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"THE EFFECT OF HIGHER INJECTION PRESSURE AND ADVANCED INJECTION TIMING ON THE PERFORMANCE AND EMISSION CHARACTERISTICS OF CRDI DIESEL ENGINE FUELLED WITH B20 WASTE COOKING OIL MIX"

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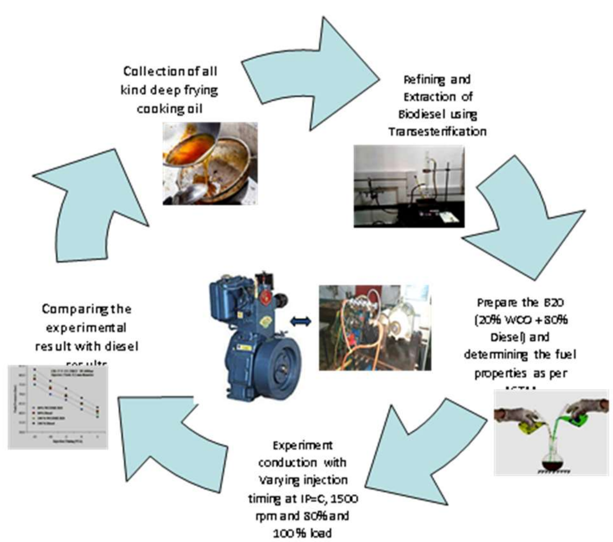
Abstract

Biodiesel's importance in the future world lies in its potential to address environmental concerns, enhance energy security, drive rural development, utilize waste resources, and benefit from technological advancements. By embracing biodiesel as a key component of the energy mix, societies can move closer to a sustainable and resilient future. The current study is on performance and emission characteristics of B20 biodiesel derive from waste cooking oil mix using in single cylinder four-stroke diesel engine integrated with Common rail direct injection system runs at constant speed of 1500 rpm. With advancing injection timings +5° CA to -15°CA and at 600 bar injection pressure, at -10° CA brake thermal efficiency had significantly improved with reduction of injection delay and combustion duration. B20 Blend biodiesel operating at higher pressure and at varying load condition results in increase in smoke, NOx and CO2. This study highlights the potential for optimizing injection parameters to enhance the environmental performance of B20 biodiesel derived from waste cooking oil mix without any modification.

Key words : waste cooking oil mix, CRDI, injection pressure, advancing, injection timing.

Graphically Abstract



1.0 INTRODUCTION

The global transportation sector is witnessing a transition towards cleaner and more sustainable alternatives to traditional fossil fuel-powered vehicles. While electric vehicles (EVs) have gained considerable attention, biodiesel engines offer distinct advantages that make them a competitive option in the quest for greener transportation. [1], [2]. [3] The key advantages of biodiesel engines over electric vehicles supported by existing infrastructure [1], range and refuelling time [3], energy storage and density [2], reduced manufacturing and disposal impact.[6] Biodiesel, a cleaner-burning alternative to conventional diesel fuel, has emerged as a promising solution. In the quest for a greener future, harnessing the potential of waste cooking oil as a feedstock for biodiesel production has gained significant attention. [4] Biodiesel is a renewable and clean-burning fuel that can be used in diesel engines without significant modifications. The successful implementation of waste cooking oil-based biodiesel production will require collaboration between governments, industries, and communities to develop robust collection systems, improve production processes, and foster a supportive regulatory framework. [5]

The global waste generated per person per day averages 0.74 kilograms, but ranges from 0.11 to 4.54 kilograms. Municipal waste generation worldwide is expected to increase by 70 % by 2050. The reasons for this include population growth, urbanization, economic growth, as well as consumer buying habits. In 2020/21, more than 200 million metric tons (MMT) of vegetable oil consumed worldwide, up from 150 MMT in 2013/14.[8] The majority of waste oils come from frying or cooking edible oils. Biodiesel production costs are 70–80% influenced by feedstock costs, so by using waste cooking oil (WCO) as feedstock, costs could be reduced to 60–70%. [7] Due to the high-temperature mixing of food's water and oil during the frying process, the recovered WCO has a high water and free fatty acids (FFA) concentration. There are several processes to extract the biodiesel from waste cooking oil, such as transesterification, pyrolysis and micro emulsification. The extraction of biodiesel from waste cooking oil (WCO) is 93% when methanol to oil molar fraction of 6:1, 60°C and calcium oxide of 1.5%wt and yields is 89.9% when 9:1, 50°C, 1.0 wt% of sodium hydroxide [9]

