INVESTIGATION OF WASTE COOKING OIL-DIESEL BLEND WITH COPPER OXIDE ADDITIVES AS FUEL FOR DIESEL ENGINE UNDER VARIATIONS IN FUEL INJECTION PRESSURE

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ABSTRACT

Fuel Injection is a significant factor when biodiesel-diesel blends are fired in diesel engines as they have very diverse property when related to diesel. The current work describes unusual experimental study of CI engine fuelled with Waste cooking methyl ester with copper oxide nano additives at varying fuel injection pressures. The Copper oxide nano additives were manufactured using homogenous addition method and were subjected to studies such as XRD and SEM characterization. These synthesized nanoparticles were later added in waste cooking oil biodiesel blend (WCO20) with levels of 10 ppm, 20 ppm, 30 ppm, and 40ppm. The results were noted from a DI-CI VCR engine coupled with an eddy current dynamometer. The addition of CuO particles reduces the ignition delay of WCO20 and raises the thermal efficiency of the engine by an average of 3.9% and limits HC emission by 15.6%.

KEYWORDS

Diesel engine, Performance and emission, NOx emission, nano fuel additives

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1. INTRODUCTION

The frequent rise in fuel prices leads to higher inflation rates which create a hard time for the common man to face day-to-day economic challenges [1, 2]. The primary fuel for the transportation sector is diesel and with a high number of diesel engines running today, researchers have been tasked to find alternate fuel for CI engines [3, 4]. Diesel engines when patented, used peanut oil and with their strategy of fuel combustion being compression ignition, thereby denser fuels can be used [5, 6]. Vegetable oils when fuelled in diesel engines in cold environments tend to clog fuel supply due to their clouding effect at lower temperatures [7, 8]. So the usage of straight oils as an alternate fuel is out of the question and hence oils need to be processed to reduce their density and viscosity such that they can be more suitable for diesel engines [9, 10]. Oils when transesterified lead to ester formation and when these esters possess properties proportional when equated to diesel fuel. But still, when the properties of pure esters are compared to conventional diesel fuel they factor out the possibility to be used as an alternative fuel to diesel engines [11, 12]. To address this issue, Esterified oils or Biodiesel are blended with diesel fuel and by doing so, the properties of the Esterified oil-diesel blend have in-line fuel properties [13, 14]. When these blends are combusted in regular diesel engines, the thermal performance is good and emissions like CO and HC are limited [15, 16, 1-3]. But the real problem which restricts the use of Blended Diesel-Oil esters is the fuel consumption rate and levels of NOx [17, 18]. Researchers performed experimentation under varying blends 10, 20 and 30% volumetric concentration with diesel and loading 25%, 50%, 75%, and 100% [19, 20]. They concluded biodiesel lowered the efficiency and enhanced the consumption at all loads. Also, the blends derived from Sterculia foetida biodiesel lowered the HC, CO, and NOx emissions at all loads when related to diesel. Yuvarajan Devarajan [30] performed experimental studies on diesel engine fueled with Ricebrain oil esterified for evaluation of emission and performance physiognomies Experimentations revealed that blends of rice bran biodiesel augmented the thermal efficiency and plummeted the BSFC values of the engine [21-23]. Furthermore, the NOx, Smoke, HC, and CO also recorded a decent fall. Shanmugam et.al [29] conducted experimentation using 1-decanol blend designated as D70L20DEC10 under variational influence of CR (16:1, 17.5:1, and 19:1) and EGR (0%, 10%, and 20%) on diesel engine characteristics. They found that the NOx emission rose with rising CR and condensed with growing EGR rates. Both HC and CO emissions dropped with higher CR values and were augmented with the insertion of EGR. They concluded the CR 19:1 and 10% EGR rate were the best operating CI engine parameters for the ternary blend. Esterified oils or Biodiesel have low calorific value due to which, the combustion of fuel is better but the amount of fuel consumed per power unit is higher [24-27]. Researchers have tried to address this issue by varying the fuel injection pressure and timing of fuel inlet into the combustion chamber [28-30]. Lower Biodiesel-diesel blends have slightly higher density and viscosity due to which the fuel management systems [8-10], have to be changed for better combustion of these denser blends [31]. Increasing the fuel inlet pressure does push the fuel further in the compressed air and thereby enhancing the fuel-air mixing process [31, 32]. But by doing so, the fuel pump and injector need to be changed

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[31-35]. Also, denser fuels when injected at higher pressure show higher fuel combustion pockets thereby exhibiting, a higher amount of uncontrolled combustion activity [16, 17]. In recent years, a lot of work is done to challenge this malfunction and one of the ways seems to be the use of nano metal oxides [13-15]. Nano metal oxides have a higher surface area than volume ratio, which tends to absorb the heat of combustion and retard the ignition delay of fuel [12]. Nano fuel additives also increase the amount of fuel combustion activity and also help in the reduction of soot formation. In addition to this, many Nano metal oxide additives also retard the formation of CO and HC emissions which signify cleaner fuel burning [19]. In the current paper, a blend of used cooking oil esters-diesel with copper oxide nano fuel additives is used to power diesel engines with variations in fuel injection pressure. The reason behind using waste cooking is to reduce the amount of wastage of used cooking oil and also the literature on enhancing the emission reduction using WCO and nanoadditives is minimal.

1.1. NOVELTY OF CURRENT STUDY

The paper concentrates on the impact of variation of fuel injection pressure (FIP), as an engine parameter and gradational dosing level of copper oxide nanoparticles WCO20 blend. WCO20 blend was chosen because the current biofuel policy framed by Government of India is the implementation of 20% biodiesel blending in diesel fuel. Also, the properties observed by the 20% blend of WCO and Diesel were in line with diesel fuel. The entire study is performed in 2 stages. In the primary stage, Copper oxide nanoparticles were synthesized using the homogenous addition method and subjected to nanoparticle studies such as XRD, and SEM for significance and morphological study. Collaterally used cooking oil is transesterified using KOH and methanol. And Finally, the synthesized Copper oxide particles are added to the WCO20 blend (80%vol.:20 %vol. diesel-waste / used cooking oil methyl ester) at various dosing levels of 10, 20, 30, and 40ppm to obtain nano fuel blends of WCO20+10ppm CuO, WCO20+20ppm CuO, WCO20+30 CuO, and WCO20+40ppm CuO. These derived four fuel blends were fuelled in a VCR-CI engine with variations in load (25%, 20% 75%, and 100%) and fuel injection pressure variations (180bar, 210Bar, and 240Bar).

2. EXPERIMENTAL PROCEDURES

2.1. NANOPARTICLE BLENDS

Copper Oxide particles were synthesized using a homogenous addition method, where 2.01 gms of potassium hydroxide and 2.87 g of Cuprous Chloride (CuCl2) were taken and mixed in deionized water (solvent). Later, this mixture was filtered filter separation process. The strained matrix was dried and sintered further with a sintering temperature of 600 deg (Celsius scale). The sintered particles were subjected to various characterization techniques to signify the formation of Copper Oxide. X-ray

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diffraction was observed on the particles (Figure 1). The observations were noted on the peaks observed in fig.1 which resemble JCPDS No 48-1548. Table 1 provides the necessary data obtained from the XRD spectra analysis. The FESEM imaging of the particles explains the flake type morphology. Figure 2 shows the FESEM images of CuO particles. The average particle size observed under 500nm magnification was around 289 nm.

