IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: Hasyuzariza M Tobib *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **469** 012079

The performance of an HCCI-DI engine fuelled with palm oil-based biodiesel

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Abstract. The increasing requirements to control emission and fuel economy are become important recently. Furthermore, the hazardous components produced by internal combustion engine forces many researchers to consider with alternative fuel which is environmental friendly and renewable sources. This study intends to investigate the performance and emission level by using palm oil blends with diesel operated on HCCI-DI engine. In this study, an experiment has carried out on single cylinder diesel engine with port fuel injection (PFI) attached at the intake manifold. Thus, PFI introduced to control combustion, it is plugged onto compression ignition engine, therefor it will completely covered 3 basic element; controlling fuel air mixing, controlling ignition timing and introducing new fuel. The HCCI-DI engine was operated at 1800 rpm with different fuel injection quantity; ω = 1.1, 1.4, 1.7 and lambda λ = 1.8, 2.3, 2.9. It has found that different fuel injection with difference palm oil blends percentages is significantly affects the engine efficiency. Blended fuels PO5 and PO10, produce higher nitrogen oxide (NO_x) and unburned hydrocarbon (UHC) emission exchange at DI mode. At HCCI-DI mode of combustion, blended fuels PO5 and PO10 increase NO_x and reduce UHC. Meanwhile carbon dioxide (CO_2) and carbon monoxide (CO) slightly reduce which no significant change for varies ω. The usage of palm oil blends on HCCI-DI engine increase the break specific fuel consumptions (BSFC) and brake mean effective pressure (BMEP) and reduce the engine performance include engine power compare with conventional diesel fuel. Thus, palm oil biodiesel operated in HCCI-DI mode of combustion have an optimal PFI quantity to operate in minimal emission levels.

1. Introduction

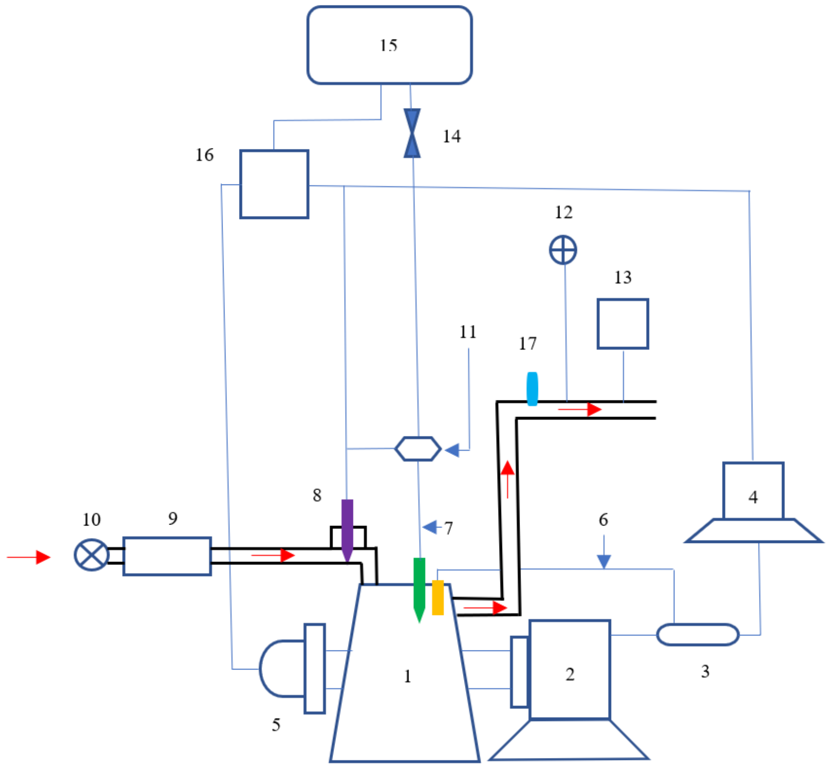
One of the biggest problems of the 21st century is linked with eventual depletion of fossil fuels, growing ambient air pollution and urgent concern about climate changes occurring because of the increased CO_2 emissions and global warming that all together provoke heavy rains, deadly floods and frequent hurricanes. In spite of high market prices, demand of mineral fuels, especially diesel fuel, increases faster than their production capabilities. Fuel consumption increases because of the growing number of diesel engine powered heavy-duty haulage trucks and city buses, agricultural tractors and self-propelled machines as well as personal light duty cars [1]. Alternative fuel as a substitute for diesel-based fuel have become increasingly important, due to environment concerns, exhausting of crude oil reserves, unstable costs and also transportation problems. Now bio-fuel getting a renewed attention because of global pressure on greenhouse reduction gas (GHGs). Variety of effort that has been undertaken by the government and private companies all around the world to resolve this problem. especially focused on reducing emissions from motor vehicles and in relation [2].

