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IMPACT OF COMPRESSION RATIO & INJECTION PRESSURE ON NO_X EMISSION BEHAVIOUR OF VCR DIESEL ENGINE POWERED BY MADHUCA LONGIFOLIA BIODIESEL

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Abstract

The energy (fossil fuel) crisis in the world is a big challenge for all the research fraternity. Very promising alternative source of energy to this is renewable sources. As an agriculture-oriented country, India cannot deny the capability of biodiesel. Again, it is a challenge to run an engine powered by biodiesel by keeping the NO_X emission within the allowable limits of emission norms. The effect of varying compression ratio (CR) & injection pressure (IP) on NOx generation was studied for VCR test rig powered by Madhuca Longifolia biodiesel here in this article. Experimentally observations were recorded by varying CRs (18:1, 17:1, 16:1, and 15:1) and IPs (600 bar, 500 bar, 400 bar, and 300 bar) with four variety of fuel blends (Diesel, B10, B20, and B30) for 25%, 50 % 75% and 100% load conditions. The result shows that the Lowest NOx was reported for 600 bar injection pressure and 15 compression ratios at 25% engine load. while increasing engine load from 25% to 100% (Full Load) with said test condition. It was found that a high compression ratio around 16 and 600 bar injection pressure gives better results than all other test parameters with respect to NO_X emission.

Keywords- Biodiesel, NO_X emission, Compression ratio, Injection pressure, VCR.

Introduction

In the present scenario, more and more internal combustion vehicles are increasing, due to which NOx and greenhouse gas emissions are increasing. Rising prices of fossil fuel and uncompromising emission regulations lead the researchers to investigate other options for diesel like biodiesel.[1]

Biodiesel has the capability to reduce the consumption of fossil fuels. It is reproducible, has no harm to the ecosystem, and could be generated in low capacity at villages. Biodiesel is also capable to provide a green and efficient source of power in a localized way in rural areas. Whatever carbon emission is generated due to combustion is almost naturalized during the photosynthesis process of biodiesel crop growth. So biodiesel and other biomass-based fuels do not increase CO_2 in the atmosphere.[2]

Lots of investigations were conducted to analyse oil extracted from various feedstock and its blends as biofuel to carry out performance and emissions analysis.

The majority of studies have observed the results of the thermal performance of biodiesel-powered machines which is found significantly lower while comparing it with diesel-powered engines, however monoxides & dioxides of carbon and unburnt HC are lower, and NOx generated is higher.[3]–[5]

The transportation system is very essential to the economic development of a nation around the globe. Energy production, which is reliant on fossil fuels like gasoline and diesel, is currently the most important issue for the global transportation sector. Due to the growth of the automobile sector, energy usage in the transportation sector has grown by 1.1 percent every year globally. Only the transport industry has a prediction to grow by 63 percent share in liquid fuel consumption from 2010 to 2040.[6]

1.1 Biodiesel

Biodiesel as per ASTM is a fuel derived as mono-alkyl esters of long-chain fatty acids extracted from feedstock such as vegetable oils or animal fats and used in internal combustion engines.[7]

The ideal replacement for the current fuel source derived from fossil resources is needed to be natural and renewable fuels such as oil extracted from vegetables, seeds, and fats. A few examples of oil extraction are Soya bean, palm, and jatropha have been the most promisingly and very often utilized for extracting oils for the creation of Bio-diesel [8]. Due to a large disparity between demand and supply for this kind of edible oil, using them to make Bio-diesel is not practicable in India. As a result, in India, only certain oils that fall into the category of non-edible seeds and do not compete with food seeds can be used to make Bio-diesel. Another requirement for this kind of non-edible seeds has the potential to grow them through mass production in non-cropped wasteland sites. In India, there are a variety of trees, bushes, and plants which can be utilized to extract oil and produce bio-diesel.

1.2 NOx

When we are talking about NOx means it includes both nitrogen oxide and nitrogen dioxide, and both of them are harmful to health and the environment.[9]. NOx contains NO as the main ingredient with a little quantity of NO_2. Nitrogen has other oxides like N_2O (nitrous oxide), NO_3 (nitrogen trioxide), and N_2O_5 nitrogen pentoxide are so less that they can be ignored. The three main NOx types are thermal-based NO_X, prompt or instantaneous NO_X, and fuel-based NO_X. The Zeldovich mechanism, which happens at high temperatures, produces thermal NOx. Within the combustion chamber, nitrogen oxides form when atoms/molecules of N_2 and atoms/molecules of O_2 react at high temperatures, as well as the NO_X production rate quickly boosted up as the temperature is increasing. Thermal NOx is thought to be the most significant part of the whole NO_X generation in an IC engine. Fenimore NO_X is another name for prompt NOx, and it is formed when intermediate hydrocarbon components combine to make it, mainly C-H and C-H_2, react with Nitrogen in the combustion process to generate C-N, which then combines with Oxygen dioxide to make NO_X, because HC components are required for quick NOx production, and it is possible when rich fuel condition is there. Within the combustion chamber, fuel components containing nitrogen- are oxidized, and fuel NO_X is created. The creation of fuel NOx can be neglected in the case of diesel and biodiesel because nitrogen is relatively low in both fuels. However, a fuel containing excessive concentrations of nitrogen can be treated by applying additives.[10]. NOx emissions are highly undesirable, and laws governing the amount of NOx that can be released are becoming more rigorous.[11]. Acid precipitation, earth surface-level ozone generation, nutrient enrichment, and smog formation are all caused by NOx emissions[9].

1.3 Effect of Compression Ratio

The impact of varying CR on various parameters of IC engines was studied by some of the researchers.

K. Sivaramakrishnan explored the performance and emissions of VCR engines and compared them with regular diesel when powered with Karanja blended with diesel (80-20%, 75-25%, and 70-30%). Experiments were conducted for CR of 15:1, 16:1, 17:1, and 18:1. It has been researched how CR affects the consumption of fuel, BTE, and emissions. Biodiesel-diesel performance was assessed experimentally using response surface methods. The blend's BTE increases with increases in CR. For B25 at full capacity and at CR 18 BTE is 30.47% recorded which was the highest amongst all blends, which is 5% more than diesel. When compared to diesel, the HC reduced for various blends. The specific fuel usage fell

as the CR increased. When compared to diesel, Karanja oil blends provide greater pressures of combustion at high CR because of ignition delay and heat release value. **B25 at CR 15 gave minimum NOx, as the compression ratio increase NOx also increases.**[12]

Pali Rosha and Saroj Kumar Mohapatra worked on different compression ratios on a mono-cylinder DI engine powered by a palm biodiesel (B20) blend. The author aimed to analyze the impact of different CR (18:1, 17:1, and 16:1) on various engine properties by running an engine with a 20% palm biodiesel blend. With the rise in compression ratio (16:1 to 18:1) the delayed ignition duration whereas a rise in peak pressure in the cylinders and brake thermal efficiency was reported. At 3.5 bar BMEP, the brake thermal efficiency data in B20 fuel were 28.9, 30.8, and 33.8% at 16:1, 17:1, and 18:1 CRs, respectively. Furthermore, rising the CR from 16:1 to 18:1 resulted in a reduction in HC, CO,

and smoke opacity emissions of 47.7, 41,

and 35.8%, respectively. Oxides of nitrogen generation increased by 41.1%. As a result, concluded that blend B20 showed effective results for a higher compression ratio 18. **B20 at CR 16 produced minimum NOx.**[13]

Jatinder Kataria and S.K. Mohapatra carried out the experimental study on a VCR diesel engine powered by biodiesel extracted from waste cooking oil with heterogeneous catalysts consideration. Because BTE is directly proportional to CR, increasing CR increases BTE. B 40 with CR 17.5 has the highest thermal efficiency at full load, which is more than diesel. Biodiesel provided a significant reduction in brake-specific energy consumption, CO, and HC values for high CR values**.**[14]

1.4 Effect of Injection Pressure

Analytical studies for different injection pressure on IC engines for various parameters is studied by some of the researchers.

