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Emissions and Performance of Diesel Engine Fueled with Waste Cooking Oil Methyl Ester Diesel Blends

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Abstract: In this study, waste cooking oil methyl ester (WCOME) and diesel were blended in 20, 40, 60 and 80% percentage volume basis. Biodiesel and the blends were tested in 4-cylinders, 4-strokes and direct injection diesel engine to investigate the emissions and performance at engine speeds of 600-3000 rpm under idle and full load. The result was compared to the data of petroleum diesel. The experimental data showed that the emissions of biodiesel and blends were much lower than B100. In comparison, the emission of biodiesel was more than 50% lower than B100. The average reductions were 76.19% for smoke opacity; and 97.62, 90.36 and 98.69% for brake specific emission factors of BS-HC, BS- CO and BS-SO_2, respectively. The engine performances were also observed. Results showed that when WCOME were used both BHP and BMEP showed slight reductions about 8.63% compared to diesel. However, higher fuel consumption, had been indicated by the BSFC. The BSFCs of B100 were recorded to be 9.45% higher than biodiesel. The Highest BTEs were also recorded at a maximum average percentage of 19.93%.

Key words: Brake Horse Power · Brake Specific Fuel Consumption · Brake Thermal Efficiency · Brake Mean Effective Pressure · Brake Specific Hydrocarbon · Smoke Opacity

INTRODUCTION

Biodiesel is a non-toxic, biodegradable and renewable fuel that is manufactured usually from vegetable oils, recycled oils, or animal fats. Biodiesel production from vegetable oil has been extensively studied in many literature reviews [1-4]. However, the raw material costs and the availability of vegetable oil feedstocks remains a major hurdle for the biodiesel production. Ma and Hanna [5] investigated that the high cost of vegetable oils, which could be up to 70% of the total manufacturing cost, has lead to the biodiesel production becomming approximately 1.5 higher than that for diesel.

Waste Cooking Oil (WCO) is an oil-based substance consisting of animal or vegetable matter that has been used in cooking or in preparing foods and is non-edible [6]. Although, there are many studies on biodiesel production using various feedstock and different oil characterizations [7], high price and availability of virgin vegetable oil resources remain obstacles to biodiesel production. Since waste cooking oil is priced 2-3 times lower than virgin vegetable oils, using WCO as source for biodiesel can greatly reduce manufacturing cost [6].

Also, despite the optimization of biodiesel production from waste cooking oil there are still obstacles to using WCO. One major obstacle is the inadequacy of information on the side effects of having a biodiesel-fueled diesel engine and the lack of information about different tested engines, operating conditions and measurement techniques, among others.

Thus, given the need for a more convincing work in biodiesel, performances and emissions of diesel engine when fueled with waste cooking oil methyl ester (WCOME) will be addressed in this study. The study looked into how the effects of WCOME on BHP, BSFC, BTE and BMEP justified engine performance and brake specific emission factors of BS-CO, BS-HC, BS- SO_2 and smoke opacity during emission testing.

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This research measured the performance and emissions of the pure WCOME (B100) and several blend variations (B20, B40, B60 and B80). Determination of engine performance and analyses of brake specific emission factors were conducted. Baseline test was conducted using pure diesel (B0) to compare its performance and emissions with those of biodiesel blends.

MATERIALS AND METHODS

Materials: Biodiesel from waste cooking oil and petroleum diesel were used for the present study. Biodiesel from WCO was purchased from Eway 54, a local company in Philippines. The petroleum diesel was obtained from SHELL De La Salle University gas station.

Methodology: Four blends of diesel and waste cooking oil methyl ester on volume basis were prepared. The blends were B20, B40, B60 and B80. Blending was done using a HEIDOLPH RZR 2012 stirrer machine.

Engine tests were carried out using an Isuzu 4BC2, 3268 cc and a Nishishiba EDDY Current Dynamometer. A Vetronix PXA-1100 Gas Exhaust Analyzer was used to measure gas emissions. The analyses of the fuels were conducted in ZEXEL Calibration Center, Commonwealth Avenue in Quezon City, Philippines.

For every new fuel, the engine was operated both at idle and 100% load at various speeds. To make sure data remained accurate for every new fuel the measurements were made after the engine had run for around 5-10 minutes. This procedure made sure of the engine's stable condition for that certain blend. The tests were repeated twice for each fuel sample to ensure that all instrumentation had stabilized and get reasonable value. The average data were then used for the analysis and discussion. In conclusion, the engine performance (BHP, BSFC, BTE, BMEP), smoke opacity and brake specific emission factors (BS-HC, BS-CO, BS-SO_2) of the biodiesel blends were compared to those for 100% petroleum diesel.

