

## Experimental investigation on performance Parameters of IC Engine Tested with sal seed biodiesel blends

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### Abstract:

The present study investigates the performance characteristics of a single-cylinder, fourstroke compression ignition (CI) engine fueled with Sal seed biodiesel blends—B10, B30, and B50—at varying injection pressures (190, 200, 210, and 220 bar). The experimental work focuses on evaluating critical engine performance parameters, namely Brake Power (B.P), Brake Thermal Efficiency (BTE), and Brake Specific Fuel Consumption (BSFC) across different engine load conditions. The results indicate that Brake Power increases progressively with engine load for all blends, with B50 demonstrating enhanced performance at higher injection pressures (particularly at 220 bar). BTE was found to improve significantly with increasing load and injection pressure, with B30 and B50 blends achieving thermal efficiencies comparable to conventional diesel at 220 bar. In contrast, BSFC decreased with rising load and pressure, with B10 exhibiting the lowest fuel consumption, followed closely by B30 and B50 under optimized conditions.

Keywords: Sal biodiesel, Performance parameters, biodiesel applications.

### 1. Introduction

The world has been facing several environmental and energy challenges caused by the everincreasing global industrialization and population growth. The twenty-first century has enhanced our awareness of environmental pollution, knowledge of the energy resources and depletion of fossil fuel sources, the oil price fluctuations and other related issues. Searching for alternative fuels from renewable resources for daily use has become a challenge. In a world that is full of competition, improvements in engine performance are of great importance for automotive manufacturers. Much research is being done on the combustion process in the combustion chamber to increase engine efficiency. These researches are done in two ways: one is experimental research and the other is numerical simulations such as computational fluid dynamics (CFD) that are widely used. Biodiesel consists of long-chain fatty acid esters. It could be derived from animals or plants. It contributes to the protection of the climate, the soil and water resources, while not producing large amounts of greenhouse gas emissions [1]. Due to the above-mentioned reasons, most countries that are dependent on fossil fuels are seeking alternative fuel sources. Biodiesel, which has the general chemical formula of  $19H35COOCH_3$ , and diesel, due to the similarity of their chemical structures, can be mixed with each other at

any percentage [2]. The amount of oxygen in the chemical structures of biodiesel and diesel is very varied. There is 1% oxygen in diesel [3]. Ten to twelve percent of the weight of biodiesel, however, is oxygen. This allows a more complete combustion, reduces energy density and reduces suspended particulate matter emissions, making it a cleaner fuel. Compared with diesel, biodiesel has a higher flash point, density, viscosity and cetane number, and it has a lower heating value (LHV) [4,5]. One of the main causes of air pollution and emissions is the consumption of about one-third of fossil fuels in internal combustion engines.

## 2. Literature Review

Sal seed oil, derived from *Bassia latifolia* (also known as Mahua or Illupai in India), has emerged as a potential non-edible biodiesel feedstock. Its high oil content and availability in dry regions make it suitable for sustainable biodiesel production.

- Jindal, S. (2010) explored various non-edible oils including Sal seed oil and highlighted its potential due to its relatively high oil yield and resistance to drought [6].
- Mishra et al. (2014) conducted a comparative analysis of Mahua (Sal seed) oil methyl ester with other biodiesels and observed comparable calorific value and better lubricity [7].

### Engine Performance Using Sal Seed Biodiesel Blends

Several researchers have evaluated performance parameters such as Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC), Exhaust Gas Temperature (EGT), and emissions.

- **Ghosh and Dutta (2012)** tested Mahua oil blends in a CI engine and observed a marginal decrease in BTE with an increase in biodiesel concentration, while BSFC increased due to higher viscosity [8].
- **Kumar et al. (2018)** studied blends of B10, B20, and B30 of Sal seed biodiesel and found that B20 offered the best trade-off between power output and emission control [9].

