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Influence of Carbon Nano-tube on Combustion, Performance and Emission Parameters of DI CI Engine Fuelled with Blends of Lemongrass Biodiesel

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ABSTRACT:

In the present investigation, bio-oil is extracted from lemongrass through steam distillation process, single stage trans esterification using methanol and potassium hydroxide at molar ration of 1:8 yielded lemongrass biodiesel. The biodiesel was characterized using gas chromatography mass spectrometry and Fourier transforms infrared spectrometry analysis and found to have Behenic and Stearic acid in prominent proportions. The Cetane number and calorific value was enhanced by ultrasonicating carbon Nano-tubes at various proportions. Kirloskar TV1 compression ignition engine coupled with eddy current dynamometer was employed to analyse the combustion, performance and emission characteristics. Addition of carbon Nano-tubes significantly affected the ignition delay and combustion duration. D80LGB20CNT100 fuel blend exhibited higher in-cylinder pressure up to 65.144 bars along with enhanced rate of heat release upto 73.953 kJ/kg at full load condition. Higher brake thermal efficiency with notable reduction in unburned hydrocarbon and smoke was seen with elevated levels of carbon-monoxide and oxides of nitrogen.

KEYWORDS:

Lemongrass biodiesel; Carbon Nano-tube; Transesterification; Combustion; Performance; Emission

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NOMENCLATURE & ABBREVIATIONS

CNT	Carbon Nano tubes
SWCNT	Single walled carbon Nano tubes
MWCNT	Multi walled carbon Nano tubes
LGO	Lemongrass oil
LGBD	Lemongrass biodiesel
TDC	Top dead centre
DEE	Di-ethyl ether
EGR	Exhaust gas recirculation
EGT	Exhaust gas temperature
GCMS	Gas chromatography mass spectrometry
FTIR	Fourier transforms infra-red spectrometer
BTE	Brake thermal efficiency
BMEP	Brake mean effective pressure
BSFC	Brake specific fuel consumption
CAD	Crank angle degree
kW	Kilo-watt
NOX	Oxides of nitrogen
CO	Carbon monoxide
UBHC	Unburnt hydrocarbons
PPM	Parts per million
CO_2	Carbon di-oxide

1. Introduction

In the present scenario, especially during the economic evolution of our nation, energy production and energy security gained greater importance in India using fossil fuel as its main energy source. Due to increasing demand of these fuels, greater chances of fossil fuel depletion have aroused. The motor vehicles are estimated to grow to 1300 million by the year 2030 all over the world. Also, the use of fossil fuel results as major source of environmental pollution. Diesel engines are used in high end vehicles all over the world due to its high thermal efficiency but it also releases high emissions [1, 2]. In order to reduce the emissions from the engine and protect the environment, new alternative fuels have become a source for energy production. Edible and non-edible oils are one of the energy sources for CI engines. These fuels can be blended with diesel and used directly in the diesel engine. Bio diesel refers to the vegetable oil or animal fat based hydrocarbons fuel consisting of long chain alkyl esters.

Biodiesel is an attractive alternative to the fossil fuels due to its bio-degradable, low emission profiles and non-toxic as compared to the petroleum fuel and also they are carbon neutral [3]. The amount of CO_2 released by the burning the biodiesel is the same amount of CO_2 absorbed during formation of raw materials. Lemongrass oil, one of the new alternate fuels to diesel engine produces less particulate matter, carbon monoxide and hydrocarbon emissions than diesel fuel. Carbon Nano materials are carbon based Nano additives added to biodiesel to improve the engine performance and reduce the output emissions due to their catalytic action along with higher surface to volume ratio. Carbon Nano tubes are hollow cylindrical carbon atom in the shape of rolled tubes of graphene and with hexagonal rings in its structure. These are classed into SWCNT and MWCNT [4-6]. El Seesy et al [7] investigated the performance, combustion and emission characteristics of direct injection compression engine fuelled with biodiesel and diesel. Addition of MWCNT to the biodiesel and diesel mixtures enhanced the peak heat release rate and decreased the ignition delay along with an increase in combustion initiation which resulted in good gross heat release rate and BTE by 16%. Subsequently, BSFC decreased by 15%. NO_x, CO and UBHC emissions were also reduced.

Selvan et al [8] and Anbarasu et al [9] investigated the effects of cerium oxide additives added in diesel and biodiesel ethanol blends on the performance of diesel engines. Ultrasonicator was used for the dispersion of Nano materials into the blend which decreased the specific fuel consumption, increased the peak pressure and decreased the ignition delay. Addition of Nano particle to the blend enhanced the combustion process and also decreased the smoke, CO and UBHC emissions. Basha and Anand [10] studied the performance and emission characteristics of biodiesel fuel emulsion added with alumina Nano particles. Various concentrations of alumina Nano particles were dispersed using the ultrasonicator. They found a decrease in the peak pressure, pressure rise rate and heat release rate on addition of Nano particles to blends. Due to addition of Nano particles to blends ignition delay shortened and enhanced the combustion characteristics. BSFC was significantly reduced due to increase in surface to volume ratio. NO_x, UBHC and CO emissions were reduced on addition of Nano particles. Also, the authors experimentally studied the effects of carbon Nano particles additives with emulsion fuel on the diesel engine performance and combustion characteristics. A decrease in the peak pressure and maximum heat release was observed by the authors due to addition of CNT.

Ghafoor et al [11] investigated the performance and emission characteristics of a six cylinder four stroke diesel engine using carbon Nano particles along with the diesel-biodiesel blend fuel. Two different concentrations of CNT were dispersed into blend by using ultra sonicator homogenizer. On addition of CNT, Cetane number increased resulting in increase in the combustion pressure and torque. The base specific fuel consumption reduced by 38.5% on CNT addition. UBHC and CO emissions are reduced by 22% and 14% respectively. Due to CNT addition, there was enough enhancement of evaporation rate which shortened the ignition delay. Basha and Anand [12] investigated the CNT along with jatropha biodiesel emulsion fuel. Different concentration levels of CNT were dispersed by using mechanical homogenizer. An enhanced brake thermal efficiency, increased evaporation rate and accelerated combustion process were reported along with reduction in UBHC, CO and NO_x emissions levels.