Relatively, HCCI-DI could be considered as compromised between HCCI and compression ignition diesel engine (CIDI) combustion. Some of the study have discovered advantage and disadvantage of combined combustion. Bendu and Murugan [3] study the diesel engine to HCCI mode of combustion by combination of DI mode for increase its performance and efficiency but have some of constraint such control of the engine charge composition. It is possible through varying the fuel injection timing, including multiple pulses, and its location, which can be within the intake port or from multiple in-cylinder fuel-injectors. The constraint such as low engine speeds, early auto-ignition can occur, possibly leading to knocking, while late auto ignition at high engine speeds will make HCCI susceptible to misfire, fuel fragmentation and incomplete combustion, the emissions that have produced is more higher, indicates more drivability problems, tends to reduce fuel economy, make the engine more noise, impact on engine durability and cause other fuel-system problems [4,5]. Another study by Das [6] focussed on used the effect of second injection timing, EGR, and premixed equivalence on the emission levels and combustion behaviour at a constant engine speed 1500 rpm and spilt ratio 80%, the premixed ratio was up to 0.38 at the second injection timing. The HC and CO emissions levels are higher than DI combustion. Study done by Ali Turkcan [7] investigated the diesel engine and operated as HCCI-DI used a tow stage direct injection (TSDI) strategy by fixed in two position one in the intake stroke and second in the end of compression stroke controlled by electronic controller. The fuel used was gasoline with different blends of methanol and ethanol until 20 E20 AND M20. The CFD outlets were compared with tests results of HCCI-DI mode. The adding of alcohol to the gasoline fuel reduced the NO_x emission levels. A study by Fathi [8] was focussed on used a multi-zone injection strategy of HCCI-DI, the experimental results were compared with the models which that better of single zone. This study leaded to over prediction of IMEP and in cylinder pressure and provides a better performance of engine. Ying et. al [9] study of HCCI-DI combustion and emissions in a DME engine. The result shows CO and HC emission for HCCI-DI were lower than those of HCCI engine. As for NOx emissions for HCCI-DI operation, it decreased remarkably at low loads with an increase in port DME aspiration quantity, while showed an increasing trend when the added with high loads. Ma, Lu, Ji and Huang [10] investigated the combustion behaviour and emission of HCCI-DI engine by varies the premixed ratio quantity. They found the NO_x increase as the premixed ratio was higher. However, HCCI-DI combustion could improve the brake thermal efficiency of at low to medium load.

