Rice Bran Methyl Ester Performance and Emission Analysis on Vcr Diesel Engine

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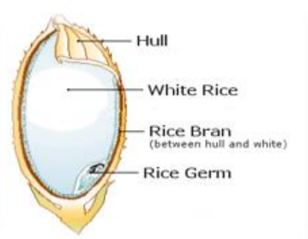
***Abstract*:**

Global Warming and the energy crisis have increased the demand to search for alternatives to the presently used fossil fuels for transportation. In recent years, interest in biodiesel as a biodegradable, clean, and sustainable energy source has grown significantly worldwide. The new cycle advancements made it conceivable to deliver biodiesel from various vegetable oils practically identical in quality to that of fossil diesel energizers with added alluring benefits. Because of this, biodiesel production of Rice Bran oil by using the base-catalyzed Transesterification method is done and Rice Bran biodiesel is obtained. The obtained biodiesel's properties are compared with diesel fuel. The work focuses on investigating Rice Bran Methyl Ester (RBME) Biodiesel on a Variable Compression Ratio (VCR) diesel engine at various Compression ratios of 15, 16, 17, 17.5, and 18. The performance characteristics like Brake Thermal Efficiency, Mechanical Efficiency, Brake Specific Energy Consumption, and emission characteristics like CO, HC, CO_2, NOx, and Smoke Opacity readings were determined at 25%, 50%, 75%, and 100% Load conditions respectively. A comparison of various parameters has been made between diesel fuel and RBME characteristics

***Keywords*:** Variable Compression Ratio (VCR), Rice Bran Biodiesel, Transesterification, Emission Analysis.

1. Introduction

A variety of lipids are found in rice bran oil, with 47% of them being monounsaturated, 33% being polyunsaturated, and 20% being saturated. Oryzanol, an antioxidant that may help prevent heart attacks, phytosterols, substances thought to help lower cholesterol absorption, and relatively high levels of Vitamin E are all present in the oil, which suggests that it may also have some health advantages.



(a) (b)

Figure 1. (a) Rabi Crop (b) Rice Bran

Biodiesel is made from rubber seed oil. The main goal of process optimization in the acid esterification process is to decrease the acid value. The produced biodiesel contains monoester, a volatile component that makes it more suitable for use as a diesel substitute in cars. [1,2]. Palm oil is converted into methyl ester by transesterification process and blended this palm oil with Diesel in different volume proportions (25%, 50%, and 75%). The ignition profile was seen to be smoother and no thumping was capable while activity with biodiesel mixes. It is demonstrated that DI diesel engines may run on biodiesel made from palm oil and its mixes [3]. It is hypothesized that this pretreatment lowers the process's overall complexity and lowers the cost of manufacturing biodiesel [4]. Raw materials used as feedstock, the acid and alkaline transesterification, several factors on the manufacture of biodiesel, free fatty acids, temperature, stirring, specific gravity and the biodegradability of the biodiesel affect the properties of biodiesels manufactured [5]. An alternative fuel for gas turbines is proposed, by running esterified Jatropha oil as its fuel. The properties of Jatropha oil are quite similar to those of diesel oil. However, since the viscosity is higher, it can be decreased by etherifying or degumming the Jatropha oil to create its biodiesel [6]. Four distinct compositions of a cotton seed oil methyl ester were made and combined with diesel. The outcomes showed that using biodiesel without changing the engine is safe [7]. Two unique biodiesels were ready from animal fat-based yellow oil with 9% free unsaturated fats and from soya bean oil. Both biodiesel fills gave critical decreases in particulates, carbon monoxide (CO), and unburned hydrocarbons, the oxides of nitrogen expanded by 11% and by 13% for the yellow oil methyl ester and soybean oil methyl ester separately [8]. It investigated and compared what the significant fuel attributes and emission characteristics are for a blend (20 vol.%) of soybean oil methyl esters (SME) and partially hydrogenated SME (PHSME) in ultra-sulfur diesel fuel (ULSD). It had better lubricity, a higher kinematic viscosity, a higher cetane number, less Sulphur, poorer low-temperature characteristics, and less oxidative stability [9]. The fuel characteristics of karabi seed biodiesel were reported to be within the ASTM D 6751-02 standard limits in a single-cylinder diesel engine. With an increase in the percentage of biodiesel in blends, BSFC increased and BTE declined. As the percentage of karabi biodiesel in blends increased, the amount of smoke, UBHC, and CO in exhaust emissions decreased but NOx levels increased [10]. Rapeseed oil and its 5%, 20%, and 70% blends with diesel fuel were subjected to engine tests, and the results showed that only low-concentration blends could bsingle coe recognized as potential candidates to be certified for full-scale use in unmodified diesel engines in terms of performance efficiency and environmentally friendly emissions (especially for B20 and lower blends)[11].

The characteristics of a diesel engine running at a compression ratio and fueled by biodiesel mixtures made from rice bran oil are presented. This is done in recognition of the importance and potential of rice-bran oil in meeting the country's energy needs as well as environmental issues [12,13,14]. Some researchers used fly ash as a material for a diesel engine's thermal barrier layer, and studied the emissions produced in running methyl esters of Rice bran, Pongamia oil, and its blend with diesel on a diesel engine using an AVL gas analyzer and the exhaust emissions were observed with the values compared for fly ash coated engine and that of the uncoated engine [15] The transesterification process has been extensively researched. They discovered that a methanol/oil molar ratio of 6:1 was ideal for base-catalyzed transesterification in the temperature range of 50 to 80°C. When 0.5 to 1 weight percent of sodium oxide is used as a catalyst, this yields a conversion of 94–95%.