Mirzaganzadeh et al [13] experimentally investigated the hybrid Nano catalyst additives containing multi walled carbon Nano tubes on emission. Two different diesel blends (B5 and B20) with different doze levels of Nano catalyst were studied. They found a subsequent rise in engine power and brake power by 7.8% and 4.91% respectively and a decrease in BSFC by 4.5%. The reason was the addition of cerium oxide Nano particles acted as catalyst and supplied oxygen molecules to the reaction which led to the complete combustion of unburned hydro carbons and CO. NO_x, CO and UBHC were reduced by up to 18.9%, 71.4% and 31.8% respectively. Karthikeyan and Parthima [14] experimentally studied the Nano catalyst additives effects containing MWCNT and Nano particles like cerium oxide on diesel engine emissions. The authors tried with two different concentrations i.e., 50 ppm, 100 ppm along with diesel biodiesel. CO, UBHC and NO_x emissions got reduced. For the combustion process, oxygen molecules were provided by the Nano particle additives which resulted in shortened ignition delay and enhanced oxidation rate.

Also, the NO_x emission rate was decreased owing to the reduction of peak pressure and temperature in the combustion chamber. Banapurmath [15] investigated the performance and emission characteristics of diesel engine fuelled with biodiesel along with graphene, silver and CNT. Two different concentrations, 25 ppm and 50 ppm were used which resulted in the rise of peak pressure and reduction in delay period. Emissions were are also reduced due to addition of graphene Nano particle which is due to its higher surface to volume ratio led to an increase in evaporation rate resulting in reduced ignition delay and enhanced combustion process. Dhinesh et al [16] investigated the performance of diesel engine by using Cympogon flexuous as the bio-diesel. Brake thermal efficiency decreased as per the results drawn from the performance characteristics and brake specific energy consumption increased along with a drop in efficiency by 6% at part load and 9% at full load. Also, there was decrease in peak pressure, ignition delay and heat release with good combustion rate.

Due to availability of the oxygen atoms in biodiesel and in its blends when compared to diesel fuel, it caused reduction in hydrocarbon and carbon monoxide emissions. Sathiyamoorthi et al [17] investigated on the combined effect of Nano emulsified lemon grass oil with DEE and EGR conducted on a single cylinder direct injection diesel engine. The specific fuel consumption increased by 10.8% due to the usage of Nano emulsified LGO25 with DEE and EGR mode. The main reason was the lower calorific value of Nano emulsified LGO25 fuel. In this present study, the main objective is to improve the performance characteristics and combustion parameters and reduce the emission from the exhaust by using multi walled carbon Nano tubes (MWCNT) as Nano metallic additive to the LGBD. All the blended fuel with Nano additive is compared with diesel and LGBD blends.

2. Materials and methods

2.1. Lemon grass oil

Lemongrass belongs to the family of Poaceae, which looks amber and reddish in color. It is abundantly available in Kerala, Maharashtra, Tamilnadu, and Karnataka. The scientific name of lemongrass is Cymbopogon Flexuous and its molecular formula of oil is $C_{51}H_{84}O_5$. Molecular weight of lemongrass oil is

777.2. Based on the percentage of weight, lemongrass oil has hydrogen, oxygen, and carbon. Due to the presence of these atoms, it makes the oil a good alternative as fuel to the diesel engine. The bio-oil was extracted from the leguminous parts of lemongrass plant through steam distillation process. The detailed illustrations of lemongrass source, oil extracting process and transesterification is shown in the Fig. 1.

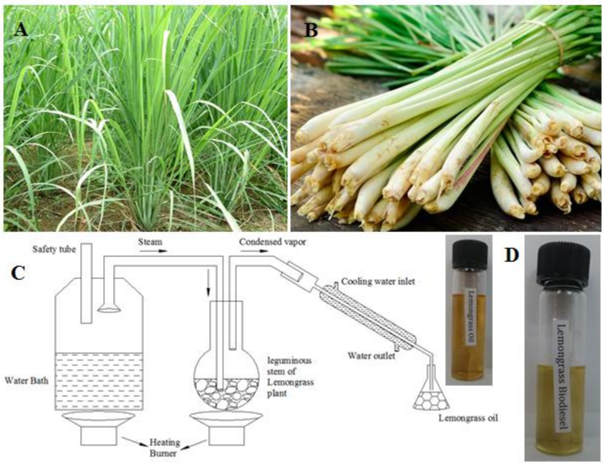

Fig. 1: Lemongrass (A, B), its oil extraction (C) and LGBD (D)

2.2. Transesterification process

Transesterification process is a method of making raw oil into biodiesel. Raw oil need to undergo this process for using it in IC engines. In this process raw lemongrass oil is processed and undergone a reaction with methanol to make it as a biodiesel. Methanol is used as a reactant, this process is called methanolysis. A measure of 1 litre raw lemongrass oil is poured into a beaker and heated up to 60°C by using the furnace or any heating device. 250ml of methanol is added to the beaker and 2.4g of potassium hydroxide is added to methanol which is already in the beaker. For proper mixing of methanol and potassium hydroxide, it is stirred well using a stirrer until they completely form as a solution. Now, the potassium methoxide solution is added to the hot oil which is heated already and it is mixed by using a stirrer for one hour by maintaining a temperature of 60^{o}C. After one hour of proper mixing, the whole mixture is transferred into a separating funnel and allowed to settle for an hour. After 1 hr, two layers are formed in the separating funnel. The top layer formed in funnel is esterified lemongrass bio fuel and the bottom layer is glycerol. Obtained bio fuel from this process is used in diesel engine by mixing it with proper ratios of diesel [3, 6].

