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Study on Combustion Performance of Palm Oil Biodiesel Blend

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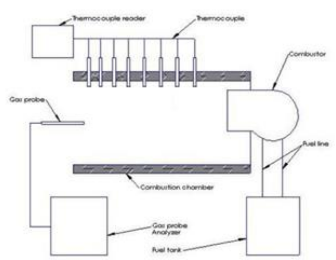
Graphical abstract



Abstract

The world today is adversely affected by the rapid growth of various industries which use fossil diesel fuel as a main source to power their respective industries. As such, these natural resources are increasingly reduced thus resulting in price increments. A study was conducted to find a way to develop alternative energy sources that are environmentally friendly and renewable. One of the potential sources of energy is palm oil. Therefore, this project is intended to look at the effect of combustion of biodiesel from palm oil which is carotino palm oil. This project will include the study of the physical characteristics of the fuel such as density, viscosity, and surface tension. In terms of combustion, it includes emissions during the combustion process, the temperature profile and the flame length. Several carotino biodiesel blends have been made, i.e. B0, B10, B20, B30, B40, B50, and B100 whereby each blend will be burned in the combustion chamber in three conditions which are at equivalent ratios of 0.6, 1, and 1.4. Temperature profile, gas emissions, and flame length for every combustion test will be recorded. An overall view from this test shows that B10 biodiesel blend shows a high potential to replace diesel due to its high energy content although the gaseous emissions are not the lowest.

Keywords: Biodiesel blend; palm oil; combustion

■1.0 INTRODUCTION

Nowadays, people seek for alternative source to replace the fossil fuel due to its depletion and the high current price of fossil fuel is really high as well as the liberation of large volumes of dangerous gas, i.e. carbon dioxide (CO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and sulphur oxides (SO_x) [1]. For example, aviation fuel is a specialized type of petroleum which is generally of higher quality than fuels used in road transport. As of 2008, the jet fuel prices had reached levels of more than three times those of 2004 [2].

Fossil fuels are fuels formed by natural processes such as anaerobic decomposition dead organisms in the soil. The age of the organisms and their resulting fossil fuels are typically millions of years, and sometimes exceed 650 million years [3]. Fossil fuels contain high percentages of carbon and include coal, petroleum, and natural gas. They range from volatile materials with low carbon and hydrogen ratios like methane, to liquid petroleum and non-volatile materials composed of almost pure carbon, like anthracite coal. Methane can be found in hydrocarbon fields, alone, associated with oil, or in the form of methane clathrates [4].

Diesel is another fossil fuel used in diesel engines which is produced from the fractional distillation of crude oil at temperature range of 170°C to 350°C at atmospheric pressure. This process will form carbon chains with mixture between 8 and 21 carbon atoms per molecule [5]. Compositions of fossil diesel fuel depend on the source of crude petroleum, purification techniques and methods of separation. Basically they are mixtures of saturated, olefinic and aromatics hydroarbon with carbon molecule content from C9 to C20 with little proportion of sulfur, nitrogen and oxygen containing organic compounds [6].

In general, diesel fuels are divided into two grades which are 1-D grade (diesel No. 1) and 2-D grade (diesel No. 2). Diesel No. 1 is generally a straight run distillate with boiling range from 170°C to 270°C while for diesel No. 2 the boiling range is from 180°C to 350°C. In general, diesel No.2 is primarily used in all vehicles with both on-road and off-road applications. Some guidelines have been established internationally for diesel fuel quality by American Society of Testing and Materials (ASTMs), while some countries have their own standards, which may vary slightly from ASTM property limits. ASTM standards are continuously reviewed and updated from time to time. In Malaysia, we also have our own standard which is known as Malaysian Standards (MS) [7].

Biodiesel can be produced from many sources. It depends on availability of the sources in each country or region. Biodiesel is currently the most widely accepted alternative fuel for diesel engine. The blending of the biodiesel and petroleum diesel can be used in existing diesel engine without modifications to the engine. Biodiesel, produced from any vegetable oil or animal fat, generally has higher density, viscosity, cloud point and cetane number, and lower volatility and heating value compared to commercial grades of diesel fuel [8, 9].

