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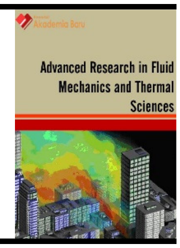

Combustion Performance of Firing Biodiesel from Waste Cooking Oil in an Oil Burner

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ABSTRACT

Depletion of fossil fuels, concerns on the environment, and the fluctuating fuel price have become the major drives in searching for sustainable alternative fuel. With these regards, a study was conducted to develop alternative diesel fuel from waste cooking oil (WCO) through esterification and transesterification processes. The study involves production of WCO biodiesel, characterisation of fuel physical properties, and determination of combustion temperature and gaseous emissions. Several fuel blends are used in the combustion test, i.e. petroleum diesel fuel, WCO B5, WCO B15, and WCO B25. Combustion test is conducted under several equivalence ratios which are 0.8, 0.9, 1.0, 1.1 and 1.2 to examine the combustion performance in the lean, stoichiometric, and rich conditions. The results suggest that increasing the percentage of WCO biodiesel in the fuel blends causes the wall temperature to decrease due to lower energy content in WCO biodiesel. Significant improvements in the emissions of NOx, SO_2, and CO are observed with 7.27%, 37.5%, and 54.5% reductions respectively for WCO B25 at equivalence ratio of 1.0. Findings from this study show that WCO biodiesel blend is a promising alternative to diesel fuel.

1. Introduction

The world is facing a threatening situation of fossil fuels depletion and environment deterioration as a consequence of rising energy demands. Various measures have been implemented to compensate the environmental pollution and fossil fuel depletion and the most desired solution is alternative fuels. Biodiesel is a renewable fuel with similar properties to diesel, comparable engine performance and less unburnt hydrocarbon and particulate matter emissions [1]. Biodiesel or also known as fatty acid methyl esters is derived from renewable lipid feedstock such as vegetable oils and animal fats. There is various feedstock such as chicken fat, beef tallow, soybean oil, rapeseed oil, canola oil, palm oil, jatropha oil, and waste cooking oil which have been investigated to be used in

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biodiesel production [2]. The important criteria to be considered when selecting for feedstock are cost and availability. Tt differs based on location and climate. For example, the common use of Soybean oil in the United States of America (USA) and Rapeseed oil in Germany as feedstock for biodiesel production are due to the availability of the feedstock [3]. In this study, waste cooking oil is chosen as feedstock due to its high availability and low cost. Utilizing waste cooking oil as feedstock in biodiesel production minimizes the environmental harms that are caused by disposing it into the ecosystem, as well as help meeting the energetic challenge [4].

The combustion performance of biodiesel is strongly associated to its physical properties and chemical composition. For instance, the fuel physical properties such as density and kinematic viscosity can affect the fuel combustion in the chamber caused by poor atomization of fuel [5]. Utilization of 100% pure biodiesel in a diesel engine require some engine modification to prevent damage to the engine components. Accordingly, blending biodiesel with petroleum diesel fuel could avoid engine modification and enhance the properties of the biodiesel blends, as well as improving the combustion performance.

The combustion of fossil fuel releases hazardous emissions such as carbon dioxide (CO_2), oxides of nitrogen (NOx), carbon monoxide (CO), oxides of sulphur (SOx), unburned hydrocarbon (UHC), and particulate matter (PM). These gaseous emissions deteriorate the environment quality and thus risking the human health. For instance, NOx at high concentration contributes to the production of photochemical smog at ground level and is a precursor to acid rain which could damage plant lives. Additionally, CO is a highly toxic gas that could reduce the capability of the blood to absorb oxygen and can cause asphyxiation and even death at high concentration. The application of biodiesel blends has shown significant results in the reduction of harmful gaseous emissions, however it slightly reduces the engine performance. A study has been conducted using biodiesel blends in a single cylinder, 4 stroke diesel engine and the results show appreciable reduction of CO, UHC, and NOx emissions [6]. Another study conducted on diesel engine using waste cooking oil biodiesel also showed that the B5 and B20 blends exhibited similar performance as that shown by diesel [7]. In another study conducted using Jatropha oil as feedstock to convert into biodiesel has shown that the biodiesel produced has similar properties as diesel and may be used as substitute to diesel in a long run [8].