1.1 Biodiesel production

Two jars of 2 liters capacity, Magnetic Stirrer, two decanters of one-liter capacity, rice bran oil, methanol, concentrated Sodium Hydroxide (NaOH), sulphuric acid (H_2SO_4), Phosphoric acid, electric heater, funnel, cotton waste.

Biodiesel Preparation Steps: The steps taken in the preparation of Biodiesel are

1. Transesterification process
2. Filtering: Filter the oil to remove solid particles using cotton waste

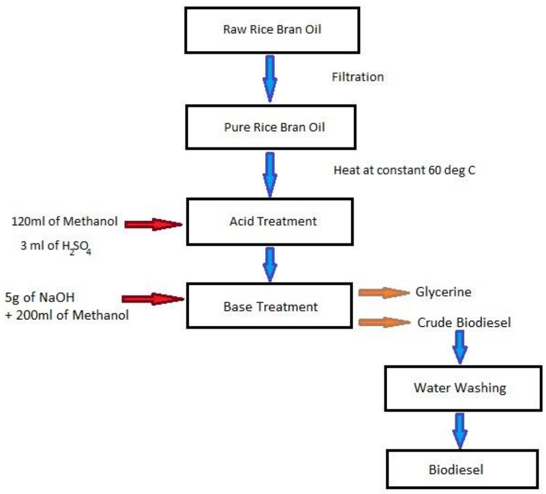


Figure 2. Transesterification Process Flow Chart

3. Removing The Water
4. Magnetic Stirrer
5. Acid Treatment

Figure 3. Filtering the oil and Pre-heating it

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Figure 4. Acid Treatment and Decantation for separation of glycerine

Figure 5. Mixing Methoxide with Rice Bran oil, and decanting to separate glycerin

Figure 6. Rice Bran Methyl Ester after first water wash and second water wash

Figure 7. Pouring out the biodiesel from decanter

(a) (b)

Figure 8. (a) Heating to remove water particles and (b) the obtained biodiesel

Table 1. Properties of Diesel and Rice Bran oil biodiesel

Property	Diesel	Biodiesel (Rice bran oil)
Density at 20 ºC g/cm^3	0.82	0.8742
Viscosity at 40 ºC mm2/s	3.4	4.63
Iodine Number J2 g/100g	6	102
Pour Point ºC	1	3
Auto Ignition Temperature ºC	225	320
Cetane Number	45	56.2
Flash Point. ºC	71	165
Oxygen content, Max wt%	0.4	11.25
Acid value, mg KOH/g	0.07	0.25
Net Heating Value, MJ/kg	43.5	32.725

2. EXPERIMENTATION

2.1 Specifications:

Table 2. Specifications of the VCR Engine Setup

Product	Research Engine test setup single cylinder, 4 stroke, Multi-fuel, VCR, Code 240
Engine	Single cylinder, 4 stroke, water-cooled, stroke 110mm, bore 87.5 mm, 661cc. Diesel mode: , CR Range 12-18, 3.5 KW, 1500 rpm. Injection variation:0-25º BTDC Petrol mode: 4.5 KW@1800 rpm, speed range 1200-1800 rpm

Compression Ratio Adjustment: After experimenting with all four loads, the compression ratio is to be changed. For this, the following steps are employed:

- Slightly loosen the Allen bolts provided on both sides of the tilting cylinder block
- To tilt the cylinder block, loosen the adjuster's lock nut and spin it while holding a spanner.
- Use the scale on the CR indicator to adjust the appropriate compression ratio.
- Tighten the lock nut of the adjuster
- Gently tighten the vertical Allen bolts (6 nos).

The results are noted in a tabular form and graphs are drawn respectively for each emission characteristic noted in the table. The emission characteristics at compression ratios 15, 16, 17, 17.5, and 18 are plotted and the variations are observed

3. RESULT AND DISCUSSION

3.1 Engine Performance Analysis with Variation in % Load

After experimenting to determine the performance, combustion parameters, and emission at each compression ratio of the VCR Engine, the calculations have been made to determine various parameters such as

Brake Power, Specific Fuel consumption, Volumetric efficiency, Specific Energy consumption, Brake thermal efficiency, Mechanical efficiency, for the different loads.

