Nigerian Journal of Technology (NIJOTECH)
Vol. 45, No. 1, March 2026, pp. 58- 74
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://dx.doi.org/10.4314/njt.v45i1.6

EFFECT OF ENGINE PARAMETERS ON THE PERFORMANCE OF CRDI ENGINE FUELED WITH COTTON SEED OIL NANO-BIODIESEL BLENDS

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ARTICLE HISTORY:
Received: June 16, 2025.
Revised: February 16, 2026.
Accepted: February 20, 2026.
Published: April 29, 2026.

KEYWORDS:
Cotton seed oil, methyl ester, CRDI, injection timing, injection pressure, nozzle geometry, combustion and emissions.

ARTICLE INCLUDES:
Peer review

DATA AVAILABILITY:
On request from author(s)

EDITORS:
Chidozie Charles Nnaji

FUNDING:
None

Abstract

Impact of Injection Timing and Injector Opening Pressure on the performance of Common Rail Direct Injection (CRDI) diesel engine fuelled with cottonseed oil methyl ester biodiesel COTSEDOB B20 and its nanoparticle-enhanced counterpart. Addition of 100 ppm graphene nanoparticles was investigated for augmenting combustion efficiency and emission control. Engine tests were performed under varying IT (10°–20°bTDC) and IOP (600–1200 bar), at 80% load. The results revealed that advancing IT to 15°bTDC and increasing IOP to 1000 bar led to a substantial improvement in Brake Thermal Efficiency, with increases of 6.51% and 8.64% for COTSEDOB B20 and COTSEDOB B20 GNP100, respectively, compared to baseline conditions. Smoke emissions were reduced by 26% (B20) and 31%, while ignition delay and combustion duration were shortened, and peak pressure was significantly elevated. The GNP100 blend exhibited superior atomization, enhanced heat release, and cleaner combustion due to graphene's excellent thermal conductivity and catalytic properties. Although NOx emissions showed a moderate increase, the overall performance and environmental impact improved markedly with nanoparticle addition. The study confirms that COTSEDOB B20, particularly with graphene nanoparticle enhancement, offers a promising conduit toward cleaner and efficient diesel engine operation under optimized injection strategies.

1.0 INTRODUCTION

The accelerating pace of urbanization, coupled with the steady rise in the global population, has significantly escalated energy demands. This growing energy requirement is intrinsically linked to human development, encompassing social, economic, and health-related dimensions. But an unsustainable and excessive dependence on fossil

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HOW TO CITE:
Keerthi, B.L., Ranganatha Swamy, L., Banapurmath, N. R., Sanjeevannavar, M.B., Nivedhitha, K.S., Ravulapati, K. and Sajjan, A.M. "Effect of Engine Parameters on The Performance of CRDI Engine Fueled with Cotton Seed Oil Nano-Biodiesel Blends", *Nigerian Journal of Technology*, 2026. 45(1), pp. 58 – 74. https://dx.doi.org/10.4314/njt.v45i1.6

fuels resulted in severe environmental damage and detrimental effects on human health [1]. In particular, the increasing dependence on diesel for engine combustion has contributed to the depletion of finite reserves, heightened price volatility, and amplified environmental pollution and health concerns. The surge in energy consumption, largely driven by fossil fuels, has exacerbated ecological risks. Transitioning towards renewable energy sources presents a viable solution to these challenges by reducing fossil fuel dependence. Furthermore, renewable and inexhaustible energy resources possess the capacity to sustainably meet future global energy demands. In this regard, biodiesel serves as a useful alternative to traditional diesel fuel. Biodiesel, which is biodegradable and derived from renewable biological sources of vegetable and animal fats, considerably reduces greenhouse gas emissions associated with diesel that is based on petroleum. Its use in diesel engines and set-up allows for seamless integration without major modifications. Moreover, the use of biodiesel contributes to energy security, rural economic development, and the circular economy by utilizing locally available feedstocks and waste materials [2, 3]. Recent research has emphasized the blending of non-edible oils such as *Ceiba pentandra*, *Mahua longifolia*, *Azadirachta indica* to enhance feedstock availability and improve the physicochemical properties of biodiesel. This multi-oil approach addresses seasonal limitations associated with single-source feedstocks while producing fuel with balanced characteristics. Furthermore, the use of novel bifunctional catalysts, particularly sulfonate esters, has demonstrated high efficiency in biodiesel conversion processes, especially in treating oils with elevated free fatty acid content. Certain biodiesel blends, particularly B20 at a compression ratio of 19, have been shown to improve BTE and drastically reduce emissions in engine performance tests. These results highlight mixed-oil biodiesel's potential as a sustainable substitute for traditional diesel [4]. The study at University of Nigeria examined the seldom elevated thermal efficiency exhibited with palm kernel oil B100 on contrary to its 10% blending with diesel at augmented engine speed boosts the exploitation of algae oil as a noble repository for the inception of biofuel [5]. The exploitation of diesel-canola oil blends in little percentage fused with tiny antioxidant induce enriched thermal efficiency and drastically attenuated smoke emission and NOx on contrary to the diesel that emphasizing the probable exertion of the trace of canola oil fused with antioxidants as deputize for diesel awfully in canola generating localities of Canada [6]. The integration of baffles within the combustion chamber has shown promise in charge distribution and improving both performance and emission characteristics. However, limited studies have investigated the combined effects of key engine operating parameters of fuel injection pressure (FIP), engine speed, and load on engines with baffles (EWB). Computational Fluid Dynamics based analyses have emerged as effective tools to simulate and compare these conditions. Notably, research indicates that EWB configurations can achieve comparable or superior performance at lower FIP levels compared to conventional engines, along with improved thermal efficiency and reduced hydrocarbon and carbon monoxide emissions. Nonetheless, increase in nitrogen oxide emissions is observed, warranting further optimization. These findings suggest that baffle-assisted combustion strategies hold potential for future high-efficiency, low-emission IC engine designs [7]. The outcome of the trials on 5 to 25% blends of Sand Apple Ethyl Esters (with Automotive Gas Oil (AGO) at baseline loading conditions unveiled the identical efficacy in terms of fuel consumption, speed and exhaust gas temperature that attained with AGO lonely spells out the adequacy of sand apple biodiesel in diesel engines [8]. The exploitation of vast quantum of refined transformer oil in diesel engine in blended form with baseline diesel shown noticeable substitution of fossil fuel [9]. The potential of nanoparticles (NPs) to improve the efficiency of diesel engines running on biodiesel has drawn more and more attention.

The potential of metal-based nanoparticles (NPs) like TiO_2, CeO_2, and Al_2O_3 to increase combustion efficiency, delay ignition, and reduce toxic emissions has been studied. The incorporation of nanoparticles shown to reduce smoke, CO, HC, and NOx emissions while simultaneously enhancing BTE and engine power output. However, most existing reviews have addressed these effects in isolation, lacking a comprehensive analysis of how nanoparticles influence the overall biodiesel combustion process, fuel stability, and cost-effectiveness [10]. Research has explored co-pyrolysis as an effective method for converting biomass and plastic waste into alternative liquid fuels. Specifically, utilising catalysts like cupric oxide (CuO) to co-pyrolyze neem cake (PNC) and mixed waste plastics (MWP) like PET and LDPE has showed potential in creating fuels with high energy density. Although performance issues still exist, it has been discovered that blending these pyrolysis oils with regular diesel improves fuel sustainability. To enhance combustion, the use of

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metal oxide nanoparticles especially cerium oxide (CeO_2) has gained traction. Studies incorporating CeO_2 into diesel-pyrolysis oil blends, such as PD20, have demonstrated notable improvements in BTE, along with significant reductions in CO and HC emissions. Furthermore, nanoparticle addition has been shown to positively influence heat release rate and peak cylinder pressure, highlighting their catalytic role in optimizing combustion. These findings highlight potential of combining co-pyrolysis fuels with nano additives to create efficient and cleaner-burning alternatives to conventional diesel [11]. Research has indicated that adding nanoparticles like ZnO to higher alcohols like propanol-2 can greatly improve the performance of biodiesel blends like Calophyllum biodiesel (CB20). Increased BTE, condensed sfc, and decreased CO, HC, NOx, and smoke emissions are noteworthy improvements. To accurately predict these outcomes, a Generalized Regression Neural Network (GRNN) model was employed, showing high prediction accuracy with minimal error. This demonstrates the effectiveness of AI-based tools in optimizing advanced biodiesel blends for sustainable engine applications [12]. Nanoparticles in biodiesel blends have been shown in studies to further improve engine performance and lower pollutants. In this context, sheep fat (SF) biodiesel blended with diesel (B20) and enhanced with zinc oxide nanoparticles has shown significant improvements. Notably, B20+ZnO blends decreased BSFC, CO, HC, NOx, and smoke emissions while increasing in-cylinder pressure, heat release rate, and BTE especially with the 100 ppm ZnO dosage. These findings support the effectiveness of nano-biodiesel blends in achieving cleaner and more efficient engine operation [13]. Studies have explored the use of advanced nanomaterials such as graphene oxide, magnesium oxide, and multi-walled carbon nanotubes in biodiesel-diesel blends. In particular, a B20 blend made from waste cooking oil biodiesel and diesel, when combined with 90 ppm of these nanoparticles, showed notable improvements in engine performance. Blends of B20+MWCNT delivered gains, with a 12.40 % increase in BTE and a 9.67 % reduction in sfc compared to diesel. This mix also showed improved combustion properties and decreased CO, UBHC, CO_2, and NOx emissions. These results demonstrate the possibility of biodiesel augmented with nanoparticles as a cleaner and more effective diesel engine fuel [14].

