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Performance and Emission Characteristics of a Single-Cylinder Four-Stroke Diesel Engine Fueled with Diesel–Rice Bran Methyl Ester–Isobutanol Blends

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Abstract- ***The increasing demand for energy and the depletion of fossil fuels have led to the search for alternative and renewable fuels for diesel engines. Biodiesel derived from vegetable oils and alcohol-based fuels are considered promising substitutes due to their renewable nature and lower emissions. In this study, the performance and emission characteristics of a single cylinder four-stroke diesel engine fueled with diesel blended with rice bran methyl ester biodiesel and isobutanol are investigated. Rice bran oil is converted into biodiesel through the transesterification process to produce rice bran methyl ester (RBME). The prepared biodiesel is blended with diesel and isobutanol in suitable proportions and tested in a diesel engine without any engine modification. The engine performance parameters such as brake thermal efficiency and brake specific fuel consumption are evaluated under different load conditions. Emission parameters including carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and smoke opacity are also measured. The present study focuses on the performance and emission characteristics of a single cylinder four-stroke diesel engine fueled with diesel blended with rice bran methyl ester biodiesel and isobutanol. The engine is tested under different load conditions to evaluate parameters such as brake thermal efficiency, brake specific fuel consumption, and exhaust emissions including CO, HC, NOx, and smoke opacity. The objective of this study is to analyze the suitability of rice bran biodiesel and isobutanol blends as an alternative fuel for diesel engines and to assess their impact on engine performance and environmental emissions.***

Blends: RBME10D90(10%RBME+90%Diesel)
RBME15D80IB5(15%RBME+80%Diesel+5%isobutanol)
RBME20D75IB5(20%RBME+75%Diesel+5%isobutanol)
RBME25D70IB5(25%RBME+70%Diesel+5%isobutanol)

I. INTRODUCTION

The rapid growth of industrialization and transportation has led to a significant increase in the consumption of conventional fossil fuels such as diesel and petrol. The continuous use of these fuels has resulted in the depletion of petroleum reserves and an increase in environmental pollution due to harmful exhaust emissions. Diesel engines are widely used in transportation, agriculture, and power generation because of their high efficiency and reliability. However, the emissions produced from diesel engines, such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter, contribute to serious environmental and health problems. Therefore, there is a growing need to find alternative, renewable, and eco-friendly fuels for diesel engines.

Biodiesel is considered one of the most promising alternative fuels for diesel engines. It is produced from vegetable oils or animal fats through a process called transesterification. Biodiesel is biodegradable, non-toxic, and contains oxygen, which helps in improving the combustion process and reducing certain harmful emissions. Ricebran oil is one of the potential sources for biodiesel production, especially in agricultural countries where rice is widely cultivated. Rice bran methyl ester (RBME) biodiesel can be blended with diesel and used in conventional diesel engines without major modifications.

In addition to biodiesel, alcohol fuels such as isobutanol are also gaining attention as fuel additives. Isobutanol has good fuel properties such as higher energy content, better miscibility with diesel, and improved combustion characteristics compared to other alcohols. The addition of isobutanol to diesel–biodiesel blends can enhance fuel atomization, improve air–fuel mixing, and help reduce certain exhaust emissions. The present study focuses on the performance and emission characteristics of a single

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cylinder four-stroke diesel engine fueled with diesel blended with rice bran methyl ester biodiesel and isobutanol. The engine is tested under different load conditions to evaluate parameters such as brake thermal efficiency, brake specific fuel consumption, and exhaust emissions including CO, HC, NOx, and smoke opacity. The objective of this study is to analyze the suitability of rice bran biodiesel and isobutanol blends as an alternative fuel for diesel engines and to assess their impact on engine performance and environmental emissions.

