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Biodiesel Produced from Pangasius Oil Operating a Diesel Engine: Case Study in Vietnam

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Abstract*— Fossil fuel is one of the sources leading to the increasing greenhouse gas that causes global warming. It is also seen that the volume of oil discovered worldwide every five years is decreasing. Finding ways to replace petrol-diesel with biodiesel for use in internal combustion engines to reduce CO2 and overcome the diminishing supply of crude oil has attracted many researchers. Viet Nam is a country known as one of the world's largest producers of catfish. We mix biodiesel produced from Vietnamese pangasius fish fat with petrol-diesel at four blend ratios of 0%, 20%, 40%, and 60% to produce samples labeled, B0, B20, B40, and B60, respectively. These biodiesel blends were then used to operate a petrol-diesel engine for experimental investigation. The results show that the torque and power would decrease as the biofuel ratio increased. However, the rate of decrease of these parameters did not exceed 16%, even when the ratio of biofuel in the biodiesel was up to 60%. The average power reduction of biodiesel blends was only about 8.70%. In terms of exhaust emissions, there was a significant reduction of CO, NOx, HC, CO_2, and smoke opacity when biodiesel was used. The CO, CO2, and smoke opacity reduction was about 64.3%,15.1%, and 23.2% for the B60 fuel. In addition, the results also indicate that it is entirely possible to use biofuel produced from pangasius fish fat for internal combustion engines without changing the engine structure.

***Keywords*— Biodiesel; pangasius oil; diesel engine; diesel fuel; emissions.**

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I. INTRODUCTION

Energy demand for the industrial and other sectors increases day by day. Forecasts predict that global energy consumption will increase from 549 billion BTU in 2012 to about 629 billion BTU in 2020 and 815 billion BTU by 2040, meaning that energy consumption will increase by 48% in 28 years [1]. Unfortunately, most of the energy sources in use today come from fossil fuels such as crude oil and coal. This is one of the main sources of pollutants leading to climate change, poor air quality, and environmental damage environment due to the increase in CO_2 and other exhaust chemicals [2].

Diversification of fuel sources such as biofuels and renewable fuels has contributed to reducing the need to exploit fossil fuels and harmful emissions, which will reduce the impact on the environment. Biodiesel is considered an effective alternative and a blended fuel source because the technical specifications are like diesel fuel but with cleaner emissions [3]–[11]. Pangasius fish fat oil can become a suitable source of diesel fuel with environmental benefits. Lin and Li studied diesel engines' operational and emission characteristics using biofuel from fish oil [12]. Their experimental results show that biodiesel from fish oil offers higher efficiency producing fewer NOx, smoke, and CO emissions than those of biodiesel produced from cooking oil. Raheman and Phadatare [13] found a CO emission reduction of about 73-94% for Karanja Methyl Ester (B100) and its mixtures (B20, B40, B60, and B80) when compared with diesel fuel. Mohamed *et al.* [14] reported that average HC emission reductions from the biodiesel fuel blends were only observed for blend ratios no higher than 40% for five different types of biodiesel compared with pure diesel fuel. Kale *et al.* [15] proposed that microalgae biodiesel and its various diesel blends will be used as promising alternative fuels for diesel engines due to their advantages.

It has been reported in several other studies reported that using pure biodiesel also causes an increase in NOx emissions [16]–[19]. Some have suggested that using biodiesel during complete combustion leads to lower CO_2 emissions than pure diesel because of the low C/H ratio in biodiesel [19], [20].

Under the current conditions in Vietnam, scientists have also been studying the application of biodiesel fuel in marine transportation and agricultural mechanization [21], seeking to experimentally determine the influence of B10 and B20 on the performance characteristics of diesel engines. Their experimental results show that NOx tends to increase when using biodiesel B10 and B20 while there is a slight decrease in the maximum power and torque. In another experimental study, Mai Duc Nghia et al. examined the effect of the early injection angle for B15 fuel in terms of the economic and environmental criteria. The results showed that for diesel engines using B15 biofuel, adjusting the early injection angle to 18^0 - 19^0 with an injection pressure of 230kg/cm^2 compared to the optimal fuel injection angle of the (18^0 with an injection pressure of 210kg/cm^2) resulted in a strong reduction of soot emissions and NOx compared to pure diesel fuel [22]. Fish fat oil can be obtained from fish parts such as the internal organs, eyes, fins, head, tail, liver, and cheeks. Discarded skin and fish tissues can also be used to produce fish oil. Raw fish oil extracted from these discarded parts can provide a rich, cheap, and stable fuel source, having a part in ensuring national energy security. This paper has conducted an experimental study to investigate the effects of biodiesel fuel produced from Vietnamese pangasius fish fat on petrol-diesel engine performance and exhaust emissions.

