Experimental study on the effects of injection timing using reuse of waste energy as a fuel on a diesel engine

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ABSTRACT

In the course of this study, an eco-friendly alternative fuel was manufactured by transesterifying waste oils with the help of alcohol and a catalyst. As required by the American society for testing and materials (ASTM) requirements, we conducted an analysis on the acquired waste cooking oil biofuel (WOB) to determine its most important properties. We were successful in producing three separate fuel mixes, which we will refer to as BF100WOB0 (100% diesel), BF80WOB20 (80% diesel and 20% biofuel), and BF0WOB100 (100% biofuel) respectively. This research used a diesel engine with direct injection; the engine had a single cylinder, and the computer that operated it was located in the cabin. The results showed that the BF80WOB20 had a 3.8% increase in fuel consumption and a 1.4% loss in thermal efficiency while it was at a temperature of 26.5° b top dead center (TDC) conditions with low injection time led to decreased levels of both nitrogen oxides (NOx) and hartridge smoke level (HSL) emissions. The addition of 20% WOB to the fundamental fuel improved the engine combustion characteristics at 26.5° b TDC. This improvement occurred at the same time.

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NOMENCLATURES

BF	Base fuel	CR	Compression ratio
BTE	Brake thermal efficiency	HSL	Hartridge smoke level
BF100WOB0	100% of base fuel and 0% of waste oil biodiesel	ITs	Injection timings
BF80WOB20	80% of base fuel and 20% of waste oil biodiesel	MROPR	Max. rise of pressure rate
BF0WOB100	0% of base fuel and100% of waste oil biodiesel	NOx	Nitrogen oxides
b TDC	Before top dead center	SFC	Specific fuel consumption
WOB	Waste oil biodiesel		

1. INTRODUCTION

Global warming and its harmful consequences on the environment and human health are making people increasingly aware of the problems that come with the modern world's reliance on fossil fuels. Less use of fossil fuels might lower dangerous emissions by a large amount. It might be done by employing clean energy instead of fossil fuels [1], [2]. Moreover, particulate matter (PM) and nitrogen oxides released by diesel vehicles pose a threat to human health, which has slowed the development of diesel vehicles (NOx).

Diesel engines are the cause of about 90% of NOx and PM emissions. PM is linked to a wide range of bad things that happen to people's health when they breathe it in. It causes respiratory and cardiovascular diseases [3], [4]. In this way, research has shown that using diesel biodiesel blends can cut carbon monoxide (CO), hydrocarbons, and particulate matter emissions by a lot. This is because biodiesel already has oxygen in it. The authors were also told about some other fuels that are better for the environment [5]. Yang *et al*. [6] we looked at how the timing of the injections influenced the combustion and emissions of a dual-direct-injection diesel/NG engine that was running hard. The data reveal that making the brakes more thermally efficient caused the CO2 emissions to rise from 15.6% to 6.4%. Overall, the time of NG injection may be shifted forward to make the thermal efficiency better. Channapattana *et al*. [7] added nickel oxide nanoparticles to a blend of Neem biodiesel and diesel fuel and ran it through a direct injection-compression ignition engine (DI-CI) engine at different fuel injection times (19, 23 and 27 b top dead center (TDC)). Based on their studies of performance and thermodynamics, they came to the conclusion that when Neem biodiesel is mixed with diesel, the thermal efficiency goes up and the amount of radiation loss goes down. Valera *et al*. [8] mixed methanol with diesel fuel and ran it through a DI-CI engine at different methanol injection rates. Based on their studies of how things work, they found that when methanol is added to diesel, the NOx emissions go down. Chaurasiya *et al*. [9] mixed 5% hydrogen, 5% diethyl ether, 5% n-butanol, and 5% microalgae with 95% diesel fuel, then ran the mixture through a DI-CI engine at different injection times (17.5-29.5° b TDC). Based on their studies of how things work, they found that the injection timings must be moved back to lower the charge temperature and reduce NO_X emissions.

