Combustion and Emission Characteristics of Palm Oil-Based Biodiesel in a Liquid Fuel Burner

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Abstract. This paper presents an experimental investigation of the combustion characteristics of palm oil methyl ester (POME) or called as biodiesel (B), in an open-ended combustion chamber or called as open-ended liquid fuel burner. The performance of conventional diesel fuel (CDF) and various percentages of POME and CDF, which are B10 (10% biodiesel) and B30 (30% biodiesel) were studied to evaluate their performance. Combustion temperature profile in the combustion chamber and exhaust emission concentrations such as NOx, CO and SO_2 have been carried out using five different equivalent ratios such as $\Phi = 0.6, 0.8, 1.0, 1.2$ and 1.4. The results show that as the biodiesel content increased, the emission significantly increased except for the NOx emission. It was also found that higher biodiesel content resulting faster combustion rate at near burner region, especially for $\Phi = 1.0$ due to higher Cetane Number (CN) although the lower overall temperature profile produced compared to CDF alone. This proved the suitability of biodiesel for an enhanced transportation engine performance in the near future.

*Keywords:*Palm oil; Combustion; Nitrogen oxide; Oil Burner; Equivalence ratio.

1. Introduction

World population growth demand a multi-fold increase in energy consumption. Various sectors such as manufacturing, industry, transportation, domestic, and agriculture depend primarily on fossil energy. Current fossil fuels are producing many kinds of emission gaseous such as smoke, carbon monoxide CO, nitrogen oxides NOx, particulate matter PM,

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and unburnt hydrocarbon UBHC. These emissions can be environmentally detrimental if not treated correctly [1]. Unfortunately, the main global concern is that, the amount of reserve fossil fuel, which decreases significantly opposing to the demand growth around the world especially in the transport industry. Petroleum reserves are depleting at breakneck pace. The known fossil fuel reserves are not only limited, but concentrated in certain regions [2]. The awareness of the acute shortage of crude oil started during 1970's when worldwide fuel sources have been controlled and reduced by the oil producing countries especially from middle-east region [3]. The critical situation has encouraged the researchers and manufacturers to explore another alternative fuel. Two ways to solve this are: adaptation of the engine to the fuel or vice versa. The later method seems more applicable considering the existing engine. Recent years, numerous efforts have been put into searching a suitable alternative fuel. The aims are to fulfil the high requirement of a wide spectrum of application with emphasis on efficiency, flexibility, reliability and environmental compatibility [4]. Aside from that, more stringent emission regulation standard demand researchers and manufacturers to find a solution and cope with the new standard. One of the possible alternatives is biodiesel. Biodiesel can be divided into two groups: animal fat-based and plant-based. Both groups have been extensively tested by researchers and manufacturers for their emission, performance and suitability [5]. This is due to its availability in large volume, among all other renewable energy sources. Biodiesel actually has been around for almost a century [6]. For modern biodiesel application, however, it can be quite a challenge. The main reason behind that are less performance output from the engine or burner. Besides that, the characteristic of the biodiesel itself, such as high density, viscosity, iodine value and poor volatility worsen the problem [7]. Problems on the engine such as atomization, injector fouling, tar depositing, contamination and even filter system reduces the application of the biodiesel alternative to current diesel. Much attention currently is focusing on the improving biodiesel characteristics [8]. In other words, the biodiesel is not as efficient as diesel in term of producing energy. While the biodiesel is more environmentally friendly, the researchers decided to blend both of them to harvest their respective advantage. The only problem left is to find the optimum ratio between both in order to produce a better fuel blend.

