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Diesel Engine Efficiency and Emissions using Biodiesel and its Blends

Jitendra Sharad Narkhede[1] , Dr.Kishor B. Waghulde[2]

P. G. Dept. of Chemistry, Gaya College, Gaya (Magadh University) Gaya -823001

Abstract:

The usage of vegetable oil as a fuel for compression ignition engines is not a fresh idea. Rudolph Diesel used peanut oil towards fuel diesel engines in the late 1800s. Petroleum-based diesel fuel has been the fuel of choice for the diesel engine for numerous years due to a plentiful resource and low fuel prices. Biodiesel is being assessed for use as a fuel for diesel engines due to its cleaner burning propensities, environmental welfares, and for energy safety causes. Diesel engine efficacy is categorized by its performance, combustion and emission parameters. All these parameters will be discoursed in detail in this section.

Keywords — **Biodiesel, Engine performance, Diesel, Combustion.**

1. INTRODUCTION

1.1 INFLUENCE OF BIODIESEL WITH OTHER FACTORS ON DIESEL ENGINE PERFORMANCE AND COMBUSTION CHARACTERISTICS:

Pure biodiesel and its blends can disturb diesel engine performance and combustion. The protuberant aspects are: brake-specific fuel consumption (BSFC), brake-specific energy consumption (BSEC), brake thermal efficiency (BTE), brake power, indicated mean effective pressure (MEP), mechanical efficiency (ME), ignition delay (ID), maximum heat transfer (MHT), and peak cylinder pressure (PCP). These factors with others will be conversed.

Dissimilar features can impact the performance and combustion features of diesel engines fuelled with biodiesel and its blends.

1.1.1 Contents and Properties of Biodiesel:

The properties of pure biodiesel and its percentage content in diesel blends can impact performance and combustion features. Investigators have assessed the performance of a Compression Ignition (CI) diesel engine with polanga-based biodiesel. One of the parameters calculated was BTE which is definite as the ratio of the power output to the power familiarized during fuel injection; the latter is the product of the injected mass flow rate and the lower heating value. 100% biodiesel accomplished best, enlightening the BTE of the engine by 0.1%. An alike trend was shown for the BSEC. Engine performance tests have shown that mahua oil methyl ester (MOME) as a fuel does not vary greatly from diesel. A slight power loss, joint with an increase in fuel consumption, was proficient. This could be due to the lower heating value of the ester. Examiners found that the respective average reductions of torque and power of waste frying oil methyl ester (WFOME) were 4.3 and 4.5% due to the higher viscosity and density and lower heating value (8.8%) of WFOME.3 It was also detected in another study that the brake torque loss was 9.1% for B100 biodiesel relative to D2 diesel at 1900 rpm as a result of the difference in heating value (13.3%), density and viscosity.

It has been stated that the blend, D82.5/tobacco seed oil methyl ester (TSOME17.5) providing the maximum rise in torque, power and thermal effectiveness. The maximum increase in power happened at 2000 rpm as 8.74 kW. This value is 3.13% higher than the power 27.84 kW obtained with diesel fuel. Additionally, the peak thermal competence was detected at 2500 rpm as 29.8%. This is nearly 2.02% higher than the thermal competence of diesel fuel.

The BTE with biodiesel was about 31.67% for jatropha methyl esters (JME) (100%) where as it was about 31.59% with diesel at 600 kPa bmep (brake mean effective pressure) and comparable trends were perceived for 20, 40, 60 and 80% biodiesel. The BSEC is slightly higher associated to diesel at all loads and this might be due to the lower calorific value of biodiesel. The peak pressure rate of cylinder pressure rise was comparable for biodiesel and its blends as associated to diesel. There was a dissimilarity of 0.2 MPa amongst the peak pressure with JME100 and diesel at full load.

