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Emission Characteristics of Different Fractions of Biodiesel in a Direct Injection Compression Ignition Engine

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Abstract **- Due to the tough "European Emission Regulation Standard" on combustion engine, studies on locating a appropriate opportunity gas in combustion engine has grown to be imperative. Of all of the opportunity fuels investigated along with Water-in-diesel emulsion (WIDE), Ethanol-diesel, Biodiesel etc., Biodiesel is the maximum promising opportunity gas to be applied in combustion engine, as it has the capability to efficiently lessen the simple pollutant emissions from the combustion engine (i.e. produce ultra-low emission vehicle). Thus, the number one goal of this studies is to analyze the emission traits of direct injection compression ignition engine (DICI) under the effect of various fractions of biodiesel. This research was carried out by using experimental approach under the subsequent technical working parameters along with stoichiometric (λ=1), specific variety of engine speed (1000 rpm- 5000 rpm), huge open throttle (WoT), most brake torque injection timing (MBT-injection timing)** ***etc. The results showed that, for a specified fraction of biodiesel, increasing engine speed brings about reduction in basic pollutant emission (i.e. BsCO, BsNOx and BsUHC) for all loads under consideration. In addition, B10 shows the best (lowest) emission characteristics for all loads under consideration [i.e. for BsCO=22.89 ppm/kW at full load, BsNOx=133.84 ppm/kW at full load and BsUHC=0.008 ppm/kW]. In light of the above, it can technically be concluded that, DICI under the impact of various biodiesel fractions could solve the problem of global warming (reduction in the basic pollutant emission). Therefore, this research support Malaysia and Oman government initiative to solve the global warming problem arising from emissions discharged by automobiles*****.**

Index Terms - Biodiesel Fractions; Brake Specific Carbon Monoxide; Brake Specific Nitric Oxide; Brake Specific Unburnt Hydrocarbon; Stoichiometric Combustion Strategy and MBT-Injection Timing