The plantation area for oil palm in Malaysia can be divided into three categories which are Peninsular Malaysia, Sabah and Sarawak. As noted, the total land converted to oil palm plantations in Malaysia shows dramatic increase within the past few years. In Sabah and Sarawak, the drastic increase in the 1990s can be attributed to the government policy in the intensification of palm oil industries in East Malaysia [10]. Carotino oil or scientifically known as palm methyl ester is a viscous refined derivative of palm oil. From previous research, the solid oxide catalyst, $Mg_xCO_{2-x}O_2$ by co-precipitation of corresponding mixed metal nitrate solutions was successfully used for production of methyl ester or carotino oil.

Basically, in preparing biodiesel, palm oil mixed with methanol and NaOH will undergo chemical conversion process and phase separation to get methyl ester. The disadvantage of this reaction is that it will produce unwanted material, glycerol. This reaction will form two layers with glycerol at the bottom layer and the crude ester which is methyl ester will be at the top layer. To remove glycerol from crude ester the product will be washed using water [11]. Then, methyl ester will undergo purification and ester separation process to get the selected molecular weight. For research purpose, normally people use rotary vacuum pump to separated ester [12]. There are four main technology processes to separated ester, i.e. dilution or micro-emulsion, supercritical methanol, transesterification and pyrolysis [13].

Usually, the oxidation of the fuel is not always complete for combustion process in a compression ignition (CI) engine. This is because the combustion occurs only at the interface between the fuel-injection system and air compressed in the cylinder. Soot particles are one the undesired product that forms in combustion process. Soot particle consists of a carbon nucleus with some inorganic material and adsorbed hydrocarbons, SO_X, other emission gases and water as follows:

$$C + O_2 = CO_2 + Q1 \quad (1)$$
$$2H_2 + O_2 = 2H_2O + Q2 \quad (2)$$
$$S + O_2 = SO_2 + Q3 \quad (3)$$

Equations 1-3 represent the heat evaluating from the reaction. These are called exotherm reactions because producing heat. It is different with endotherm which the process that need heat to form reaction. However, even the combustion process produce heat that give benefit to us, the reaction of sulphur oxide with water will produced different types of sulphur acid which can cause acid rain and corrosion.

■2.0 METHODOLOGY

2.1 Physical Properties of Fuel

The physical properties of Carotino Palm Oil biodiesel (B100) and its blends (B10, B20, B30, B40 and B50) as well as petroleum diesel (B0) are showed in Table 1. These properties were tested using standard procedures at N11 laboratory, Faculty of Chemical Engineering and Petroleum Engineering at Universiti Teknologi Malaysia. B10 refers to the fuel with volumetric blend ratio of 10% Carotino Palm Oil biodiesel and 95% petroleum diesel. B20, B30, B40 and B50 are defined in the same manner as B10. The fuels tested experimentally for combustion performance are B0, B10, B20, B30, B40 and B50. From Table 1, it can be noticed that the density, kinematic viscosity, surface tension and specific gravity all increases as the amount of Carotino Palm Oil biodiesel proportion increases. However, only B0, B10, B20, and B30 meet the standard value for all physical properties.

2.2 Experimental Set-up

Figure 1 shows the schematic of experimental set-up for combustion test. The set-up includes a conventional burner, thermocouple, thermocouple reader, electronic gas analyser, airspeed reader, fuel tank, a camera, and combustion chamber. The sample fuel to be tested was stored at the fuel tank and was then delivered to a conventional burner which initiated the combustion using excess fuel and air passed from the main compressor until reached stable condition (30 minutes). The combustion test has been done at different equivalent ratio. The lowest equivalent ratio mean less airflow and rich of fuel, while highest equivalent ratio has less fuel consumptions but exceed air.