II. MATERIALS AND METHOD

A. Material for Testing

We synthesized the biodiesel used in the experimental investigation from the fat of the pangasius fish (also called Vietnamese catfish or Basa fish) obtained from the fat left as waste after fish processing at the Seafood Processing Department, Faculty of Food Technology, Nong Lam University in Ho Chi Minh City, Vietnam. The fat was taken from various fish parts, including the abdomen, back, and visceral fat. Blood and dirt were removed with clean water, and the fat was thinly sliced 2 to 3 mm thick. It was then heated from 90-100^{0}C, crushed, and filtered to get liquid fat. After that, it was washed with a saltwater solution sedimentation to get the clean fat. The biodiesel synthesis process from pangasius fish fat is shown in Fig.1. The synthesis is conducted according to the following procedure:

1) Stage 1: Acid catalyst: The raw materials and ethanol are added to the reaction vessel at a ratio of 1: 0.2. The reaction mixture is heated to a temperature of about 55^{0}C and maintained temperature for one hour before adding the H_2SO_4 95% catalyst. Then, stirring continuously at a speed of 500 - 600 rpm for 2 hours. The temperature is maintained at 55^{0}C. Stirring and heating in this phase are meant to perform esterification of the free fatty acids in the fish oil. The conversion equation can be expressed as:

$$RCOOH + C2H5OH \rightarrow RCOOC2H5 + H2O \quad (1)$$

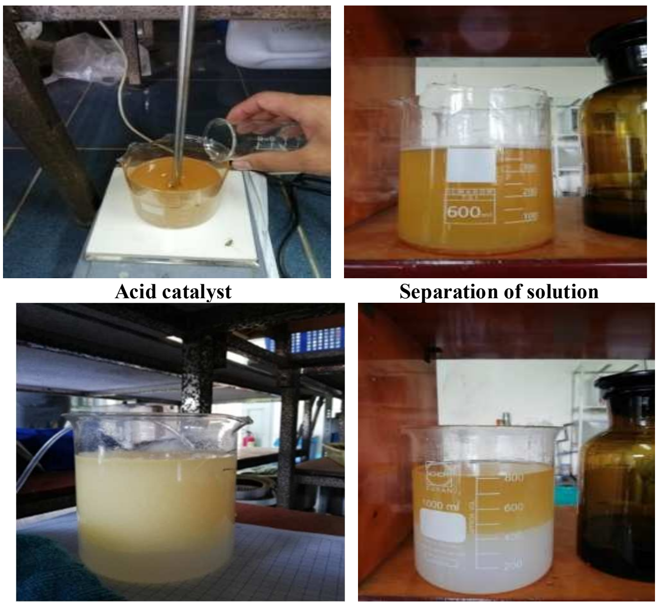
After stopping heating, the mixture is left to sit for 8 hours or overnight. After being left alone the mixture is neutralized with enough ethoxide to remove H_2SO_4 to finish the acid catalyst stage and facilitate the implementation of the base catalytic phase:

$$2KOH + H2SO\ 4 \rightarrow K2SO4 + H2O. \quad (2)$$

2) Stage 2: Base catalyst: The neutral mixture is heated to the appropriate reaction temperature. The remaining ethoxide is added to the mixture, and it is stirred at a speed of 500-600 rpm for one and a half hours, and then stirring and heating are stopped. At this stage, the esterification transition between triglycerides and ethanol occurs to form ethyl-ester. The stirring process helps the ethanol substance to form ethyl-ester. This process also improves the catalysts' ability to interact well and increase reaction efficiency. The solution is then left alone for one hour, where it separates into two distinct layers. The glycerin and solid impurities in the bottom layer are removed from the solution every 20 minutes. The upper layer is crude biodiesel.

Ethoxide preparation: An alkali compound was used as a catalyst to dissolve with the ethanol. The amount of ethanol used for each experiment was calculated so that the total volume of ethanol used was exactly as specified in the chosen ratio.