It was found that the upsurge of biodiesel percentage in the blends resulted in a slight reduction of both power and torque over the whole speed range for dissimilar blends (B20, B30, B50, B70, B80 and B100) of biodiesel and diesel on a six-cylinder direct-injection (DI) diesel engine.15 It was stated that the torque reduced with the increase in cotton seed oil methyl ester (CSOME) in the blends (B5, B20, B50, B75 and B100) due to the higher viscosity and lower heating value of CSOME. The higher viscosity of biodiesel, which enhances fuel spray penetration, and thus increases air–fuel mixing, has been used to describe the recovery in torque and power for biodiesel relative to diesel in some of the literature. Though, a few authors decided that the higher viscosity results in power losses, for the reason that the higher viscosity decreases combustion competence due to poor fuel injection atomization.

1.1.2 Engine Load and Speed:

It has been witnessed that the engine power and torque are augmented by the application of a low heat rejection (LHR) engine, mostly due to the augmented exhaust gas temperatures before the turbine inlet in the LHR engine. With upsurge in load, the BSFC of biodiesel decreases. One probable reason for this trend might be the higher percentage rise of brake power with load as associated to fuel consumption. Though, Gumus and Kasifoglu displayed that the BSEC primarily decreased with increasing engine load until it reached a least value and then augmented slightly with further increasing engine load for all kinds of fuels (B5, B20, B50, B100 and diesel).26 Researchers have that reported that the BTE was comparable to that of diesel at part and full load and that it was better at 400 kPa bmep as associated to diesel for all blends of JME with diesel.

1.1.3 Injection Timing and Pressure

Investigators have studied the effects of the engine design parameters viz. compression ratio and fuel injection pressure on the enactment with regard to constraints such as fuel consumption and BTE with JME as the fuel. It was found that the joint increase of compression ratio and injection pressure upsurges the BTE and decreases the BSFC. A high injection pressure creates smaller droplets with lower momentum and hence shallow penetration. Likewise, a low injection pressure results in a larger droplet size and high peak pressure throughout the range of process of the engine.

Investigators retarded the injection timing by 3 uCA on a single-cylinder, obviously aspirated (NA), air-cooled (AC), DI diesel engine furnished with a pump–line–nozzle type fuel-injection system, and they detected that the BSFC increased for both B50 and pure RME (rapeseed methyl ester), though the increase was not important.

1.1.4 Additives

Keskin et al. examined the impact of Mg- and Mo-based fuel additives on diesel engine performance for an engine running on tall oil biodiesel. The authors found that the engine enactment values did not vary suggestively with biodiesel fuels.

It was also evidenced that diethyl ether can be used as an additive in biodiesel to increase its performance characteristics. An experimental investigation was steered to calculate the effects of using methanol as an additive in biodiesel–diesel blends on the engine performance, emissions and combustion features of a DI diesel engine under flexible working conditions. BD50 (50% biodiesel and 50% diesel by volume) was prepared as the baseline fuel. Methanol was added to BD50 as an additive at 5 and 10% by volume (denoted as BDM5 and BDM10). The results specify that combustion starts later for BDM5 and BDM10 than for BD50 at low engine loads, but is almost identical at high engine loads. At a low engine load of 1500 rpm, BDM5 and BDM10 show alike peak cylinder pressures and peak pressure rise rates to BD50, and a higher peak heat release rate than that of BD50. At low engine loads of 1800 rpm, the peak cylinder pressure and the peak pressure rise rates of BDM5 and BDM10 are lower than those of BD50, and the peak heat release rate is alike to that of BD50. The crank angles at which the peak values happen are later for BDM5 and BDM10 than for BD50. At high engine loads, the peak cylinder pressures, the peak pressure rise rates and the peak heat release rates of BDM5 and BDM10 were higher than those of BD50, and the crank angle peak values for all verified fuels were nearly the same. The power and torque outputs of BDM5 and BDM10 were somewhat lower than those of BD50.