### Biodiesel and IC Engine Performance

Biodiesel is an eco-friendly and renewable alternative to fossil diesel, produced through the transesterification of vegetable oils or animal fats. Numerous studies have focused on the impact of biodiesel blends on engine performance and emissions, showing promising results in reducing harmful pollutants with marginal compromise on engine efficiency.

- Demirbas, A. (2009) emphasized that biodiesel reduces CO, HC, and particulate matter emissions significantly compared to fossil diesel, with comparable brake thermal efficiency (BTE) [10].
- Knothe, G. (2005) noted the importance of fuel properties such as viscosity, cetane number, and oxygen content on combustion performance in CI engines [11]. [12] **Guhan et al. (2016)** used optimization strategies and different kinds of numerical evaluation techniques for increasing the overall efficiency of the engine. For maintaining uniform flow of combustible particles in the combustion chamber, the important combustion process parameters were optimized. Inside the upper body of the engine, by using numerical optimization methods, the flow of combustion particles was improved. [13] **Maheshwari et al. (2011)** used multi objective evaluation method for enhancing the combustion aspects of internal combustion engine. The different process variables regarding improvement of combustion were recorded and using statistical evaluation techniques, the appropriate operating conditions of the internal combustion engine was

predicted for achieving enhanced combustion efficiency. Also, the process parameters were optimized for achieving better combustion, thereby reducing NO<sub>x</sub> emissions [14] **Nikazadfar et al. (2019)** 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. [15] **Mariani et al. (2019)** 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 NO<sub>x</sub> emissions was observed. [16] **Izadiamoli et al. (2018)** 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 [17] **Krishnamoorthi et al. (2019)** 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. [18] **Singh et al. (2019)** conducted experiments on internal combustion engine and evaluated its performance. The engine was fueled with cassia tora oil. For enhancement of the performance of the internal combustion engine, the important process parameters were optimized by using statistical evaluation techniques. A relatively new technique such as response surface methodology was used.

### Optimization Techniques in CI Engines

[19] **Saxena et al. (2019)** attempted different optimization methods for increasing engine combustion efficiency. Nano particle incorporated bio diesel blends was used for enhancing the combustion aspects. For identifying the appropriate blend of Nano particle, multi criteria objective optimization strategy was used. The significant process parameters were identified and empirical relationships were developed regarding the input process parameters and output responses. [20] **Yang et al. (2018)** conducted combustion evaluation experiments and used waste heat recovery technique for increasing combustion efficiency. The important waste heat recovery system process parameters were optimized so as to enhance the combustion aspects. On using waste heat recovery system in the existing engine setup, a significant reduction in undesirable waste gases was observed. The combustion parameters were optimized by using artificial neural network which incorporates fuzzy logics and statistical evaluation techniques. [21] **Singh et al. (2018)** conducted experiments using direct injection engine. Bio fuel such as pongamia oil was used for running the engine. For enhancing the pongiamia oil fuelled direct injection engine, the vital technological process parameters were enhanced by using response surface methodology. On running the engine at optimized parameters of pongamia oil fuelled engine increase in cylinder combustion efficiency was found.

### 3. Methodology

This methodology outlines the systematic approach adopted to evaluate the performance of a single-cylinder CI engine fueled with Sal seed biodiesel blends (B10, B30, and B50). The methodology includes the preparation of biodiesel blends, engine test setup, instrumentation, operating conditions, and the procedure used for measuring key performance parameters Brake Power (B.P), Brake Thermal Efficiency (BTE), and Brake Specific Fuel Consumption (BSFC) at various fuel injection pressures (190, 200, 210, and 220 bar) and engine loads.