Washing biodiesel: The biodiesel was created with an alkali catalyst, so it was necessary to adjust the pH of the solution to produce a neutral environment. A little H_3PO_4 10% acid was added to the water before washing the biodiesel with creating air bubbles method. The bubbling was performed for 8 hours, and then the solution was left alone for 30 minutes to obtain biodiesel with neutral pH and brighter color. The biodiesel collected was mixed with petrol-diesel at different blending ratios of 0%, 20%, 40%, and 60% to produce samples called B0, B20, B40, and B60, respectively, for experimental investigation.



Acid catalyst **Separation of solution**

Biodiesel washing phase **Product after washing**

Fig. 1 Synthesis of biodiesel from pangasius fish fat

B. Experimental layout

The engine tests were conducted on a mechanical conveyor. The controlled engine speeds could be seen on a computer screen. The engine speed, engine power, and motor torque units are rpm, kW, and Nm, respectively. The motor load was measured by using a force sensor. A speed sensor was used to measure the engine speed. The fuel consumption was measured by using an electronic scale with an error of ± 0.1

g, and a maximum weight of 3000 g. The experimental layout is shown in Fig.2.

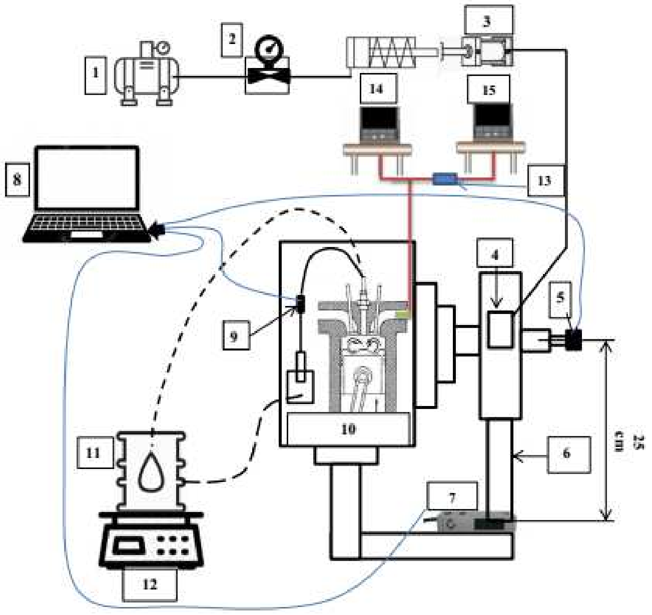


Fig. 2 Experimental layout: (1) compressed air tank, (2) pressure regulator, (3) main pneumatic cylinder, (4) brake cylinder, (5) speed sensor, (6) lever, (7) engine force gauge, (8) computer, (9) pressure sensor, (10) engine, (11) fuel tank, (12) scale, (13) smoke filter, (14) opacimeter OP 160, (15) exhaust analyzer KEG 500

Before carrying out the tests, the injection pressure and the accelerator need to be calibrated according to the parameters of the test engine. In addition, the fuel filter, lubricant, and air filter have to be renewed. The experiments were carried out after the test engine had been heated to 850-900 C. The test engine must run for a while to consume any remaining fuel from the previous test before starting a new experiment. Tests were conducted for four different kinds of fuel, starting with B0 followed by B20, B40, B60. The performance and emission tests were performed at full load, and the engine speed was changed in 100 rpm steps for each type of fuel.

TABLE I
ENGINE SPECIFICATIONS

Model	EMEI 185N
Type of engine	Static, four-stroke, uniform combustion chamber, water cooled, direct injection, one cylinder.
Number of cylinders	1
Cylinder diameter	85 mm
Stroke	90 mm
Maximum power	5.88 kW
Fuel consumption	281.5 g/kW

III. Results and Discussion

A. Torque

According to the theory of internal combustion engines, the engine torque increases to the maximum at a critical point and then decreases with increasing engine speed. The engine was fully fueled for the torque tests and then run at variable speeds ranging from 1000 rpm to 2300 rpm, increasing in 100 rpm increments. The torque changes obtained using the various fuel mixtures (B0, B20, B40, B60) are shown in Fig.3. The results show that the torque decreased as the mixing ratio increased. This may be due to the higher viscosity and lower calorific value of the biodiesel.

