

Rubber Seed Oil Derived Biodiesel-Mineral Diesel Blend as an Alternative Fuel in Compression Ignition Engines

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Abstract- In the face of the upcoming energy crisis, biofuels have come up as a promising alternative for mineral fuels like diesel and gasoline. With the prospect of developing a suitable alternative fuel, rubber seeds were collected and the kernel was separated from the shells using an expeller. From the dried kernels, oil was extracted using a soxhlet extractor. The extracted oil was tested for its FFA content, before subjecting for esterification in the presence of methanol and conc. sulphuric acid catalyst. The esterified oil was further subjected to trans-esterification in the presence of methanol and NaOH to obtain methyl ester and glycerin. The resulting methyl ester was washed to remove the retained impurities, and then dried to evaporate the water content present in the biodiesel. The rate of conversion from crude oil to biodiesel was almost 80%. The biodiesel was then tested for its fuel properties according to ASTM standards, and then tested for its performance parameters in a four cylinder, four stroke CI engine test rig. It was further tested for its emission parameters. According to the results of the project, there was an increase in Brake Specific Fuel Consumption in the case of biodiesel blends when compared to that of petroleum diesel. When it came to Brake Thermal Efficiency, there was a slight decrease in the case of biodiesel blends. When it came to Emissions, the lower blends and emissions lower than that of mineral diesel, whereas the blends with greater proportion of biodiesel had higher emission rate than petroleum diesel. When tested as a substitute fuel in a CI engine powered vehicle, it showed a decrease in performance proportional to increase in biodiesel in the blend.

Index Terms- Biodiesel; Biofuel; Rubber-seed oil; Alternative fuel; CI Engines

I. INTRODUCTION

The burgeoning industrial development and the rise in traffic has resulted in an incessant demand for energy. As a result, the pressure on fossil fuels has increased. What with the depleting wells of petroleum and natural gas, it has become difficult to meet this demand, and this has led to the energy crisis. Even today, fossil fuels are the major sources of energy, especially in the transportation sector, mostly because of their established availability and cost effectiveness when compared to other forms of energy. But the limited reserves of non-renewable fuels have necessitated the need for investing in alternative fuels that can eventually replace fossil fuels. Renewable alternative fuels will not only assuage the effects of the energy crisis by balancing supply with demand, but will also help in strengthening the economy by reducing dependency on petroleum producing countries for crude oil. With these developments in the field of energy, biofuels have emerged as one of the potential alternatives.

Diesel fuel has maintained its status and one of the most prominent sources of fuel because of its high thermodynamic efficiency. The most common form of diesel is derived from fractional distillation of crude petroleum oil. But with the development of alternative sources, other forms of diesel have emerged, such as biodiesel, gas to liquid diesel, coal to liquid diesel, biomass to liquid diesel, etc. Its origin dates back to late nineteenth century, when a German inventor Rudolf Diesel invented the compression ignition engine. He experimented with coal dust, vegetable oil, and many other sources to find the most efficient fuel for his engine. During the World Exhibition in Paris, 1900, he used 100% peanut oil to run the engine. He stated that, "diesel engine can be fed with vegetable oil, and this would help considerably in the development of agriculture of countries which use it."

Biodiesel is one of the alternative fuels vying to take the position of fossil fuels, and it has proved itself as comparable to that of mineral fuels, and in some areas, even better. Biodiesel can be defined as the fatty acid methyl or ethyl esters derived from vegetable oils and animal fats. Since the vegetable oil is derived from vegetable seeds which are renewable, and dependent on agriculture, it has a potential of strengthening the agricultural sector as well as reducing the expenditure over imported fuels. As the demand for seed oil increases, agriculturists might start growing more oil-seed bearing plants like soya bean (*Glycine Max*), peanut (*Arachis Hypogaea*), sunflower (*Helianthus*), rapeseed (*Brassica Napus*), coconut (*Cocos Nucifera*), karanja (*Milletta Pinnata*), neem (*Azadirachta Indica*), cotton (*Gossypium*), mustard (*Brassica*), linseed (*Linum Usitatissimum*), and castor (*Rissinus Communis*). Usually, non-edible seed-oils are preferred for production of biodiesel since they do not compete with food sources. Since the methyl ester derived from the seed-oil has high viscosity, the use of which will potentially cause fuel system blockage and spray injector blockage in engine systems