2.3. Fuel properties

Density and calorific values of the lemongrass oil are almost nearer to the values of diesel. By this, it is understood that the lemongrass oil can be used as a fuel in the diesel engine along with some proportions of diesel. The different fuel properties that affect the engine performance are viscosity, cetane number, boiling point and heat value .Viscosity is important as it affects the engine performance by affecting the fuel injection system and fuel atomization. The viscosity of diesel is lower than the lemongrass oil. Therefore, raw lemongrass oil viscosity needs to be reduced. This is done by using transesterification process where heavy viscous oils are converted to biodiesels. On addition of CNT to lemongrass oil, density of the blend decreased when compared to LGBD which is a good sign to use it in the diesel engine. Kinematic viscosity also decreases on addition of CNT to LGBD. Combustion and evaporation depends upon the viscosity value of the fuel. Viscosity and air fuel interaction are inversely proportional to each other. Cetane number also affects the combustion characteristics and it directly impact on the ignition delay. Cetane number and ignition delay are inversely proportional i.e. high cetane number gives lower ignition delay and good combustion diffusion. Along with cetane number, calorific value also affects the burning process or combustion process. The cetane number of lemongrass oil is increased after adding CNT additives to it thus allowing a shorter ignition delay. The presence of oxygen content improves the combustion quality of the fuel. The oxygen content in the lemongrass oil is 10% by weight %. All these properties are listed in Table 1 [18, 23].

Table 1: Comparison of properties of raw lemongrass bio fuel, diesel and Nano blended lemon grass biodiesel

Property	Densityk g/m^3	Kinematic viscosity mm^2/s	Calorific value MJ/kg	Flash point ^{o}C	Cetane number
Raw Lemon grass	921	5.21	35	72	48
LGBD	905	4.6	37	55	52
LGBD20 D80	843	3.21	42.193	49	47.5
LGBD20 D80 CNT 50	842.5	3.47	42.75	45	48.6
LGBD20 D80 CNT 100	843.2	3.89	43.1	43	49
LGBD20 D80 CNT 150	844.1	4.02	43.87	41	51

2.4. Preparation of CNT blended biodiesel

After forming the biodiesel blend by the above procedure, CNT blending is done by either using mechanical homogenizer or ultrasonicator apparatus. The properties of Carbon Nanotubes are specified in Table 2. To start the blending process of CNT a measure of 50 mg of CNT is added in the blend. Then, the whole solution is stirred with the help of a mechanical homogenizer until it forms a solution. The same is followed for other two blends and the blend which is formed finally is dark green in colour.

Table 2: Properties of carbon Nanotubes

Type	Multiwall CNT
Color	Black Powder
Purity	>98%
Average Diameter	11-15 nm
Average Length	1-6 μm
Surface area	372 m^2/g

3. Experimental setup

The experimental arrangement consists of single cylinder, 4 strokes, diesel engine connected to an eddy current type dynamometer for loading. Engine is operated at various load conditions namely no load, 25% load, 50% load, 75% load, and full load respectively.

Fig. 2 shows the schematic arrangement of test engine setup. The load is increased by keeping the speed as constant for the test procedure. Power produced by the engine is 5.2 kW with 200 bar injection pressure and 23° before top dead centre. Cylinder pressure is measured by using the piezoelectric pressure transducer which is fitted on the engine cylinder and a crank angle encoder is fixed on the flywheel to measure the pressure with respect to crank angle. Combustion analyser is used to measure the combustion aspects with the support of charge amplifier which receives the input signals from encoder. For P-θ diagram, computer interfaces the signals given by the engine indicator. Labview based "Enginesoft" is used for on -line performance evaluation. A computerized diesel injection pressure measurement is also used. Table 3 lists the specifications of Kirloskar TV1, Type 1 cylinder, 4 strokes and water cooled Diesel engine and instrumentation.

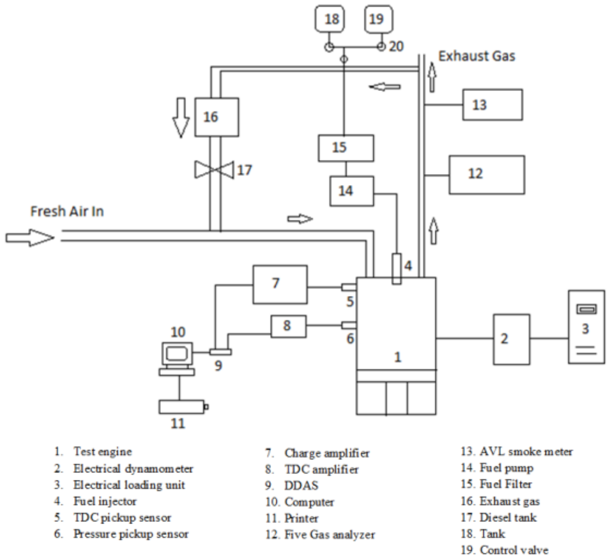

Fig. 2: Test engine setup

Table 3: Engine specifications

Parameter	Description or value
Engine spec.	5.2 kW of power at 1500 rpm, stroke 110 mm, 87.5 mm of bore. 661 cc, CR 17.5
Dynamometer	Water cooled eddy current
Load indicator	Digital, Range 0-50 kg, Supply 230 VAC
Load sensor	Load cell, type strain gauge, range 0-50 kg
Temperature sensor	Type RTD, PT100 & Thermocouple, Type K
Temperature transmitter	Type two wire, Input RTD PT100, Range 0–100 Deg C, I/P Thermocouple, Range 0–1200 Deg C, O/P 4–20mA
Piezo sensor	Range 5000 PSI, with low noise cable
Crank angle sensor	Resolution 1 Deg, Speed 5500 RPM with TDC pulse
Data acquisition device	NI USB-6210, 16-bit, 250 kS/s.
Fuel flow transmitter	DP transmitter, Range 0-500 mm WC
Air flow transmitter	Pressure transmitter, Range (-) 250 mm WC
Rota meter	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH

Experimentation is carried out using diesel and blends of LGBD with diesel. LGBD blends are made with different proportions of diesel and biodiesel by using magnetic stirrer. Biodiesel blends are made with three different proportions of diesel and biodiesel in volume basis namely B20D80, B10D90 and B30D70. As various studies have suggested B20D80, is the blend taken for the present study. For the study, 300 ml of blend D80LGBD20 is formed in the ratio of 240ml of diesel and 60 ml of LGBD. These quantities are measured by using the measuring jar. After measuring, the solution is poured into the beaker and a magnetic pellet is dropped into the beaker. The beaker is placed on the magnetic stirrer and it is allowed to rotate for around 30 min at 400-500rpm. Human errors, accuracy of the instrument, selection of equipment's and its calibration, surrounding factors are the main reasons for the occurrence of uncertainties and errors while measuring performance, combustion an emissions parameters. Accuracy values are tabulated in Table 4 for reference. Uncertainty analysis was carried out to avoid such factors and to ensure precision. Based on the values of accuracy considering root mean square formulae result was drawn which is 2.04%.