INTRODUCTION

Fuel plays an important role in internal combustion engine (ICE). The most common fuels utilize in ICE today are diesel and petrol. These two fuels also known as fossil fuels. The reasons why peoples preferred those fuels in ICE are because of their availability, competitive price and high energy density. [1-2] However, the implementation of these fossil fuels (petrol and diesel) in ICE generates high emissions which make environment very unsafe (i.e. not eco-friendly fuel and global warming) and also carcinogenic to human health (respiratory system). In addition, those fossil fuels are derived from petroleum oil which is not renewable (i.e. depleting reservoir) and due to this non-renewability, their prices are expected to go up. Hence, due to negative impact of these fossil fuels on the environment and some other reasons, conducting investigation to the alternative fuel to be utilized in ICE to serve as fuel substitution and reduce the exhaust emissions in ICE become necessary. Alternative fuels such as water in diesel emulsion (WIDE), Natural gas, H2O, Ethanol-diesel, Biodiesel, etc. have been proposed as viable solutions to the aforementioned problems. Of all the proposed alternative fuels, biodiesel is the most promising alternative because it can reduce the greenhouse effect and global warming because of its high cetane number and high lubricity level but low in sulphur content. There are many publish literatures regarding the engine emission of the DICI. Tarkan Sandalci et al, 2015 conducted experimental research on "Performance and Exhaust Emissions of Diesel Engines, using Ethanol-Diesel blends" and the result showed that, using those blend's fuels can reduce CO_2 emissions up to 27.9% - 33.9% at 1950 rpm.[3] Suresh Vellaiyan et al, 2016 presented a retrospective review on the impact of WIDE and additives on the diesel engine performance and emissions with the finding that emulsion fuels decreased NOx emissions by 45 percent with emulsion fuels of diesel-in-water (W/D) while particulate matter emission was reduced about 80% -90%.[4] Furthermore, K. Naima and A. Liazid, 2013 reviewed a research laboratory on Waste oils as alternative fuel for diesel engine. The result concludes that smoke opacity level and CO, CO2, SO2 emissions can be reduced by using waste cooking oils methyl ester and O2, NO, NO2 level will be higher with waste vegetable oils-based fuel.[5] More so, Sundar Raj Chockalingam et al, 2017 conducted an experimental study on effective application of ethanol in diesel engines and the result showed that the addition of 10% ethanol with diesel reduced 17.7% in smoke and increased 11.4% of NOx emission.[6] In addition, Debdut Maji et al, 2018 conducted an experimental investigation on the use of water emulsified diesel in a single cylinder compression ignition engine and it was concluded that using water emulsified diesel (WED) reduced NOx emission with maximum reduction of 14.46% while hydrocarbon emission increased when using WED.[7] In furtherance, S.Kirankumar et al, 2015 conducted an experimental investigation on an "Engine Performance and Emission with Ethanol and Diesel-Biodiesel Blends". The result showed that cylinder pressure is lower at higher ethanol percentage which enhanced the reduction of NOx and CO emissions.[8] Also, Achmad Praptijanto et al, 2015 conducted a simulation study on the "Effect of Ethanol Percentage for Diesel Engine Performance Using Virtual Engine Simulation Tool". The result of the research showed that the ethanol has less carbon emission compared to diesel fuel which increase the quantity of oxygenated fuel.[9] Furthermore, Ahmad Muhsin Ithnin et al, 2014 conducted research on the prospects of utilizing water-in-diesel emulsion fuel in diesel engine and its potential. The outcome of this research indicates that using W/D emulsion fuel, increased unburn hydrocarbon and carbon monoxide exhaust emission, but NOx emission seems to be lowered.[10] Farzad Jaliliantabar, 2017 studied an "Evaluation of the performance and emission of a single cylinder diesel engine fuelled by biodiesel and using EGR" and the result concluded that the usage of EGR and biodiesel reduced CO emission by 4.04%, 12% for medium speed engine and 1.73% for high speed.[11] Moreover, Santosh Kumar Dash and Pradip Lingfa, 2018 studied performance evaluation of Nahar oil-diesel blends in a single cylinder direct injection diesel engine. The conclusion showed that, hydrocarbon and monoxide emissions are reduced by 8.64% and 8.34% respectively using blending of 10% Nahar oil and diesel fuel.12] Even though much research has been done to improve the emission characteristics of direct injection compression ignition engines, there is still emissions in direct injection compression ignition engines. As a result, the main a technical communication gap regarding the use of various fractions of biodiesel (B0, B7, and B10) to reduce goal of this research is to undertake an experimental analysis into the emission characteristics of a DICI under the impact of a different biodiesel proportion and spell out the emission behavior of the engine.

COMBUSTION EQUATION REPRESENTING BIODIESEL

The combustion equation utilize for this research is stoichiometric combustion. Normal combustion equation for diesel was used to represent biodiesel equation in this research. It is given as: [13]

$$4C_{12}H_{23} + 71(O_2 + 3.76N_2) \leftrightarrows 48CO_2 + 46H_2O + 3.76N_2$$

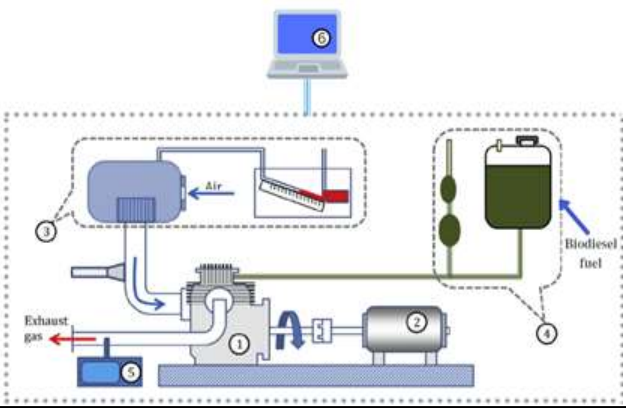
EXPERIMENTAL SET UP AND PROCEDURE

The experimental investigation of effects of biodiesel fractions on emission characteristics was conducted with a single cylinder four-stroke engine located in Universiti Kebangsaan Malaysia (UKM). The schematic diagram of the experimental setup is given in figure 1 while technical operating parameters of the engine is given in table 1.