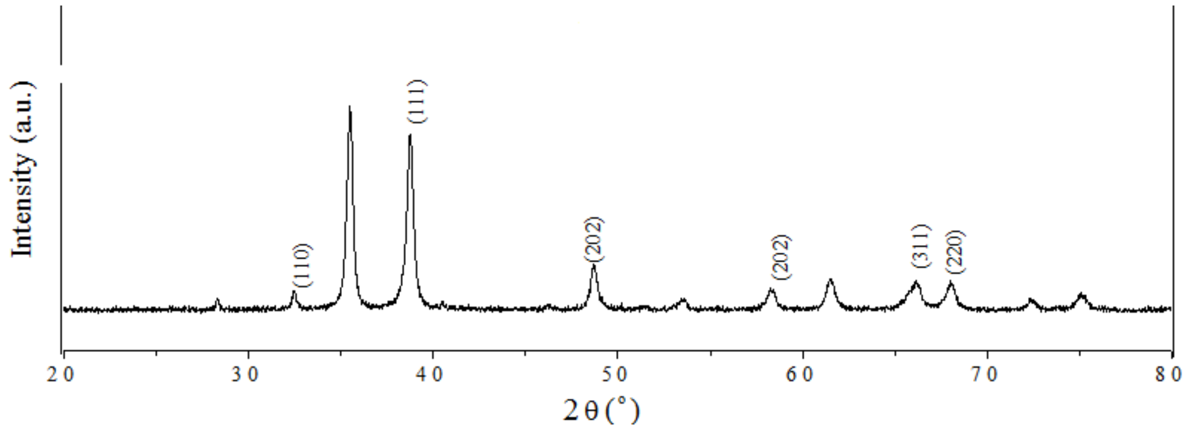

Figure 1. X-ray diffraction of CuO nanoparticles.

Table 1. Characterization of copper oxide nano additives.

Parameters	Size
Lattice constant (c)	4.259
% phase	5.41
Crystalline size	89.35
Theoretical density	37.36 nm
Axial ratio (C/A)	5.95e5 g/cm3
Average particle size	305.59 nm

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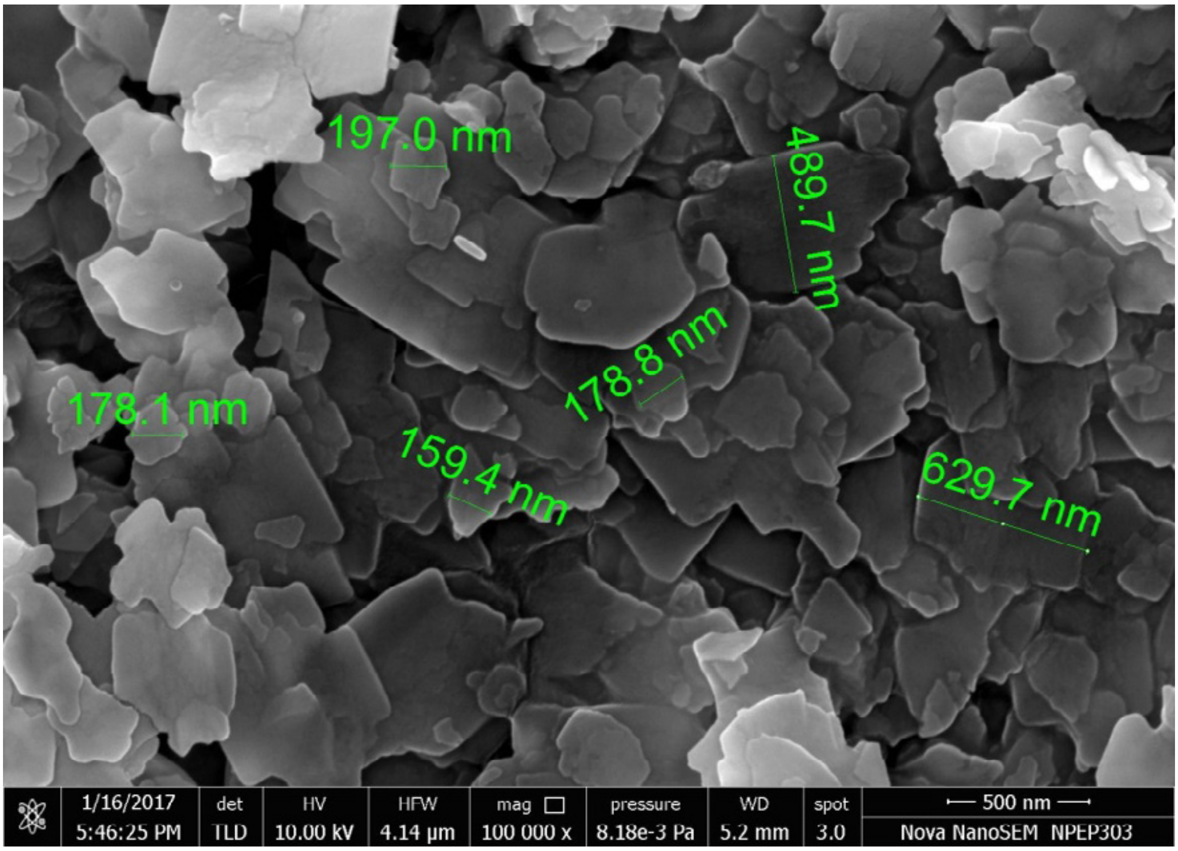

Figure 2. FESEM of CuO nanoparticles.

2.2. BIODIESEL PREPARATION

Used cooking oil was obtained from the local restaurants that used refined rice bran oil for cooking or frying food items. This oil was first sieved for removal of impurities and later transesterified using a known volume of methanol and KOH as reaction catalysts using the soxhlet apparatus [28]. The time for the transesterification reaction was kept at 2hrs and the reaction temperature was maintained at 65 deg. Celsius. Later the obtained esterified mixture was subjected to gravity separation, where the bioester was separated. These derived esters were later washed several times to remove traces of methanol and KOH. The washed used cooking oil methyl esters were later blended with diesel to volumetric proportions of 20%vol. Methyl esters: 80 % vol. Diesel.

2.3. PREPARATION OF TEST FUELS

Four solutions (150 ml) of Isopropyl alcohol were taken and copper Oxide nanoparticles particles were dissolved at various concentration levels of 10, 20, 30, and 40ppm. Later these four nano fuel solutions were added to the Used Cooking oil methyl ester blend WCO20. Later this biodiesel having CuO nano fuel were subjected to ultra sonication at preset rpm. Further, diestrol surfactant was added to bring up better mixing through surface modification. So a total of 04 Biodiesel test fuels were prepared and designated as WCO20+10ppm CuO, WCO20+20ppm CuO,

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WCO20+30 CuO, and WCO20+40ppm CuO. The properties of solutions are tabulated in Table 2.

Table 2. Thermo physical properties of test fuels.

Property	Standard	WCO20	WCO20+10 ppm	WCO20+20 ppm	WCO20+30 ppm	WCO20+40 ppm	Diesel
Density, kg/m3	IS 1448 P:16	844	847	851	855	859	825
Calorific value, MJ/kg	IS 1448 P:6	40.52	40.66	40.69	40.72	40.67	42.62
Kinematic Viscosity at 40 0C	IS 1448 P:25	4.25	4.23	4.21	4.15	4.14	2.83
Flash point, 0C	IS 1448 P:20	91	96	95	96	96	69
Cloud point, 0C	IS 1448 P:10	8.9	9.1	9.2	9.2	9.2	6.2
Pour point, 0C	IS 1448 P:10	4.5	4.6	4.6	4.7	4.7	3.4
Cetane index	Calculative Method	51	-	-	-	-	42

3. EXPERIMENTAL SETUP

The experimentation of 04-derived WCO20 blends having CuO particles was tested on a Direct Fuel Injection-VCR test rig. The engine was governor controlled for a preset speed of 1500rpm and the specifications of the engine are tabulated in Table 03. Figure 3 elaborates the line sketch of the test setup. The observation relating to thermal performance and emissions were noted at CR17.5 and injection timing of 23 deg. bTDC. The engine was warmed by using diesel as starting fuel and later changed for the remaining fuels. Also, the engine was allowed to run until stabilization. The readings were noted at incremental loads of 25%, 50%, 75%, and full engine load and at pulsating fuel injection pressures of 180bar, 210bar, and 240 bar pressures. The variation of Injection pressures was done by using calibrated injectors of defined fuel injection pressures of 180bar, 210bar, and 240bar. The specification of the fuel injectors is tabulated in table 04. Uncertainty analysis was performed using all the values of instruments and emission responses. The Overall error of the amount of uncertainty was around ±2.29%. Table 05 displays all the instrument's range and accuracy and level of vagueness.