The proposed effort intends to establish a methodical approach to the use of used cooking oil as a biofuel for the partial replacement of diesel fuel in CI engines. This will be accomplished via the use of a CI engine. In addition, a unique technique is used by changing the injection time (18.5-26.5° b TDC) at varying concentrations, and this study is expected to be the first of its sort to be published using BF80WOB20 mix. In light of this, the purpose of this study is to investigate the performance, combustion, and emission characteristics of a waste cooking oil biofuel mix with various injection timings.

2. PRODUCTION OF WASTE PLASTIC OIL BIODIESEL AND EXPERIMENTAL

2.1. Production of waste cooking oil biodiesel

Palm oil, sunflower oil, mustard oil, and soya oil were chosen for this study because they may be used in many different ways in the kitchen and have a broad variety of fatty acid profiles. In the Indian state of Tamil Nadu, there is a city called Chidambaram. In Chidambaram, there is a market where the oils were bought. Biodiesel was made by melting down leftover cooking oils and putting them together with alcohol and potassium hydroxide. Through a chemical process called transesterification, used cooking oils were turned into waste cooking oil biodiesel (also called WOB) [10]–[12]. Before the transesterification procedure could start, the WOB samples were filtered to get rid of any contaminants that could have been there. Table 1 shows what the fuel is and how it works. The process of preparing biofuel is shown in Figure 1. Figure 2 shows a sample of fuel. Figure 2(a) contains Basefuel100 (BF100) and Figure 2(b) contains WOB100.

Table 1. Belongings of various energies

Property	BF100WOB0	BF80WOB20	BF0WOB100
Cetane number	45-52	52.9	49.5
Density (kg/m^3) at 15 °C	838	849.5	874.75
Flash point (°C)	61.2	52.6	36.5
Viscosity (mm^2/s) at 40 °C	3.8	3.59	3.64
Calorific value (MJ/kg)	45.5	44.6	40.4

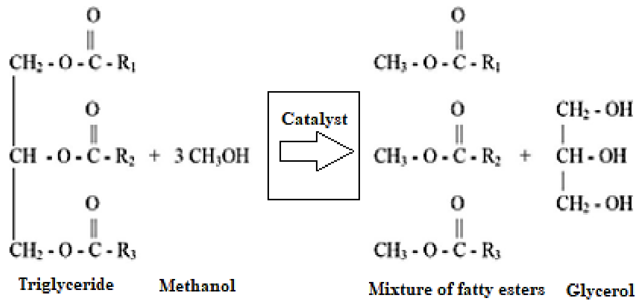

Figure 1. The process of preparing biofuel

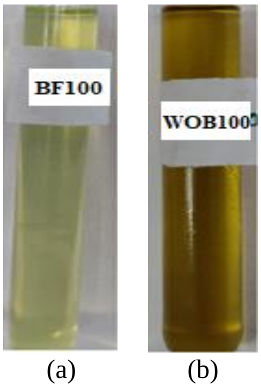

Figure 2. Fuel sample of (a) Basefuel100 and (b) WOB100

2.2. Experimental test ring

A simplified diagram of the testing setup is shown in Figure 3. A summary of the test environment's capabilities is provided in Table 2. The engine was loaded using a dynamometer. The amount of gasoline flowing through the system at any one moment was determined with the use of a fuel meter. In order to gauge the air flow rate, an air box was also fitted to the motor. The temperature of the exhaust gas was measured with the help of a thermocouple and a digital temperature monitor. The cylinder pressure was measured and recorded with the use of a charge amplifier and a pressure transducer that was affixed to the engine's cylinder head. NOx, HC, and CO exhaust levels were measured using an exhaust gas analyzer (Testo-350). Each test was conducted using an interface for a data collection system at the maximum engine speed of 1,500 rpm.

