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Effect of CNT Additives on Performance and Exhaust Emissions of a Diesel Engine Fueled with Non Edible Biodiesel Fuel

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Abstract: Energy demands for petroleum products are increasing since its rate of fuel consumption is increasing. The whole world suffers from shortage of petroleum products. Therefore it is necessary to find alternative fuels of fuel consumption reduction and harmful exhaust emission. Biodiesel was produced from jatropha oil by esterification followed by transesterification process. The aim of this paper is to measure performance and exhaust emissions of a diesel engine using jatropha biodiesel blends by adding appropriate concentrations of carbon nano additives. Carbon nano additives were mixed with biodiesel blends at the rate of 25mg/l, 50 mg/l and 100 mg/l as 25, 50 and 100 ppm. An experimental investigation was carried out on a single cylinder diesel engine at different engine loads using Jatropha biodiesel and nano additives. Measured physical and chemical properties of jatropha biodiesel (B20) were found to be within ASTM standards. Tests showed a considerable enhancement in engine performance and exhaust emission compared to biodiesel blends without nano additives. Experimental test results indicated that adding carbon nano particles to biodiesel fuel decreased about 5.71% in brake specific fuel consumption and 13.34% increased in brake thermal efficiency compared to pure diesel fuel. Combustion of jatropha biodiesel (B20C50) resulted in decreases in CO, NO_x, and smoke emissions by about 36.36, 57.14 and 43.66%, respectively as compared to diesel oil. Jatropha biodiesel blend with CNTs at concentration of 50 ppm is environmentally friendly and achieved better engine performance compared to other fuels. Thus it is recommended to use jatropha biodiesel with carbon nano-additives as an alternative fuel in diesel engines.
Keywords: Jatropha oil, Biodiesel, Carbon nanotubes, Performance, Emissions.

I. INTRODUCTION

Environmental concerns, global warming and depletion of diesel oil announce the need to explore suitable alternative fuels. Edible vegetable oils have higher prices, so there is a motivation to produce biodiesel from non-edible vegetable oils such as jatropha oil and waste cooking oil to use as fuels. Biodiesel is becoming one of the growing alternative fuels for several beneficial reasons such as its clean emission profile and being easy to use. Biodiesel is a green fuel and can be a substitute to diesel fuel [1].

Biodiesel is made from chemical processing of vegetable oil, where fats are converted into methyl esters. Biodiesel is a renewable fuel. The most important properties of biodiesel are: higher lubricity which reduces wear of engine, it has good cetane rating, no sulfur content, the higher content of oxygen in biodiesel than diesel oil results in better combustion efficiency and hence complete combustion. The calorific value of biodiesel is less by about 7% than petroleum diesel oil. Biodiesel has higher viscosity than diesel oil lead to poor atomization and fuel mixing with air during the injection delay period. Biodiesel is quite simple and easy to handle, biodegradable, nontoxic, and free of sulfur and aromatics. Diesel engine produces less emissions and greenhouse gases other than NO_x for burning biodiesel. It can be used in current diesel engines with little or no modifications. It can be used as pure biodiesel (B100) or in blends such as B20 (20% biodiesel). Biodiesel increases engine life. Thermal efficiency of engines burning jatropha biodiesel-diesel blends decreases with increase in the percentage of biodiesel in the blends due to lower calorific value of biodiesel compared to diesel oil [2–4]. Currently, nano-particles are materialized to utilize as an additive/fuel borne catalyst with the emulsion fuels [5–11, 12, 13]. Recently, several scientists and researchers have incorporated various additives to improve fuel properties of biofuels and emulsion fuels [12-17].

Biodiesel (methyl or ethyl esters of fatty acids) possesses characteristics similar to those of diesel while the biggest difference is its oxygen content resulting in a more complete combustion and consequently higher energy generation [18, 19]. Nevertheless, the overall energy obtained through biodiesel combustion is less than that of diesel fuel. There is increase in NOx emission for biodiesel

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about diesel oil [20-22]. Boutonnet et al. [23] studied addition of monodispersed metal in form of micro emulsion. They showed that it is possible to prepare mono dispersed suspensions of metals in organic solvents by dissolving them in ionic form in the interior of reversed micelles in micro emulsions followed by reduction with an appropriate reducing agent [21–25]. Basha and Anand [27] carried out experimental investigations to study the effects of alumina nanoparticle blended into jatropha biodiesel on combustion characteristics of a diesel engine. They looked into ultrasound assisted inclusion of alumina nanoparticles at two different rates of 25 and 50 ppm. A considerable enhancement of 29% in brake thermal efficiency compared to the neat biodiesel at full load.

Basha and Anand [28] investigated the potential application of nano-alumina particles and carbon nanotubes (CNT) at two concentrations of 25 and 50 ppm in a diesel engine with different jatropha biodiesel–diesel blends. They observed maximum thermal efficiencyof 28.9% at full load for jatropha biodiesel supplemented with 25 ppm CNT. NOx and smoke emissions were reduced for nanoparticles in jatropha biodiesel fuels compared to neat jatropha biodiesel fuel. The magnitude of smoke opacity observed was 57% for JBD25A25CNT, whereas there were 60%, 58% and 67% for JBD50CNT, JBD50A and JBD at full load, respectively. NOx emissions observed were 1282 ppm for JBD, whereas it was measured at 1015, 1001, and 985 ppm for JBD50A, JBD50CNT, and JBD25A25CNT at the full load, respectively [29].

Tewari et al. [30] reported combustion characteristics of multi walled carbon nanotubes blended into biodiesel fuel. They used a mechanical homogenizer to disperse the catalyst at two different levels of 25 and 50 ppm. A considerable enhancement in brake thermal efficiency and a reduction in exhaust emission due to the incorporation of CNTs in biodiesel fuel. Catalyst activity strongly depends on the size of particles. Smaller particles possess higher catalytic activity [30–33]. Nano-scale particles spread more uniformly within the liquid and are more stable than those out of this range. Nano-catalysts are much more effective [34–36]. A number of experimental studies were also conducted on the effect of cerium oxide nano-particles as an additive to various fuel mixtures in diesel engines. The results showed that the cerium oxide nano-particles could be used as additive to diesel fuel and diesel–biodiesel–ethanol mixture to achieve a completer combustion and significant reductions of exhaust emissions [37, 38].

Sajith and Sobhan [39] reported the impact of cerium oxide on physicochemical properties of B100 as well as engine performance and emissions parameters. There is increase in fuel flash point and viscosity owing to the inclusion of the cerium oxide nanoparticles. Addition of nanocatalyst at concentrations ranging from 40 to 80 ppm resulted in reduction of hydrocarbon emissions from 25% to 40% and at its highest inclusion rate of 80 ppm led to 30% reduction in NOx. Addition of cerium oxide nanoparticles led to decreases in CO, NO and smoke emissions. Addition of cerium oxide nanoparticles decreased the ignition delay and accelerated earlier initiation of combustion and lowered the heat release rate when compared with diesel–biodiesel–ethanol blend. Boutonnet et al. [40] highlighted that the use of heterogeneous solid catalysts would not be practical, as continuously exposing a supplied catalyst to the extremely higher temperatures encountered in the combustion environment would quickly deactivate the catalyst. Yetter et al. [40] and Dreizin [41] have critically reviewed the reports on addition of metal nanoparticle and observed that the nano-size metallic powders possess high specific surface area and could lead to high reactivity. They have also revealed that adding nano-additives to fuels facilitate shortened ignition delay and reduce soot emissions.