Murat Kadir YESILYURT carried out the experimental work of varying IP on a CI engine powered by waste cooking oil biodiesel (WCOB) and its 5-30% (v/v) mixing proportion in diesel fuel. Observations were recorded for six different pressure of fuel injection (170-220 bars), 11 different engine speeds (1000-3000 rpm), and at full load conditions to find out the best pressure for favorable results. The study showed that fuel blends might use in a diesel engine with no modifications. By considering all the observations, the best fuel pressure of

Table 1:Effect of Compression Ratio

Sr. No	Fuel	CR	Optimized CR	Outcome		Author & Year	Ref.
				Thermal Performance	Emission		
1	Karanja biodiesel B20, B25, B30,	15,16, 17,18	18, B25, Max load	BSFC, ↓ BP, BTE, CP ↑	SMOKE ↓ CO, HC, ↓ NO_X ↑	K. Sivaramakrishnan-2017	[12]
2	PALM B20	16,17, 18	18, B20	BSFC, EGT, ID ↓ BP, BTE, ↑	SMOKE CO, HC, ↓ NO_X ↑	Rosha P, Mohapatra SK, Mahla SK Energy-2019	[13]
3	Waste cooking Oil B20, B40, B60, B80, B100	15, 17.5	17.5 B40	BP, BTE ↑ BSFC ↓	SMOKE, ↓ CO, HC, ↓ NO_X ↑	Jatinder Kataria, S.K. Mohapatra-2018	[14]
4	Jojoba methyl Ester Biodiesel	18,20, 21.5, 22,23	18, JME100	BSFC, EGT, CP ↓ BP, BTE, ↑	NO_X, ↓ CO, HC, ↓	Meshack Hawi, Ahmed Elwardany-2019	[15]
5	Biodiesel (palm oil) + fuel (methanol) BM5, BM10, BM15	16,17, 18	18 BM5	BSFC, EGT, CP, ↓ BP, BTE, ↑	SMOKE ↓ CO, HC ↓ NO_X ↑	Y. Datta Bharadwaz, B. Govinda Rao-April-2016	[16]
6	(Jatropha biodiesel and turpentine oil) JBT50, JBT70, JBT90, JB	15.5, 17, 18.5, 20	20, JBT50	BSFC, EGT, ↓ BP, BTE, CP, ↑	SMOKE, ↓ CO, HC, ↓ NO_X ↓ CO_2 ↑	Pankaj Dubey, Rajesh Gupta, Renewable energy-2017	[17]

injection for WCOB and fuel blends was discovered to be 210 bar. [18]

V Channapattana , Abhay A Pawar aimed to study experimentally the effect of fuel injection pressure (180-240 bar) on single cylinder VCR, engine powered with Honne biodiesel and diesel blends. The engine's CR is set to 18 instead of the designated 17.5 CR value. The performance of blended fuel compared with diesel. The results showed that the BSFC for Honne biodiesel is 0.042 Kg/kw hour more than that of Diesel oil at 240 bar IP. The study shows the differences in thermal performance parameters at various IPs ranging from 180 bar to 240 bar in 30 bar incremental steps while keeping a constant CR of 18 and a full load of 12 kg. The time of injection was kept fixed at the designated value of 23° bTDC. In comparison to all other blends, Honne biodiesel (B100) emits the fewest hazardous emissions. Furthermore, regardless of the fuel used, emissions are reduced at a greater CR of 18 and IP of 240 bar. The rise in IP causes an increase in NOx emissions. As the blend percentage increases, the NOx emissions increase. B20 blend provides superior thermal performance than other Honne biodiesel blends, but it produces higher amounts of exhaust pollutants.[19]

Pankaj Shrivastava, Tikendra Nath Verma experimented on B20, B40, and B100 Roselle biodiesel blends by changing the injection pressure of fuel (180-260 bars) at various engine loading conditions (25-100%). The results showed rising in injection pressure deteriorates the ignition delay period, and smoke emission, and indicated thermal efficiency. Increasing the injection pressure resulted in higher BSFC, cylinder pressure, CO_2, and oxide of nitrogen emission.[20]. Very few researchers have experimentally investigated the behaviour of NO_X by varying Compression ratio and fuel injection pressure for the mono-cylinder CI engine which is fueled by Madhuca Longifolia biodiesel blends

2 Experimental Material and Methods

2.1 Madhuca longifolia (Mahua) tree- a biodiesel feedstock

There are around 84 varieties of mahua, five of them are present in India and can be distinguished by their leaf structure.[24][25]. Madhuca longifolia, latifolia, butyracea, bourdillonii, and neriiolia are the 5 scientific names for Indian species.[25][26]. The Mahua tree is a well-known tree that is spotted in Indian forests that belongs to the Sapotaceae family. It is a multi-use tree known by different

Table 2: Effect of Injection Pressure

Sr. No	Fuel	IP (bar)	Optimized IP (bar)	Outcome: Thermal Performance	Outcome: Emission	Author & Year	Ref.
1	Waste cooking Oil Biodiesel	170,180,190,200,210,220	170	BP, BTE↑ BSFC↓	SMOKE NO_X, CO_2 ↑ HC↓	Murat Kadir YESILYURT-2018	[18]
2	Honne Biodiesel B20, B40, B60 B80, B100	180,210,240	180, B20	ID↓ BTE, BP↑ BSFC, EGT↑	SMOKE, CO, HC CO_2, NO_X↑	V Channapattana, Abhay A Pawar, -2015	[19]
3	Roselle Oil RB20, RB40, RB100	180,200,220,240,260	180, RB20	BTE, BP, ID↓ BSFC, EGT, CP↑	CO, HC, SMOKE ↓ NO_X, CO_2 ↑	PankajShrivastava, Tikendra N Verma-2020	[20]
4	Waste cooking Oil Biodiesel	220,240,260,280,300	280 with IT25.5°(bTDC)	BSFC, ID↓ BP, BTE, CP↑	CO, HC, SMOKE↓ NO_X, CO_2↑	G.R. Kannan, R. Anand-2012	[21]
5	Honge Oil and its blend B10, B20, B40, B80, B100	205,220,240,260,280,	220, B20	BSFC, EGT, ID↓ BP, BTE, CP↑	CO, HC, SMOKE ↓ NO_X, CO_2 ↑	N R Banapurmath∗, P G Tewari, and R S Hosmath-2009	[22]
6	Pongamia oil methyl ester (POME20)	185,200,210,220,230	185, POME20	BSFC, ID↓ BP, BTE, CP↑	CO, HC, ↓ SMOKE NO_X, CO_2 ↑	S.Jaichandar,K.Annamalai-2013	[23]

The components like roots, bark, fruits, and seeds of the mohua are medicinal. The wood of mohua is very strong, hefty, and brown. The bark of mahua is rough and greyish, with cracks and wrinkles. Leaves of mahua are thick and oblong; when split, they release a milky sap. The flowers of Mahua are cream-colored and cluster at the ends of the branches. Mahua flowers, which are eaten fresh, are high in carbs, proteins, minerals, and vitamins.[27] Figure 1(a) also depicts mahua blooms and dried flowers. Fruits are elliptical and around 1.19-1.95 inches long, with fleshy greenish flesh. As seen in Fig 1(b), a fruit of mahua bears 1-4 sparkling elliptical form brown-colored seeds.

