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المعالجة بالماء من زيت النخيلين
كوقود لمحركات الديزل – دراسة تجريبية

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الخـلاصـة

تناولت هذه الدراسة استخدام الطاقة المائية لمعاملة الزيوت النباتية كوقود وتحليل الانبعاثات وخصائص أداء الحقن المباشر 4 – جدفة محرك الديزل، اسطوانة– تبريد واحدة، 4.4 كيلو واط، بسرعة ثابتة من 1500 دورة في الدقيقة، ونسبة الضغط 1:17.5. وكان نفط بالمولين المكرر استخدام الطاقة المائية ني مو كمحفز في 60 بار و 360 درجة مئوية. تم استخدام نفط بالمولين المكرر بالطاقة المائية كوقود ومقارنة مع تحولات استرات ميثيل الأحماض الدهنية. خصائص بترو ديزل ، فيم، وتعامل الطاقة المائية للنفط المكرر بالمولين قورنت مع معايير اليورو الرابع الهندية. وأجريت التجارب بشكل منهجي عن طريق مزج نفط بالمولين المكرر للمعالجة المائية بنسبة 25% (B25) و 100% (B100) من حيث الحجم وفي الأحمال المختلفة مثل 0%، 25%، 50%، 75%، و 100%. تم قياس الانبعاثات (CO، HC، NOx، FSN) والأداء (BSFC وفرامل الكفاءة الحرارية) لتحليل الاحتراق. وأظهرت النتائج التجريبية أن هناك انخفاض في CO و HC و NOx وBSFC بينما كان هناك زيادة في كفاءة الفرامل الحرارية بالمقارنة مع وقود ديزيل النفطي. وكان ضغط الاحتراق ومعدل إطلاق نار لB100 مساوي تقريبا للديزل. لا يتطلب إجراء أي تعديل في محركات الديزل.

Hydro Treatment of palmolein oil as fuel for diesel engines – An experimental study

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ABSTRACT

The present study investigates the use of hydro treated vegetable oil as fuel and analyzes the emission and performance characteristics of the Direct Injection 4 – stroke Diesel engine, air-cooled single cylinder, 4.4 kW, constant speed of 1500 rpm, and compression ratio 17.5:1. The Refined Palmolein oil was hydrotreated using Ni-Mo as catalyst at 60 bar and 360°C. The hydrotreated refined palmolein oil was used as a fuel and compared with the transesterified fatty acid methyl esters. The properties of petro diesel, FAME, and hydro treated refined palmolein oil were compared with Euro IV Indian standards. The experiments were conducted systematically by blending the hydro treated refined palmolein oil by 25% (B25) and 100% (B100) by volume and at different loads such as 0%, 25%, 50%, 75%, and 100%. The emission (CO, HC, NOx, and FSN), performance (BSFC and Brake thermal efficiency) combustion analysis were measured. The experimental results showed that there was abatement in CO, HC, NOx, and BSFC while there was increase in brake thermal efficiency when compared with petro diesel fuel. The combustion pressure and heat release rate for B100 were almost equal to the diesel. No modification was required in the diesel engine.

NOMENCLATURE

HVO: Hydrotreated vegetable oil.

RPM: Refined palmolein oil.

HRPM: Hydrotreated refined palmolein.

PD: Petro diesel.

BIS: Bureau of Indian Standards

FAME: Fatty acid methyl esters.

GHG: Greenhouse gas emission

LHSV: Liquid hourly space velocity.

B25: Hydrotreated refined palmolein oil biodiesel 25% blend

B100: Hydrotreated refined palmolein oil biodiesel 100%

CO: Carbon monoxide.

HC: Hydrocarbon.

NOx: Nitrogen oxide.

FSN: Filter smoke number.

SLPH: Standard liter per hour.