At Fixed Compression Ratio 17.5

Table 3. Load vs Brake Specific Energy Consumption

% Load\CR	BSEC		Brake Thermal Efficiency		Mechanical Efficiency	
	Diesel	RBME	Diesel	RBME	Diesel	RBME
0	0	0	0	0	0	0
12.5	15.976	14.027	6.259	6.259	16.148	17.401
25	8.604	7.846	11.621	12.531	27.634	29.382
50	5.444	4.875	18.366	19.268	42.859	45.152
75	4.447	4.097	20.425	22.485	52.381	54.934
100	3.978	3.749	25.132	26.335	59.376	61.731

Load Vs Break Specific Energy consumption

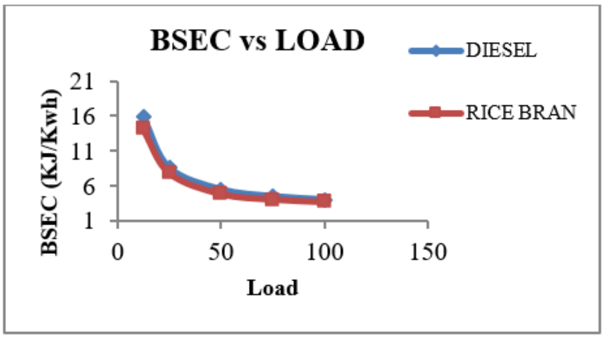

Figure 9. Variation of BSEC with load at CR 17.5

The BSEC values are more for Diesel than for RBME. For Diesel, the BSEC values tend to decrease from 15.97 to 3.97, and for RBME, the BSEC values vary from 14.02 to 3.74. It is found that with an increase in load, the specific energy consumption is found to decrease steadily for both diesel and RBME. Compared to diesel, biodiesel has a lower calorific value, hence more fuel is required to produce the same output.

Load Vs Brake Thermal Efficiency

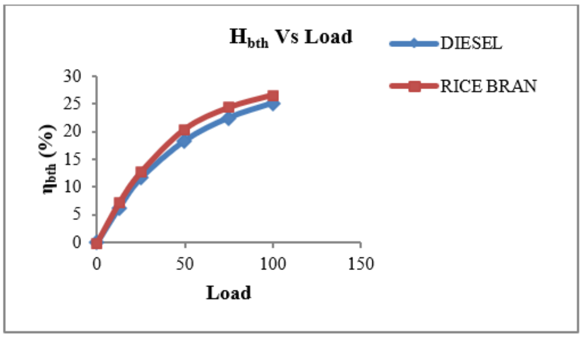

Figure 10. Variation of BTH with Load at CR 17.5

All test fuels have seen an increase in BTE with increasing load. This could be explained by the fact that when the load grows, the suction pressure that develops will be higher, which may have led to an effective combustion. A similar pattern was seen for the methyl esters of many additional biodiesels. But compared to diesel, biodiesel has a higher BTE. The improved lubricity of the esters may be the cause of this.

Load Vs Mechanical Efficiency

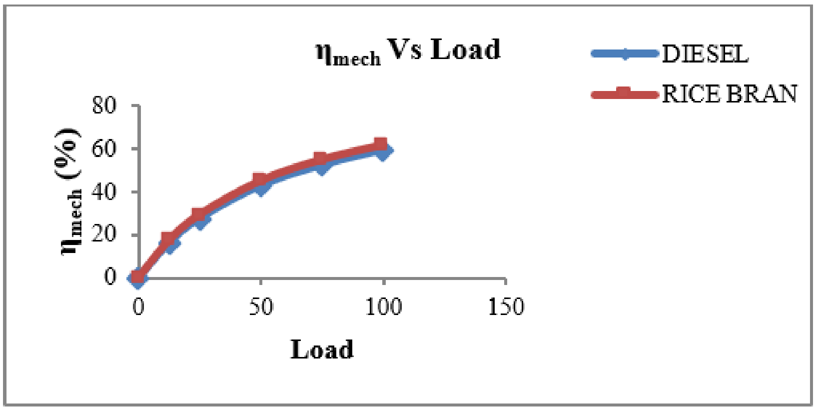

Figure 11. Variation of η_{mech} with Load at CR 17.5

The Mechanical efficiency increases with the increase of the load capacity on the engine. The η_{mech} registered a considerable increase in a parabolic way for nearly all the compression ratios the full load efficiency values being 59.37% for diesel and 61.73% for RBME fuel. The mechanical efficiency of biodiesel is found to be higher than the of diesel fuel.

3.2 Emission Analysis at CR 17.5 with Variation in % Load

Table 4. Carbon Monoxide Vs Load

% LOAD\CR	CO		HC		CO_2		NOx		SMOKE	
	Diesel	RBME	Diesel	RBME	Diesel	RBME	Diesel	RBME	Diesel	RBME
0	0.08	0.07	28	12	1.1	0.6	61	19	51.6	59.5
12.5	0.06	0.04	26	10	1.6	0.9	146	51	66.8	87.1
25	0.04	0.04	15	7	1.2	0.7	123	47	53.9	91.4
50	0.05	0.04	15	7	1.4	0.9	217	84	56.3	95.8
75	0.05	0.04	14	2	1.5	0.8	248	92	64.1	85.4
100	0.01	0.09	6	8	0.9	2.1	143	242	57.7	82.7

Carbon Monoxide Vs Load

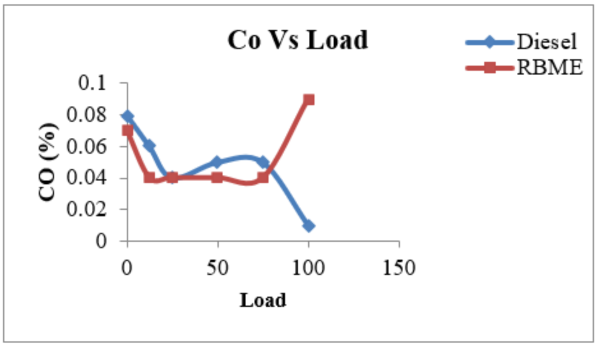

Figure 12. Variation of CO emissions vs Load at CR 17.5

When there is insufficient oxygen to oxidize the fuel, CO often forms. Diesel engines typically operate with surplus air, resulting in lower CO emissions than those of gasoline engines. With an increase in load, the CO emissions for both Diesel fuel and RBME were found to decrease at 3/4th (75 %) load.

