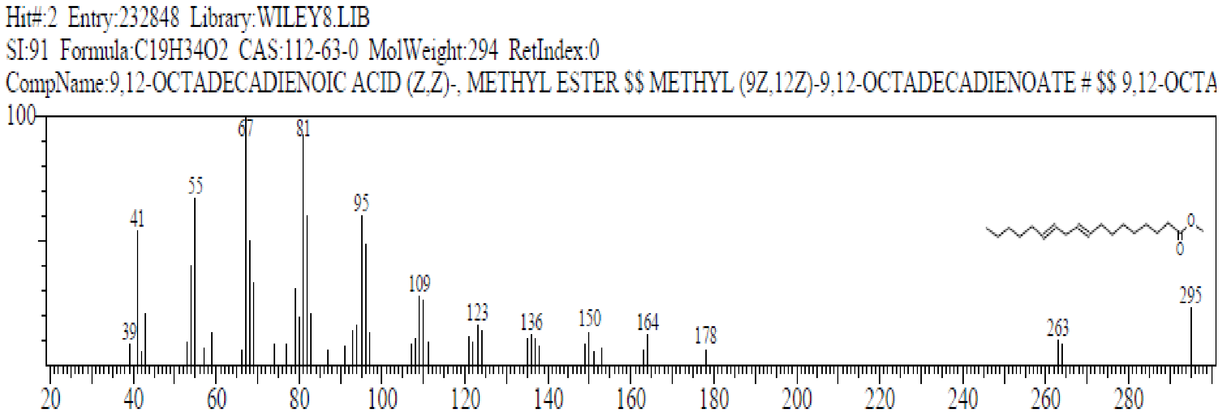

Fig. 4. GC-MS chromatogram of *Nyamplung* methyl esters produced using electromagnetic induction at optimized conditions (6:1 of methanol-to-oil molar ratio, 65℃ reaction temperature, 2 wt.% of KOH and 1.2 min reaction time).

In general, the biodiesel produced at all reaction times showed that the most compound from *nyamplung* oil biodiesel was methyl ester 9.12 octadecanoate (m/z=295). The percentage of the second largest major component of oleate methyl ester, while the methyl ester stearate and palmitate methyl ester are the third and fourth most components. The most major component found in *nyamplung* oil biodiesel as shown in the graph of the following fragments is methyl ester 9.12 octadecanoate. 9.12 octadecanoic methyl ester is a compound that has a mass of 295. The compound fragments identified have the molecular formula $C_{19}H_{34}O_2$.

The fatty acid profile of methyl ester produced from the transesterification of methyl ester was shown in Fig. 4. The methyl ester constituents such as methyl oleate, methyl steareate, and methyl palmitate were main products of transesterification reaction using *nyamplung* as a feedstock (Table 1).

3.4 Results

After the separation and washing process, biodiesel is obtained by 43.92%. The fuel properties of *nyamplung* biodiesel in this work were summarized in Table 5. It was concluded that all the properties of *nyamplung* biodiesel (Table 2) were in the range of SNI, ASTM D6751-02, and EN 14214 standards. Based on the table, density resulted already fulfills the SNI standard around 0,85-0,89 gr/cm3. The density is influenced by molecule weight, moistures, and free fatty acid in biodiesel. Besides, the density is also influenced by carbon chain and not the fat degree of biodiesel. Biodiesel density will reduce as well as the increase of carbon chain and non-fat degree.

TABLE 3. *Nyamplung* biodiesel properties compared with those of SNI, ASTM D6751, ASTM PS 121, EN 14214, and EN 14214

Properties	ASTM D6751 (USA)	ASTM PS 121	EN 14214	C1 Biodiesel	SNI	This Study
Acid value (mg KOH/g)	<0.5	<0.5	<0.5	0.34	0.8	0.8
Density (20^0C) (g/ml)	0.87-0.9	0.7328	No specific	0.877	0,850 - 0,890	0.882
Kinematic viscosity, 40^0C (mm^2/s)	1.9-6.0	1.9-6.0	3.5-5.0	5.6872	2.3-6.0	5.54

3.5. Discussion

Second-generation biodiesel is gaining more interest in the market as a sustainable alternative of diesel fuel. However, to produce biodiesel from new sources and continue to develop these in the market, various aspects must be examined. In this study, the potential of *nyamplung* plant was evaluated as a source of second-generation biodiesel. Oil was pressed from dry seed kernels, and oil properties have been analysed. Oil has been esterified to produce biodiesel using a two-step esterification technique, and the physicochemical properties were assessed.