BTE: Brake thermal efficiency

INTRODUCTION

The gloomy picture of fuel crisis in India gives a glimpse of the sad fuel status across the globe. The steady increase in fuel demand, the rising price of pure diesel, and theincrease in exhaust emissions lead to global warming. The hydrotreated vegetable oil (HVO) reduces the green house emissions and improves the performance of the diesel engines. HVO can be used directly as a fuel in diesel engines and it is a good alternative for diesel fuel. The hydro treated oil was compared with the Euro-IV standards of diesel fuel. Vedaraman *et al* (2011) took the methyl esters of palm oil prepared by transesterification process and different blends for their study (B20, B30, and B40) and found that B20 blend could reduce CO and HC by 28% and 30% respectively and that NOx could be reduced by adding 2% of distilled water. Another study on the impact of various biodiesel fuels obtained from edible and non-edible oils on engine exhaust gas and noise emissions reported by Rizwanul *et al*. (2013) revealed that palm biodiesel could reduce CO and HC (between 20% and 50%) particulate matter whereas NOx increased with FAME content in blend. It was also observed, by the foregoing authors, that smoke increased at higher loads based on the methyl esters in the blend. Enweremadu & Rutto (2010) found that by comparing the used cooking oil and fresh edible oil, the hydrocarbons were lower and that the NOx emissions were higher for used cooking oil. The combustion, performance, and emission were noticeably almost the same for the fresh oil biodiesel. Da-Yong *et al*. (2011) developed ethylene glycol mono methyl ether palm oil monoester and tested it in a diesel engine, and they observed adecrease in smoke and nitrous oxide when compared with diesel fuel. No change in CO and HC was observed. Guzman *et al*. (2010) produced high cetane index renewable fuel from crude palm oil using hydro processing with ($NiMo/\gamma Al_2O_3$) catalyst between 40bar and 90 bar. This produced more paraffin with diesel. The study by Johan *et al*. (2013) revealed that the removal of triglyceride from non-edible jatropha oil using sulfide TMN/ α-Al 203 as a catalyst with the support material mesoporous α-alumina could yield green diesel. A study by Premkartikkumar *et al*. (2014) revealed that brake specific fuel consumption, unburnt hydrocarbon, and smoke were decreased whereas the NOx increased because of the oxygen enriched hydrogen gas mixed with diesel at the normal operating temperature from 30° C to 35 ° C. Aatola *et al*. (2008) stated that hydrotreated vegetable oil compared with EN590 sulphur-free diesel could decrease in SFC, NOx, and smoke by 6%, 16%, and 23% respectively. Ndayishimiye and Tazerout, (2011) experimented with the mixture of palm oil (PO) and waste cooking oil that was treated with transesterification process to produce esters. The esters were tested as fuel in compression ignition (CI) engines. As a result, the brake thermal efficiency increased for the PO/ diesel blends. HC emissions for all those fuels except for the PO/diesel blends were found lower, while CO emissions increased for all types of fuels. NOx emissions were higher at lower load, but lower at full load, for the engine fueled with PO, and lower at both middle and full load for the engine fueled with the esters. Silva *et al*. (2003) reported the results obtained while testing the technical feasibility of using oleic sunflower methyl ester (SME) blended with diesel fuel in proportions up to 30% in an unmodified diesel bus engine. One finding was that the smoke opacity was slightly reduced when SME was used in the proportion of 30%. Their experimental testing seemed to indicate that oleic SME could be a suitable replacement of diesel fuel and could be used safely in compression ignition engines in proportions as high as 30%. Kiatkittipong *et al*. studied the different types of catalyst for producing diesel from palm oil at various operating parameters.

The Ni-Mo/γ-Al_2 O_3 catalyst yields more diesel. Soo-Young reviewed the hydrotreated oil and transesterified vegetable oil, observing that the hydrotreated vegetable oil showed reduction in emissions without changing the engine operating parameters. Garcia-Davila *et al*. produced diesel fuel from jatropha oil using hydrodesulfurization Co–Mo/Al_2 O_3 and Ni–Mo/Al_2 O_3 catalyst at various operating conditions. Daniel *et al*. studied the production of hydrotreated vegetable oils and transesterified oils and concluded that hydrotreated oils produced less green house gases than the other oils. Song Chen found that by hydrotreating the vegetable oils at minimum hydrogen pressure hydrocarbon fuel could be produced using the Nobel catalyst.

This paper presents the findings of biodiesel prepared using hydrotreatment processes besides highlighting the properties. An increase in some of the emissions in transesterification and decrease in all the emissions in hydrotreatment process were observed. The objective of the present study is to analyze the use of the hydrotreated refined palmolein oil; in two different blends,namely, B25 and B100. These HRPMs were tested in 4S DI diesel engine, and the emission and performance of the diesel engine were compared to find the feasibility of the use of HRPM vegetable oil as an alternative fuel for diesel in India.