Improper disposal of fish waste, which exceeds 130 million tonnes annually worldwide, poses serious environmental risks. In response, recent studies have explored its conversion into biodiesel as a sustainable solution for both waste management and energy production. Fish waste biodiesel (FWBD), when blended with diesel and alcohols like n-butanol, has shown potential for use in compression ignition engines. However, the direct use of FWBD can negatively impact engine performance. To address this, the incorporation of nanoparticles such as zinc oxide (ZnO) and graphene has been investigated. These additives enhance combustion and emission properties; ZnO-based nano-fuels have been shown to significantly reduce NOx, CO, HC, and smoke while increasing braking thermal efficiency by 6.75%. This highlights the viability of nanoparticle-enhanced fish waste biodiesel as a dual-purpose strategy for renewable fuel production and environmental waste management [15].

Recent advancements in biodiesel research have highlighted effectiveness of nanoparticle additives in refining engine performance and emission control. While biodiesel-diesel blends, such as those derived from palm seed oil, often underperform compared to conventional diesel, incorporating calcium oxide (CaO) nanoparticles has shown promising results. Specifically, a 40% biodiesel mix supplemented with 50 ppm CaO nanoparticles showed decreased bsfc and increased brake thermal efficiency. Notably, NOx emissions were reduced by up to 12.8% when compared to pure diesel, as were CO, HC, and smoke. These findings underscore potential of nano-enhanced biodiesel as a viable and cleaner alternative for compression ignition engines [16]. Research has focused on integrating metal oxide nanoparticles with biodiesel to enhance engine performance and reduce emissions. Synthesised utilising environmentally friendly techniques like extracts from Spondias mombin, copper oxide nanoparticles have demonstrated encouraging properties such as polycrystalline structure and particle sizes ranging from 10 to 75 nm. CuO nanoparticles blended *Guizotia abyssinica*, improved BTE and significantly reduced carbon monoxide and particulate matter emissions. Additionally, machine learning-based optimization (MLO) techniques, such as gradient descent and simulated annealing, effectively optimized biodiesel yield and composition. These findings underscore the potential of bio-derived nanomaterials and AI-driven methods to develop cleaner, more efficient biodiesel blends for sustainable energy solutions [17]. Studies have emphasized the importance of accurately modelling cylinder liner deformations in internal combustion engines to understand their effect on piston ring tribology. Deformations in both axial and radial directions significantly influence friction, wear, and lubricant behaviour in the piston–cylinder interface.

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Emerging research incorporates sophisticated rheological models, including the Power Law, to more accurately replicate real-world performance, whereas older models frequently ignore the complicated viscosity of non-Newtonian lubricants with nano-additives. The use of ZnO and MWCNT nanoparticle-enhanced lubricants has shown notable improvements, including reduced friction and wear. For instance, recent analyses incorporating Archard's wear model and blow-by simulations indicate that nanoparticle-lubricated oils can reduce compression ring friction force by up to 21%, reinforcing the tribological benefits of nano-additives in engine design optimization [18]. Recent advancements in nano-lubricants have shown that incorporating carbon-based nanostructures can significantly enhance engine performance and tribological behaviour. Nano graphite and spherical carbon nanoparticles, when added to engine oil, have demonstrated remarkable improvements in both wear and friction characteristics. Tribological testing revealed a sevenfold reduction in wear and over thirteen-fold reduction in friction with nano-graphite based lubricants. Additionally, performance metrics such as fuel consumption, bsfc, and BTE improved notably, along with reductions in exhaust gas temperature and harmful emissions. These findings underscore the potential of carbon nanostructure-enhanced lubricants as effective solutions for improving engine efficiency and promoting environmental sustainability [19]. 1-Heptanol, a renewable alcohol from biomass, provided eco-friendly alternative to conventional diesel. Recent studies using single-cylinder CRDI engines have explored its effects on combustion and emissions when blended with diesel. A 50 % 1-heptanol/diesel blend demonstrated notable reductions in NOx and smoke emissions by 27 % and 26 %, respectively highlighting its environmental benefits. However, advanced injection timing slightly reduced BTE and increased BSFC, along with higher HC and CO due to enhanced premixed combustion. These findings suggest that 1-heptanol can be effectively utilized in diesel engines with minimal modifications, offering a viable pathway toward cleaner and more sustainable fuels [20].

The development of biodiesel and the application of nanoparticles to improve internal combustion engine emissions and performance have advanced significantly, according to the literature. While various biodiesel feedstocks and metal oxide nanoparticles have been studied, limited work has been done on cotton seed biodiesel blended with graphene nanoparticles, despite graphene's superior thermal and catalytic properties. Additionally, most studies focus on multi-injection strategies in CI engines, with minimal emphasis on single injection modes under CRDI systems. This highlights a clear research gap in exploring the combined effects of cotton seed biodiesel and graphene nanoparticles under single injection strategy in CRDI engines, which could offer improved combustion, efficiency, and emission outcomes.

2.0 MATERIALS AND METHODOLOGY ADOPTED

The present segment discusses on the adoption of fuels for evaluation of CRDI engine performance. ASTM standards are adopted to evaluation of fuel physico-chemical properties.

2.1 Physico-chemical Properties of Nano-biodiesel blends

Biodiesel (COTSEDOB B100) is prepared from cotton seed oil using transesterification process and its B20 blend (COTSEDOB B20) is prepared by mixing it with diesel in 20:80 volume ratio. Further nano biodiesel blends of COTSEDOB B20 were prepared using probe sonication method. Graphene nanoplatelet (GNP) with varied percentage from 60 to 120 ppm were dispersed in the B20 blend using SDS (Sodium dodecyl sulfate) as surfactant. Accordingly, the nano-biodiesel blends are designated as COTSEDOB B20 GNP 60, COTSEDOB B20 GNP80, COTSEDOB B20 GNP100 COTSEDOB B20 GNP120 respectively. Among these COTSEDOB B20 GNP100 exhibited good fuel properties. Physico-chemical characteristics of diesel, COTSEDOB B 20, and COTSEDOB B20 GNP100 biodiesel blends are shown in Tables 1. Specifications of the engine is shown in Table 2. The COTSEDOB biodiesel and their nano-blends are displayed in Figure. 1.

(a) (b)

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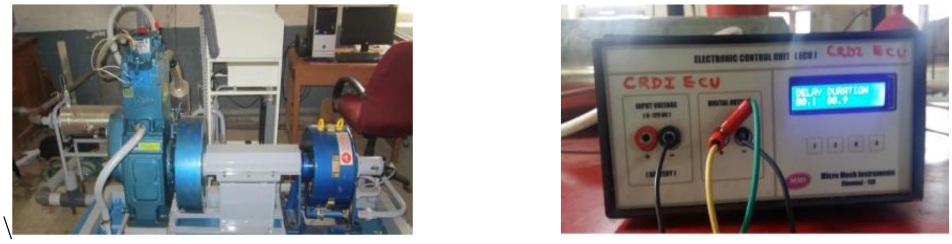
Figure 1: Cotton seed biodiesel (a) B100 and B20 (b) Nano-biodiesel blends.

Table 1: Properties of diesel, COTSEDOB B100 and COTSEDOB B20

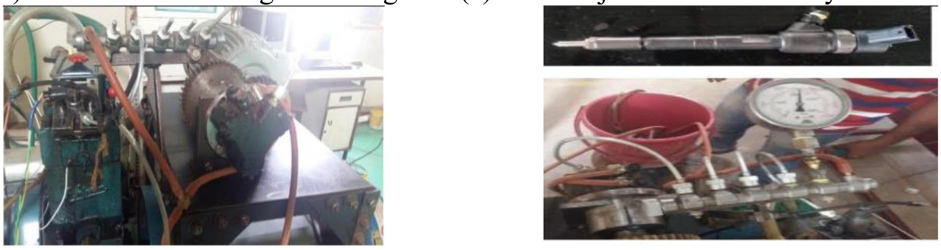
Sl. No.	Properties	Diesel	Cotton seed oil	COTSEDOB B100	COTSEDO B B20	COTSEDOB B20 GNP100
1	Density (kg/m^3)	830	910	887	894	900
2	Calorific value (kJ/kg)	43,000	38,568	39000	39716	40,168
3	Flashpoint (°C)	54	220	160	118	124
4	Cetane Number	45-55	---	---	44	---
5	Kinematic Viscosity (mm^2/s)	2.3	25.56	4.8	4.2	5.2

3.0 EXPERIMENTAL SETUP

Figure2 (a) unfolds four-stroke, DI diesel engine adapted for experimentation that comprises of a single cylinder with water-cooling facility bearing a displacement volume 662 cm^3 with a compression ratio of 17:1, capable for developing 5.2 kW at a rated speed of 1500 rev/min. Table 3 witness specifications of the engine. Figure 2 (b) shows the CRDI engine test rig with electronic control unit (ECU) as shown in Figure 2 (c). Electronic control unit injects the biodiesel blends at varied injection timing and duration in the CRDI diesel engine. Testing is done on an engine incorporated with toroidal reentrant combustion chamber (TRCC) ran at manufacturer specified speed of 1500 rpm using. Figure 2 (d) shows a 7-hole CRDI injector with a 0.2 mm utilized in each hole. In the modified CRDI engine, mixes of biodiesel are injected at varying injection pressures and timings. The ECU facility is used in our Internal Combustion Engines (ICEs) Lab, Department of mechanical engineering, KLE Technology University, Hubballi



(a) Conventional CI engine test rig (c) CRDI injectors facilitated by the ECU



(b) CI engine integrated with the CRDI system (d) Fuel IOP is recorded using a CRDI injector and a pressure gauge.

Figure 2. Experimental test rig was depicted schematically.