Biodiesel or methyl esters of vegetable oils contain less or no sulfur, aromatic hydrocarbons, metals or heavy carbon residues [11]. Low amount of sulfur means decreasing the levels of corrosive sulfuric acid dilutes in the engine crankcase oil in a longer duration [13]. Moreover, since the absence of sulfur in biodiesel, it reduces the formation of acid rain. Agarwal et. al [12] have studied the use of vegetable oils in diesel engines. Palm oil biodiesel is one of treasure alternative fuel which able to operated in CI engine with different blends rate [14]. Rashed et. al [15] discussed the used of biodiesel fuel such as palm oil and jatropha in CI engine. Biodiesel fuel effect on emission levels and performance of engine. The biodiesel reduce the brake power and increased the BSFC than diesel fuel. Also, the emission levels of CO was reduced and HC also, increased in NO_x emission levels than diesel fuel. Furthermore, a study by Prabu et al [16] discussed the internal combustion engine fuelled with palm oil biodiesel and preheated it with different load conditions and compared with pure diesel with constant speed 1500 rpm. The NO_x increased 1.9% that diesel. So, the palm oil blends with diesel fuel will be a promising alternative biodiesel fuel in future. Vegetable oils offer almost the same power output with slightly lower thermal efficiency when used in diesel engine. Higher cetane number rating for biodiesel (ranges between 49 and 62) is another parameter for biodiesel to have combustion efficiency improvement in diesel engines [17,18]. Therefore, some vehicle manufacturers are positive about the use of biodiesel, citing lower engine wear as one of the fuel's benefits [16,17]. Reduction of engine emissions is a major research aspect in engine development with the increasing concern on environmental protection and the stringent exhaust gas regulation. The concern of this project is to analyze the performance and emission of an HCCI-DI engine with the blended palm oil PO5 and PO10 and compared with diesel fuel. The performance of HCCI-DI engine parameter like power, brake specific fuel consumption (BSFC) and brake mean effective pressure (BMEP). Amount of emission parameter such as a CO_2, NO_x, UHC and CO been evaluated.

2. Experimental Setup

The schematic diagram of experimental setup is shown in Figure 1.



1) Diesel Engine 2) Dynamometer 3) Controller Device 4) Personal Computer 5) Decoder 6) Pressure Sensor 7) Direct Injection 8) Port Fuel Injection 9) Heater 10) Anemometer 11) High Pressure Pump 12) Air/Fuel Ratio 13) Gas Analyser 14) Fuel Valve 15) Fuel Tank 16) ECU 17) Temperature sensor

Figure 1. Schematic diagram of engine test bed.

Table 1. The specifications of engine

Engine type	Vertical cylinder, 4-cycle air-cooled diesel engine
Injection type	Direct injection
Number of cylinder	1
Compression ratio	20.1
Displacement	219 cc
Bore × stroke	70 × 57 mm
Injection type	Direct injection

A Yanmar engine model 0.219L single cylinders, four stroke and direct injection fuel system was used in this project as shown in Figure 1. Measurement equipment fitted on the engine to gauge the engine performance and emissions. Table 1 shows the specifications of engine were used in this project.

The test will be conducted at Thermodynamics Lab, University Putra Malaysia. Engine operated with HCCI- DI mode with compositions biodiesel (PO 5 & PO 10) and compare with diesel fuel operate dual mode HCCI and DI. Table 2 shown the details of fuels. Data are being recorded when engine speed at 1800 rpm for the performance and the emissions. The performance was evaluated the value of power, brake thermal efficiency, brake specific fuel consumption (BSFC) and brake mean effective pressure (BMEP). Figure 2 shows the summarize of engine testing procedure.

Table 2. Fuels specifications

Types	Calorific Value (Mj/kg)	Density (g/ml)	Kinematic viscosity (mm^2/s)
Diesel fuel	41.5958	0.8397	3.387
PO5	37.4086	0.8364	3.6904
PO10	38.7267	0.8360	3.714