MATERIALS AND METHODS

The base material, refined palmolein oil, was purchased from a local market. The catalyst (Ni-Mo), Na_2 SO_4, NaOH, Ni-Mo, and hydrogen gas were purchased from the suppliers concerned.

PRODUCTION OF HYDROTREATED OIL AND PROPERTIES:

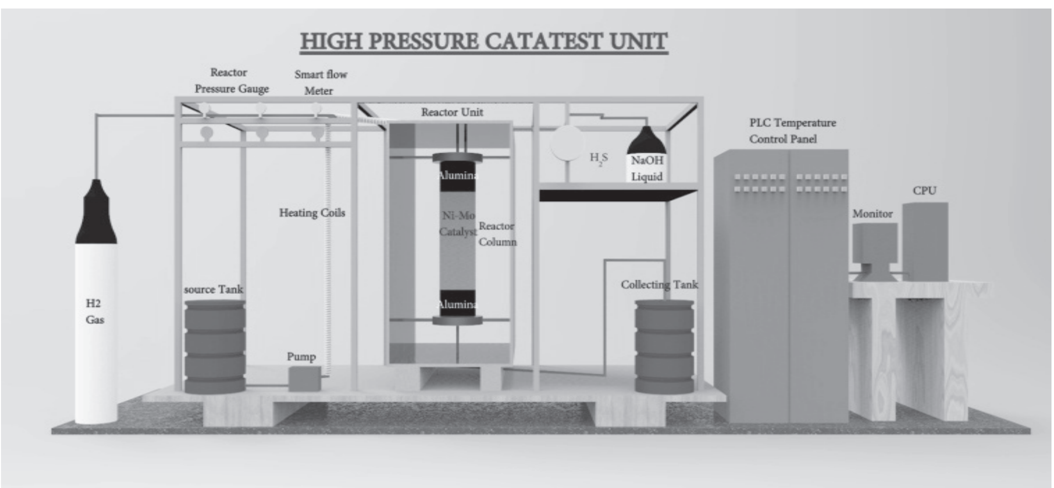

Figure 1. Schematic diagram of the hydrotreatment of plant.

The hydrogenated oil was produced by using catatest reactor. The refined palmolein is preheated up to 120°C. The preheated palmolein oil was treated with H2 gas at a pressure of 60 bar and at a temperature of 350°C in the presence of Ni-Mo catalyst. The LHSV is maintained at 2 hr-1. The hydrotreatment ofplant is shown in the Figure 1.

$$LHSV = \frac{\text{Feed rate of the oil}}{\text{Volume of the Catalyst}} \ hr^{-1}$$

The n-alkanes are formed during the decarboxylation and decarbonylation process. This reduces the sulphur, density and high cetane index when compared to petrodiesel. During this process the hydrotreated refined palmolein oil is converted into high paraffinic oil. The N_2 and O_2 were removed during the denitrification and deoxygenation process. The water content in the oils is removed by adding sodium sulphate anhydrous AR ($Na_2 SO_4$). Thus, the moisture-free HRPM is obtained. The FEED, FAME, and HRPM are shown in Figure 2 throughFigure 4. The oil with high paraffinic content is achieved.

Specification of high pressure catatest unit:

Design operating condition

1. Temperature - up to 550° C
2. Pressure - 250 bar
3. Liquid flow meter - 600 ml/hr
4. H2 flow rate - 30 – 300 SLPH

Figure : 2 RPM

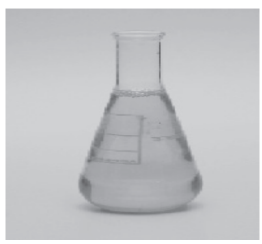

Figure : 3 FAME

Figure: 4 HRPM

The properties of the HRPM were compared with those of diesel (Euro IV), biodiesel standards (ASTM), and FAME as shown in Table -1. The cetane number and calorific value are high when compared with diesel. The density is lower, the flash point is slightly higher than diesel and it is safe to transport and store. The kinematic viscosity is within the range of the petro diesel fuel

Table 1. Properties of diesel, biodiesel standards, FEED, FAME, and HRPM.