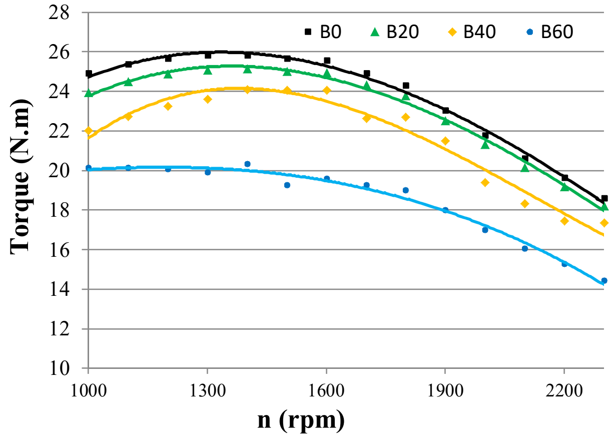


Fig. 3 Torque change with different fuels

Hence, a high viscosity fuel will result in a decrease in the amount of fuel injected into the oil pump, and the volumetric efficiency of the engine will be lower, thus the torque will decrease. For the B20 fuel, the torque is higher than for other fuels, close to that of the petrol-diesel (B0). The highest engine torque obtained in the tests if for B0. The calorific value of B20 is close to that of B0, so this could be a reason for the increase in torque. As can be seen in Fig.3, the torque values obtained when using B0 and B20 are higher than for B40 and B60. The largest difference in the torque obtained using the B0 and B60 fuels at 1500 rpm was 24.8%. In comparison to B0, the torque values obtained from the engine decreased by an average of about 2.6%, 8.48%, and 15.62% for B20, B40, and B60, respectively. In addition, at low engine speeds, the mixture of air and fuel is not well mixed due to the weak suction force, resulting in incomplete combustion. At higher engine speeds, the amount of fuel provided by a high-pressure pump is still lower because the biodiesel has a high viscosity. Therefore, the torque obtained using the biodiesel blends B40 and B60 is still quite low when compared to the B0 and B20 fuels.

B. Power

With the lower calorific value and higher biodiesel viscosity, the combustion of the mixture B60 is less efficient than the combustion with diesel fuel. The delay in the combustion of the mixture because of the high viscosity of the mixture is long and leads to incomplete combustion. In addition, the calorific value of biodiesel is lower than that of diesel fuel. Thus, there is a slight decrease in torque and power when using this fuel. The dependence of maximum power on the percentage of biodiesel with different engine speeds can be seen in Fig.4. When using B60 fuel at 1800 rpm, the maximum power is 3.58 kW, which is also the lowest value compared to the other fuel samples with smaller mixing ratios. The power obtained from the engine decreases in value by 2.5%, 8.48%, and 15.13% when using B20, B40, B60, respectively. The average power reduction for the biodiesel blends is about 8.70%.

The maximum power difference between the petrol-diesel and the biodiesel blend increases with an increase in the ratio of biofuel in the biodiesel blend.