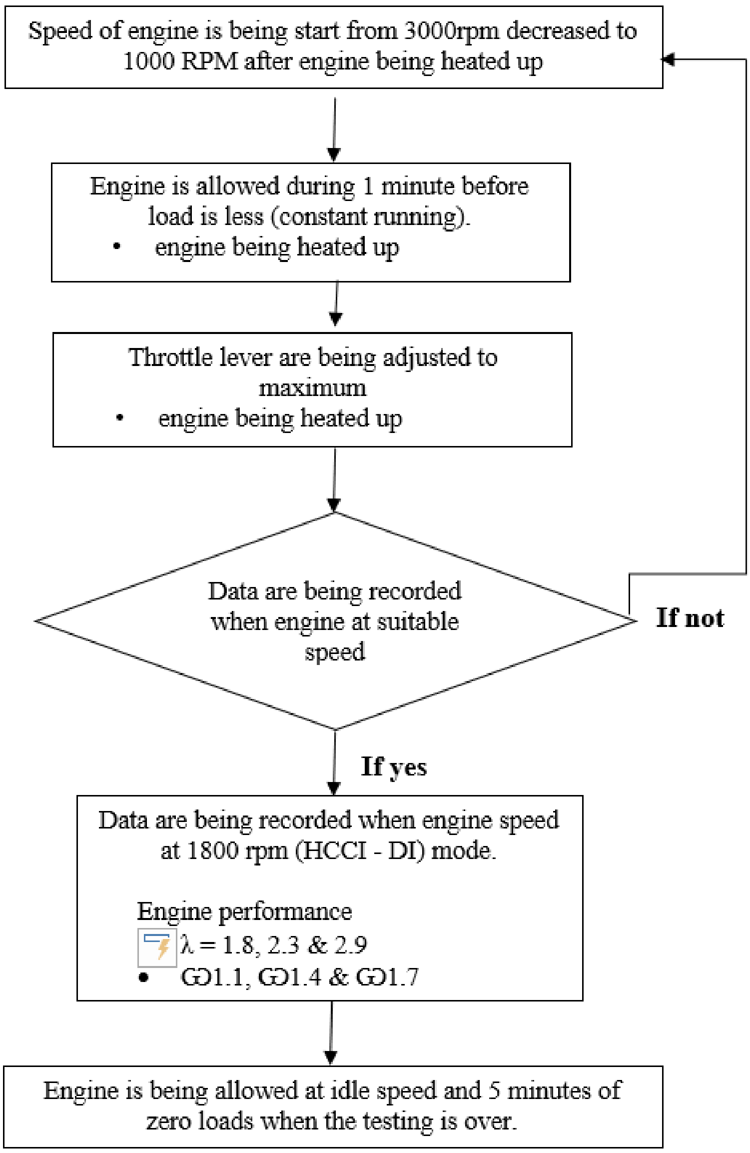


Figure 2. Engine Testing Procedure

3. Results

Figure 3 shows the engine power is higher when the operated at DI mode compared HCCI-DI mode. Power decreases when λ increase for all fuel. When ω increase engine power decrease, this indicate the engine close generate almost on HCCI mode. At difference ω, engine power almost consistent for all fuel at constant λ = 2.9 as shown in Figure 3. It because the higher density of palm oil biodiesel blends increases from mixture momentum and consequently penetration depth in-cylinder, whereas higher viscosity and surface tension of biodiesel prevents sufficient breaking of the biodiesel during injection process. In addition, heating value of PO5 and PO10 is higher than diesel fuel. Therefore, shows a reduction in combustion become of its higher viscosity and big atomized injection. In bad circumstance can be oil and clogs fuel filters and injectors in engines. The result in agreement with Ndayishimye et al [17] which they used diesel fuel as baseline data and compered with palm oil operated with diesel engine. The engine performance which is power and emission were improved, the HC and CO was decreased, and the NO_x increased at low load than higher load.

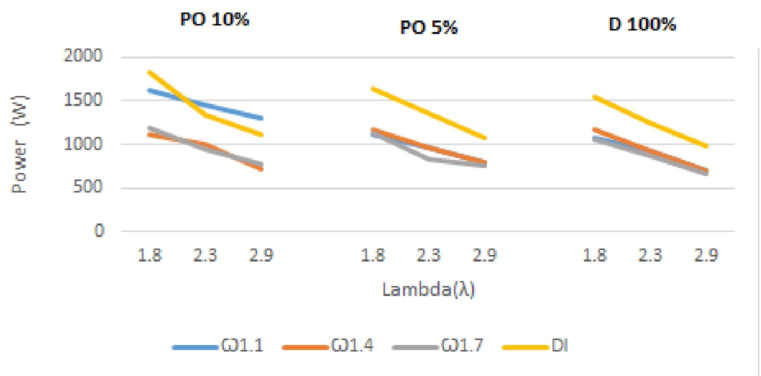


Figure 3. Comparison of engine power output for difference blends PO5 and PO10 with diesel conventional fuel at ω = 1.1, 1.4, 1.7 with varies lambda condition.

