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Optimization of Engine Parameters for Performance and Emissions of Sal Bio-Diesel

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Abstract: The optimization of engine parameters for higher performance with emission reduction characteristics of Sal biodiesel being presented as a potential alternative diesel fuel source from a promising renewable fuel source - the Sal tree plant. This study investigates the impact of biodiesel blends (B10, B30, B50) on emissions (CO, CO2, O2, HC, NOx) in a diesel engine. The research aims to identify the optimal blend ratio that minimizes harmful emissions while maintaining acceptable engine performance. Experimental analysis, including engine performance tests and emissions measurements, will be conducted to evaluate the effects of different biodiesel blends on pollutant levels. The findings will contribute to the development of more sustainable and environmentally friendly diesel engine systems that utilize renewable fuel sources.

***Keywords**: Sal biodiesel, Emissions, fuel economy, biodiesel applications.*

1. Introduction

The natural resources in the world have a wide range of application in the field of science and technology. Some of the natural resources such as coal, crude oil and so forth are employed in power plants, boilers, and some automotive engines. But they are getting exhausted day-by-day due to the increasing demand for these natural resources. In India, the energy demand increases at a rate of 6.5% per annum while the crude oil demand of the country that is met by imports is about 80%. Therefore, energy security becomes a key issue for the nation as a whole Also, there is a huge amount of pollution in the atmosphere due to the burning of these natural resources. Hence, it has become essential to transition towards alternate fuels. Nowadays, the utilization of biodiesel is gaining popularity as it is a clean fuel produced from domestic and renewable resources. Biodiesel can be blended in any proportion with diesel to obtain a biodiesel blend It's more environment-friendly and non-toxic than ordinary diesel and when blended with diesel, improves the mechanical efficiency of engines. Usage of biodiesel in the engine will reduce emissions of sulphur dioxide (SO_2), which is the primary cause of acid rain. It has high lubrication properties which improves the life and the performance of the engine. Safety of operation is also improved due to it's high flash point. Working with biodiesel is safer than working with diesel and it can be used in engines without any modifications Numerous car manufacturers like Massey-Ferguson, Passage, John Deere, Volkswagen, Mercedes, Volvo, BMW etc have acknowledged the fact that biodiesel is a fuel that is compatible with their current line of diesel vehicles The disadvantage is that the price of biodiesel is quite high and availability is less. It also decreases the fuel economy and increases the exhaust emissions.

1.1 Objective:

The primary objective of this study is to optimize the blends of Sal bio-diesel (B10, B30, B50) for emissions performance in diesel engines. By analyzing the emissions of CO, CO2, O2, HC, and NOx, we aim to identify the optimal blend that minimizes harmful emissions while maintaining engine efficiency.

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2.Literature Review

Significant research work has been documented with regards to the production, characterization and engine applications of biodiesel derived from variety of vegetable oils. Nikazadfar et al. **[1]** conducted performance experiments using turbo charged engine. The calibration procedure was modified and accordingly a better optimization strategy was developed for enhancement of the engine performance. A significant increase in brake thermal efficiency of the turbo charged engine was observed on using multi objective optimization techniques. The optimization method was used for reducing undesirable emissions from the turbo charged engine. Mariani et al. **[2]** conducted combustion evaluation experiments by using optimization methods. A significant increase in overall efficiency was observe. The peak pressure was predicted and the variations in peak pressure upon varying the combustion process parameters were identified. The important combustion aspects were identified and by using optimization technique, a reduction in NOx emissions was observed. **Izadiamoli et al. [3]** conducted experiments on internal combustion engines. For enhancing the efficiency of the engine, the exhaust gas was recirculated in the engine. The design was developed and the exhaust gas recirculation process parameters were optimized for better combustion. By using optimization, the combustion was found to be better. Krishnamoorthi et al. **[4]** conducted experiments by using chaulmoogra oil biodiesel fuelled internal combustion engine. For enhancement of the combustion properties, the important engine process parameters were optimized. A significant increase in the combustion efficiency was observed. A reduction in emissions was observed on using optimization techniques. As the combustion was better, the exhaust gases contained lower amount of carbon dioxide. Raman, L.A., Deepanraj **[5]** prepared fuel blend of biodiesel from rapeseed oil and diesel which then tested and reported as lesser in BTE, peak pressure, heat release rate, with decrease in CO and HC emission, but reported that there is raise in EGT and brake specific fuel consumption (BSFC) with increase in NOx and smoke emissions. Chaurasiya, P. K **[6]** has conducted an experiment using biodiesel from Jatropha, Soybean and Waste Cooking Oil blend and reported results as, there is decrease in NOx emission as compared to diesel fuel but Jatropha shows lowest, and WCO shows highest values among biodiesel blends. At the same time all biodiesel blends shows increase in BSFC and EGT with lower values for CO emissions. Koh and Ghazi **[7]** reviewed the different biodiesel production routes using Jatropha curcas oil, highlighting molar ratio of alcohol to oil, catalyst concentration, reaction temperature and reaction time as the main factors affecting the biodiesel yield. The performance of biodiesel in diesel engines has been extensively investigated. The engine power output was found to be equivalent to that of diesel fuel. Dhar et al. **[8]** reported maximum torque for 10% and 20% KOME blends which were higher than mineral diesel. Higher Karanja biodiesel blends produced slightly lower torque. These findings are similar to results reported by Karnwal et al. **[9].** Similarly, Raheman and Ghadge **[10]** found comparable performance of Mahua biodiesel and its blends with petroleum-based diesel. Other findings include; emissions reduction, increase brake power and BSFC. The BSFC, for all biodiesel–diesel blends increase with increasing blending ratio and decreases with increasing engine speed Raheman and Ghadge **[11]** found that, CO, UHC and smoke emissions of Karanja biodiesel blends were lower than that of mineral diesel but NOx emissions were slightly higher. Shehata et al. **[12]** prepared biodiesel from Cotton seed, Palm and Flax oils, showing less brake power, high BSFC, lower CO and smoke with marginal increase in NOx emissions. Murlidharan et al. **[13]** indicated almost similar results. Mufijur et al. **[14]** have also reported reduction in UHC and CO emissions but higher NOx emission.