Table 4: Uncertainty analysis

Parameters	Accuracy	% of
	Measured factors	
Speed	± 1 rpm	0.2
Temperature	± 1°C	0.3
Load	± 0.03 %	0.15
Time	± 2 sec	0.3
Exhaust gas temperature	± 0.80 %	0.2
In-Cylinder pressure	± 0.052 bar	1.3
UBHC	± 1 ppm	0.3
CO_2	± 0.02%	0.23
NO_x	± 1 ppm	0.3
Smoke opacity	± 0.1%	0.45
	Calculated factors	
Brake thermal efficiency	±1.04%	1
BSFC	± 1.3 %	0.55
Brake Power	± 0.52 %	0.62
Brake Torque	± 0.44 %	0.3

4. Result and discussions

4.1. LGBD characterization

FT-IR spectrometer analysis is done to identify the functional groups and bands with respect to different vibrations. FT-IR analysis is done by using Perkin Elmer system with a scan range of 450-4000 cm^{-1}. Resolution of the instrument is 1.0 cm^{-1}. By FT-IR analysis it is found that the biodiesel has different strong bands, i.e. strong carbonyl group occurring in the range of (O-H) 2500-3300 cm^{-1}. Two strong alkane groups occur at same region i.e. 2850-3000 cm^{-1}(C-H). Strong alcohol bond occurs in the range of 3200-3600cm-1. Weak multiple bands (aromatic), (C=C) occur in the range of 1400-1600 cm^{-1}. Two bands (N-O) occur in the range of 1345-1385 cm^{-1}. Medium - weak (amine), bond occur in the range of 1080-1360 cm^{-1}. Strong (C-O) alcohol group occur in the range of 1000-1300 cm-1. Strong amide group occur in the range of 1640-1690 cm^{-1}. These are functional groups that are found out by using FT-IR analysis is shown in Fig. 3. JOEL Gate GC mate 2 double focusing high resolution data system was used to identify the fatty acid methyl esters in LGBD. NIST 1 and 4 libraries interpreted the GCMS data with reference to scan and ions in the chromatogram. Fig. 4 shows the GCMS chromatogram of LGBD and the fragmentation pattern of Behenic acid and Stearic acid at retention time of 26.73 and 22.15 respectively.

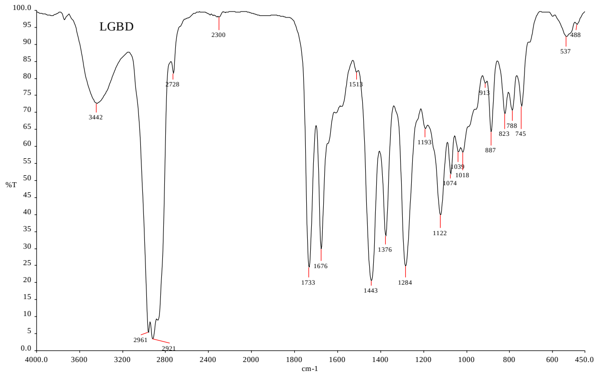

Fig. 3: FT-IR characteristic spectrum of LGBD

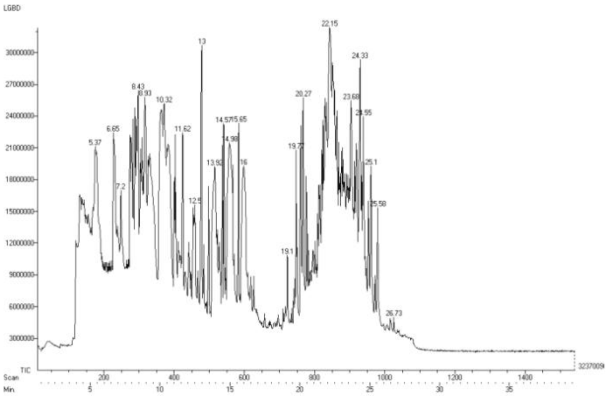

Fig. 4: GC-MS results for LGBD

4.2. Combustion analysis

The change of cylinder pressure with respect to crank angle is a major factor for combustion analysis and it is recorded for all test fuels as shown in Fig. 5. One of the major parameter that affects combustion and evaporation is viscosity. Viscosity and air fuel interaction are inversely proportional to each other and higher the viscosity lesser the air fuel interaction. At no load condition, the peak pressure of D80LGBD20 is 43.342 bar, while for D80LGBD20CNT50, D80LGBD20 CNT100 and D80LGBD20CNT150 are 43.962 bar, 43.489 bar and 43.371 bar respectively. The peak gross value of D80LGBD20 is slightly lower than MWCNTs blend D80LGBD20CNT. Due to the addition of MWCNTs to the blend, the combustion process is accelerated. MWCNTs has higher thermal conductivity when compared to other blends and also the Cetane number is increased on addition of CNT. Therefore, evaporation rate also increases which results in shortened ignition delay. Another reason is that the surface area to volume ratio is higher for MWCNTs which enhanced the heat transfer thereby improving the combustion process.

The peak cylinder pressure at part load for D80LGBD20 is 55.270 bar while for D80LGBD20CNT50, D80LGBD20CNT100, D80LGBD 20CNT150 are 55.309 bar, 57.618 bar and 56.761 bar respectively. Here also, the same pattern occurs on addition of CNT. At full load condition, as seen in Fig. 5, the peak pressure for D80LGBD20 is 64.451 bar while for D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 it is 64.846 bar, 65.144 bar and 63.735 bar respectively. When compared with all readings i.e., at no-load, part load, full load, the maximum peak pressure occurs at D80LGBD20CNT100 blend as compared to D80LGBD20.