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Table 3. Engine Specifications.

Manufacture	Kirloskar Oil.
SFC	251 g/kWhr.
Rated power	5.4 kW at 1500 RPM
Standard CR	17.5:1
Bore	87.5 mm
Stroke	110 mm
Injection Timing	23 deg before TDC
Inlet valve open bTDC	4.5 deg bTDC
Exhaust valve open	35.5 deg b BDC
Inlet valve close	35.5 deg a BDC
Exhaust valve close	4.5 deg a TDC

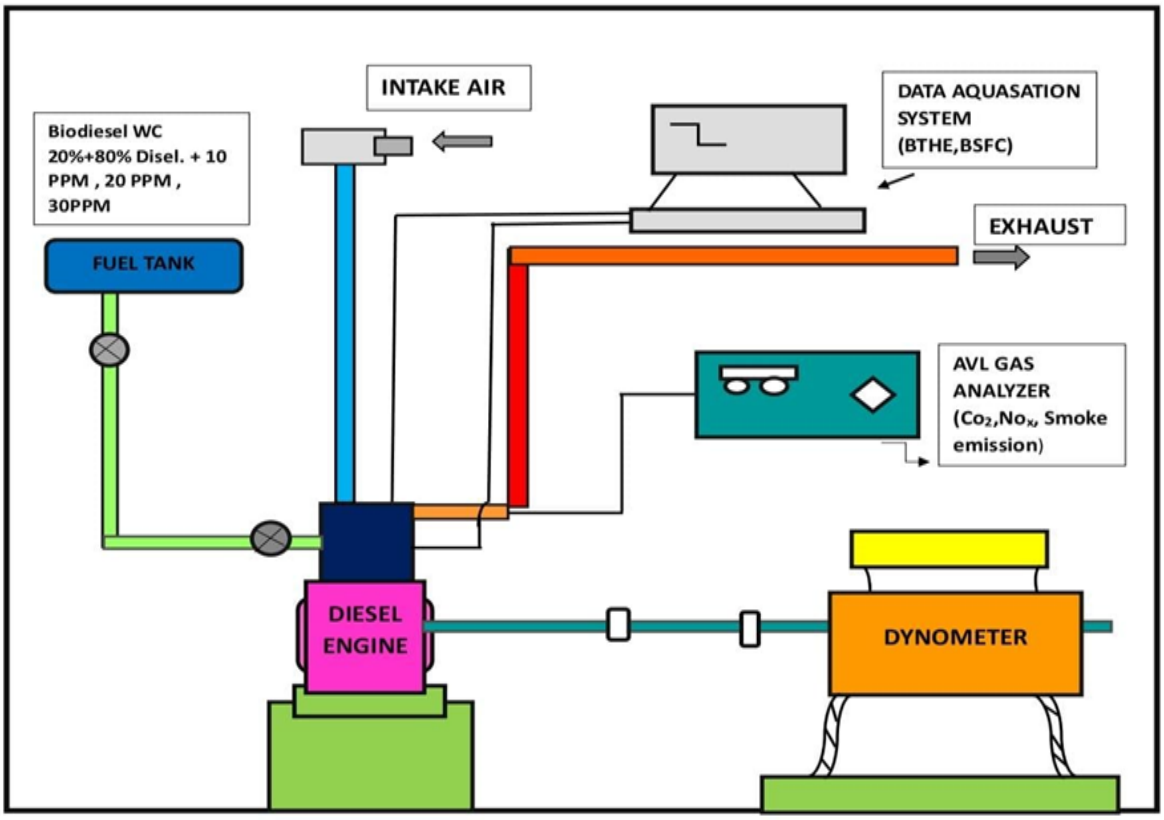

Figure 3. Schematic diagram of experimental engine test setup.

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Table 4. Injector specifications.

Injector Make	Bosch
Fuel Injection pressure	180,210, 240bar
Number of Holes	3
Type of Injection	Jerk type
Nozzle Hole diameter(mm)	0.16

Table 5. Device specifications and terminology.

Device specification	Range	Accuracy	Uncertainties
Carbon monoxides (CO)	0-10.00%	±0.01%	±0.1
Carbon Dioxides (CO2)	0-20.00%	±0.01%	±0.15
Oxides of Nitrogen (NOx)	0-5000 ppm	±1 ppm	±0.2
Oxygen (O2)	0-25.00%	±0.01%	±0.1
Hydrocarbons (HC)	1-1500 ppm	±1 ppm	±0.2
Exhaust gas temp. (EGT)	0-5000C	±10C	±0.1
Tachometer	0-10000 rpm	±10 rpm	±0.2
Fuel flow meter	1-30 cc	±0.1 cc	±0.5

4. RESULTS AND DISCUSSION

The results of the engine are categorized into two stages. In the first stage, the performance results of the engine were measured in terms of thermal efficiency, rate of fuel consumption, and the temperature of combusted gases. In the next phase, the emissions studies coming out of the engine are measured by using AVL make gas analyzers and smoke meters. All Performance and emissions responses were noted varying loads with increments of 25% loading and at static Engine Volumetric ratio of 17.5 and Fuel Injection timing of 23 deg. bTDC.

4.1. PERFORMANCE STUDIES

4.1.1. BRAKE THERMAL EFFICIENCY

The derived thermal efficiency of 04 nanoparticle-dosed WCO20 blends, WCO20 blend, and Diesel is portrayed in Figure 4. The observations were noted for 06 fuels in incremental loads of 25%. It could be illustrated from Figure 4 that as the load is incremented the BTHE values also rose. Also, we could so see that the addition of CuO additives does boost the BTHE values. The amount of rise in BTHE for WCO20 with 10ppm, 20ppm, 30ppm, and 40ppm is when compared to base blend (WCO20) and the rise thermal output observed for WCO20+10ppm, WCO20+20ppm,

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WCO20+30ppm, and WCO20+40ppm when compared to diesel was. This was due to the phenomenon of secondary atomization and the micro explosion of Cu-Isopropyl alcohol nano fuel emulsion. These emulsified fuels tend to shorten the ignition delay and there increasing the combustion duration due to which the BTHE values were found high. When Nano additive-alcohol solution is exposed to higher pressure and temperature environment, leads to an explosion of alcohol. Later this explosion or combustion further diminishes the ignition delay of the WCO20 fuel. This catalytic combustion activity is responsible for the enhanced thermal efficiency phenomenon. Furthermore, the initiation of higher fuel inlet pressure does provide better mixing of air/fuel and thereby contributing to retarded fuel ignition delay. Also, we could observe the maximum thermal efficiency was observed for WCO20 having 20ppm of CuO at 240bar. The observations found are in line with [21, 22].