1.2 DURABILITY TESTS OF DIESEL ENGINES OPERATED USING BIODIESEL AND ITS BLENDS:

Durability tests are more time-consuming and costly than tests of engine power, economy and emissions. For stability studies, the subsequent features were examined: carbon deposit, engine wear, and problems in the fuel system. Carbon deposits are linked to soot formation during combustion of fuel in the engine and fuel oxidation. Investigators studied the effect of a 20% rice bran oil methyl ester blend with mineral diesel biodiesel on the wear of in-cylinder engine mechanisms during 100 h tests. Carbon deposits on the cylinder head, injector tip, and piston crown of the biodiesel engine were meaningfully lowered associated with mineral diesel due to the lower soot formation during combustion of biodiesel. It was also stated that biodiesel increases carbon deposits in the combustion chamber. Fraer et al. studied tear-down study on a 1996, Mack MR 688 p model vehicle with six cylinders and a compression ratio of 16.5 : 1 which produced 300 horse power at 1950 rpm and was used for postal dedications. The engine and fuel system constituents were disassembled, inspected and assessed to associate wear features after four years of operation and more than 6 00 000 miles on B20, no alteration in wear or other issues were noted during the engine tear-down. The cylinder heads of the B20 engines limited a large amount of sludge around the rocker associations that was not found in the diesel engines. The sludge confined high levels of Na possibly produced by accumulation of soap in the engine oil. The B20 engines essential injector nozzle additional during the evaluation and tear-down period. This was due to the use of out-of-specification fuel. The biological impurities could have been the cause of filter plugging.

Biodiesel is operational at reducing friction when used as an additive in diesel fuel at low levels. Throughout tribological inquiries of lubricating oils, it was found that the amount of wear debris, soot, resinous compounds, oxidation products, and the moisture content was lesser for lubricating oil drawn from the biodiesel-fueled engine associated with the diesel-fueled engine. The enhanced performance of the biodiesel-fueled system is maybe attributed to the inherent lubricity of biodiesel, ensuing in lower wear of vital moving constituents. The content of wear metals debris such as Fe, Cu, Al and Pb abridged with increasing addition of palm oil to biodiesel blends, which formed lower wear metal concentrations than ordinary diesel, due to the effect of the corrosion inhibitor in the fuel and lube oil.

1.3 INFLUENCE OF BIODIESEL ON EXHAUST EMISSIONS FROM DIESEL ENGINES:

Commonly, the combustion procedure in a CI engine happens only at the interface amongst the fuel-injection system and air compressed in the cylinder. Therefore, oxidation of fuel is not permanently complete. Imperfect combustion of the fuel creates carbon monoxide (CO), hydrocarbons (HCs), particulate matter (PM) and oxygen-containing compounds such as aldehydes. In addition, the temperature in the cylinder during combustion also stimulates the fabrication of NOx from nitrogen and oxygen in the air.

1.3.1 Particulate Matter, Carbon Monoxide and Hydrocarbon Emissions

Mostly there is decline in PM, CO and HC emissions during use of biodiesel and its blends comparative to neat diesel. In this section we will discuss the numerous reasons behind this. Dissimilar factors can impact the PM, CO and HC emission features of diesel engines fuelled with biodiesel and its blends.

1.3.1.1 Content and Properties of Biodiesel

1. Particulate Matter: Use of pure biodiesel sources a decrease in PM emissions. Lately, WFOME was tested to check its emissions.14 The concentration of PM was lower, relative to diesel, by 23–47%. For the reason that of the irrelevant sulfur content, sulfur dioxide emissions were lesser by 50–100% for diverse blends.

2. Carbon Monoxide: CO emissions decrease when pure biodiesel is used as a diesel engine fuel. Experimentations have been carried out to evaluate the emission features of a single cylinder; four-stroke inconstant compression ratio multi-fuel engine fuelled with WCOME and its blends with standard diesel. Tests were steered using fuel blends of 20, 40, 60 and 80% biodiesel with standard diesel, with an engine speed of 1500 rpm, a static compression ratio of 21 and at dissimilar loading situations. The use of the blends ensued in a reduction in CO emission. With growing biodiesel content in the blends, CO emissions decrease due to an increase in oxygen content.

3. Hydrocarbons: HC emissions decrease when pure biodiesel is used in its place of diesel in diesel engines. Tests have been steered using fuel blends of 20, 40, 60 and 80% biodiesel with standard diesel, with an engine speed of 1500 rpm, a stable compression ratio of 21 and at dissimilar loading situations. Use of the blends resulted in a decrease of HC emissions. Numerous investigators have agreed that HC emissions decline with growing biodiesel percentage in the blend.