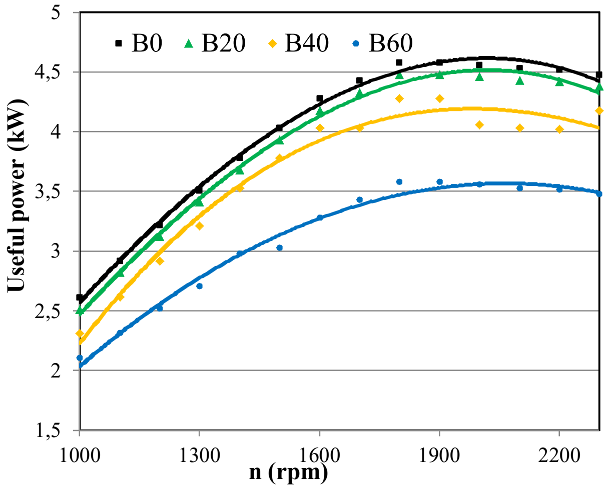


Fig. 4 Useful power vs engine speed for different biodiesel blend ratios

C. *Specific fuel consumption (ge)*

The engine is tested on a test conveyor belt to determine the fuel consumption over time (gram/h) and the output power Ne (kW). The specific fuel consumption (ge) is the parameter used to evaluate the engine's fuel efficiency. A comparison of specific fuel consumption between the different biodiesel blends (B20, B40, and B60) and petrol-diesel fuel (B0) is illustrated in Fig.4. The experimental results indicate that the specific fuel consumption might increase as the biodiesel blend ratio increases when the engine is run with the biodiesel blends. Comparison is made to the petrol-diesel (B0) fuel. The difference in specific fuel consumption is about 0.77%, 3.38 %, and 5.44% using B20, B40, and B60, respectively. A higher biodiesel ratio leads to greater specific fuel consumption. In addition, the minimum specific fuel consumption is also tested for each case, using B0, B20, B40, and B60. When the engine is operated with B0 fuel at full load at a speed of 1700 rpm, this parameter is 320.80 g/kWh. Similarly, testing the engine's operation with the biodiesel blends, we find that these parameters have values of 320.56 g/kWh (at 1800 rpm), 330.62 g/kWh 336.46 g/kWh (at 1900 rpm) corresponding to B20, B40 and B60, respectively. The higher viscosity and lower calorific value of the biodiesel than those of petrol-diesel might be the main reasons for these results.

In the case of full loading with a low engine speed, the specific fuel consumption when using B20 is observed to have the lowest value compared to the other fuels, even the petrol-diesel fuel. This may be due to the amount of oxygen in the fuel and its properties, speeding up the reactions and leading to a complete combustion at low speed.

Figure 6 shows the CO emissions obtained during experimental investigation for the different fuels, including B0, B20, B40, and B60. In comparison with B0, there is an average reduction in CO emissions of about 42.9%, 61.9%, and 64.3% for B20, B40, and B60, respectively. Fuel combustion inside a diesel engine depends on how the mixture of air and fuel is injected into the combustion chamber. The richer fuel mixtures cause a lot of CO to be created during combustion. In addition, under a full or heavy load working regime, the engine needs more oxygen during the combustion stage, and the biodiesel contains more oxygen than the petrol-diesel.

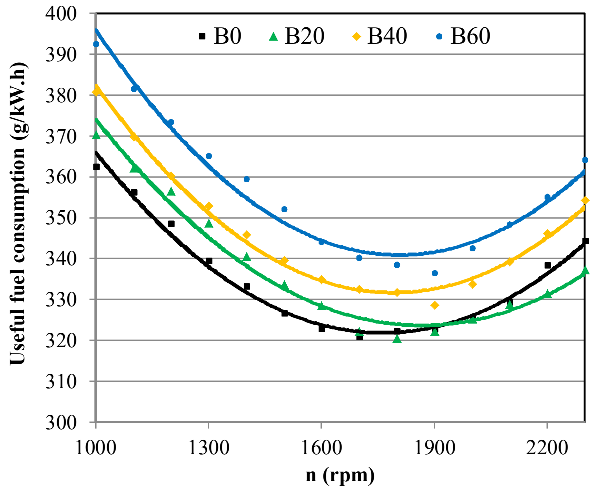


Fig. 5 Useful fuel consumption vs engine speed with different biodiesel blends

D. *CO emissions*

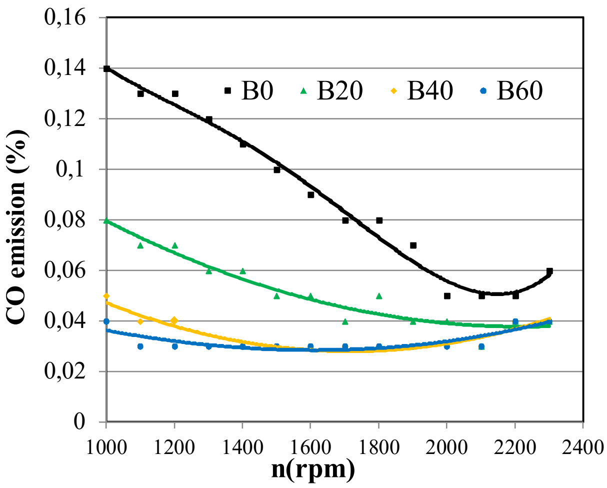


Fig. 6 CO emissions vs engine speed for different biodiesel blends

In contrast to oxygen in the air, oxygen in the fuel accelerates the internal combustion for the fuel-rich injections. The oxygen content in the biodiesel molecule is higher than in the petrol- diesel, resulting in more complete and cleaner combustion, as reported by previous studies [16], [19]. This leads to better fuel burning than is the case when using biodiesel. A perfect combustion process due to the increased oxygen content in the flame coming from the biodiesel molecules is the main reason for reducing CO emissions. As shown in Figure 6, there is a reduction in the CO emission values when using the B40 and B60 fuels due to the higher oxygen content. Therefore, the CO emissions decreased with the use of biodiesel.