Table 1 Physical property of carotino palm oil biodiesel blends

	Density, g/cm3	Surface tension, mN/m	Viscosity, mm/s²	Cloud Point, ˚C
Standard range	**0.81-0.87**	**23-28**	**1.5-5.8**	**18>**
Diesel	0.836	27.1	3	-12
B10	0.835	28	3.6	-9
B20	0.839	28.04	4	-7
B30	0.84	28.2	5.7	-6
B40	0.843	28.26	10.2	-3

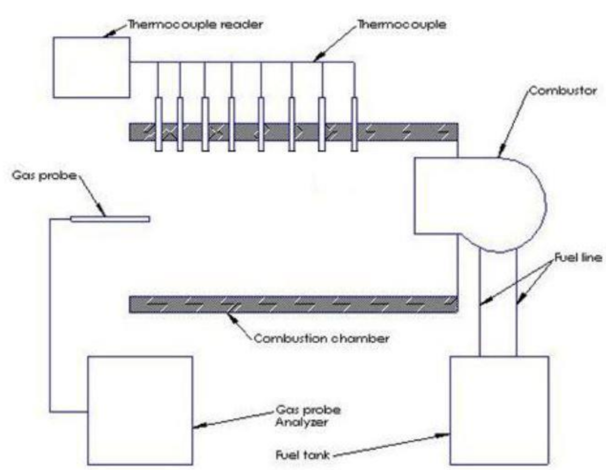


Figure 1 Schematic of experimental set-up for combustion test

2.3 Measurement Procedures

B0 was poured into the fuel tank. The conventional burner was switched on and set at equivalent ratio equal to 0.6. The camera was mounted on a tripod to capture flame length with high consistency and to avoid vibration. For gas emission measurement, sample fuel then burned in the combustion chamber until reach the stable condition (30 minutes). Automatic gas analyzer will record the rate of emission and at the same time thermocouple reader will give the result of temperature along the combustion chamber. After finishing the measurement, the tank and fuel supply line were cleaned and flushed using the next testing fuel. The whole experiment was repeated by replacing B0 with B10, B20, B30, B40 and B50. The experiment was repeated again at equivalent ratio 1 and 1.4. The connecting chamber that connects to automatic gas analyzer is placed near the combustion chamber to measure gas emission.

3.0 RESULTS AND DISCUSSION

The experimental results for combustion test will include gas emissions, temperature profile and flame length. The highest emission for NO_X, SO_2, and CO_2 mostly occur at equivalent ratio equal to 1 for each blends fuel. When fuel is more than the air, it will released highest content of CO gases. The pattern for gas emission, wall temperature and flame length at all equivalent ratio are same but different in value. Only combustion at equivalent ratio equal to 1 will be discussed.

3.1 Gas Emission Analysis Based on Type of Fuel Blends

Gas emission was measured at exit plane of the combustion chamber by connecting the chamber to the automatic gas analyser. In order to replace the fossil diesel fuel, it is important to know if the emission from combustion of palm oil biodiesel blends can reduce the greenhouse gases or not. Figures 2-4 show the emission rate of NO_X, SO_2, and CO respectively for each fuel blends at different equivalent ratio. From the graph at equivalent ratio equal to 1, B50 show the lowest emission rate of NO_X followed by diesel fuel at rate 33ppm and 36ppm respectively. The highest NO_X emission recorded by B20 at rate 42 ppm. As we know, this gas in some condition react with the oxygen in the air to produce ozone, which is also an irritant and eventually form nitric acid when dissolved in water.

B50 also noted as the blend fuel that emit the lowest SO_2 gases with rate 3 ppm. B10 and B30 emitted same amount of SO_2 with diesel fuel at rate 7 ppm. While again, B20 emitted the highest SO_2 but not really high if compare with diesel fuel. From the graph, as the amount of palm oil carotino increase in the blend, the amounts of SO_2 emitted are decreased. Emission of sulphur compounds especially SO_2 are directly related to the sulphur content inside the fuel. In normal combustion, sulphur dioxide (SO_2) will make up to 95% of all sulphur oxides released.