designed for mineral diesel, it might be necessary to blend the obtained biodiesel with mineral diesel. In this work, rubber seed oil has been used for the production of biodiesel by the method of two-step trans-esterification. The obtained biodiesel has been blended with mineral diesel in different proportions, i.e. B5 (biodiesel:diesel=5:10), B10, B15, B20, B30. The resulting blends have been tested in a four cylinder, four stroke diesel engine, and the calculated performance parameters are compared with that of mineral diesel to justify the viability of rubber seed oil derived biodiesel as an alternative fuel in C.I. engines.

II. PRODUCTION OF BIODIESEL

The production of biodiesel was undertaken in a step by step process, from the collection of rubber seeds to the testing of biodiesel (Fatty Acid Methyl Ester) in a CI engine. The equipment needed for the production of biodiesel were shell remover, soxhlet extractor, burette for titration, round bottom flasks, triple neck flask, measuring flasks, separating funnel, holders, heater, condenser, and a beaker. The chemicals required were n-hexane, methanol, conc. sulphuric acid, NaOH salt, NaOH solution, phenolphthalein indicator, and isopropyl alcohol.

2.1 Feedstock

The rubber seeds needed for the production of biodiesel were collected from a rubber tree plantation in Chikmagalur, Karnataka, India. The weight of the collected seeds was around 20kg. They were washed and dried, before separating the kernel from the shells using a de-shelling machine. After separating the rotten kernel, the final yield was around 12kg. The rubber seed kernel was further dried to remove any moisture content.

2.2 Extraction of Oil

The rubber seed kernel was finely ground before placing it in the thimble of the soxhlet extractor in batches to undergo soxhilation. Another receiving flask was filled with n-hexane and placed on a heater. The soxhlet extractor was fixed above the flask, and a condenser was placed above it. When the heater was turned on, the solvent moved up the distillation arm and into the thimble containing the kernel. The condenser ensured that no solvent vapors escaped from the extractor. The rubber seed oil in the kernel dissolved in the n-hexane, and it was siphoned off when the thimble was filled. The solvent and oil mixture were subjected to evaporation above 100 degree Celsius to separate the solvent and to remove any moisture content.

2.3 Testing of FFA Content

The testing of FFA content was carried to ascertain whether the free fatty acid content in the obtained oil was below the accepted standard for biodiesel. The weight of the oil taken for the purpose of testing was 1.04gm, and to this, 15ml of isopropyl alcohol was added as a solvent, along with 5-6 drops of phenolphthalein indicator. In a burette, 0.1 Normal NaOH was taken, and titrated against the solvent mixture.

$$FFA\ Content = \frac{28.2 \times Normality\ of\ NaOH \times Titration\ Value}{Weight\ of\ oil} \quad (2.1)$$

Using the above formula, the FFA content was found to be 29%. Since this was well above the specified standards, the oil had to be subjected for acid esterification to reduce the excessive acid content of the rubber seed oil.

2.4 Esterification

For the first trial of this process, one liter of extracted oil was taken in a triple neck flask and was heated to 60 degree Celsius, and that temperature was noted using a thermometer. A magnetic stirrer was placed inside the flask and the oil was stirred for some time for the uniform distribution of heat. A condenser was fixed above the flask and a steady flow of water was maintained through it. In a separate measuring flask, 300ml of methanol was taken, and 25ml of H₂SO₄ was added to it. The catalyst mixture was stirred lightly and poured into the triple neck flask containing the raw oil. The mixture was stirred again to ensure even blending of the catalyst and oil. It was maintained at 60 degree Celsius for about an hour, and then was poured into a separating funnel. The liquid mixture was allowed to cool and settle for 24 hours. A darker layer of acid ester was formed at the bottom of the flask, below a lighter layer of esterified oil. When measured, the esterified oil was 1050ml and the acid ester was 251 ml.