Increasing the injection pressure in a unmodified diesel engine can have several effects on its performance and emission like improved atomization, reduce particulate matter (PM), improve fuel efficiency, improve power output and also depends on engine design, fuel properties. The experimental results using B20 waste cooking oil (20% Biodiesel and 80% diesel), B30 (30% biodiesel 70% diesel) and B50 (50% biodiesel, 50% Diesel) shows the reduction of carbon oxide (CO) and hydrocarbon emission (HC) but increases in nitrogen oxide (NOx) emissions. For B20 blend brake thermal efficiency(BTE), specific fuel consumption (SFC) and reduced engine efficiency compared to other two blends at 16.5, 17.5and 18.5 compression ratio (CR).[11] For varying engine loads 25% to 100 % and 1400 rpm condition , the result should increases in cetane number by adding bio-ethanol , SFC increases by 16.1%, 27.54%, BTE increased upto 9.44% and 3.88% without and with bio-ethanol. The biofuel increase cylinder pressure, heat release rate and exhaust temperature.[14] The when B20 WCO is injected at higher pressure 200-2500 bars in diesel engine NOx emission will reduces. [12] Atomization and evaporation have major impact on air-fuel mixing and the combustion process. A numerical and experimental analysis is investigated that the higher spray tip penetration, lower sauter means diameter (SMD), and decreased cone angle is obtained at 1100 bar to 1600 bar injection pressure. The results showed for B100, B25 and Diesel that the spray tip penetration increases by 19.86%, 14.90% and 14.50% respectively, cone angle decreases by 6%, 5% and 3,4% and 25%, 33,33% and 25,4% decrease for SMD.[13] The researcher concluded that the CO emission is less with low and medium loads but higher at full loads operating conditions as those of commercial biodiesel without modification.[15]

The research conducted on waste cooking oil performance and emission characteristics has shed light on the potential of that renewable energy source as a viable alternative to fossil fuels. The findings have shown that waste cooking oil biodiesel exhibits favourable combustion properties, comparable to or even better that conventional diesel fuel, while significantly reducing harmful emissions such as carbon monoxide, particle matter and sulphur dioxide.[17], [18] The research has highlighted the importance of proper pre-treatment techniques and blending ratios to optimize the performance and emission of waste cooking oil biodiesel. The use of suitable catalysts and efficient transesterification processes can enhance the fuel properties and ensure its compatibility with existing diesel engines, thus promoting its wider adoption in the transportation sector. [19],[20] Despite the significant progress made in understanding the performance and emission characteristics of waste cooking oil biodiesel, there are still some notable gaps that have been identified. One such gap is the limited availability of standardized testing protocols and evaluation methods specific to waste cooking oil biodiesel. The absence of universally accepted standards makes it challenging to compare research findings accurately and hinders the development of comprehensive regulations and guidelines for the industry. Further investigations are needed to assess the long-term durability and reliability of engines running on waste cooking oil biodiesel. This includes studying the impact of biodiesel on engine components, such as fuel injectors, fuel pumps, and exhaust systems, over extended periods of operation.[16],[19] Such studies will contribute to building confidence among stakeholders and addressing concerns related to the performance and maintenance aspects of using waste cooking oil biodiesel as a sustainable fuel alternative

The current study concentrated on evaluating B20 biodiesel made from mixed cooking oil waste gathered from local retailers and hotels.etc using a single-cylinder, four-stroke, dual-fuel diesel engine with a common rail direct injection system (CRDI). The performance and emission characteristics of B20 biodiesel are determined by variable injection time and compared to the conventional diesel performance under various load situations at a higher injection pressure of 600 bar, and constant speed of 1500 rpm,.