Hydrocarbon Vs Load

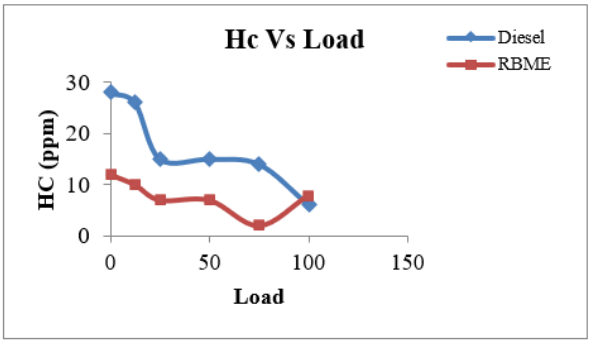

Figure 13. Variation of HC emissions vs Load at CR 17.5

Depending on the engine's load and speed, the concentration of HC in diesel exhaust can range from a few ppm to several thousand ppm. Numerous distinct hydrocarbons from the fuel fed to the engine and partially burnt hydrocarbons created during combustion make up the HC in diesel exhaust. The graph shows that HC emissions of RBME were lesser than that of diesel fuel with RBME having HC emissions at 3/4th (75 %) load is 2 ppm while Diesel fuel has 14 ppm. This drop was brought on by higher biodiesel cetane numbers and higher gas temperatures.

Carbon Dioxide Vs Load

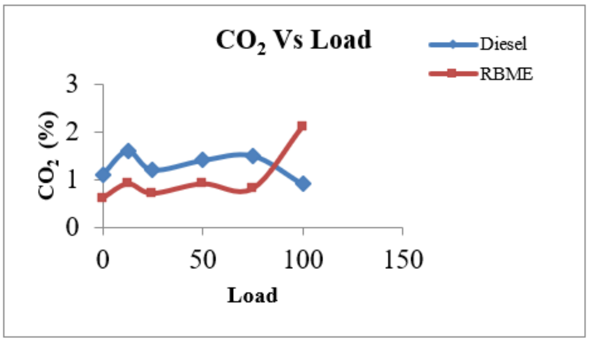

Figure 14. Variation of CO_2 vs Load

CO_2 emission of biodiesel was higher than diesel fuel. This resulted from the fuel burning entirely. Utilizing the unused oxygen profile of test fuels, this could be verified. In the graph drawn between CO_2 emission levels vs. Load, the emissions of RBME were found to be lesser than diesel fuel up to $3/4^{th}$ (75 %) load and greater than that of conventional diesel fuel at full load condition. The reason for an increase in CO_2 levels in the exhaust can be due to the complete combustion of the hydrocarbons.

Oxides Of Nitrogen Vs Load

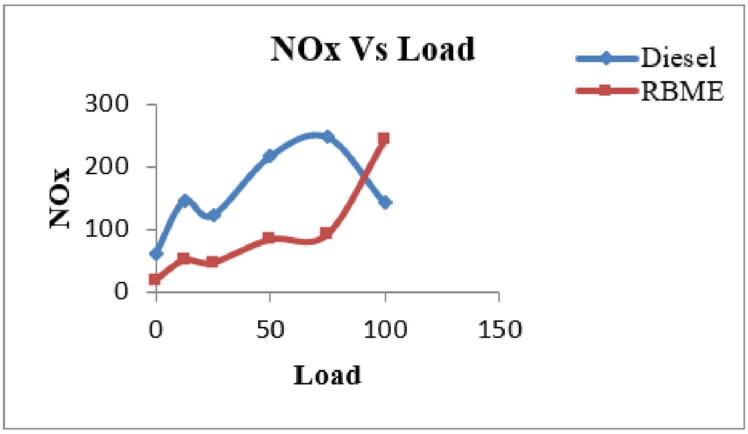

Figure 15. Variation of NOx vs Load

Using biodiesel will result in better combustion, which will raise the temperature in the combustion chamber and increase the amount of oxygen present, which will increase the amount of NOx produced by biodiesel-powered engines. Up to $3/4^{th}$ (75 %) load Condition NOx emission of Biodiesel is found to be lesser than diesel. NOx emission of Biodiesel is found to be higher than diesel at full load conditions because of their higher exhaust gas temperature. NOx was produced as a result of the fuel's higher temperature and oxygen concentration. According to the literature, biodiesel combustion typically results in higher NOx emissions than diesel.