A piezo-electric pressure transducer (resolution: 0.1450 mV/kPa, model: HSM 111A22, make: PCB Piezotronics) used adopted for cylinder pressure measurement is seated in the cylinder head. An earlier report regarding the HRR is computed using the ensemble values of the pressure crank angle history, which is collected over about 100 cycles. The values of HRR are calculated by using first law of thermodynamics and governing equations [Hohenberg 1989, Hayes and Savage 1986]. The Hartridge smoke meter is used to detect smoke emissions under steady state engine operating circumstances, while the Delta 1600S non-dispersive infrared gas analyzer is used to monitor NOx and HC exhaust emissions. The beginning of the combustion phase is assessed using differential cylinder pressure

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time data with crank angle and HRR magnitudes. The duration of combustion is the point at which 90% of the heat is discharged. Ignition delay is the amount of time that passes between the beginning of fuel injection and the beginning of ignition.

Table 2: Specifications of the engine

Make and model	**Kirloskar, TV1**
No. of Cylinders	One
Orientation	Vertical
Cycle	4 Stroke
Ignition System	Compression Ignition
Bore X Stroke	87.5mm X 110mm
Displacement Volume	660 cc
Compression Ration	17.5: 1
Rated Power	5.2 kW (7 HP) @1500 rpm

4.0 RESULTS AND DISCUSSIONS

The current segment summarizes the effects of injection time and injector opening pressure on the performance of CRDI engines when they run on B20 blends of COTSEDOB and COTSEDOB B20 GNP100 with diesel.

4.1 Performance Characteristics

The effects of injection time and injector opening pressure on the Brake Thermal Efficiency (BTE) of a CRDI engine operating at 80% and 100% load with blends of COTSEDOB B20 and COTSEDOB B20 GNP100 with diesel is shown in figures 5(a), and 5(b). The diversified thermal efficiency was observed for different fuels under consideration with injection timing advancement or retardation. Lower energy composition and massive viscous nature of biodiesel blends instigated to exhibit inferior thermal efficiency commensurately to conventional diesel operation that could necessitates abundance mass of biodiesel infused into the engine cylinder to have identical engine power output. Figure 5(a) depicts improved thermal efficiency for both fuels with the retarded injection timing of the pilot fuel. In spite of that, more elevated thermal efficiency was witnessed at retarded injection timing of 10°BTDC for diesel mode of operation, meanwhile the refined effectuality was examined with advanced injection timing of 15°BTDC for biodiesels. The results obtained were in good agreement with the published literature [20, 21, 22]. Figure 5(b) revealed COTSEDOB B20 GNP100 with maximum efficiency compared to B20 blend due to enhanced combustion activity of the GNP nanoparticles added in the biodiesel at 15°BTDC injection timing. In real time applications B20 blends can be effectively used for automotive applications like those in buses, railways, and tractors though they perform poorer when compared diesel fuel operation.

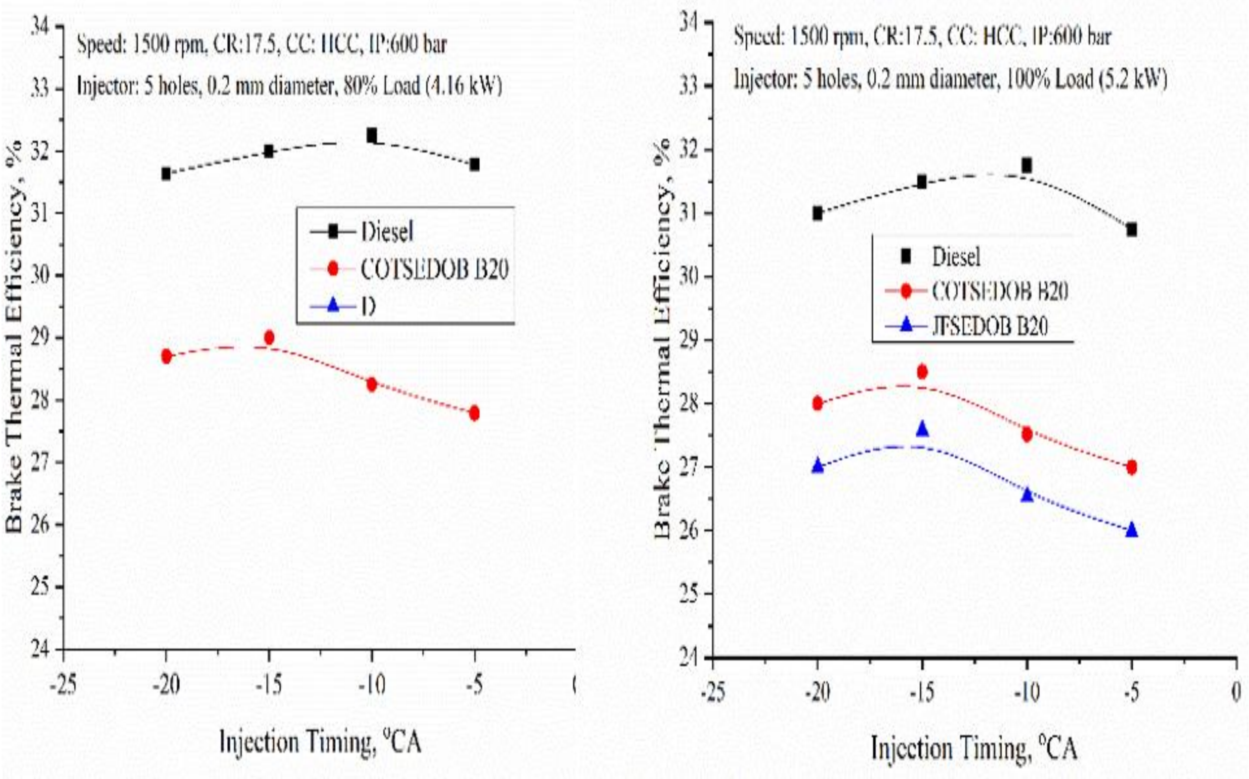

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Figure 5: (a) Effect of IT on BTE for 80 & 100% loads.

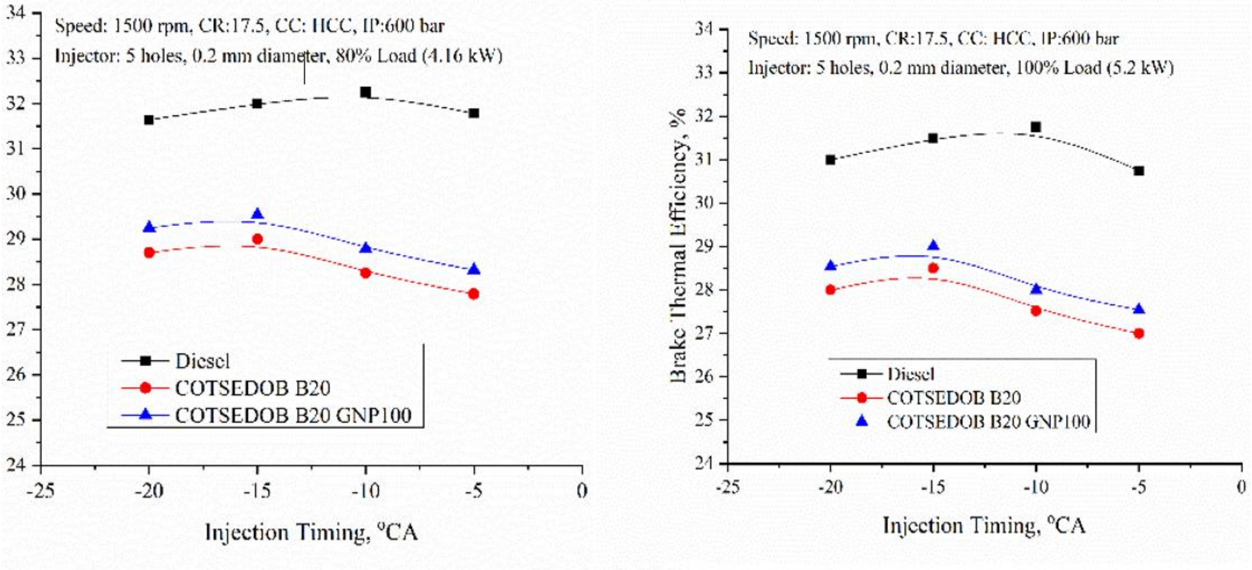

Figure 5: (b) Effect of IT on BTE for 80 & 100% loads.

Figure 6(a) and 6(b) shows how the engine's potentiality is affected by variations in injector opening pressure. The enhanced efficiency was detected with amplified injection pressure to the extent of 1000 bar for the pilot fuel eventually declines. Elevated pressures up to 1000 bar contribute to refined atomization of injected fuels that could induce uniformity in air-fuel composition which foster to shortened ignition delay. Thermal efficiency of CRDI engine worsens with biodiesels in contrary to diesel by virtue of inappropriate mixture formation that stemmed from their immense viscous characteristics [11, 13, 14]. In spite of this the diminution in efficiency at 1200 bar perhaps the aftereffect of limitation of CRDI engine system.

Figure 6(b) exhibited higher BTE with elevated pressures till 1000 bar for COTSEDOB B20 GNP100 compared to B20 blend due to enhanced catalytic combustion with addition of GNP nanoparticles added in the biodiesel.

As the injection pressure increases the BTE of the CRDI engine increases. Similar results were obtained and were in good agreement with the published literature [20, 21, 22]. However, use of nano-biodiesel blends at higher injection pressures needs long term engine operation before they can be recommended for real time commercial vehicle applications.