Figure 1 Rice Bran Oil

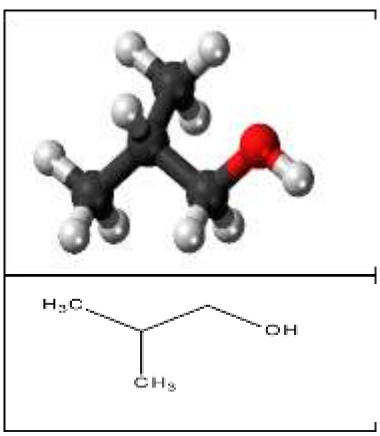

Figure 2 n –IsoButanol

1.1 Physical Properties of Rice Bran Biodiesel

Table of 1.1- Key Physical Properties of Rice Bran Biodiesel

Property	Typical Value	Unit	Significance
Density(@15°C)	870–892	kg/m³	Affects fuel injection and spray
Kinematic Viscosity (@40°C)	3.5–5.4	mm²/s(cSt)	Influences atomization
Flash Point	165–210	°C	Safety during storage
Calorific Value	38–41	MJ/kg	Energy content
Cloud Point	10 to 6.5	°C	Cold flow behavior
Pour Point	-11 to -2	°C	Minimum flow temperature
Cetane Number	50–56	–	Igni tion quality

1.2 Advantages of Rice Bran Biodiesel

- Compatible with Existing Diesel Engines
- Cost-Effective & Economical
- Supports Rural & Agricultural Economy
- Better Safety & Handling
- Good Fuel Properties

1.3 Objectives of the Present Work

The main objectives of the present research work are:

1. To produce biodiesel from Rice Bran Oil using the trans esterification process.
2. To prepare different fuel blends consisting of diesel, RBME biodiesel, and Isobutanol.
3. To experimentally investigate the performance characteristics of a single cylinder four stroke diesel engine using these fuel blends.
4. To evaluate the exhaust emission characteristics including CO, HC, NOx, CO_2, and smoke opacity.

II. EXPERIMENTAL SEP UP

The experimental setup consists of a single cylinder, four-stroke, direct injection diesel engine used to evaluate performance and emission characteristics.

The engine is coupled with an eddy current dynamometer to apply and measure different load conditions. Fuel consumption is measured using a burette and stopwatch arrangement for accurate readings. Air intake is measured with the help of an air box and manometer setup. An exhaust gas analyzer is used to measure emissions such as hydrocarbons (HC), carbon monoxide (CO), oxygen (O_2), and oxides of nitrogen (NOx). A smoke meter is used to determine smoke opacity and particulate emissions. A pressure transducer is fitted to the cylinder to measure in-cylinder pressure variations. The pressure data is recorded using a data acquisition system for combustion analysis. The engine is operated at constant speed under varying loads to observe performance changes. Proper calibration and steady-state conditions are maintained before recording readings to ensure accurate results.

2.1 IsoButanol

Fig: 2.1 2.1 IsoButanol

2.2.1 Properties of n-Butanol
Chemical formula: $C_4H_{10}O$

Boiling temperature: 108°C

Density: 0.802 g/ml

Molar mass: 74.12 g/mol Melting point: -89.8

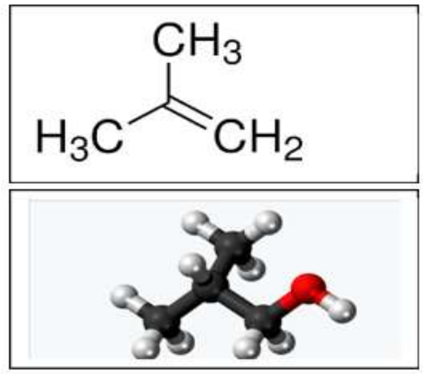

Fig: 2.2 Crystal Structure (ref: 3)

2.2 TRANSESTERIFICATION PROCESS
The transesterification process is used to produce biodiesel from rice bran oil. This process converts the raw oil into Rice Bran Methyl Ester (RBME), which has properties similar to diesel fuel and can be used in engine applications. Initially, the raw rice bran oil is filtered to remove dust and solid impurities, and then it is heated to remove any moisture content present in the oil.