Smoke Opacity Vs Load

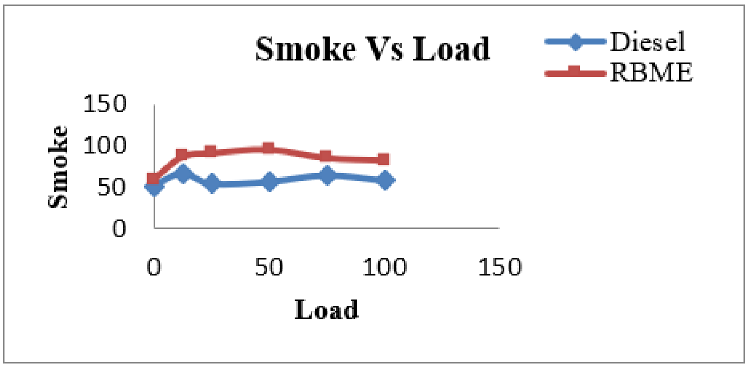

Figure 16. Variation of Smoke No. vs Load

Smoke would be produced as a result of the gases' shorter residence durations in the combustion chamber. The graph shows the variation of the Smoke Opacity Rating concerning the load applied for diesel and RBME biodiesel. It is learned that the smoke number gradually increases from no load to full load condition. Due to the less oxygen content in the biodiesel, the RBME biodiesel resulted in a higher amount of smoke as compared to diesel.

Table 5. Performance Characteristics At Various Compression Ratios For 3/4th Load

CR	BSEC		Brake Thermal Efficiency		Mechanical Efficiency	
	Diesel	RBME	Diesel	RBME	Diesel	RBME
15	4.368	4.213	23.25	23.52	55.194	60.245
16	4.321	4.056	23.05	24.64	56.444	58.841
17	4.254	4.136	23.97	25.35	62.538	60.154
17.5	3.856	4.352	26.41	22.64	63.015	57.534
18	4.134	4.036	24.63	20.76	63.242	63.814

3.3 Engine Performance Analysis with Variation in Compression Ratio

Compression Ratio Vs Brake Specific Energy Consumption

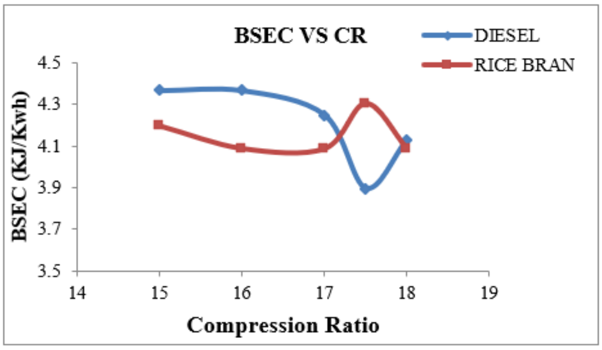

Figure 17. Variation of BSEC vs CR

Multiplying the specific fuel consumption and calorific value of the fuel yields the specific energy consumption. By drawing a graph using brake-specific energy consumption and different Compression Ratios (CRs) such as CR 15, 16, 17, 17.5, and 18, one can compare diesel and Rice Bran Methyl Ester (RBME). It is found that with an increase in load, the specific energy consumption is found to decrease steadily for both diesel and RBME as the power per unit fuel consumption increases at higher compression ratios. The BSEC values are more for Diesel than for RBME. The maximum BSEC for diesel is 4.368 KJ/KWh at CR 15 and the maximum BSEC for RBME is 4.352 KJ/KWh at CR 17.5.

Compression Ratio Vs Brake Thermal Efficiency

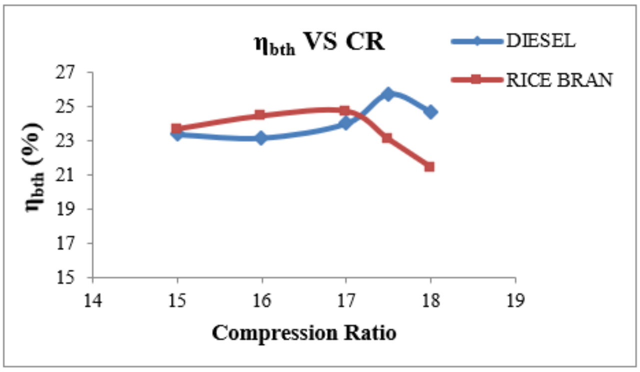

Figure 18. Variation of η_{bth} vs CR

As the load grows, a stronger suction pressure would emerge, which may have led to an efficient combustion, one explanation for the RBME's improved efficiency. The methyl esters of numerous other biodiesels showed the same tendency. However, it has been discovered that biodiesel has a higher η_{bth} than diesel. This might be as a result of the esters' increased lubricity.

