Development of Biofuel for Diesel Engines of the Fishing Vessels from Coconut Oil

Ho Duc Tuan[1], Mai Duc Nghia[2]*
[1]Faculty of Transportation Engineering, Nha Trang University, Nha Trang City, Vietnam
[2]Faculty of Mechanical Engineering, Air Force Officer's College, Nha Trang City, Vietnam

Abstract: Biofuels are made from vegetable oils and animal fats, which have great potential as an alternative to traditional fuels to reduce environmental pollution. In addition to functioning as an oxygen booster for combustion, biofuels are renewable. Moreover, another advantageous characteristic of biofuels is the ease of mixing them with traditional fuel, without any need for complicated equipment. However, there are many factors affecting the application of biofuel to engines such as the geography of each country or region, its climate, and ingredients to serve human needs for food, while biofuels are developed from many different sources of raw materials. Vietnam is a country located in the tropical monsoon region, thus having great potential in developing raw materials for biofuel production. The main raw material sources, for now, are fish fat, jatropha oil, and coconut oil. Among them, coconut oil is considered one of the abundant raw materials, because the natural and social conditions in Vietnam are suitable and favorable for the growth of coconut trees. In this paper, the development of coconut oil production will be presented, as well as the method of using coconut oil (C10) as fuel for diesel engines of fishing vessels. The experimental research results show that the amount of soot emission from diesel engines using C10 fuel is lower compared to that of engines using traditional fuel (DO). ***Keywords*:** Biofuel, coconut oil, diesel fuel, diesel engine, soot emission.

1 Introduction

Nowadays, the demand for fuel and petroleum products is strongly rising for internal combustion engines, leading to many problems that need to be solved such as fuel being increasingly exhausted; environmental pollution due to engine exhaust is increasing, leading to many negative consequences affecting humans' health and social development [1,3]. To overcome these limitations, many technological measures and solutions have been proposed and applied worldwide to ensure energy security and reduce environmental pollution [4,8,12]. Among the alternative energy sources to petroleum currently in use such as solar energy, wind energy, etc., research biofuels used for internal combustion engines are of primary concern, due to their suitable characteristics and the availability of raw materials. According to the forecast of the International Energy Agency (IEA), the energy development trend worldwide by 2050 will be made up of 23% of diesel (DO), 27% of biofuels, the rest are other fuels [5,7,13]. Biofuels are derived from vegetable oils and animal fats, which have great potential as a fuel to replace traditional fuels. In addition to functioning as an oxygen booster for combustion, biofuels are also renewable. In addition, an advantageous feature of biofuels is that it is easy to blend with conventional fuels, without the need for complicated equipment. The main sources of raw materials for biofuel production are vegetable oils, which are mainly extracted from plants with high oil content such as Soybean oil, Rapeseed oil in Europe; Sunflower oil in the USA; Coconut oil, Palm oil, Jatropha oil in Asia [3,5,9]. However, many factors affect biofuels' application to internal combustion engines, such as the geography of each country - region; climate; ingredients to serve human food needs, while biofuels are produced using different materials. Vietnam is a country located in the tropical monsoon region, with great potential in developing raw materials for biofuel production. The main sources of raw materials at present

* Corresponding author: nghiamaiduc@gmail.com

time for production are basa fat, jatropha oil, and coconut oil. Among them, coconut oil is considered one of the abundant raw materials because the natural and social conditions in Vietnam are suitable and favorable for the development of coconut trees [5,14]. According to the Asian Pacific Coconut Community (APCC), coconut trees are grown in 93 tropical countries, and the coconut growing area of the countries in the association accounts for 85.05%. In particular, Vietnam's average coconut yield is always higher than the average of APCC countries. Currently, Vietnam has grown nearly 170 thousand hectares of coconut trees and ranks high in terms of coconut oil production and coconut oil exports in the world (Figure 1, Table 1) [6,13].