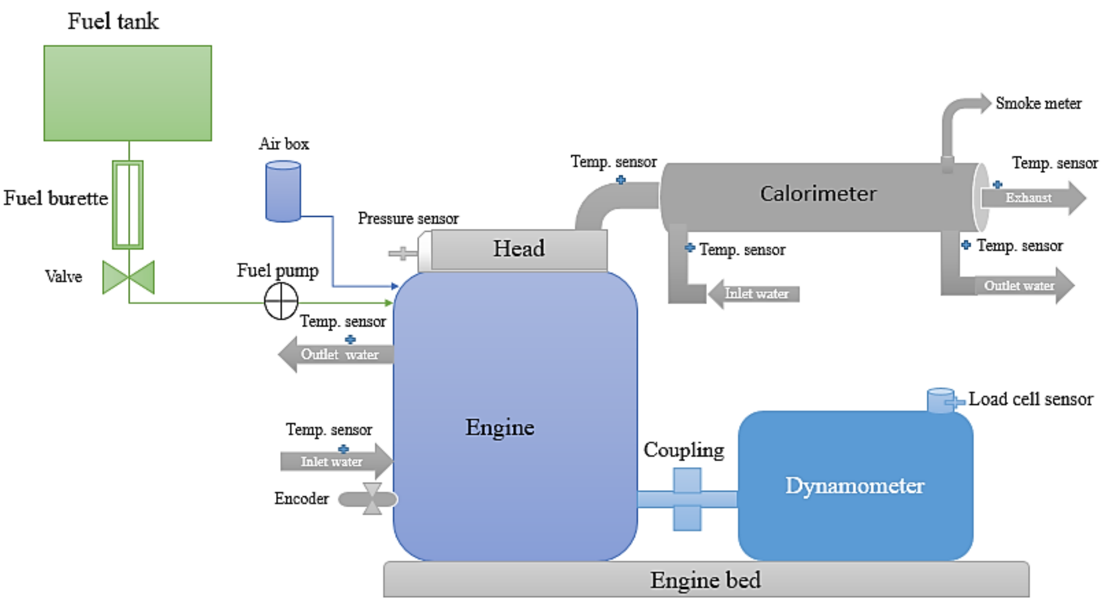

Figure 3. Test setup

Table 2. Provisions of assessment machine

Limits	Limits value
Engine stroke/cylinder	Four/one
Higher than fuel injection pressure	230 bar
Rated speed	1,500 rpm
Dimension of bore/stroke	80/110 mm
Advanced fuel injection timing	17.5-27.5° b TDC
Compression ratio	18.5
Method of cooling	Water

2.3. Experimental error analysis

An uncertainty analysis is of utmost significance for the experimental investigations since the outcome of the analysis provides the readers with an idea about the correctness and repeatability of the data that were delivered to them. Accordingly, a total uncertainty value of the findings is computed by making use (1) [12] and basing it on the information shown in Table 3. The section of the text devoted to the nomenclature provides readers with an explanation of the symbols. According to (1), the total amount of suppositional uncertainty is 2.36%.

$$T = [(E_1)^2 + (E_2)^2 + \cdots (E_n)^2]^{1/2} \quad (1)$$

Table 3. Uncertainties

Apparatus	Uncertainty
Angle encoder	±0.2%
Pressure	±0.5%
Smoke	± 1.0%
Temperature	±0.5%
CO_2	± 0.5-1.0%
NO_X	± 0.5-1.0%
Burette measurements.	±1.0%
Load meter	±0.2%
Indicator of speed	±1.0%