2.0 Fuel properties

The extraction procedure for biodiesel from waste cooking oil involves several steps. First, the waste cooking oil is collected and filtered to remove any solid impurities. Next, the oil is heated to a 65^0 C temperature to reduce its viscosity. Then, a catalyst, 1% sodium hydroxide, is added to initiate the transesterification process. The mixture is stirred vigorously to ensure complete reaction. After the reaction, the mixture is allowed to settle, and the biodiesel layer is separated

Catalyst Research Volume 23, Issue 2, September 2023 Pp. 895-905

from the glycerol layer. The biodiesel is further washed with water to remove any remaining impurities and dried to remove excess moisture. Finally, the purified biodiesel is ready for use as a renewable fuel source. the B20 blend is prepared mixing with convectional diesel and determine the properties of B20 biodiesel with help of SLN test laboratory, Bangalore. The properties of biodiesel are noted in table 1.

Table 1: Biodiesel fuel properties

Parameters/properties	Standard	Diesel	B20
Kinematic Viscosity mm²/s	ASTM D445	2.5	2.3
Flash Point ⁰C	ASTM D93	55	73
Calorific value kJ/kg	ASTM D5865	43481	42845
Density kg/m³	ASTM D4052	830	839
Cetane Number	ASTM D613	50	51
Cloud point ⁰C	ASTM D5773	-9.3	-7
Pouring point ⁰C	ASTM D5949	-11.4	-12

3.0 Experimental Setup

To determine the performance characteristic of B20 blend, the diesel engine test rig with specification detailed in table 3. The layout of the complete test rig with integrated CRDI system is shown in figure 3. High-pressure injection CRDI capability is utilized to fully utilize the energy from biodiesels and ensure a smooth combustion process. Pressure relief valves are used to control the pressure during fuel injection. The injection timing (IT) and injection duration (ID), is controlled by an appropriate electronic control unit (ECU). The start of injection (SOI) designates the starting point of the fuel injection (19^0 bTDC), while the ID period denotes the time gap between the start of injection and that point. The 5.2 KW braking power (BP) diesel engine was appropriately adjusted for injecting the WMCO biodiesel at high pressure utilising the CRDI system installed with an electronic control unit (ECU). To optimise fuel IT at 80% and 100% loads at constant 1500 rpm speed and IP of 600 bar, IT changed from 15^0CA bTDC to 5^0CA aTDC in steps of 5^0CA in the initial phase of the experiment. Smoke was recorded using a Hartridge smoke meter, while HC, CO, and NOx were measured using a DELTA 1600 gas analyzer that uses nondispersive infrared technology.

Figure 1: Duel fuel Diesel engine test rig

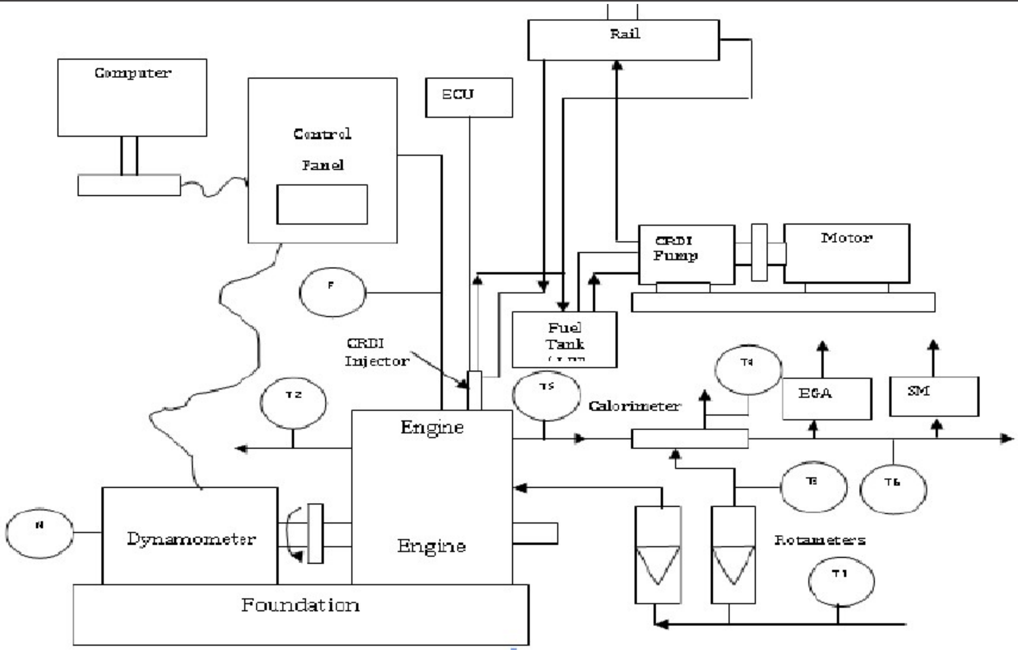
Figure 2 : CRDI system integrated to Diesel engine