As we know, lately compositions of CO in the atmosphere remain increased from time to time. It formed when the fuel is not completely burned with air, thus, the carbon contained in the fuel will react with oxygen in the air to form carbon monoxide. Again, B50 blend show the lowest emission of CO during combustion process which is lower than CO emitted by diesel fuel. Higher oxygen content in biodiesel contributes to a complete fuel oxidation in locally fuel-rich regions which leads to a decrease in CO emission.

Theoretically, gas emission rate for fuel blend will decrease as the percentage volume of palm oil carotino oil increase. So, diesel fuel must have the highest emissions rate followed by B10, B20, B30, B40 and B50. This occur due to error during the experiment conducted such as environment air condition that disturb the movement of released gas from flow into connecting chamber before the emission rate measured by automatic gas analyser. Anyway, B50 shows the great potential to replace diesel fuel because have the lowest rate of emission.

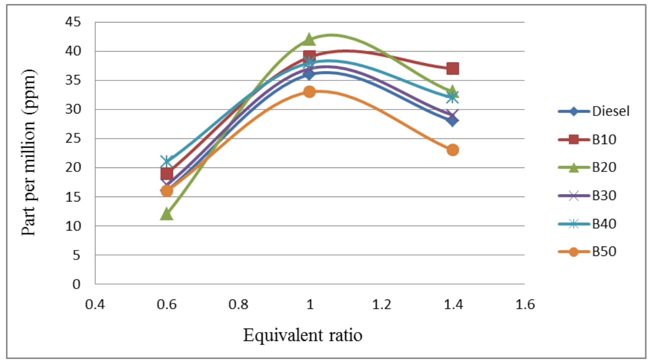


Figure 2 NOx emission

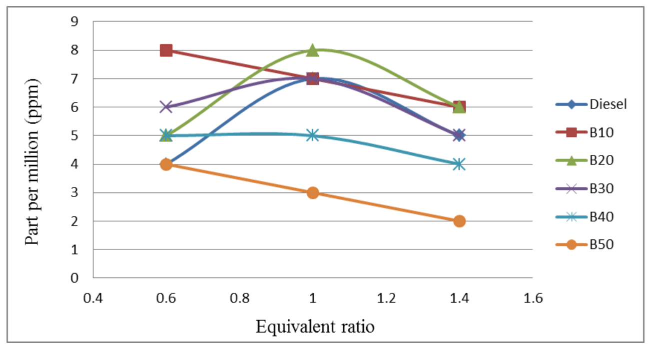


Figure 3 SO_2 emission

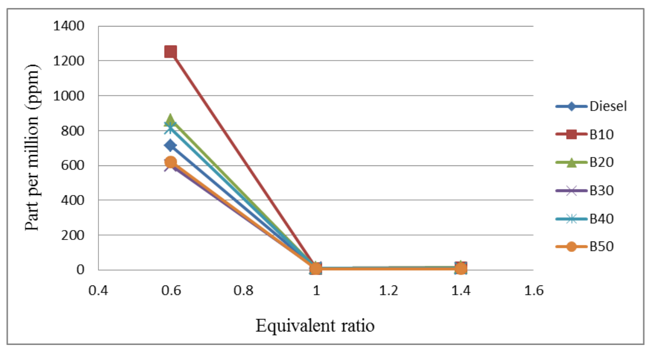


Figure 4 CO emission

3.2 Temperature Profile

During doing the combustion test, temperature along the combustion chamber has been recorded. There are two areas of temperature which is wall temperature and inside temperature. There are eight points along the combustion chamber where the temperature has been recorded for wall temperature. While for inside temperature only three points recorded due to lack of probe. The three locations are at the front, middle and at the end of combustion chamber.

From graph in Figure 3, it shows that diesel fuel has the highest temperature profile during combustion test followed by B10. There is a trend of temperature where when the percentage volume of palm biodiesel increase, the temperature profile along combustion chamber will decreased. However, the different of temperature profile for all biodiesel blends are small. B50 and B40 show the lowest temperature profile. The reason of having high temperature profile is because diesel and B10 have high energy content. On the other hand, B30, B40 and B50 biodiesel blends shows lower temperature profile because it might have lower energy content compare to others.