In this study, WCO biodiesel is produced through esterification and transesterification procedures and is then blended with petroleum diesel fuel in several proportions which are B5, B15, and B25 where the number denotes the volume percentage of WCO biodiesel in the blend. Characterisation of physical properties such as density, specific gravity, kinematic viscosity, calorific value, and surface tension are conducted to investigate the effects of WCO biodiesel on the properties of the fuel blends. Combustion tests are then performed for all fuel blends including diesel fuel under equivalence ratio of 0.8, 0.9, 1.0, 1.1, and 1.2 indicating fuel-lean, stoichiometric, and fuel-rich conditions. The wall temperature during combustion and the gaseous emissions at the exhaust are collected and analysed.

2. Experimental Test

2.1 Production of Biofuel

The WCO biodiesel is prepared according to the procedure of two-step transesterification process due to high content of fatty acid in the WCO feedstock. The two-steps indicate the processes to produce methyl esters which are the esterification and transesterification process. There are several phases in producing biodiesel namely the pre-treatment, esterification, transesterification, and post-treatment processes. Firstly, the pre-treatment process is done by heating the WCO for one hour on a rotary evaporator and filtering the WCO to remove any solid waste substances from the oil. Next, the esterification process is conducted by adding methanol (MeOH) of 50% from the volume of WCO and sulphuric acid (H_2SO_4) of 1.5% from the volume of WCO at reaction temperature of 60°C and reaction time of three hours while being stirred at 400 rpm as shown in Figure 1. The methyl ester is collected for subsequent processes while the glycerol is removed as waste. Then, the transesterification process is conducted by adding methanol (MeOH) of 25% from the volume of WCO and potassium hydroxide (KOH) of 1% from the mass of WCO, reacted at 65°C for 2 hours while being stirred at 400 rpm as shown in Figure 1. The methyl ester is again collected and the glycerol was removed as waste. Following the transesterification process, the collected methyl ester underwent post-treatment process through washing with distilled water at temperature of 50°C to 60°C to remove any unreacted reactants. The methyl ester is then filtered and heated for 30 minutes while being stirred at 400 rpm. Finally, the refined end product which is methyl ester or also known as biodiesel is produced.

The WCO biodiesel produced is then blended with Pure Diesel Fuel (PDF) from Petronas at several proportions which are B5, B15, and B25. The B5 blend refers to the fuel with volumetric blend ratio of 5% WCO biodiesel and 95% PDF. The physical properties of WCO biodiesel (B100) and its blends (B5, B15, and B25) as well as PDF (B0) were tested according to American Society for Testing and Materials (ASTM) standard procedure.

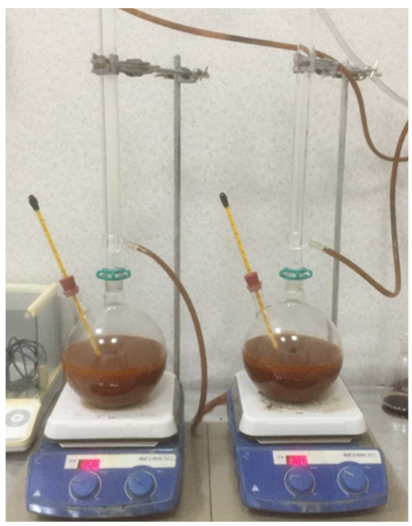


Fig. 1. Experimental setup for esterification and transesterification processes

2.2 Combustion Experiment

Figure 2 shows the schematic of the experimental set-up for combustion test. The combustion tests are conducted using Baltur Light Oil Burner with a Steinen Standard Oil Burner nozzle installed which is placed into a 1 m open-ended mild steel combustion chamber insulated with Hy-cast cement. The wall temperatures during combustion are obtained via eight Type – K thermocouples placed 0.1 m apart from the burner and the temperature readings are observed using a Graphtec GL220 Midi Logger. The emissions from the combustion are collected and analysed at the exhaust of the combustion chamber by using Horiba ENDA 5000 Gas Analyser.