S. No.	Properties	Euro - IV Bharat stage *1460:2005* Diesel	ASTM D–751 (IS 5607:2005)	RPM (FEED)	FAME	B100 (HRPM)
1.	Calculated cetane index	51	-	36	52	103
2.	Density at 15 ° C kg / m^3	820 – 845	860-900	917.5	873.4	786.1
3.	Kinematic viscosity at 40 ° C cst	2 – 4.5	1.9 – 6	35.2	4.9	3.36
4.	Flash point ° C min	35 ° C	130 ° C	220	262	89.5
5.	Calorific value kJ/kg	44,000	-	36,764	37,046	44,891

Table – 2 Specification of test engine

Type : Kirloskar Oil Engine TAF 1, vertical, 4S, single acting, high speed C.I diesel engine

Combustion	: Direct injection
Rated power	: 4.3 kW
Rated speed	: 1500 rpm
Compression ratio	: 17.5: 1
Injector type	: Single 3-hole jet injector
Fuel injection pressure	: 210 bar
Dynamometer	: Eddy current
Cubic capacity	: 661.5 cm3
Fuel tank capacity	: 6.5 liters

EMISSION MEASUREMENT

The specifications of emission measuring equipment are given in Table- 3. A Five Gas Analyzer (AVL DIGAS 444 Analyzer) was used to measure the NOx, HC, CO, CO_2, and O_2 in the exhaust stream. A smoke meter was used to measure the filter smoke number. Each fuel was tested thrice and the average results were taken and shown graphically.

Table - 3. Details of measuring systems

1. AVL pressure transducer GH 14D/AH01	
2. Data analyzer from engine	- AVL PIEZO CHARGE AMPLIFIER
3. To measure pressure	- AVL 365C ANGLE ENCODER INDI ADVANCED
4. Smoke meter	- AVL SMOKE METER 415
5. Gas Analyzer (NOx, HC, CO, CO_2, O_2)	- AVL DIGAS 444 Analyzer

EXPERIMENTAL SETUP:

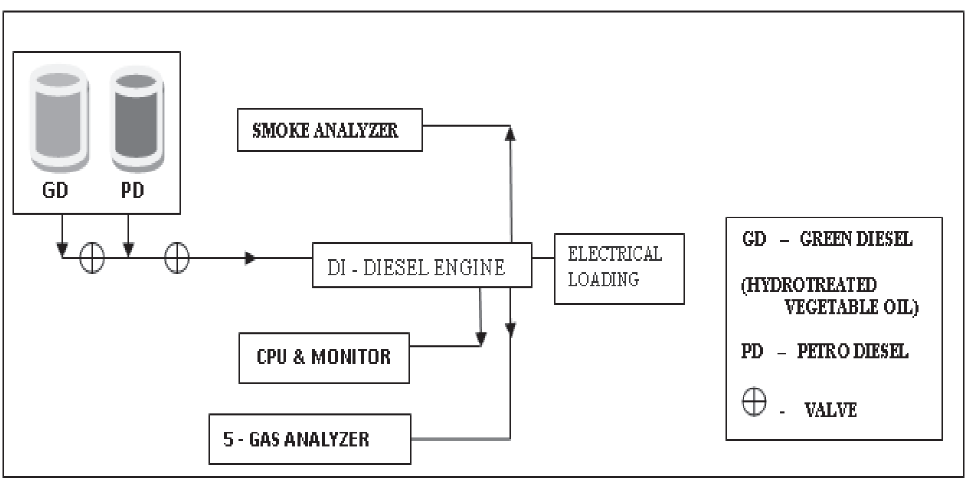

Figure – 5 Experimental of the compression ignition engine.

The stationary vertical 4-stroke DI diesel engine was used to evaluate the emission and performance of the HRPM at various blends and loading conditions and at a constant speed of 1500 rpm. The specifications of the DI diesel engine are shown in Table 2. The AVL 365C Angle Encoder, is used to measure the in-cylinder pressure. It is located at the center of the cylinder head.

The emission parameters like CO, HC, CO_2, and NOx and the performance of the brake specific fuel consumption and brake thermal efficiency were measured and evaluated. The load on the engine was applied using the alternator and the rheostat. The eddy current was used for loading and coupled to the engine for various loadings (0%, 25%, 50%, 75%, 100%) and at various blends (25%HRPM + 70% PD (B25), 100% HRPM(B100)). A flow meter was used to measure the brake specific fuel consumption. The AVL DIGAS444 5 Gas Analyzer was used to measure the exhaust gas emissions (CO, CO_2, HC, NOx, and O_2). The AVL Smoke Meter 415 was used to measure the filter smoke number. The schematic diagram of the experimental setup is shown in Figure 5.