Fig: 3.3 Transesterification Process

Fig:2.4 Base Treatment

Fig: 2.5 Decantation to remove

Fig:2.6 Water washing

Flow Chart Of Transesterification

Rice Bran Oil

↓

Oil Heating (Moisture Removal)

↓

Preparation of Alcohol + Catalyst

↓

(Methanol + / KOH NaOH)

Transesterification Reaction (Oil + Alcohol Catalyst in Reactor)

↓

Settling / Separation

↓

↓	↓
Biodiesel (Methyl Ester)	Glycerol (By-product)

↓

Water Washing

(Removal of impurities)

↓

Drying Process

↓

Pure Rice Bran Methyl Ester (RBME)

↓

Blending with Diesel +Isobutenal

↓

Fuel Ready for Engine Testing

Fig:2.7 Processing of rice bran oil

2.3 Blending Process

The blending process is essential for improving fuel quality and reducing harmful emissions in diesel engines. Biodiesel, being renewable and eco-friendly, is a suitable alternative to conventional diesel fuel. Mixing Rice Bran Methyl Ester (RBME) with diesel and isobutanol in different proportions helps achieve a balance between engine performance, cost, and emission control. Blends such as RBME10D90 and RBME20D75iB5 are prepared to study their impact on engine behavior. The addition of biodiesel reduces dependence on fossil fuels and lowers carbon emissions, while isobutanol enhances combustion due to its oxygen content and better volatility. Compression ignition engines efficiently utilize these blends without major modifications. Direct injection engines offer better efficiency but face higher emissions issues. RBME and isobutanol blends help reduce smoke and improve combustion. These blended fuels are tested under various conditions and compared with pure diesel. Overall, the blending approach provides a promising solution for sustainable and cleaner energy use.

Fig:2.8 PURE DIESEL

Fig:3.11 RBME10D90

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Fig:3.12 RBME15D80NB5

Fig:3.13 RBME20D75iB5

Fig:3.14 RBME25D70iB5

3.4 EXPERIMENTAL ENGINE SETUP OF ENGINE

The engine setup consists of single cylinder, four stroke, Diesel engine connected to eddy current type dynamometer for loading. It is provided with necessary instruments for combustion pressure and crank angle measurements. These signals are interfaced to computer through engine indicator for Pressure crank angle-PV diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The set up has standalone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. The engine setup consists of single cylinder, four stroke, Diesel engine connected to eddy current type dynamometer for loading. It is provided with necessary instruments for combustion pressure and crank angle measurements.

3.13 Experimental Engine Set Up

These signals are interfaced to computer through engine indicator for Pressure crank angle-PV diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The setup has standalone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. The setup enables study of engine performance for brake power, indicated power, frictional power, BMMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance. Lab view based Engine Performance Analysis software package "Engine soft" is provided for on line performance evaluation. While on line testing of the engine in RUN mode necessary signals are scanned, stored and presented in graph.

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IV. RESULT AND DISCUSSIONS

4.1 BLENDS USED

- D100 – Pure Diesel
- RBME10D90 – Mixture of 10% Rice Bran Methyl Ester Biodiesel and 90% Diesel
- RBME15D80IB5 – Mixture of 15% Rice Bran Methyl Ester Biodiesel, 80% Diesel, and 5% Isobutanol
- RBME20D75IB5 – Mixture of 20% Rice Bran Methyl Ester Biodiesel, 75% Diesel, and 5% Isobutanol
- RBME25D70IB5 – Mixture of 25% Rice Bran Methyl Ester Biodiesel, 70% Diesel, and 5% Isobutanol

GIVEN DATA (For S.NO 1)

- $W_1 = 2\ \text{kg}$
- $W_2 = 0.3\ \text{kg}$
- Speed $N = 1500\ \text{rpm}$
- Time for 10 cc fuel = 74 sec
- Calorific Value

$$CV = \frac{42791\ \text{kJ}}{\text{kg}}$$

- Density of diesel

$$\rho = 0.84\ \text{kg/litre}$$

Step 1: Net Load (W)

$$W = W_1 - W_2$$
$$W = 2 - 0.3 = 1.7\ \text{kg}$$

Step 2: Brake Power (BP)

$$T = W \times g \times R$$
$$T = 1.7 \times 9.81 \times 0.15 = 2.50\ \text{Nm}$$

Step 3: Fuel Consumption (FCH) Formula:

$$BP = \frac{2\pi NT}{60 \times 1000}$$
$$BP = \frac{2 \times 3.14 \times 1500 \times 2.50}{60 \times 1000}$$

Where:

- $V = 10\ cc$
- $t = 74\ sec$

$$FCH = \frac{0.84 \times 10 \times 3600}{74 \times 1000}$$
$$FCH = 0.052\ \text{kg/hr}$$