BSFC reduce when the engine at DI mode compared to HCCI-DI mode for all tested fuel at engine speed 1800 rpm as shown in Figure 4. BSFC increase when λ increase for all fuel. The result in agreement with Fang et al [19] as they increase the value of EGR and pilot quantity the fuel consumption increased. The graph obtained shown the brake BSFC increases due to fuel consumed amount compared on λ and ω setting. It was shown up that using variety of palm oil blends slightly disturbing value in term of fuel consumption. One possible explanation for this increasing could be due to lower heating value, and higher density of blended fuels compared to diesel fuel.

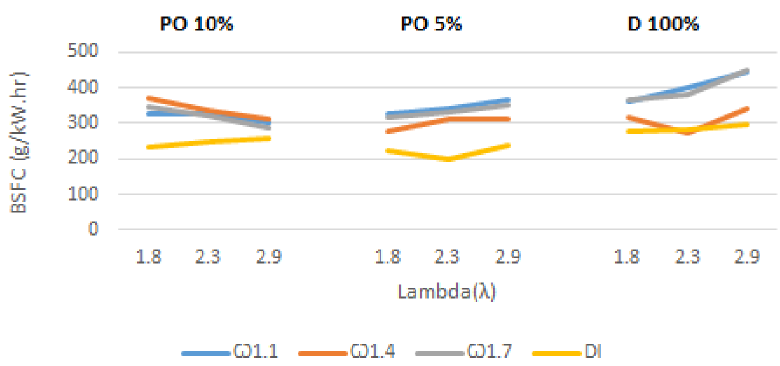


Figure 4. Comparison of BSFC for difference blends PO5 and PO10 with diesel conventional fuel at ω = 1.1, 1.4, 1.7 with varies lambda condition.

Figure 5 shows BMEP decrease when λ increase for all tested fuels for both DI and HCCI-DI mode. It was observed that, when ω increase BMEP for PO10 decrease in respect to λ. For PO5 and diesel fuels there no significant change when ω increase. This situation contribution from value of cloud point and calorific value for each tested fuels were mean the temperature at which dissolved fuel from blended fuel are no longer completely soluble, precipitating as a second phase giving the fuel a cloudy appearance. This term is relevant to several applications with different consequences of crude oil [18]. Hence BMEP versus λ clearly indicated as the richer mixture will led to increase BMEP for all tested fuels.

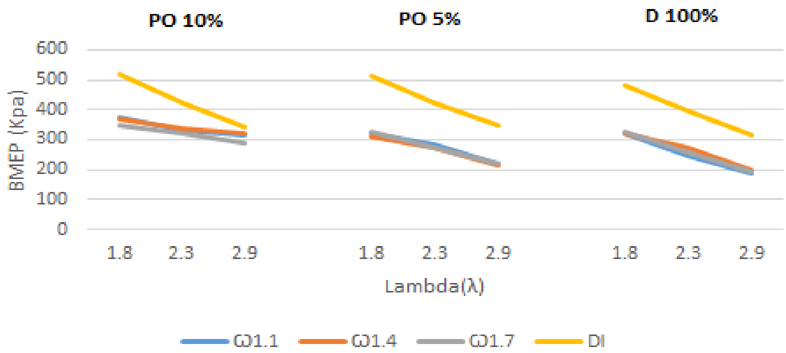


Figure 5. Comparison of BMEP for difference blends PO5 and PO10 with diesel conventional fuel at ω = 1.1, 1.4, 1.7 with varies lambda condition.

Basically, NO_x at DI operation higher compare HCCI mode [20]. Figure 6 shows NO_x decreases as increase ω. The amount of NO_x emission increases when operated in blended fuels compared to diesel fuels in both HCCI-DI and DI mode. The increase in NO_x emission for blended fuels was due to increase in oxygen content compared to diesel fuel. NO_x emissions increase with increase in percentage of palm oil blends with diesel fuel. A study by Sharon et. al [21] on CI engine which was operated at full load, reported the NO_x emission levels were higher as the amount of blends rates of biodiesel increases.