3.Methodology

The following methodology used to prepare biodiesel blend for the experimentation.

***3.1 Sal* seed oil Extraction:** It is extracted from the seeds it can also know as the Shorea robusta in India. Shorea robusta is a large, deciduous tree up to 50 m in height. Under normal conditions the tree attains a height of 18-32 m and girth of 1.5-2 m. Bole is clean, straight and cylindrical but often bears epicormic branches. Crown is spreading and spherical. Bark is dark brown and thick, with longitudinal fissures deep in poles, becoming shallow in mature trees it provides effective protection against fire. The seed contains 14-15% fat it has calyx and wings and de-winged seeds contain a thin, brittle seed pod. The kernel has 5 segments covering the embryo 2 kg (4.4 lb) of seeds give 1 kg (2.2 lb) of kernel. The seeds are 10.8% water, 8% protein, 62.7% carbohydrate, 14.8% oil, 1.4% fiber and 2.3% ash. The process of sal seed oil extraction involves several steps, including cleaning, drying, crushing, and pressing. First, the seeds are cleaned to remove any impurities and dried to reduce the moisture content. The dried seeds are then crushed to break the outer shell and release the oil. The crushed seeds are then subjected to hydraulic pressing to extract the oil. The extracted oil is filtered to remove any remaining impurities.

Figure;1 Sal Seed oil extraction

3.2 Preparation of sal seed biodiesel

Transesterification is the process of exchanging the alkaly group of an ester compound by another alcohol. These reactions are often catalyzed by the addition of an acid or a base. The processed oil is transferred to a three necked flask and is kept on a hot plate magnetic stirrer, heated to 70^0C After the temperature reaches to 70^0C, 150 ml of Methanol and 6.5 gm of NaOH are mixed in a beaker and then added to the three necked flask, which is kept in a constant stirring condition at a speed of 800 rpm. The reaction is allowed to proceed for duration of 2 hours. After the reaction is completed, the solution is allowed to cool down. Upon cooling, it is then transferred to a Separatory funnel, where it is allowed to settle down for a duration of 12 hours. The separation of layers takes place, where the upper layer is the biodiesel which appears brownish in colour. The lower layer is the Glycerin, an unwanted product that is separated from the biodiesel, by draining it into a beaker. The biodiesel is then washed with warm water (70^0C) in order to remove the methanol present in the biodiesel. The biodiesel has to be washed till the water used does not change colour after the wash. The biodiesel is then heated to a temperature of 100^0C to remove any traces of water content present in it. The biodiesel is then stored for further tests to be conducted on it.

Figure: 2 Formation of layer, water washing, Biodiesel and glycerin

3.3 Nano Additives:

Cerium oxide (CeO_2): The activation energy of cerium oxide acts to burn off carbon deposits within the engine cylinder at the wall temperature and prevents the deposition of non-polar compounds on the cylinder wall results reduction in HC, CO, CO_2 and NO_X emissions. These cerium oxide nano-particles can be used as additive in diesel and diesel-biodiesel blend to improve complete combustion of the fuel and reduce the exhaust emissions significantly. The distribution range of 1-100nm

Zinc oxide (ZnO): It acts as high catalytic activity and distribution range of 30-200nm by adding Zinc oxide nano particles significantly lowers the smoke, CO, HC, and NOx emissions and simultaneously improves the BTE and decreases the BSFC of the diesel engine.

Table: 1 Compositions For Research

Blend name	Composition
Diesel	0 % BD +100 % D
B10	10% BD + 89.8 D + 100 PPM CeO_2 + 100 PPM ZnO
B30	30% BD + 69.8 D + 100 PPM CeO_2 + 100 PPM ZnO
B50	50% BD + 49.8 D + 100 PPM CeO_2 + 100 PPM ZnO

Table: 2 Proportions of diesel, bio-diesel and Nano additives

Name	units	DB30	DB10C100Z100	DB30C100Z100	DB50C100Z100
Density	Kg/m^3	842	0.825	0.845	0.86
Viscosity	mm^2/se	4.6	4.1	4.3	4.8
Cetane number		48.3	39.5	43.5	53.8
Flash point	^{0}C	56	55	58	62
Fire point	^{0}C	72	58	60	64
Calorific value	Kj/kgk	38756	39757	39854	39957

Table:3 Properties of Nano particles

Item	Specification	
Manufacturer	Vedayukt India private limited	Vedayukt India private limited
Molecular formula	CeO_2	ZnO
Average particle size	50-105nm	30-200nm
Color Appearance	Pale yellow	white
Morphology	Spherical	Spherical
Purity	99.9%	99.9%
Bulk density	<0.2 g/cm^3	-
True density	7.132 g/cm^3	-
Specific surface area SSA	30-50 m^2/g	30-50m^2/g

4. Results and Discussions

Compare the findings of studies on CO, CO2, O2, HC, and NOx emissions in biodiesel blends. Analyze the impact of varying the blend ratio on emissions. To reduce emissions without sacrificing engine performance, identify the optimal blend ratio. Compare emissions from conventional diesel and biodiesel blends, and discuss the advantages and disadvantages of using biodiesel.