**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

#### Preparation of sal seed biodiesel

Transesterification is the process of exchanging the alkyl 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°C. After the temperature reaches to 70°C, 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°C) 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°C 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

#### Nano Additives:

**Cerium oxide (CeO<sub>2</sub>):** 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<sub>2</sub> and NO<sub>x</sub> 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 NO<sub>x</sub> emissions and simultaneously improves the BTE and decreases the BSFC of the diesel engine

**Table 1:** Proportions of diesel, biodiesel and Nano additives

Blend name	Composition
Diesel	0 % BD +100 % D
B10	10% BD + 89.8 D + 100 PPM CeO <sub>2</sub> + 100 PPM ZnO
B30	30% BD + 69.8 D + 100 PPM CeO <sub>2</sub> + 100 PPM ZnO
B50	50% BD + 49.8 D + 100 PPM CeO <sub>2</sub> + 100 PPM ZnO

Name	units	DB30	DB10C100Z100	DB30C100Z100	DB50C100Z100
Density	Kg/m <sup>3</sup>	842	0.825	0.845	0.86
Viscosity	mm <sup>2</sup> /se	4.6	4.1	4.3	4.8
Cetane number		48.3	39.5	43.5	53.8

Flash point	<sup>0</sup> C	56	55	58	62
Fire point	<sup>0</sup> C	72	58	60	64
Calorific value	Kj/kgk	38756	39757	39854	39957

Item	Specification	
Manufacturer	Vedayukt India private limited	Vedayukt India private limited
Molecular formula	CeO <sub>2</sub>	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 <sup>3</sup>	-
True density	7.132 g/cm <sup>3</sup>	-
Specific surface area SSA	30-50 m <sup>2</sup> /g	30-50m <sup>2</sup> /g

**Table 2: Kirloskar engine model parameters**

Make and Model	Kirloskar model TV 1
Engine type	4 stroke single cylinder, constant speed, direct injection CI Engine
Bore x Stroke	80 x 110 mm
Rated power	3.68 Kw at 1500RPM
Specific volume	0.552 liter
Compression Ratio	17.5
Loading	Eddy current dynamometer, water cooling
Fuel injection	23 BTDC
Engine Speed	1500 rpm
Injection pressure	240bar



**Figure 3:** Engine Setup

#### 4. Results and Discussions

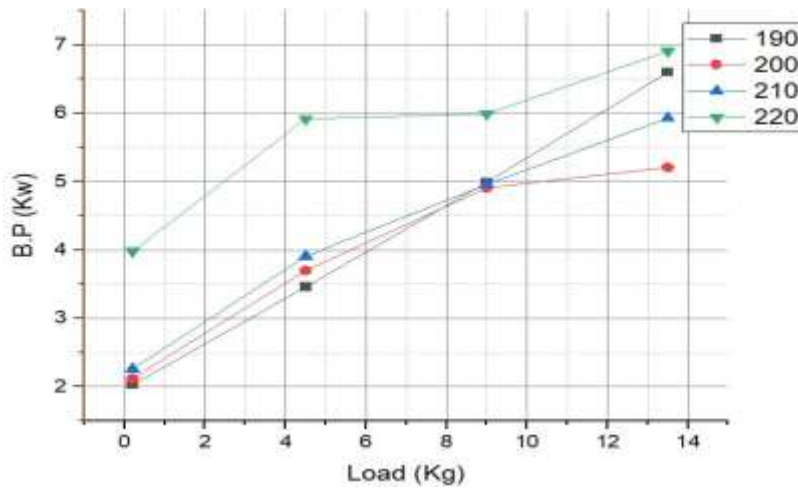
Sal seed oil, a non-edible feedstock, has been identified as a sustainable alternative to conventional diesel when transesterified into biodiesel. In this study, biodiesel blends B10 (10% biodiesel + 90% diesel), B30, and B50 are tested in a CI engine to evaluate performance under varying injection pressures (190, 200, 210, 220 bar) and engine loads

#### Sal seed bio diesel –B10 with different performance parameters (B.P, BTE, BFSC)

To investigate the performance parameters 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 3:** Sal seed bio diesel –B10 with B.P

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	2.03	2.12	2.26	3.98
4.5	3.46	3.70	3.910	5.92
9	4.99	4.91	4.96	5.99
13.5	6.60	5.21	5.93	6.910