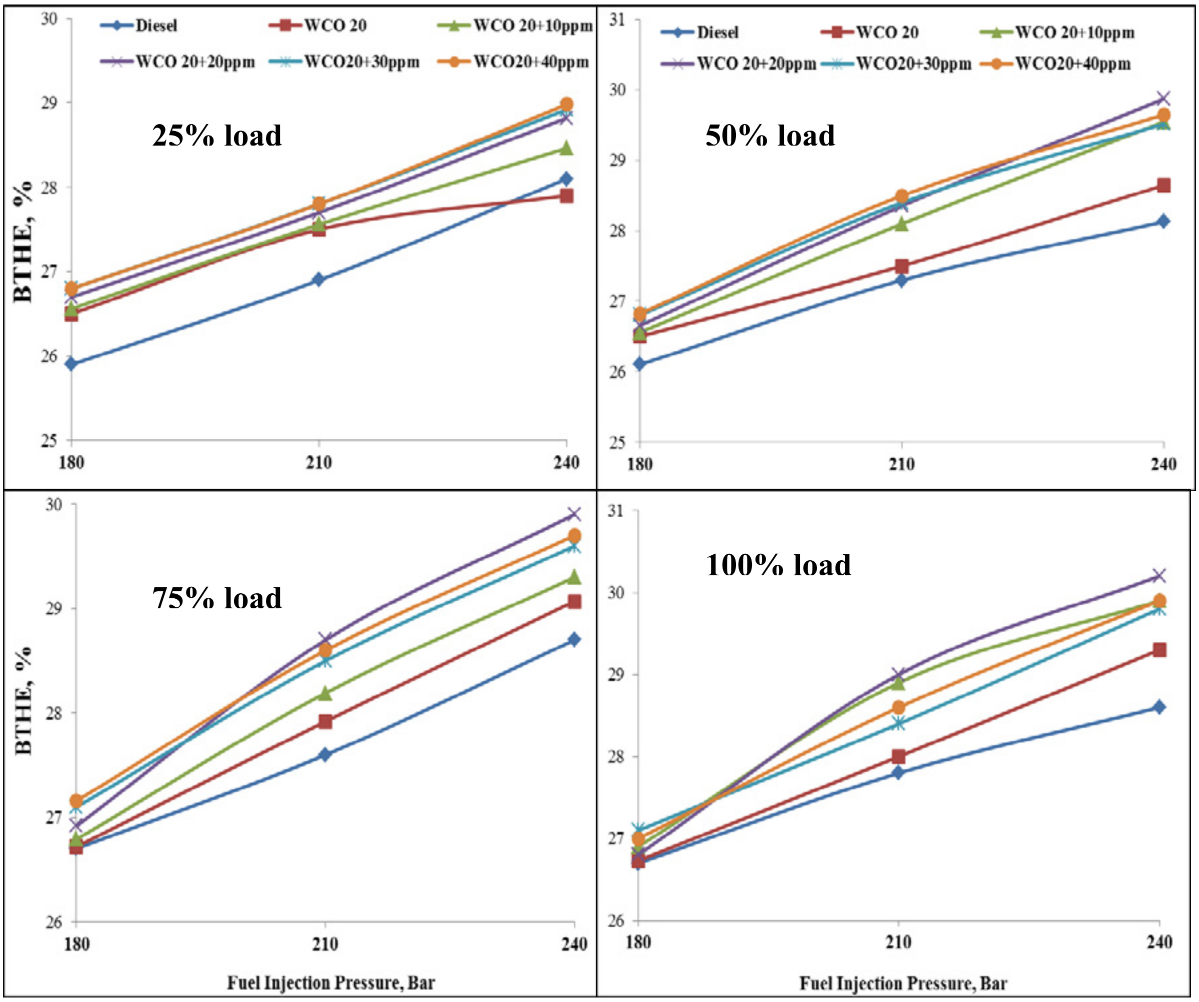

Figure 4. Variation of brake thermal efficiency at varying injection pressures, loads and levels of CuO.

4.1.2. BRAKE SPECIFIC FUEL CONSUMPTION

The main limiting factor why Biodiesel blends are not so extensively used is due to the fuel consumption rates and Figure 5 exhibits the BSFC values for varying FIP(fuel Injection pressure) and load variations. The least BSFC values for loads were shown by diesel and this was due to the higher heating value of diesel which contributes to

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attaining higher HRR values [24]. It could be observed that when Copper oxide was added to WCO20 blends the BSFC values does plummet to a small extent. The percentile decline found when WCO20 with 10ppm, 20ppm, 30ppm, and 40ppm of CuO was doped was 1.6%, 4.2%, 3.3%, and 3.2% respectively when compared to the base blend. The addition of these oxide additives in the WCO 20 blend does retard the fuel ignition delay and thereby time allocation for the total amount of fuel combustion per KW of power is more. However, the values of BSFC of WCO20 with CuO were not promising when compared to diesel. Also, it could be noted that at higher FIP and at full load conditions, the BSFC values were least for all test fuels. Biodiesel which is denser and has a higher flash point does require enhanced fuel injection pressure for them to stream into denser compressed air. The amount of decline of BSFC values when injection pressure was changed from 210bar to 240 bar for WCO 20, WCO+10ppm of CuO, WCO+20ppm of CuO, WCO20+30ppm of CuO, and WCO20+40ppm of CuO was 3.4%, 4.6%, 4.3%, and 4.2% respectively.

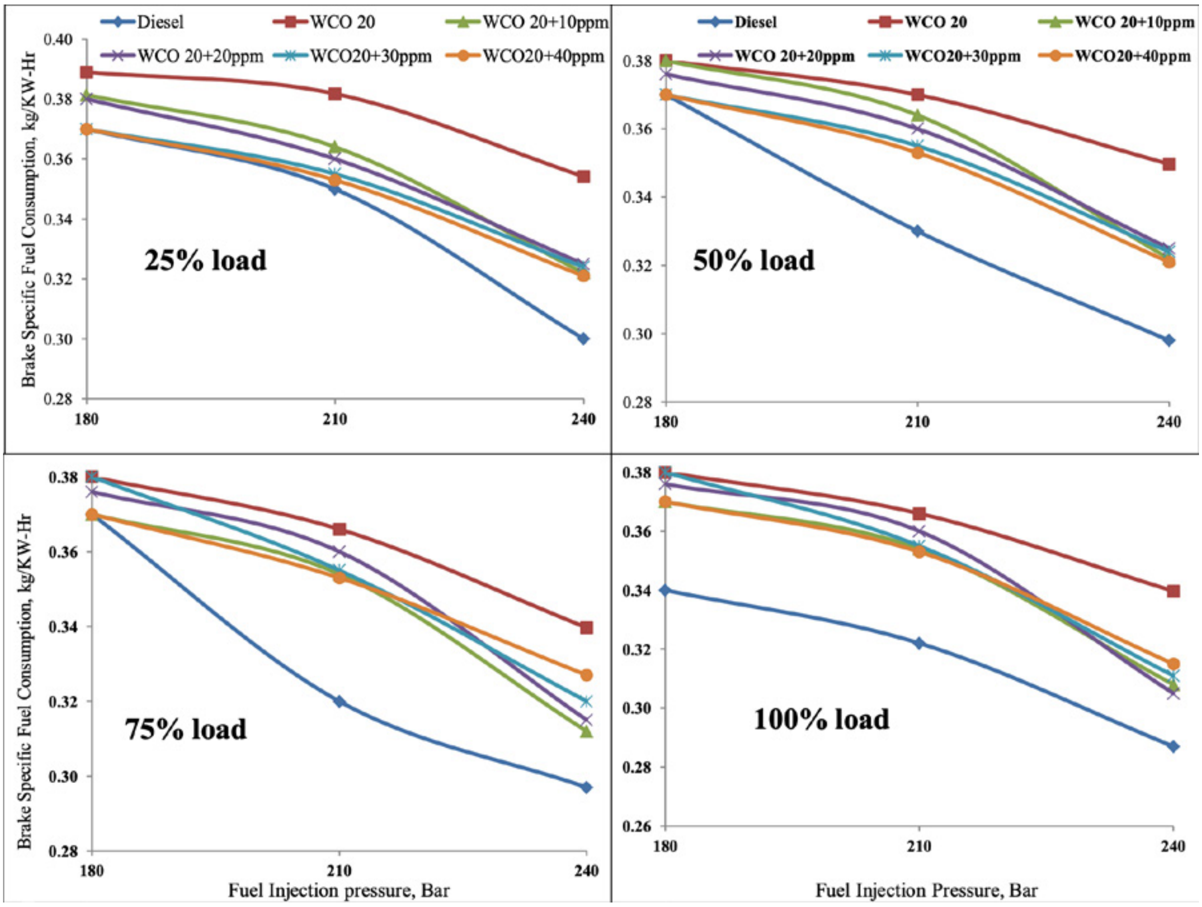

Figure 5. Variation of brake specific fuel consumption at varying injection pressures, loads and levels of CuO.