Table 3 depicts the overall growth trend of Madhuca longifolia, (One Year Cycle) and reflects seed availability

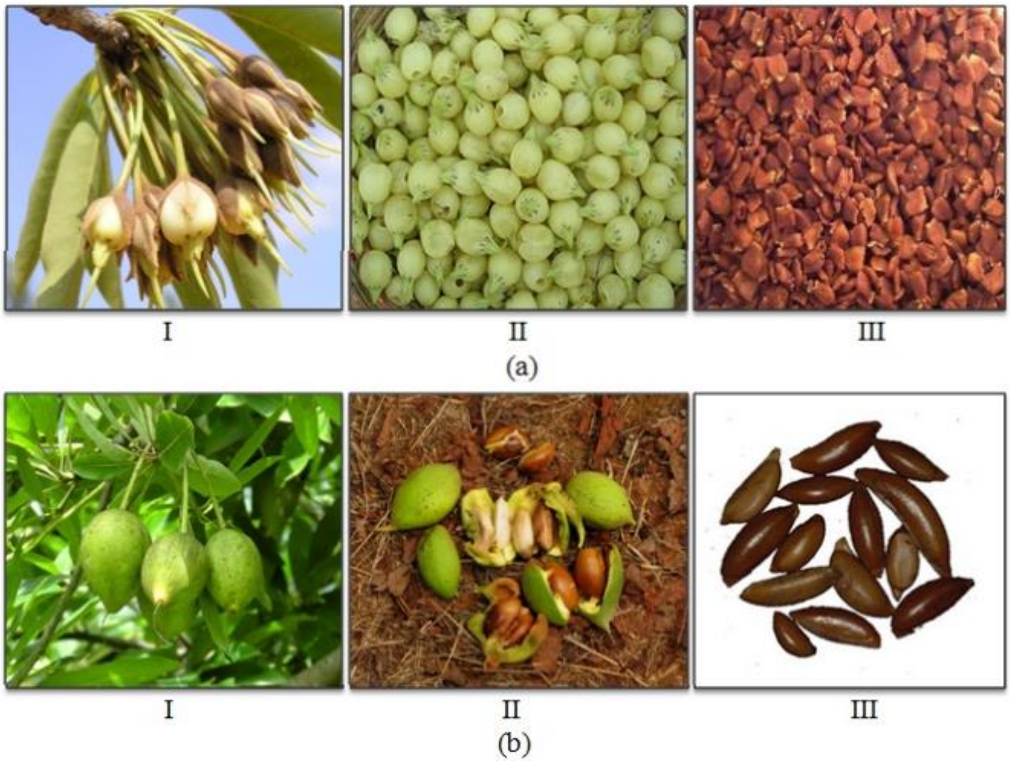

Figure 1: (a) Mahua flowers and (b) Mahua fruits with seeds[25]

.*Table 3: Madhuca longifolia (A year cycle)*

	February	March	April	May	Jun	July	August	September
Blossom	■	■	■	■				
Fruits		■	■	■				
Leaf Fall		■	■					
Pods				■	■	■	■	
New leaf				■	■	■	■	
Seeds					■	■	■	■

The biodiesel of mahua minimizes dependency on fossil fuels. The global warming potential (GWP) was determined which is 7 times lower compared to the Petro-diesel value, and it was reported that the acidification and eutrophication potential of the Mahua system were negligible.[28]. Diesel vehicles release 11 pm per MJ, while biodiesel releases less than 0.01 pm per MJ, potentially contributing significantly to pollution-free air. [25][29]. Furthermore, from this process mahua seed cake is obtained and it is used as fertilizer, detergent, pesticide compost for earthworms, organic shampoos, burns of seed cakes lays mice and insects, and so on. In another way, it is utilized in the production of biogas and activated charcoal. The mahua system's NEG is 17.17 MJ/working unit. When compared to Jatropha and the Pongamia biodiesel system, the Mahua plant has a higher CO_2 sequestration potential (from 0.2 to 5.8 t CO_2/hectare).[25][30].

2.1.1 Madhuca Longifolia oil as biodiesel

Mahua seed output ranges from 10-225 kilograms for a tree. The output of mahua seeds is mostly determined by the tree's age and size. In India, mahua seed oil extraction is projected to be 18 lakh metric tonnes per annum.[31]. Mahua seed has 315.51ppb of total aflatoxin, while mahua oil contains 220.66ppb.[25][32]. It also contains saponins and tannins that are harmful to humans, and as a result, Madhuca Longifolia oil is classified as non-addible.[25][33]

2.2 Preparation of Biodiesel Fuel

2.2.1 Transesterification process

1. Material: 1-liter oil sample, methanol, KOH solution, methanol, three neck glass flask, heating mental, separating funnel with bottom side valve.

2. Pre-treatment: 1 liter of Madhuca Longifolia oil is cleaned and heated for 2-5 minutes at 60°C. Poured into a flask with three necks. This 3-neck glass container is heated mentally and has the magnetic starring capability. A thermocouple was installed to measure temperature. For dehydration and impurity filtration, the oil is heated for 10 minutes between 60°C to 65°C. It is then allowed to return to room temperature.[34]

3. Transesterification: A base catalyst is used for this process. 15 gm potassium hydroxide (KOH) blended with 300 ml methanol (CH_3OH). The solution derived was placed into the oil for 60 minutes at 60°C. [34]

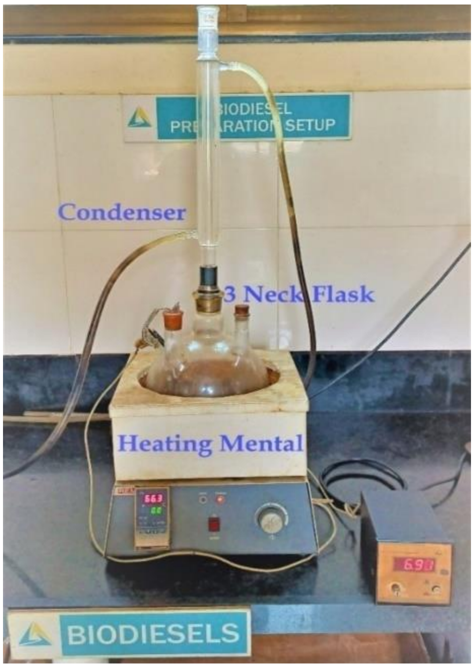

Figure 2:Biodiesel Preparation Setup

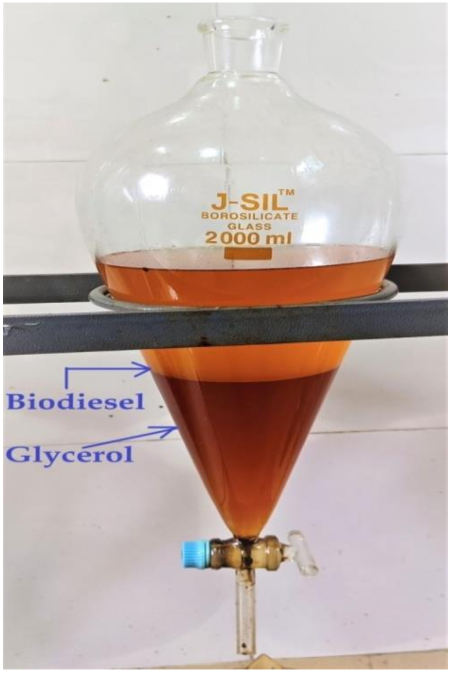

Figure 3: Biodiesel and glycerol separation

Separation: Glycerine and FAME separated after an hour of transesterification reaction. Around 8-10 hours are spent settling and separating. The bottom layer of glycerine separated, and biodiesel in the form of FAME derived. To condense ethanol, a condenser was utilized. For water washing, 100 ml of distilled water at 50 degrees Celsius was blended with 100 ml of oil. Methanol and associated impurities are rinsed away in water washing. Water, on the other hand, can be added to oil. We obtained a yield of 85% to 90%.