RESULT AND DISCUSSIONS

Brake Horse Power: As can be seen in Fig. 1, the values of BHP for all tested fuels were very close and followed by increments with diesel fuel registering the highest BHP, followed by B20, B40, B60, B80 and B100 registering the lowest BHP. High BHPs were obtained when the engine was fueled by blends with low biodiesel content.

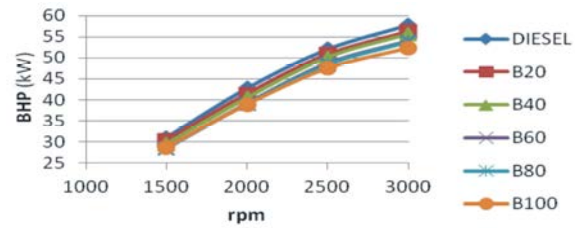

Fig. 1: Variation of Brake Horsepower with Engine Speed

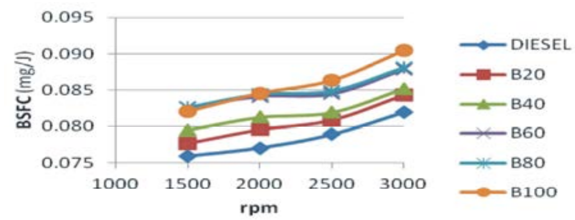

Fig. 2: Variation of Brake Specific Fuel Consumption with Engine Speed

The difference in average brake power of diesel-biodiesel and its blends was observed only by less than 10% with diesel possessed higher BHP values.

The low BHP values were attributed to low heating values [8] and resulted in lower engine power [9]. These low values could also be due to biodiesel's high density and viscosity that resulted to fuel flow problems [10]. Overall, it could be said that the BHP of WCOME and its blends in the present study resembled the BHP of diesel.

Brake Specific Fuel Consumption (BSFC): BSFC is the ratio of specific fuel consumption to the brake power, thus, lower BSFC is expected [11]. However it was found that the average BSFC of B100 was 9.45% higher than that of diesel fuel. BSFCs were lowest for diesel fuel and highest for B100. It increased proportionally with the addition of biodiesel blends. This was due to the low heating value of the blends. Diesel has a higher heating value than biodiesel. As consequence, the heating value of biodiesel blends increased linearly by addition of more diesel. The reason of higher BSFC of WCOME and its blends was because of the low heating value of WCOME and its blends compared to diesel fuel. Low heating value on the fuel means that more fuel would be required to produce the same energy and result in a high BSFC [12].

Brake Thermal Efficiency: From Fig. 3 it was observed that BTE increased with the addition of biodiesel in the blends. Among all fuels tested, the BTEs were lowest for diesel fuel and highest for B100. The average differences were 9.41, 14.08, 15.36, 16.13 and 19.93% for B20, B40, B60, B80 and B100, respectively.

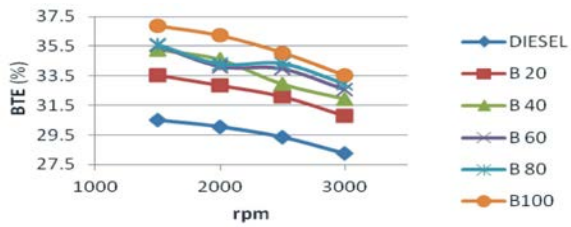

Fig. 3: Variation of Brake Thermal Efficiency with Engine Speed

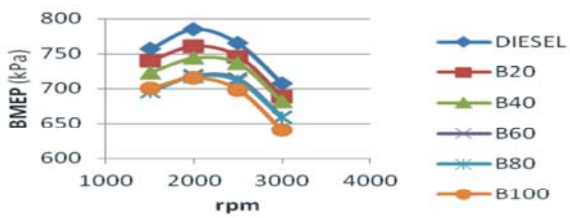

Fig. 4: Variation of Brake Mean Effective Pressure with Engine Speed

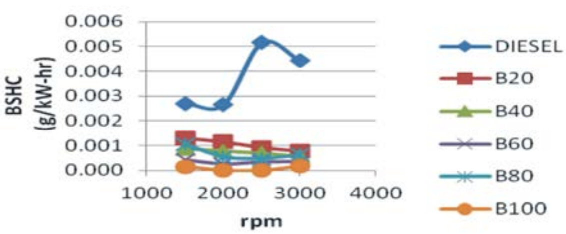

Fig. 5: Variation of Hydrocarbon with Engine Speed

A study by Murillo, et al. [13] observed that BTEs of B100 were higher than that of diesel. However, compared to diesel, the blends were found to have low BTEs. The high value of BTE when WCOME and blends was used might be due to high oxygen content of WCOME resulting in better combustion [14].