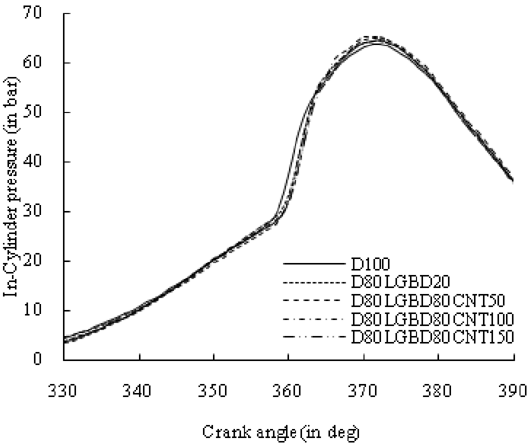

Fig. 5: In-cylinder pressure vs. Crank angle at full load

Heat release correlations (Fig. 6) are another important factor to know about the combustion process in CI engine. D80LGBD20 blend has higher Cetane number than diesel fuel which helps for better diffusion combustion rather than premix combustion. At no load condition, the rate of heat release for D80LGBD20 is 39.645 J/kg while for D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 it is 40.032 J/kg, 39.25512511 J/kg, and 41.128 J/kg respectively. By observing the curves, the addition of MWCNTs increases the rate of heat release when compared to D80LGBD20. Cetane number differentiates the curves but the depressed calorific value and higher viscosity also does the same.

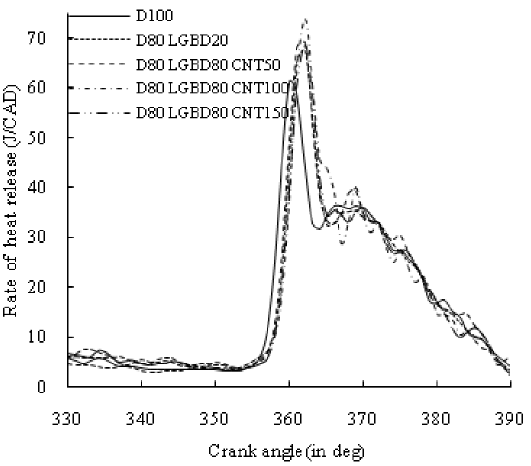

Fig. 6: Variation of heat release rate with crank angle at full load

At part load condition, the peak heat release of D80LGBD20 is 71.471 J/kg while for D80LGBD20CNT50, D80LGBDCNT100 and D80LGB D20CNT150 it is 71.218 J/kg, 71.742 J/kg, and 73.981 J/kg respectively. In part load condition, D80LGBD20CNT100 has the highest peak heat release rate when compared to other blends. At full load condition, as seen in Fig. 6, the peak heat release rate of D80LGBD20 is 67.541 J/kg, and for the blends are 69.032 J/kg, 73.953 J/kg, and 68.742 J/kg for D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 respectively. Observing the results, it is clear that the peak heat release rate is given by D80LGBDCNT100 when compared to other fuel blends as shown in Fig. 6 [20, 21].

Combustion process reflects itself with the pressure rise rate. If the combustion process is either fast or slow, the pressure rise rate also differs. Under the normal conditions the positions of the peak pressure rise rate takes place after top dead center. Peak pressure rise rate indicates the heat release rate due to premixed mode of combustion. The rate at which the heat is released is indicated by the rate of pressure rise. At part load condition, the maximum rate of pressure rise for D80LGBD20 is slightly lower than the base diesel oil. This is happened due to laminar burning velocity which led to decrease in combustion rate. The addition of MWCNTs into LGBD20 blend led to increase in fuel droplet evaporation rate due to which better fuel air mixing occurs. Therefore, the peak pressure rise rate has increased when compared to D80LGBD20. At no load condition, the peak pressure rise rate of D80LGBD20 is 2.798 bar, while for D80LGBD20CNT50, D80LGBD20 CNT100 and D80LGBD150 it is 3.058 bar, 2.997 bar, and 2.913 bar respectively.

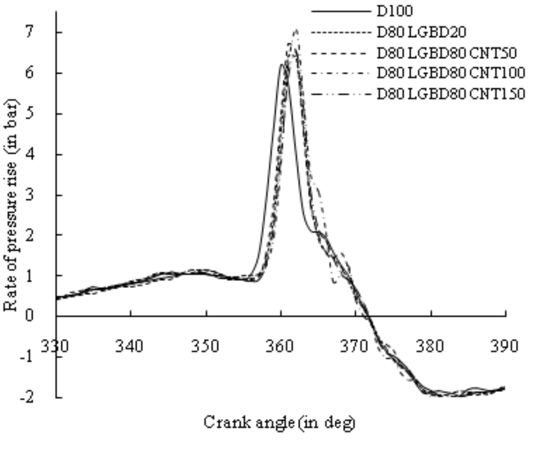

Fig. 7: Variation of pressure rise rate with crank angle at full load

At part load condition, i.e. after increasing the load to certain extent the peak pressure rise rate of D80LGBD20 is 6.584 bar, while for D80LGBD20CNT50, D80LGBD20CNT100, D80LGBD CNT150 are 6.583767708bar, 7.09995833 bar, 6.8509833 bar respectively. At full load (Fig. 7) the pressure rise rate of D80LGBD20 is 6.40128125bar while for D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 are 6.702 bar, 7.039 bar and 6.503 bar respectively. On observing the results obtained between rates of pressure rise versus crank angle, D80LGBD20CNT100 shows the maximum peak pressure rise rate when compared to all other blends at all load conditions as noticed in Fig. 7.

Cumulative heat release rate (Fig. 8) gives the information about the combustion process in a diesel engine. At no load condition, D80LGBD20 gives 0.497 kJ while for D80LGBD20CNT50, D80LGBDCNT100 and D80LGBD20CNT150 it is 0.493 kJ, 0.483 kJ, and 0.488 kJ respectively. For diesel, it is around 0.491 kJ. The peak gross heat release of D80LGBD20 is slightly higher than that of diesel whereas it is least for D80LGBD20CNT100. At part load, the peak gross heat release of D80LGBD20 is 0.744 kJ while it is 0.746 kJ, 0.762 kJ, and 0.751 kJ for D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 respectively. As seen in Fig. 8, the peak gross heat release at full load condition for D80LGBD20 is 0.981 kJ, while for D80LGBD20CNT50, D80LGBD20 CNT100 and D80LGBD20CNT150 it is 1.027 kJ, 0.973 kJ and 0.974 kJ respectively. Also the maximum values of gross heat release are obtained at 50 ppm and 100 ppm of MWCNT addition to D80LGBD20 when compared to other blends.