Table 2: Specification of Duel fuel test rig

Model and Make	**Kirloskar TV1**
Type of Engine	4 stroke Direct injection Diesel Engine, one Cylinder, water cooled
Orientation	Vertical
Piston geometry	TRCC
Stroke, Bore	110mm, 87.5 mm
Displacements Volume	600 CC
Compression Ratio	17.5 : 1
Arrangement of values	Overhead
Combustion chamber	Open chamber
Power rated	7 HP
Cooling medium	Water cooled
Dynamometer	Length 0-180m, 5.2kW @1500 rpm
Fuel Measurement unit range	0-50 ml
Injector	Bosch , 0.2mm Dia 600bar -1200 bar

Table 3: Uncertainty analysis of Diesel engine test rig

Measured variable	Accuracy (±)
Load, N	0.1
Engine speed, rpm	3
Temperature, °C	1
Fuel Consumption, g	0.08
Measured Variable	**Uncertainty (%)**
HC	±3.4
CO	±2.1
NOx	±2.6
Smoke	±1.6
Calculated Parameters	**Uncertainty (%)**
BTE, %	±1.1
HRR, J/°CA	±1.2



F- Fluid flow differential pressure unit, EGA Exhaust Gas Analyser, LPP – low pressure pump, N- speed encoder, SM- smoke meter, T1 & T3- Inlet water temperature, T2- Outlet engine jacket water temperature, T4 – outlet calorimeter water temperature.

Figure 3: Shows layout of CRDI engine test Rig.

4.0 Result and Discussion

4.1 Effect on injection timing (IT) on the performance of engine

The experiment was performed on a built-in CRDI diesel engine using WMCO B20 blend and locally available diesel at loads of 80% and 100%, respectively. Figure 4 demonstrates that at IT 10^0 CA bTDC BTE is maximal due to improved injector atomization at 600 bar IP, improved air fuel amalgamation, and decreased wall wetting, all of which contribute to more beneficial fuel combustion. The CRDI facility's maximum BTE was achieved with baseline diesel, combined was 3.27 % and 3.67 % lower at 80% & 100% load. Due to its higher viscosity and lower energy content, B20 blend gasoline produced a negligible difference in the CRDI engine's performance compared to diesel fuel.