2.2.2 Biodiesel Properties:

It is essential to understand the various qualities related to biodiesel to compare them to the properties of traditional petro-diesel. Samples of B10, B20, B30, and B100 are prepared (Fig-4) and important properties of these blends were tested in the laboratory as per ASTM standards.

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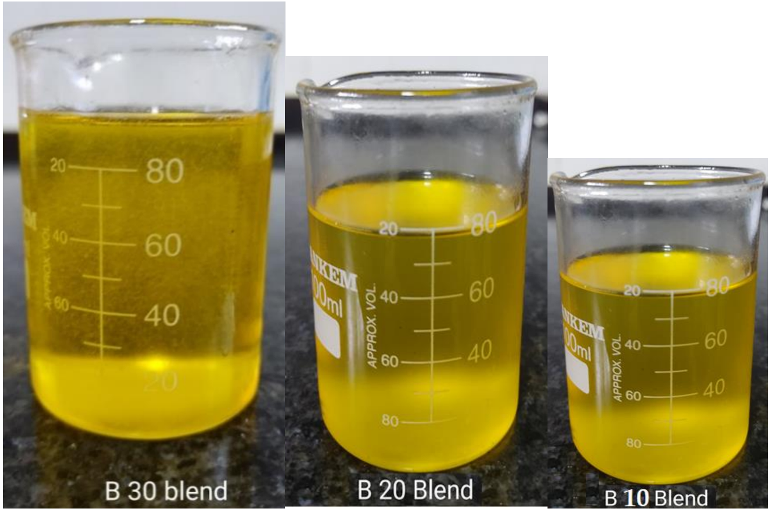

Figure 4: B10, B20, B30 Biodiesel Blend

Table 4: Madhuca Longifolia fuel property

Sample/ Properties	Calorific value	Density At 25 °C	Acid Value	Flash Point	Fire Point	Kinematic Viscosity@40 °C	Dynamic Viscosity @40 °C
Unit	KJ/kg	Kg/M³	Mg of KOH/gm of oil	°C	°C	cSt	cP
ASTM Standard	D4809	D287	D6751	D93-58T	D93-58T	D445	D445`
St. Diesel	45236	816	0.6	53	56	2.09	1.73
B10	44074	826	0.73	61	67	2.79	2.30
B20	42941	828	0.79	68	74	2.93	2.43
B30	42256	832	0.89	71	77	3.08	2.56
B100	42034	871	1.31	101	110	4.98	4.34
Raw Oil	39932	910	2.20	256	270	39.6	36.0

Oxygen stability

The stability of oxidation of the fuels considered is shown in Fig.5. The Induction period is 8.3 hrs, which meets the standards set by ASTM (D-6751 minimum 3 hrs), and IS-15607 (minimum 6 hrs). Limited oxidation stability may adversely cause issues during usage as the fuel is exposed to high temperatures.

2.3 Experimental setup

A mono-cylinder, 4-stroke CRDI VCR engine is coupled to an eddy current-type dynamometer for loading. By using a tilting cylinder block mechanism, the compression ratio can be set without halting the engine or interrupting the combustion chamber geometry.

2.3.1 Engine Specifications

Specification of the Test rig is as below table-5.

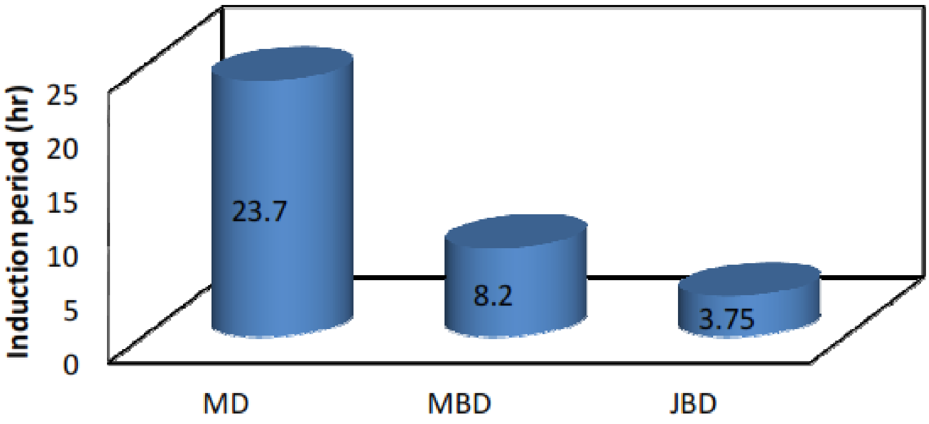

Figure 5: Oxidation Stability of Mineral Diesel, Madhuca Longifolia, and Jatropha biodiesel[35]

Table 5: Engine Specifications

Engine	Make Kirloskar, Momo cylinder, water cooled,4 stroke
Bore	87.5 mm,
Stroke	110 mm
Power	3.5 KW,
Cubic Capacity	661 cc.
Speed	1500 rpm,
Compression Ratio	12-18.
Dynamometer	Eddy current, water jacketed
Common rail	With pressure sensor and pressure regulating valve