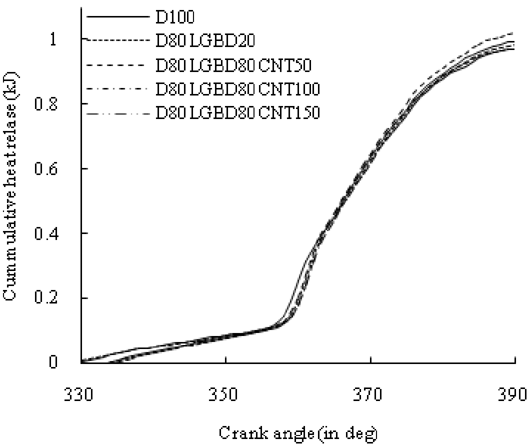

Fig. 8: Variation of cum. heat release with crank angle at full load

4.3. Performance analysis

Fig. 9 shows the variation of brake thermal efficiency with BMEP for D100, D80LGBD20, D80LGBD20 CNT50, D80LGBD20CNT100, and D80LGBD20CNT 150 respectively. Brake thermal efficiency of the engine is defined as the ratio of heat equivalent of the work delivered by the engine to the heat energy received by the engine as fuel. Brake thermal efficiency depends upon the properties of the fuel i.e. Cetane number, calorific value, viscosity and oxygen content in the fuel. At minimum load brake thermal efficiency for D100 and D80LGBD20 is 0.125 % and 0.157 % whereas it is 0.164 %, 0.187 %, 0.174 % for D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 respectively. It is observed that LGBD and its Nano blends have higher brake thermal efficiency than diesel due to its fuel properties. MWCNT aid the oxidation in the engine thus leading to an efficient combustion process and reduction in fuel consumption.

At part load, i.e., 3.16 bar of BMEP, the brake thermal efficiency for D100 and D80LGBD20 is 28.789% and 30.7893% whereas it is 31.458%, 32.78%, and 30.5% for D80LGBD20CNT50, D80LGBD20CNT100, and D80LGBD20CNT150 respectively. At part load condition, it is clear that D80LGBD20CNT100 shows the maximum brake thermal efficiency. A similar trend for full load i.e., 6.17 bar of BMEP condition is observed for D80LGBD20 (BTE is 37.78%) whereas it is 38.784%, 40.789%, 36.78% for D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 respectively. By observing the plotted results, maximum brake thermal efficiency is obtained by D80LGBD20CNT100 blend.

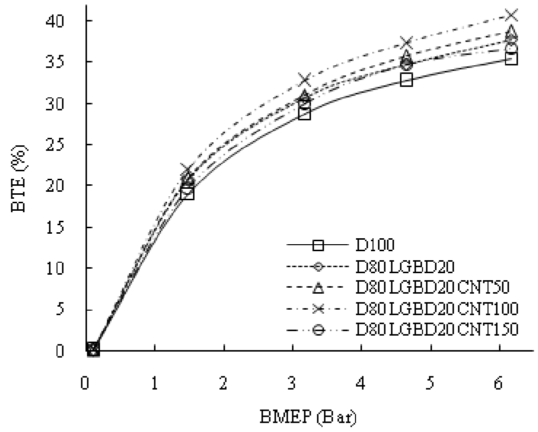

Fig. 9: Variation of BTE

BSFC is an important characteristic that decides the performance of any engine. Engine fuelled with biodiesel shows the higher BSFC. It is due to the low calorific value of biodiesel i.e. calorific value of LGBD is lesser compared to diesel. As seen from Fig. 10, at minimal load i.e., 0.1bar, D100 and D80LGBD20 shows BSFC as 2.258 kg/kwhr and 2.458 kg/kwhr respectively. The blends of LGBD with CNT shows 2.315 kg/kwhr, 2.110 kg/kwhr and 2.365 kg/kwhr for D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 respectively. Based on this result, it is clear that BSFC is higher for D80LGBD20 and it is lower for D80LGBD20CNT100. The specific fuel consumption is inversely proportional to fuel energy conversion efficiency i.e., thermal efficiency. At part load i.e., 1.48bar BSFC for D100 and D80LGBD20 is 0.65 kg/kwhr and 0.69 kg/kwhr respectively.

The blends D80LGBD20CNT50, D80LGBD20CNT 100 and D80LGBD20CNT150 show 0.648 kg/kWhr, 0.582 kg/kWhr, 0.598 kg/kWhr respectively. Here also, the D80LGBD20 shows higher BSFC and D80LGBD20CNT100 show minimum BSFC. D80LGBD20 shows more BSFC because of larger fuel combustion in the premixed combustion stage, which results in excess burning in the premixed combustion stage. At full load condition i.e. 6.17 bar D100 and D80LGBD20 is 0.235 kg/kWhr and 0.241 kg/kwhr. The blends D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 are 0.231 kg/kwhr, 0.194 kg/kwhr and 0.214 kg/kwhr respectively. Based on the results it is clear that BSFC is lower for D80LGBD20CNT100 blend. Therefore maximum reduction of BSFC is obtained for a concentration of 100 ppm CNT in D80LGBD20 LGBD.