4.1 Sal seed bio diesel –B10

To investigate the CO% emission performance of a Sal seed bio-diesel blend B10 under various pressure conditions. Considering the impact of pressure variations on combustion properties and pollution emissions, this is crucial for practical application in diesel engines.

Table:4 Sal seed bio diesel –B10 with CO%

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	0.090	1.046	1.058	1.076

4.5	0.096	1.059	1.065	2.058
9	2.089	2.76	2.81	3.23
13.5	3.26	3.82	3.94	4.36

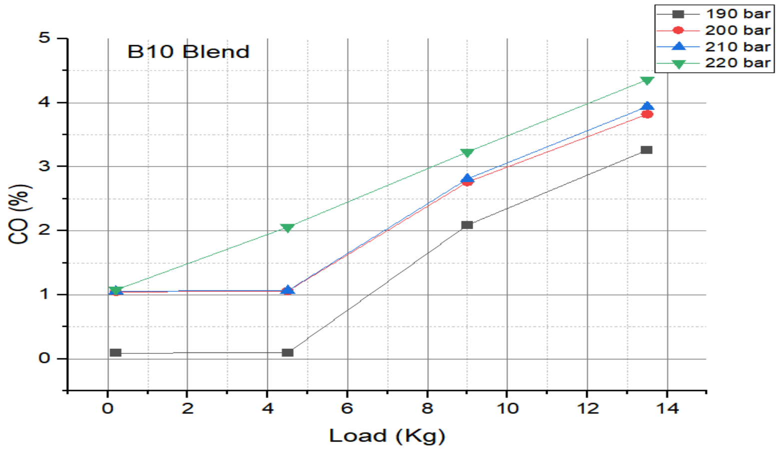

Figure:3 Load vs CO %

This figure shows that CO emissions from the biodiesel B10 blend of a Sal seed can be both load and injection pressure dependent. Higher injection pressures tend to yield lower CO, especially at higher loads. However, a more inclusive performance and emissions assessment of the engine would have to consider other aspects as well

Table:5 Sal seed bio diesel –B10 with $C0_2$ %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	1.86	2.16	3.64	3.79
4.5	2.83	3.87	3.90	4.52
9	3.91	4.61	4.72	5.43
13.5	4.68	5.39	5.86	6.28

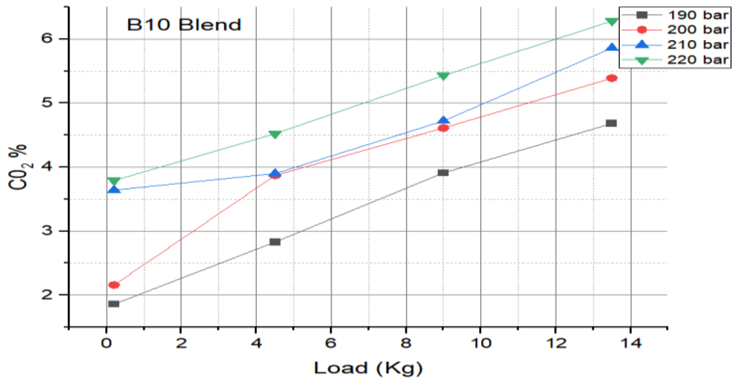

Figure:4 Load vs CO_2 %

Above figure indicates that injection pressure and load may influence CO2 emissions from a biodiesel B10 blend obtained from Sal seed. At lower pressures for injection, namely 190 and 200 bar, there is a slight increase in CO2 emissions with higher loads, possibly due to less optimal atomization and mixing of fuel leading to partial combustion.

Table:6 Sal seed bio diesel –B10 with 0_2 %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	18.92	17.93	17.31	16.84

4.5	17.87	16.72	16.59	14.38
9	17.56	14.59	15.47	12.62
13.5	16.48	13.96	12.48	11.60

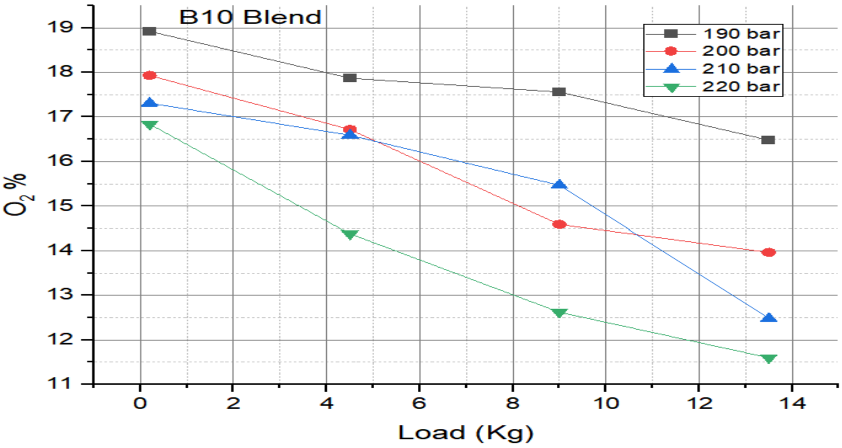

Figure:5 Load vs O_2%

The figure shows that O2 emissions from a Sal seed biodiesel B10 blend can be sensitive to both load and injection pressure. Higher injection pressure tends to result in lower levels of O2 emissions, especially at higher loads, and thereby suggests more complete combustion. However, the absolute performance and emission characteristics of the engine would require further factors to be studied.