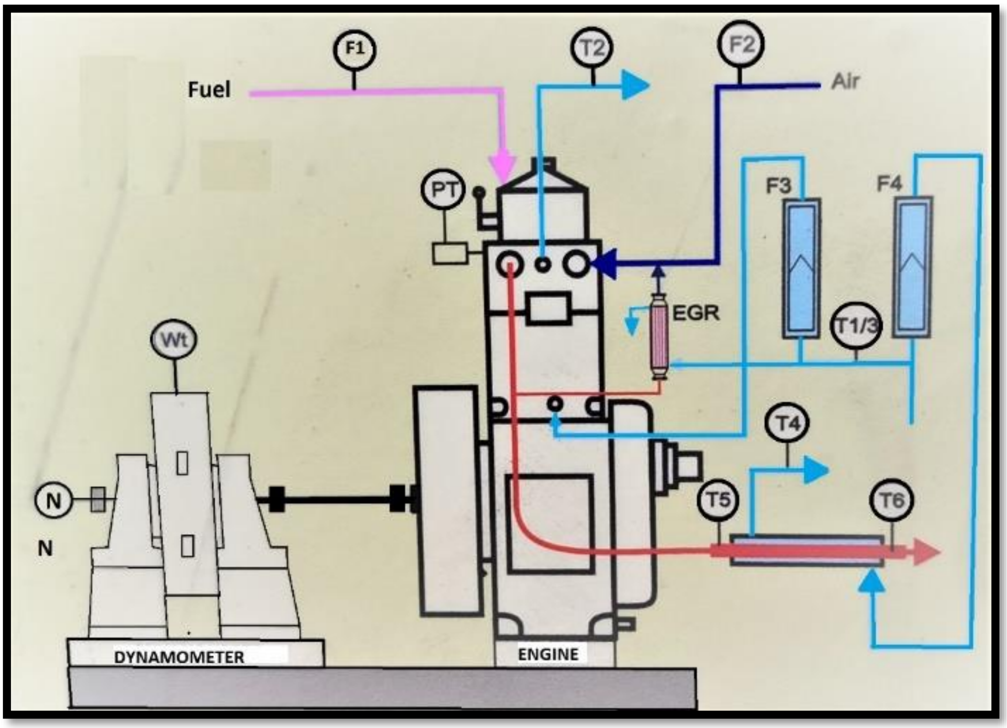

Figure 6: Schematic diagram of the Test rig

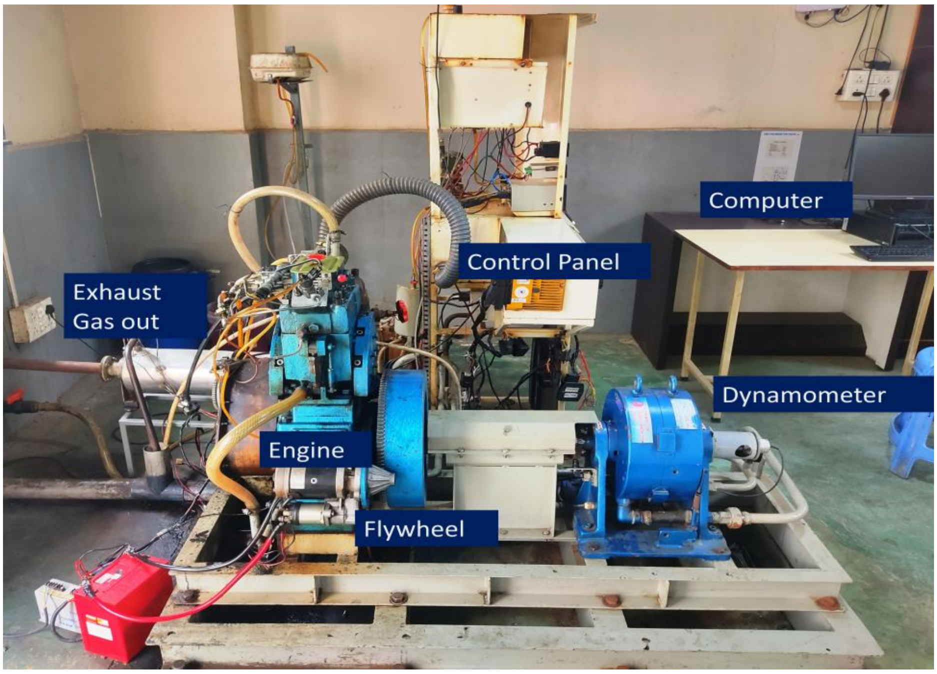

Figure 7: Experimental setup

Table 6:Sensor number, location, and details for computerized engine setup

Sr	Number	Description/Location	Unit	Sensor/Device
1	(T1)	Engine Jacket In	°C.	RTD PT 100
2	(T2)	Engine Jacket Out	°C.	
3	(T3)	Calorimeter In	°C.	
4	(T4)	Calorimeter Out	°C.	
5	(T5)	Exhaust Gas Temperature Before Calorimeter. (Engine)	°C.	Thermocouple K type
6	(T6)	Exhaust Gas Temperature After Calorimeter. (Calorimeter)	°C.	Thermocouple K type
7	(F7)	Air Flow Transmitter	mm WC	Pressure transmitter
8	(F8)	Fuel Flow Transmitter	mm WC	Differential pressure transmitter (DPT)
9	(F9)	Load Cell Sensor	kg	Strain gauge
10	(P10)	Cylinder Pressure Transducer	bar	PCB pizoelectronics USA
11	(R12)	Engine Rpm (CA) Sensor	Crank angle	Encoder
12	(F3)	Engine Jacket Cooling Water Flow Rate	LPH	Rotameter
13	(F4)	Calorimeter Cooling Water Flow Rate	LPH	Rotameter

Figure 8: Smoke Meter

Figure 9: Exhaust gas Analyser

2.4 Uncertainty analysis

The below table shows the accuracy of other instruments and sensors which are used in the experimental setup

Table 7:Details of instruments & sensors attached to the experimental setup

Name of device/instrument	Used for	Accuracy
Pressure sensor	In-cylinder pressure	±1%
Analog temperature Transmitter	Water and exhaust gas temp	±0.5%
Speed indicator	RPM indicator	± 0.05% F.S.
Encoder	Crank angle and RPM	± 0.25%

Load cell	Measure load	± 0.25 % F.S. (± 0.125 kg)
Load indicator	Display applied load	± 0.2% F.S.
Differential pressure transmitter	Fuel flow rate	±0.1%
Pressure transmitter	Air flow rate	±0.5%
Rotameter	Water flow rate	± 2% F.S.

Table 8: Emissions Measurement Device Details

AVL437 Standard	**Smoke Opacity measurement**	
Measurement range	430 mm ±5 mm	
Measurement	Range	Resolution/Accuracy
Absorption (K Value)	0 to 99.99 m^{-1}	0.01 m^{-1}
Opacity	0 to 100%	0.1 %
Engine speed (RPM)	400 to 6000 min^{-1}	1 min^{-1}
Oil temperature	0 to 150 ^{0}C	1 ^{0}C
Linearity check	≈ 50% of the measured range	

*Table 9:Emissions Measurement Device Details (**AVL444N Gas Analyser)***

Parameter	**Unit**	**Measurement**	**Resolution**	**Accuracy**
CO	% Vol	0 to 15% Vol	0.01% Vol	<0.6 %: ±0.03 % Vol ≥0.6 %: ±5 % ind. Val
HC	ppm Vol	0 to 20,000	1 ppm /10 ppm <2000 RPM / >2000RPM	<200ppm Vol: ±10 ppm Vol ≥200ppm Vol: ±5 % ind. Val
CO_2	% Vol	0 to 20	0.1 % Vol	<10%: ±0.5 % Vol ≥10%: ±5 % ind. Vol
O_2	% Vol	0 to 25	0.01 % Vol	<2%: ±0.1 % Vol ≥2%: ±5% ind. Vol
NO	ppm Vol	0 to 5000	1 ppm Vol	<500ppm Vol: ±50 ppm Vol ≥500ppm Vol: ±10% of ind. Val
Speed	RPM	400 to 6000 RPM	1 RPM	±1% of ind. Vol
Oil Temp	^{0}C	0 to 125	1^{0}C	±4 ^{0}C
Lambda (λ)	-	0 to 9.999	0.001	Calculations of CO, CO_2, HC, O_2

Table 10:Experimental Readings Uncertainty in Results/Readings

Sr	**Parameter**	**Uncertainty**	**Unit**
1	Nitric Oxide	± 68.49	ppm

3 Result and discussion

For the experimental study of the effect of compression ratio and injection pressure, we have taken four compression ratios 18, 17, 16, and 15, and four injection pressure 300 bar, 400 bar, 500 bar, and 600 bar respectively. So, the experiment was conducted by varying these fours Compression ratios and four injection pressure for four fuel blends. All the set of operating conditions were run for 25%, 50%, 75%, and 100% engine load. Speed for the engine was kept constant at 1500 rpm.

3.1 ICEnginesoft-Software

ICEEngineSoft software is a LabVIEW-based software engine performance monitoring system. This software is connected to the engine ECU and collects all the data during the testing. All the data is stored in an organized manner and can be abstracted whenever required.