Sabourin et al. [42], Roos et al. [43] and Roger [44] have reported that adding nano-size particles to the fuel act as a liquid fuel catalyst and thereby enhance the ignition and combustion characteristics of the engine. Arianna et al. [45] have utilized cerium oxide nano-particles as a combustion improver in water/diesel emulsion fuel and there was a significant reduction in exhaust emissions such as CO and HC. Moy et al. [46] reported that CNT could act as a potential nano-additive for the fuels to enhance the burning rate of the fuel, improve the cetane number, act as an anti-knock additive, promote clean burning and suppress the smoke formation. Sadhik Basha and Anand [47–50] have conducted a series of experiments in a single cylinder diesel engine using CNTs and Alumina nanoparticles as additive with diesel, biodiesel, water–diesel emulsion fuels. They observed an appreciable increase in the brake thermal efficiency and reduced harmful emissions compared to neat diesel and biodiesel. On such basis, the other way to introduce catalysts as investigated in the present study would be to dissolve them in fuel so that they could be added on a continuous basis. More importantly, soluble catalyst particles do not settle out during the injection stage and neither interferes with the engine operation [50–52].

II. MATERIALS AND METHODS

A. Jatropa Oil Extraction Process

Egyptian jatropha fruits are cultivated in high temperature dry weather in Upper Egypt. Jatropha seeds before processed must be peeled. Mechanical pressing was deployed to extract oil from jatropha seeds. Mechanical press extraction is used because of its higher yield. Better yield and favorable screw operating conditions were achieved to obtain oil with the proper properties. Screw

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press extraction method was used to extract oil at extraction temperature of 100°C and motor speed of 60 rpm. Screw press produces higher oil yield from the seeds of up to 20% [53].

B. Biodiesel Production Process

A two stage process is used for the esterification of the jatropha oil. The first is called esterification, and this is used to reduce the free fatty acid content in jatropha oil by esterification with methanol (99% purity) and acid catalyst (sulfuric acid of 98% purity) in three hours reaction at 80 C. In the second stage, called transesterification, jatropha oil is heated up to 70°C in a round bottom flask to drive off moisture and stirred vigorously. The triglyceride portion of the jatropha oil reacts with methanol having a density of 0.791 g/cm^{3}and base catalyst (potassium hydroxide - 99% pure), which is dissolved in methanol in a molar ratio of 6:1 in a separate vessel and was poured into round bottom flask while stirring the mixture continuously. After completion of the transesterification process, the mixture is permitted to settle down under gravity in a separating funnel for 24 hours. The formed products were jatropha oil, methyl ester, and glycerin. The glycerol layer was removed and the raw fatty acid methyl ester was washed by water in order to remove all the un reacted meth oxide. It was then heated to remove the water traces to obtain clear biodiesel. Biodiesel production photographic viewis shown in Fig.1 and it is mixed with diesel in different proportions to form different blends such as B20 (20% jatropha biodiesel and 80% diesel oil) by volume.

Fig.1: Biodiesel production process.

C. Physical And Chemical Properties Of Biodiesel

Table 1 tabulates the measured physical and chemical properties of biodiesel blends. The heating value of jatropha biodieselis less than that diesel oil. The heating value of fuel determines the available heat to produce the engine power. Cetane number is a measure of the combustion quality of a fuel in diesel engine and is related to the volatility of the fuel and ignition delay time. The higher cetane number leads to shorter ignition delay. Flash point temperature is critical for fuel safe handling and storage. Flash points of jatrophabiodiesel are higher than that for diesel oil, so, handling and storage of these oil are relatively less hazardous as compared to petro diesel.

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Table 1: Physical and chemical properties of jatropha biodiesel compared to diesel fuel and ASTM standards.

Properties	Method	Diesel oil	Jatropha biodiesel (B100)	Jatropha biodiesel (B20)
Density units at 15.56 C	ASTM D-4052	829	876	835
Kinematic Viscosity at 40C	ASTM D-445	1.2	1.8	1.3
Flash Point, C	ASTM D-93	75	121	75
Heating Value kJ / kg	ASTM D-224	42000	38789	39300
Cetane Number	ASTM D-13	45	42.62	52

D. Experimental set up

The experiments were performed on a single cylinder, four stroke, and direct injection diesel engine. It develops a power of 5.775 kW at 1500 rpm. The technical specifications of the engine were summarized in Table 2. A schematic drawing of the experimental set up is depicted in Figure 2. The engine output brake power was measured by an AC generator, of maximum electric power output of10.5 kW, coupled directly to the current test engine. The intake air-flow was measured by using a sharp edge orifice supported in the side of an air box whose function was to dampen the pulsating airflow into the engine. A U- tube manometer was used to measure the pressure drop across the orifice. The temperature at different locations in the experimental set up such as those of intake air manifold and exhaust gases was measured by using a thermocouple probes of type (K). A fuel tank of 0.5 Liter capacity was mounted for feeding the engine with diesel and biodiesel fuels. One burette with stopcock and two way valve was utilized to measure the fuel flow rate and for selecting either diesel or biodiesel fuels. OPA 100 smoke meter and MRU DELTA 1600-V Gas Analyzer were employed for the measurements of smoke opacity and exhaust gas concentrations (CO, HC, $CO_2$and NO_x). The experiments were carried out for various engine loads from zero to full load for a constant rated speed of 1500 rpm throughout the tests.