Generally, biodiesel provides a significantly reduced in emission like CO, UBHC, SOx and PM but the opposite was observed in NOx [9-10] that was tested for Marotti oil methyl ester and they concluded that the use the diesel content decreased their performance such as brake thermal efficiency (BTE) and exhaust gas temperature (EGT) also decreased. Among the blends, B20 emitted lesser UBHC, CO and smoke, but the largest amount of NOx along with increased BTE. Supported by [11] they found out that B20 of Mahua oil methyl ester produced the highest BTE. But as the biodiesel content increased, CO, HC, EGT and NOx also increased opposing other studies. Another study by [12] observed that an increased in Pongamia oil methyl ester produced lesser BTE, CO and smoke emission. Therefore, this study is done with the intention of understanding the characteristics of palm oil based biodiesel to reduce the emission gasses. The intention of this study is important to understanding the combustion and emission characteristics of palm oil based biodiesel in a liquid fuel burner. For this study, Malaysia can use the alternative fuel for daily work.

2. Methodology

In this paper, palm oil was modified using transesterification process to improve their properties. The product is Palm Oil Methyl Ester (POME) which was produced using an alkali catalyst transesterification process. Methanol 25% (by oil volume) and 1% potassium hydroxide KOH were added together with palm oil and stirred at 1000 rpm speed for 2 hours at temperature 60ŗC using magnetic stirrer. The products were biodiesel on the top while glycerin at the bottom, which can be separated. Later, distilled water was sprayed to biodiesel (POME) and again reheated at temperature 60ŗC to remove any excess impurities and remaining glycerin [1-3].

2.1. Fuel Blends and Physical Properties

POME was mixed with CDF to produce biodiesel series such as B10, B20 and B30 blends. The blends were sampled accordingly to test its properties using standard procedure. The information is shown in Table 1.

Table 1. Fuel blends properties

Properties	CDF	B10	B30
%POME Volume	0	10	30
%CDF Volume	100	90	70
Density (kg/m^3)	835.75	837.78	845.42
Kinematic Viscosity 40˚ (mm^2/s)	3.0623	3.8375	3.9985
Surface Tension (mN/m)	29.57	29.83	30.50
Calorific Value (kJ/kg)	45628	45118	44098

2.2. Experimental Set-Up

The experiment set-up consists of Industrial Grade Light Air Burner as shown in Figure 1 using a standard commercial spray nozzle, utilizing type K-thermocouple which is able to measure temperature up to 1200˚Celsius in an open-ended steel combustion chamber with 1m length. The temperature was recorded using a Midi data logger which was constantly recorded throughout the experiment. The emission later was directed to Horiba Enda 500 gas analyzer in the separate room to ensure fresh air supply in the experiment room. For this experiment, five equivalent ratios were used 0.6, 0.8, 1.0, 1.2, and 1.4. The equivalent ratio was calibrated using anemometer based on air mass volume rate setting on the burner prior experiment. A constant fuel supply of 1.5gal/h has been provided using the same nozzle. The burner specification is shown in Table 2.

Table 2. Burner specification (Baltur IL BT 14G/W Light Oil Burner)

Capacity	Fuel	Voltage	Power Output	Thermic Capacity
7.5-14.5 kg/h	1.5˚ E/20˚ C	230 V	140 kW	87-172 kW

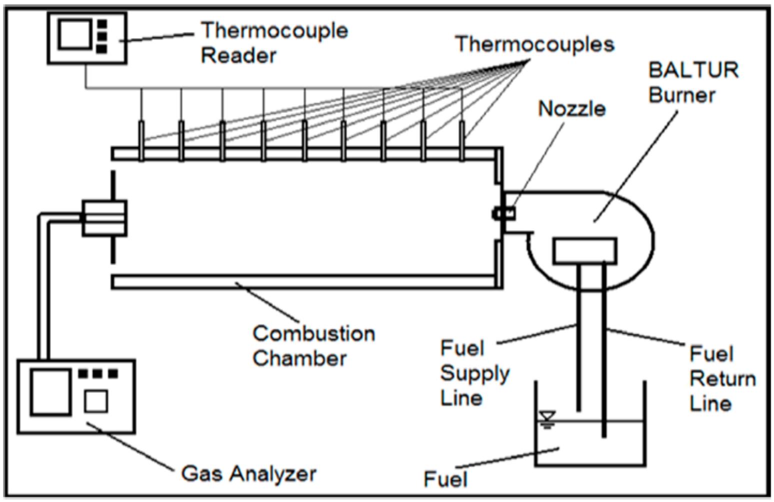


Figure 1. Experimental Set-up.