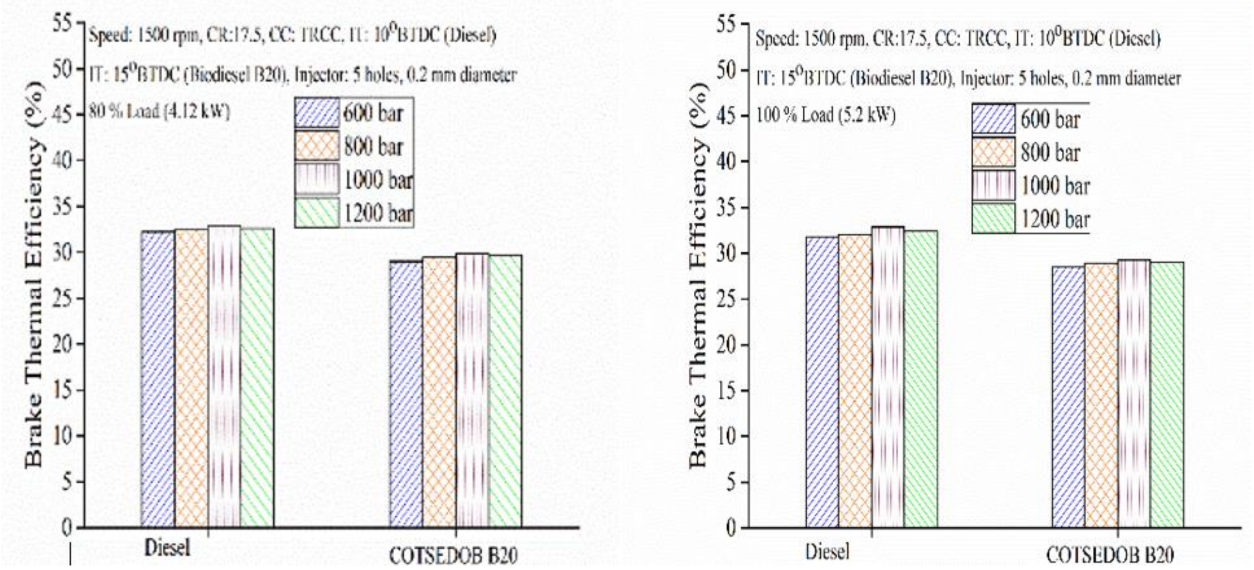

Figure 6: (a) BTE vs. IOP variation for B20 mixes at 80 and 100% loading.

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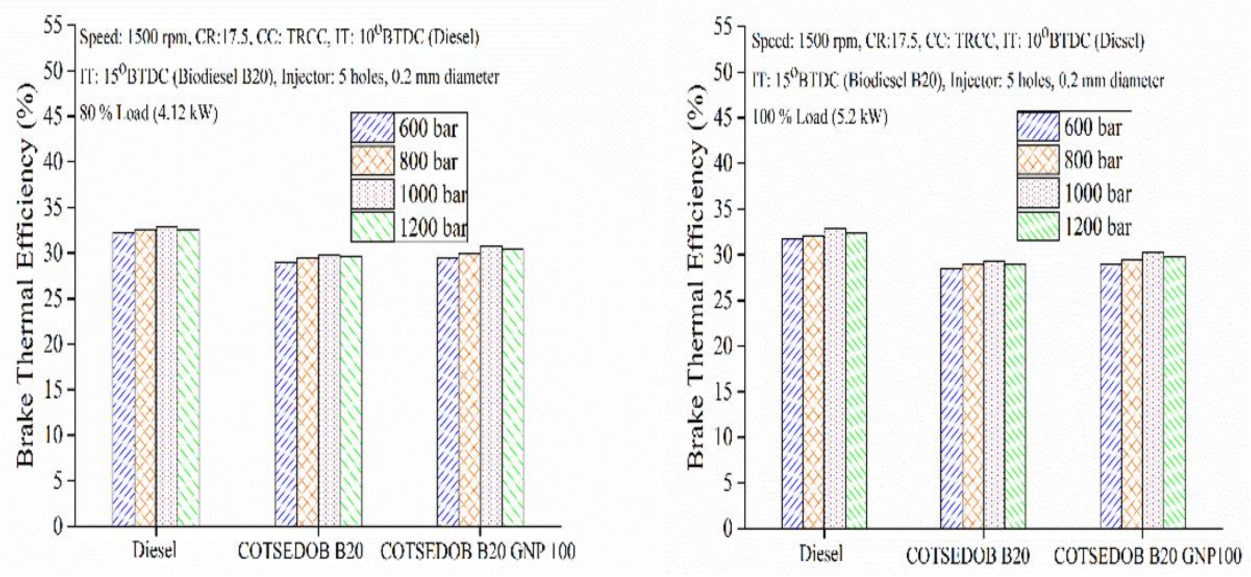

Figure 6: (b) Difference between BTE and IOP for B20 blends at 80 and 100% loading.

In both cases of above parameters, COTSEDOB B20 GNP100 blend showed higher BTE compared to COTSEDOB B20 due to its comparatively lower viscosity & higher calorific value (CV) as well.

4.2 Emission Characteristics Smoke Emission

When the CRDI-engine is driven by blends of COTSEDOB B20 & COTSEDOB B20 GNP100, the effects of fuel injection time and injector opening pressure on smoke emission are shown in Figs. 7(a), and 7(b) at 80 and 100% loaded circumstances, respectively. Biodiesel blends discharge huger emissions of smoke relative to diesel owing to inappropriate air fuel composition that come up within the cylinder as a consequence of their vaster viscous nature. Figure 7(a) and 7(b) reveals downsized emissions of smoke that taken place for COTSEDOB B20 & COTSEDOB B20 GNP100 with an advancement of injection timing from 20°BTDC to 15°BTDC successively beyond which it increased. Prolonged delay period as a consequence of advanced injection timing offers longer period for the combustion to prevail for B20 blends that scaled down emissions of smoke. Improved combustion with higher BTE of COTSEDOB B20 GNP100 resulted into lower smoke compared to B20 [12, 14, 16]. Despite this, steeper smoke emissions perceived nearer TDC and at injection time retarded below 10°BTDC that perhaps because of wider phase of diffusion combustion that one attenuated thermal efficiency.

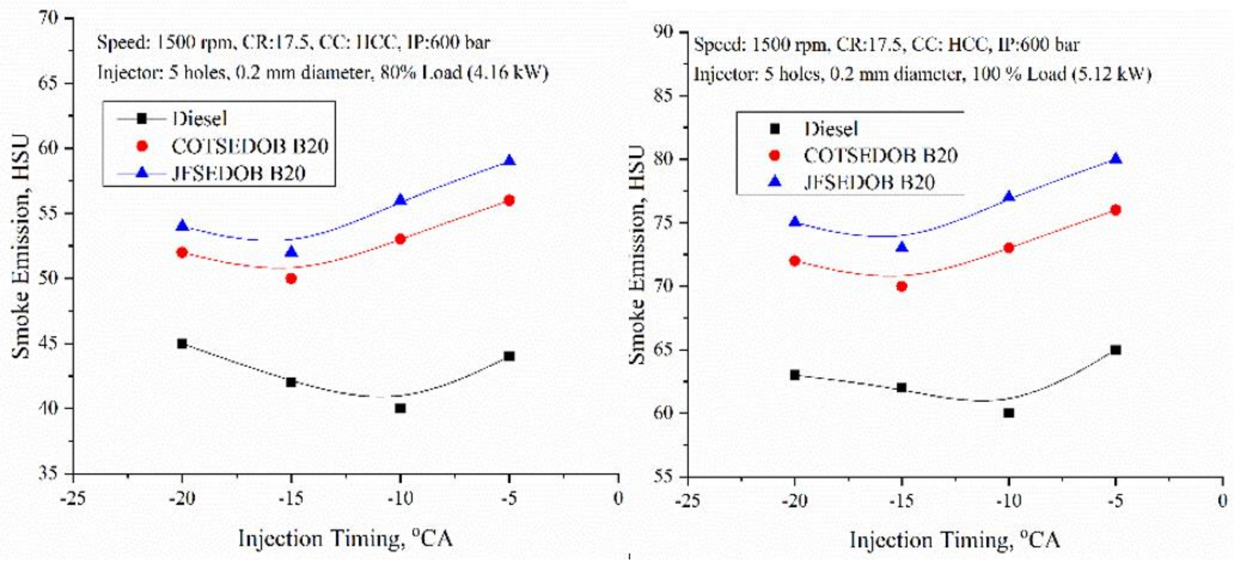

Figure 7: (a) S-E vs. IT variation for B20 blends at 80 and 100% loading.

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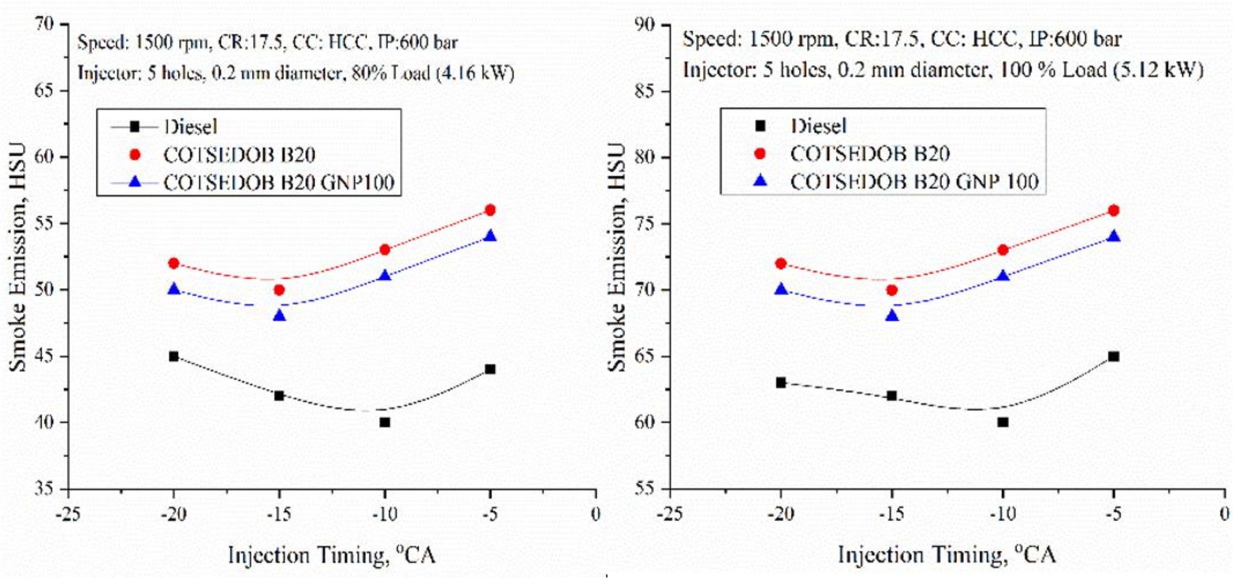

Figure 7: (b) Difference between S-E and IT for B20 blends at 80 and 100% loading.