Table:7 Sal seed bio diesel –B10 with HC %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	238	242	248	254
4.5	254	251	259	268
9	278	264	267	272
13.5	288	276	289	288

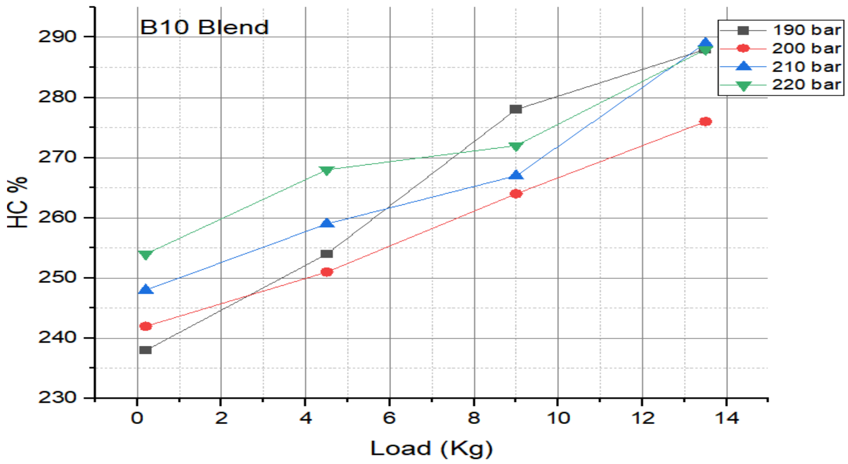

Figure:6 Load vs HC %

The figure demonstrates that HC emissions from a Sal seed biodiesel B10 blend can be influenced by both load and injection pressure. As injection pressure increases (210 and 220 bar), HC emissions generally decrease, especially at higher loads. This suggests that higher injection pressures lead to better fuel atomization and mixing, resulting in more complete combustion and reduced HC emissions.

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Table:8 Sal seed bio diesel –B10 with NO_X %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	463	476	484	492
4.5	584	543	568	568
9	689	684	689	689
13.5	786	876	826	858

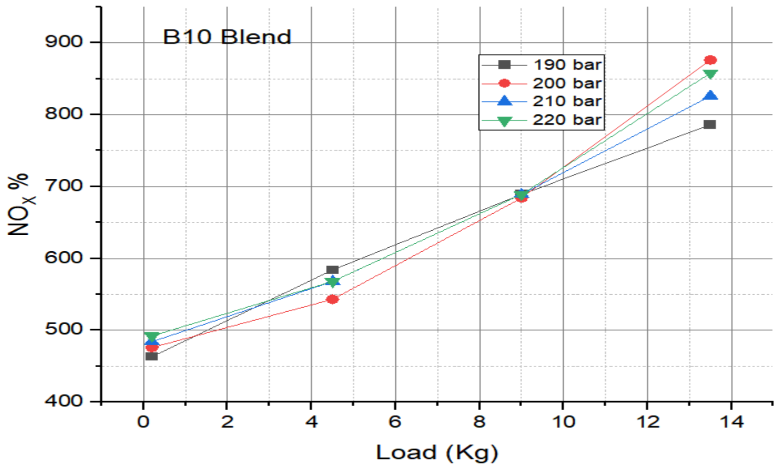

Figure:7 Load vs NO_X %

The optimum injection pressure may depend on desired characteristics of engine performance, for example, with regard to power output and fuel efficiency. NOx tends to be slightly lower at lower injection pressures (190 and 200 bar), notably at higher loads. This might be due to less effective fuel atomization and mixing, which leads to lower combustion temperatures.

Table:9 Sal seed bio diesel –B10 with Smoke %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	10.75	12.42	13.20	14.8
4.5	12.96	14.51	14.26	15.34
9	16.74	16.76	15.53	16.73
13.5	18.36	18.48	18.58	18.62

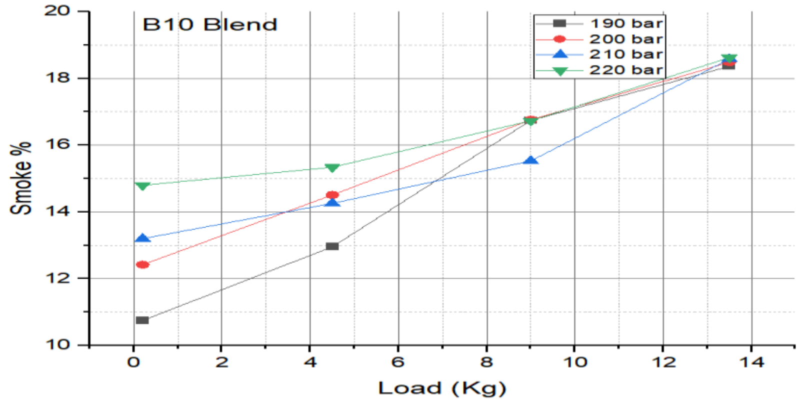

Figure:8 Load vs Smoke %

Above figure to depict the relationship between engine load (in kg) and smoke percentage for a B10 blend of Sal seed bio diesel at various fuel injection pressures (190, 200, 210, and 220 bar). Increasing the injection pressure generally reduces smoke emissions for Sal seed biodiesel (B10 blend) across all load levels. Higher injection pressures (210 bar and 220 bar) are more efficient in reducing smoke emissions, likely due to better atomization and more complete combustion.

4.2 Sal seed bio diesel B30:

To investigate the % emission performance of a Sal seed bio-diesel blend B30 under various pressure conditions. Considering the impact of pressure variations on combustion properties and pollution emissions, this is crucial for practical application in diesel engines.