A number of experiments were conducted in a DI diesel engine at various loading conditions (0%, 25%, 50%, 75%, and 100%) and at different blends (B25 and B100) using hydrotreated refined palmolein oil. The engine tests were performed at a constant speed of 1500 rpm. The engine was run at no load condition for 10 minutes, for each proportion of the blend before applying the load. The loads were gradually increased for each blend in steps of 25 % upto 100% at constant speed of 1500 rpm for B25 and B100. The emissions were observed in the exhaust stream using the AVL DIGAS444 5 Gas Analyzer and were measured.

RESULTS AND DISCUSSION

Brake specific fuel consumption (BSFC):

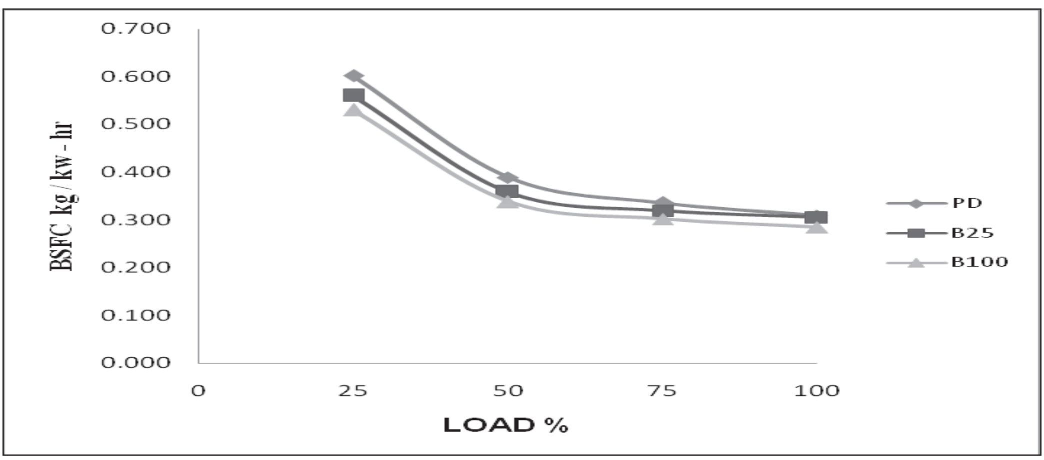

Figure 6. Variation of BSFC with respect to PD, B25, and B100.

The brake specific fuel consumption of different blends of hydrotreated vegetable oil is shown in Figure 6. From the graph, it is clear that there was a decrease in fuel consumption in the cases of B25 and B100 compared with petrodiesel. The BSFC for B25 and B100 was reduced by 7.09%

and 15.43%, respectively, at a full load condition and at a constant speed of 1500 rpm. This could be due to the lower density of the hydrotreated vegetable oil.

Brake thermal efficiency (BTE)

The performance and the brake thermal efficiencies of the HRPM are shown in Figure 7. It may be noted that, at the initial load condition, the BTE was the same as diesel up to 25% of load. As the load increased, there was an increase in BTE in B25 and B100 compared with petrodiesel. The thermal efficiency of B25 and B100 went up by 9.54% and 16.51%, respectively, at a full load condition. This could be due to the higher calorific value of the hydrotreated vegetable oil.

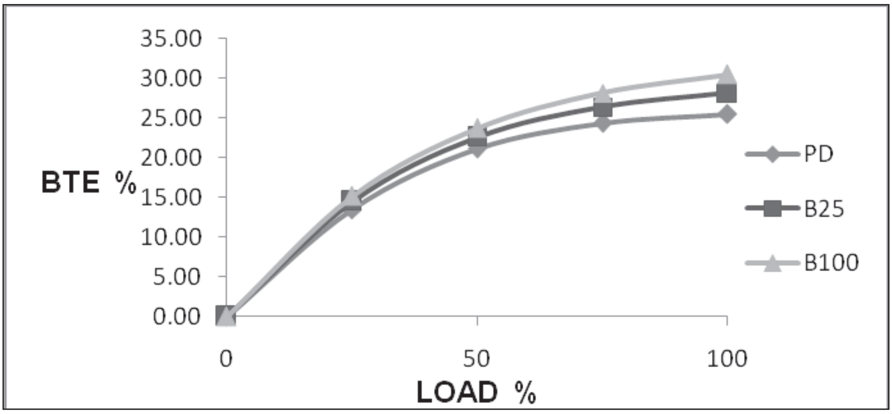

Figure – 7. Variation of BTE with respect to PD, B25, and B100

Carbon monoxide (CO)