3. Results and Discussion

3.1. Gas Emission Analysis based on Type of Fuels Blends

3.1.1. Effect of biodiesel blends on NOx emissions

The graph between emission and different equivalent ratio has been plotted in Figure 2. It was observed that both SO_2 and CO emission decreased as the biodiesel content increased but oppositely for NOx emission. At lean region, the NOx production, mostly because of thermal effect due to high temperature region at mid-length of combustion chamber. At rich region, the increment of NOx can be explained by the high amount of oxygen content in the excess biodiesel, which increased the production of NOx by an oxidation process of fuel-bound nitrogen. In addition, fuel NOx also is much more sensitive to stoichiometric conditions.

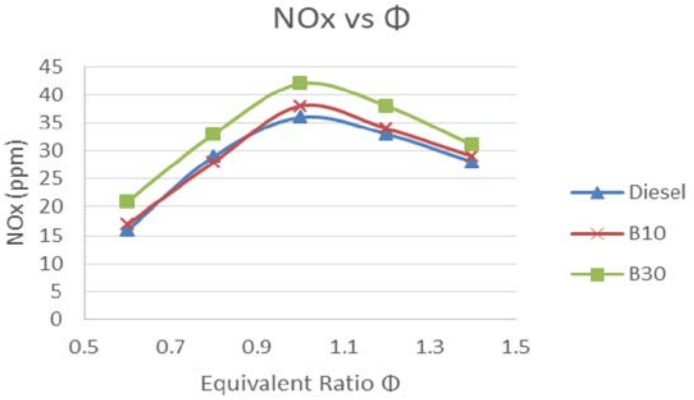


Figure 2. NOx concentration profile for different fuel blends at five equivalent ratios.

3.1.2. Effect of biodiesel blends on CO emissions

Figure 3 shows the carbon monoxide emission decreased as the biodiesel content increased due to better combustion process. The higher amount of oxygen and lower carbon content in the blends were responsible for this situation. The lowest value of CO can be observed at stoic condition and later rise significantly at rich region. At rich region, excess fuel, resulting incomplete combustion due to low oxygen content in the mix. At 1.4, the CO production reached plateau condition. It was suggested that, the excess fuel was no longer become a factor and CO production reached its limit.

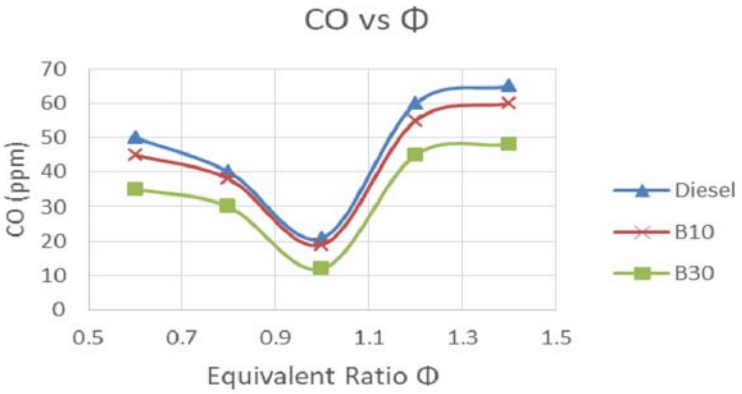


Figure 3. CO concentration profile for different fuel blends at five equivalent ratios.

3.1.3. Effect of biodiesel blends on SO_2 emissions

Figure 4 shows and focuses on lean region, the temperature was increasing, and excess air was available thus favouring the production of SO_2. It can be observed that SO_2 gradually increased until it reached its peak at stoichiometric condition. At rich condition, less oxygen limits SO_2 production thus gradually decreased until 1.4.