1.3.1.2 Engine Load

1. Particulate Matter: Engine load plays a major role in the PM emissions of biodiesel. Investigators tested mahua biodiesel and its blends at dissimilar loads on a single-cylinder, four-stroke, WC Ricardo E6 engine, and found that the smoke level augmented sharply with the rise in load for all fuels tested. They explained that this was chiefly due to the reduced air-to-fuel ratio at higher loads when larger quantities of fuel are injected in to the ignition chamber, much of which goes unburnt into the deplete.

2. Carbon Monoxide: The literature reports that CO emissions upsurge with increasing engine load. The key reason for this increase is for the reason that the air-to-fuel ratio decreases with increasing load, which is typical of all internal combustion engines. In contrast, it was stated that CO emissions abridged with increasing load, for the reason that the increase in combustion temperature lead to more complete combustion during higher loads. It was also established that CO emissions decline as the load increases, but that they increase marginally at heavy or full loads. Other investigators have found that CO emissions were lower at intermediary loads, but higher at low or no loads, heavy loads and full loads.

3. Hydrocarbons: The effect of engine load on HC emissions for biodiesel has been chiefly studied, but the assumptions reached were unreliable. Investigators showed experimentally an increase in HC emissions with load rise due to high fuel consumption at high loads. Though, others found that the HC emissions for biodiesel decrease as the load increases.

1.3.1.3 Engine Speed

1. Particulate Matter: The higher the engine speed, the lower PM emissions are. This is for the reason that of enhanced combustion effectiveness which can be attributed to a rise in turbulence effects with an increase in engine speed, improving the extent of complete combustion. Though, Utlu and Kocak stated that the influence of engine speed seemed to fluctuate as PM emissions abridged at low speed, and augmented in the range 2000–4000 rpm, then decreased again above 4000 rpm.

2. Carbon Monoxide and Hydrocarbons: These emissions decline for biodiesel with increasing engine speed as outcome of better air–fuel mixing procedures and an increase in the fuel-to-air uniformity ratio.

1.3.1.4 Injection Timing

1. Particulate Matter: In general, the start of injection of biodiesel happens earlier than for diesel due to its higher density and viscosity and lower compressibility. Hence, investigators have studied the effect of injection timing and presented that the smoke emission with biodiesel normally increased when the injection timing was retarded. Originally the smoke level of reference diesel falls when the injection timing is progressive to 23u from 19u before top dead centre (BTDC) and then upsurges when the injection timing is progressive more.

2. Carbon Monoxide and Hydrocarbons: It has been indicated that CO and HC emissions decrease when the injection timing is progressive for biodiesel fuels. Investigators tested the effect of the use of stunted ignition timing (by 3 uCA) on the emissions of biodiesel from rapeseed oil, and found that the impedance resulted in augmented CO and HC emissions.

1.3.1.5 Analysis of Aforementioned Discussion

Based on study above, the following assumptions can be drawn: (a) PM, CO and HC emissions decrease when pure biodiesel is used in its place of diesel. (b) PM, CO and HC emissions for biodiesel decrease with increasing biodiesel content. The feedstock of biodiesel and its properties have an effect on PM, CO and HC emissions, particularly the chain length and saturation level. (c) Most scholars have found that the there is an upsurge in PM, CO and HC emissions with growing engine load. (d) The higher the engine speed, the lower the PM, CO and HC emissions. (e) The progress in injection timing of biodiesel errands lower PM, CO and HC emissions.

1.3.2 NOx Emissions:

NOx emission is discussed distinctly for the reason that most investigators believe that these emissions upsurge with the use of pure biodiesel, consequently in this section we will confer the numerous reasons for this. Dissimilar factors can impact the NOx emission features of a diesel engine fuelled with biodiesel and its blends.