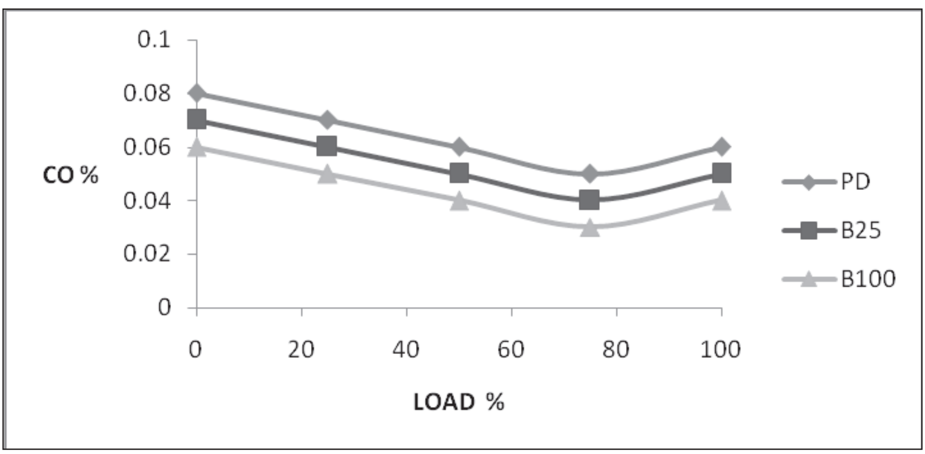

Figure – 8. Variation of CO with respect to PD, B25, and B100

The emissions of CO for the hydrotreated refined palmolein vegetable oil are shown in Figure 8. The emission results of B25 and B100 were compared with those of petrodiesel (PD). A significant decrease in B25 and B100 was observed. At a full load condition, the B25 got reduced by 16.66%, whereas the B100 got reduced by 33.33%. This could be due to the higher cetane number and the presence of sufficient oxygen in the air-fuel mixture that would have resulted in better combustion and reduction of the CO in the exhaust.

Hydrocarbon (HC)

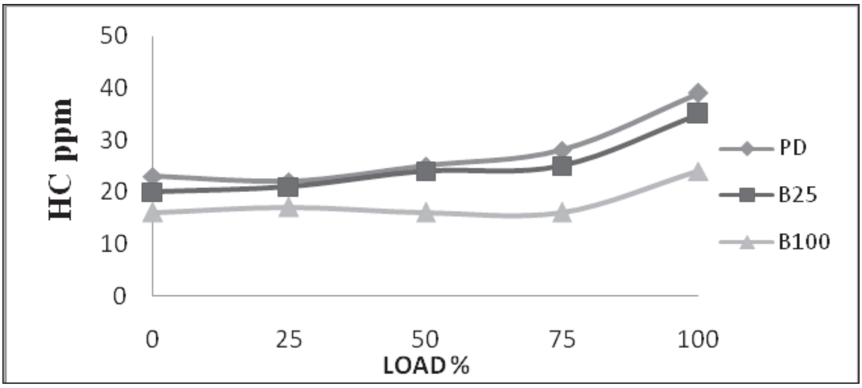

Figure 9. Variation of HC with respect to PD, B25, and B100.