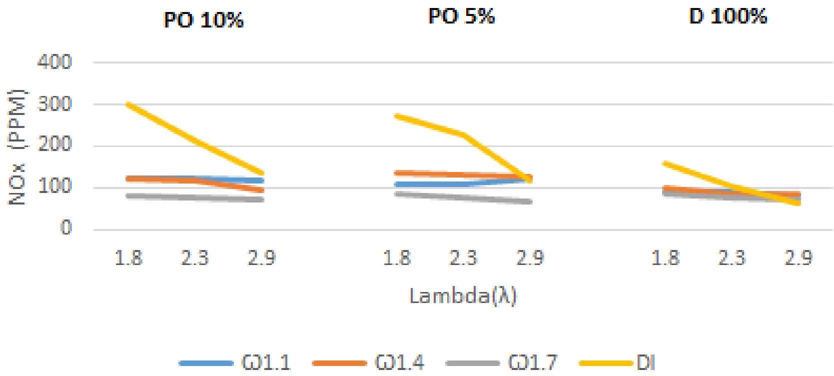


Figure 6. Comparison of NO_x for difference blends PO5 and PO10 with diesel conventional fuel at ω = 1.1, 1.4, 1.7 with varies lambda condition.

Figure 7 shows UHC emissions are much lower in DI mode compared HCCI-DI for all tested fuels. As graph showed UHC emission for diesel fuels were slightly higher than blended fuels in both DI and HCCI-DI. It was observed, in DI mode, UHC emissions increased for both biofuel PO5 & PO10 at all engine loads compared to diesel fuel , due to higher viscosity of palm oil. The study done by Sharon, et. al [21] used biodiesel (palm oil) and tested in DI diesel engine with different load which that the HC emission levels was 38.09% and 19.05 for the B100 and B75. Increasing the percentage of biodiesel in biodiesel blends reduces UHC emissions are attributed to the higher cetane. There is slightly reduction in UHC emissions for palm oil biodiesel PO10 and PO5 at all ω with respect to λ. Adding palm oil to diesel fuel increases oxygen content resulting in better combustion, and this results lower UHC emissions.

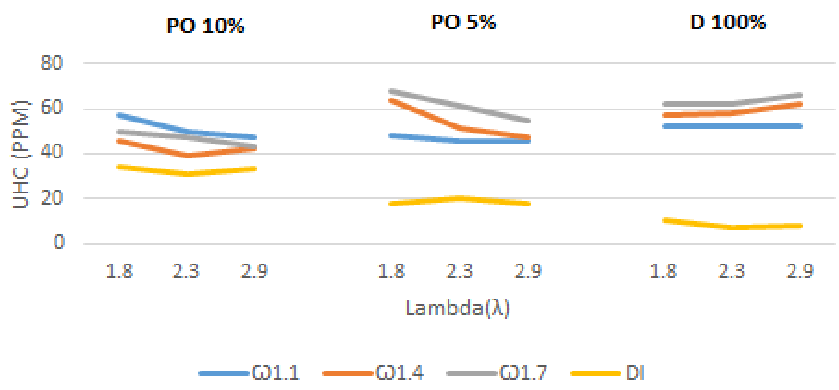


Figure 7. Comparison of UHC for difference blends PO5 and PO10 with diesel conventional fuel at ω = 1.1, 1.4, 1.7 with varies lambda condition.

When ω increase CO_2 drop due to HCCI mode, means varies ω, will affects in term of CO_2 as shown in Figure 8. CO_2 decrease when λ increase for all tested fuels in both DI and HCCI-DI mode. Adding the palm oil blends PO5 PO10 leads higher CO_2 in DI mode. Whereas, the value of CO_2 at PO10 reduce in HCCI-DI mode compared to other.