Table:10 Sal seed bio diesel –B30 with CO%

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	0.091	1.052	2.029	3.075
4.5	1.043	2.063	3.096	4.057
9	3.028	3.054	4.24	5.39
13.5	4.67	4.37	5.49	6.97

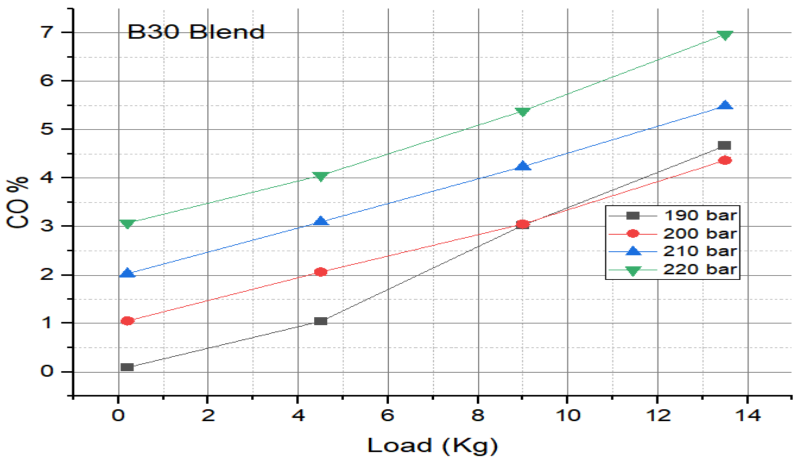

Figure:9 Load vs CO %

The above figure illustrates the relationship between Load (Kg) and CO% emissions for a B30 blend of Sal seed biodiesel at various injection pressures. In general, the graph indicates that higher loads result in increased CO emissions with the B30 blend. This trend remains consistent across different injection pressures, with the highest CO emissions recorded at the highest pressure of 220 bar.

Table:11 Sal seed bio diesel –B30 with $C0_2$ %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	1.96	2.29	2.61	3.46
4.5	3.48	3.94	4.26	4.64
9	4.69	4.89	5.36	5.28
13.5	5.66	5.71	6.03	6.33

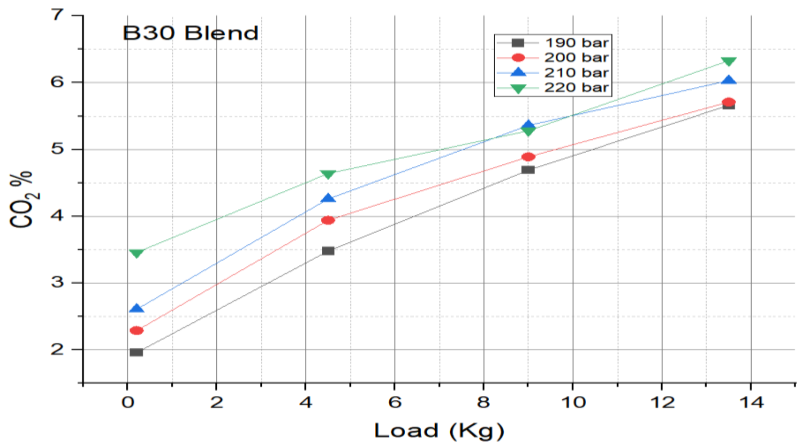

Figure:10 Load vs CO_2 %

In this figure shows the relationship between Load (Kg) and CO_2% (Carbon Dioxide percentage) for a B30 blend of Sal seed biodiesel at different injection pressures. The CO_2% for the 220 bar injection pressure is the highest, while the 190 bar pressure shows the lowest CO_2 emissions for the same load.

Table:12 Sal seed bio diesel –B30 with 0_2 %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	19.28	19.16	18.28	17.48
4.5	18.79	18.69	17.39	16.19
9	16.82	16.42	16.39	14.32
13.5	14.56	14.20	15.21	12.40

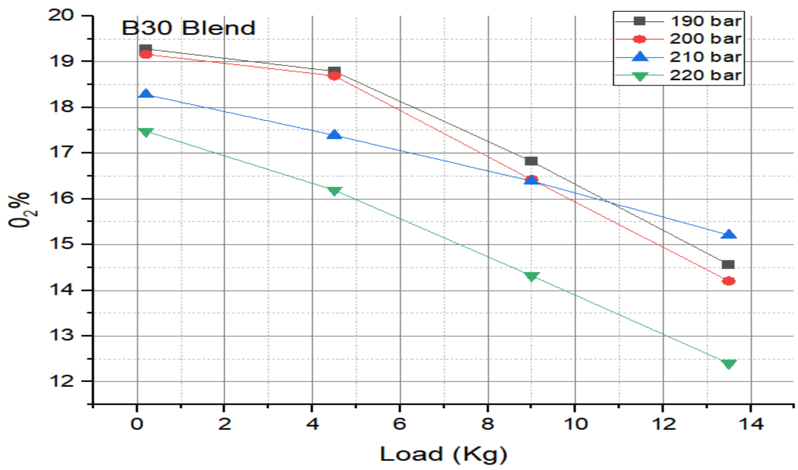

Figure:11 Load vs O_2%

The figure indicates that the O_2 emissions of a Sal seed biodiesel B30 blend may vary based on the load and injection pressure. Higher injection pressures result in lower O_2 emissions, particularly at higher loads, leading to more complete combustion. However, it's important to evaluate the overall performance and emissions of the engine while considering various parameters.