The results of hydrocarbon emissions are shown in Figure 9. There was a significant decrease in hydrocarbon in the cases of B25 and B100 by 10.25% and 38.46% compared with those in case of petrodiesel. This could be due to the higher hydrogen content in the fuel which increases the combustion, leading to reduction in unburnt hydrocarbon

Nitrogen oxide (NOX):

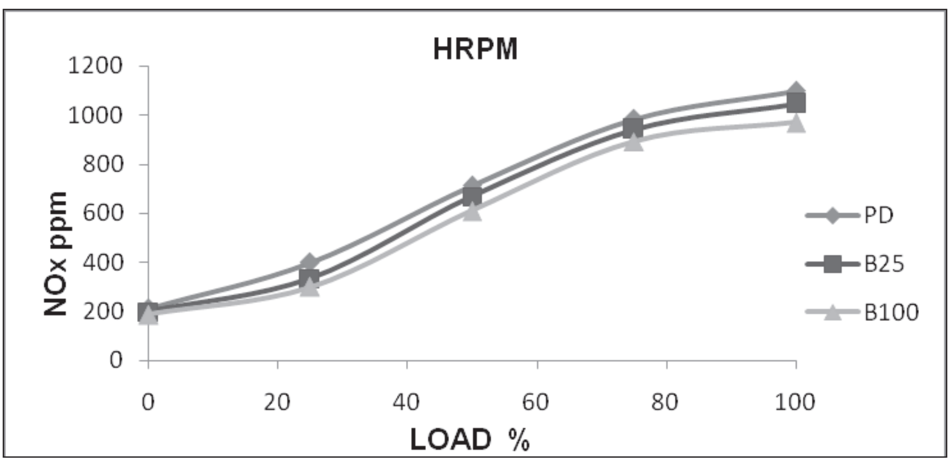

Figure – 10 Variation of NOx with respect to PD, B25, and B100 for HRPM

The NOx emission-graph of the hydrotreated refined palmolein is shown in Figure - 10. The NOx emissions got reduced based on the engine specifications, fuel type, and the test procedure. The remarkable change was observed in the cases of B25 and B100 of the hydrotreated refined palmolein oil. The NOx got reduced in the cases of B25 and B100 by 4.73% and 11.74% respectively. This could be due to the less oxygen content in the fuel which reduced the temperatures of the engine and reduced NOx.

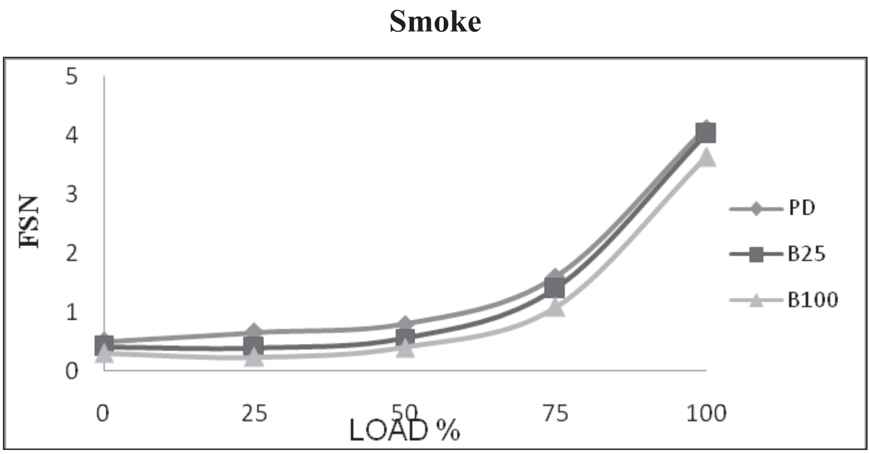

Figure – 11 Variation of FSN with respect to PD, B25, and B100

Figure 11 shows a marginal decrease at the initial conditions for B25 and B100. As load increased, the FSN decreased for B25 and B100 by 2.42% and 11.89%, respectively, compared with petrodiesel. This could be due to the presence of more hydrogen atoms in the HRPM, and that would have led to complete combustion. The soot formation was less by 7% compared with petro diesel.

Heat release rate analysis:

The combustion characteristics of hydro-treated palm oil vegetable oil can be compared with cylinder pressure, peak pressure, and heat release rate as shown in Figure – 12.