Table 2: Engine specifications

No.	Engine parameters	Specification
1	Engine model	DEUTZ F1L511
2	Number of cylinders	1
3	Number of Cycles	Four stroke
4	Cooling type	Air cooled
5	Bore (mm)	100
6	Stroke (mm)	105
7	Compression ratio	17.5:1
8	Fuel injection advance angle	24º BTDC
9	Rated brake power (kW)	5.775 at 1500 rpm
10	Number of nozzle holes	1
11	Injector opening pressure (bar)	175

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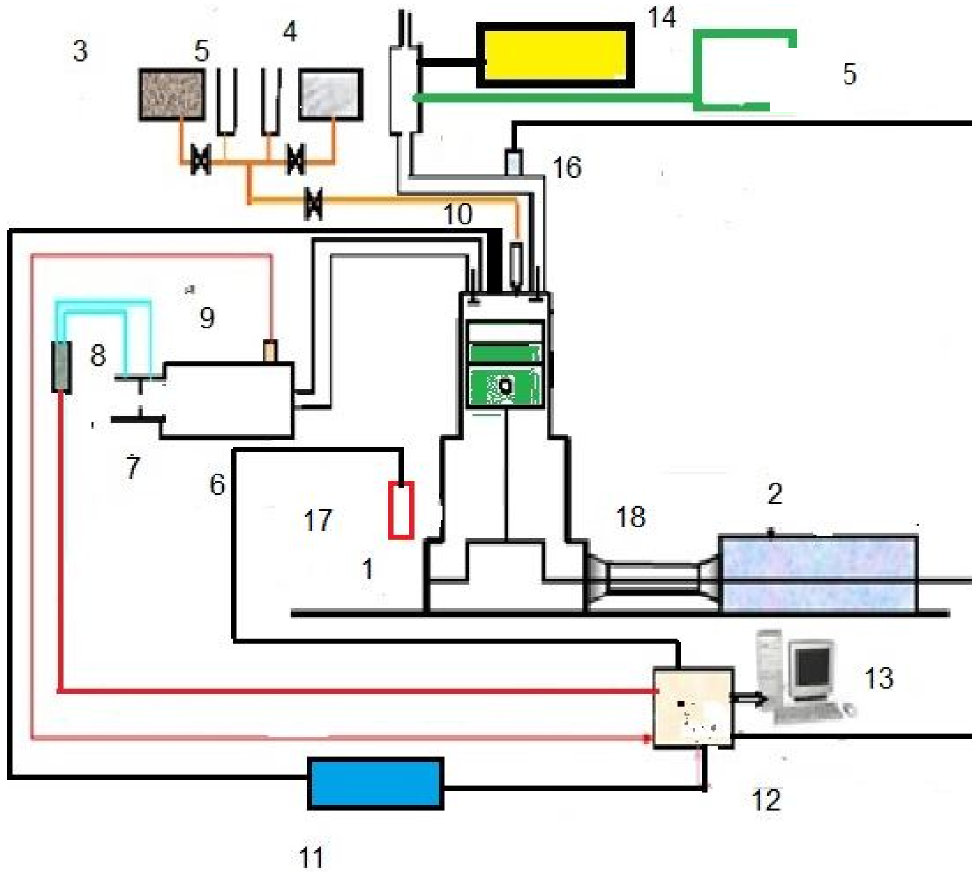

1. Diesel engine
2. AC generator
3. Diesel tank
4. Fuel tank
5. Burette
6. Air surge tank
7. Orifice
8. Pressure differential meter
9. Intake air temp. thermocouple
10. Piezo pressure transducer
11. Charge amplifier
12. Data acquisition card
13. Personal computer
14. Exhaust gas analyzer
15. Smoke meter
16. Exhaust gas temp. thermocouple
17. Proximity switch
18. Cardan shaft

Fig. 2:Schematic diagram of the experimental setup.

III. RESULTS AND DISCUSSIONS

A. Brake Specific Fuel Consumption

Figure3illustrates the effect of adding CNT's with (25, 50, and 100ppm) to jatrophabiodiesel (B20) on brake specific fuel consumption for different engine loads. The results in this figure depict that brake specific fuel consumption gets lower as the engine load increases for all used diesel, jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100) fuels. Brake specific fuel consumptions for all nano concentration through large range of loads are lower than that of jatopha biodiesel without additive (B20) and fossil diesel (D100). The reason for this is due to the existence of oxygen molecules along with the CNTs. This phenomenon is due to the result of CNT nano addition which promotes combustion. The lowest brake specific fuel consumption observed as376.843 gm/kW.hfor (B20C25)blend whereas it is 422.799 g/kW.h for pure diesel (D100) at half load. Improvement in brake specific fuel consumption is observed with the addition of nano particles with biodiesel blends.

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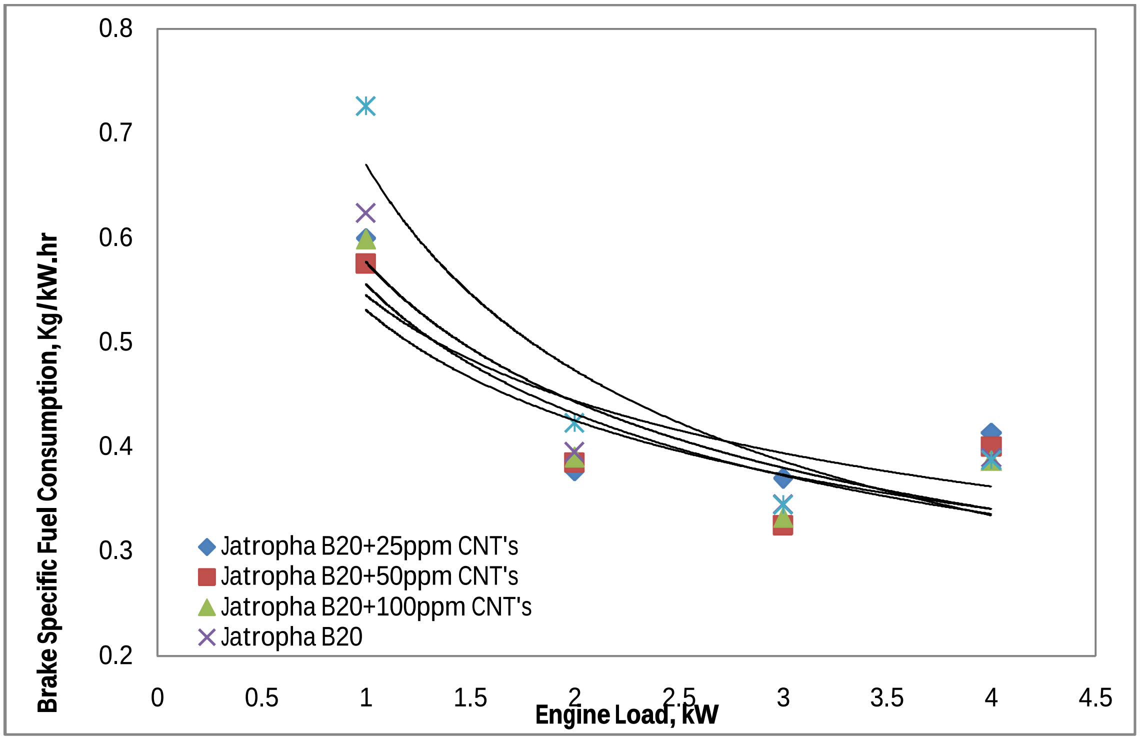

Fig.3:Variation of brake specific fuel consumption with engine load.