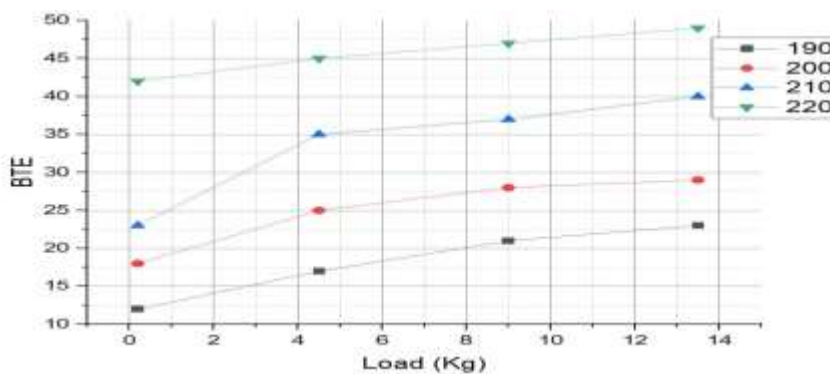


**Figure 4: Load vs B.P**

This figure presents the variation of Brake Power (B.P) with engine load for a B20 blend (20% Sal seed biodiesel + 80% diesel) tested at four different injection pressures: 190, 200, 210, and 220 bar. The Brake Power of the B20 Sal seed biodiesel blend improves consistently with increased injection pressure.

**Table 4: Sal seed bio diesel –B10 with BTE**

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	12	18	23	42
4.5	17	25	35	45
9	21	28	37	47
13.5	23	29	40	49



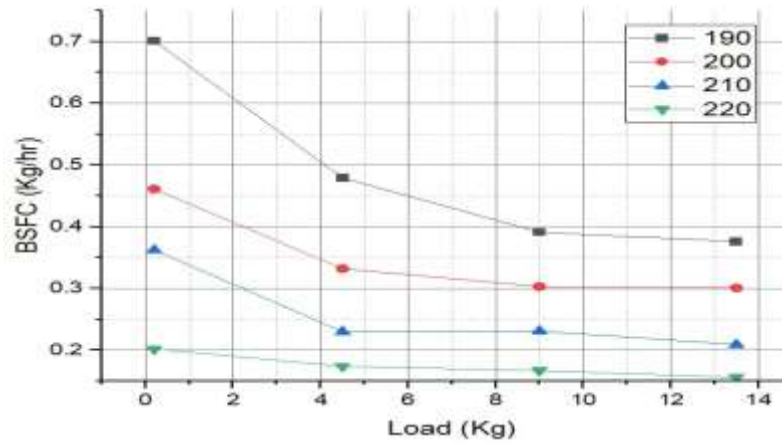
**Figure 5: Load vs BTE**

This figure illustrates the variation of Brake Thermal Efficiency (BTE) with respect to engine load for a B20 blend (20% Sal seed biodiesel + 80% diesel) tested at four different injection pressures: 190, 200, 210, and 220 bar.

**Table 5: Sal seed bio diesel –B10 with BSFC**

Load (kg)	190 bar	200 bar	210 bar	220 bar
0.2	0.701	0.461	0.362	0.202

4.5	0.479	0.332	0.230	0.174
9	0.391	0.303	0.231	0.167
13.5	0.376	0.301	0.209	0.156



**Figure 6:** Load vs BSFC

This figure shows how Brake Specific Fuel Consumption (BSFC) varies with engine load for a B20 blend (20% Sal seed biodiesel + 80% diesel), under different injection pressures: 190, 200, 210, and 220 bar. The lowest BSFC is achieved at 220 bar, confirming that higher injection pressure improves combustion efficiency and reduces fuel consumption.