Brake Mean Effective Pressure: The BMEPs of diesel, biodiesel and biodiesel blends tested at full load are summarized in Fig. 4. For all fuels tested, the highest BMEP values were reached by diesel fuel. The percentage differences in BMEP with diesel as the base shows only less than 10% in the average drop of BMEP values. B20 was found with the minimum difference between diesel and biodiesel blends with a 2.65% average drop. Meanwhile, B100 showed the maximum average drop differences in BMEP with diesel with an 8.63%.

Brake Specific Hydrocarbon (BS-HC): The BS-HC emissions of diesel, biodiesel and its blends are shown in Fig. 5. Among the fuel tested, B100 produced the lowest BS-HC with average drop of 97.62% compared to diesel fuel. It was followed by B60, B80, B40 and B20 with 89.82, 79.17, 77.95 and 67.99%, respectively. The percentage differences in hydrocarbons emissions presented in g/kW-h with diesel as the base. In this study, average BS-HC was found to be 0.0037g/kW-h when diesel was used; while it was 0.0001g/kW-h for B100.

In the present study, BS-HC emissions tended to decrease at high engine speeds. This could be the result of high engine speeds causing an increase in inlet airflow, which triggered the atomization process that resulted in a more uniform fuel mixture [15, 16].

Brake Specific Carbon Monoxide (BS-CO): CO emissions were mostly comes from the incomplete combustion. When B100 was used, the average drop in BS-CO compared to the exhaust when diesel fuel used was 90.36%. This value has followed by the average drop for B60 at 91.67% and then by those of B80 at 89.72%, B40 at 86.61% and B20 at 76.53%. The mean BS-CO were presented in g/kW-h and showed the values of diesel fuel was 14.8536g/kW-h, followed by B20, B40, B60, B80 and B100 with 3.0262, 1.7627, 1.1389, 1.3094 and 1.1397g/kW-h, respectively.

As observed from the results, the formation of carbon monoxide in diesel fuel was the highest among the fuels tested. When engine speed increased more fuel were injected. Fortunately, there had been enough oxygen as needed for a complete combustion. When there was too much fuel. However, insufficient oxygen for complete combustion a rich condition would occur and more HC would be produced [17].

Brake Specific Sulfur Dioxide (BS-SO_2): The formation of BS-SO_2 can be observed in Fig. 7 which gives an overview of the different amounts of BS-SO_2 formed by WCOME and its blends. This average percentage difference for the blends B20, B40, B60, B80 and B100 were recorded at 30.86, 47.05, 60.24, 78.23 and 98.69%, respectively.

The emission factors of SO_2 were 0.0039, 0.0639, 0.1173, 0.1576, 0.2048 and 0.2952 g/kW-h for B100, B80, B60, B40, B20 and diesel, respectively. When B100 was used, there were hardly any SO_2 emissions found. This could be because biodiesel possessed very low sulfur content resulted in lower SO_2 emission.

Smoke Opacity: Fig. 8 shows the variation of the smoke opacity of diesel, WCOME and its blends related to engine speed. It can be observed that smoke opacity of WCOME and its blends were all lower than diesel fuel. The increments were as expected, where the fuel with higher percentage of biodiesel produced lower smoke