3. RESULTS AND DISCUSSION

3.1. Specific fuel consumption

The values of specific fuel consumption (SFC) are shown in Figure 4 for a variety of injection timings when Figure 4 shows the values of SFC for a number of different injection timings while the engine was running under full load conditions. When the engine was operating at its maximum load, for instance, the SFC values for BF80WOB20 were higher than those of BF100WOB0 (408.4, 257.3, 252, 250.2, and 244.7 g/kWh) at 18.5, 20.5, 22.5, 24.5, and 26.5° b TDC respectively, and the SFC was higher by 4.3% at an injection timing of 26.5° b DTC. Because biodiesel has a lower heating value than regular diesel, it takes more fuel to create the same amount of heat, which leads to an increase in the SFC. This is one of the reasons why biodiesel contributes to an increase in greenhouse gas emissions. The value of the SFC increases if there is a higher quantity of each component present in the combination. When compared to diesel, the study shows that proper ignition leads to a drop in SFC concentration with increasing load. This phenomenon is not seen with diesel. The higher density of biodiesel fuel in comparison to gasoline fuel is another factor that contributes to the rise in SFC that occurs with increasing percentages of biodiesel [13]. When the engine was operating at its maximum capacity, a rise in the temperature within the cylinder as well as an increase in the quantity of oxygen contained in the alternative contributed to an improvement in the mixes' fuel consumption [14].

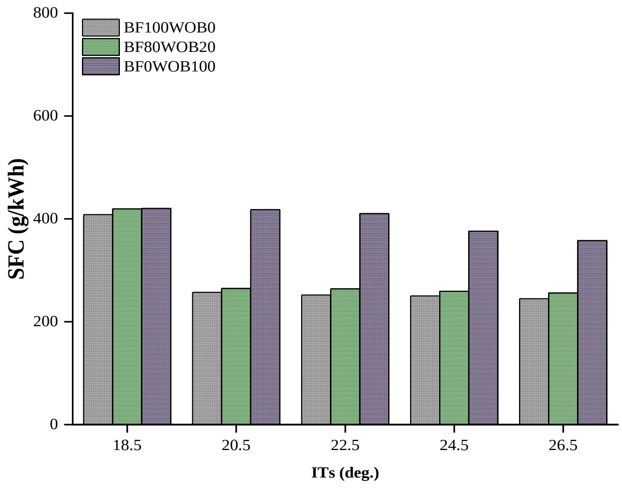

Figure 4. Specific fuel consumption with air force institute of technology (AFIT'S)

3.2. Brake thermal efficiency

Figure 5 presents the values of brake thermal efficiency (BTE) for a number of different injection timings. The ratio of the power output of the engine to the energy content of the fuel that is injected into the combustion chamber is referred to as the BTE. The mass flow rate of the fuel, in combination with the fuel's lower heating value, is used to calculate the total amount of energy that the fuel contains. The biodiesel showed a modest improvement in terms of BTE, which may be attributed to the fact that there was less fuel atomization in the combustion cylinder. This might be due to the fact that diesel has a lower viscosity than biodiesel [13], which is a fuel made from vegetable oils. While biodiesel has a greater viscosity. The BTE of the examined gasoline mixes is shown in Figure 4 for a variety of different engine loads. The braking energy transfer efficiency, also known as the BTE, is measured as the ratio of the braking power to the heat equivalent of the fuel that was used. Due to the lower energy contents, the BTE for all fuel blends was generally lower than that of diesel fuel [14]. If we compare BF80WOB20 and BF100WOB0 at full load, we find that at 18.5° and 26.5° b DTC earlier injection time, the BTE values for the latter are lower by 2.0% and 3.1%, respectively. Fuel combustion efficiency of the mixes was enhanced while the engine was operating under full load due to an increase in cylinder temperature and the quantity of oxygen present in the alternative. Therefore, it increased BTE and enhanced combustion efficiency. At higher engine loads, the increased in-cylinder temperature and heat of release rate caused the BTE for 18.5° b TDC, 20.5° b TDC, 22.5° b TDC, 24.5° b TDC, and 26.5° b TDC to be 30.82%, 32.5%, 33.9%, 33.9%, and 33.9% higher, respectively, than WOB blends.