4.1.3. EXHAUST GAS TEMPERATURES

Exhaust gas temperatures (EGT) of the CI engines play a prominent role in the formation of oxides of nitrogen emissions [18]. Also, higher combustion rates display higher HRR and EGTs. Figure 6 explains the temperatures of exhaust gases formed after combustion at varying Loads and FIP's for all 06 test fuels. WCO20+20ppm displayed Peak EGT values for 240bar pressure and at full load conditions and diesel displayed the least EGTs for all loads and FIP's. The rise in EGT was found when the FIP was changed from 210bar to 240 bar for WCO 20, WCO+10ppm of CuO, WCO+20ppm of CuO, WCO20+30ppm of CuO, and WCO20+40ppm of CuO was 5.6%, 6.2%, 8.3%, 7.8%, and 7.7% respectively when compared to diesel. Also, the EGT ascent percentile at 240bar for WCO+10ppm of CuO, WCO+20ppm of CuO, WCO20+30ppm of CuO, and WCO20+40ppm of CuO was 3.6%, 4.5%, 3.9%, and 3.7% respectively when compared with Base blend WCO20. This might be due to higher injection pressure and good cetane rating of fuel which tend to control the combustion activity and thereby reduce the fuel ignition delay.

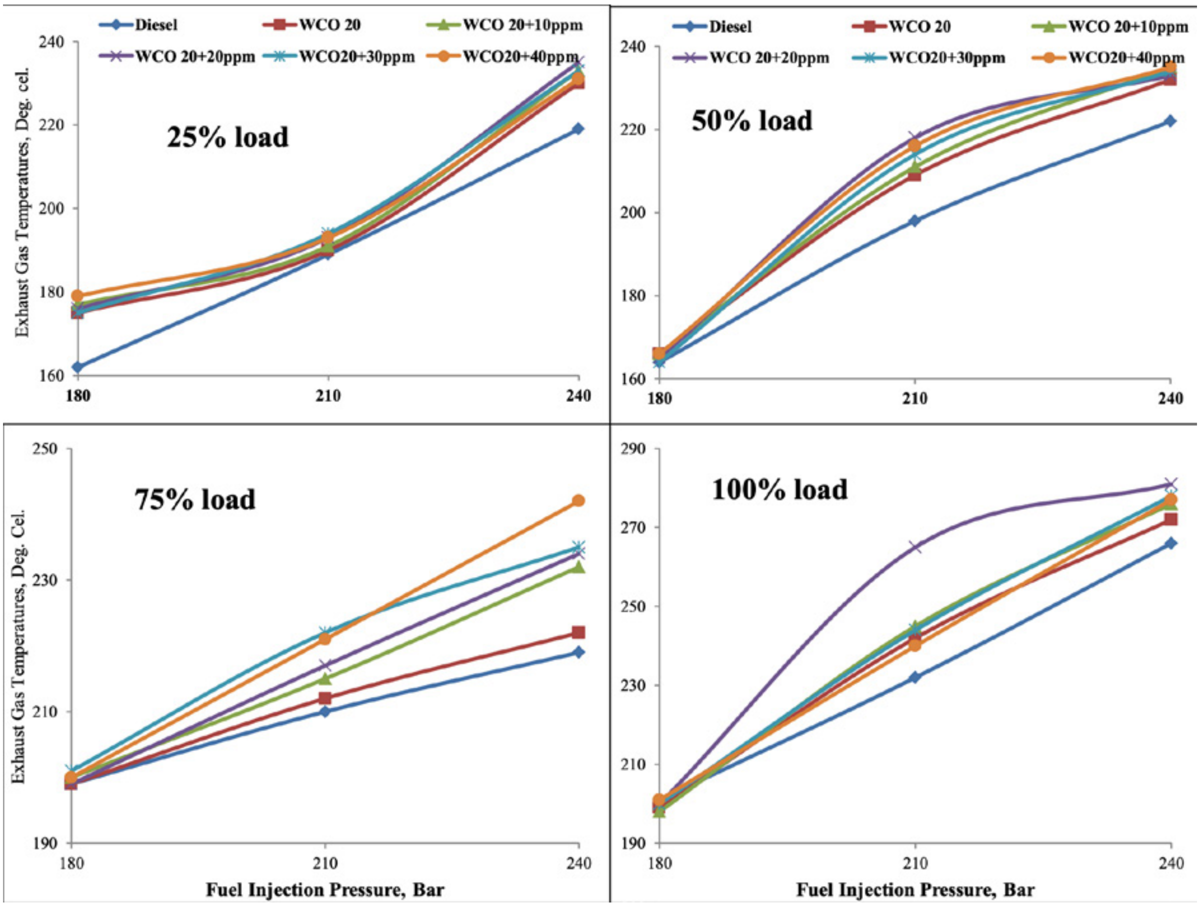

Figure 6. Variation of exhaust gas tempratures at varying injection pressures, loads and levels of CuO.

4.2. EMISSION STUDIES

4.2.1. OXIDES OF CARBON

During the oxidation of fuel, the products do have the presence of carbon dioxide as a result. Furthermore, its conventional wisdom that, the higher the CO2 levels, the better the combustion of fuel [4, 6]. On the other hand, the presence of CO in the exhaust gases of fuel combustion signifies incomplete combustion. It can be observed from Figure 7 and Figure 8 the percentile presence of CO and CO2, respectively, for all 6 fuels incremental load and fuel injection pressure. It could be observed that amount of CO2 increases with increasing load and fuel injection pressure. Diesel

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exhibits the least CO2 levels when compared with WCO20. Also, the presence of CuO in WCO20 shoots up the levels of CO2. The percentile rise in CO2 levels when CuO is added in WCO with adulteration levels of 10ppm, 20ppm, 30ppm, and 40ppm is 2.8%, 4.9%. 4.4% and 3.7% when compared with WCO20. Also, with the enhancement in the Injection pressure from 210bar to 240bar, the rise in CO2 levels found were 2.3%, 3.2%, 3.5%, 7.6%, 6.1%, and 6.2% for Diesel, WCO 20, WCO+10ppm of CuO, WCO+20ppm of CuO, WCO+30ppm of CuO, and WCO+40ppm of CuO respectively. Emulsified esters have good cetane number and the presence of nanoadditives does retard the fuel ignition delay and thereby incrementation combustion duration due to which the formation of dioxides are more than CO.