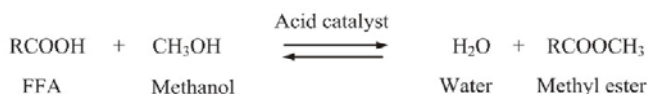


Fig. 2.1 Acid Catalyzed Esterification

2.5 Trans-esterification

Before trans-esterification, the FFA content was tested again, and it was found to be 3.01%, which agreed with the specified standards of ASTM for biodiesel. For the next step of the process, the esterified oil was taken in a triple neck flask and a condenser was fixed above its center neck. The heater was turned on, and the oil was stirred for uniform distribution of heat. In a measuring flask, 5gm of finely powdered NaOH was taken and 250ml of methanol was added to it. The mixture was stirred thoroughly before pouring into the

flask containing the esterified oil. It was allowed to heat for an hour at 60 degree Celsius. The entire mixture was then poured into a separating funnel and allowed to settle for 24 hours. At the end of this process, two layers were formed in the funnel, the top layer was methyl ester (biodiesel) and the bottom layer was glycerin. The yield obtained from 1050ml of esterified oil after separation was 870ml of methyl ester and 180ml of glycerin.

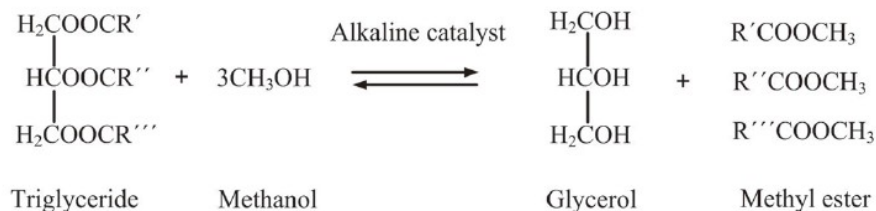


Fig. 2.2 Alkaline Catalyzed Trans-esterification

2.6 Washing

The methyl ester was washed with water to remove the residual methanol and other soluble impurities present in it. In this process, warm water was directly poured into the separating funnel, such that the water having higher density would absorb the soluble matter and collect at the bottom of the funnel. The solution was removed using the outlet tap and the process was continued until the methyl ester (biodiesel) was free of impurities.

2.7 Drying

The washed biodiesel was poured into a beaker and heated in a heating mantle. The temperature was maintained at 100 degree Celsius to allow the evaporation of residual water. The resulting solution was RSO B100 biodiesel.

III. EXPERIMENTATION

The biodiesel was tested for various fuel properties like density, viscosity, calorific value, flash point, fire point etc., and these were compared to that of mineral diesel fuel.

Table 3.1 Comparison of Fuel Properties

Properties	Diesel	Biodiesel
Density (Kg/m ³)	825	877
Kinematic Viscosity (cSt)	3	5.13
Flash Point (°C)	70	155
Fire Point (°C)	80	170
Calorific Value (KJ/Kg)	45,300	38,400

3.1 Blending of Biodiesel

The biodiesel was blended with mineral diesel in proportions of 5:95(B5), 10:90(B10), 15:85(B15), 20:80(B20), and 30:70(B30).

3.2 Experimental Setup

The engine used for testing the performance parameters of the different blends was a four stroke, four cylinder water cooled compression ignition engine. The engine was coupled to a brake drum dynamometer to measure the output. The flow rates of engine and calorimeter were maintained using a calibrated rotameter. An exhaust analyzer was affixed to the exhaust outlet to analyze the emissions, and a smoke pump was used to measure smoke opacity.