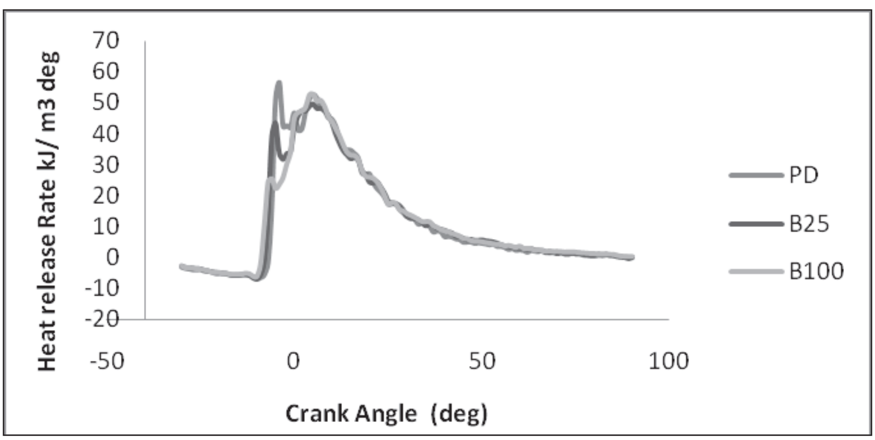

Figure – 12. Heat release rate for PD, B25, and B100 at full load condition

Figure - 12 shows a comparison of the heat release rate of petrodiesel, HT B25, and HT B100 at full load condition. The various stages of combustion were observed for PD, HT B25, and HT B100. The peak pressure values for petrodiesel, B25, and B100 were 56.764 kJ/m^3 deg at 3° BTDC, 49.528 kJ/m^3 deg at 4° ATDC, and 52.767 kJ/m^3 deg at 4° ATDC respectively. The rate of heat release being higher for B100 due to the higher calorific value and high hydrogen content in the B100 fuel was observed when compared with B25.

Pressure-crank angle analysis

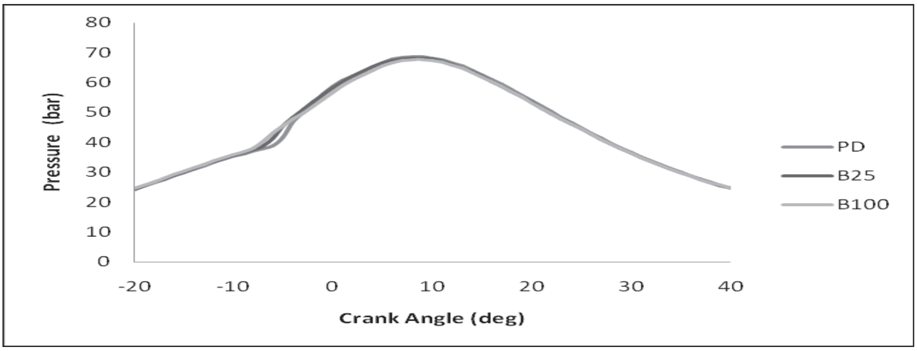

Figure 13. Variation of pressure-crank angle diagram for PD, B25, and B100 at full load condition.

Figure – 13 shows the variation of cylinder pressure with respect to crank angle for PD and blends of biodiesel (B25 and B100) at full load condition. A similar pattern of the gas pressure in the cylinder was observed for PD, B25, and B100. A marginal decrease in peak pressure was observed for HT B100 compared with PD and HT B25. This could be due to the lower specific fuel consumption of the hydro-treated vegetable oil. The peak cylinder pressure values for PD, B25,and B100 were 67.667 bar at 7° ATDC, 68.174 bat at 7° ATDC, and 68.614 bar at 8° ATDC respectively. The range of peak cylinder gas pressure for biodiesel was between 7° ATDC and 8° ATDC. Similar results had been obtained by Rao *et al*., (2008). A shorter ignition delay was observed in HT B25 and HT B100. This could be due to the higher calculated cetane index value.

CONCLUSIONS

The present study investigated the exhaust emissions and the performance of the hydrotreated refined palmolein vegetable oil without modifying the engine parameters at different blends of biodiesel. A series of tests were conducted at a constant speed of 1500 rpm. The following results were obtained from the experiment at full load condition

1. The emissions of CO, HC, CO_2, and NOx for B25 and B100 got reduced by 16.66%, 33.33%, 10.25%, and 38.46%, and 4.93%, 12.34%, 4.73%, and 11.74%, respectively, whereas an increase in NOx and CO, was observed in FAME.
2. The specific fuel consumption decreased by 7.09% and 15.43% respectively, for B25 and B100, whereas the brake thermal efficiency increased by 9.54% and 16.51%, and in FAME an increase in BSFC and a decrease in BTE were observed.
3. There was not any noise and less smoke was observed in HRPM.

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