1.3.2.1 Content and Properties of Biodiesel: Most researchers believe that NOx emissions upsurge with the use of pure biodiesel. Though, there are a few reports which show that NOx emissions decline with use of pure biodiesel. The literature also shows that NOx emissions increase with the upsurge in content of biodiesel in blends. For instance, investigators tested a HSDI, four-cylinder, 1.6 L; turbocharged (TU) diesel engine fuelled by biodiesel and its blends B30, B50 and B100 and detected that the upsurge in NOx emissions for B30, B50 and B100 was 20.6, 25.9 and 44.8%, respectively. Experimentations with WCOME blends of 20, 40, 60 and 80% lead to an increase in NOx emissions.

1.3.2.2 Engine Load: NOx emissions rises as the engine load increases as a consequence of the higher combustion temperatures existing at higher engine loads. As the load increases, the complete fuel-to-air ratio increases, resultant in an increase in the average gas temperature in the combustion chamber and therefore NOx creation which is sensitive to temperature increases. Though, it was also found that NOx emissions upsurge at light loads, though NOx emission increases at middle and high loads might also be due to timing variations made by the light-load advance mechanism on the fuel injection pump.

1.3.2.3 Engine Speed: Some investigators found that NOx emissions abridged with increasing engine speed due to the shorter residence time available for NOx formation, which might be the result of rises both in the volumetric efficacy and flow velocity of the reactant combination at higher engine speeds.

1.3.2.4 Injection Timing: Hirkude and Padalkar found that NOx emissions augmented as the injection timing was abridged. But others found that a decline in injection timing occasioned in reduced NOx emissions.

1.3.2.5 Exhaust Gas Recirculation: Zheng et al. examined the effect of EGR on a single-cylinder, four-stroke, NA, DI diesel engine, and found that there were slight alterations in NOx emissions amongst biodiesels and diesel, but NOx emissions for all fuels diminished with increasing EGR. Investigators operated a single-cylinder engine with dissimilar EGR ratios and found that, there was no important change amongst diesel and neem biodiesel with a 5–30% EGR ratio, though they witnessed an increase in NOx emissions without EGR.

1.4 CO_2 EMISSIONS:

It has been conveyed that the use of biodiesel outcomes in fewer carbon dioxide (CO_2) emissions than diesel during whole combustion due to the lower carbon-to-hydrogen ratio. This is accredited to the fact that biodiesel is a low-carbon fuel, so has a lower essential carbon-to-hydrogen ratio than diesel. Though, it has also been stated that CO_2 emissions rise or are alike, due to more effectual combustion. Biodiesel can cause a 50–80% decrease in CO_2emissions related to petroleum diesel. Experimentations with WCOME blends of 20, 40, 60 and 80% lead to decrease of CO_2 emissions.

1.5 NON-REGULATED EMISSIONS: There has been growing interest in recent times in the non-regulated emissions such as carbonyl, aromatic and polyaromatic mixtures from biodiesel.

1.5.1 Carbonyl Compounds: Diverse factors can impact carbonyl compounds emission features of diesel engine fuelled with biodiesel and its blends.

1.5.1.1 Content and Properties of Biodiesel: It has been found that carbonyl compound emission upsurges when using pure biodiesel or its blends for the reason that of their higher oxygen content. Fontaras et al. found 13 carbonyl compounds in exhaust gases and measured their concentrations over numerous driving cycles with a B100 biodiesel and petroleum diesel and the results established a important rise of carbonyl emissions with the use of pure biodiesel, possibly due to the oxygen atoms in the ester molecules.

1.5.1.2 Engine Load and Speed: Carbonyl compound emissions augmented when the engine was run on biodiesel and its blends at 10, 33, and 55%.93 Formaldehyde emissions augmented when the engine load was improved from 0.08 to 0.38 MPa, but reduced when the engine load was increased from 0.38 to 0.70 MPa. Formaldehyde emissions improved with engine load under medium and high engine loads at an engine speed of 1200 rpm, and reduced with engine load under medium and high engine loads at an engine speed of 1400 rpm.

1.5.1.3 Additives: Formaldehyde and acetaldehyde emissions augmented with increasing methanol fraction in a biodiesel blend fuel associated with diesel fuel.75 Formaldehyde emissions augmented with the methanol fraction, and the writers established that exhaust formaldehyde was mostly produced from the methanol.