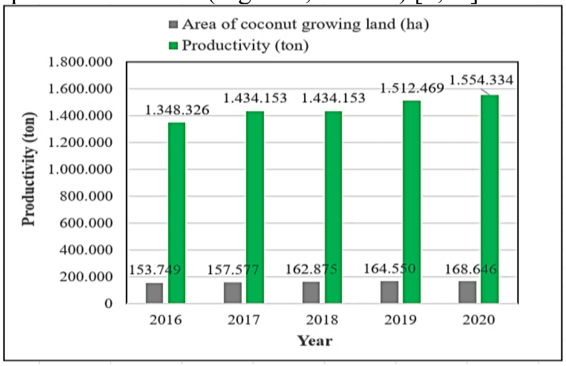

Fig. 1. Development and productivity of coconut growing area in the southern provinces of Vietnam

Table 1. Compare the production and area of coconut cultivation in Vietnam with some countries

N0	Countries	Coconut growing area (thousand ha)	Productivity (Billion fruit)
1	Indonesia	3.600	16
2	Philippines	3.500	15
3	India	2.100	22
4	Sri Lanka	450	2.9
5	Vietnam	153	1.3
6	Thailand	206	1

From the advantages of Vietnam's coconut oil source, the analysis above shows that using a mixture of diesel - coconut oil as fuel for diesel engines will minimize the dependence on non-renewable fuels and reduce environmental pollution. However, some Physico-chemical properties of the diesel-coconut oil mixture such as viscosity, surface tension, density, and volatility are not like those of diesel oil (DO), so when used in diesel engines, they do not achieve high efficiency and result in low mixing ratio as shown in Figure 2 [5-6,12]. Therefore, the fuel mixture will be heated to have suitable readings as fuel for fishing boats' diesel engines.

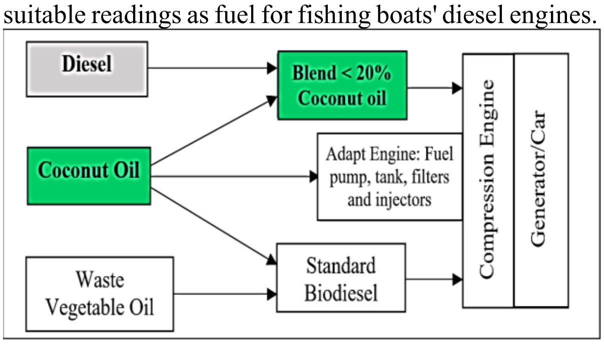

Fig. 2. Using biofuel from coconut oil for diesel engines

2 Materials and methods

2.1 Fuel

Coconut oil has a higher viscosity than diesel oil, so when mixing coconut oil into diesel oil, it needs to be heated to about 80^0C, to reduce the viscosity of the mixture closer to that of DO fuel. Table 2, Figure presents the chemical composition and parameters of coconut oil compared with diesel oil and the parameters of the diesel-coconut oil mixture at different mixing ratios [11]. In this study, a mixture of C10 (10% coconut oil and 90% diesel oil) was used.

Table 2. Chemical composition and fuel parameters of coconut oil and diesel oil

Indicators	Coconut oil	Diesel oil
Carbon, [%]	72.00	86.60
Hydrogen, [%]	12.00	13.40
Oxygen, [%]	16.00	0.00
Ratio C/H	6.00	6.46
Density, [g/cm^3]	0.915	0.836
Surface tension at 20^0C/40^0C, [mN/m]	33.4/28.4	26.2/23.4
Ash mass, [%]	0.02 ÷ 0.05	
Iodine mass, gI$_2$/100g	21.3 ÷ 22.1	
Viscosity at 20^0 C, [cSt] Viscosity at 40^0 C, [cSt]	30 ÷ 37 28.92 ÷ 29.03	3 ÷ 6 1.3 ÷ 2.4
Cetane number, [CN]	40 ÷ 42	45 ÷ 50
Turbidity point, [^{0}C]	20 ÷ 28	(-14) ÷ (-18)
Flashpoint, [^{0}C]	110	60
Heat value, [MJ/kg]/[Kcal/kg]	37.10/8875	43.80/10478