1) *Brake Thermal Efficiency:* Brake thermal efficiency for different engine loads for diesel, jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100)fuels are given in Figure 4.This is so because of the less brake specific fuel consumption as the engine load increases. The thermal efficiency is increased for nanobiodiesel blends compared to diesel fuel (D100). The brake thermal efficiency rises by increasing the share carbonnano-particles in the fuel blends which reflects the improved combustion and the effective energy conversion of fuel to useful work. The mainreason of this power rising can be attributed to the produced energy inside the cylinder by increasing the surface to the volume ratio of nano-particles and enhancing the heat transfer coefficient. Carbon nanocatalyst reduces the ignition delay and combustion duration of fuel which leads to higher peak cylinder pressure and faster heat release rate. (B20C25) produced an increase in thermal efficiency by up to 20% at 50% of engine load compared to diesel oil.

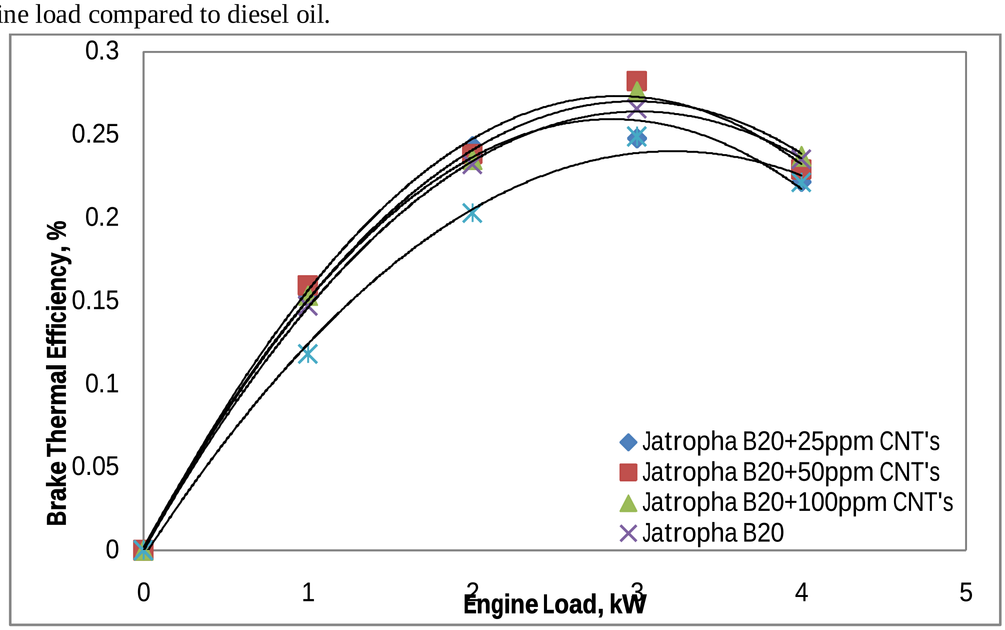

Fig.4: Variation of brakethermal efficiency with engine load.

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2) *Exhaust Gas Temperature:* The exhaust gas temperature at different engine loads for neat diesel (D100), jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100) are shown in Fig. 5.The exhaust gas temperature increases with increase in engine load. This increase may be a result of higher temperature inside the engine cylinder, which leads to more fuel burning to meet higher engine load requirement. Exhaust gas temperature increases as the load increases. The addition of CNT nano-particles to jatropha biodiesel (B20) lead to decreases in exhaust gas temperature. Nano particles lead to improved combustion, and higher engine thermal efficiency which results in a reduction in the enthalpy loss in the exhaust. Jatropha biodiesel (B20C25) at 75% of engine load allowed a significant decrease in exhaust temperature by up to 30% as compared to diesel fuel.

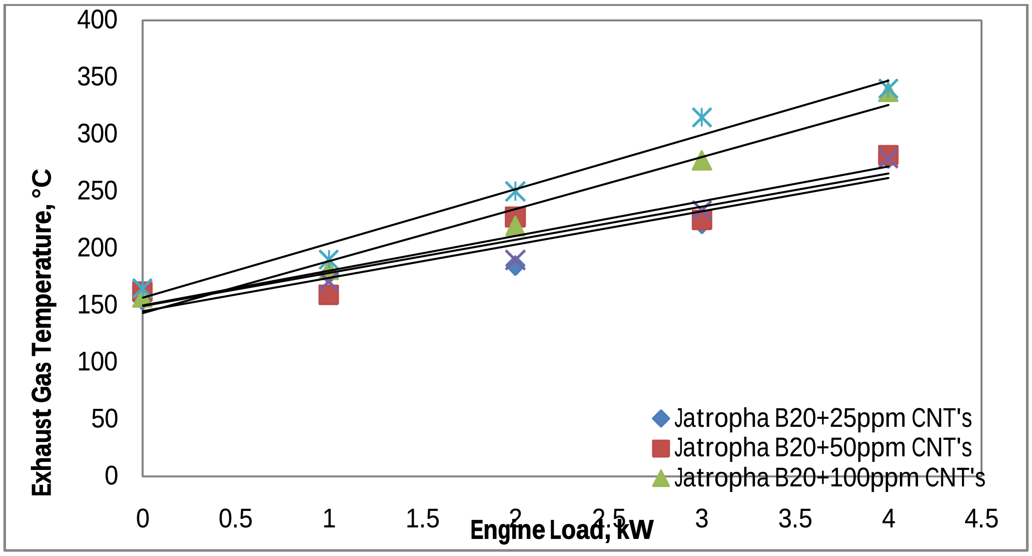

Fig.5: Variation of exhaust gas temperature with engine load.

3) *Air-Fuel Ratio:* Effect of air-fuel ratio on engine load for diesel (D100), jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100) are noted in Figure 6. Air-fuel ratio decreases for all tested fuels due to the increase of fuel consumption. Air-fuel ratio is estimated on mass basis. The addition of nanoparticleis followed by increase of air-fuel ratio due to the decrease in fuel consumption over pure diesel oil. Air-fuel ratios for all blends with additives are higher than for neat diesel due to decrease in fuel consumption and increase of output power. Biodiesel blend (B20C50) showed an increase in air-fuel ratio by up to 23% at 25% of engine load compared to diesel oil.

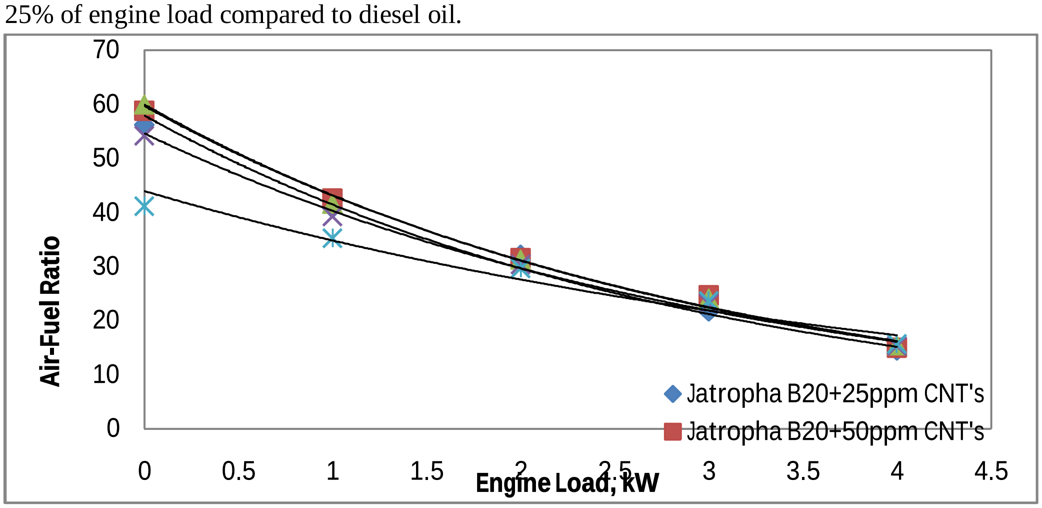

Fig.6: Variation of air-fuel ratio with engine load.