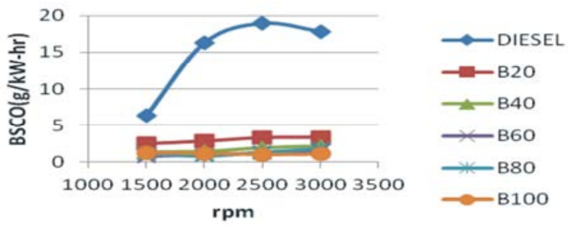

Fig. 6: Variation of Carbon Monoxide with Engine Speed

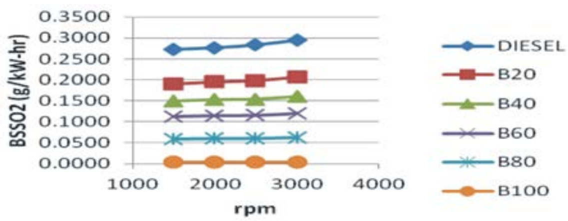

Fig. 7: Engine Emission Factors of SO_2 versus Engine Speed

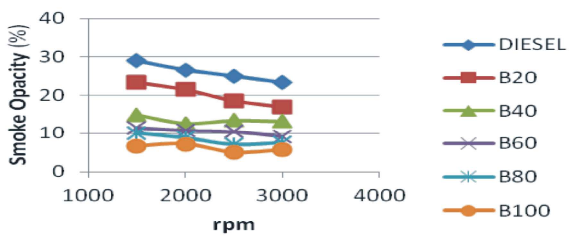

Fig. 8: Variation in Smoke Opacity Engine Speed

opacity as well. Pure biodiesel or B100 reduce smoke opacity compared to diesel fuel by 76.19%, followed by B80, B60, B40 and B20. The average reductions are 67.52, 59.71, 47.77 and 22.89% for B80, B60, B40 and B20, respectively.

The lower smoke opacity in biodiesel and its blends explained more complete combustion due to higher cetane index and oxygen content [18]. According to Canakci *et al.*, [16] since the smoke is highly dependent on oxygen and sulfur content of the fuel, no wonder that smoke opacity was found to be lower when diesel was blended with biodiesel.

At low engine speed, the percentages of smoke opacity were high and as the engine speed increased the smoke opacities decreased. At high engine speeds the air turbulence and fuel oxidation increased, resulted at low smoke production [16].

CONCLUSIONS

In the present research biodiesel from waste cooking oil methyl ester (WCOME) and its blends B20, B40, B60 and B80 were tested on a four-stroke, direct-injection diesel engine. The results have shown that WCOME and its blends can be tapped as a good substitute or petroleum diesel supplement. This can be noticed from the emissions and performance tests done in this study.

BHP and BMEP showed a slight reduction when biodiesel and diesel were used,. The maximum average drop on BHPs and BMEPs when biodiesel was used were 8.63% as compared to diesel. The increases on BTEs were observed with the maximum average percentage of 19.93%. The higher BTEs indicated higher oxygen content in the fuel and more complete combustion. However, higher fuel consumptions were also indicated by the BSFC. BSFCs of B100 were recorded to be higher by 9.45%.

The exhaust emissions were presented in g/kW-hr for BS-HC, BS-CO, BS-SO_2 and smoke opacity in BSU. The emissions factor of WCOME and its blends were found to be much lower compared to those for petroleum diesel. When B100 was used the average emission factors were 0.0001g/kW-h for HC, 1.1397g/kW-h for CO, 0.00391g/kW-h for SO_2 and for smoke opacity it was lower by 76.19% compared to diesel fuel.

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Persian Abstract

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چکیده

در این مطالعه، از ترکیب متیل استر موجود در پسماند روغن خوراکی (WCOME) و دیزل بر اساس درصد حجمی ۲۰، ۴۰، ۶۰ و ۸۰٪ مخلوط شد. از بیودیزل و سوخت ترکیبی در یک موتور دیزل با ۴ سیلندر، ۴، ضربه ای، و تزریق مستقیم استفاده گردید و میزان تولید گازهای گلخانه ای و همچنین عملکرد سرعت موتور در ۶۰۰–۳۰۰۰ دور در دقیقه تحت بار غیر کامل و کامل مورد آزمایش قرار گرفتند. نتایج به دست امده با داده های دیزل مشتق شده از نفت مقایسه شد. داده های تجربی نشان داد که تولید گازهای گلخانه ای از بیودیزل و سوخت ترکیبی بسیار کمتر از B100 بودند. در مقایسه، انتشار بیودیزل بیش از ۵۰ درصد کمتر از B100 بود. متوسط کاهش ۷۶.۱۹٪ برای کدورت دود بودند و ۹۷.۶۲، ۹۰.۳۶، و ۹۸.۶۹٪ برای قطع عوامل انتشار خاص از BS-HC، BS-CO، و $BS\text{-}SO_2$ بود. عملکرد موتور نیز مورد بررسی قرار گرفت. . نتایج نشان داد که زمانی که WCOME مورد استفاده قرار گرفت کاهش کمی در مورد BHP و BMEP حدود ۸.۶۳ ٪ در مقایسه با دیزل نشان دادند. با این حال، مصرف سوخت بالاتر، توسط BSFC نشان داد شده است. BSFCs از B100 به ۹.۴۵ درصد بالاتر از بیودیزل ثبت شده است. بالاترین BTEs نیز در حداکثر ۱۹.۹۳٪ گزارش شده است.