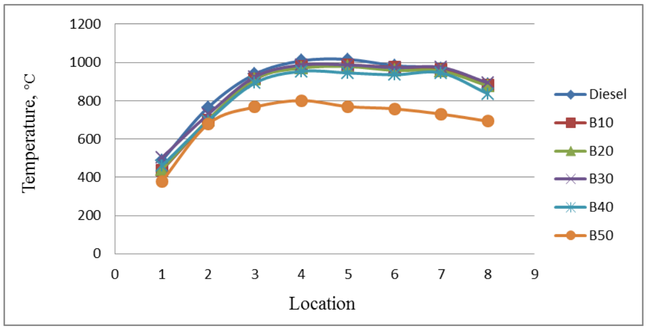


Figure 5 Wall temperatures at equivalent ratio 1

Besides that, inside temperature will give the actual temperature of the flame during combustion process. But, due to lack of experimental stuff only three locations in the combustion chamber have been recorded the temperature. For sure, the inner temperature will give higher value than the wall temperature. Graph in Figure 4 show the temperature profile inside the combustion chamber. Basically the inner temperature of the combustion chamber gives the same pattern as the wall temperature. However, there are a little different in terms of value. For diesel fuel, temperature profile along combustion chamber wall is nearly same with others biodiesel blends while for inside region the temperature is not even close with other biodiesel. From inner temperature profile we can said that fossil diesel is much better than biodiesel blend due to high energy content.

3.3 Flame Length

Flame length tightly related to the temperature profile in combustion test. Flame length does not depend on fluid dynamics, but only on the fuel characteristics such as fuel type, pool diameter, and burning rate. A rough picture of flame length has been taken as shown in Figure 5. Figure shows that the highest flame length is recorded by diesel fuel and B10 which is 90 cm. For B20 and B30 biodiesel blends the flame length are around 75 cm and the shortest flame length record by B40 and B50. This is due to low energy content in B40 and B50 biodiesel fuel. The flame at equivalent ratio equal to 1 looks brighter than the flame at equivalent ratio 0.6. The soot formations also decrease at this condition.