As the injection timing is advanced the B20 blends performed better when compared to diesel fuel operation and similar data were obtained in the published literature [20, 21, 22]. However, use of nano-biodiesel blends (COTSEDOB GNP100) greatly reduces the smoke emissions but their use needs time testing for commercial vehicle applications

Figure 8(a) and 8(b) exposed the impact of distinct injector opening pressure on the intensity of emission of smoke. The persistent finer atomization for the whole of the chosen infused fuels as result of augmented injector opening pressure induce adequate combustion that could potentially cut down the smoke emissions. Consistent trend is continued till 1000 bar ahead of which emission of smoke upraised detrimental effect of extensive injector opening pressures. Compared to diesel, B20 blends exhibit relatively higher smoke emissions. The uniqueness in the composition of B20 blend of COTSEDOB GNP100 marginally let down the emissions up against COTSEDOB due to addition of GNP nanoparticles with improved BTE [11, 14, 15]. The higher injection pressures result into lower smoke emissions for B20 blends [20, 21, 22]. Although the COTSEDOB GNP100 produces lower smoke compared to B20 biodiesel its commercial use and needs are based on the economic viability.

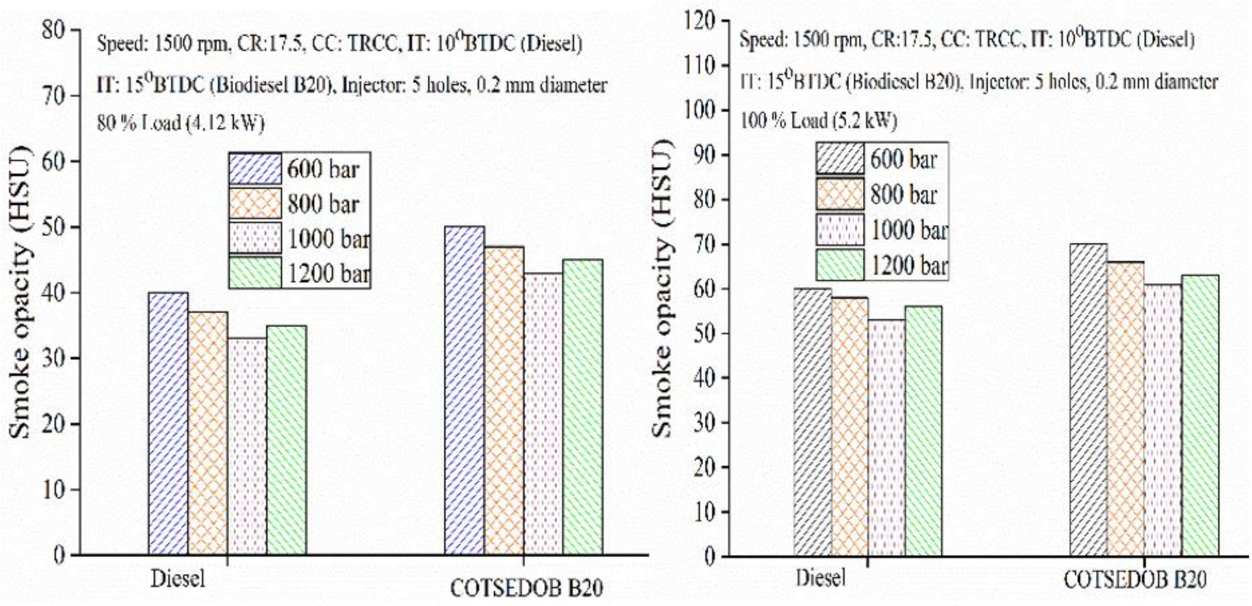

Figure 8: (a) S-E vs. IOP variation for B20 blends at 80 and 100% loading.

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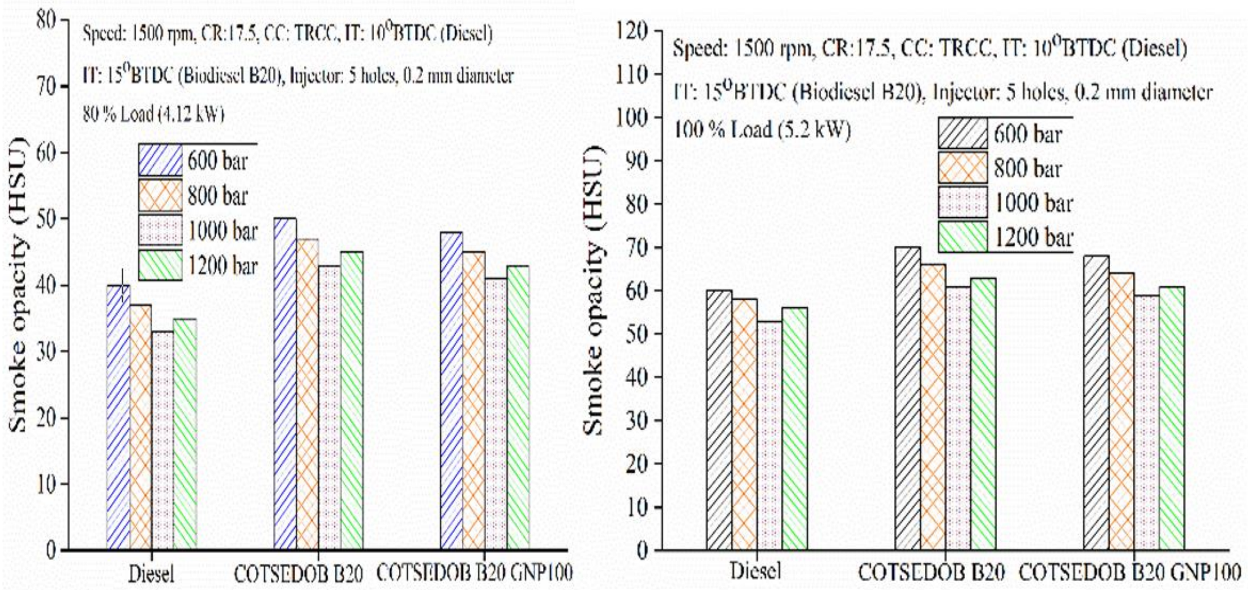

Figure 8: (b) Variation between S-E and IOP for B20 blends at 80 and 100% loading.

4.2.1 NOx Emissions

The effects of the CRDI-engine's fuel injection time and injector opening pressure on NOx emissions at 80 and 100% loaded situations respectively, when it is fuelled by B20 blends of COTSEDOB B20 & COTSEDOB B20 GNP100, are shown in figures 9(a) and 9(b) respectively. There was an augmentation of peak pressure and high heat release rate as consequence of supplemented fuel that being infused by virtue of extended delay period eventuated by advancement in the injection timing that escalates the emission of NOx for all the biodiesel blends. NOx emissions noticed to be reduced with BDFs that could be the resultant of underlying cetane number and subsidiary temperatures of gases in persist in the combustion chamber in contradiction of diesel as depicted in Figure 9(a) [10, 11]. COTSEDOB B20 GNP100 showed higher NOx for advanced injection timings compared to COTSEDOB B20 due to higher in-cylinder temperatures prevailing as shown in fig 9(b). B20 and their nano-biodiesel blends exhibited lower NOx emissions when compared to diesel fuel operation [21, 22].

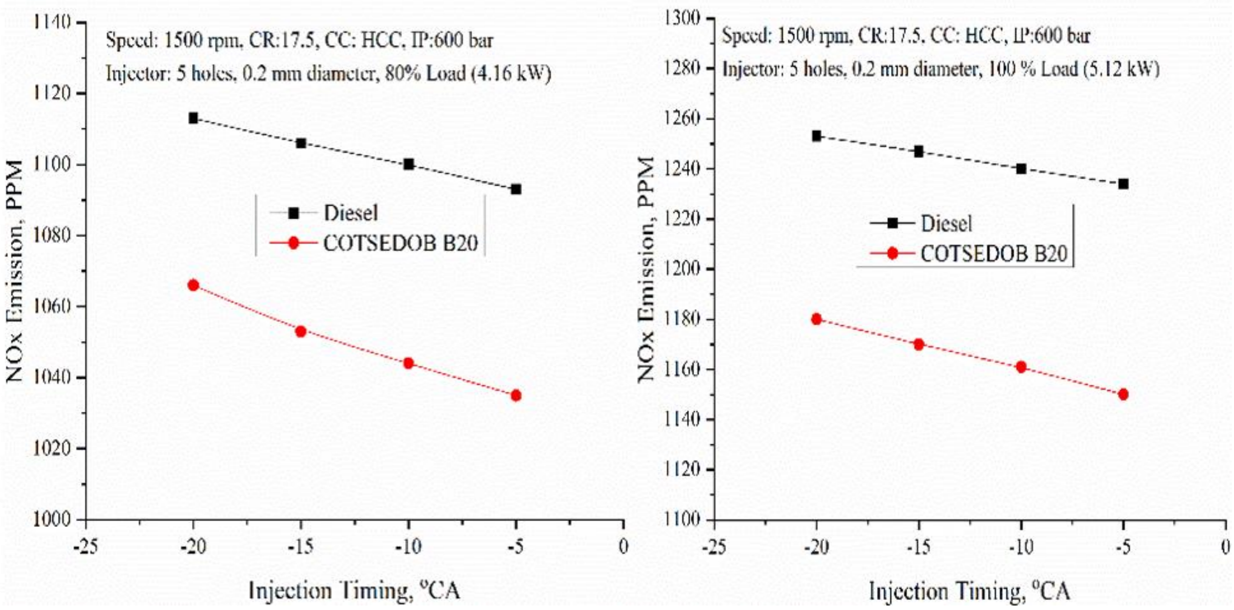

Figure 9: (a) NOx-E vs. IT variation for B20 blends at 80 and 100% loading.