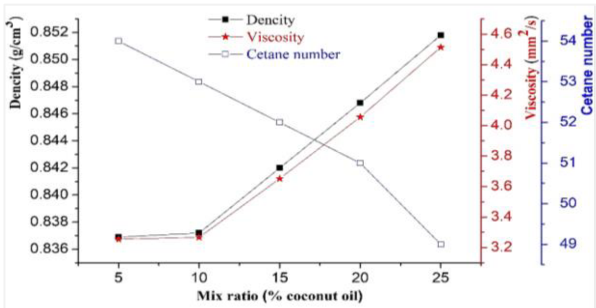

Fig. 3. Mixture fuel parameters at different mixing ratios

2.2 Diesel engines of fishing vessels

Based on the data on diesel engines of fishing boats being used in Vietnam [2,15], the paper in this study uses the Yanmar 4CHE engine of Yanmar Company, Japan, as the testing engine. Engine parameters are given in Table 3.

Table 3. Engine and experimental parameters

Type	**4CHE, unified combustion chamber**
Number of cylinders	4
Cylinder diameter x piston stroke, [mm]	105x125
Power, [Hp/rpm]	70/2300
Compression ratio	16.4
The engine speed of experimental, [rpm]	1800
Load, [%]	0; 20; 40; 60; 80
Number of nozzle holes x diameter x spray direction	4 x 0.32 x 1400
Injection timing ^{0}BTDC	180 BTDC
Injection pressure, [bar]	210
Rod length, [mm]	215
Intake Valve Closed - IVC, Exhaust Valve Open - EVO	
IVO	160 BTDC
IVC	520 BTDC
EVO	520 BTDC
EVC	160 BTDC

2.3 Experimental setup

The article presents the experimental research method, and the experimental layout diagram is shown in Figure 4. A diagram of the equipment system which mixes diesel fuel - and coconut oil with heating by the engine's coolant water before supplying fuel to the engine is shown in Figure 5. The experimental procedures are performed according to the Japanese engine experimental cycle [10].

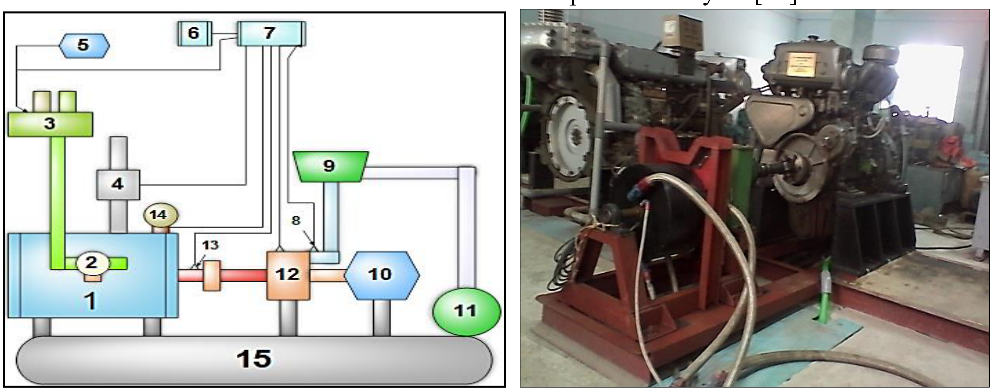

Fig. 4. Experimental setup diagram and photo-realistic

1 - Engine, 2 - Three-way valve to change fuel into the engine, 3 - Mixing device, 4 - Exhaust gas sensor and exhaust gas meter, 5 - Power supply, 6 - Computer, 7 - Sensor connection device, 8 - Coolant sensor, 9 - Coolant tank, 10 and 12 - Regulator and load (torque) for engine, 11 - Pump, 13 - Speed sensor, 14 - Throttle adjustment mechanism, 15 - Engine platform.