3.2 Effect of various Compression ratios and injection pressure on NOx emission

The Higher side values of compression ratios in low-capacity diesel engines lead to an increase in pressure inside the cylinder chamber and thus increase heat release rate and lowering delay period the compound effect of which may increase in NOx generations. Increasing injection pressure also leads to increases in NOx values significantly but with the aid of EGR and by increasing EGR rates increase in injection pressure can accommodate NOx generations. The observation table for these various combinations is mentioned in the following tables

Sr. No	Fuel	Compression Ratio	Injection Pressure (Bar)
1	Diesel	15, 16, 17, 18	300, 400, 500, 600
2	B10	15, 16, 17, 18	300, 400, 500, 600
3	B20	15, 16, 17, 18	300, 400, 500, 600
4	B30	15, 16, 17, 18	300, 400, 500, 600

3.2.1 Injection Pressure- 600 bar

As discussed, methodology in the result and discussion section trials were conducted and various plots have been prepared. Fig 10 shows a comparison of NOx emission for diesel and biodiesel blends for fixed injection pressure at 600 bar. Further, it shows variations in compression ratios and load conditions. Here in experiments, compression ratios varied from 15 to 18 in four steps i.e. 15,16,17, and 18. And for all this compression ratio at 600 bar injection pressure NOx vs fuels graph plotted. Such four different load conditions were compared. The highest NOx 1953 ppm reported for B20 blends while keeping CR as 18 at 75% engine load condition with 600 bar fuel pressure of injection. The compound effect of an increase in engine load, compression ratio, and biodiesel blending at high injection pressure leads to increase NOx because of the insufficient octane rating demanded by the engine, more lean mixture, and lowered ignition delay period.

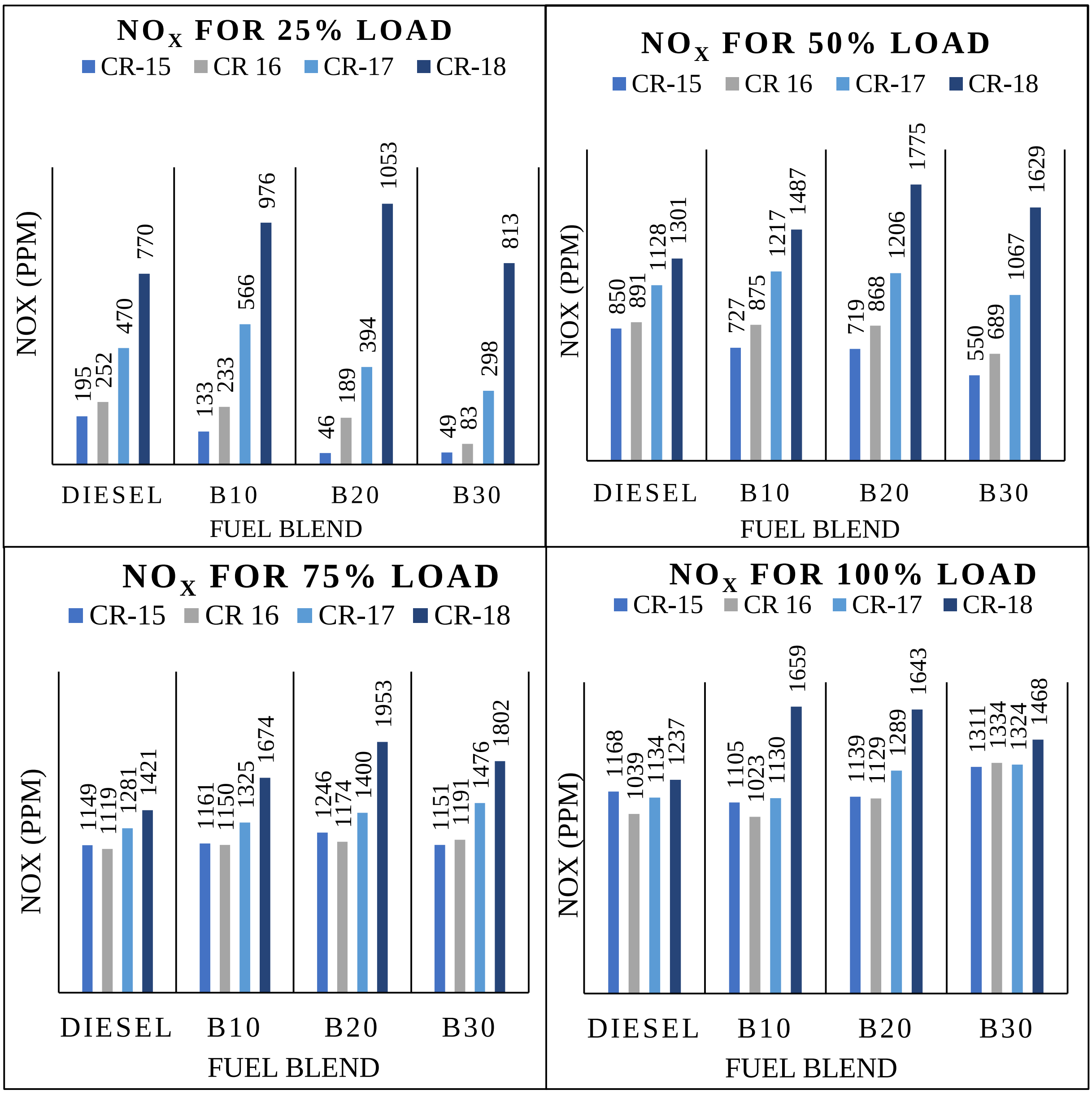

Figure 10: IP-600 bar: NOX emission for different fuel blends at different engine load conditions

All these lead to an increase in the surrounding temperature in combustion reaction which causes NOx generations. The lowest NOx 46 ppm was reported for B20 blends while keeping CR as 15 at 25% engine load condition and for 600 bar injection pressure. The best results for NOx were obtained at partial engine load conditions and lower compression ratios. However, for 1500 rpm diesel engine majority of readings falls in the permissible range but readings above 1200 ppm should be critically observed and taken care of by further NOx reduction techniques