Figure 10(a) and 10(b) indicates an enhancement in the magnitude of emission of NOx with an intensified injector pressure from 600 bars to 1000 bar. Through enhanced atomisation, which maintains the temperature of the gases in the cylinder at the highest point of the cycle, elevated injector pressure

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speeds up the combustion process. Improved scattering of the fuel and ultra-fine mist prompts to more desirable fusion induces shorten ignition delay that generates immense heat release rate and elevated temperature of the gases noticed at uplifted injector pressure supplementary upraises the emission of NOx for diesel fuel. BDFs with low-level cetane number and minor premixed burning span leads to subsidiary emissions of NOx [11, 14]. COTSEDOB B20 GNP100 showed higher NOx for increased pressures compared to COTSEDOB B20 due to higher in-cylinder temperatures occurring as shown in Fig 10(b). Higher injection pressures result in increased NOx emissions for B20 and their nano-biodiesel blends but were still comparatively lower when compared with diesel fuel operation [21,22].

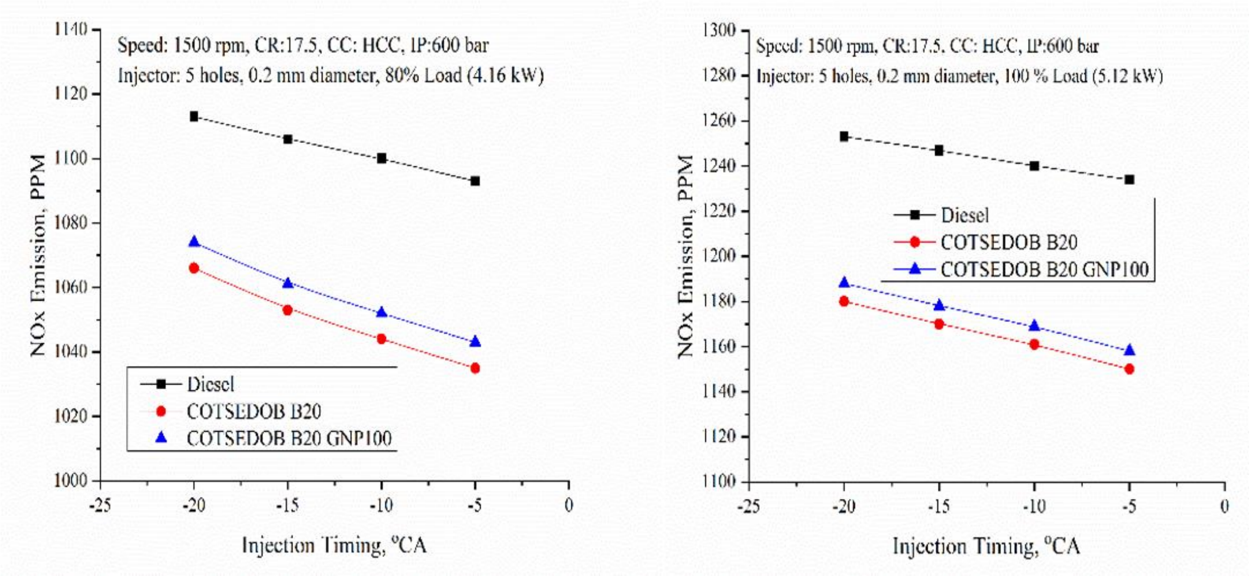

Figure 9: (b) Variation between NOx-E and IT for B20 blends at 80 and 100% loading.

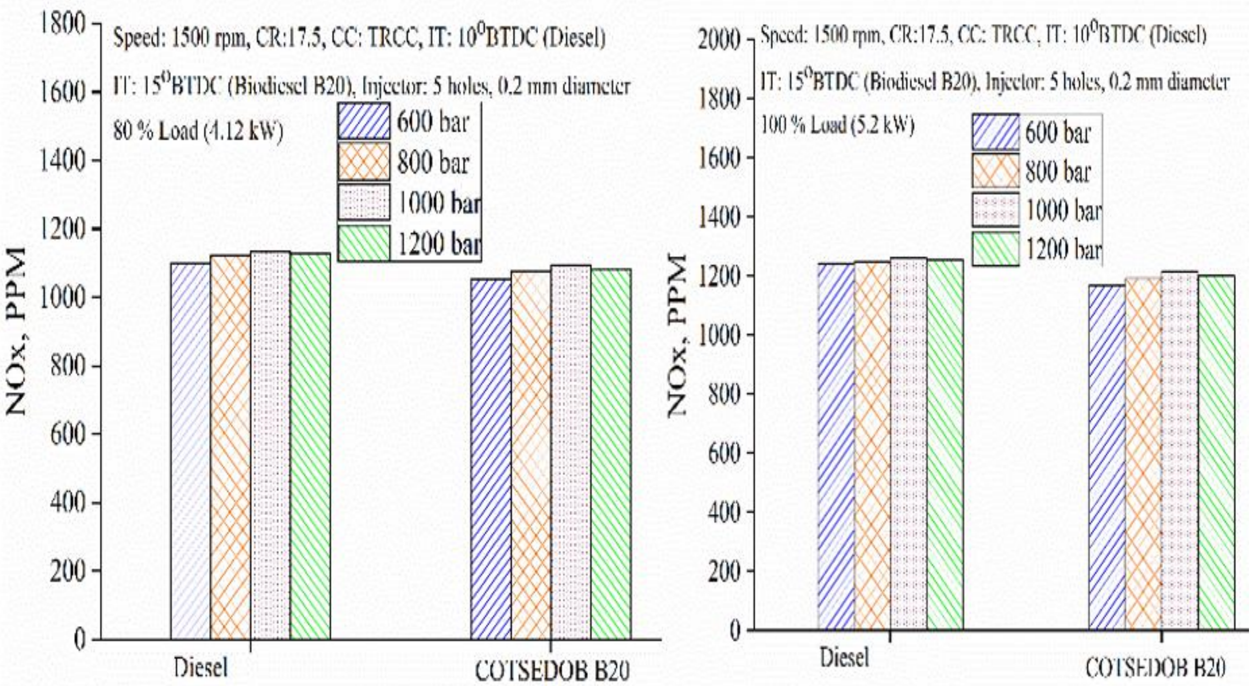

Figure 10: (a) NOx vs. IOP variation for B20 blends at 80 and 100% loading.

Figure 10(a) and 10(b) indicates an enhancement in the magnitude of emission of NOx with an intensified injector pressure from 600 bars to 1000 bar. Through enhanced atomisation, which maintains the temperature of the gases in the cylinder at the highest point of the cycle, elevated injector pressure

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speeds up the combustion process. Improved scattering of the fuel and ultra-fine mist prompts to more desirable fusion induces shorten ignition delay that generates immense heat release rate and elevated temperature of the gases noticed at uplifted injector pressure supplementary upraises the emission of NOx for diesel fuel. BDFs with low-level cetane number and minor premixed burning span leads to subsidiary emissions of NOx [11, 14]. COTSEDOB B20 GNP100 showed higher NOx for increased pressures compared to COTSEDOB B20 due to higher in-cylinder temperatures occurring as shown in Fig 10(b). Higher injection pressures result in increased NOx emissions for B20 and their nano-biodiesel blends but were still comparatively lower when compared with diesel fuel operation [21,22].

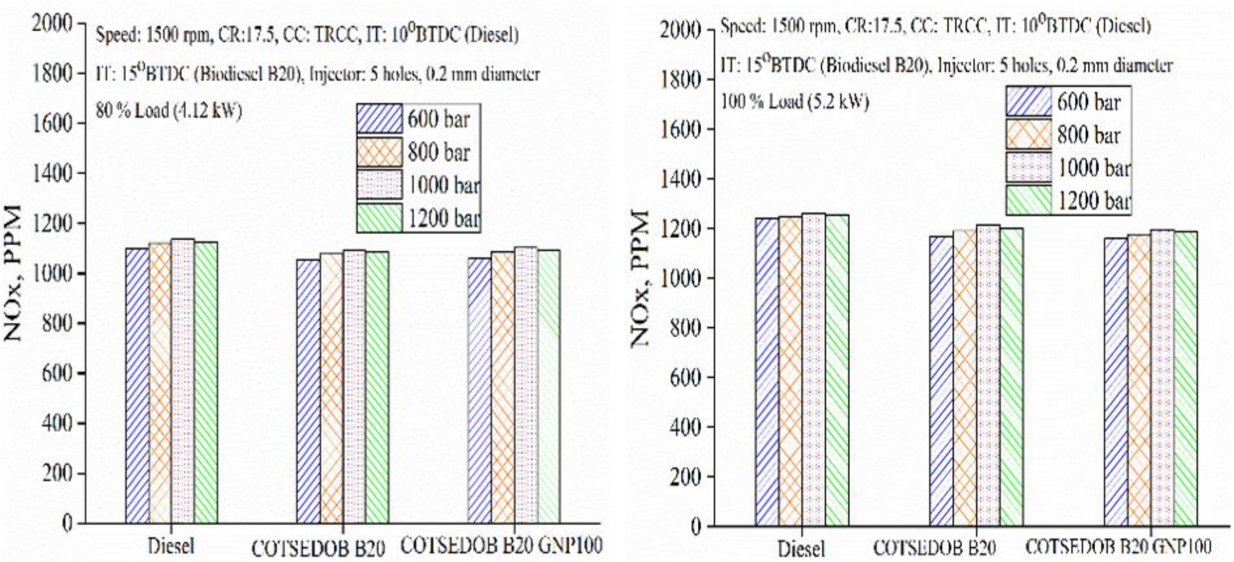

Figure 10: (b) Changes in NOx versus IOP for B20 blends at 80 and 100% loading

4.3 Combustion Characteristics

When the CRDI-engine is powered by B20 blends of COTSEDOB & COTSEDOB B20 GNP100, Figure 11(a), 11(b) and 11(c) determines the impact of fuel injection timing and injector opening pressure on ignition delay, combustion duration, and peak pressure at 80 and 100% loaded conditions, respectively. Combustion duration and ignition delay for chosen BDFs are perceived to be vaster and lesser peak pressure at all injection timings in contrast to diesel.