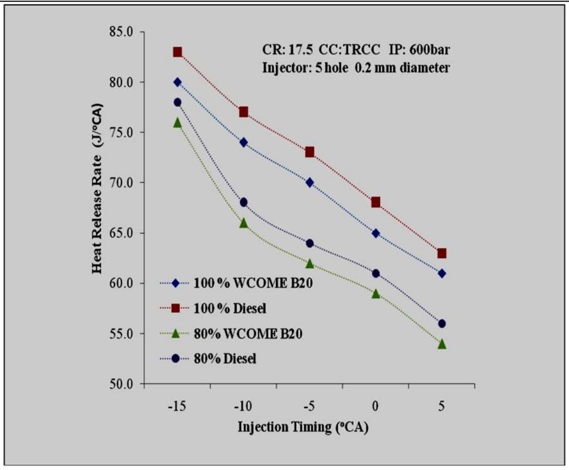


Figure 4: shows the variation of heat release rate with injection timings

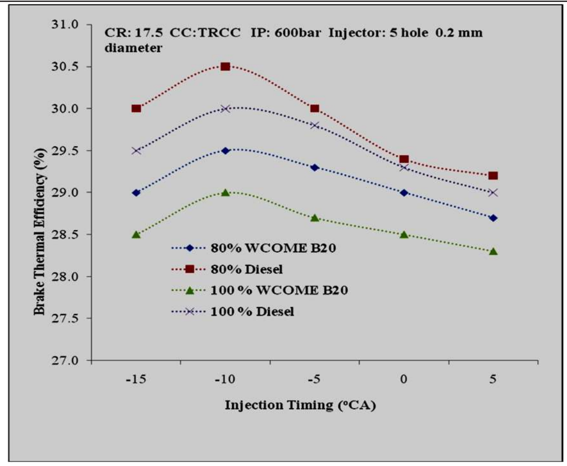


Figure 5: shows the variation of brake thermal efficiency with injection timings

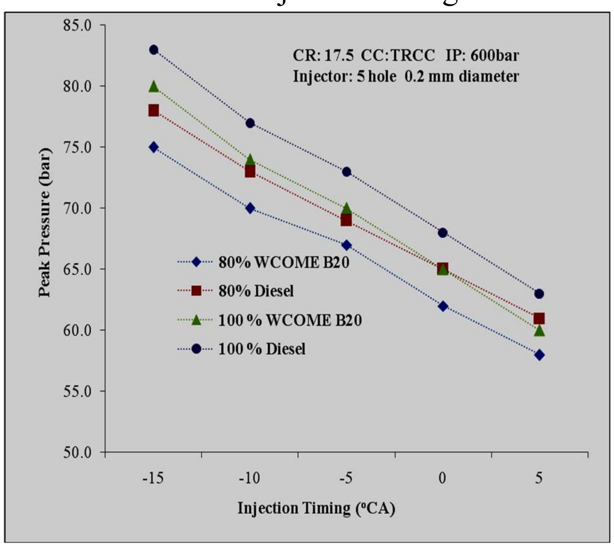


Figure 6: shows the peak pressure with injection timings

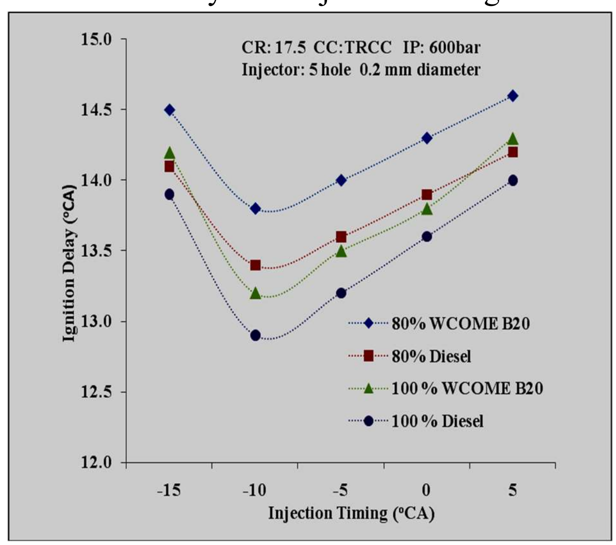


Figure 7: shows the injection delay with injection timings

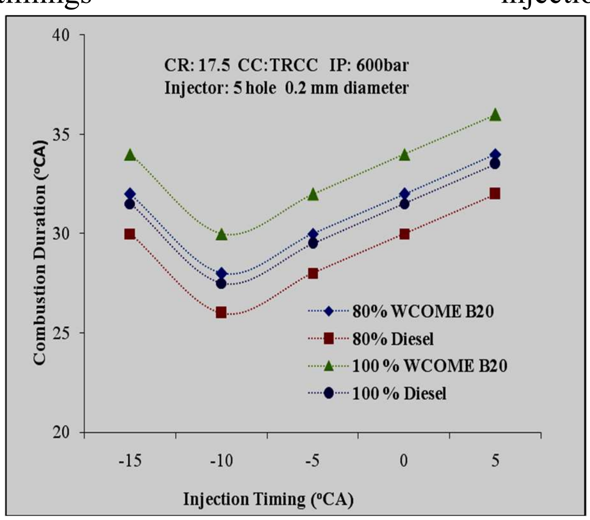


Figure 8: shows the combustion durations with injection timings

Heat release rate (HRR) (figure 4) and peak pressure (PP) (figure 6) is reduces with varying injection timings due to lower calorific values compared to conventional diesel. HRR reduces by 0.65% and 0.67 % at 80% and 100 % load but HRR is higher at 100% load than 80% load. The peak pressure reduces by 0.46% and 0.51% at 80% and 100% load due to Diesel engines have longer ignition delays (figure 7), which cause more fuel to build up within the cylinder, lengthen the uncontrolled combustion phase, and result in higher cylinder pressure. The ignition delay and combustion duration reduces with at 10^0 CA bTDC by 2% , 1.8% and 8% , 10% at 80% and 100 % load conditions compared to other injection timings due higher Cetane number. Injection delay period and combustion duration increase with increases with load increase, which causes more fuel to accumulate in the cylinder before it is ready for atomization and proper mixing, which results in a shorter combustion duration compared to other biodiesel blends. Additionally, because biodiesel has a higher latent heat of vaporisation than diesel, it takes longer to vaporise, which results in longer combustion duration than diesel.

4.2 Effect of injection timings on emission characteristics

The variation of emissions such as smoke, hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxide (NOx) with IT 10^0 CA bTDC are evaluated at IOP 600 bar pressure and are shown in Figs. 9-12. Biodiesel WCO fuel has lower carbon content than diesel fuel, which results in smaller amount CO_2 emissions. Employing WCO biodiesel blends can lower emissions such smoke, unburned HC, CO, and CO2. Smoke reduces by 25%, 27%, HC reduced by 31.45%, 27%, and CO reduces by 14.2% , 12.2% at 80% and 100 % load condition resepectively. It was found that CO emission dropped as engine load increased at part load before increasing again at full load. This resulted from increased fuel use, which produced a richer combination of air and fuel. The WCO biodiesel's higher oxygen concentration compared to diesel fuel, which resulted in a more complete burning.