According to [34, 35], the advantageous characteristics of

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biodiesel over diesel fuel include reduced exhaust gas emissions and toxicity, high flash point, sustainability, non-flammability, and a domestic. With rapid modernization and technological development, fuel is not only required to provide energy but also lubricity. It must emit little pollution and be chemically stable without affecting the environment. In line with this requirement, lubricating additives should be incorporated to reduce the sulfur from diesel through hydrotreatment. The advantage of biodiesel compared to diesel fuel is because its raw materials are available on an ongoing basis, higher combustion efficiency, lower sulfur and aromatic content, and higher numbers of satanic. While the disadvantages, are having higher viscosity, lower energy content, higher nitrogen oxide emissions, and lower engine speed.

In terms of environmental aspects, biodiesel is considered carbon neutral, because carbon dioxide is released into the atmosphere after being consumed as fuel and has been recycled or reused for plant vegetable oil growth [36]. Biodiesel has a cetane number higher than diesel because of its long chain fatty acid with double bonds 2–3, without aromatic and containing 10-11% oxygen according to its weight. The characteristics possessed by this biodiesel can reduce carbon dioxide (CO) emissions, hydrocarbons (HC) and particulates in flue gas compared to diesel [37].

IV. Conclusion

This paper investigates the potential of *nyamplung* seeds for biodiesel production. In the current study, the condition of the esterification and transesterification reaction was optimized using electromagnetic induction radiation. Under optimized conditions, the results of esterification of biodiesel were obtained 65.96%, with a fairly short time (1.2 minutes). The properties of *nyamplung* biodiesel were determined and were found to meet SNI, ASTM D6751 and EN 14214. The results of this study indicate that *nyamplung* oil from Kebumen district is a potential biodiesel of *nyamplung* biodiesel raw material and biodiesel can serve as an alternative to petrodiesel.

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References

[1] Chen C-H, Chen W-H, Chang C-M J, Lai S-M, Tu C-H, "Biodiesel production from supercritical carbon dioxide extracted Jatropha oil using subcritical hydrolysis and supercritical methylation," *Journal of Supercritical Fluids*, vol. 52, pp. 228-234, 2010.

[2] Chao-Rui Chena, Yang-Jung Chenga, Yern-Chee Chingc, Daina Hsiang, Chieh-Ming J. Changa, "Green production of energetic Jatropha oil from de-shelled Jatropha curcas L. seeds using supercritical carbon dioxide extraction," *J. of Supercritical Fluids*, pp. 137–143, 2012.

[3] May Ying Koh, Tinia Idaty Mohd. Ghazi, "A review of biodiesel production from Jatropha curcas L. oil," *Renewable and Sustainable Energy Reviews*, pp. 2240–2251, 2011.

[4] Azhari, Faiz M, Yunus R, Ghazi TIM, Yaw TCS, "Reduction of free fatty acids in crude jatropha curcas oil via an esterification process," *International Journal of Engineering and Technology*, vol. 5, issue 2, pp. 92–98, 2008.

[5] Shah S; Gupta MN, "Lipase catalyzed preparation of biodiesel from Jatropha oil in a solvent free system," *Process Biochemistry*, pp. 409–414, 2007.

[6] Jain S; Sharma MP, "Prospects of biodiesel from Jatropha in India: A review. *Renewable and Sustainable Energy Reviews*," pp. 763–771, 2010.

[7] Lu H; Liu Y, Zhou H, Yang Y, Chen M, Liang B, "Production of biodiesel from Jatropha curcas L. oil," *Computers and Chemical Engineering*, pp. 1091–1096, 2009.

[8] Tiwari AK; Kumar A, Raheman H, "Biodiesel production from jatropha oil (Jatropha curcas) with high free fatty acids: an optimized process," *Biomass and Bioenergy*, pp. 569–575. 2007.