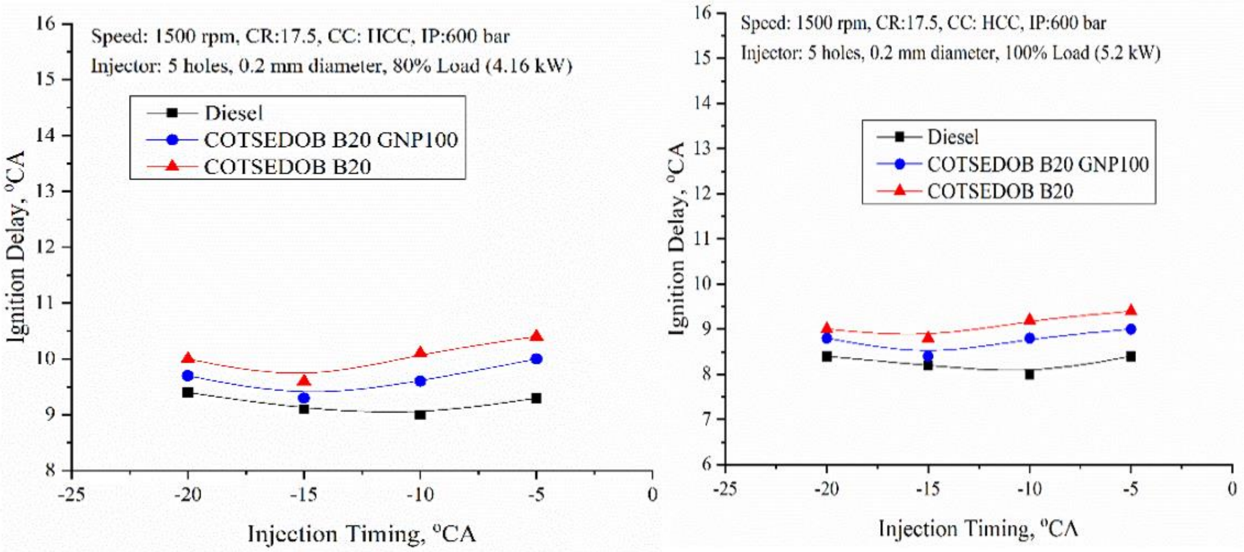

Figure 11: (a) Variation of ID versus IT for B20 blends at 80 and 100% loading.

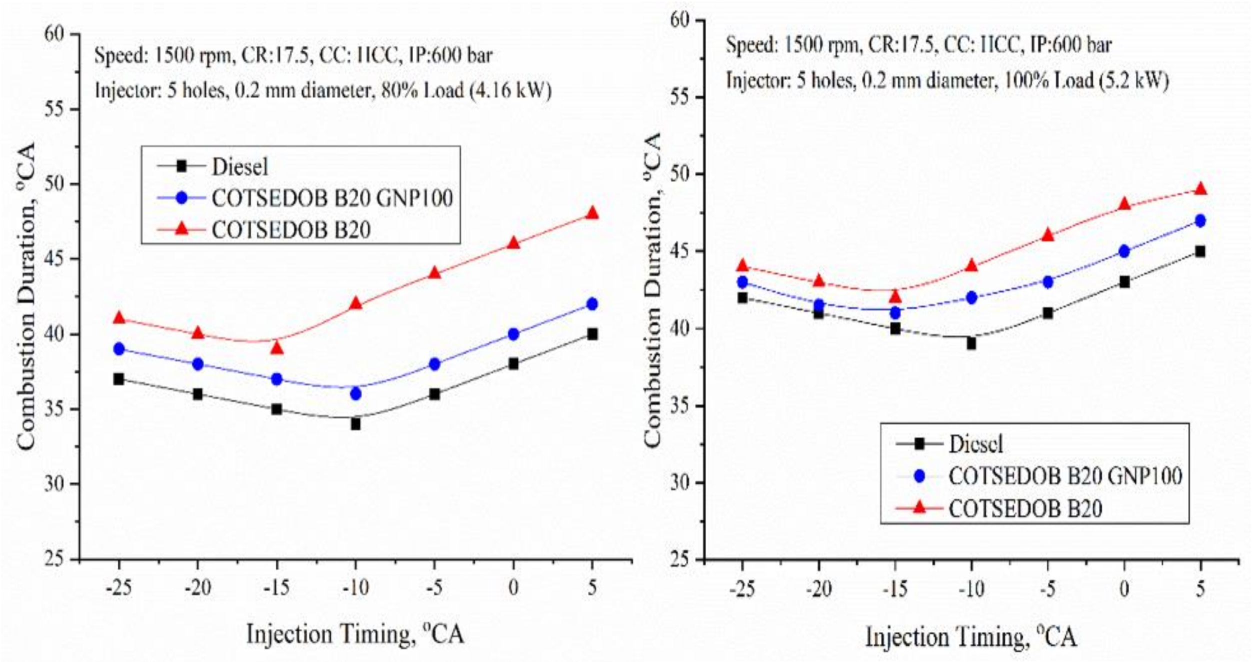

Figure 11: (b) CD vs. IT variation for B20 blends at 80 and 100% loading.

COTSEDOB B20 showed higher ID, CD and lower PP compared to diesel as shown in Figure 11. However, with COTSEDOB B20 GNP100 powered CRDI engine performance improves due to heightened catalytic combustion and hence lower ID, CD and higher PP were obtained compared to B20 blend [11, 14, 15]. This is attributable to enhanced thermal efficiency and peak pressures witnessed at those injection timings emanated from the combustion of integral segment of fuel at cited revised injection timings during premixed combustion phase that effectuates lesser values of combustion duration and ignition delay exclusively. When injection timings are delayed past 10ºBTDC, there is greater combustion duration and an ignition delay, respectively. B20 and nano-biodiesel blends exhibited higher delay periods and combustion duration and lower peak pressures when compared to diesel fuel operation. Similar results were reported in the published literature [21, 22].

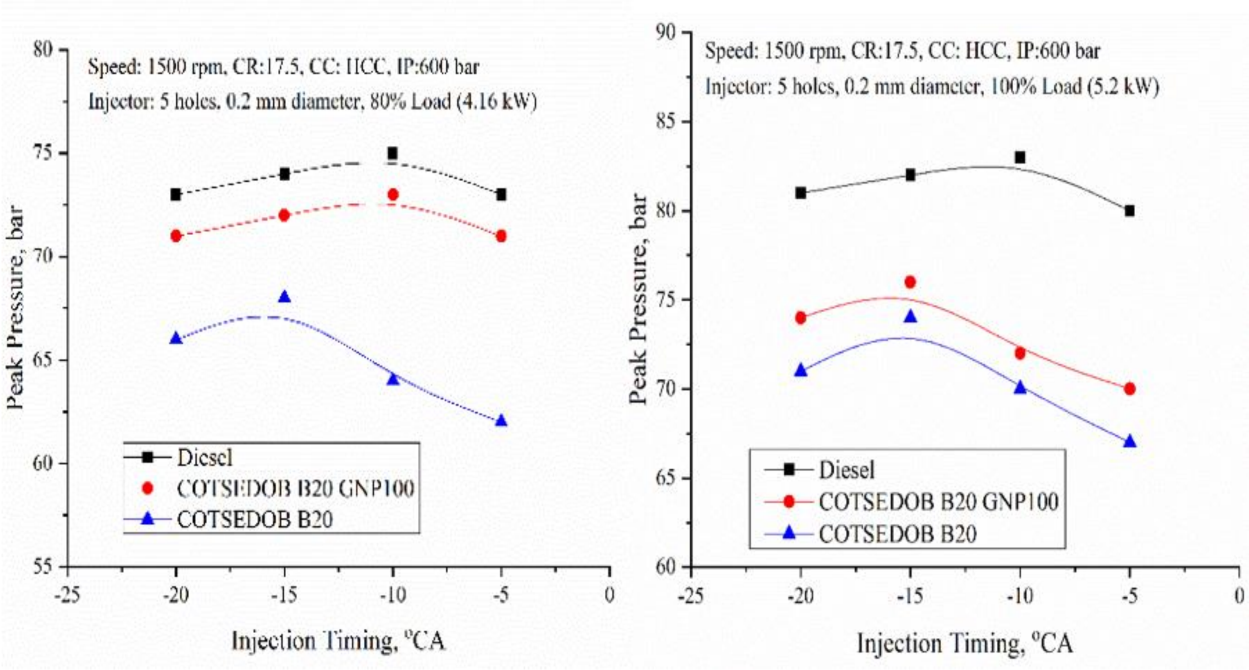

Figure 11: (c) PP vs. IT variation for B20 blends at 80 and 100% loading.