Compression Ratio Vs Mechanical Efficiency

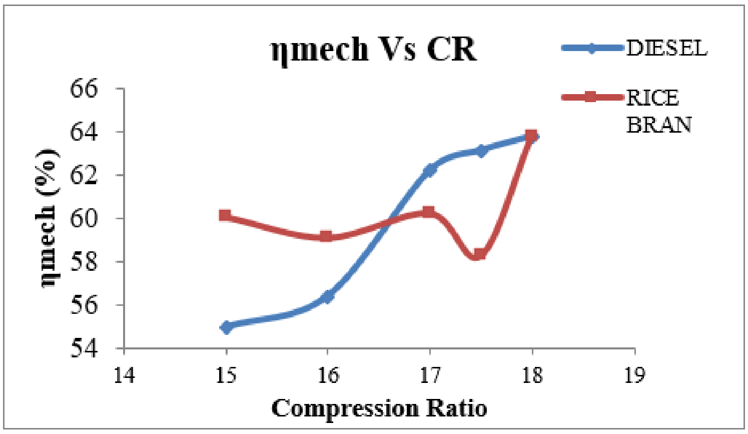

Figure 19. Variation of η_{mech} Vs CR

The brake horsepower (delivered power) to the advertised horsepower ratio is known as mechanical efficiency (power provided to the piston). The graph depicts the mechanical efficiency is fluctuating with compression ratio. It has been discovered that biodiesel has a higher mechanical efficiency than diesel fuel. The η_{mech} registered a considerable increase in a parabolic way for nearly all the compression ratios. The efficiency values are 63.24% for diesel and 63.81% for RBME fuel at compression Ratio 18.

It is observed that different efficiencies of RBME are found to be high when compared with those of diesel.

3.4 Emission Analysis with Variation in Compression Ratio

Table 6. Emission Characteristics at Various Compression Ratios For 3/4th Load

CR	CO		HC		CO2		Nox		Smoke	
	Diesel	RBME	Diesel	RBME	Diesel	RBME	Diesel	RBME	Diesel	RBME
15	0.15	0.14	55	43	5.8	6.7	583	762	90.1	81.8
16	0.09	0.15	43	37	4.2	6.4	462	643	84.4	90.7
17	0.1	0.12	51	37	6	6.2	711	679	63.3	89.9
17.5	0.05	0.04	14	2	1.5	0.8	248	92	64.1	85.4
18	0.02	0.06	8	6	1.2	1.1	226	157	53.4	79.4

Compression Ratio Vs Carbon Monoxide

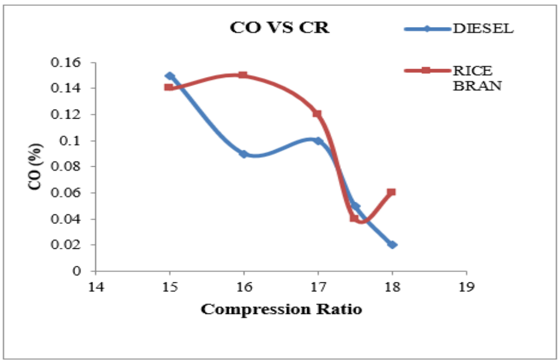

Figure 20. Variation of CO emissions vs CR

Fuels that burn partially result in the formation of CO, which is most easily created by fuels made of petroleum since they have an oxygen-free molecular structure. From the graph, it is observed that the values of CO emissions tend to reduce for both the RBME and Diesel fuel. The reason for the decrease in CO emission can be due to complete combustion at higher compression ratios.

Compression Ratio Vs Hydro Carbon

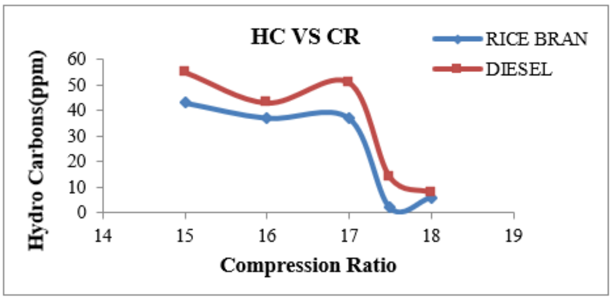

Figure 21. Variation of HC emissions vs CR

Depending on the engine's load and speed, the concentration of HC in diesel exhaust can range from a few ppm to several thousand ppm. Numerous distinct hydrocarbons from the fuel fed to the engine and partially burnt hydrocarbons created during combustion make up the HC in diesel exhaust. The graph shows the variation of HC Emissions with an increase in Compression ratio. It is seen that for both diesel and RBME, the values of HC seem to be decreasing with an increase in compression ratio. Due to the increased gas temperature and greater cetane number of biodiesel, the HC emissions of RBME were lower than those of diesel fuel.

Compression Ratio Vs Carbon Dioxide

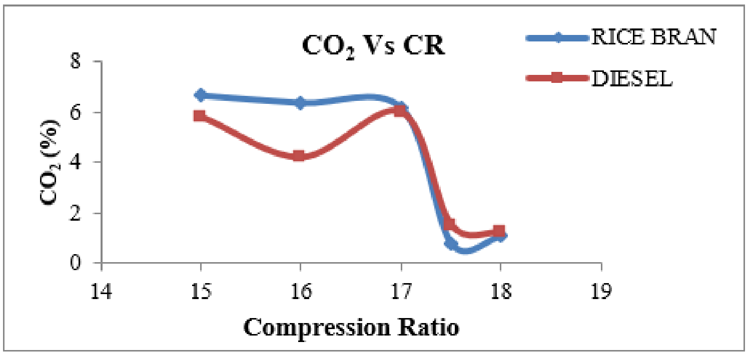

Figure 22. Variation of CO_2 emissions vs CR

CO_2 emission of biodiesel was higher than diesel fuel. This resulted from the fuel burning completely. Utilizing the unused oxygen profile of test fuels, this could be verified. In the graph drawn between CO_2 emission levels vs. Compression ratio, the emissions of RBME were found to be greater than those of conventional diesel fuel. The Value of CO_2 emissions was found to decrease with an increase in the CR. RBME has emissions ranging from 6.7 to 1.1% and diesel fuel has emissions ranging from 5.8 to 1.2%.