The combustion tests are performed under several equivalence ratios (Ø) which are 0.8, 0.9, 1.0, 1.1, and 1.2. The equivalence ratios of 0.8 and 0.9 represent lean fuel mixture, a condition where air is more than fuel. Meanwhile, equivalence ratios of 1.1 and 1.2 represent rich fuel mixture where fuel is more than air. A stoichiometric condition with the amount of air and fuel that is chemically correct, is represented by Ø = 1.0. The combustion tests are performed for all WCO biodiesel blends including PDF and the results of wall temperature and emissions are analysed.

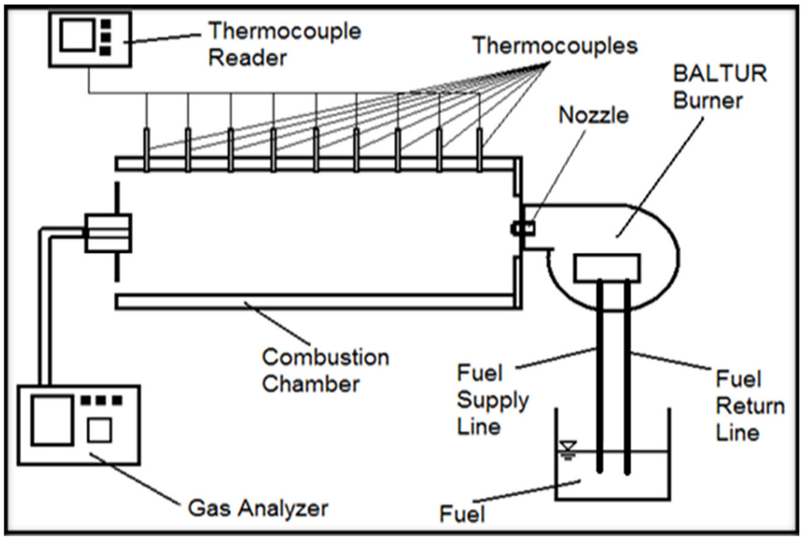


Fig. 2. Schematic of combustion experimental test setup

3. Results and Discussion

The experimental results of this study include fuel properties, wall temperature profiles, and emissions concentrations from combustion tests.

3.1 Fuel Properties

The density, specific gravity, calorific value, kinematic viscosity, and surface tension of WCO biodiesel blends and PDF were determined according to ASTM D941, ASTM D287, ASTM D240, ASTM D445, and ASTM D971 respectively. Table 1 shows the physical properties of each fuel sample. It can be observed that PDF has the lowest value of density, specific gravity, kinematic viscosity, and surface tension. Meanwhile, WCO B100 shows the highest value of density, specific gravity, kinematic viscosity, and surface tension. However, for calorific value, PDF has the highest value and WCO B100 has the lowest value. It can be concluded that the density, specific gravity, kinematic viscosity, and surface tension of the fuels increase as the percentage of WCO biodiesel increases in the fuel blends. On the other hand, the calorific value decreases with increasing percentage of WCO biodiesel in the fuel blends. However, it can be seen that B5 properties are closely similar to that of PDF.

3.2 Wall Temperature Profile

During the combustion tests, the wall temperatures along the combustion chamber were recorded by eight thermocouples placed along the combustion chamber. Figure 3 shows the wall temperature profiles for the combustion tests under several equivalence ratios. Similar trends can be observed where the temperature starts to increase from the first thermocouple placed at 0.1 m from the burner to about 0.6 m to 0.7 m distance from the burner, but then decreases at 0.8 m. This phenomenon is due to the hottest region of the flame where the combustion is most effective at the distance of 0.6 m and 0.7 m from the burner. In addition to that, it can also be observed that PDF burns at the highest temperature while WCO B25 burns at the lowest temperature. This can be related to the calorific value property which is defined as the energy content in a substance. PDF has the highest calorific value and it decreases as the percentage of WCO biodiesel in the fuel blends increases. Therefore, PDF with highest calorific value produced highest wall temperature compared to fuel blends with lower calorific value due to the energy content in the fuels [9].