B. Comparison of diesel engine performance fuelled with Jatropha biodiesel blended with CNT

Table 3 indicates comparison of diesel engine performance when we use jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100)at 75% of engine load compared to diesel oil. Specific fuel consumption for jatropha biodiesel (B20C25) and

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(B20C100) decreased by about 5.71 and 3.63%, respectively compared to diesel oil, and increased for jatropha (B20) and(B20C25) by about 0.11 and 7.34%, respectively compared to conventional diesel oil. Thermal efficiency for jatropha biodiesel (B20),(B20C50) and (B20C100) increased by up to 6.75, 13.34 and 10.89% compared to diesel fuel, however for (B20C25) biodiesel it is decreased by about 0.44%, respectively compared to diesel oil. Exhaust gas temperature were decreased by about 25.93, 29.63, 28.57 and 11.90%, respectively, for jatropha biodiesel (B20),(B20C25), (B20C50) and (B20C100) when compared to petroleum diesel. Air-fuel ratio for jatropha biodiesel (B20C50) and (B20C100) were increased by up to 6.05 and 3.76% compared to diesel fuel, but for (B20) and (B20C25) decreased by about 0.11 and6.84%, respectively compared to diesel oil. All these depict that jatropha biodiesel (B20C50)nano-blend gives better engine performance.

Table 3: Comparison of engine performance for jatropha biodiesel blended CNT.

No.	Performance	Jatropha (B20)	Jatropha (B20C25)	Jatropha (B20C50)	Jatropha (B20C100)
1	Specific fuel consumption	+0.11%	+7.34%	-5.71%	-3.63%
2	Thermal efficiency	+6.75%	-0.44%	+13.34%	+10.89%
3	Exhaust gas temperature	-25.93%	-29.63%	-28.57%	-11.90%
5	Air-fuel ratio	-0.11%	-6.84%	+6.05%	+3.76%

C. Emission characteristics

1) *Co Emissions:* The variation of carbon monoxide emissions with engine load for diesel (D100), jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100) are indicated in Figure 7. For all tested fuels, there is a decrease in CO emission with the increase in engine load at part load but it returns to increase up at full load. This is due to increase of fuel consumption which leads for rich air-fuel mixture. This is a consequence of incomplete combustion due to inadequate air in the air fuel mixture. Compared with pure diesel fuel, a significant reduction of CO emission throughout the engine load range was observed when biodiesel and its blends were used. CO emission reduction is mainly due to more oxygen content of biodiesel than diesel fuel, which leads to more complete combustion and ensures less CO emission. Nano-additives posses better combustion characteristics and enhanced surface area to volume ratio which results in better oxidation of the fuel mixture and hence enhances the combustion efficiency of the test fuel. In addition, fuel based oxygen accelerated the process of combustion and more complete combustion. Furthermore, CNTs have larger surface contact area that raised the chemical reactivity which consecutively shortened the ignition delay. Due to the shorten ignition delay effect associated with the CNT blended fuels, the degree of fuel-air mixing and uniform burning could be improved in the presence of potential CNT led to complete combustion. Jatropha biodiesel blended CNT (B20C50) produced an abundant decrease in CO emission up to 36.36% at 75% of engine load compared to diesel oil.

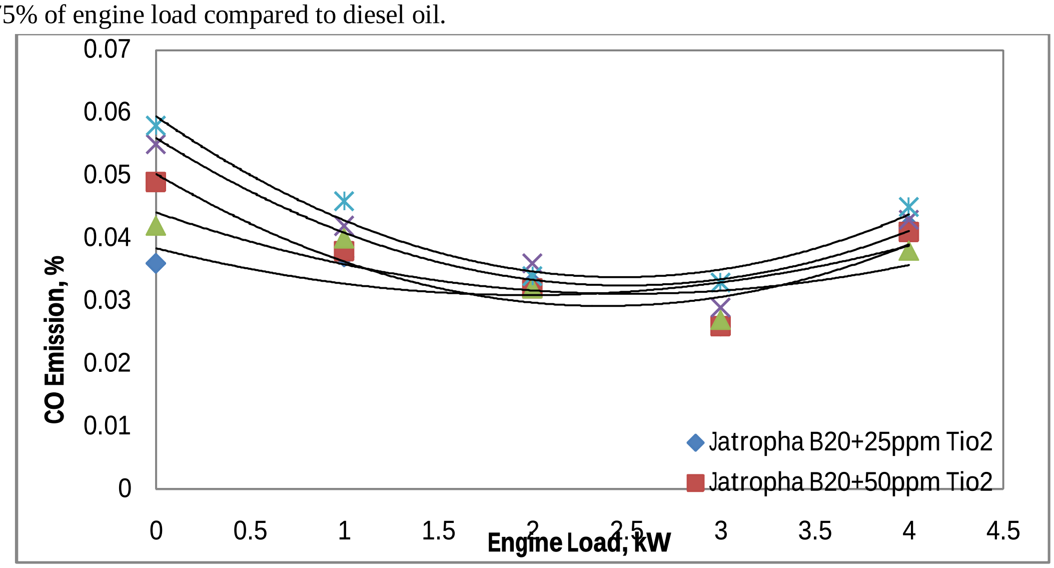

Fig.7: Variation of CO emission with engine load.

2) *Co_2 Emissions:* Effect of CO_2 emissions with engine load for diesel (D100), jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100)are depicted in Figure 8. As the engine load increased, CO_2 emission increased which is due to the higher fuel consumption associated with increase in engine load. Lower CO_2 emissions were noticed for all tested biodiesel blends with CNT nanoparticles about jatropha biodiesel blend B20 and diesel oil. This is because nanoparticle additives contain oxygen and carbon contents which are less in the same fuel volume consumed for the same engine load. This reduction in CO_2 emission is due to higher oxygen content in biodiesel blends with CNT additives than that diesel oil. Burning of jatropha biodiesel blended CNT (B20C50)brought down CO_2 emission significantly up to 26.65% at 75% of engine load compared to diesel oil.