Table:13 Sal seed bio diesel –B30 with HC %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	246	249	243	236
4.5	257	255	259	247
9	268	262	265	259
13.5	271	289	279	264

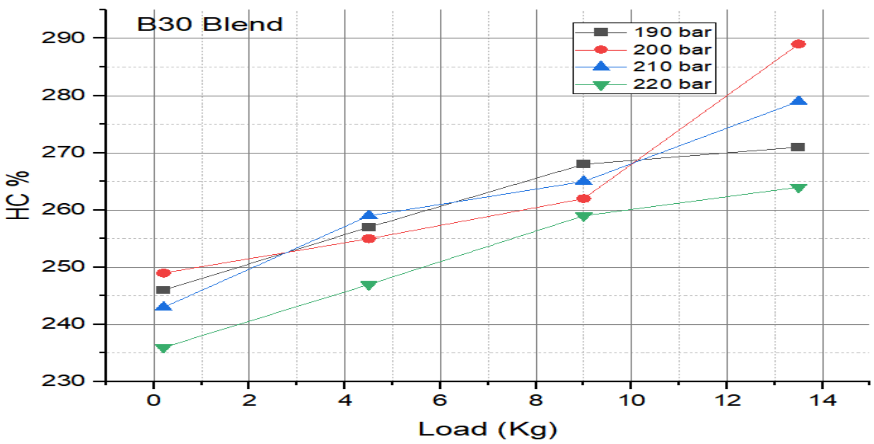

Figure:12 Load vs HC %

In this figure HC emissions contribute to air pollution and smog formation. Reducing HC emissions is crucial for improving air quality.As the load on the engine increases (more work is required), HC emissions generally rise for all injection pressures. This is a common trend in internal combustion engines due to incomplete combustion of fuel.

Table:14 Sal seed bio diesel –B30 with NO_X %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	469	474	496	498
4.5	585	586	678	659
9	634	648	989	978
13.5	868	878	1024	1019

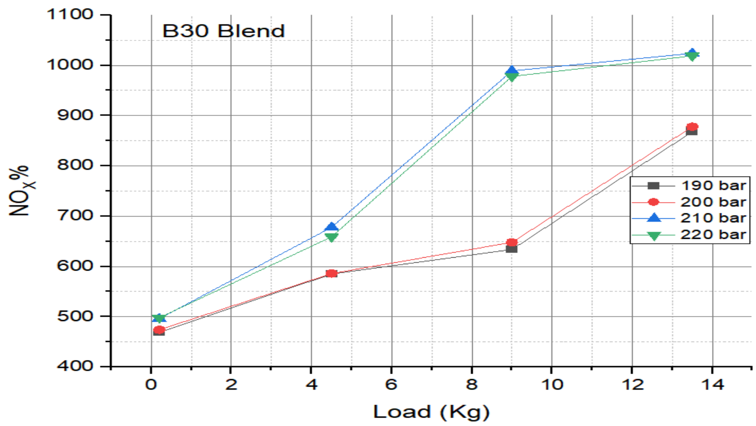

Figure:13 Load vs NO_X %

Above figure to present the optimal injection pressure would depend on desired engine performance characteristics, for example, desired power output and desired levels of fuel efficiency. If the engine is highly rated for NOx emissions at lower loads, injection pressures tend to be even higher. However, comprehensively assessing the engine performance and emissions also consider another aspect.

Table:15 Sal seed bio diesel –B30 with Smoke %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	12.89	13.52	13.81	12.68
4.5	13.84	14.84	14.56	14.28
9	16.84	16.43	16.87	15.63
13.5	18.49	18.82	18.79	17.42

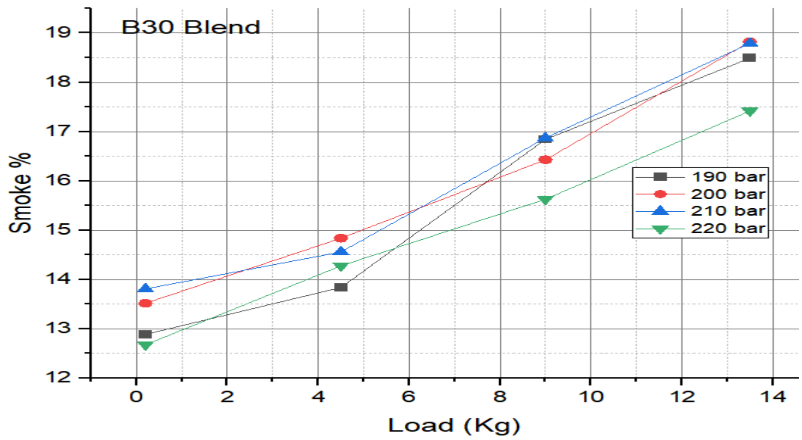

Figure: 14 Load vs Smoke %

The figure illustrates the fact that smoke emissions from a Sal seed biodiesel B30 blend can be affected by both the load and the injection pressure. Slightly higher injection pressures have a tendency to result in minimal smoke emissions at higher loads. Nonetheless, a comprehensive analysis of engine performance and emissions would be necessitated by considering other factors.

4.3 Sal seed bio diesel B50:

To investigate the emission performance of a Sal seed biodiesel blend (B50) under various pressure conditions, considering the impact of pressure variations on combustion properties and pollution emissions. This is crucial for practical application in diesel engines.