Step 4: Specific Fuel Consumption (BSFC)

$$BSFC = \frac{FCH}{BP}$$
$$BSFC = \frac{0.052}{0.4}$$
$$BSFC = 0.131\ \text{kg/kWh}$$

Step 5: Brake Thermal Efficiency (BTE)

Step 6: Indicated Power (IP)

$$ME = \frac{BP}{IP} \times 100$$

Step 7: Indicated Thermal Efficiency (ITE)

$$IP = \frac{BP \times 100}{ME}$$
$$IP = \frac{0.4 \times 100}{19.7}$$
$$IP = 2.03\ \text{kW}$$
$$IT$$

Step 8: Mechanical Efficiency (ME)

$$ME = \frac{BP}{IP} \times 100$$
$$ME = \frac{0.4}{2.03} \times 100$$
$$ME = 19.7\%$$

FINAL RESULTS

$$W = 1.7\ \text{kg}$$
$$BP = 0.4\ \text{kW}$$
$$FCH = 0.052\ \text{kg/hr}$$
$$BSFC = 0.131\ \text{kg/kWh}$$
$$BTE = 8.46\%$$

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$IP = 2.03\text{ kW}, ITE = 8.46\%, ME = 19.7\%$

OBSERVATIONS TABLES

Table of 4.1-D100Pure Diesel

S.NO	W (kg)	PEED (N)	TIME IN CC	BP (kW)	IP (kW)	FCH (kg/h)	BSFC (kg/kWh)	BTE (%)	ITE (%)	ME (%)
1	1.7	1500	74	0.4	2.03	0.052	0.131	8.46	8.46	19.7
2	3.4	1500	70	0.8	2.43	0.116	0.145	14.34	14.34	32.9
3	5.1	1500	69	1.2	2.8	0.314	0.262	18.39	18.39	42.9
4	6.8	1500	62	1.6	3.19	0.451	0.282	23.25	23.25	50.2

4.2 Brake Specific Fuel Consumption

The ratio of the mass flow rate of the fuel delivered to the engine to the braking power obtained at a crankshaft is known as brake specific fuel consumption, and it reflects how efficiently the fuel is used to produce brake power.

The BSFC specifies the efficiency with which a certain amount of gasoline is turned into brake power. Thus, regardless of other parameters such as engine capacity, engine size, number of cylinders, etc., it is simple to compare the efficiencies of different engines on this basis.

Table 4.2 - Load Vs Brake Specific Fuel Consumption

S.NO	BLENDS	BSFC (kg/kwh)			
		25% of full load	50% of full load	75% of full load	100 % of full load
1	D100	0.131	0.145	0.262	0.282
2	RBME10D90	0.106	0.131	0.238	0.267
3	RBME15D80IB5	0.095	0.103	0.204	0.224
4	RBME20D75IB5	0.087	0.094	0.181	0.198
5	RBME25D70IB5	0.081	0.087	0.093	0.187

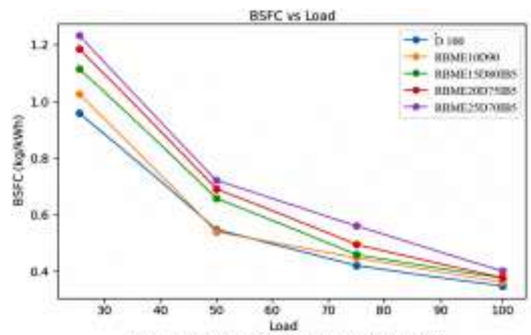

Fig: 4.1 Load Vs Brake Specific Fuel Consumption

4.2.1 Brake Thermal Efficiency

The amount of power available at the crankshaft of the engine is referred to as brake power. It's also determined by the product of the available torque at the crankshaft and the crankshaft's angular speed. The brake thermal efficiency is a type of engine thermal efficiency that is defined as the ratio of brake power at the engine crankshaft to power generated by fuel combustion. The amount of power taken by the engine crankshaft out of the total power created by the burning of the fuel is shown by the brake thermal efficiency.