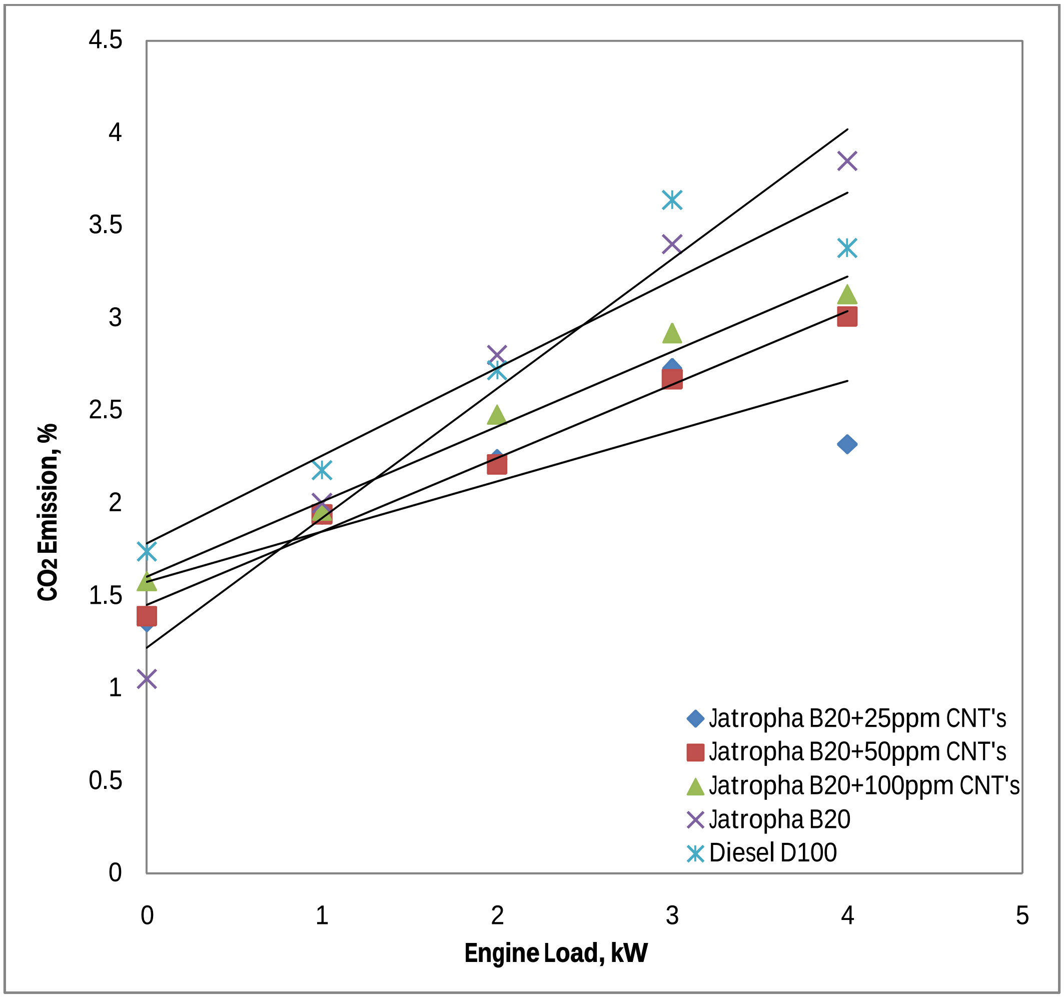

Fig. 8: Variation of CO_2 emissions with engine load.

3) *No_x Emissions:* Figure 9 presents the effect of engine load on NO_x emissions for diesel (D100), jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100). NO_x emissions for all tested fuels are greater than that for diesel oil. NO_x emissions increased with increase in engine load due to the higher cylinder temperature and higher adiabatic flame temperature. Formation of NO_x is favored by higher combustion cylinder temperatures, availability of oxygen, and lower ignition delay. Combustion of biodiesel in diesel engines produces more NO_xemission because it contains oxygen in its composition. When sufficient oxygen is present in the fuel, complete combustion takes places which results higher cylinder temperature. Thermal $NO_x$is mainly the cause of this due to the presence of the fuel bound oxygen and higher NO_x emission. NOxemission is higher when nano particles concentration increases. The concentration of nano particles in biodiesel blends increased, NOx emission increased. The lower air entrainment and air fuel mixing rates in case ofnano biodiesel blends may result in low peak cylinder temperature and NO_x values compared to diesel oil. Jatropha biodiesel blended CNT (B20C25) oil accomplished a significant decrease in NO_x emissionup to 62.34% at 75%of engine load compared to diesel oil.

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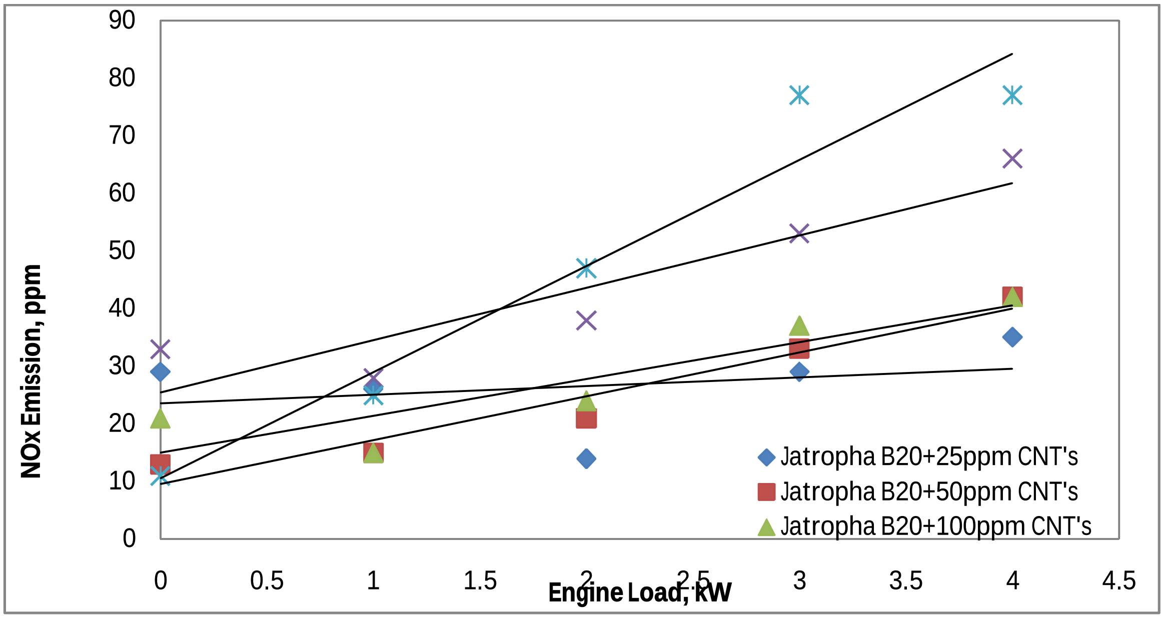

Fig.9: Variation of NOx emission with engine load.