[9] Melero, J.A, Bautista, L., F, Morales, G., Iglesias, J, Sánchez-Vázquez, R, "Biodiesel production from crude palm oil using sulfonic acid-modified mesostructured catalysts," *Chemical Engineering Journal, Article in press*. 2009.

[10] A.N. Alkabbashi, Md Z. Alam, M.E.S. Mirghani**,** A.M.A. Al-Fusaiel**.** "Biodiesel production from crude palm oil by transesterification process," *Journal of Applied Sciences* (17), pp. 3166-3170, 2009.

[11] Edward Crabbe, Cirilo Nolasco-Hipolito, Genta Kobayashi, Kenji Sonomoto, Ayaaki Ishizaki, "Biodiesel production from crude palm oil and evaluation of butanol extraction and fuel properties," *Process Biochemistry*, vol. 37, issue 1, pp. 65-71, 2001.

[12] Soni Sisbudi Harsono, "Biodiesel production from palm oil technology," *Research Journal of Agricultural Science*, vol. 43, issue 4, pp. 80-85, 2011.

[13] Kaieda, M.; Samukawa, T, Matsumoto, T, Ban, K.; Kondo, A, Shimada, Y, Noda, H, Nomoto, F, Ohtsuka, K, Izumoto, E, Fukuda H, "Biodiesel fuel production from plant oil catalyzed by Rhizopus oryzae lipase in a water-containing system biofuel's engineering process technology without an organic solvent," *Journal of Bioscience and Bioengineering*, vol. 88, no. 6, pp. 627-631, 1999.

[14] Samukawa, T, Kaieda, M, Matsumoto, T, Ban, K.; Kondo, A, Shimada, Y, Noda, H, Fukuda H, "Pretreatment of immobilized candida antarctica lipase for biodiesel fuel production from plant oil," *Journal of Bioscience and Bioengineering*, vol. 90, no. 2, pp. 180-183, 2000.

[15] Silva, C.C.C.M.; Ribeiro, N.F.P, Souza, M.M.V.M, Aranda, D.A.G, "Biodiesel production from soybean oil and methanol using hydrotalcites as catalyst," *Fuel Processing Technology*, vol. 91, pp. 205–210. 2010.

[16] Cao, W, Han, H, Zhang, J, "Preparation of biodiesel from soybean oil using supercritical methanol and co-solvent," *Fuel*, vol. 84, pp. 347–351, 2005.

[17] Lee, J. H., Kwon, C.H., Kang, J. W., Park, C., Tae, B., Kim, S.W, "Biodiesel production from various oils under supercritical fluid conditions by candida antarctica lipase B using a stepwise reaction method," *Applied Biochemistry and Biotechnology*, vol, pp. 454–464, 2009.

[18] Chia-Hung Su, Hoang Chinh Nguyen, Uyen Khanh Pham, My Linh Nguyen and Horng-Yi Juan, "Biodiesel production from a novel nonedible feedstock, Soursop (Annona muricata L.) Seed Oil, *Energies*, 11, 2562, pp. 1-11, 2018.

[19] Rao H. S., Rao T. V., Reddy K. H, "Palm oil and Callophylluminophyllum oil are potential feed stocks for future biodiesel in compression ignition engines: A Review," *International Journal of Mechanical Engineering and Technology*, vol. 4, issue 5, pp. 301-312, 2013.

[20] Jahirul M. I., Brown J. R., Senadeera W., Ashwath N., Laing C., Leski-Taylor J., Rasul M. G., "Optimisation of bio-oil extraction process from beauty leaf (Calophylluminophyllum) oil seed as a second generation biodiesel source," *Procedia Engineering*, pp. 619-624, 2013.

[21] M.I. Jahirul, R.J. Brown W., Senadeera, N. Ashwath, M.G. Rasul , M.M. Rahman, Farhad M. Hossain, Lalehvash Moghaddam, M.A. Islam , I.M. O'Hara, Physio-chemical assessment of beauty leaf (Calophyllum inophyllum) as second-generation biodiesel feedstock, Energy Reports, pp. 204 – 215, 2015.