TABLE 1
TECHNICAL OPERATING PARAMETERS OF THE ENGINE.

No.	Parameter	Range
1.	Speed	1000 rpm – 5000 rpm
2.	Combustion strategy	Stoichiometric, λ=1
3.	Biodiesel fraction	B0, B7, B10, B20
4.	Throttle valve	WIDE (WoT)
5.	Injection timing	MBT-injection timing (40° BTDC)

FIGURE. 1
THE SCHEMATIC DIAGRAM OF THE EXPERIMENTAL SETUP.



1. Engine 2. Dynamometer 3. Air intake metering system
4. Biodiesel fuel metering system 5. Gas analyzer
6. Electronic control unit

Description

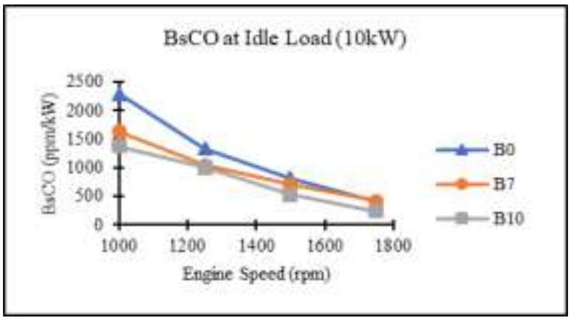
- The supply system of the experimental setup consists of biodiesel, biodiesel fuel metering system, air intake metering system, pressure regulator etc.
- The experiment was conducted after running the engine until the oil and coolant temperature reach 70℃ and 100℃ respectively. This is to achieve the stable operation of the engine.
- The experiment was started by injecting the biodiesel fuel into the engine cylinder when the engine piston is near TDC (40°BTDC). This is called MBT-injection timing. Electronic control unit (E.C.U) was used to control various technical operating parameters of the engine such as engine speed, WoT, Stoichiometric mixture (λ=1.0) etc. The experiment was repeated for various fractions of biodiesel up to B10. Portable gas analyzer was used to collect emission characteristics data of the engine, such as CO, NOx and UHC.

RESULTS AND DISCUSSION

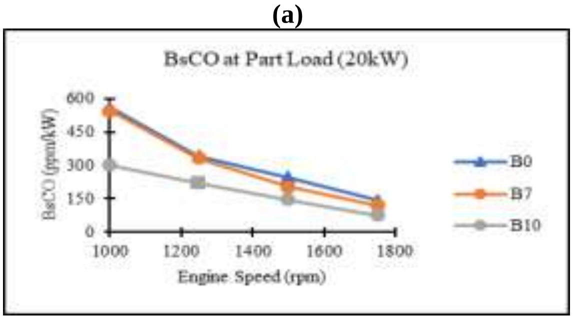
A. Brake Specific Carbon Monoxide (BsCO) Emission.