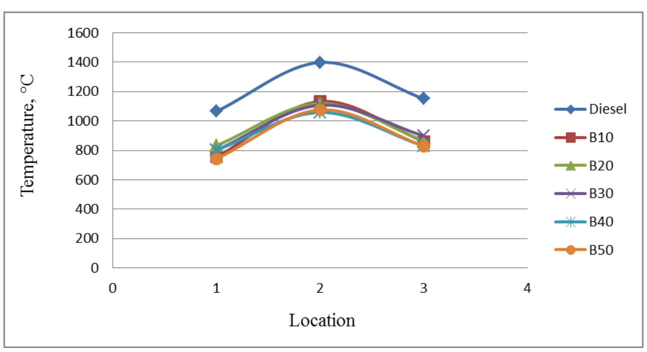


Figure 6 Inside temperatures at equivalent ratio 1

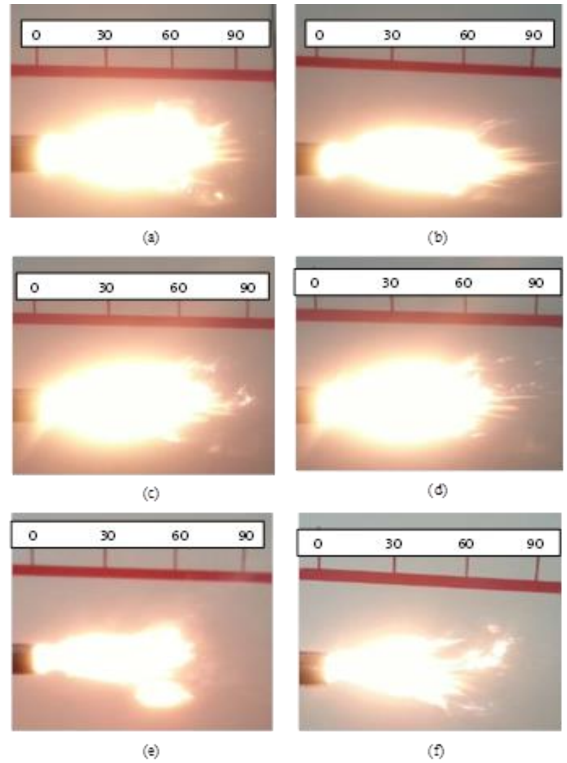


Figure 5 Flame length at equivalent ratio 1

4.0 CONCLUSION

As summary, Carotino palm oil early was blended with petroleum diesel at different blends of B0, B10, B20, B30, B40 and B50. The physical properties and combustion experiment has been conduct. From the results of this study, the following conclusions could be drawn:

(1) The density, viscosity< pour point, cloud point, and surface tension of fuels will increase as the percentage of Carotino palm oil in blends increase.
(2) In term of gas Gas emission, no uniform pattern but B50 has the lowest emission rate.
(3) In term of temperature profile, B10 are suitable to replace diesel fossil fuel due to high temperature profile nearly diesel fuel which mean high energy content
(4) Overall, diesel fuels have better performance compare to biodiesel blends

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References

[1] Piccot, S. D., Buzun, J. A., & Frey, H. C. 1990. *Emissions and Cost Estimates for Globally Significant Anthropogenic Combustion Sources of NOx, N_2O, CH_4, CO, and CO_2.* NTIS, Springfield, VA (USA).
[2] Shafiee, S., & Topal, E. 2010. A Long-term View of Worldwide Fossil Fuel Prices. *Applied Energy*. 87(3): 988–1000.

[3] Mann, P., Gahagan, L., & Gordon, M. B. 2003. *Tectonic Setting of the World's Giant Oil and Gas Fields.*

[4] Novaczek, Irene, September 2000. *Canada's Fossil Fuel Dependency*.

[5] Chris, D. C. 2006. Implementing Phytoremediation of Petroleum Hydrocarbons. Methods in Biotechnology. *Phytoremediation: Methods and Reviews.* London, UK: Springer. 99–100.

[6] Nikanjam, M. 1992. Lubricity of Low Aromatics Diesel Fuel.

[7] Suzuki, S., Hori, M., Nakamura, H., Tezuka, T., Hasegawa, S., & Maruta, K. 2013. Study on Cetane Number Dependence of Diesel Surrogates/Air Weak Flames in a Micro Flow Reactor with a Controlled Temperature Profile. *Proceedings of the Combustion Institute*. 34(2): 3411–3417.

[8] Graboski, M. S., & McCormick, R. L. 1998. Combustion of Fat and Vegetable Oil Derived Fuels in Diesel Engines. *Progress in Energy and Combustion Science*. 24(2): 125–164.

[9] Schumacher, L. G., Wetherell, W., & Fischer, J. A. 1999. Cold Flow Properties of Biodiesel and Its Blends with Diesel Fuel. In *ASAE/CSAE-SCGR Annual International Meeting, Toronto, Ontario, Canada, 18-21 July, 1999*. American Society of Agricultural Engineers (ASAE).

[10] Abdullah, A. Z., Salamatinia, B., Mootabadi, H., & Bhatia, S. 2009. Current Status and Policies on Biodiesel Industry in Malaysia as the World's Leading Producer of Palm Oil. *Energy Policy*. 37(12): 5440–5448.

[11] Abdullah, A. Z., Razali, N., Mootabadi, H., & Salamatinia, B. 2007. Critical Technical Areas for Future Improvement in Biodiesel Technologies. *Environmental Research Letters*. 2(3): 034001.

[12] Eevera, T., Rajendran, K., & Saradha, S. 2009. Biodiesel Production Process Optimization and Characterization to Assess the Suitability of the Product for Varied Environmental Conditions. *Renewable Energy*. 34(3): 762–765.

[13] Koh, M. Y., & Mohd Ghazi, T. I. 2011. A Review of Biodiesel Production from Jatropha Curcas L. Oil. *Renewable and Sustainable Energy Reviews*. 15(5): 2240–2251.