3.2.2 Injection Pressure- 500 bar

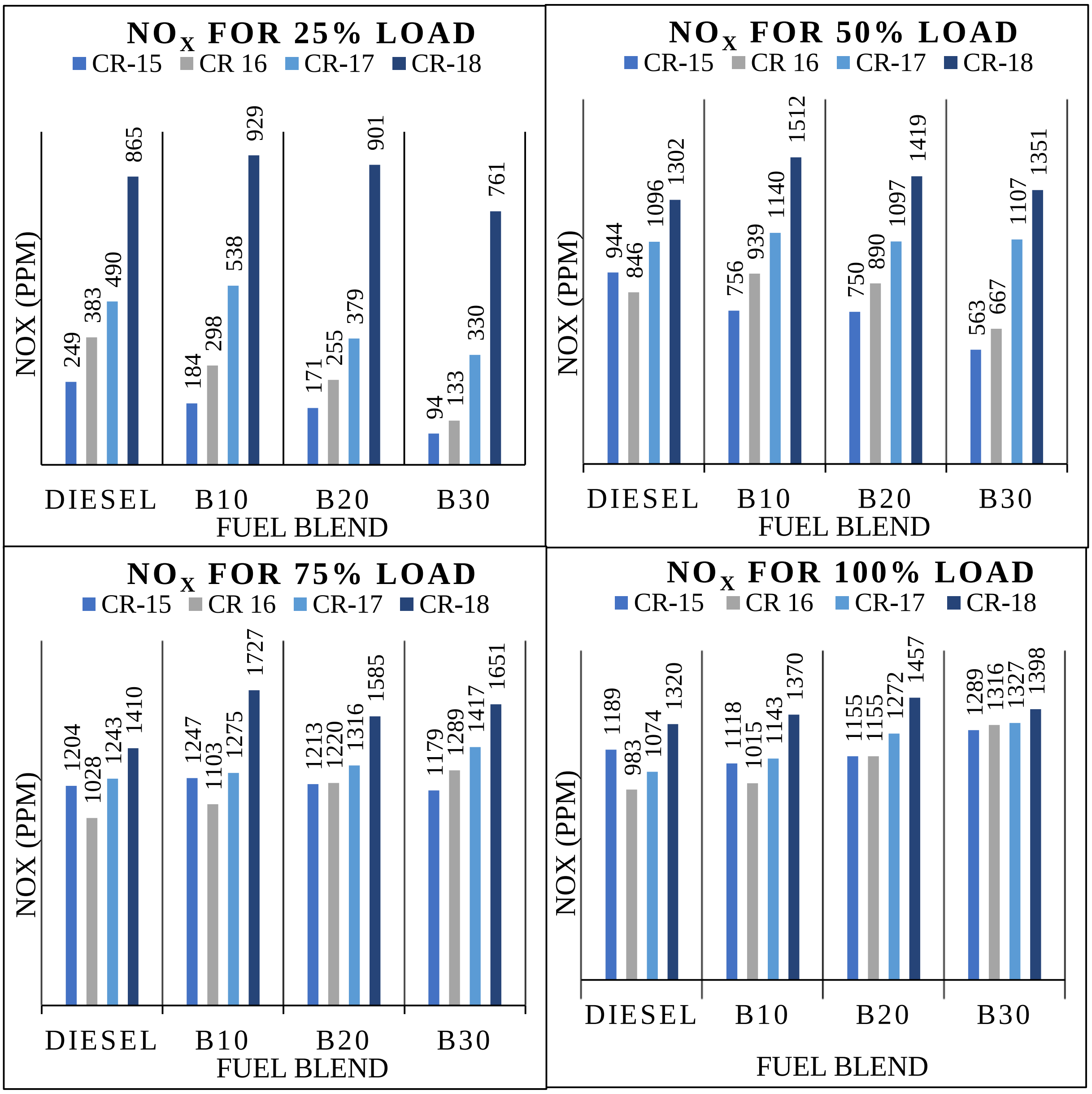

Figure 11:IP-500 bar: NO_X emission for different fuel blends at different engine load conditions

The above plot (Fig 11) shows a comparison of NOx with diesel and biodiesel blends for fixed injection pressure at 500 bar. The highest NOx 1727 ppm was reported for B10 blends while keeping CR as 18 at 75% engine load condition and for 500 bar injection pressure.

The lowest NOx 94 ppm was reported for B30 blends while keeping CR as 15 at 25% engine load condition and for 500 bar injection pressure.

3.2.3 Injection Pressure- 400 bar

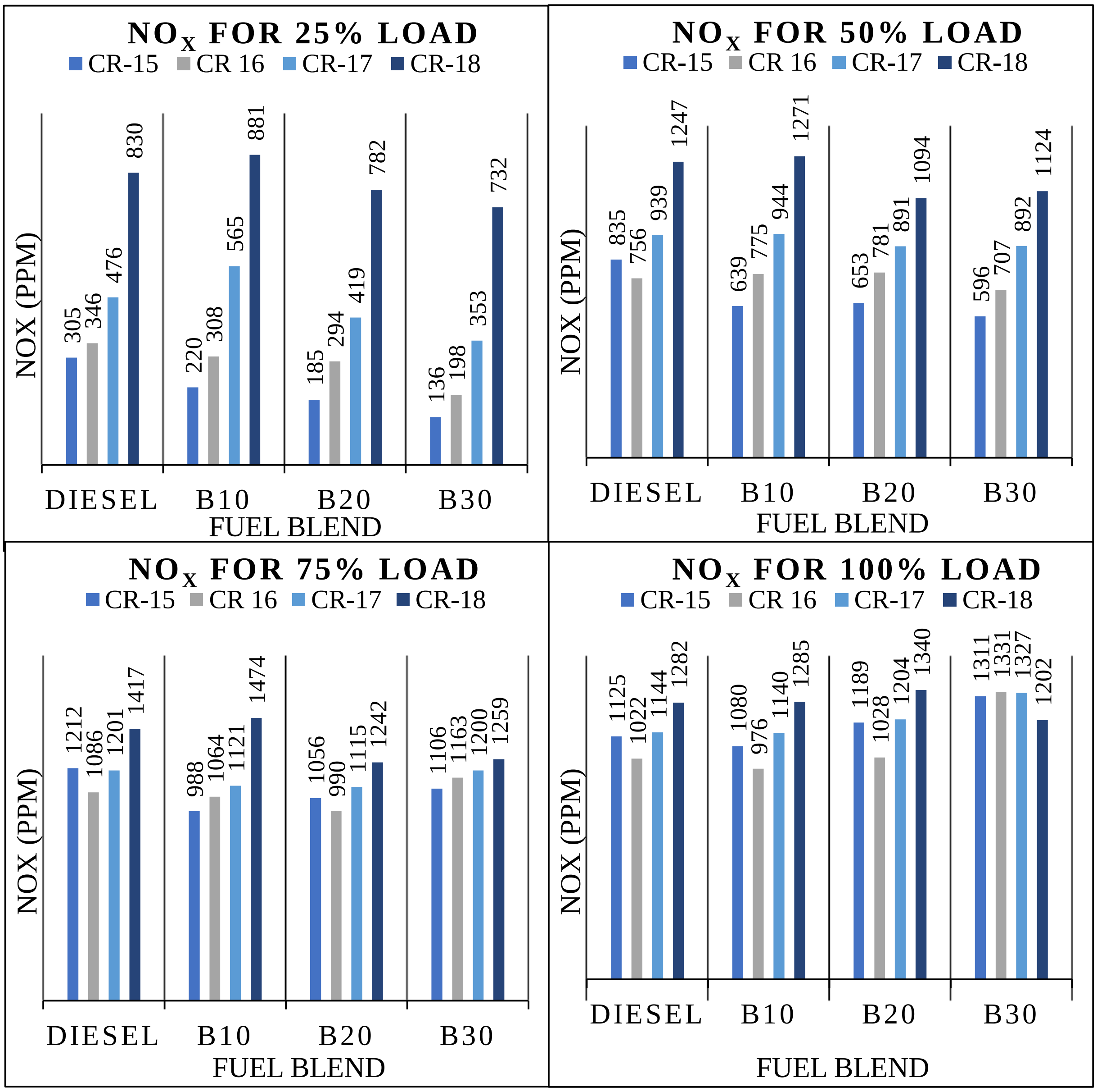

Figure 12: IP-400 bar: NO_X emission for different fuel blends at different engine load conditions

ppm was reported for B 10 blends while keeping CR as 18 at 75% engine load condition and for 400 bar injection pressure. The lowest NOx 136 ppm was reported for B 30 blends while keeping CR as 15 at 25% engine load condition and for 400 bar injection pressure.