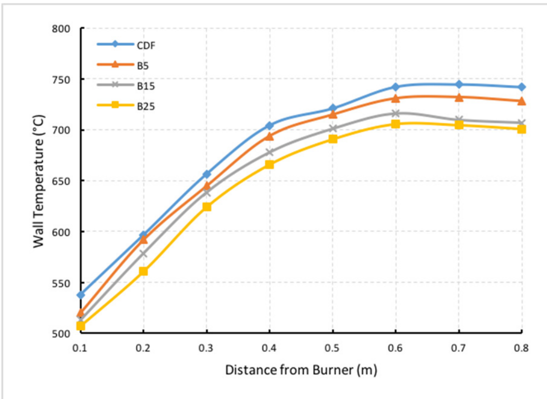
Table 1
Physical properties of fuel samples

Fuel	Density	Specific Gravity	Calorific Value	Kinematic Viscosity at 40°C	Surface Tension
Unit	**g/cm³**		**MJ/kg**	**cSt**	**mN/m**
Standards	ASTM D941	ASTM D287	ASTM D240	ASTM D445	ASTM D971
PDF	0.8437	0.840	45.29	3.34	28.6
B5	0.8451	0.841	45.07	3.69	29.2
B15	0.8456	0.843	44.65	3.74	29.7
B25	0.8491	0.845	43.92	3.86	29.9
B100	0.8665	0.860	39.83	4.21	31.1

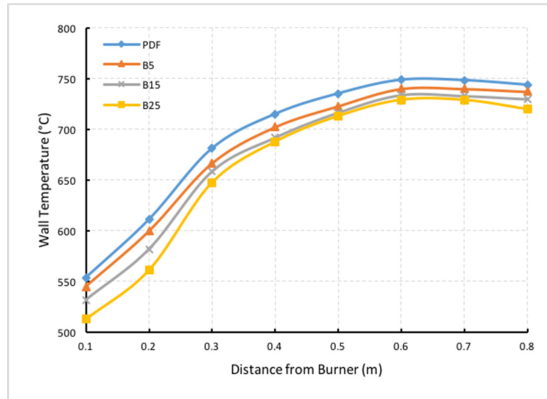
The combustion at equivalence ratios of 0.8 and 0.9 are in the lean fuel condition which describes the condition where there is more air than fuel. The temperature profile in Figure 3 at equivalence ratio of 0.8 shows that the highest temperature is achieved by PDF which is 744.5°C, followed by 731.9°C for WCO B5, 716°C for WCO B15, and 705.5°C for WCO B25. These peak temperatures are obtained at the distance of 0.6 m and 0.7 m from the burner. Similar trend is observed at equivalence ratio of 0.9, where the highest temperature is achieved by PDF at 748.7°C, followed by 739.9°C for WCO B5, 733.6°C for WCO B15, and 728.8°C for WCO B25.

It can be observed that the peak temperature decreases as the percentage of WCO biodiesel increases in the fuel blends due to the aforementioned energy content of the fuel. The high combustion temperature by PDF is attributed to the high energy content of PDF which then releases greater heat energy during combustion[10]. The reduction of temperature for the equivalence ratio of 0.8 for WCO B5, WCO B15, and WCO B25 as compared to PDF are 1.69%, 3.83%, and 5.34% respectively, whereas the temperature reduction for equivalence ratio of 0.9 for all WCO blends as compared to PDF are 1.18%, 2.02%, and 2.66% respectively. These show that there is only a slight difference between WCO fuel blends and PDF, therefore this finding suggests that the WCO biodiesel blends is acceptable for the application in a diesel burner.

Furthermore, it can be deduced from the wall temperature profiles that the temperature rises as the equivalence ratio increases. A possible explanation of this result is that as the equivalence ratio increase, having excess amount of fuel in the fuel-air mixture releases more heat energy during combustion which then resulted in the increase of the wall temperature [11]. Apart from that, the physical properties of the fuel blends which are the density, kinematic viscosity, and surface tension also play a role in the combustion performance in terms of atomization of fuel during the fuel injection process. The result suggests that there is a relationship between surface tension, kinematic viscosity, and density as the surface tension increases with kinematic viscosity and density. The present findings seem to be consistent with other research which found that the fuel with higher density, kinematic viscosity, and surface tension produces poor atomization and large droplet size which causes poor combustion compared to fuels with lower density, kinematic viscosity, and surface tension [12].