Table 4.3 - Load Vs Brake Thermal Efficiency

S.NO	BLENDS	BTE (%)			
		25% of full load	50% of full load	75% of full load	100% of full load
1	D100	8.46	14.34	18.39	23.25
2	RBME10D90	7.85	14.03	18.01	22.85
3	RBME15D80IB5	7.35	12.63	17.77	22.56
4	RBME20D75IB5	7.03	11.95	16.79	22.05
5	RBME25D70IB5	6.87	11.25	17.23	21.78

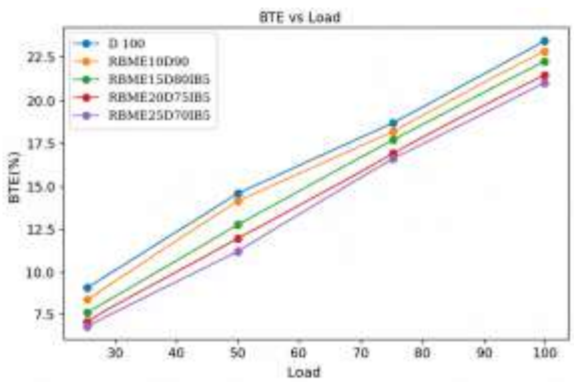

Fig: 4.2 Load Vs Brake thermal efficiency

4.2.2 Indicated Thermal Efficiency

The amount of power developed inside the engine cylinder is referred to as indicated power. It is also determined by the pressure of the gases acting on the piston during the power stroke. The indicated thermal efficiency is a type of engine thermal efficiency that is defined as the ratio of indicated power developed inside the engine cylinder to the power generated by fuel combustion. The amount of power produced within the engine cylinder out of the total power created by the burning of the fuel is shown by the indicated thermal efficiency.

Table 4.3 - Load vs Indicated Thermal Efficiency

S.NO	BLENDS	ITE (%)			
		25% of full load	50% of full load	75% of full load	100% of full load
1	D100	42.9	43.58	43.89	48.58
2	RBME10D90	41.68	43.21	43.68	48.35
3	RBME15D80IB5	41.32	43.02	43.58	46.23
4	RBME20D75IB5	41.02	42.05	42.86	46.02
5	RBME25D70IB5	40.89	42.58	42.78	45.86

4.2.3 Mechanical Efficiency

The Mechanical efficiency is measure of the effectiveness with which a mechanical system performs. It is usually the ratio of the power delivered by a mechanical system to the power supplied to it, and because of friction, this efficiency is always less then one. Mechanical efficiency increases with increase in engine load for all the tested fuel blends. This is mainly because frictional losses become less significant compared to the useful power output at higher loads.

Table 4.4 - Load Vs Mechanical Efficiency

S.NO	BLENDS	ME (%)			
		25% of full load	50% of full load	75% of full load	100% of full load
1	D100	19.7	32.9	42.9	50.2
2	RBME10D90	18.8	32.3	42	49.2
3	RBME15D80IB5	17.1	29.1	38.2	45.1
4	RBME20D75IB5	14.6	25.5	34.3	40.7

5	RBME25D70IB5	13.5	23.8	32	38.5

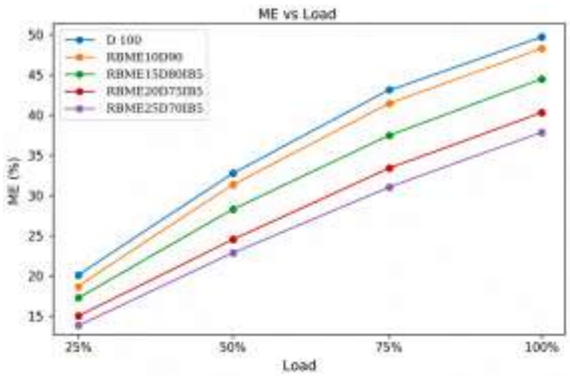

Fig: 4.4 Load Vs Mechanical efficiency

2.2.4 Hydrocarbon Emissions

Diesel combustion is heterogeneous in nature, unlike spark-ignited engines, where the combustible mixture is generally homogeneous. A cylinder filled with high-temperature compressed air is injected with diesel fuel. Emissions produced by burning this heterogeneous air/fuel combination are influenced by the conditions present not only during combustion, but also during expansion and, in particular, prior to the exhaust valve opening.