3.2.4 Injection Pressure- 300 bar

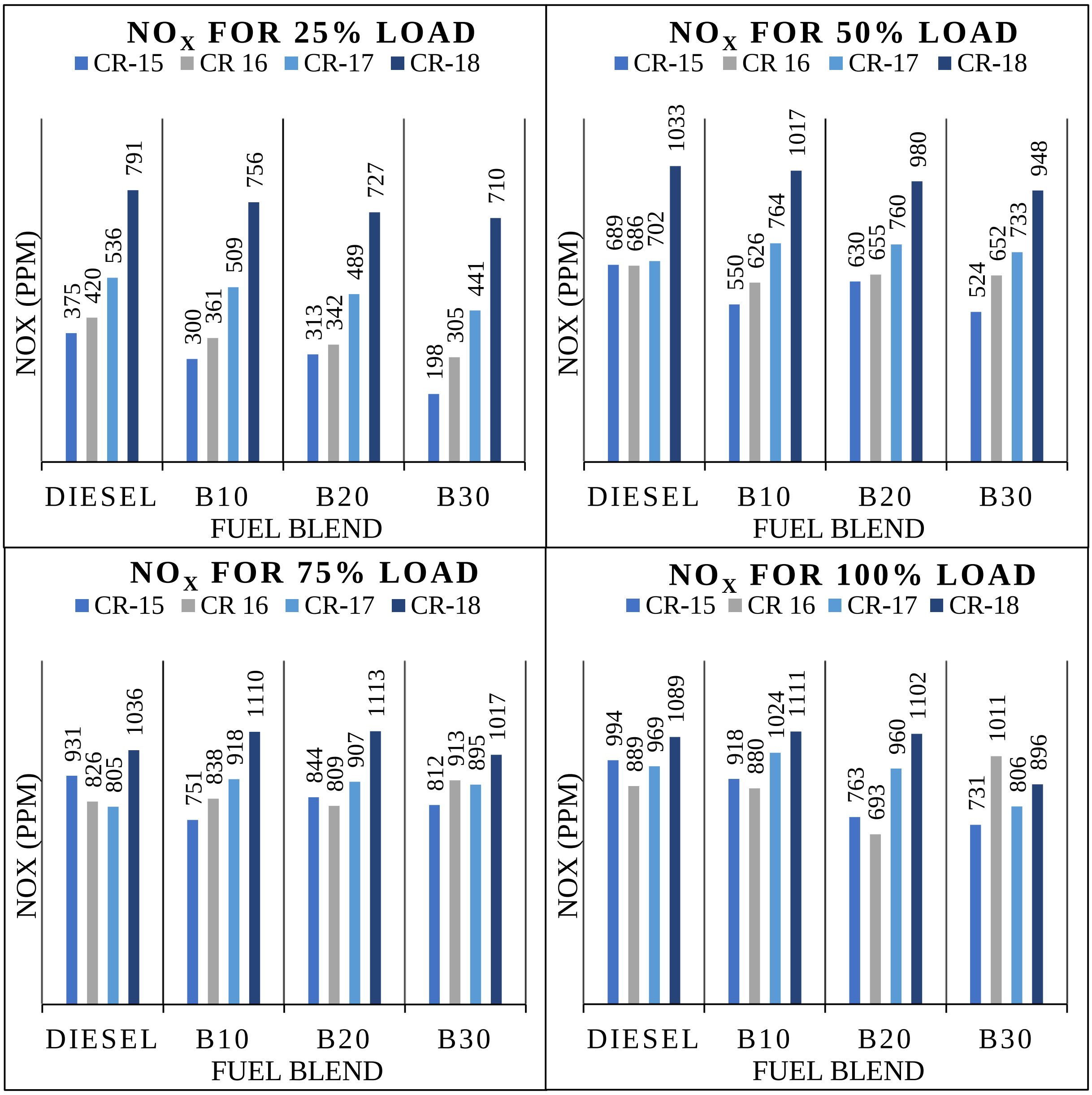

Figure 13: IP-300 bar: NO_X emission for different fuel blends at different engine load conditions

The above plot (Fig-13) shows a comparison of NOx with diesel and biodiesel blends for fixed injection pressure at 300 bar. The highest NOx 1113 ppm was reported for B 20 blends while keeping CR as 18 at 75% engine load condition and for 300 bar injection pressure. The lowest NOx of 196 ppm was reported for B 30 blends while keeping CR as 15 at 25% engine load condition and for 300 bar injection pressure.

The highest 1953 ppm of NOx was recorded for injection pressure at 600 bar compared to the same parameters like fuel blends and compression ratios that to the other injection pressure values. That gives a clear indication of the adverse effect of an increase in injection pressure on NOx. On the contrary lowest value of NOx 46 ppm reported for the same injection pressure at 600 bar while compared to other values of injection pressure leads to conclude the importance of compression ratios and fuel blends which are equally important parameters that affect NOx generations. By viewing engine capacity and working engine load conditions parameters like injection pressure, compression ratios, and fuel blends should be fixed for lowering NOx values.

4 Conclusion:

Experiments were carried out on mono-cylinder VCR engines by varying CRs (18:1, 17:1, 16:1, and 15:1) and IPs (600 bar, 500 bar, 400 bar, and 300 bar) with four varieties of fuel blends (Diesel, (B10, B20, and B30) of Madhuca Longifolia) for 25%, 50 % 75% and 100% load conditions.

For small and medium size CI engine injection parameter is a key factor that triggers NOx generation, at 600 bar injection pressure in this experimentation highest NOx found this is due to lower ignition delay at high injection pressure, a short delay causes leaner mixture which increases gas temperature that causes higher NOx.

There is a huge impact found in keeping lower compression ratios for small and medium size CI engines. Usually at the lowest designed compress ratios engine gives higher NOx but at 16 CR lowest values for NOx were received for almost all sets of experiments.

There were multiple trials where NOx values in biodiesel blends were found lower compared to diesel. This shows with little or no modification the diesel engine can adopt biodiesel blends as either primary or secondary fuels. Though further investigations on other parameters like combustion and ecological to establish biodiesel blends as a fuel for CI engines are essential to be carried out.

The lowest NOx reported at 600 bar injection pressure and 15 compression ratios at 25% engine load point out that keeping higher injection pressure is allowed if you optimize compression ratios. Further to this, while moving from 300 bars to 600 bars injection pressures NOx can be kept lower size by running the engine at the lowest compression ratio (15) and partial engine load (25%). Also, while increasing engine load from 25% to 100% (Full Load) with said test condition it was found that a high CR around 16 gives better results amongst all other test parameters.

However, for 1500 rpm diesel engine majority of readings fall in the permissible range but readings above 1200 ppm should be critically observed and taken care of by further NOx reduction techniques for those fixed values of injection pressure and compression ratio, and fuel blend.

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Nomenclature:

°C	Degree Centigrade
BSFC	Brake Specific Fuel Consumption (G/Kwh)
NO_x	Nitrogen Oxides
TDC	Top Dead Centre
CR	Compression ratio
IP	Injection pressure
VCR	Variable Compression Ratio
B10	Blend Containing 90% of Diesel and 10% Madhuca longifolia biodiesel
B20	Blend Containing 80% of Diesel and 20% Madhuca longifolia biodiesel
B30	Blend Containing 70% of Diesel and 30% Madhuca longifolia biodiesel
HC	Hydrocarbon
CO	Carbon monoxide
CO_2	Carbon dioxide
BTE	Brake Thermal Efficiency
BSFC	Brake Specific Fuel Consumption
EGT	Exhaust Gas Temperature
CI	Compression Ignition
bTDC	Before Top Deed Centre