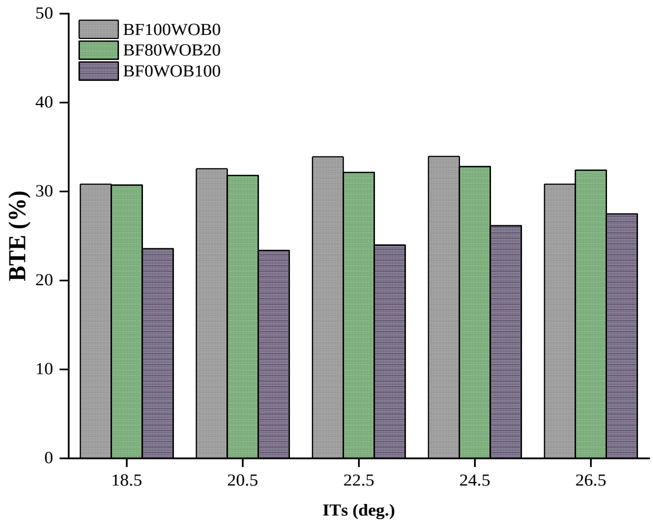

Figure 5. BTE with advanced fuel injection times (AFITs)

3.3. Cylinder pressure

Figure 6 shows a depiction of the link between crank angle and cylinder pressure for each of the test fuels. This connection can be observed for each of the test fuels. When the engine was filled to its full capacity, the BF100WOB0, BF80WOB20, and BF0WOB100 all followed the same pattern with regard to the pressure within their respective cylinders. When measured against BF100WOB0 (89.3, 110.2, 116.3, 122.9 and 127.2 bar), the maximum cylinder pressure of BF80WOB20 (85.7, 92.3, 92.7, 108.1,113.3) at 18.5° b TDC, 20.5° b TDC, 22.5° b TDC, 24.5° b TDC and 26.5° b TDC with 100% load is shown to be lowered by 4.0%, 16.1%, 20.1%, and it's possible that the high viscosity of the WOB, the high latent heat of evaporation, and the poor igniting qualities are all to blame for this [15], [16].

3.4. Maximum rate of pressure rise

Figure 7 illustrates the maximum rate of pressure rise (MROPR) as well as the injection for each of the test fuels. The exhaust gas temperature (EGT) of the BF100WOB0, BF80WOB20, and BF0WOB100 all followed the same pattern when the engines were loaded to their maximum capacity. In comparison to BF100WOB0 (4.2, 5.9, 6.2, 6.5 and 6.8 bar/deg.), the MROPR of BF80WOB20 (3.9, 4.0, 4.2, 4.3 and 4.6 bar/deg.) at 18.5° b TDC, 20.5° b TDC, 22.5° b TDC, 24.5° b TDC and 26.5° b TDC with 100% load is seen to be 7.1%, 32.2%.