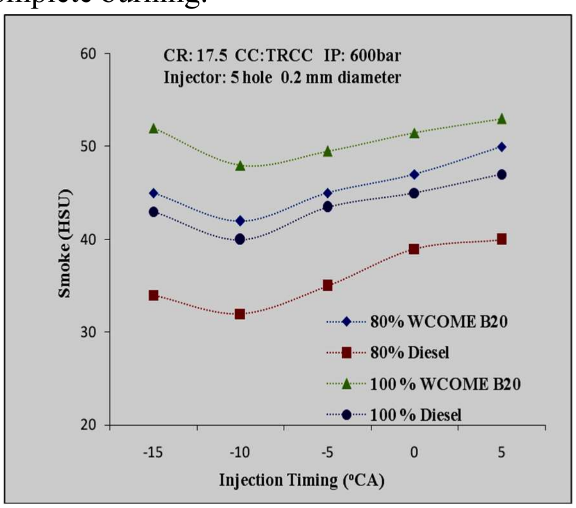


Figure 9: shows the smoke vs injection timings

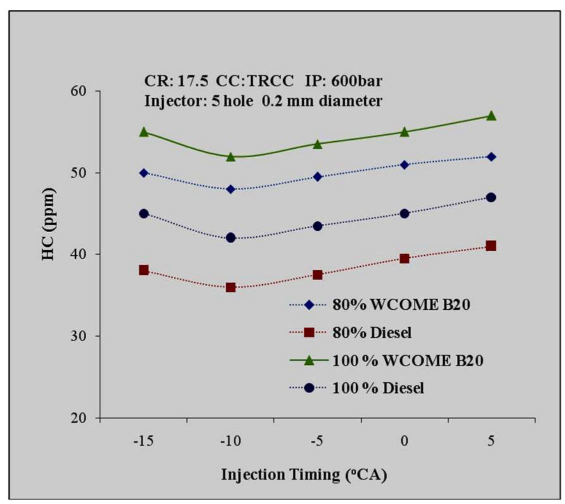


Figure 10: shows the hydrocarbons vs injection timings

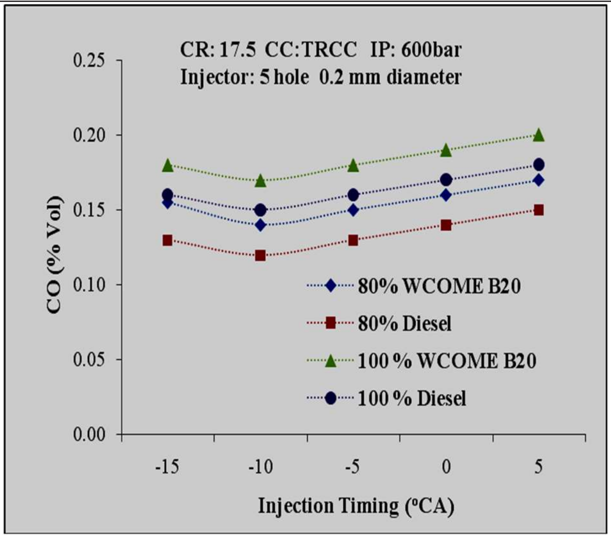


Figure 11: shows the carbonmonoxide vs injection timings

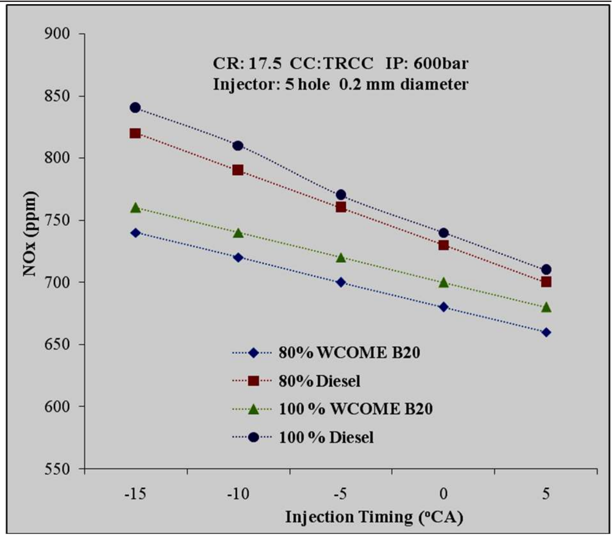


Figure 12: shows the nitrogen oxide vs injection timings

The fluctuation of HC emissions with engine load for biodiesel blends made from waste cooking oil. At 80% load, HC emissions for all tested fuels were decreased, but increasing at engine load. Additionally extending combustion timing were large fuel particle size, injection timing, and nozzle choking. The reason for this was that when more fuel was injected at greater loads, there was proportionately less oxygen available. Higher cetane number fuels shorter ignition delays may also result in less over-mixed fuel, which is the main source of unburned hydrocarbons. The increasing cylinder combustion temperatures and higher adiabatic flame temperatures, NOx emissions increased as engine load increased. Higher cylinder combustion temperatures and the availability of oxygen favoured the generation of NOx. Both the cetane enhancer's ethyl-hexyl nitrate (EHN) and di-tert-butyl peroxide (DTBP) are efficient in lowering NOx from biodiesel. The antioxidant TBHQ is also effective, however at the studied concentration, NOx reduction was only marginal, and TBHQ may increase PM emissions.

5.0 Conclusion

The single cylinder diesel engine runs with Mix WCO biodiesel blend B20 at constant speed 1500 rpm and constant injection pressure 600bar. The performance and emission chararitisc are determines for 80% load and 100% load condition with varying injection timings. The following are the conclusions could be summarized as:

- The extraction of biodiesel from Mix WCO gathered in the neighbourhood using a transesterification test setup is successful. Using ASTM standards, the B20 WMCO biodiesel's properties were evaluated and found to be equivalent to diesel fuel.

- At 80% and 100% engine loading, respectively, single injection aided CRDI engine fuel injection under optimal circumstances demonstrated enhanced overall engine performance. IT of 10 deg CA bTDC at IP of 600 bar, were chosen as the optimised specifications for diesel and B20 WMCO biodiesel due to its outstanding performance.

- Retarding the IT from 15^0 to 10^0 CA bTDC enhances BTE and reduces emission overall, with the exception of NOx, while simultaneously lowering ID, CD, PP, and raising HRR, correspondingly.

Overall, injecting the biodiesel Mix WCO B20 near to TDC, with higher injection pressure may significantly enhance the CRDI Diesel Engine performance.

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