Compression Ratio Vs Oxides Of Nitrogen

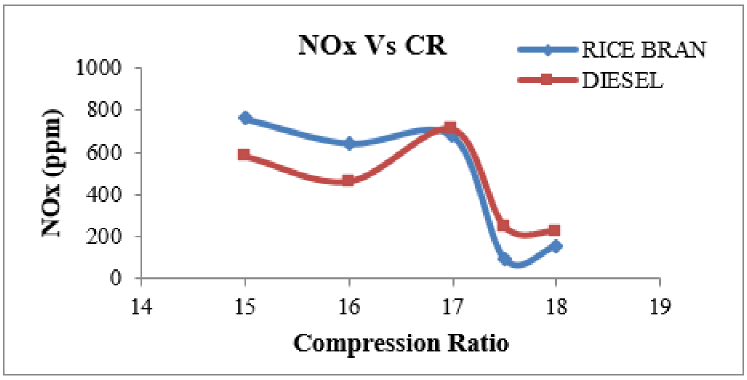

Figure 23. Variation of NOx emissions vs CR

In the graph plotted between NOx emissions and Compression ratios, the value of NOx emissions was found to be decreasing for both RBME and Diesel fuel with rice bran fuel having more NOx emissions than diesel. The highest NOx emissions were obtained for CR 15 with diesel and RBME having 583 and 762ppm respectively.

Compression Ratio Vs Smoke No.

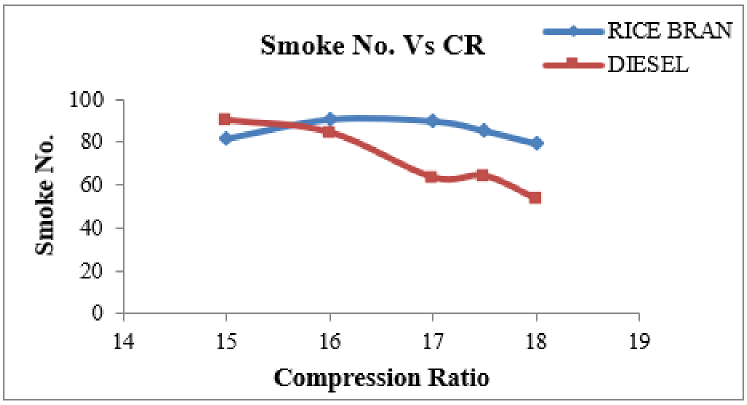

Figure 24. Variation of Smoke No. vs CR

Smoke would be produced as a result of the gas's shorter residence durations in the combustion chamber. The graph shows the variation of Smoke Opacity Rating concerning Compression Ratios applied for diesel and RBME biodiesel. It is learned that the smoke number gradually decreases from 15 CR to 18 CR. The smoke number of Diesel decreased from 90.1 to 53.4, while Smoke No. of RBME decreased from 90.7 to 79.4 respectively.

4. CONCLUSIONS

The following conclusions are drawn from the experimentation conducted on a Variable Compression Ratio Diesel Engine with diesel and Rice Bran Methyl Ester (RBME).

- The performance and Emission study of a VCR Diesel engine operated on Diesel, Rice Bran Methyl Ester (RBME) oils at various compression ratios indicates no major modifications required in an existing diesel engine.
- The experimental investigations have shown that the Compression Ratio 17.5 was found to be the optimal compression ratio because it obtained nearly accurate results of the performance and emission analysis.
- It is observed from the emission analysis at a 17.5 Compression Ratio the emission of RBME is lesser than the diesel up to 3/4th (75 %) load condition.
- The Brake Specific Energy Consumption of Rice Bran Methyl Ester (RBME) was found to decrease with an increase in the load, with RBME being 5.79% less than diesel fuel at full load conditions. This may be attributed to the lower calorific value of the fuel.
- The Brake thermal Efficiency was found to increase in a parabolic form with an increase in load and it was found that the value of the Brake thermal Efficiency of RBME is 5.73% more than diesel fuel at full load conditions at a Compression ratio of 17.5. This is due to the complete combustion of biodiesel.
- All of these experiments were conducted to characterize biodiesel, and the results showed that practically all of its key characteristics are remarkably similar to those of mineral diesel, making it a viable contender for use in CI engines.

REFERENCES

[1] D.F. Melvin Jose, R. Edwin Raj, B. Durga Prasad, Z. Robert Kennedy, A. Mohammed Ibrahim, "A multi-variant approach to optimize process parameters for biodiesel extraction from rubber seed oil", Applied Energy 88 (2011) 2056 – 2063.

[2] Tamilselvan, R., Periyasamy, S. Erratum to "A novel investigation in the performance, combustion, and emission characteristic of variable compression ratio engine using bio-diesel blends". J Mech Sci Technol 36, 3775 (2022). https://doi.org/10.1007/s12206-022-0651-3

[3] A. Sharon, K. Karuppasamy, D.R. Soban Kumar, A. Sundaresan, " A test on DI engine fueled with methyl esters of used palm oil", Renewable Energy 47 (2012) 160 – 166.