Figure 2 (a) to (c) indicates the connection between the concentration of BsCO at varying biodiesel fractions towards engine speed at extraordinary load conditions. Increasing the engine speed brings approximately decrement withinside the concentration of BsCO for all biodiesel fractions under consideration. This is so because the oxygen content in biodiesel gives the best combustion phase when the engine speed is increased and consequence upon this, concentration of carbon monoxide (CO) emission will be reduced. Comparing the concentration of BsCO at different biodiesel fractions, it is clear that B10 gives the lowest emission concentration of BsCO and this is because of its flash point (the lowest temperature of fuel where the vapour will ignite). Furthermore, examining the concentration of BsCO at different load conditions under consideration shows that the lowest concentration of BsCO emission occurs at full load (40kW) in comparison to the other loads. This is so because, biodiesel have higher cetane number (56) compared to pure diesel (49.2) and this enhances the better auto ignition quality. In addition, considering the data point for the emission concentration of BsCO at B10 and B0 and at two different engine speed which are 1000rpm and 1750- rpm respectively under full load condition [i.e. figure 2(c)]. For B10, the emission concentration of BsCO for the two-engine speed under consideration are 91.35ppm/kW and 22.89ppm/kW. This yields approximately 75% reduction in emission concentration of BsCO at this operating condition. While for B0, and with the same technical operating condition under consideration, the emission concentrations are 166.45ppm/kW and 56.11ppm/kW respectively. This give approximately 66% reduction. Thus, from foregoing analysis, it can be concluded that slightly more significant reduction was observed with B10 (biodiesel engine) as compare to B0 (diesel engine). This might be due to the flash point of the biodiesel. Good agreement is achieved between these experimental results and (Ahmet Mucak et al, 2016) [14] and (M. M. Rashed et al, 2016) [15].

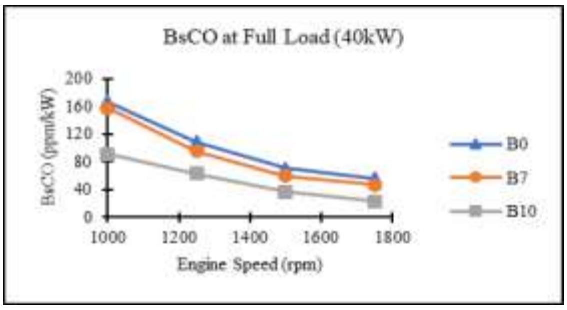
FIGURE. 2
RELATIONSHIP BETWEEN CONCENTRATIONS OF BSCO AT DIFFERENT BIODIESEL FRACTIONS AGAINST ENGINE SPEED AT DIFFERENT LOAD CONDITIONS



(a)



(b)



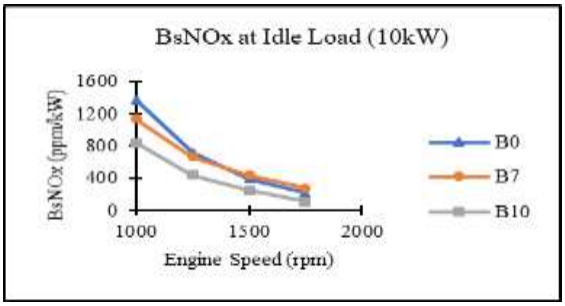
(c)