**Sal seed bio diesel –B30 with different performance parameters (B.P, BTE, BFSC)**

To optimize performance, the engine is tested under varying loads and injection pressures, which significantly influence combustion characteristics. By evaluating these parameters, the feasibility and effectiveness of using the B30 Sal seed biodiesel blend as a sustainable diesel alternative can be accurately assessed.

**Table 6: Sal seed bio diesel –B30 with B.P**

Load (kg)	190 bar	200 bar	210 bar	220 bar
0.2	2.09	2.26	2.39	3.96
4.5	3.39	3.86	3.94	5.89
9	4.90	4.98	4.91	5.98
13.5	5.91	5.96	5.89	6.54

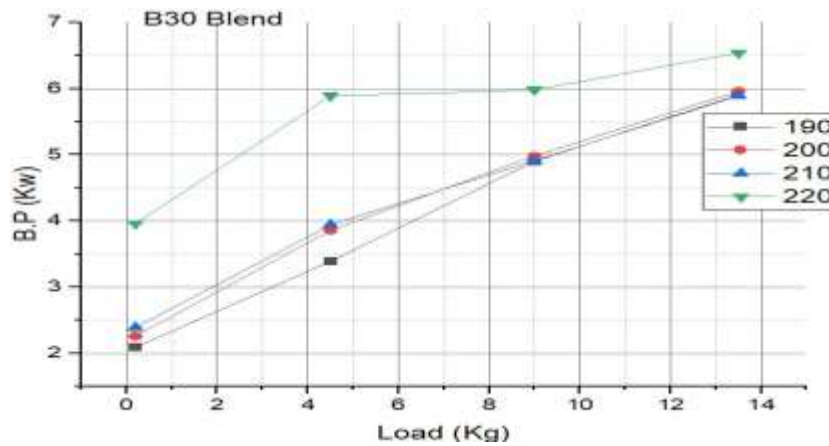


Figure 7: Load vs B.P

Above figure The B30 blend of Sal seed biodiesel demonstrates maximum Brake Power at 220 bar, confirming that increased injection pressure enhances combustion efficiency, thereby improving power output under increasing engine loads.

Table 7: Sal seed bio diesel –B30 with BTE

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	16	23	26	45
4.5	25	37	38	46
9	33	40	45	47
13.5	34	44	47	50

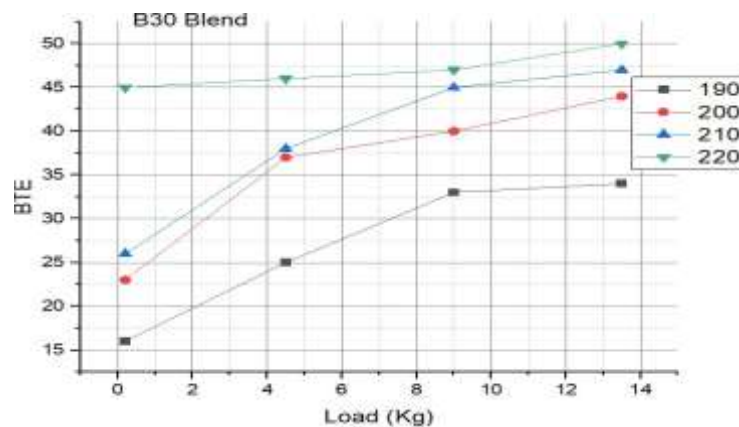


Figure 8: Load vs BTE

The figure illustrates the variation of Brake Thermal Efficiency (BTE) with engine load for a B30 blend (30% Sal seed biodiesel + 70% diesel) at various injection pressures (190, 200, 210, and 220 bar). The Sal seed B30 biodiesel blend shows maximum thermal efficiency at 220 bar, validating that higher injection pressures facilitate better atomization and combustion, ultimately enhancing energy conversion efficiency.