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Figures 12(a), 12(b), and 12(c) give the impression that, for the COTSEDOB B20 and COTSEDOB B20 GNP100 powered CRDI engine, combustion duration and ignition delay decrease while peak pressure increases as injector opening pressure increases [10, 11, 14]. This could be because the injected fuel burns more richly and there is less ignition delay at higher injector opening pressure. Combustion duration and ignition delay elevates at immense pressure of 1200 bar is noticed on account of declined heat release rate and peak pressure by virtue of part of fuel reposed in the clefts that evades combustion. However, B20 blends of COTSEDOB and COTSEDOB GNP100 respectively bear higher combustion duration and ignition delay mightier on contrary to diesel. Near B20 blends, COTSEDOB B20 blend showcase enhanced values of combustion duration and ignition delay and more elevated peak pressure in contrast to COTSEDOB B20 GNP100 at 1000 bar. B20 exhibited higher delay periods and combustion duration when compared to diesel fuel operation. B20 nano-biodiesel blends exhibited comparatively lower delay periods and combustion duration and lower peak pressures when compared to B20 and diesel fuel operation. Similar trends of combustion characteristics for biodiesel blends were reported in the literature [21, 22].

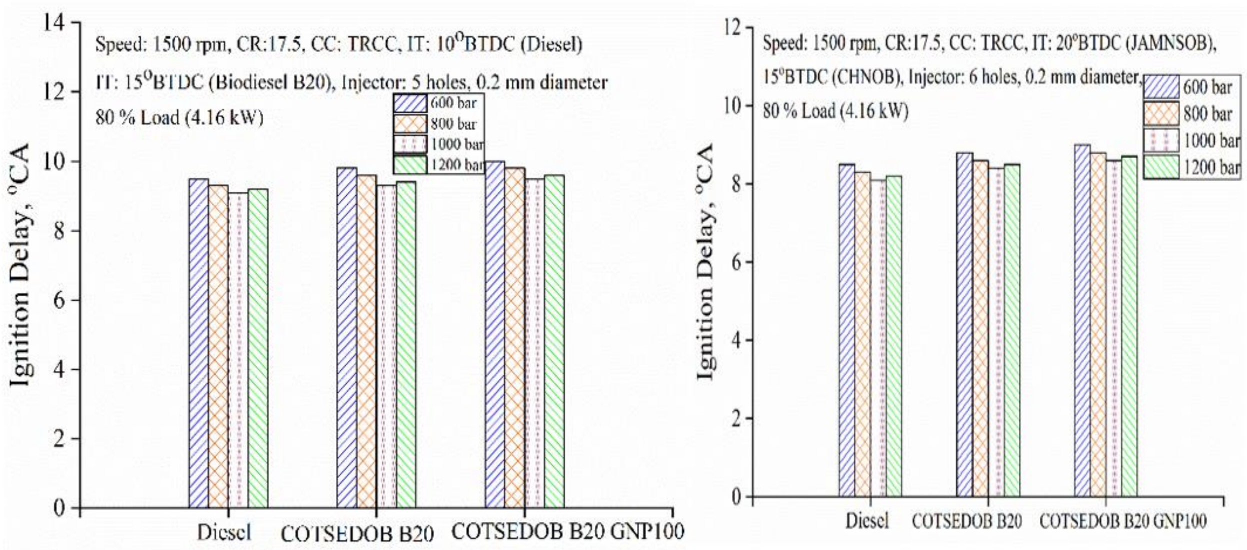

Figure 12: (a) ID vs. IOP variation for B20 mixes at 80 and 100% loading.

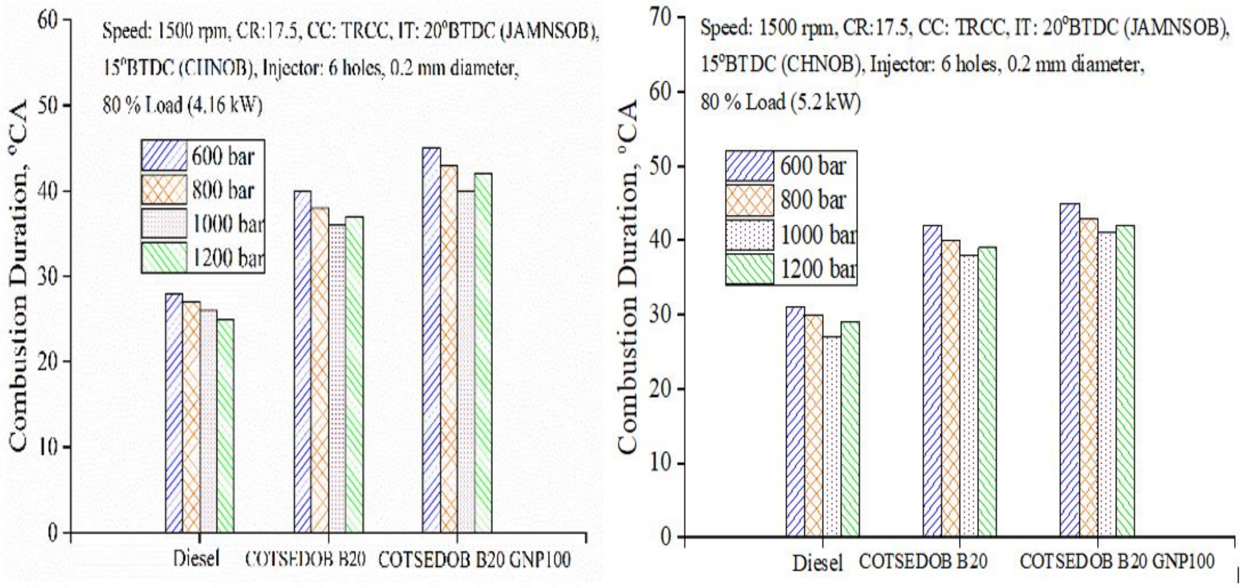

Figure 12: (b) CD vs. IOP variation for B20 mixes at 80 and 100% loading.

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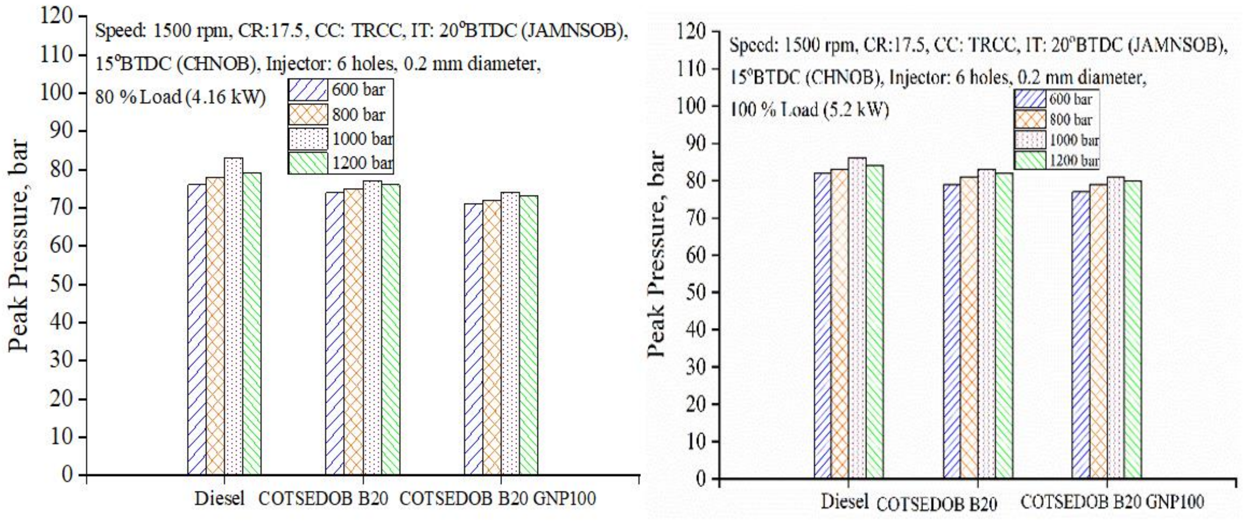

Figure 12: (c) PP vs. IOP variation for B20 blends at 80 and 100% loading.

5.0 CONCLUSIONS

Adoption of COTSEDOB B20 and COTSEDOB B20 GNP100 in high pressure assisted CRDI modified diesel engine is thoroughly predominant by IT, IOP and NG. The conclusions drawn from study carried out are listed below.

- Advancement in IT from 20 to 15°BTDC, for the B20 blends of biodiesels boosts BTE, lowers emission of smoke with increase in NOx. An increment in IT inflates PP while Combustion parameters viz., ID, CD declines.

- Significant rise in BTE when IOP elevated from 600 to 1000 bar for B20 blends of biodiesels. An increment in IOP inflates PP while Combustion parameters viz., ID, CD declines.

- Optimizing the parameters of IT and IOP of CRDI can effectively address the ill effects of diesel engines. For optimized injection timing (15°BTDC) and injection opening pressure (1000 bar) for COTSEDOB B20 and COTSEDOB B20 GNP100 when compared to baseline parameters of (20°BTDC) and injection opening pressure (600 bar), at 80% load BTE increased by 6.51, 8.64%, smoke decreased by 26, 23.07%, NOx increased by 10, 15%, ID decreased by 8, 9%, CD decreased by 10, 12% and PP increased by 14, 18% respectively.

Most of the recent diesel vehicles are operated with CRDI facility for automotive traction applications. This is suitable for the present work as biodiesel and nano-biodiesel blends used are more viscous and hence needs to injected with extremely higher injection pressures of more than 1000 bar. Real time applications of the nano-biodiesel blends in high pressure CRDI engine need longer times of operation before they can be commercially viable for vehicular traction.

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