4) *Hc Emissions:* Figure 10 shows the variation of HC emissions with engine load for diesel (D100), jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100). HC emissions for all tested fuels are lower at part engine load, but increased at higher engine loads. Large fuel particle size, injection timing, and nozzle choking also increase combustion timing. This is related to the relatively less oxygen available when more fuel is burned at higher engine loads. The shorter ignition delay associated with fuels of higher cetane number could also reduce the over mixed fuel which is the primary source of unburned hydrocarbons. HC emissions of jatropha biodiesel blends (B20C50) and (B20C100) are higher than diesel fuel, but with decreasing the concentration of nano-particles, HC emissions decrease. Higher viscosity and poor volatility of jatropha oil result in poor air-fuel mixing and more hydrocarbon emissions. Adding lower concentration of nano-additives to jatropha biodiesel (B20) led to improving vaporization, increase of fuel air mixing rates and complete combustion which all result in lower hydrocarbon emissions. The existence of chemically bound oxygenin biodiesel enhances the combustion rate, shortens the combustion duration period which results in reduction of HC emissions. HC emission of most jatropha biodiesel nanoblended at a large range of engine load is the same as for diesel oil.

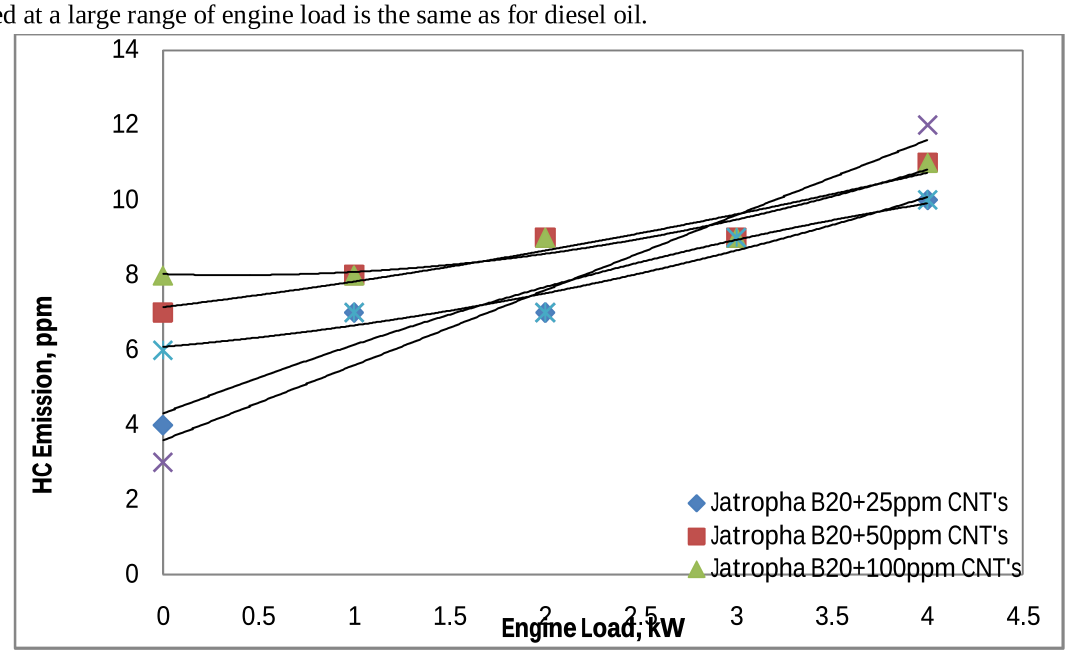

Fig.10: Variation of HC emission with engine load.

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5) *Smoke Opacity:* The variation of smoke emissions with engine load for diesel (D100), jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100) are shown in Figure 11. For all tested fuels, there is an increase of smoke emission with increase of engine load. This is due to the increase in fuel consumption which heads to rich air-fuel mixture. The decrease in smoke density emissions for Jatropha (B20) and Jatropha with CNT nano-additives at engine load is due to the existence of more oxygen molecules and lower carbon content in the fuel as compared to that of diesel oil which lead to better combustion. Jatropha biodiesel blended CNT (B20C100) decreased smoke emission abundantly by up to 50.7% at 75% of engine load compared to diesel oil.

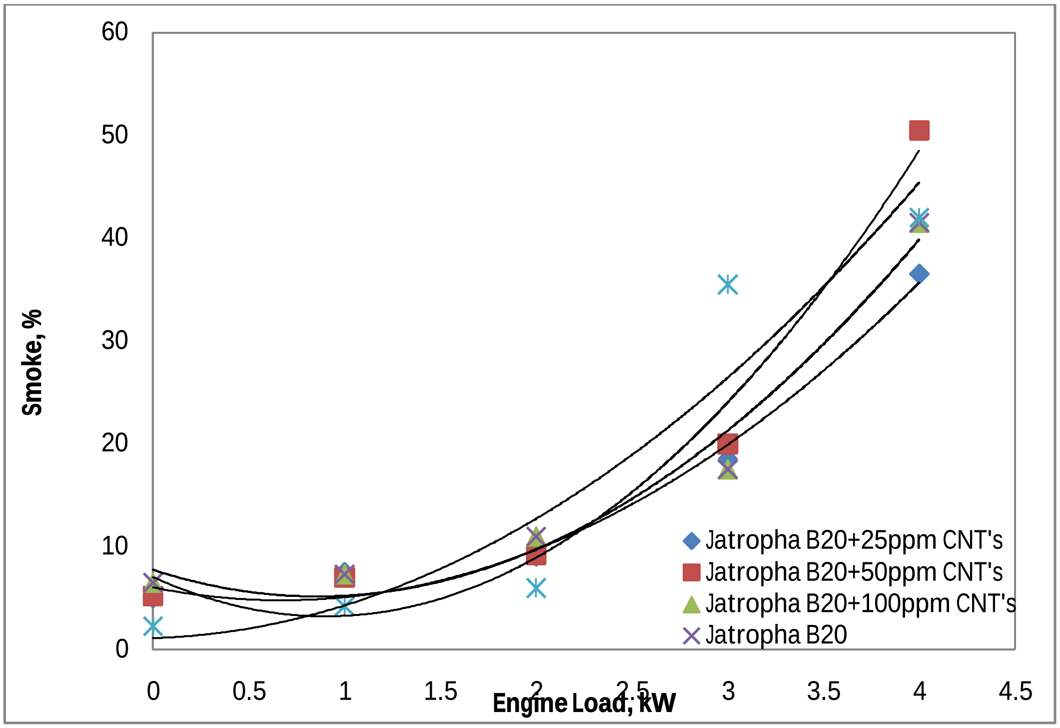

Fig.11: Variation of smoke emission with engine load.