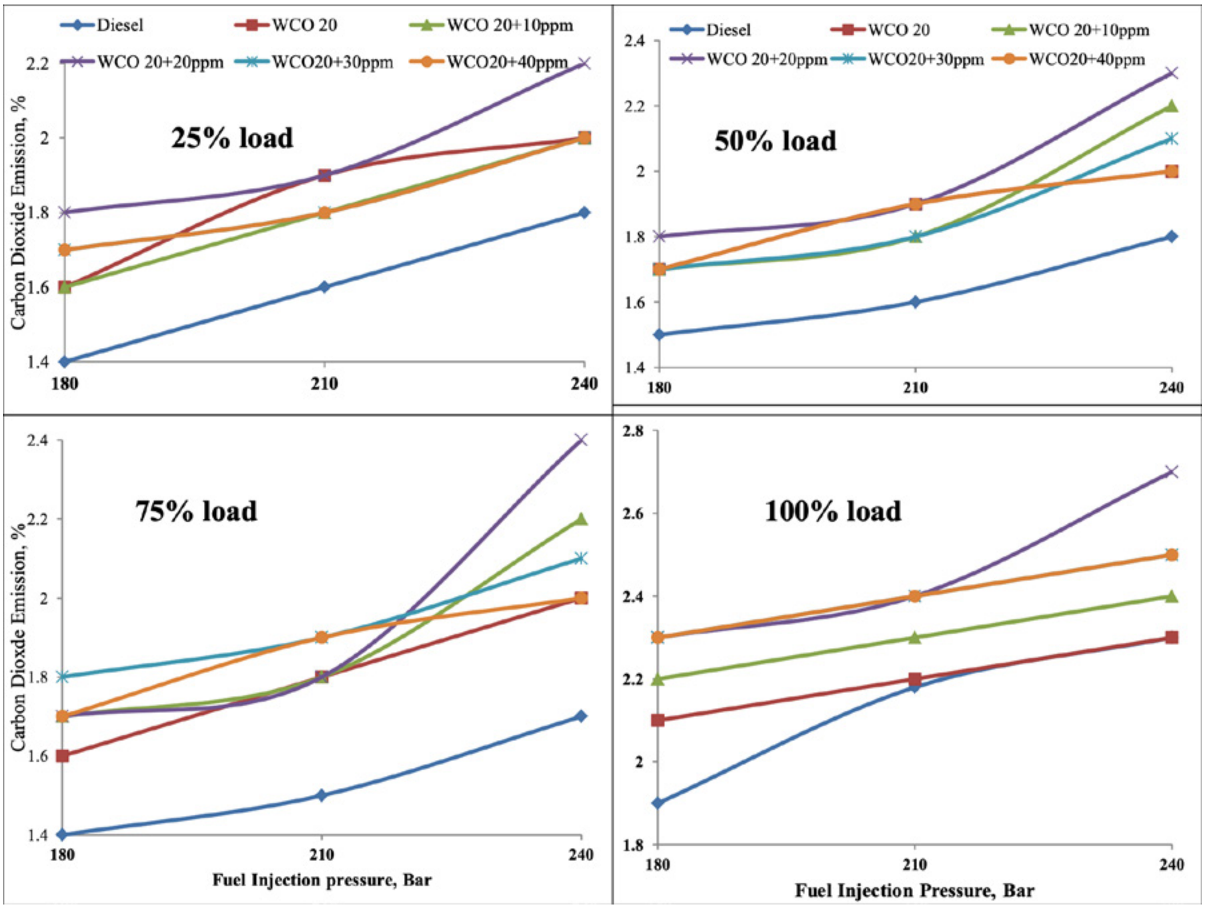

Figure 7. Variation of CO2 emissions at varying injection pressures, loads and levels of CuO.

4.2.2. CARBON MONOXIDE

When the levels of carbon dioxide rise, the levels of CO reduce for test fuels. Figure 8 explains the levels of CO emissions. It could be observed that Diesel fuel combustion provides the highest CO levels when compared to other fuels. The levels of CO declined with a gradual rise in engine loads and fuel injection pressure which are in line with the findings of [7, 11]. Also, the addition of CuO in the base blend further reduces the CO emission. The percentile descent in CO levels when CuO is added in WCO20 with sullying levels of 10ppm, 20ppm, 30ppm, and 40ppm is 1.9%, 3.8%. 3.4% and 3.2% respectively when compared with the base blend. Also, with the enhancement in the Injection pressure from 210bar to 240bar, the rise in CO2 levels

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found were 2.3%, 3.2%, 3.5%, 7.6%, 6.1%, and 6.2% for Diesel, WCO 20, WCO+10ppm of CuO, WCO+20ppm of CuO, WCO+30ppm of CuO and WCO+40ppm of CuO respectively.

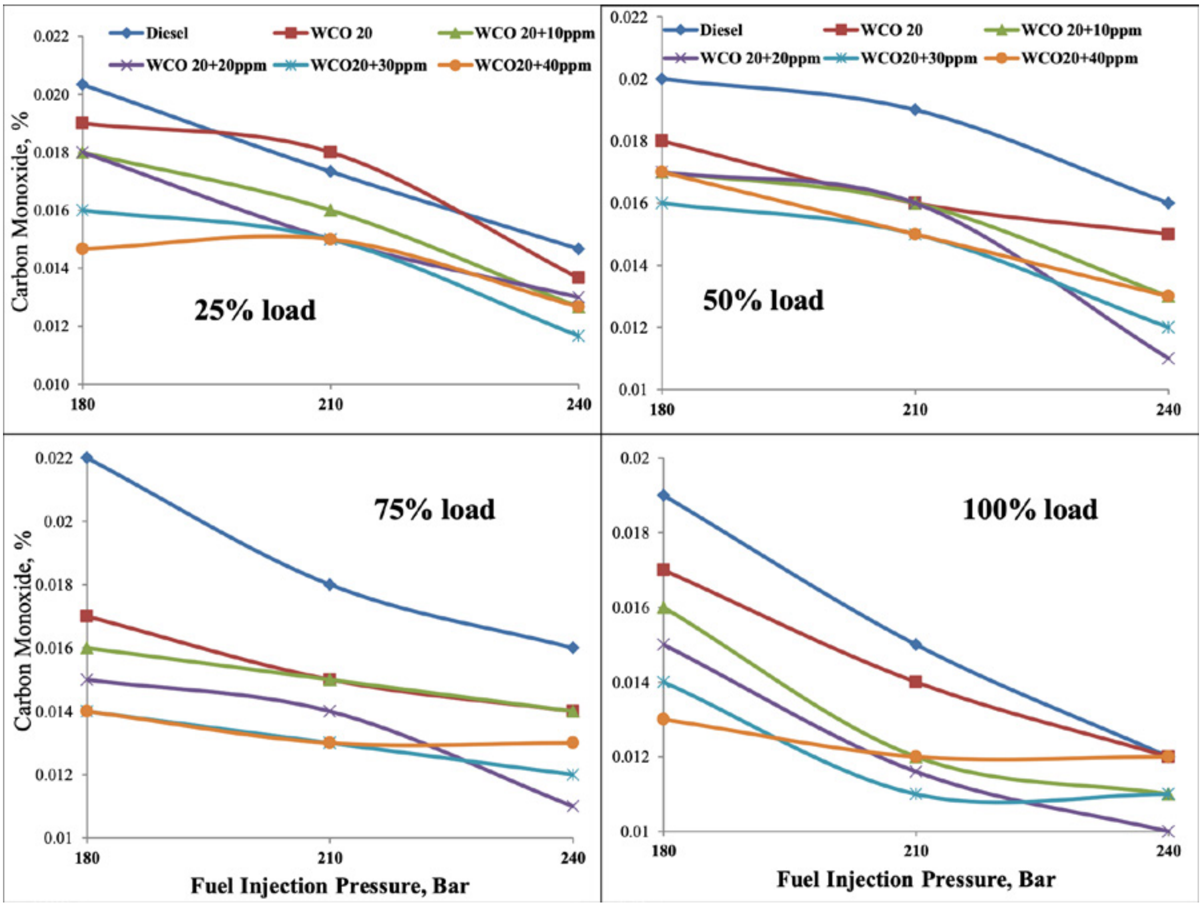

Figure 8. Variation of CO emissions at varying injection pressures, loads and levels of CuO.