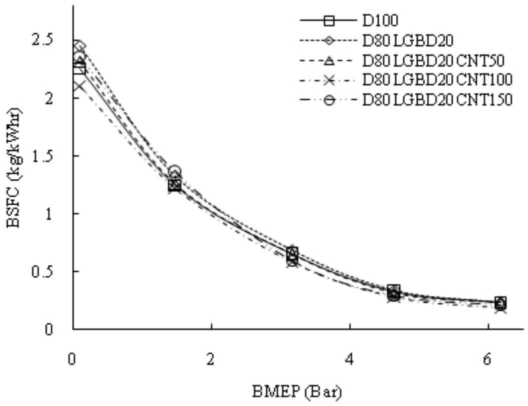

Fig. 10: Variation of BSFC with BMEP

4.4. Emission analysis

Fig. 11 shows the variation of UBHC emission. On close observation of the data, it is clear that D80LGBD20 led to a considerable increase in the emission of UBHC when compared to diesel. Higher viscosity may be the reason for the increase in UBHC. Due to the increase in viscosity of biodiesel, combustion attainment takes longer time. Incorrect combustion of layers might also be the reason. Fraction of hydrocarbons is carried away by these layers which escape from the denser and longer fuel spray in case of D80LGBD20. At 25% load condition, 17 ppm, 18 ppm, 16 ppm, 16 ppm and 18 ppm of UBHC is recorded for diesel, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 respectively. The same trend is observed at 50% load; here also UBHC values are 16 ppm, 18 ppm, 19 ppm, 21 ppm and 23 ppm for Diesel, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT 100 and D80LGBD20CNT150 respectively. Due to the addition of MWCNT to the blend it shows a positive effect towards the UBHC emissions. Due to their addition to the blend, it improves the combustion characteristics of the fuel. At full load condition, UBHC emissions of diesel, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 are 41 ppm, 39 ppm, 39 ppm, 41 ppm and 43 ppm respectively. UBHC emissions are increased with increase in the load conditions. In general UBHC emissions at all load conditions is higher for D80LGBD20CNT150 blend.

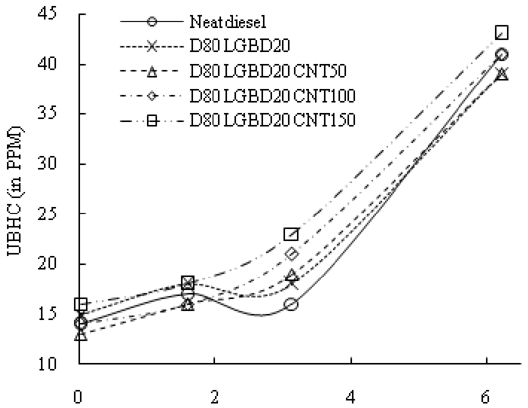

Fig. 11: Variation of UBHC emission

Fig. 12 shows the variation of CO emissions with respect to BMEP for diesel, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100, and D80LGBD20CNT150. It is clear that D80LGBD20 fuel produced more carbon monoxide emissions when compared to diesel at all load conditions. At no load condition, D100, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 are 0.049%, 0.091%, 0.053%, 0.044% and 0.042% respectively. At no load condition D80LGBD20 emits more CO than other blends. At no load condition, fuel supplied is less. This more CO emission is due to the higher viscosity of the fuel blend. At 25% load, the CO emission is 0.027%, 0.032%, 0.029%, 0.032% and 0.033% for diesel, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 respectively. In this load condition, D80LGBD20CNT 150 emits more carbon monoxide. At 75% load condition, the CO emission is 0.018%, 0.028%, 0.019%, 0.021% and 0.017% for diesel, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT 100 and D80LGBD20CNT150 respectively. At full load condition, the same is 0.0112%, 0.165%, 0.165%, 0.174% and 0.131% for diesel, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 respectively. On observing all the load conditions, D80LGBD20CNT100 emits considerably more carbon monoxide emissions.

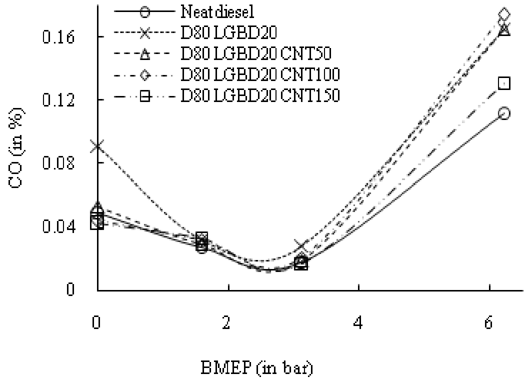

Fig. 12: Variation of CO emission

Fig. 13 shows the variation of CO_2 with BMEP. In diesel engine, as the combustion precedes it leads to formation of two different components. H2O and CO_2 are considered as the complete combustion products because carbon dioxide is released as combustion takes place. If there is a good combustion rate, then carbon dioxide formation will be high when compared to UBHC and CO emissions. At no load condition, the CO_2 emission neat diesel, D80LGBD20, D80LGBD20 CNT50, D80LGBD20CNT100 and D80LGBD20CNT 150 are 1.87%, 2.05%, 1.97%, 2.01% and 1.97% respectively. It is clear from the results that D80LGBD20 forms more percentage of carbon dioxide at no load condition which means that good combustion is taking place for this blend. This may be due to calorific value and density of the fuel. At 25% of load, 3.45%, 3.28%, 3.49%, 3.46%, 3.35 for D100, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT 100 and D80LGBD20CNT150 respectively. At this load condition, D80LGBD20CNT50 releases more percentage of CO_2. It is understood that addition of CNT affects the combustion process. At 50% of load condition 5.07%, 5.35%, 5.23%, 4.73% and 5.16% for D100, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150. At full load condition, D100, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100, D80LGBD20CNT150 are 8.85%, 9.2%, 9.13%, 8.9% and 8.91% respectively. Based on the results it is understood that increasing the load increased the carbon dioxide emissions and D80LGBD20 considerably emits more amount of carbon dioxide. Oxides of nitrogen affect the brake thermal efficiency which in turn reflects on the BSFC which has an overall impact on the efficiency of the engine.