[4] K.V. Thiruvengadaravi, J. Nandagopal, P. Baskaralingam, V. Sathya Selva Bala, S. Sivanesan, "Acid-catalyzed esterification of karanja (pongamia pinnata) oil with high free fatty acids for biodiesel production", Fuel 98 (2012) 1 – 4.

[5] Y.C. Sharma, B. Singh, S.N. Upadhyay," Advancements in development and characterization of biodiesel: A review", Fuel 87 (2008) 2355 – 2373.

[6] A. Rehman, Deepak R. Phalke, Rajesh Pandey, "Alternative fuel for gas turbine: Esterified Jatropha oil – Diesel blend", Renewable Energy 36 (2011) 2635 – 2640.

[7] R.Anand, G.R. Kannan, K.Rajasekhar Reddy and S.Velmathi. "The Performance and emissions of a variable compression ratio diesel engine fuelled with bio-diesel from cottonseed oil". ARPN Journal of Engineering and Applied Sciences. ISSN 1819 – 6608. November 2009.

[8] Bhaumik M and Maity K, "Multi-response optimization of EDM parameters using grey relational analysis (GRA) for Ti-5Al-2.5Sn titanium alloy", World Journal of Engineering, Volume 18, Issue 1, 7 Jan 2021, Pages 50-57.

[9] Mustafa Canakci and Jon H. Van Gerpen, "Comparision of Engine Performance and Emissions for Petroleum Diesel fuel, Yellow Grease Biodiesel, and Soyabean oil Biodiesel", Presented as paper No. 016050 at the 2001 ASAE Annual International Meeting Sacramento Convention Center Sacramento, California, USA July 30 - August 1, 2001.

[10]Pradeep, A.V.,Satya Prasad, S.V.,Suryam, L.V. and Prasanna Kumari, P, "A comprehensive review on contemporary materials used for blades of wind turbine", Materials Today: ProceedingsVolume 19, 2019, Pages 556-559.

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[11] Bryan R.Moser and Aaron Williams, "Exhaust emissions and fuel properties of partially hydrogenated soybean oil methyl esters blended with ultra-low sulfur diesel fuel", Journal of Fuel Processing Technology, Vol 9o, pp. (1122 – 1128), 2009.

[12] Dilip Kumar Bora "Performance of single-cylinder diesel engine with karabi seed biodiesel". Journal of Scientific and Industrial Research Vol 68, November 2009, pp.960- 968

[13] Allu, V.P., Raju, D.L. and Ramakrishna, S."Performance analysis of cryogenically treated plus tempered carbide inserts in turning of Inconel 718 using cryogenic minimum quantity lubrication cooling technique(Article)", Journal of Engineering Tribology, Volume 233, Issue 12, 1 December 2019, Pages 1810-1819.

[14] Ekrem Buyukkaya. "Effects of biodiesel on a DI diesel engine performance, emission, and combustion characteristic" Elsevier-Fuel 89 (2010) 3099–3105

[15] Lin L, Ying D, Chaitep S, Vittayapadung S (2009) "Biodiesel production from crude rice bran oil and properties as fuel". Appl Energy 86(5):681–688

[16] Sinha S, Agarwal AK (2007) Experimental investigation of the combustion characteristics of biodiesel (rice-bran oil methyl ester)-fuelled direct injection transportation diesel engine. Proc Inst Mech Eng Part D J Automob Eng 221(8):921–932

[17] Saravanam S, Nagaranjan G, Rao GLN, Sampath S (2010) Combustion characteristics

of a stationary diesel engine fuelled with a blend of crude rice bran oil methyl ester and diesel. Energy 35(1):94–100

[18] M. Mohamed Musthafa, S.P. Sivaprakasam, M. Udayakumar, "Comparative studies on fly ash coated low heat rejection diesel engine on performance and emission characteristics fuelled by rice bran and pongamia methyl ester and their blend with diesel". Journal on Energy, www.elsevier.com

[19] Yi-Hsu Ju, Shaik Ramjan Vali, Chau-Chin Lei, Arief Widjaja. "Biodiesel from Rice Bran Oil". Chemical Engineering, National Taiwan University of Science and Technology.

[20] Ram Prakash, S.P. Pandey, S. Chatterji, S.N. Singh, "Emission Analysis of CI Engine using Rice Bran oil and their esters". Article 24 JERS Volume II Issue 1 January – March 2011.

[21] N.R. Banapurmath, P.G.Tewari, V.S. Yaliwal, Satish Kambalimath, Y.H Basavarajappa, "Combustion characteristics of a 4 stroke CI engine operated on Honge oil, Neem and Rice Bran oils when directly injected and dual-fuelled with producer gas induction". Renewable Energy 34 (2009) 1877 – 1884.

[22] M. Mohamed Musthafa, S.P. Sivaprakasam, M. Udayakumar, "Comparative studies on fly ash coated low heat rejection diesel engine on performance and emission characteristics fueled by rice bran and pongamia methyl ester and their blend with diesel". Journal on Energy, www.elsevier.com