[22] Joker, D. "Calophyllum inophyllum L. Seed, Leaflet No. 87, August 2004," *Forest & Landscape Denmark*, 2004.

[23] Anonim. "Action plan for the development of alternative energy based on *Nyamplung* plants, 2010-2014 (In Indonesia)," Ministry of Forestry, 2008.

[24] Said T, Dutot M, Martin C, Beaudeux JL, Boucher C, Enee E. "Cytoprotective effect against UV-induced DNA damage and oxidative stress: role of new biological UV filter," *European Journal of Pharmaceutical Sciences*, 30 (3–4), pp. 203–210, 2007.
[25] Dweek, A. C. & T. Meadows, "Tamanu (Calophyllum inophyllum L.) the Africa, Asia Polynesia & Pasific Panacea," *International J. Cos. Sci*, 24, pp. 1-8, 2002.
[26] Su, C.H., "Recoverable and reusable hydrochloric acid used as a homogeneous catalyst for biodiesel production," Appl. *Energy*, 104, pp. 503–509, 2013.
[27] Li, Q., Zheng, L., Cai, H., Garza, E., Yu, Z., Zhou, S.,"From organic waste to biodiesel: Black soldier fly,*Hermetia illucens*, makes it feasible," *Fuel*, 90, pp. 1545–1548, 2011.
[28] Amini, Z., Ong, H.C., Harrison, M.D., Kusumo, F., Mazaheri, H., Ilham, Z, "Biodiesel production by lipase-catalyzed transesterification of Ocimum basilicum L. (sweet basil) seed oil," *Energy Convers. Manag*, 132, pp. 82–90, 2017.
[29] Ramadhas, A., Jayaraj, S., Muraleedharan, C., "Characterization and effect of using rubber seed oil as fuel in the compression ignition engines," *Renew. Energy*, 30, pp. 795–803, 2005.
[30] Emil, A., Yaakob, Z., Kumar, M.S., Jahim, J.M., Salimon, J., "Comparative evaluation of physicochemical properties of Jatropha seed oil from Malaysia, Indonesia and Thailand," *J. Am. Oil Chem. Soc*., 87, pp. 689–695, 2010.
[31] Berchmans, H.J., Hirata, S, "Biodiesel production from crude Jatropha curcas L. seed oil with a high content of free fatty acids," *Bioresour. Technol*., 99, pp. 1716–1721. 2008.
[32] Çaylı, G., Küsefoglu, S, "Increased yields in biodiesel production from used cooking oils by a two step process: Comparison with one step process by using TGA," *Fuel Process* Technol, 89, pp. 118–122, 2008.
[33] Hayyan, A., Alam, M.Z., Mirghani, M.E., Kabbashi, N.A., Hakimi, N.I.N.M., Siran, Y.M.; Tahiruddin, S., "Reduction of high content of free fatty acid in sludge palm oil via acid catalyst for biodiesel production," *Fuel Process. Technol*., 92, pp. 920–924, 2011.
[34] Habibulla, M., Masjuki, H.H., Kalam, M.A., Rizwanul Fattah, I.M., Ashraful, A.M.,Mobarak, H.M., "Biodiesel production and performance evaluation ofcoconut, palm and their combined blend with diesel in a single-cylinder dieselengine," *Energy Convers. Manage*. 87, pp. 250–257, 2014.
[35] .Mofijur, M., Masjuki, H.H., Kalam, M.A., Atabani, A.E., Arbab, M.I., Cheng, S.F., Gouk, S.W., "Properties and use of Moringa oleifera biodiesel and diesel fuelblends in a multi-cylinder diesel engine," *Energy Convers. Manage*, 82, pp. 169–176, 2014.
[36] Barnwal BK, Sharma MP., "Prospects of biodiesel production from vegetables oils in India," *Renewable & Sustainable Energy Reviews*, pp. 363–78, 2005.
[37] I.M. Rizwanul Fattah, H.H. Masjuki, M.A., Kalam, M.A., Wakil, A.M. Ashraful, S.A. Shahir, "Experimental investigation of performance and regulated emissions of a diesel engine with Calophyllum inophyllum biodiesel blends accompanied by oxidation inhibitors," *Energy Conversion and Management*, 83,pp. 232–240, 2014.