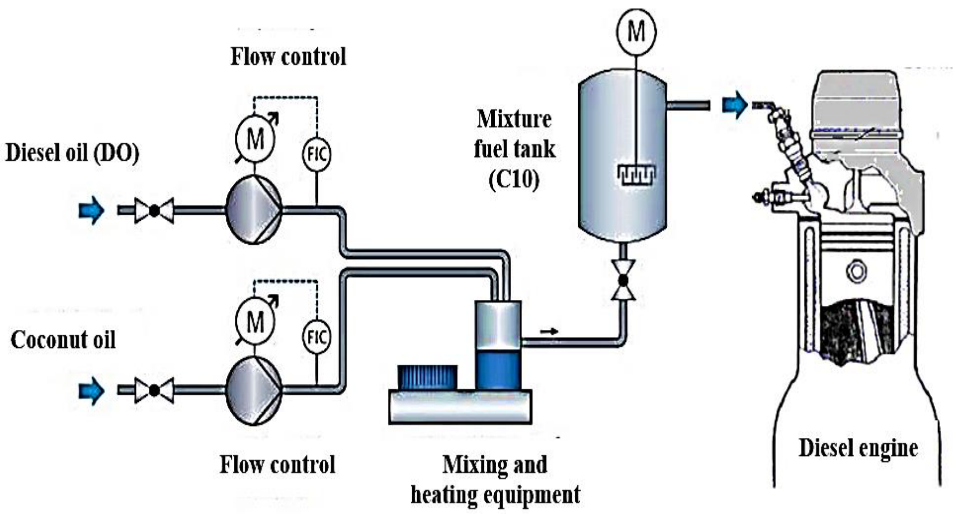

Fig. 5. Mixture fuel supply diagram to the engine

2.4 Measuring equipment:

The hydraulic brake Dynomite 13:
The hydraulic brake Dynomite 13 of Land Sea Company - the USA and the attached measuring device (Figure 6) are used to cause load and measure torque (load), and power. Loading the engine is done through torque adjustment in the hydraulic brake (M_b):

$$M_b = G_w.C.(T_{in} - T_{out}), \quad [N.m] \qquad (1)$$

The engine torque (M_e) will be equal to the sum of the torque calculated on the dynamometer and the torque in the hydraulic brake:

$$M_e = M_b + p.l, \quad [N.m] \qquad (2)$$

Engine power is determined:

$$N_e = n.M_e / 9550, \quad [kW/h] \quad (3)$$

Specific fuel consumption is determined:

$$g_e = G_e / N_e, \quad [g/kW.h] \quad (4)$$

In the above formulas: G_w - the amount of water required for the brake to work [kg]; C - the specific water heat [J/kg.K]; T_{in}, T_{out} - the temperature at inlet and exit brake [K]; p – dynamometer [N]; l - swing arm length [m]; n - the test engine speed [rpm]; G_e - hourly fuel consumption [l/h].

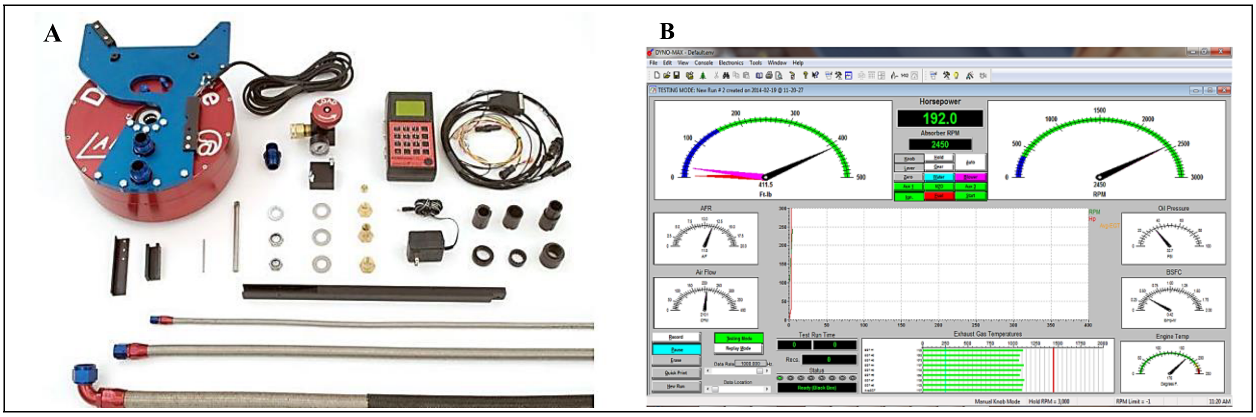

Fig. 6. Hydraulic brake and measuring devices (A), power meter program interface (B)