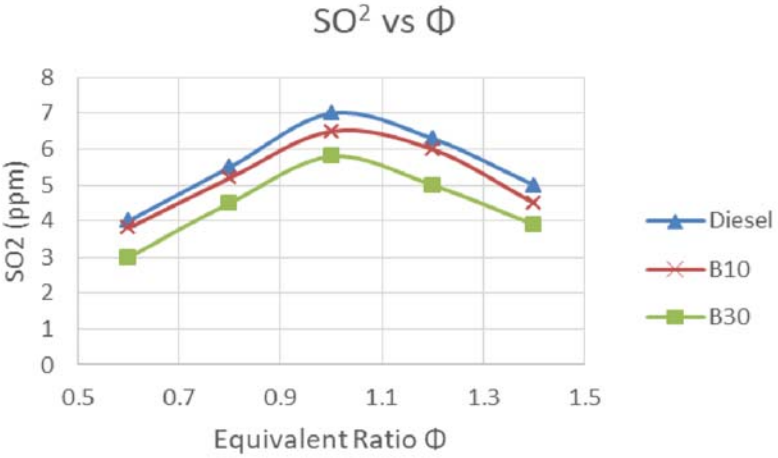
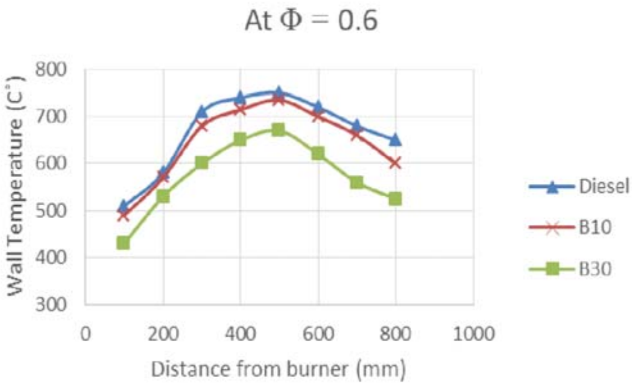
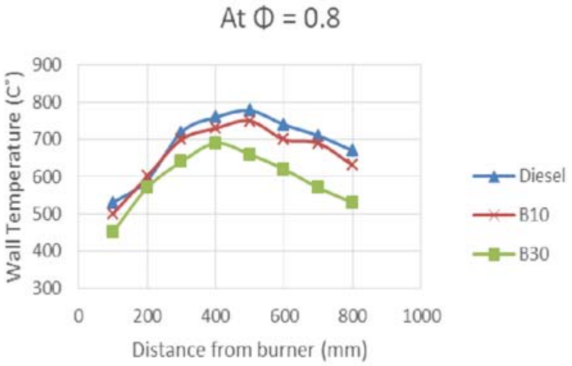


Figure 4. SO_2 concentration profile for different fuel blends at five equivalent ratios.