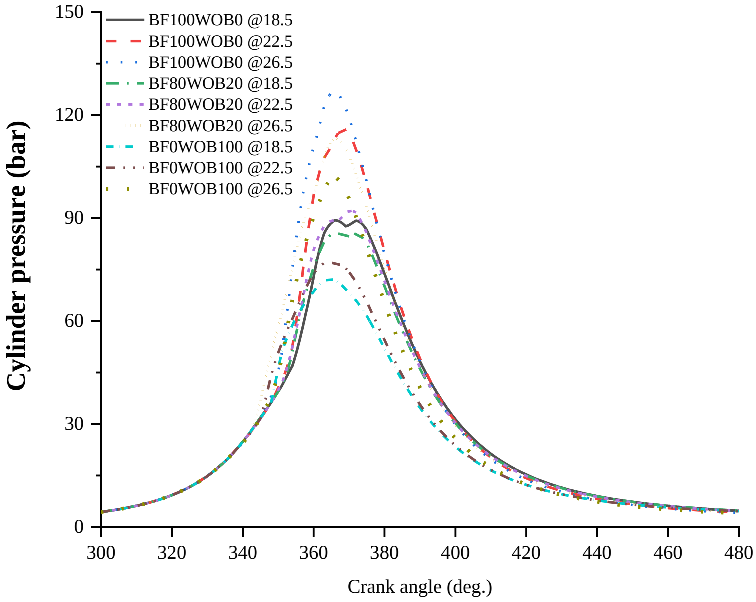

Figure 6. Cylinder pressure with ITs

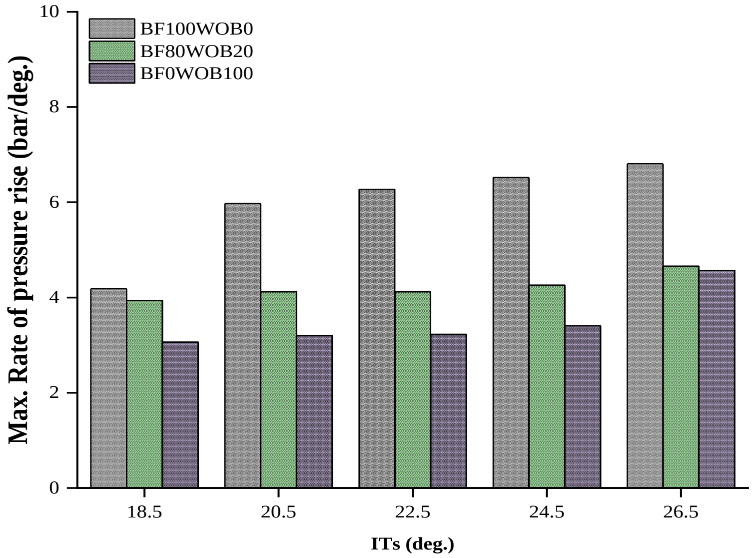

Figure 7. Maximum rate of pressure rise with ITs

3.5. NOx emission

Figure 8 depicts the range of nitrogen oxides (NOx) emissions achieved by varying the injection time for base fuel and biodiesel techniques. When the engines were loaded to their maximum capacity, the NOx emissions from BF100WOB0, BF80WOB20, and BF0WOB100 all followed the same pattern. In comparison to BF100WOB0 (827.8, 2352.5, 3052.9, 3450.8 and 4012.9 ppm), the NOx levels of BF80WOB20 (732, 1822.5, 2525, 3003.4 and 3569.) at 18.5° b TDC, 20.5° b TDC, 22.5° b TDC, 24.5° b TDC and 26.5° b TDC with 100% load are observed to be 11.5%, 22.5% One possible explanation for this is because the WOB has a lower temperature [17], [18]. When certain operating conditions, such as the air-to-fuel ratio, are present, there is a general tendency for NOx emissions to rise as the combustion temperature rises while the ignition timing advances the cetane number [19]-[21]. This is a pattern that can be observed under certain circumstances.

3.6. Smoke emission

By employing fuels with large volatilities, it is possible to efficiently cut down on the amount of smoke emitted at early injection timings. When it comes to fuel blends, the effect of oxygenated content in decreasing smoke emissions was major when the diesel energy ratio was increased, but the influence of fuel volatilities became predominant when the diesel energy ratio was dropped. This is because the diesel energy ratio is directly proportional to the amount of smoke emissions produced by the fuel [22], [23]. Both fuels and loads contributed to an increase in the amount of smoke being emitted by the engines. When the quantity of incoming fuel grew along with the increased load, adequate air was unable to be given, and as a consequence, the amount of smoke that was created as a result of the rich mixture also increased correspondingly [24], [25]. Figure 9 depicts the range of HSL emissions achieved by varying the injection time for base fuel and biodiesel techniques. When the engines were loaded to their maximum capacity [26], the patterns of smoke emission produced by BF100WOB0, BF80WOB20, and BF0WOB100 were identical. In contrast to the smoke emission of BF100WOB0 (50.4, 39.8, 37.9, 35.6, and 34.2 HSL), the smoke emission of BF80WOB20 (50.8, 47.8, 47.8, 40.9, and 39.2 HSL) at 18.5° b TDC, 20.5° b TDC, 22.5° b TDC, and 24.5° b TDC and 26.5° b TDC with 100% load is noted to be 0.78%.