The device MSA-PC-SE.NR 00601 is used to measure the smoke opacity of diesel engine exhaust:
The MSA-PC-SE.NR 00601 instrument of Beissbarth - Germany, and measurement program interface (Figure 7), used to measure soot emissions through the exhaust smoke opacity. The MSA-PC uses local flow measurement technology to directly and continuously measure the supplied exhaust gas samples. The measurement technique is based on the coverage of the exhaust sample in the measurement range, from transparent to completely dark. The transparency level is recognized as no smoke in the sample tube (0%), and the dark level is recognized as completely covered (99.9%). Opacity (N%): 0 ÷ 99.9%.

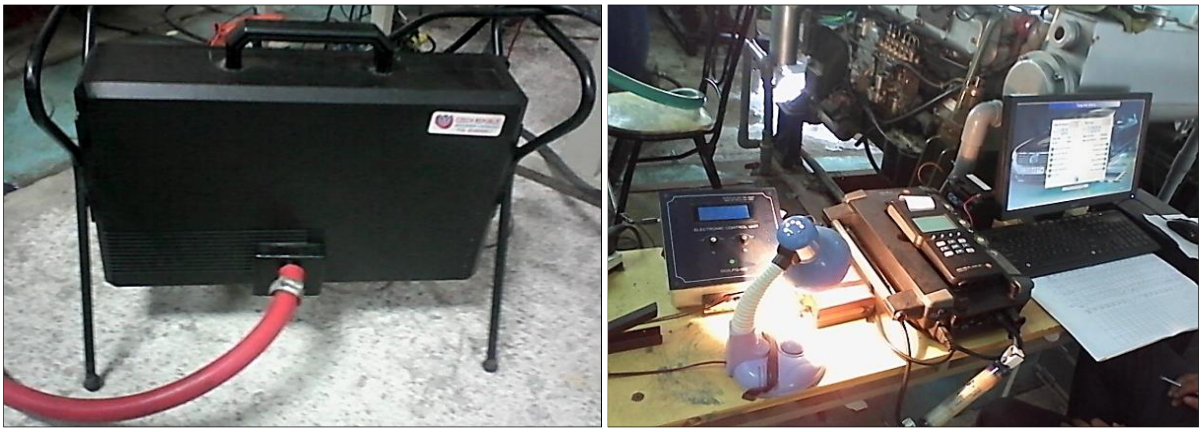

Fig. 7. The smoke meter MSA-PC-SE.NR 00601

3 Research results and discussion

Figure 8 shows the test results of a diesel engine when using a mixture of fuel, diesel - coconut oil (C10). The engine power is reduced, leading to a higher fuel consumption rate than that of the engine using traditional diesel fuel. However, in Figure 9, the soot emission of engines using C10 is lower than that of diesel fuel. This is a favorable factor to reduce pollutant emissions from diesel engines because coconut oil contains lower sulfur and carbon mass, and it minimizes the amount of soot, resulting in reduced soot emissions. It is because the amount of soot emitted after the intake valve works is the difference between the amount of soot formed and the amount of soot oxidized.