(a)



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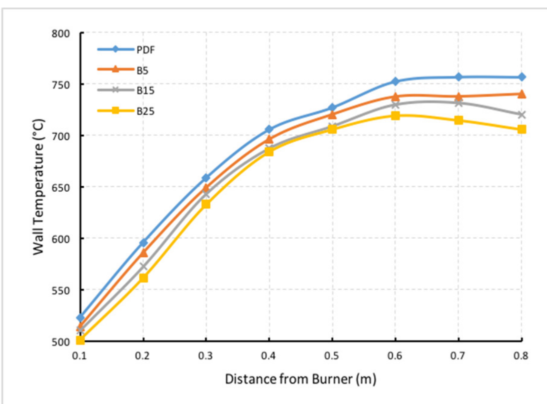

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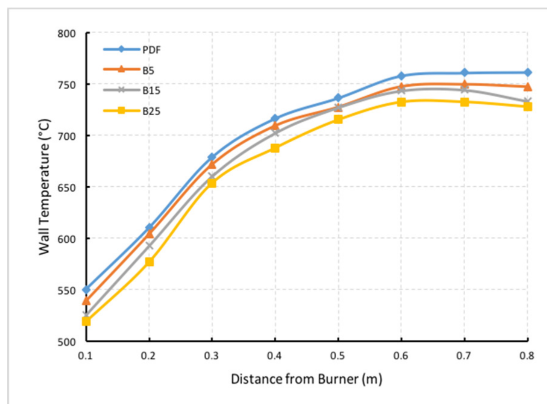

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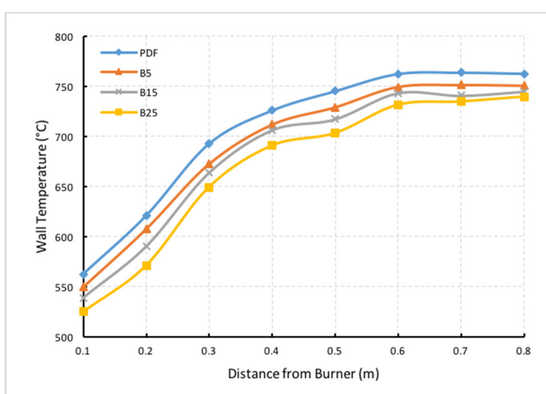

(e)

Fig. 3. Temperature profiles for equivalence ratios of (a) 0.8, (b) 0.9, (c) 1.0, (d) 1.1, and (e) 1.2

3.3 Gaseous Emissions

The gaseous emissions generated from the combustion of PDF and WCO biodiesel blends were collected and analysed by Horiba Enda 5000 gas analyser and the results are in parts per million (ppm). The findings have important implications for developing alternative fuel to replace PDF. In this study, emissions of oxides of nitrogen (NOx), sulphur dioxide (SO_2), and carbon monoxide (CO) which are toxics to human and environment are discussed.

3.3.1 NOx emission

As shown in Figure 4, the highest NOx emission is emitted by PDF which is 55 ppm, followed by 54 ppm, 53 ppm, and 51 ppm by WCO B5, WCO B15, and WCO B25 respectively. The reduction of NOx emissions of WCO blends B5. B15, and B25 as compared to PDF are 1.82%, 3.64%, and 7.27% respectively. This result supports the claim that WCO biodiesel is a promising alternative to PDF as it contributes to lesser NOx emissions.

It can also be observed that the NOx emissions gradually increase from lean region with equivalence ratios of 0.8 and 0.9 until reached the maximum emissions at equivalence ratio of 1.0, and then decrease in the rich region with equivalence ratios of 1.1 and 1.2. The observed increase of NOx emissions could be attributed to the increase in temperature as equivalence ratio increases. This scenario promotes the formation of NOx which is caused by the thermal effect producing thermal NO [13]. Meanwhile, the reduction of NOx emissions in the fuel rich region with equivalence ratio 1.1 and 1.2 where air is less than fuel occurs because of the restricted amount of air. The peak emission of NOx occurs at stoichiometric condition with equivalence ratio 1.0 and this is because nitrogen tend to react with oxygen due to the sufficient amount of oxygen in the complete combustion [14].