3.3 Engine Specifications

Make: Kirloskar
No. of cylinders: 1
No. of strokes: 4
Bore diameter, D: 80mm
Stroke length, L: 110mm
Capacity: 3.68kW
Power: 5bhp
Speed: 1500 rpm

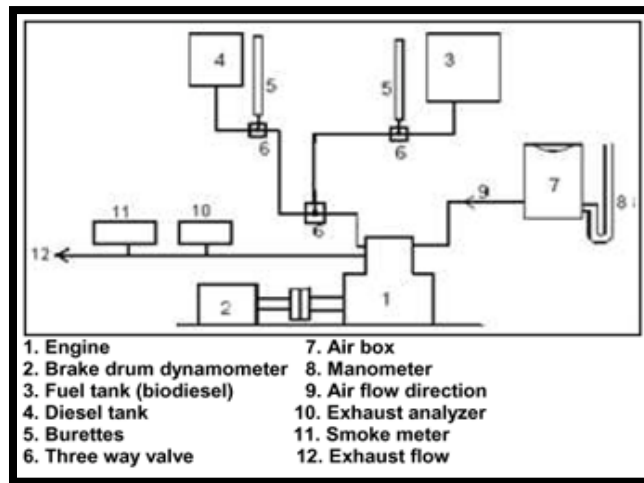


Fig. 3.1 Engine Setup

3.4 Experimental Procedure

The engine was started at no load condition using diesel as fuel. The water flow rate to the engine and calorimeter was stabilized, and the readings were noted down for different loads by keeping the speed as a constant. The time taken for 10cc of fuel consumption was measured using a stop watch. This procedure was repeated for B5, B10, B15, B20, B30 blends. The emissions such as hydrocarbons (HC), carbon dioxide (CO₂), carbon monoxide (CO), and nitrogen oxide (NO) were measured using a gas analyzer fitted to the exhaust.

IV. RESULTS AND FINDINGS

From the readings obtained, important performance parameters such as brake specific fuel consumption (BSFC) and brake thermal efficiency (η_{bth}) were calculated. The emission gases like CO, CO₂, HC, NO_x, and the smoke opacity were also measured using a gas analyzer and a smoke meter.

4.1 B00 (100% Diesel)

Table 4.1 Performance Parameters

Load	BP (kW)	TFC (kg/hr)	BSFC (kg/kW-hr)	η_{bth} (%)
4	1.44	0.720	0.5000	15.89
8	2.58	1.009	0.3911	20.32
12	3.69	1.320	0.3577	22.22
16	4.68	1.600	0.3418	23.25

Table 4.2 Emission Readings

Load	CO	CO ₂	HC	NO _x	Smoke Opacity
4	0.032	1.8	21	214	28%
8	0.080	4.7	24	391	49%
12	0.100	6.7	29	580	72%
16	0.110	8.1	33	790	87%

4.2 Biodiesel Blends at Full Load

Table 4.3 Performance Parameters

Blend	BP (kW)	BSFC (kg/kW-hr)	BTE (%)	CO (ppm)	CO ₂ (ppm)	HC (ppm)	NO _x (ppm)	Opacity (%)
B00	1.44	0.342	23.25	0.110	8.9	33	790	87
B05	2.58	0.350	23.23	0.084	8.0	20	760	73
B10	3.69	0.360	23.39	0.060	8.0	16	720	74
B15	4.68	0.362	22.47	0.064	8.1	15	740	75
B20	4.70	0.364	22.55	0.067	7.9	14	780	74
B30	5.03	0.389	21.37	0.079	8.6	19	801	80

4.3 Performance Curves

The curves corresponding to the performance parameters and emission characteristics are discussed below.