Table 4.5 - Load Vs Hydrocarbons

S.NO	BLENDS	Un Burned Hydrocarbon (ppm)			
		25% of full load	50% of full load	75% of full load	100% of full load
1	D100	28	25	24	23
2	RBME10D90	25	24	23	22
3	RBME15D80IB5	19	18	17	15
4	RBME20D75IB5	11	11	10	9
5	RBME25D70IB5	10	9	8	7

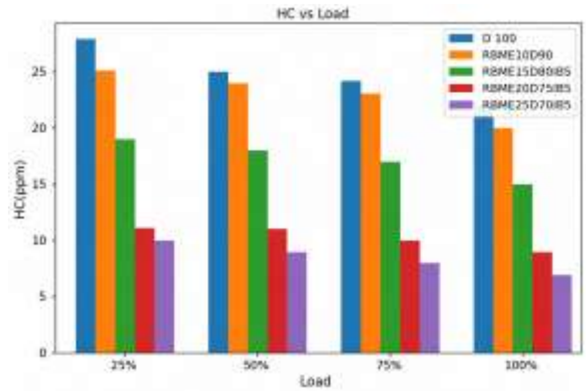

Fig: 4.5 Load Vs Mechanical efficiency

4.2.5 Oxides of Nitrogen

NOx emissions increase with increase in engine load for both diesel and biodiesel blends. This is mainly due to higher combustion temperatures at higher loads. The availability of oxygen in biodiesel further enhances the formation of NOx. Biodiesel and its blends generally produce higher NOx emissions compared to pure diesel. This is because biodiesel has a higher oxygen content in its molecular structure. The higher cetane number of biodiesel leads to shorter ignition delay. As a result, more fuel undergoes premixed combustion, increasing in-cylinder temperature and pressure. Overall, NOx emissions rise with load and are higher for biodiesel blends than diesel.

Table 4.6 - Load Vs Oxides of Nitrogen

S.NO	BLENDS	Oxides of Nitrogen (%Vol)			
		25% of full load	50% of full load	75% of full load	100% of full load
1	D100	250	390	630	770
2	RBME10D90	313	428	652	807
3	RBME15D80IB5	363	455	674	823
4	RBME20D75IB5	370	485	690	845
5	RBME25D70IB5	380	520	710	868

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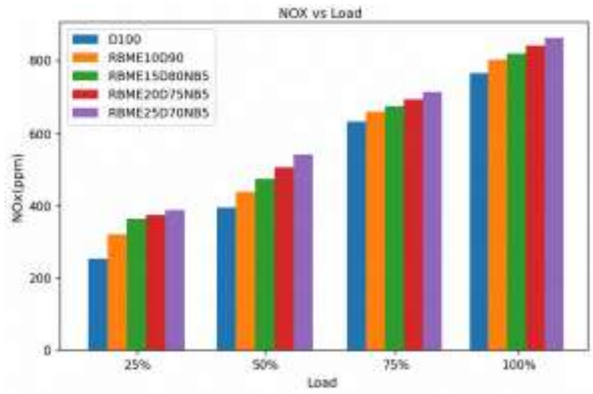

Fig: 4.6 Load Vs Oxides of Nitrogen

4.2.5 *Carbon Monoxide*

Like other internal combustion engines, a diesel engine turns chemical energy in the fuel into mechanical power. Diesel fuel is a blend of hydrocarbons that, in an ideal combustion process, would create just carbon dioxide (CO2) and water vapour. (In fact, diesel exhaust gases are mostly CO2, H2O, and the unused portion of engine charge air.) Other sources can contribute to pollutant emissions from internal combustion engines, usually in minor amounts but occasionally containing highly dangerous materials.