Table 8: Sal seed bio diesel –B30 with BSFC

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	0.514	0.373	0.334	0.195
4.5	0.346	0.231	0.226	0.188

9	0.258	0.218	0.197	0.183
13.5	0.250	0.19	0.184	0.180

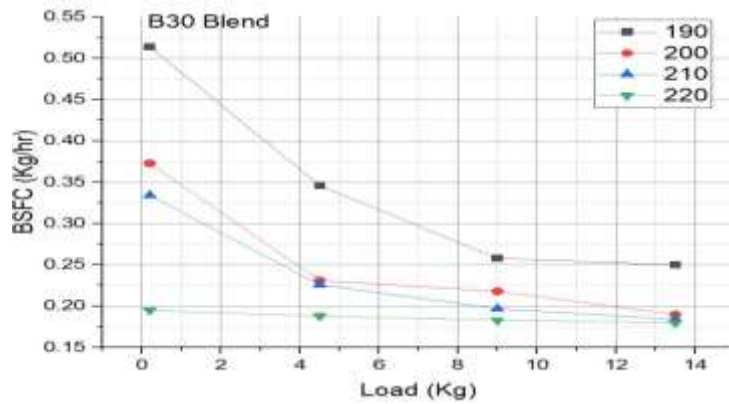


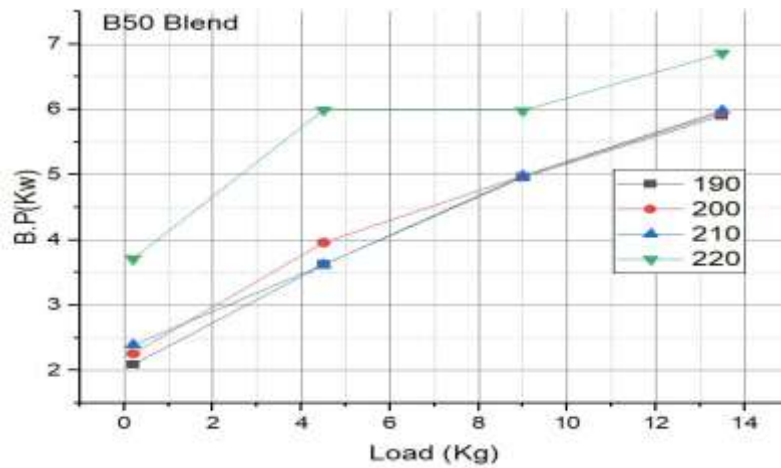
Figure 9: Load vs BSFC

The Figure presents the variation of Brake Specific Fuel Consumption (BSFC) with engine load (Kg) for a B30 blend (30% Sal seed biodiesel + 70% diesel), tested at four different injection pressures: 190, 200, 210, and 220 bar. The B30 blend performs most efficiently in terms of fuel consumption at 220 bar, especially at higher loads. The decrease in BSFC with increased injection pressure confirms that better atomization and combustion occur at higher pressures, leading to improved engine performance.

**Sal seed bio diesel –B50 with different performance parameters (B.P, BTE, BFSC)** B50 blend refers to a fuel mix containing 50% Sal seed methyl ester biodiesel and 50% conventional diesel. This blend is tested in a single-cylinder CI engine to evaluate its performance at varying engine loads and injection pressures. These results suggest that Sal seed biodiesel (B50 blend) performs efficiently in CI engines at higher injection pressures, with 210 bar being ideal for fuel economy and thermal efficiency, and 220 bar excelling in maximum power output.

Table 9: Sal seed bio diesel –B50 with B.P

Load (kg)	190 bar	200 bar	210 bar	220 bar
0.2	2.09	2.26	2.39	3.71
4.5	3.62	3.96	3.62	5.99
9	4.96	4.98	4.98	5.98
13.5	5.91	5.95	5.98	6.86