4.2.3. HYDROCARBON EMISSION

Hydrocarbon emission is eminent in fuel combustion even though diesel engine operates in Lean air-fuel mixture ratios. Figure 9 shows the obtained ppm levels of HC emission for all test fuels at varying loads and fuel injection pressures. It was observed that with incrementation of engine load and fuel Injection pressure the levels of HC emission reduced. Diesel showed the highest HC emission when compared to the rest test fuels. It could be observed that with a change in fuel injection pressure from 210bar to 240bar, the percentile descent in HC emission for Diesel, WCO 20, WCO+10ppm of CuO, WCO+20ppm of CuO, WCO+30ppm of CuO, and WCO+40ppm of CuO is 5.56%, 11.76%, 12.5%, 20%, 18.75%, and 13.6% respectively. Also the addition of CuO in WCO20, the observed decent in HC emission was 6.67%, 21%, 16.7% and 17.6% for 10ppm, 20ppm, 30ppm and 40ppm respectively. These are in line with the findings [6, 23].

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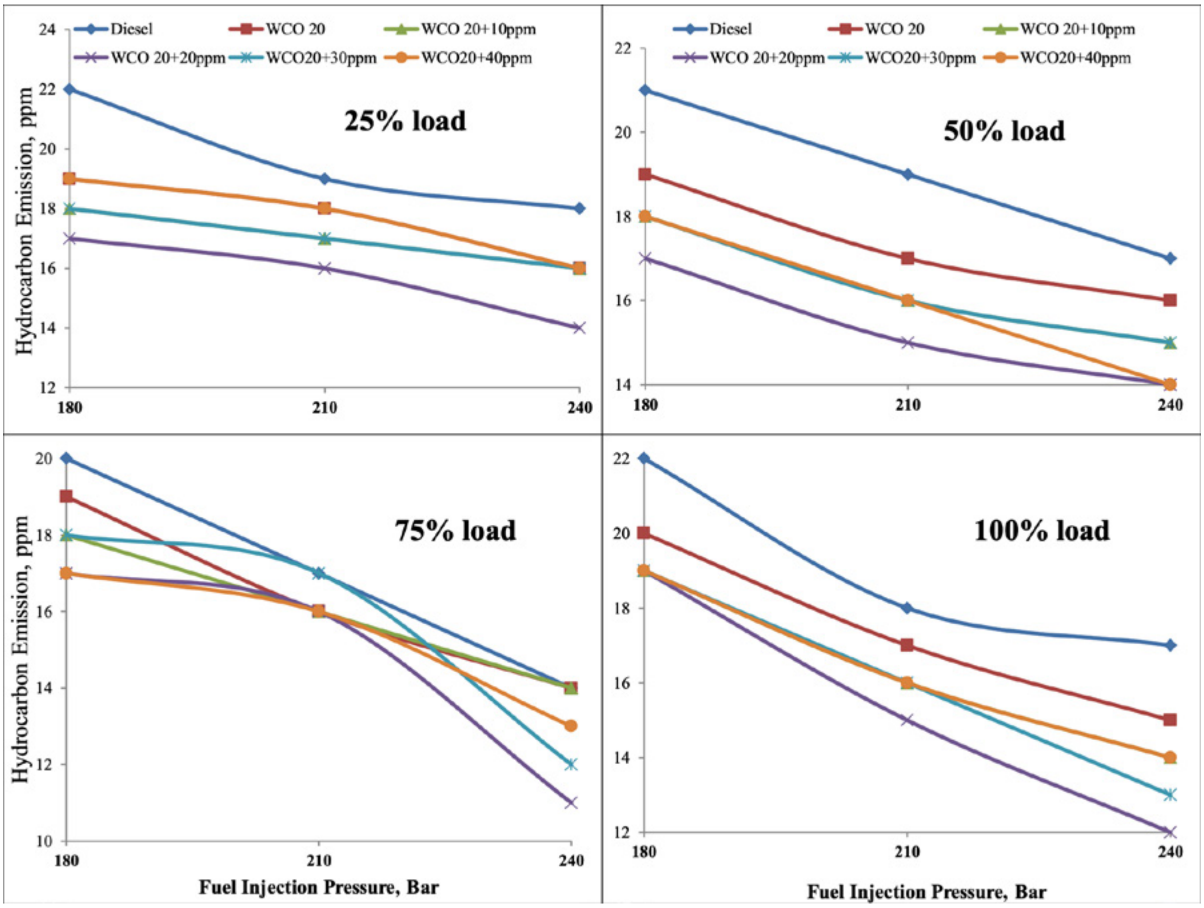

Figure 9. Variation of HC emissions at varying injection pressures, loads and levels of CuO.

4.2.4. NITROGEN OXIDE EMISSION

The development of Nitrogen oxides is inevitable as the combustion of fuel will lead to heat generation and which in turn acts as a catalyst for the formation of NOx [20, 27]. It could be observed from Figure 10 that with incrementation of load and fuel injection pressure leads to rise in levels of NOx [25, 26]. The temperatures of combusted gas play a direct role in signifying the NOx emission as higher EGT leads to higher combustion temperature and higher temperature acts as a catalyst for NOx formation. Most researchers have often discussed the heavy rise in NOx levels with higher volumes of Biodiesel in biodiesel-diesel blends (BDD) which limits the use of higher BDD blends. In the current study, it was found that the addition of CuO in the WCO20 blend ascents the NOx levels but to a small extent. It was observed that higher fuel injection pressure of 240Bar, the ascent found for NOx with 10ppm, 20ppm, 30ppm, and 40ppm addition of CuO in WCO20 was found to be 1.5%, 2.89%, 3.78%, and 4.8% respectively. Similar observations were noted by Keskin et.al.[28] with 8ppm and 16ppm of manganese dioxide nanoparticles in vegetable oil biodiesel blends led to an increased NOx emission.