E. *NOx emissions*

The variation of NOx emissions corresponding to engine speed for different types of fuels tested at a full load working regime is shown in Fig.7. The experimental results show that there was a reduction in NOx emissions when using the biodiesel blends (B20, B40, and B60) compared to using petrol-diesel (B0) with reductions of approximately 1.2%, 5.3%, and 10.3% for B20, B40, and B60, respectively. Figure 7 also shows that the changes in NOx emissions obtained using the different biodiesel blends tend to be like the one obtained using petrol-diesel fuel. Furthermore, it is interesting to note that the highest NOx emissions obtained at the full load working regime are recorded for B20. The reason might be the excess oxygen supplied with the oxygen generated from the biofuel making for faster and more perfect combustion. In addition, the oxygen generated from the fuel is more efficient than the external oxygen supplied by the air during the production of NOx.

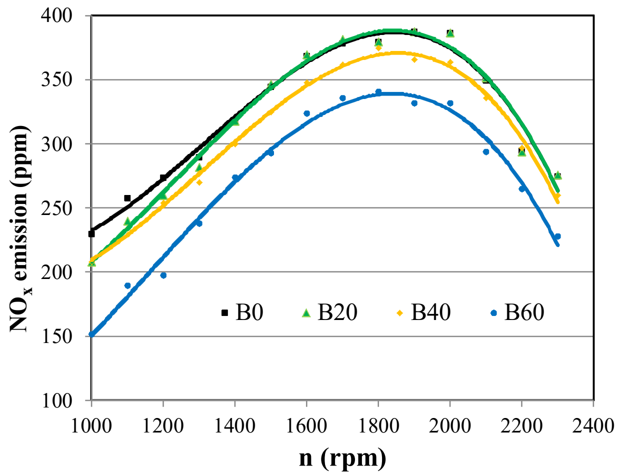


Fig. 7 NO_x emissions vs engine speed for different biodiesel blends

F. HC emissions

The changes in HC emissions according to the engine speed for B0, B20, B40, and B60 fuel are presented in Fig. 8. In comparison with B0, there is a decrease in the average HC emissions of 21.7%, 31.2%, and 35.8% for B20, B40, and B60, respectively. The HC emissions obtained for B20, B40, and B60 are quite a bit lower than that for the petrol-diesel case. This might be because biodiesel contains more oxygen, enough for oxidation when mixing parts of fuel and air, improving combustion.

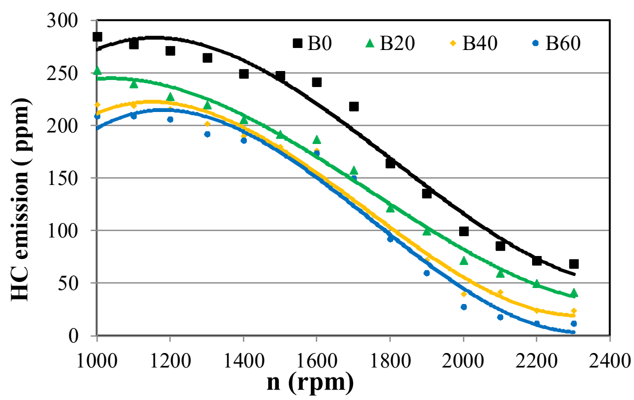


Fig. 8 HC emissions vs engine speed for different biodiesel blends

Fig. 8 also shows that high HC emissions are generated at low engine speeds in all cases for different fuels. This might be due to the highest fuel consumption for the low-speed range of the engine. In addition, it can also be seen that the HC emissions decrease for all fuels when the engine speed is increased. As the engine speed increases, the gas flow increases, and then the pressure in the cylinder and the temperature also increases. For these reasons, the oxidation rate of HC should increase at higher speeds, making possible a significant reduction in HC emissions [4], [19].

G. CO_2 emissions

The amount of CO_2 in the exhaust gas is an important parameter indicating whether the combustion is complete or not. The CO_2 emissions in all cases for the different biodiesel mixtures (B20, B40, and B60) and B0 fuel are presented in Fig.9. In general, it can be seen that the CO_2 emissions obtained when using the biodiesel blends are lower than when using petrol-diesel, with average reductions of 3.8%, 8.2%, and 15.1% when using B20, B40, and B60, respectively. The average CO_2 emissions reduction for the case of using biodiesel is 9.03%, and the lowest CO_2 emissions are observed for B60, at all engine speeds. As a result, the CO_2 emissions will increase following an increase in the engine speed, as shown in Fig. 9.