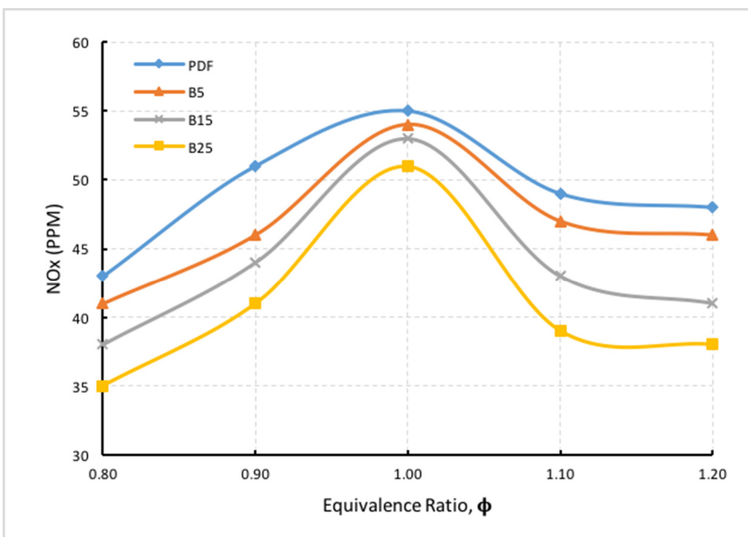

Fig. 4. Graph of NOx emissions against equivalence ratio

3.3.2 SO_2 emission

The graph of SO_2 emissions against equivalence ratio (Ø = 0.8, 0.9, 1.0, 1.1, 1.2) emitted by PDF, B5, B15, and B25 WCO biodiesel blends is presented in Figure 5. From the graph, it can be seen that the highest SO_2 emission is produced by PDF at 16 ppm, whereas the WCO biodiesel blends of B5, B15, and B25 produced 14 ppm, 13 ppm, and 10 ppm respectively. The reductions in the emissions of SO_2 as compared to PDF are 12.5% for WCO B5, 18.75% for WCO B15, and 37.5% for B25. Maximum emissions of SO_2 occurred at stoichiometric condition of equivalence ratio 1.0 for all fuel blends. This is explainable by the fact that during complete combustion, the amount of air supplied is sufficient for the sulphur compounds in the fuel to react with oxygen and thus producing SO_2 [15]. Similar trend is observed with SO_2 emissions where the emissions increases gradually in the lean fuel region and reached its maximum emission at stoichiometric, and finally decreases in the fuel rich region. The significant reduction of SO_2 emissions in WCO B5, B15, and B25 blends is attributed to lower sulphur content in the WCO blends as compared to PDF.