Table:16 Sal seed bio diesel –B50 with CO%

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	2.098	3.092	4.056	4.078
4.5	3.090	4.086	5.076	5.046
9	4.86	5.90	6.84	6.94
13.5	6.07	6.89	7.86	7.96

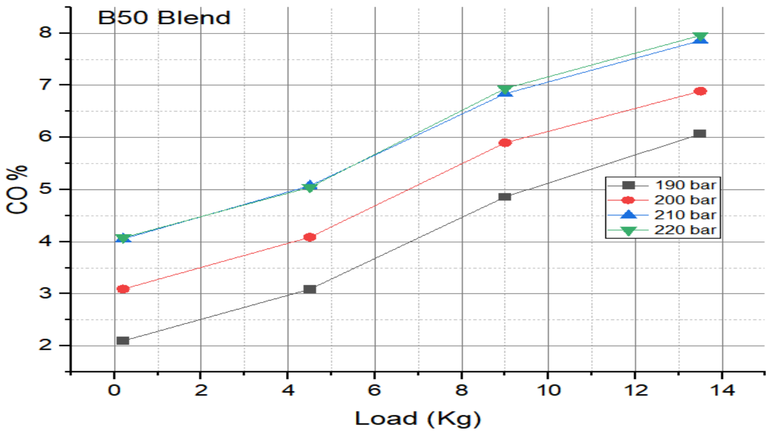

Figure: 15 Load vs CO %

The Figure of Load (Kg) vs. CO% emissions for a B50 blend of Sal seed biodiesel at different injection pressures shows a positive trend of CO% with load at all injection pressures. The trend suggests that with increased loads, the CO emissions increase as well, while higher pressures are accompanied by increased CO emissions at the same level of load.

Table:17 Sal seed bio diesel –B50 with $C0_2$ %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	3.86	3.95	3.99	4.68
4.5	4.58	4.89	4.98	5.98
9	5.89	5.91	5.93	6.41
13.5	6.46	6.66	6.73	6.96

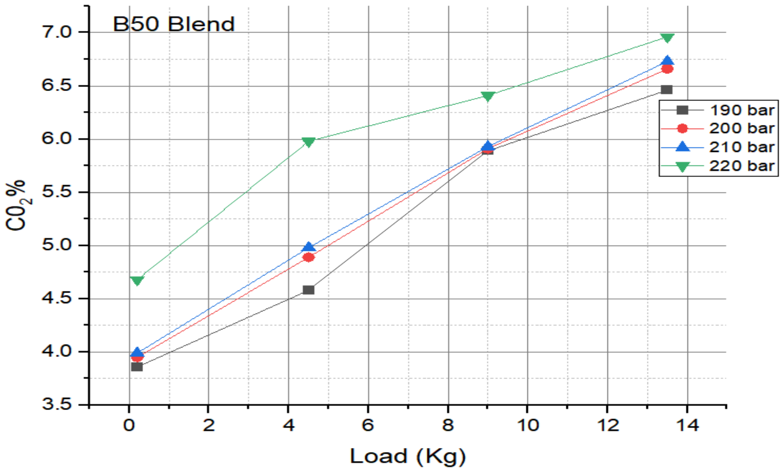

Figure:16 Load vs CO_2 %

The carbon dioxide (CO2) emissions percentage and load (in kilogrammes) connection for a B50 biodiesel blend made from Sal seed oil is shown in the given graph. The individual lines stand for different injection pressures, which range from 190 bar to 220 bar. Emissions of carbon dioxide tend to fall with increasing injection pressure, particularly at higher loads (between 210 and 220 bar). This provides additional evidence that increased injection pressures improve fuel atomisation and mixing, leading to improved combustion and decreased CO_2 emissions.

Table:18 Sal seed bio diesel –B50 with 0_2 %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	19.48	19.67	18.84	18.98
4.5	18.89	18.69	17.96	17.69
9	17.62	17.89	17.49	17.89
13.5	14.56	15.86	16.64	15.84

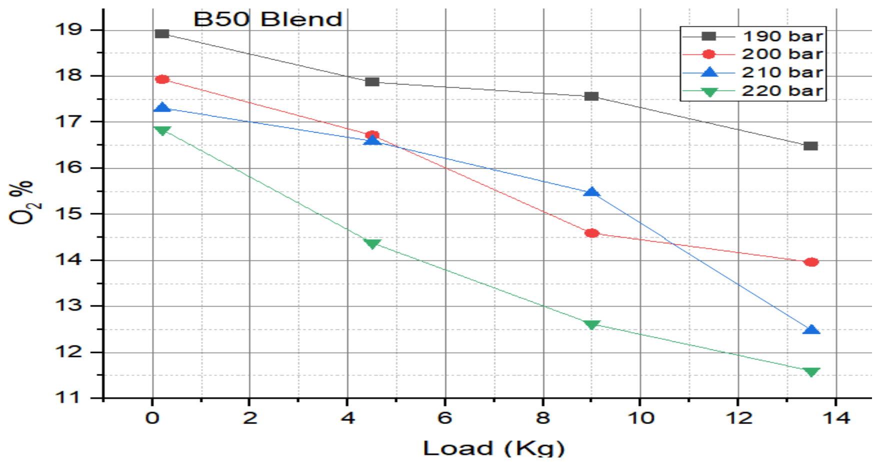

Figure:17 Load vs O_2 %

A higher proportion of oxygen at higher loads is indicative of improved combustion efficiency as engine load increases. At greater injection pressures (210 bar and 220 bar), more oxygen is produced, which further indicates that combustion has taken place. Low injection pressures (190 bar and 200 bar) are associated with less efficient combustion because they result in reduced residual oxygen during injection.