4.3.1 Brake Specific Fuel Consumption (BSFC)

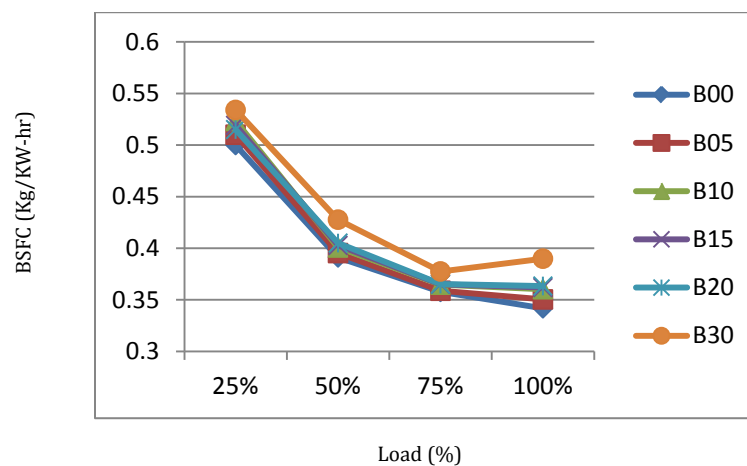


Fig 4.1 Variation of Brake Specific Fuel Consumption with Load

The BSFC of B05 blend is 2%, and that of B30 blend is 8% more than that of mineral diesel, and this might be attributed to the fact that biodiesel has much lesser calorific value and higher viscosity when compared to that of diesel. This might lead to incomplete combustion, and hence, result in greater consumption of fuel.

4.3.2 Brake Thermal Efficiency (η_{bth})

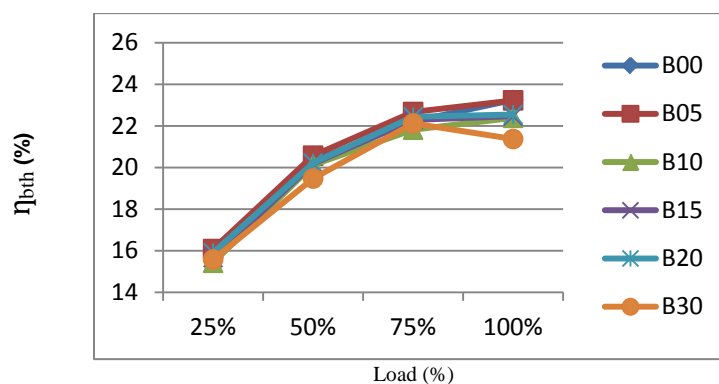


Fig 4.2 Variation of Brake Thermal Efficiency with Load

Brake thermal efficiency of B5 blend is 0.1% higher, and that of B30 blend is 8% lower than that of mineral diesel. Since B5 has a slightly higher lubricating property than mineral diesel, and a calorific value near to that of mineral diesel, its BTE is also slightly

higher than that of mineral diesel. As the proportion of biodiesel increases, the combustion efficiency keeps on decreasing due to the decreasing calorific value, and hence, the BTE of B30 is considerably lower than that of mineral diesel.

4.3.3 Smoke Opacity

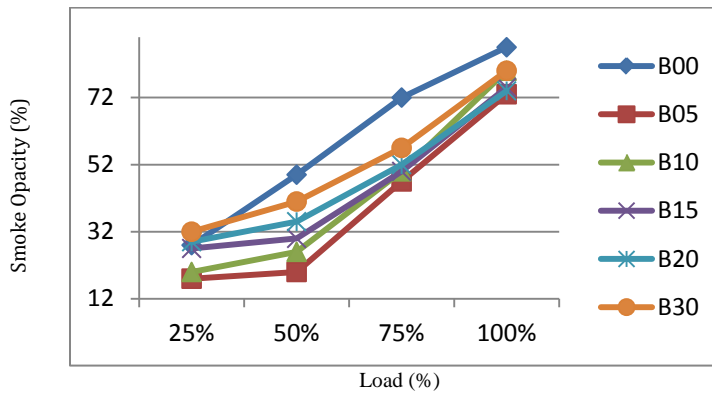


Fig 4.3 Variation of Smoke Opacity with Load

Diesel fuel (B00) has the higher smoke opacity when compared to the blends, and it keeps on increasing from B5 with the increase in the blend ratio. The reason why B5 has less smoke opacity might be because of the internal oxygen content present in the biodiesel which improves the combustion. As the blend ratio increases, the viscosity of the fuel increases, due to which incomplete combustion takes place. This in turn increases the opacity of the smoke.