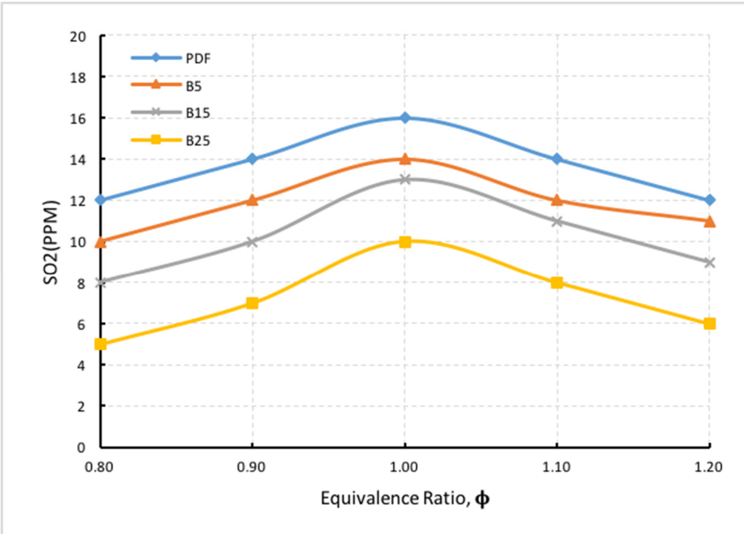

Fig. 5. Graph of SO_2 emissions against equivalence ratio

3.3.3 CO emission

The emissions of CO obtained from the combustion tests are presented in Figure 6. It is apparent from the graph that at stoichiometric condition, PDF emitted the highest concentration of CO at 22 ppm, whereas the WCO blends emitted 12 ppm, 11 ppm, and 10 ppm for B5, B15, and B25 respectively. Significant reductions of CO emissions are observed in WCO biodiesel blends as compared to PDF, with the data shows reductions of 45.5%, 50%, and 54.5% for B5, B15, and B25 respectively. A contrasting trend from that of NOx and SO_2 emissions is observed for emissions of CO where the emissions started off at high concentration at equivalence ratio 0.8 and decreases at it approaches equivalence ratio of 1.0. It finally starts increasing again in the fuel rich region at equivalence ratio of 1.1 and 1.2. The result is consistent with other study that states the decrease in the CO emissions as it reached stoichiometric combustion is due to the promotion to a more complete combustion where the oxygen fully reacts with the carbon atom and thus producing carbon dioxide (CO_2)[16]. A possible explanation for the high concentration of CO emissions in the fuel-lean and fuel-rich regions is that insufficient oxygen to complete the reaction to form CO_2 and thus producing incomplete combustion[17]. The CO emissions decrease with increasing percentage of WCO biodiesel in the blends due to oxygen enrichment in the fuel which contributes to improved and better combustion.

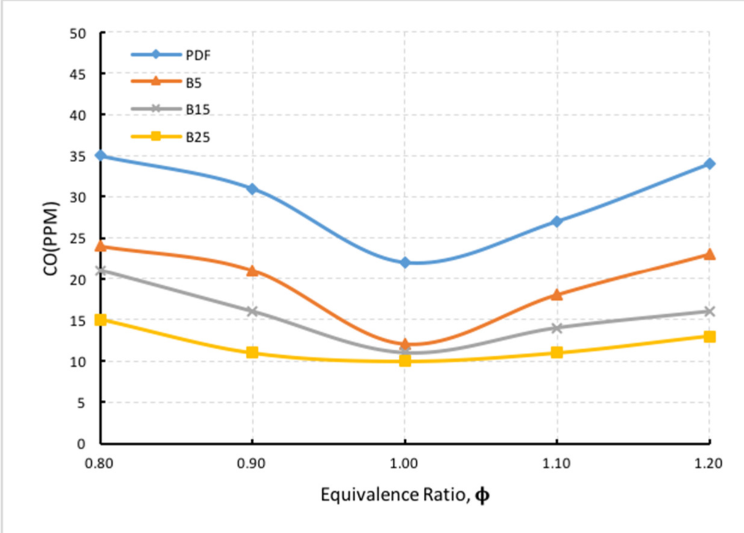

Fig. 6. Graph of CO emissions against equivalence ratio

4. Conclusion

All in all, it can be concluded from the results obtained that the density, specific gravity, kinematic viscosity and surface tension increases as the percentage of WCO biodiesel in the blend increases. However, the calorific value decreases as the percentage of WCO biodiesel in the blend increases. The results of this study indicate that the wall temperature decreases with increasing percentage of WCO biodiesel in the blend that is attributed to the calorific value of the fuels. The higher the calorific value of fuel, the higher the wall temperature will be. Moreover, higher temperature was obtained at fuel-rich equivalence ratio of 1.1 and 1.2 because more fuel is being combust. This study has also demonstrated that lower temperature is observed for fuel-lean equivalence ratio of 0.8 and 0.9 due to insufficient fuel to combust. The results of this investigation have shown that the emissions of NOx, SO_2, and CO reduces as the percentage of WCO biodiesel increases in the blends. An implication of this is that it supports the claim that biodiesel produces lower emissions of harmful gases as compared to PDF. Hence, WCO biodiesel has a good potential as an alternative fuel.

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References

[1] Shirneshan, Alireza. "HC, CO, CO2 and NOx emission evaluation of a diesel engine fueled with waste frying oil methyl ester." *Procedia-Social and Behavioral Sciences* 75 (2013): 292-297.