B. Brake Specific Nitric Oxide (BsNOx) Emission.

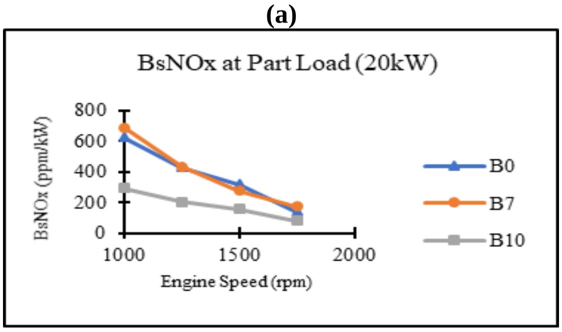
Figure 3 (a) to (c) shows the variation between concentration of BsNOx at different biodiesel fractions against engine speed at different load conditions. Increasing the engine speed brings about decreasing trend in the concentration of BsNOx for all biodiesel fractions under consideration. This is so because combustion temperature in the engine cylinder reduced and consequent upon this, the concentration of BsNOx is reduced. Comparing the concentration of BsNOx at different biodiesel fractions, it is obvious that B10 gives the lowest emission concentration of BsNOx. This might be largely due to the fact that the density of biodiesel is greater when the biodiesel fraction increasing. The higher the density, the lower the concentration thus the concentration of B10 will be the lowest. In addition, examining the concentration of BsNOx at different load conditions under consideration indicates that the lowest concentration of BsNOx emission occurs at full load (40kW). This is due to more efficient combustion occurring at this operating condition engine as compared to the other load conditions. Furthermore, consider data point for the emission characteristic of concentration of BsNOx at B10 and B0 and at two different engine speed which are 1000rpm and 1750 rpm under full load condition [i.e. figure 3(c)]. For B10, the emission concentration of BsNOx for the two engine speed under consideration are 288.85ppm/kW and 133.84ppm/kW respectively. This represents approximately 55% reduction in the concentration of BsNOx emission at this operating condition of the engine. While for B0, and with the same technical operating parameters under consideration, the emission concentrations are 533.49ppm/kW and 216.77ppm/kW respectively. This gives approximately 60% reduction in the emission concentration of BsNOx at this operating condition of the engine. Thus, from the above analysis, it is technically plausible to say that more significant increment was observed with B10 (biodiesel engine) as compare to B0 (diesel engine). This might be so, because of the better ignition quality of biodiesel as compared to pure diesel. The results obtained here are coherent with (Saheed Wasiu et al, 2018) [16] and (A. Data and B. K. Mandal, 2016) [17].

FIGURE. 3

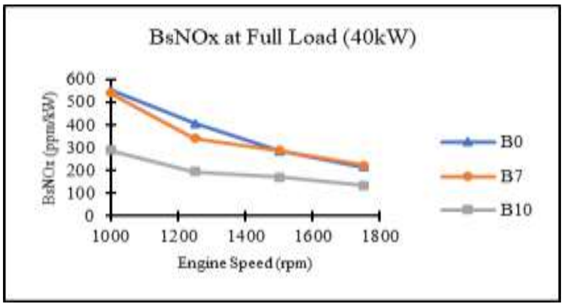
RELATIONSHIP BETWEEN CONCENTRATIONS OF BSNOX AT DIFFERENT BIODIESEL FRACTIONS AGAINST ENGINE SPEED AT DIFFERENT LOAD CONDITIONS



(a)



(b)

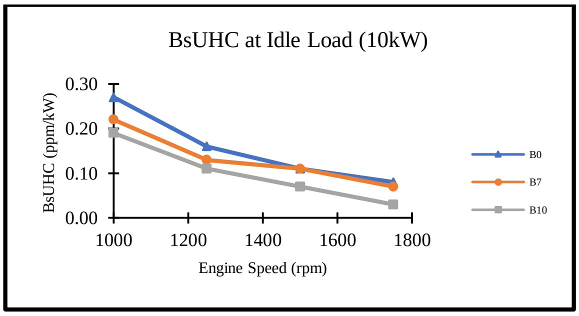


(c)

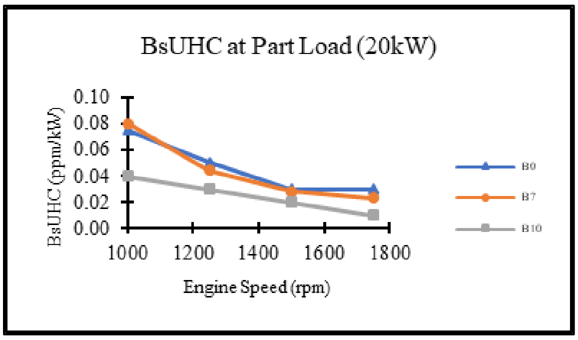
C. Brake Specific Unburnt Hydrocarbon (BsUHC) Emission.