4.3.4 Carbon Monoxide (CO) Emissions

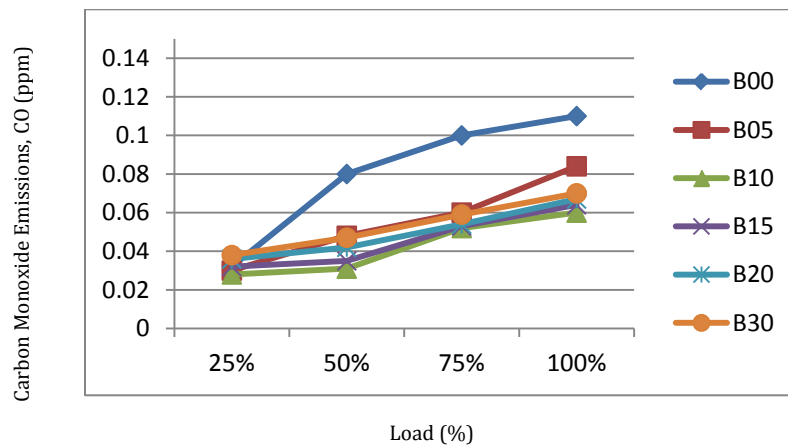


Fig 4.4 Variation of CO emission with Load

Mineral diesel fuel (B00) has higher rate of Carbon Monoxide emissions when compared to the biodiesel blends. B5 has considerably lower CO emission and it decreases till B15, after which it starts increasing. The reason for this can be that the higher amount of oxygen present in B5 to B15 blends will convert most of CO emissions to less toxic CO₂ gases. Thus the emission of CO will be reduced. Since the amount of oxygen in the fuel keeps reducing for blends higher than B15, the CO emissions keep on increasing.

4.3.5 Carbon Dioxide (CO₂) Emissions

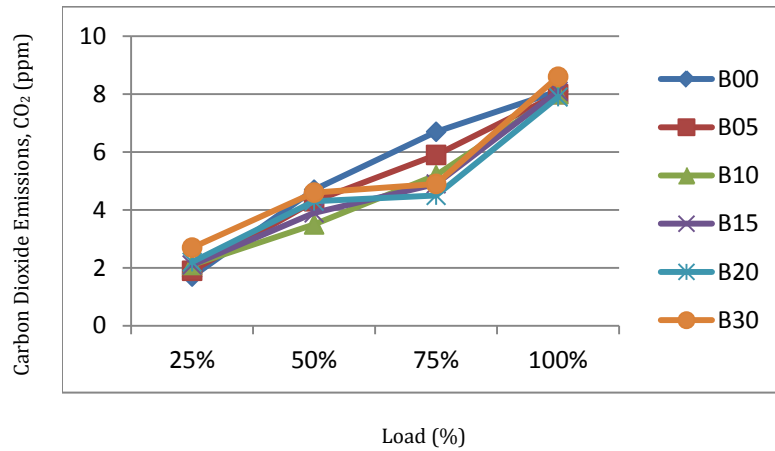


Fig 4.5 Variation of CO₂ emission with Load

The CO₂ emissions increase with the increase in load. The Carbon Dioxide emission depends on the amount of oxygen present in the fuel. If greater amount of oxygen is present in the fuel, the amount CO₂ also increases. Since higher rate of combustion is needed for higher power output, the amount of fuel burnt is more, which will cause increase in the CO₂ levels.