Table 4.7 - Load Vs Carbon Monoxide

S.NO	BLENDS	Carbon Monoxide (% Vol)			
		25% of full load	50% of full load	75% of full load	100% of full load
1	D100	0.131	0.145	0.262	0.282
2	RBME10D90	0.106	0.131	0.238	0.267
3	RBME15D80IB5	0.095	0.103	0.204	0.224
4	RBME20D75IB5	0.087	0.094	0.181	0.198
5	RBME25D70IB5	0.081	0.087	0.093	0.187

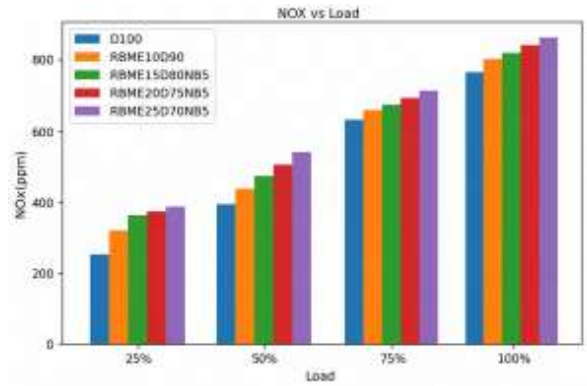

Fig: 4.7 Load Vs Carbon Monoxide

4.2.7 Oxygen

Like other internal combustion engines, a diesel engine operates using air that contains oxygen required for combustion. Oxygen plays a vital role in the burning of fuel inside the engine cylinder.In an ideal combustion process, oxygen reacts completely with the fuel to produce carbon dioxide and water vapour. However, in practical conditions, not all the oxygen supplied is consumed during combustion, and a certain amount remains in the exhaust gases. The presence of oxygen in the exhaust indicates the air–fuel ratio and the completeness of combustion Higher oxygen levels generally indicate a lean mixture, while lower levels indicate a rich mixture.

Table 4.8 - Load Vs Oxygen

S.NO	BLENDS	Oxygen (%)			
		25% of full load	50% of full load	75% of full load	100% of full load
1	D100	13.11	14.31	15.2	16.33
2	RBME10D90	14.53	15.63	16.45	17.44
3	RBME15D80IB5	16.31	18.48	20.5	21.46
4	RBME20D75IB5	18.23	20.45	22.12	24.3
5	RBME25D70IB5	20.07	22.08	23.19	25.76

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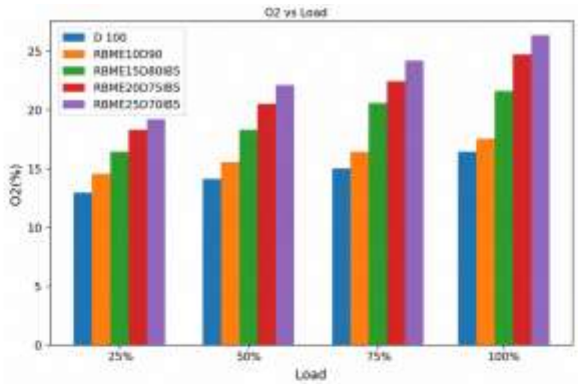

V. SUMMARY AND CONCLUSIONS

5.1 *Summary*

5.2 The study evaluates the performance and emission characteristics of a single-cylinder four-stroke diesel engine using diesel, RBME biodiesel, and isobutanol blends. It aims to assess the feasibility of replacing conventional diesel with eco-friendly fuels without engine modification. Key performance parameters such as brake power, fuel consumption, and efficiencies are analysed to understand engine behaviour. Combustion characteristics are examined using in-cylinder pressure and heat release analysis. Overall, the study focuses on improving fuel efficiency and combustion quality using blended fuels.Conclusions

5.3 The engine operated smoothly with diesel, rice bran methyl ester biodiesel, and isobutanol blends without any modifications. Fuel consumption decreased and efficiency improved with increasing load, though blends showed slightly lower efficiency due to lower calorific value. Emissions of hydrocarbons and carbon monoxide were significantly reduced, indicating cleaner combustion. Oxygen levels increased, showing better air–fuel mixing, while nitrogen oxide emissions rose slightly due to higher temperatures. The addition of isobutanol enhanced atomization and combustion quality. Overall, the blends showed acceptable performance with reduced emissions, making them a viable alternative to diesel.

- Higher percentage blends of rice bran methyl ester biodiesel and isobutanol can be tested
- Experiments can be extended to multi-cylinder diesel engines
- More emission parameters like NOx, CO and smoke can be analysed
- Different injection pressures and timing can be studied
- Engine performance can be tested at different speeds and loads
- Long-term engine durability and wear analysis can be carried out
- Use of fuel additives to improve combustion can be explored

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