Table: 19 Sal seed bio diesel –B50 with HC %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	266	274	284	289
4.5	278	285	296	292
9	288	293	298	320
13.5	291	299	307	343

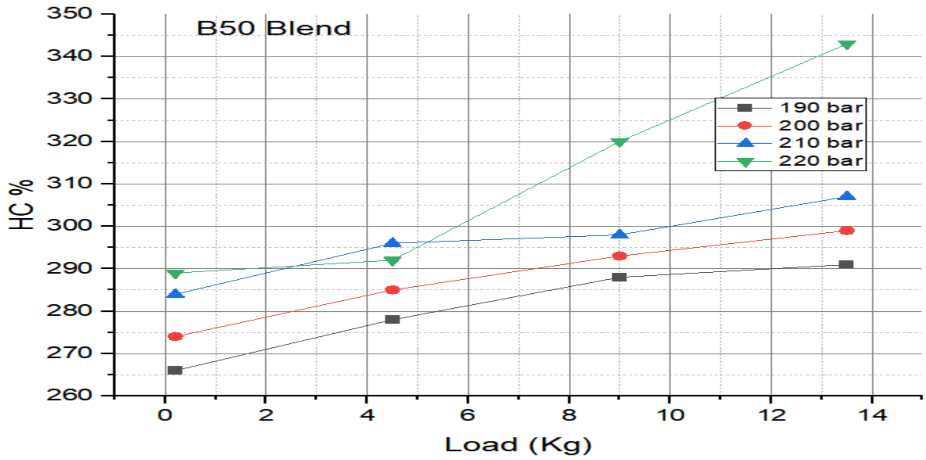

Figure:18 Load vs HC %

The percentage of hydrocarbon (HC) emissions varies with engine load in kilograms for the B50 blend of Sal seed biodiesel, depending on different fuel injection pressures: 190, 200, 210, and 220 bar. Higher injection pressures, especially 220 bar, lead to increased HC emissions with load for the B50 blend of Sal seed biodiesel. This increase could be due to poor combustion or inadequate fuel atomization at these very high pressures for this blend, resulting in incomplete combustion and higher amounts of unburnt hydrocarbons. On the other hand, lower pressures, such as 190 bar, result in relatively lower HC emissions, suggesting better combustion efficiency for the B50 blend at lower injection pressures.

Table:20 Sal seed bio diesel –B50 with NO_X %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	479	484	634	756
4.5	685	785	898	998
9	984	996	1029	1038
13.5	1028	1032	1102	1120

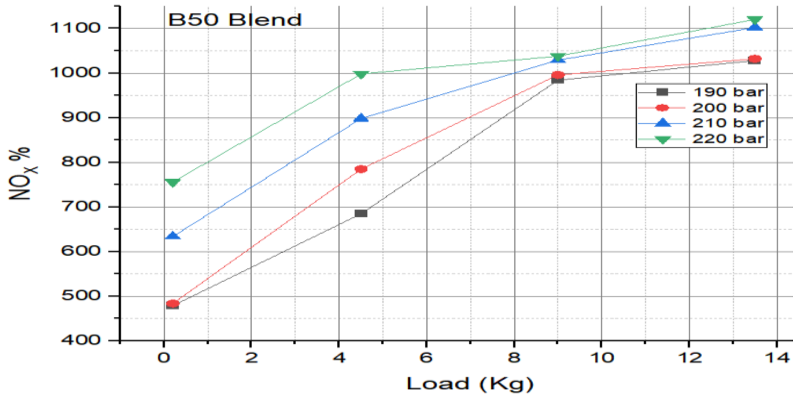

Figure:19 Load vs NOx %

The graph shows that NOx emissions of a Sal seed biodiesel B50 blend can be susceptible to load and injection pressure. Higher injection pressures tend to go hand-in-hand with higher NOx emissions, particularly at higher loads. In a comprehensive assessment of the performance of the engine and emissions, however, other variables should be considered.

Table:21 Sal seed bio diesel –B50 with Smoke %

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	14.89	16.69	17.49	17.59
4.5	16.37	17.57	18.97	18.37
9	17.64	18.69	18.69	18.79
13.5	18.47	19.45	19.85	19.95

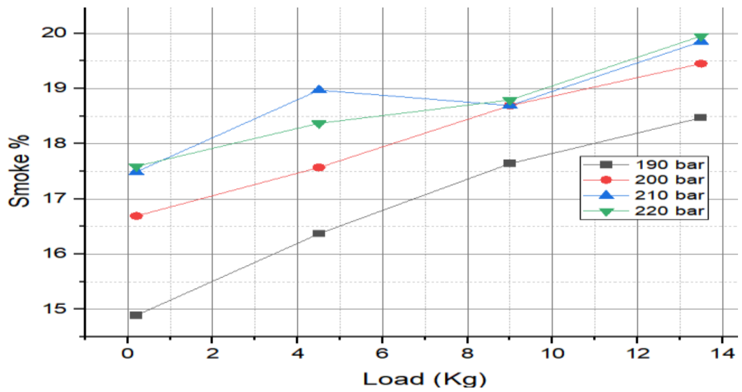

Figure:20 Load vs Smoke%

To show the relationship of the engine load in kg as related to the smoke percentage for a B50 blend of Sal seed biodiesel at different fuel injection pressures (190, 200, 210 and 220 bar).Generally, increasing the pressure results in a significant reduction in smoke emissions of Sal seed biodiesel (B10 blend) at all levels of load. Higher pressure will be more efficient in reducing smoke, by better atomization and complete combustion.

Conclusions:

This study investigated the emissions performance of Sal bio-diesel blends (B10, B30, B50) in a diesel engine.

- Increasing biodiesel content generally led to reduced CO and HC emissions.
- NOx emissions showed a slight increase with higher biodiesel blends.
- CO2 and O2 emissions were marginally affected by the biodiesel content.
- The B30 blend was identified as the optimal blend, offering the best

compromise between emission reductions and engine efficiency.

These results contribute to the ongoing research on alternative fuels and provide valuable insights for the development of cleaner diesel engines. Future studies should focus on long term engine performance and durability tests using the optimal B30 Sal bio-diesel blend.

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