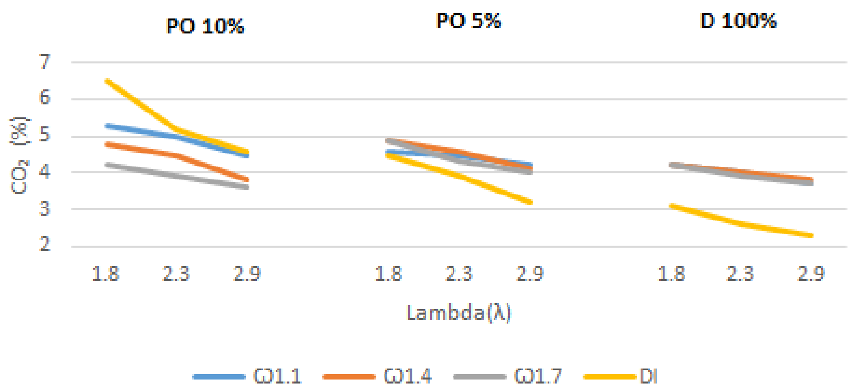


Figure 8. Comparison of CO_2 for difference blends PO5 and PO10 with diesel conventional fuel at ω = 1.1, 1.4, 1.7 with varies lambda condition.

CO for diesel was lower compared to blended fuels [21]. It was observed, CO at DI mode always showed lower range compared to HCCI-DI mode for all tested fuels. The decrease of CO emission for biodiesel in DI compared with HCCI-DI was due to more oxygen molecules and lower carbon content in biodiesel blends as compared to that of diesel fuel which lead to better combustion. As the λ increase CO reduces as the mixture become lean which that was less fuel and more oxygen content. The results in agreement with Das et al and Ma et al [10,22].

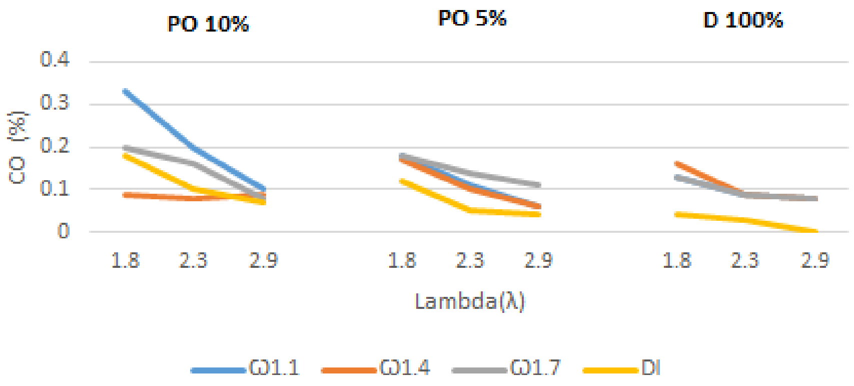


Figure 9. Comparison of CO for difference blends PO5 and PO10 with diesel conventional fuel at ω = 1.1, 1.4, 1.7 with varies lambda condition.

4. Conclusion

This study investigates the performance of PO5 and PO10 and compared against with diesel fuels that are readily available in the market in DI and HCCI-DI mode. It has found that different fuel injection with difference palm oil blends percentages is significantly affects the engine efficiency. The usage of palm oil blends on HCCI-DI engine increase the break specific fuel consumptions (BSFC) and reduce the engine performance of the diesel include engine power compare with conventional diesel fuel. At DI mode, blended fuels PO5 and PO10, produce higher NO_x and UHC emission with lower CO_2. At HCCI-DI mode of combustion, reduces the NO_x while increase the UHC. Meanwhile, as palm oil blends increase UHC decrease also NO_x reduce at ω = 1.7. Thus, palm oil biodiesel operated in HCCI-DI mode of combustion have an optimal PFI quantity to operate in minimal emission levels.

Acknowledgement

The author would like to thank Universiti Putra Malaysia and Universiti Malaysia Pahang (www.ump.edu.my) for providing research facilities and providing the fund. The study is also funding by research grant IPM 9483100 and Ministry of Higher Education Malaysia through the FRGS research project RDU160152.

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