4.3.6 Hydrocarbon (HC) Emissions

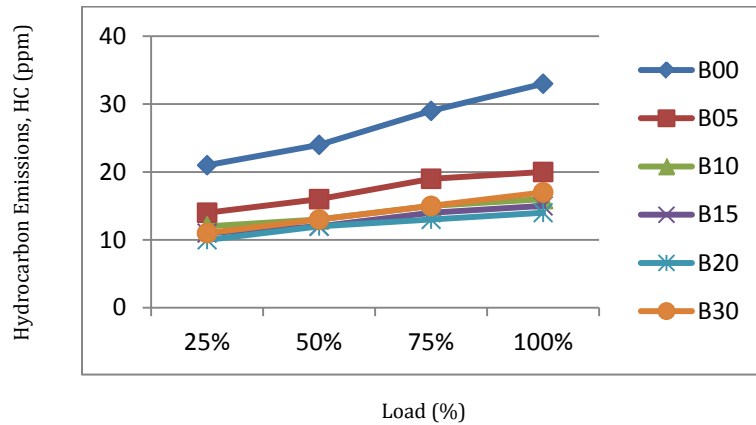


Fig 4.6 Variation of HC emission with Load

HC emissions are caused due to the incomplete combustion of carbon compounds in the fuel. As load is increased, the fuel consumption increases, which means that the amount of fuel present in the air-fuel mixture will be more, and the oxygen present in it is less. Since the oxygen content is more in B5 to B20 blends, the combustion rates will be higher, and the HC emission decreases, but for blends higher than B30, the HC emission increases with the increase in fuel consumption and decrease in oxygen in the intake mixture.

4.3.7 Nitric Oxide (NO_x) Emissions

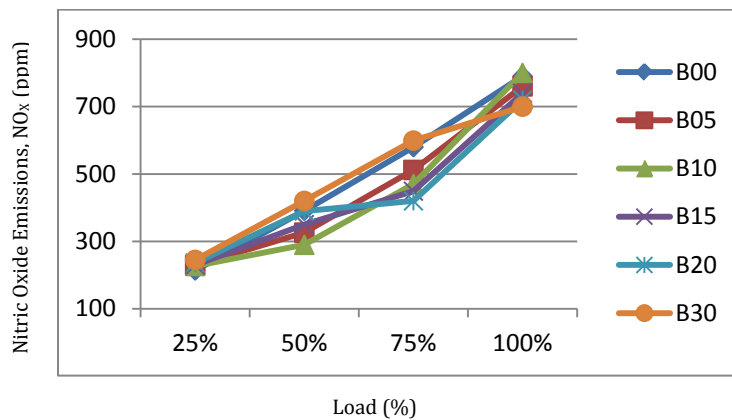


Fig 4.7 Variation of NO_x emission with Load

Most of the nitrogen content present in the exhaust gases is in the form of nitric oxide. The formation of Nitric Oxide mostly depends on the oxygen content in the cylinder during the power stroke and the temperature. The reason why the formation of Nitric Oxide increases for blends higher than B20 might be because the time required for the combustion of fuel is more due to greater viscosity and lower calorific value. This results in a delay of energy release at the end of power stroke due to which the exhaust gases will be subjected to very high temperature. At this temperature, the oxygen content in the exhaust gases reacts with oxygen to form Nitric Oxide. The increase in NO_x emissions can also be attributed to the nitrogenous compounds present in the Biodiesel.

V. CONCLUSION

In this study of rubber seed derived biodiesel as an alternative fuel, fatty acid methyl ester was successfully produced from crude rubber seed oil. According to the results of the project, there is a 2.5% increase in Brake Specific Fuel Consumption in the case of B5 blend, and a 14% increase in BSFC in the case of B30 blend when compared to that of petroleum diesel. When it came to Brake Thermal Efficiency, there is a 0.08% decrease in the case of B5 blend, and 8.08% decrease in the case of B30 blend. When it comes to Emissions, there is a 0.23% decrease for B5 blend, and 0.28% decrease for B30 blend in the case of Carbon Monoxide emission, and a 0.54% decrease for B5 blend, and 0.42% decrease for B30 blend in the case of Hydrocarbon emissions when compared to that of petroleum diesel. In the case of smoke opacity, there is a decrease of 0.1% for B5 blend, and 0.08% decrease for B30 blend when compared to that of petroleum diesel. From the observations, it is evident that the lower blends are suitable for use in Compression Ignition engines with none or minimum modifications. Even though rubber-seed oil biodiesel-mineral diesel blend is a suitable alternative fuel, further research is required in order to increase its efficiency.

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