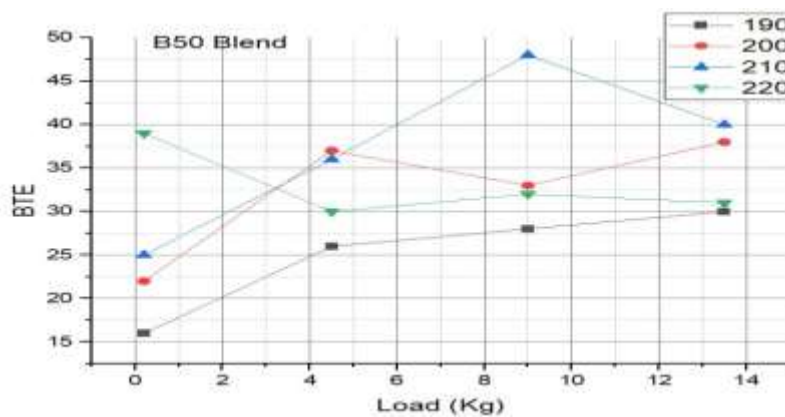


**Figure 10: Load vs B.P**

The B50 blend performs better at higher injection pressures, with 220 bar giving the best brake power output across varying loads. This indicates that optimizing injection pressure is essential for maximizing engine performance when using biodiesel blends.

**Table 10: Sal seed bio diesel –B50 with BTE**

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	16	22	25	39
4.5	26	37	36	30
9	28	33	48	32
13.5	30	38	40	31



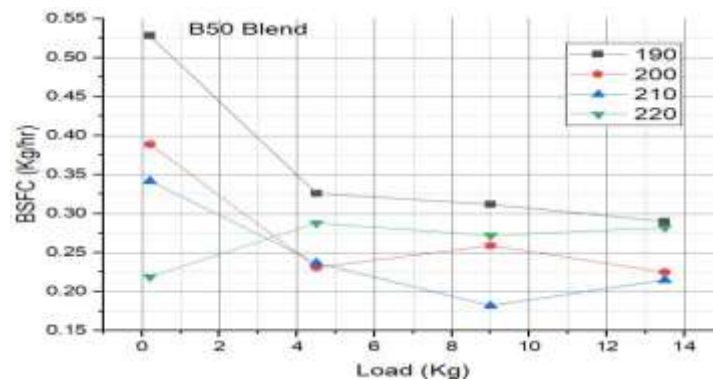
**Figure 11: Load vs BTE**

The optimal injection pressure for maximum BTE using B50 blend is 210 bar, especially at mid-range loads. This suggests that better atomization and air-fuel mixing at this pressure enhance combustion efficiency. Very low (190 bar) or very high (220 bar) pressures are less efficient across most load ranges.

**Table 11: Sal seed bio diesel –B50 with BFSC**

Load (Kg)	190 bar	200 bar	210 bar	220 bar
0.2	0.528	0.389	0.342	0.219
4.5	0.326	0.231	0.237	0.288

9	0.312	0.259	0.182	0.272
13.5	0.290	0.225	0.215	0.282



**Figure 12:** Load vs BSFC

The minimum BSFC and hence maximum fuel efficiency is achieved at 210 bar injection pressure, especially under moderate to high loads. High BSFC at 190 bar confirms that lower injection pressure leads to incomplete combustion and more fuel consumption for the same output.

### Conclusions:

The experimental study was conducted to evaluate the performance characteristics of a singlecylinder CI engine fueled with Sal seed biodiesel blends — specifically B10, B30, and B50 — at various fuel injection pressures (190, 200, 210, and 220 bar) and engine loads (0 to 14 kg). The key performance metrics assessed were Brake Power (B.P), Brake Thermal Efficiency (BTE), and Brake Specific Fuel Consumption (BSFC). Based on the detailed observations and results, the following conclusions are drawn:

- Sal seed biodiesel, especially at B30 proportion, is a promising alternative to conventional diesel when used with optimized injection pressures.
- The study highlights that fuel injection pressure is a critical parameter in achieving higher efficiency and lower fuel consumption.
- Adoption of B30 with injection pressure of 220 bar can lead to a sustainable and efficient CI engine performance with reduced reliance on fossil fuels.

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