Figure 4 (a) to (c) shows the relationship between concentration of BsUHC at different biodiesel fractions against engine speed at different load conditions. Increasing the engine speed bring about decrement in the emission concentration of BsUHC for all biodiesel fractions under consideration. This is because when the engine speed is increased the in-cylinder gas and exhaust gas temperature will increase, and this leads to increase in Hydrocarbon emission burn up and consequent upon this unburnt hydrocarbon (UHC) will reduced. Comparing the concentration of BsUHC at different biodiesel fractions, it is obvious that B10 gives the lowest emission concentration of BsUHC. This might be due to the fact that decreasing fuel concentration and increasing oxygen concentration essentially offset the effect of decreasing bulk gas temperatures and consequent upon this, the emission concentration will be the lowest at B10. In furtherance, examining the concentration of BsUHC at different load condition under consideration, it shows that the lowest concentration of BsUHC emission occurs at full load (40kW). This reason is largely due to more complete combustion experience at that operating condition of the engine. More so, consider the data point for the emission concentration of BsUHC at B10 and B0 and at two different engine speed which are 1000rpm and 1750 rpm under full load condition [i.e. Figure 4.3(c)]. For B10, the emission concentration of BsUHC for the two engine speed under consideration are 0.02ppm/kW and 0.008ppm/kW respectively. This presents approximately 60% reduction in the emission concentration of BsUHC at this operating condition. While for B0, and with the same technical operating parameter under consideration, the emission concentrations are 0.03ppm/kW and 0.01ppm/kW respectively. This shows nearly 67% reduction in the emission concentration of BsUHC at this operating condition. Thus, it is obvious that more significant increment in the emission concentration of BsUHC was obtained with B10 (biodiesel engine) as compare to B0 (diesel engine). This reason why this is so is because of the higher lubricity level but lower sulphur content in biodiesel that guarantee the better ignition quality as compare to pure diesel. The experimental results obtained here is in line with what is obtained by (D. Babu and R. Anand, 2017) [18] and (K. N. Gopal and R. T. Karupparaj, 2015) [19].

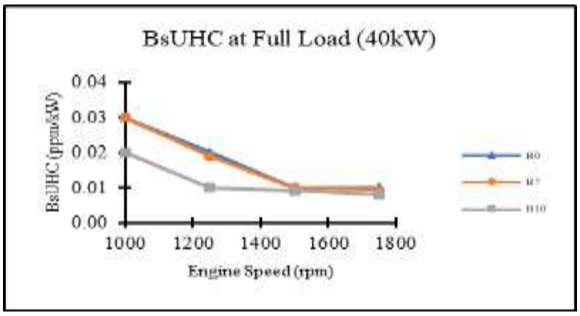
FIGURE. 4
RELATIONSHIP BETWEEN CONCENTRATIONS OF BSUHC AT DIFFERENT BIODIESEL FRACTIONS AGAINST ENGINE SPEED AT DIFFERENT LOAD CONDITIONS



(a)



(b)



(c)

Conclusion

Experimental research has been performed to examine the outcomes of various fractions of biodiesel (B0, B7 and B10) on a direct injection compression ignition engine at diverse load conditions (idle, part and complete load). The fundamental findings are summarized below viz:

1.
   (a) For a given biodiesel fraction, increasing the engine speed brings about decrement in emission concentration of **BsCO** for all load conditions under consideration. This is largely due to oxygen content in biodiesel giving the best combustion phase when the engine speed is increased.
   (b) For a specified biodiesel fraction, increasing the engine speed brings about decreasing trend in emission concentration of **BsNOx** emission for all load conditions under consideration. This is so because, combustion temperature in the engine cylinder reduced.
   (c) For a given biodiesel fraction, increasing the engine speed brings about reduction in emission concentration of **BsUHC** emission for all load conditions under consideration. This is because when the engine speed is increased the in-cylinder gas and exhaust gas temperature will increase, and this leads to increase in Hydrocarbon emission burn up.
2. It is obvious that from the experimental results obtained, that **B10** portrays the best (lowest) emission characteristics for all load conditions under consideration. [i.e. for **BsCO**=22.89 ppm/kW at full load, **BsNOx**=133.84 ppm/kW at full load and **BsUHC**=0.008 ppm/kW].

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