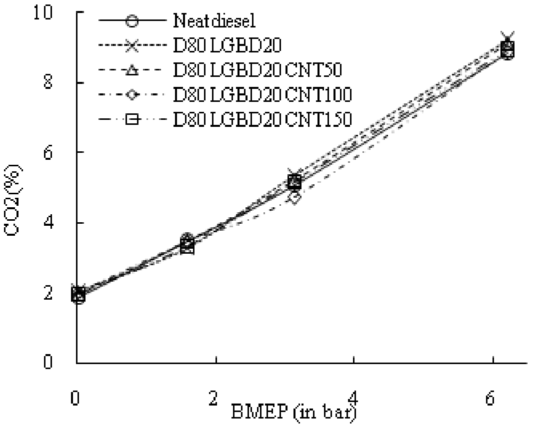

Fig. 13: Variation of CO_2 emission

Fig. 14 shows the variation of oxides of nitrogen with regarding to BMEP. Due to high in-cylinder temperature, oxides of nitrogen occur. This emission occurs due to the presence of oxygen atoms in the biodiesel wherein the fuel gives its oxygen atoms to form oxides of nitrogen. At no load condition, diesel, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 gives 167 ppm, 132 ppm, 174 ppm, 200 ppm and 207 ppm of NO_x. At no-load condition D80LGBD20CNT150 emits more oxides of nitrogen. At 25% load condition the same is 460 ppm, 457 ppm, 547 ppm, 501 ppm and 534 ppm for D100, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 respectively.

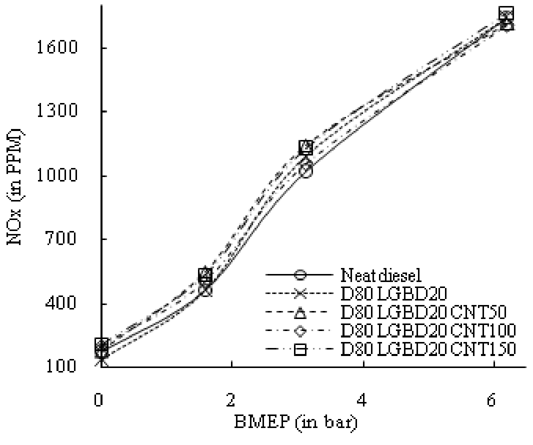

Fig. 14: Variation of NO_x emission

On addition of CNT, there is a rise in oxides of nitrogen emission. At 50% load condition, the NO_x emissions of D100, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 are 1015 ppm, 1090 ppm, 1140 ppm, 1055 ppm and 1123 ppm respectively. Same trend follows here also. At full load condition, the same for D100, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 are 1744 ppm, 1740 ppm, 1714 ppm, 1702 ppm, 1763 ppm respectively. Air- fuel ratio is the main reason for smoke emission. Emission occurs due to insufficient amount of air present in combustion zone. As seen in Fig. 15 no-load condition, 1.6%, 3%, 1%, 1.9% and 1.7% for D100, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 respectively. At this condition, D80LGBD20 emits more smoke emission whereas the CNT blends of LGBD emit less smoke opacity. At 25% load condition, the same for D100, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 are 3.5%, 6.7%, 2.1%, 2.8% and 2.8% respectively. While at 50% of load condition, 7.5%, 14.8%, 4.9%, 5.8%, and 7.2% of smoke opacity is observed for D100, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100, and D80LGBD20CNT150 respectively. In general addition of CNT to the biodiesel causes a considerable decrease in the smoke opacity. This is due to rapid secondary effects which reduced the soot formation and improved the reactant mixture. At full load condition, the smoke opacity is 61.3%, 52.5%, 55.2%, 52.4%, and 52.7% for D100, D80LGBD20, D80LGBD20CNT50, D80LGBD20CNT100, and D80LGBD20CNT150 respectively [19, 22].

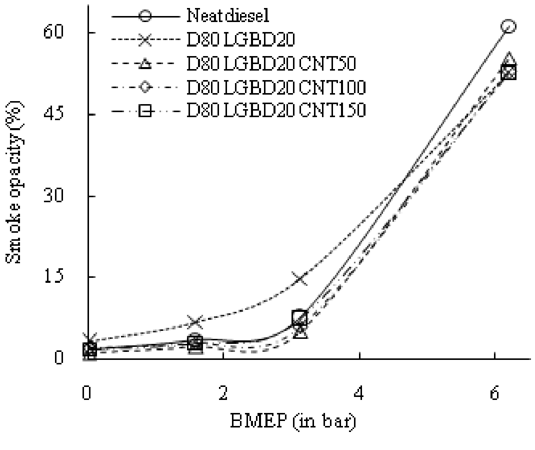

Fig. 15: Variation of smoke emission

5. Conclusions

The lemongrass oil was extracted through steam distillation of the leguminous section of lemongrass plant. The bio-oil was transesterified using potassium hydroxide and methanol at molar ratio of 1:8. Blending the methyl esters of LGO with CNT significantly improved the cetane number and calorific value of the test fuel. The performance, emission and combustion characteristics of the Compression ignition engine fuelled with LGBD ultrasonicated with CNT additive are summarized below. On addition of CNT, the combustion phenomenon was accelerated with higher rate of het release. Ignition delay was also considerably decreased when CNT was blended with the test fuel. At full load condition, the peak pressure for D80LGBD20 is 64.45195 bars while for D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 is 64.846 bar, 65.1444 bar, 63.735015 0bars respectively. Brake thermal efficiency is improved on addition of CNT to the biodiesel. At full load condition the BTE for D80LGBD20 is 37.78% while it is 38.784%, 40.789%, 36.78% for D80LGBD20CNT50, D80LGBD20CNT100, and D80LGBD20CNT150 respectively.

The BSFC at full load condition for D100 and D80LGBD20 is 0.2356 kg/kWhr and 0.2415 kg/kWhr, whereas for D80LGBD20CNT50, D80LGBD20CNT100 and D80LGBD20CNT150 it is 0.23154 kg/kWhr, 0.19458 kg/kWhr and 0.2145 kg/kWhr respectively. Due to addition of CNT to the biodiesel blend, there is a considerable decrease in the NO_x emissions. At full load condition D80LGBD20 emits 1749 ppm NO_x whereas D80LGBD20CNT100 emits only 1702 ppm of NO_x emission. Smoke opacity is also considerably reduced. On observing the results of LGBD along with CNT, the Nano-metallic additive MCWNT has influence of the characteristics of the engine on using them. It helps to improve the engine performance and considerably reduce the emissions.

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