D. Comparison Of Diesel Engine Emissions Fuelled With Jatropha Biodiesel Blended With Cnt

Table 4 presents comparison of diesel engine exhaust emissions fuelled diesel (D100), jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100) at 75% of engine load compared with diesel oil. CO emissions were reduced up to 12, 30, 36 and 30% for jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100), respectively compared to diesel oil. CO_2 emissions were decreased to 6, 25, 26 and 19% for jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100), respectively compared to diesel oil.NO_x emissions were decreased up to 31, 62, 57and 19% for jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100), respectively compared to diesel oil. HC emission for jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100) is the same as for diesel oil. Smokeemissions decreased to 50, 47, 43 and 50% jatropha biodiesel (B20), (B20C25), (B20C50) and (B20C100), respectively compared to diesel oil. Engine exhaust emissions were less for jatropha biodiesel blend CNT (B20C50) about all fuels.

Table 4: Comparison of engine emissions for jatropha biodiesel blended CNT.

No.	Emissions	Jatropha (B20)	Jatropha (B20C25)	Jatropha (B20C50)	Jatropha (B20C100)
1	CO	-12.12%	-30.30%	-36.36%	-30.30%
2	CO_2	-6.59%	-25%	-26.65%	-19.78%
3	NO_x	-31.17%	-62.34%	-57.14%	-19.15%
4	HC	0%	0%	0%	0%
5	Smoke	-50.70%	-47.89%	-43.66%	-50.70%

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IV. CONCLUSIONS

Performance and exhaust emissions characteristics of jatropha-CNTs nano-blended fuels were investigated in a single cylinder, constant speed, and direct-injection diesel engine. The present experimental data concludes the following:

A. Engine tests with the modified biodiesel with CNTs at different dosing levels of 25, 50 and 100 ppm showed that brake thermal efficiency was relatively better as compared to that of jatropha biodiesel fuel and neat diesel fuel at optimized operating conditions and the brake thermal efficiency recording maximum rise of 13% for (B20C50).
B. Brake specific fuel consumption decreased up to 5% for all tested fuels compared to diesel fuel and this affecting the air-fuel ratio by increased up to 6%, but the brake specific fuel consumption increased for jatropha (B20) and (B2025).
C. Exhaust gas temperature decreased for all tested nano blended jatropha biofuel compared to neat diesel.
D. Exhaust emission levels of CO, CO2 and NOx are appreciably reduced with the addition of CNTs. It is understood that CNTs being thermally stable promotes the formation of carbon and reduction of nitrogen oxide, thus acting as an effective catalyst, when added in the nano particle form. HC emission of most jatropha biodiesel nano blended at a large range of engine load is the same as for diesel oil.
E. The smoke density of diesel was decreased on addition of carbon nano-tubes by about 47-50%, especially at medium load due to higher catalytic activity, higher surface to volume ratio and enhancing fuel air mixing in the combustion chamber.
F. Carbon nanotube additive to jatropha biodiesel blended fuel is efficient in improving performance and reducing the exhaust harmful pollutants from diesel engine. A dosing level of carbon nano-tubes in the range of 50 ppm is recommended to achieve the best engine performance with optimal emissions reductions and combustion characteristics, particularly to remove the disadvantages related to use of biodiesel blends about diesel fuel.

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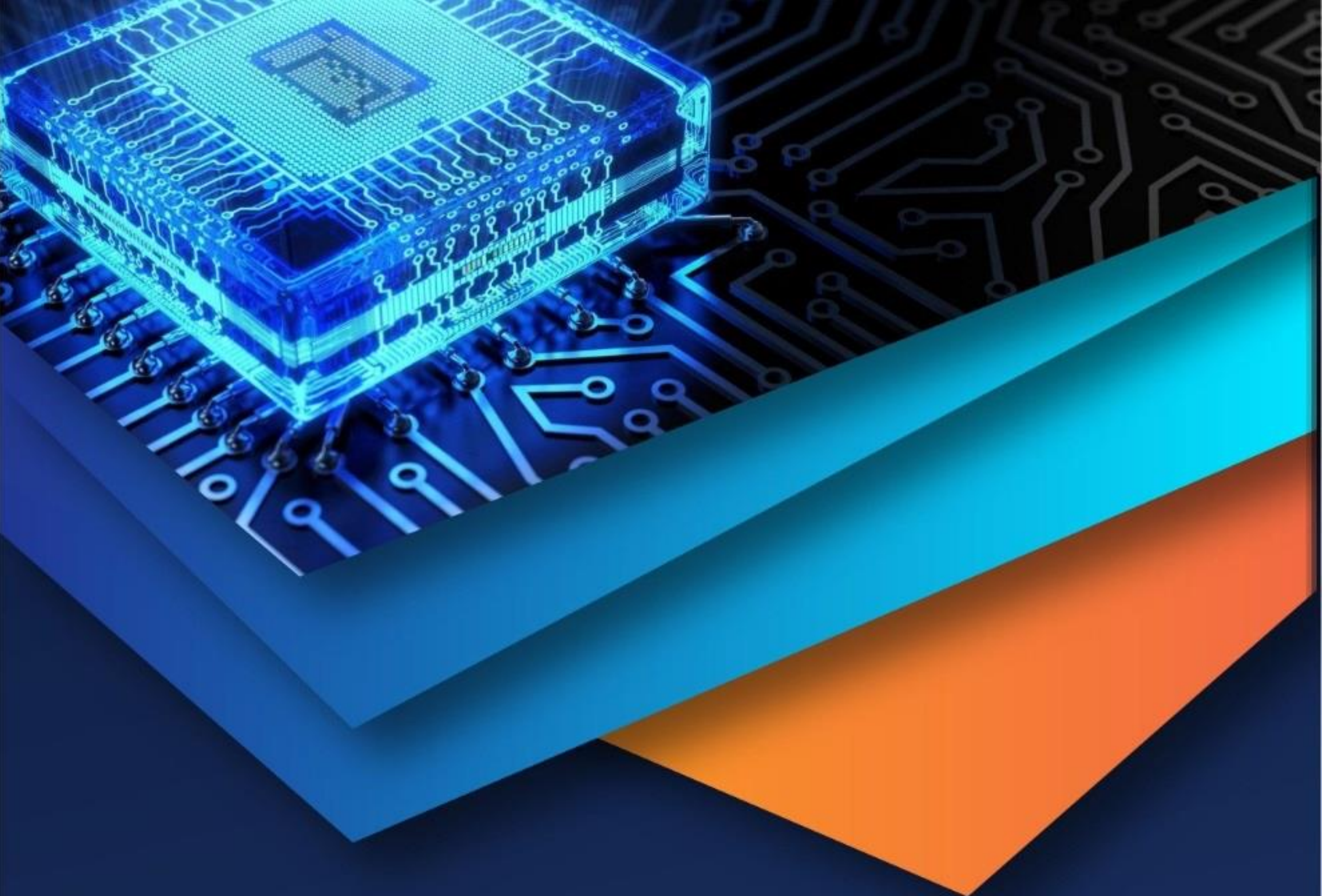

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