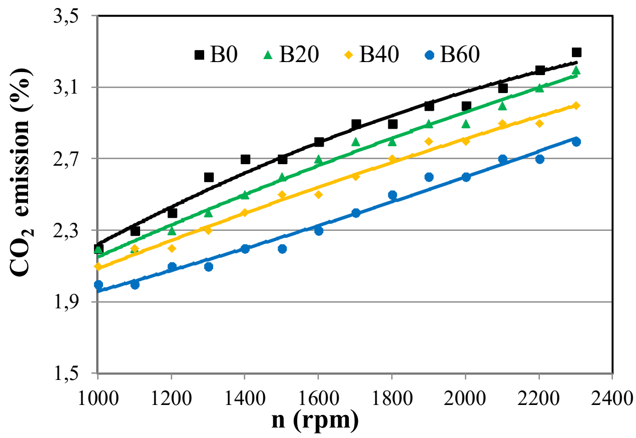


Fig. 9 CO_2 emissions vs engine speed with different biodiesel blends

The percentage of carbon mass in the petrol-diesel fuel is higher than in the biodiesel fuel, so, during the combustion stage, the CO_2 emissions will be lower for biodiesel than petrol-diesel. The vortex of the air intake into the cylinder increases in combination with the oxygen in the biodiesel, making a significant contribution to the thoroughness of the reaction of the fuel in the engine cylinder. Therefore, the CO emissions decrease when biodiesel is used.

H. Smoke opacity

The change in smoke opacity for different fuels is shown in Fig.10. It has been reported by some previous studies [18], [19] that fuel with a longer burning phase shows lower particulate emissions and higher NOx emissions under high load operation.

As can be seen in Fig.10, the observed smoke emissions are lower for B40 and B60 than B0 and B20. As the speed increases, the smoke opacity decreases. In comparison with B0, the average smoke opacity decreases 9.1%, 15.9%, and 23.2% corresponding to the use of B20, B40, and B60, respectively.

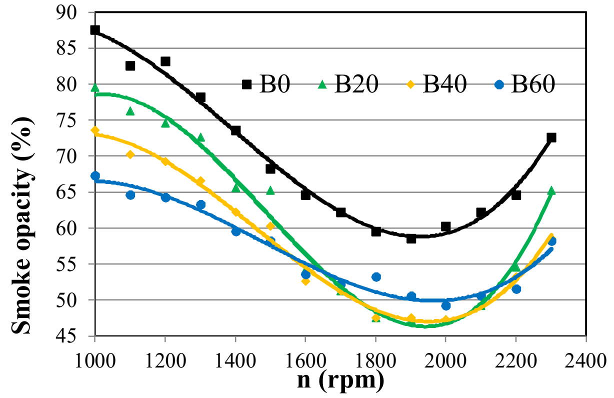


Fig. 10 Smoke opacity vs engine speeds for different biodiesel blend ratios

IV. Conclusion

The working parameters and the gas emissions of a petrol-diesel engine powered by biofuel produced from Vietnamese pangasius fish fat mixed with petrol-diesel fuel at four blend ratios of 0%, 20%, 40%, and 60% (B0, B20, B40, and B60, respectively) have been studied and presented in this paper. With an increase of the mixing ratio in the mixture, there is a decrease in the torque and power while the specific fuel consumption increases. In addition, there is a reduction in NOx, CO, CO2, HC emissions, and smoke opacity. Specifically, the results indicate that in comparison to B0, there is an average reduction in CO emissions of about 42.9%, 61.9%, and 64.3%; a reduction in NOx emissions of about 1.2%, 5.3%, and 10.3%; a decrease in average HC emissions of 21.7%, 31.2%, and 35.8%; an average reduction of CO2 emissions of 3.8%, 8.2%, and 15.1%; and an average decrease in smoke opacity of 9.1%, 15.9%, and 23.2%, corresponding to B20, B40, and B60, respectively. However, some problems with biofuels remain, including viscosity reduction, larger-scale biodiesel production, more efficiency, and cleaner emissions which need to be considered in further studies.

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