1.6 Statistical Relationship between Biodiesel Performance and Emission Characteristics with Fatty Acid Methyl Ester Composition

The effect of the unsaturated fatty acid methyl ester (FAME) configuration of biodiesel on the combustion, performance and emissions features of a diesel engine was inspected and correlated. For this experimentation, 13 diverse biodiesel fuels with dissimilar fatty acid compositions were selected. Performance and emissions tests on a single-cylinder DI diesel engine were led using these biodiesel fuels. The investigators also recognized the statistical relationship amongst performance, combustion and emission characteristics and FAME content.

1.6.1 Correlation of Combustion Parameters: It has been evidenced that the fuel dynamic injection timing is absolutely correlated with the percentage of unsaturation (X) and the density. That is, the fuel-injection timing is quicker for higher density fuels. The fuel-injection timing is mostly predisposed by the fuel possessions, such as its majority modulus and viscosity. The higher the bulk modulus and the viscosity, the faster the injection timing is. The bulk modulus of unsaturated FAMEs is greater than that of saturated FAMEs and upsurges with increasing density. Eqn (1) shows the variant of ignition delay (ID) with X:

$$ID=0:0962X+4:6837\ (R^2=0:898)$$

where for every 1% upsurge in X, an increase of 0.0962 units (in terms of degree crank angle) in ID is detected. There is only poor correlation among dynamic injection (DI) and X [eqn (2)]:

$$DI=0:0438X+12:655\ R^2=0:129\ldots \qquad (2)$$

MHR=0:062X+76:65 (R^2 =0:032)… (3)

PCP=0:0779X+71:898 (R^2=0:427)…. (4)

The variation of total combustion duration (TCD) with X is shown in eqn (5):

TCD=0:2806X+72:202 (R^2 =0:939)…..(5)

Eqn (6) shows the variation of the cumulative heat release (CHR) with X:

CHR=2:7572I+1269:4 (R^2 =0:0801)… (6)

The correlation coefficient is very poor.

1.6.2 Correlation of Performance Parameters

Eqn (7) shows the variation of the BSFC with X with good R^2:

BSFC=0:0005X+0:2921 (R^2 =0:880)… (7)

From eqn (7), it can be determined that every 1% rise in unsaturation might result in an upsurge of 0.0005 units (g kWh21) in BSFC. It can be specified that the BSFC increases with increasing percentage of unsaturation, subsequently an increase in X will effect in an increase in density and in a decline in heating value.

1.6.3 Correlation of Emission Parameters:

Eqn (8) shows the greatly correlated difference of NOx emissions with X:

NOx=0:0666X+8:5833 (R^2 =0:972) (8)

An increase of 0.0666 units (g kWh21) in NOx might hence be estimated for every 1% upsurge in unsaturation. There is merely a poor correlation amongst CO emissions and X [eqn(9)]:

CO=0:0401X-0:2245 (R^2 =0:667) (9)

From eqn (9), the possible increase in CO emissions might be proposed as 0.0401 units (g kWh21) for every 1% upsurge in unsaturation. There is also only a poor between HC emissions and X [eqn(10)]:

HC=0:002X+0:2001 (R^2=0:597) (10)

This correlation analysis demonstrates that CO and HC emissions are definitely correlated with the percentage of unsaturation. That is CO and HC emissions upsurge with increasing unsaturation.

Eqn (11) shows the variation of smoke with X:

S=-0:0163X+2:2909 (R^2 =0:786) (11)

The gradient among the amount of smoke and the percentage of unsaturation is 20.0163. It is hence proposed that every 1% increase in unsaturation might result in a drop of 0.0163 units (Bosch Smoke Unit (BSU)) in smoke.

CONCLUSION

While preparing this paper, found that there is lot of info existing on biodiesels, but the info is either dispersed, or it does not cover every feature of biodiesels. In this paper, the impact of biodiesel with other influences such as additives, on diesel engine performance and combustion and emission features are discoursed. Durability tests of diesel engines functioned using biodiesel and its blends are also discussed. Statistical relationships amongst biodiesel performance and emission features and fatty acid methyl ester composition are also discoursed concisely.

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