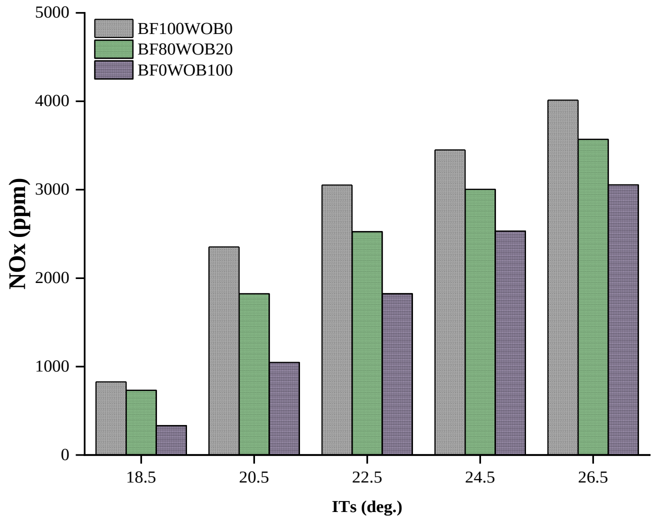

Figure 8. Engine NOx emission with ITs

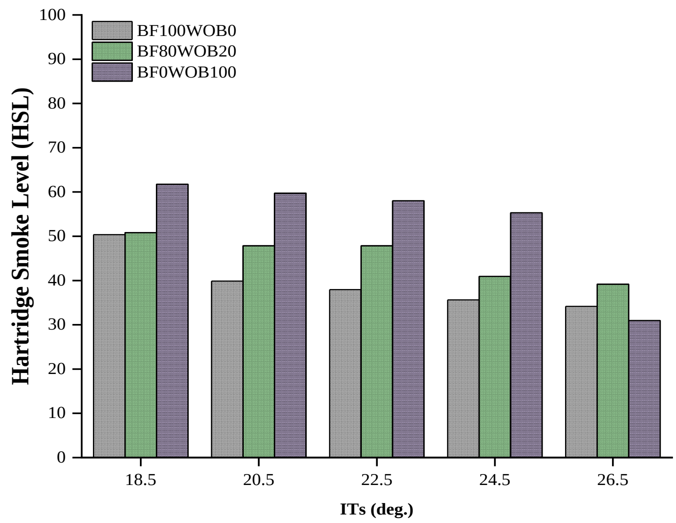

Figure 9. HSL emission with ITs

4. CONCLUSION

The density and flash points of biodiesels generated with a greater percentage of WOB are well within the standards for biodiesel in terms of density and temperature. Biodiesels derived from waste oil have calorific values that are slightly lower than those of base fuel. This is due to the fact that biodiesel is made from waste oil. Compared to BF100WOB0 (89.3, 110.2, 116.3, 122.9, and 127.2 bar), the maximum cylinder pressure of BF80WOB20 (85.7, 92.3, 92.7, 108.1, 113.3) at 18.5° b TDC, 20.5° b TDC, 22.5° b TDC, 24.5° b TDC, and 26.5° b TDC with 100% load is lower by 4.0%, 16.1%, 20.1%, 12.0% and 10.9%, respectively at 18.5 CR. This base fuel, which is made from used oil, makes a little more smoke than the base fuel itself does. When compared to the basic fuel, there may be significant differences in the quantity of NOx that is released. The quantity of BTE that is decided by WOB isn't as high as the amount that is determined by base fuel. It has been shown that BF80WOB20 produces 11.0% less NOx at 26.5° b TDC and 100% load than BF100WOB0 does at 18.5 CR. The current experimental study operated using BF80WOB20 blend at various injection timings together with full load condition, and the results showed 22.5° to 26.5° b TDC improved operating condition for the engine.

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