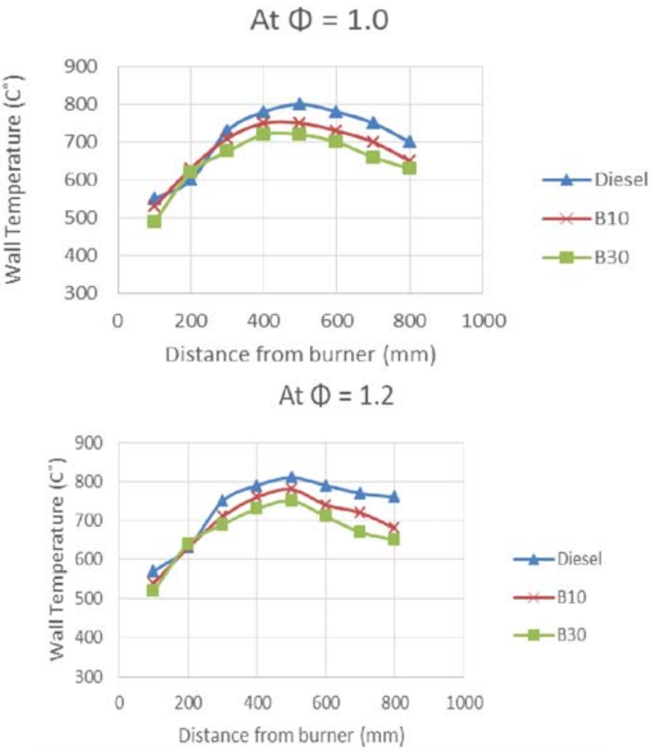
3.2. Wall Temperature Profile

In general, the combustion temperature will increase as the fuel to air mixture increased. In this paper, five different equivalent ratios were investigated. Although, the thermocouple only measure the wall temperature of the combustion chamber, it was sufficient enough to capture the overall temperature of the combustion process. From Figure 5 (a) to (e), it can be observed that as the fuel-air mixture increased, the overall combustion temperature also increased. This is because the higher heat released due to extra fuel in the mixture. Maximum temperature points were located at the mid-length of the chamber at 400-600 mm distance from the burner. In this region, the fuel and air were completed mixed and homogeneously combusted together thus resulting peak temperature points logged. For $\Phi < 1$, in Figure 5(a) and (b), B10 blend and the diesel burning temperature profile were near apart and gradually separated as the $\Phi > 1$ as shown in Figure 5(d) and 5(e). During $\Phi < 1$, the temperature started to drop gradually at the end of the combustion chamber. But in the rich environment $\Phi > 1$, the temperature profiles were almost the same at the end of the chamber and this can be concluded that due to excess fuel at that region, the burning process becomes longer and distributed along the chamber. At 100-200 mm region, the biodiesel showed higher temperature profile especially when $\Phi>1$. This can be explained by higher Cetane Number (CN) of biodiesel. CN has a close relation with ignition rate. Higher CN reduced the ignition rate which provides a better combustion process. This is where the advantage of biodiesel blends because biodiesel blends have higher CN compared to diesel. Therefore, CN can be easily increased with increasing the biodiesel ratio in the blend composition.

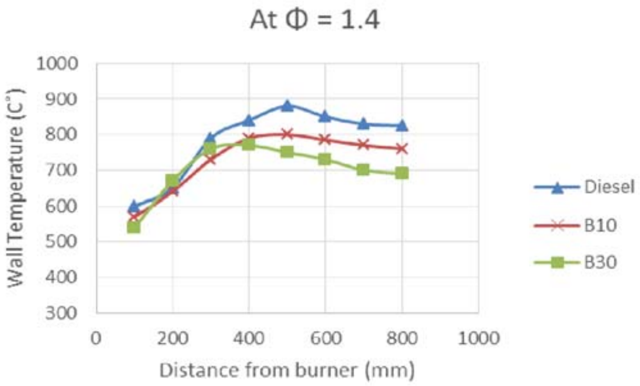




a) Temperature profile at Φ = 0.6
b) Temperature profile at Φ = 0.8



c) Temperature profile at Φ = 1.0
d) Temperature profile at Φ = 1.2



e) Temperature profile at Φ = 1.4

Figure 5. Wall temperature profile at different equivalent ratios.

4. Conclusion

Combustion experiment was conducted using CDF and POME blends of B10 and B30. The combustion performance of POME blends was compared to CDF under several air mass-fuel ratios. The properties differences of the blend affect the performance and emission product. As the diesel contents increased, the calorific value of blends decreased which explained the lower overall combustion chamber temperature compared to diesel alone. However, the advantage of higher biodiesel content can be observed at the 0-200 mm distance from the burner where both B10 and B30 outperform the diesel with respect to its performance especially when Φ=1.0 which caused by lower ignition rate due to higher Cetane Number. Lower ignition rate means faster and better combustion thus proving the potential of POME biodiesel for transport application near future. Besides, significant reductions in CO and SO_2 emission can be observed as the biodiesel content higher but NOx emission was higher mainly due to fuel NOx. Thus, it is recommended that future research will focus on reducing the NOx emission with emphasis on improving biodiesel properties through appropriate process.

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