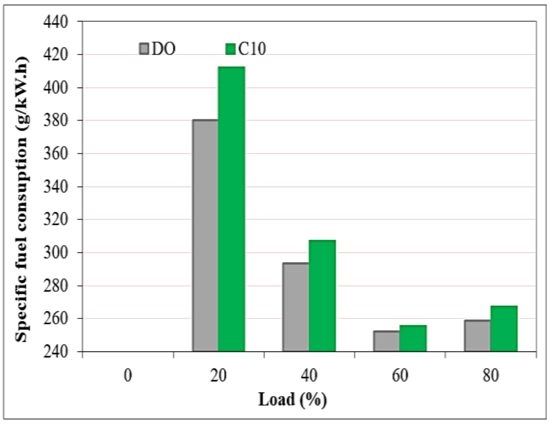

Fig. 8. Comparison of specific fuel consumption DO and C10

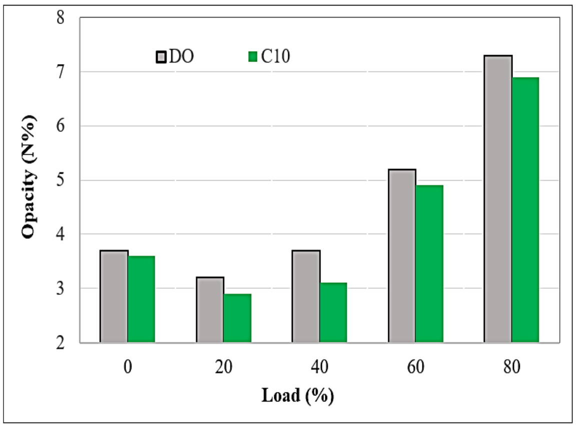

Fig. 9. Comparison of soot emission of fuel DO and C10

4 Conclusion

When using a mixture of fuel, diesel - coconut oil (C10) for diesel engines of fishing vessels, it has higher fuel consumption and lower soot emissions compared with the engine using traditional fuel. On this basis, it is possible to figure out solutions to improve the combustion progress of diesel-coconut oil mixture to increase power, reduce fuel consumption for the engine, and contemporaneously reduce emissions (soot emissions). Hence, the development of biofuel for diesel engines of fishing vessels from coconut oil will reduce environmental pollution and the use of renewable raw materials.

Reference

1. A. K., Agarwal, A. Dhar, *Renew. Energy*, **52**, 283-291. (2013) https://doi.10.1016/j.renene.2012.10.015
2. B. B. Challen, Rodica1999: Diesel Engine Reference Book. ISBN O 7506 2176 1 Library of Congress Cataloguing in Publication Data (1999).
3. C. Venkataramana Reddy, B.K. Venkanna and S.B. Wadawadagi. *Bioresour. Technol.* **10** (2) (2010).
4. D. A. Taylor. Introduction to Marine Engineering, Elsevier Butterworth - Heineman. Paperback ISBN: 9780750625302 (2003).
5. G. Vaitilingom, "Coconut oil as fuel for diesel engines" FIT, Suva. Fiji Department of Energy and Fiji Institute of Technology (2009).
6. Novarianto, H. *CORD*, **38**, 22-29 (2022) https://doi.org/10.37833/cord.v38i.453
7. IEA - International Energy Agency. Technology Roadmap, Biofuel for Transport. OECD/IEA, Paris (2011).
8. K. Kannan. and M. Udayakumar, *J. Eng. Appl. Sci*. **5**(5), pp42 (2010).
9. M. A. Kalam, M, Husnawan, & H. H. Masjuki, *Renew. Energy*, **28**(15), 2405-2415 (2003).
10. K. Mollenhauer and H. Tschoeke, Handbook of Diesel Engines, *Springer-Verlag Berlin Heidelberg* (2010). https://doi. 10.1007/978-3-540-89083-6.
11. Mai Duc Nghia and Nguyen Manh Cuong., Research on Solutions to Improve the Combustion Efficiency of Biofuel in Diesel Engine by Simulation and Experiment, 16th International Symposium on Advanced Science and Technology in Experimental Mechanics, 3-6 November 2021, Hanoi, Vietnam, Organized by Institute of Mechanics – Vietnam and the Japanese Society for Experimental Mechanics, Proceedings, ISBN: 978-604-76-2463-8 (2021).
12. S. Bari. Diesel Engine - Combustion Emissions, and Condition Monitoring, ISBN 978-953-51-1120-7, Publisher: Intech, Chapters Published April 30, (2013) https://doi.10.5772/2782.
13. Proceedings of the international conference "Vietnamese coconut trees - Values and potentials", Vietnam National University Publishing House, Ho Chi Minh City, Vietnam, August (2014).
14. S. M. M. Samarakoon, L. H. P. Gunarathne, J. Weerahewa, *CORD,* **38***, 1-7 (2022).* https://doi.org/10.37833/cord.v38i.431 .
15. Test Record of Yanmar 6EY18AL x 400 kW Engine. n.d. Yanmar Co., Ltd. Webpage : https://www.yanmar.com/marine/wp-content/uploads/2020/05/Operation-Manual_4JH3DTE-49961-202851.pdf