[2] Issariyakul, Titipong, and Ajay K. Dalai. "Biodiesel from vegetable oils." *Renewable and Sustainable Energy Reviews* 31 (2014): 446-471.

[3] Huang, Daming, Haining Zhou, and Lin Lin. "Biodiesel: an alternative to conventional fuel." *Energy Procedia* 16 (2012): 1874-1885.

[4] Abdul Raqeeb, M. "Biodiesel Production from Waste Cooking Oil." *Journal of Chemical and Pharmaceutical Research* 7, no. 12 (2015): 670-81

[5] Mat Yasin, Mohd Hafizil, Rizalman Mamat, Ahmad Fitri Yusop, Rafidah Rahim, Amir Aziz, and Liyana Amer Shah. "Fuel physical characteristics of biodiesel blend fuels with alcohol as additives." *Procedia Engineering* 53 (2013): 701-706.
[6] Attia, Ali MA, and Ahmad E. Hassaneen. "Influence of diesel fuel blended with biodiesel produced from waste cooking oil on diesel engine performance." *Fuel* 167 (2016): 316-328.
[7] Ramlan, N. A., A. A. Abdullah, and W. J. Yahya. "Combustion Performance and Exhaust Emission Analysis of Diesel Engine using Waste Cooking Oil." *J. Adv. Res. Fluid Mech. Therm. Sci.* 12 (2015): 11-20.
[8] Aliyu, Abubakar Sadiq, Abdulkarim Ali Deba, Haruna Saidu. " Green energy initiative: An overview of biodiesel production from jatropha feedstock in Nigeria", *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 35, Issue 1 (2017) 11-22.
[9] Can, Özer. "Combustion characteristics, performance and exhaust emissions of a diesel engine fueled with a waste cooking oil biodiesel mixture." *Energy Conversion and Management* 87 (2014): 676-686.
[10] Mofijur, M., H. H. Masjuki, M. A. Kalam, M. G. Rasul, A. E. Atabani, M. A. Hazrat, and H. M. Mahmudul. "Effect of biodiesel-diesel blending on physico-chemical properties of biodiesel produced from Moringa oleifera." *Procedia Engineering* 105 (2015): 665-669.
[11] Adaileh, Wail M., and Khaled S. AlQdah. "Performance of diesel engine fuelled by a biodiesel extracted from a waste cocking oil." *Energy Procedia* 18 (2012): 1317-1334.
[12] Hou, Junxing, Zhenhua Wen, Zhiqiang Jiang, and Xinqi Qiao. "Study on combustion and emissions of a turbocharged compression ignition engine fueled with dimethyl ether and biodiesel blends." *Journal of the energy institute* 87, no. 2 (2014): 102-113.
[13] Palash, S. M., M. A. Kalam, H. H. Masjuki, B. M. Masum, IM Rizwanul Fattah, and M. Mofijur. "Impacts of biodiesel combustion on NOx emissions and their reduction approaches." *Renewable and Sustainable Energy Reviews* 23 (2013): 473-490.
[14] Lanjekar, R. D., and D. Deshmukh. "A review of the effect of the composition of biodiesel on NOx emission, oxidative stability and cold flow properties." *Renewable and Sustainable Energy Reviews* 54 (2016): 1401-1411.
[15] Cordiner, Stefano, Vincenzo Mulone, Matteo Nobile, and Vittorio Rocco. "Effects of waste cooking oil biodiesel use on engine fuel consumption and emissions: a study on the impact on oxidation catalyst and particulate filter." *Energy Procedia* 61 (2014): 953-957.
[16] Gopal, K. Nantha, Arindam Pal, Sumit Sharma, Charan Samanchi, K. Sathyanarayanan, and T. Elango. "Investigation of emissions and combustion characteristics of a CI engine fueled with waste cooking oil methyl ester and diesel blends." *Alexandria Engineering Journal* 53, no. 2 (2014): 281-287.
[17] Elshaib, A. A., M. M. Kamal, and A. A. Elahwany. "Performance of a diesel engine fueled by waste cooking oil biodiesel." *Journal of the Energy Institute* 87, no. 1 (2014): 11-17.