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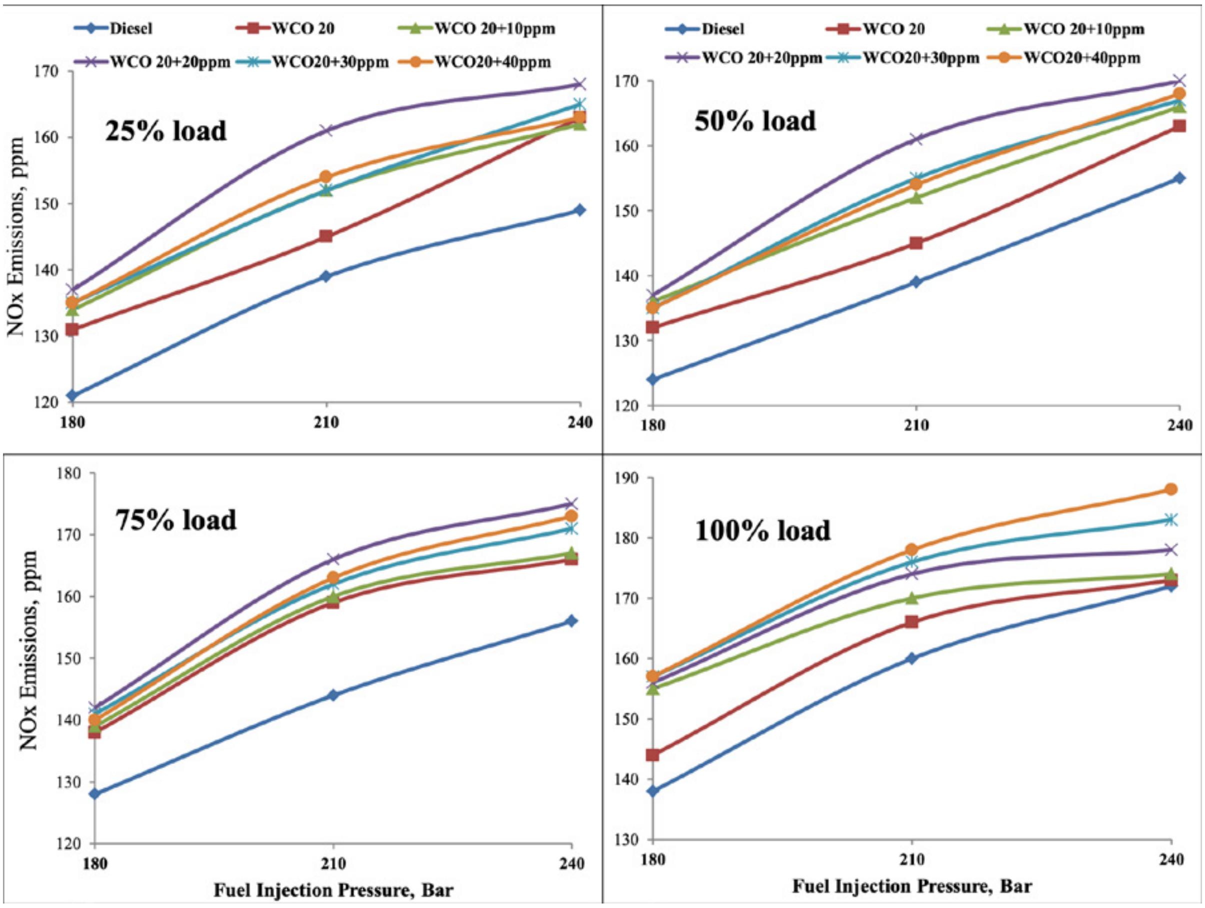

Figure 10. Variation Of NOx emissions at varying injection pressures, loads and levels of CuO.

4.2.5. SMOKE LEVELS

The measured smoke levels for all 6 test fuels could be observed in Figure 11. The Hartrige Smoke Levels diminished with gradual incrementation of fuel injection pressure and engine loads. It could be observed that WCO20 HSU levels were much higher than that of diesel. It could be observed that with IOP 240 bar, the rise in HSU levels when compared to Diesel were 17%, 11.2%, 10.3%,10.2%, and 10.8% respectively for WCO20 having 0, 10ppm, 20ppm, 30ppm and 40ppm of CuO. Also, with the addition of CuO in WCO20 at 240 bar pressure, the descent of HSU found was 1.9%, 6.4%, 4.7%, and 4.3% respectively when compared to the Base blend (WCO20).

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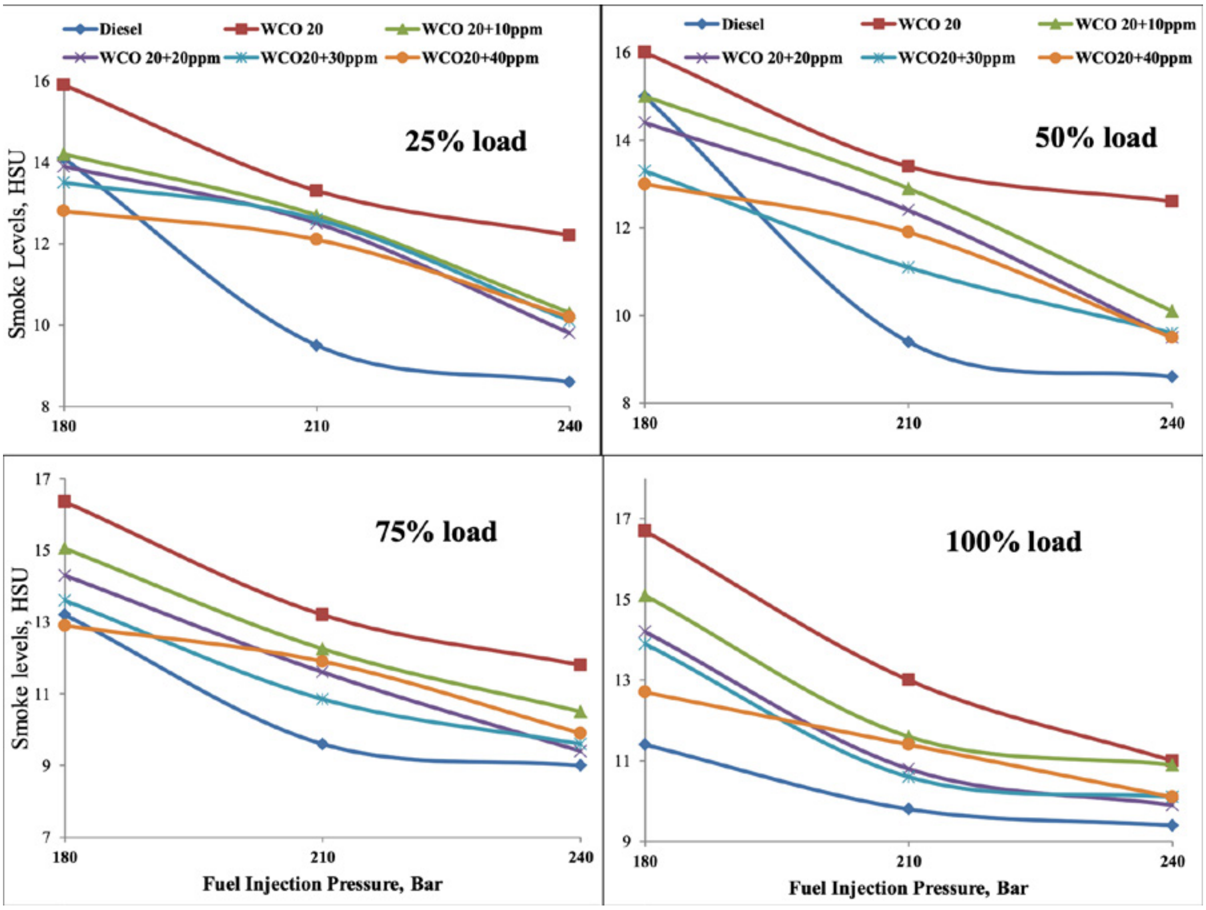

Figure 11. Variation of smoke levels emissions at varying injection pressures, loads and levels of CuO.

5. CONCLUSIONS

The present explains the performance and emission features displayed by engine when fuelled with Waste Cooking oil blend and with addition of copper oxide fuel additives with dosing levels of 10ppm, 20ppm, 30ppm and 40ppm. The engine observations were noted at increasing loads and variations in fuel inlet pressure. Below are some major inferences witnessed.

1. The addition of CuO in WCO20 does retard the Viscosity of fuel and increases the density of fuel.
2. The Presence of Copper oxide Nano-additives in WCO20 blend does contribute in reducing the ignition delay. This reduction helps in obtaining the complete combustion of fuel.
3. Higher Fuel Injection pressure does play a promising role in improvement in Performance and emission features of engine. Also the inculcation of CuO at Higher FIP of 240bar does further promote in constricting the levels of NOx.
4. The BTHE of the engine rose with the addition of CuO in WCO20. Also the BSFC values were limited by the addition of CuO in WCO20.
5. The Levels of HC and CO retarded with the addition of CuO in WCO20 even at higher fuel injection pressures. The average decline found for CO and HC

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emission with addition of 20ppm CuO in WCO20 were 2.9% and 12.6% respectively.

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