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Experimental Investigationson Air-Cooled Diesel Engine with Biodiesels as Alternate Fuels

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Abstract

Biodiesels of simarouba, rubber seed and rice bran were produced from their respective feed stocks by trans esterification process and tested in an air cooled diesel engine as a substitute fuels. The experimental investigation aims in accessibility of using neat biodiesels in anunmodified stationery diesel engine meant for agriculture and gen-set applications in India. Diesel and neat biodiesels of simarouba, rubber seed (non-edible oils) and rice bran (edible oil) were used for conducting tests at varying load conditions (0, 25%, 50%, 75% and 100%). The performance (brake thermal efficiency, brake specific fuel consumption), exhaust emissions (CO, HC and smoke opacity) and combustion results (cylinder pressure rise and heat release rate) were analyzed and compared with diesel operation. The performance of engine was dropped, peak cylinder pressure rise and heat release rate were reduced as compared to conventional diesel. On the other hand the engine showed significant reductions of exhaust emissions(except NO_x) while running with neat biodiesels. The combustion studies revealed that the ignition delay was shorter for biodiesels tested compared to diesel and was increasing with the load. The neat simarouba biodiesel was proved to be better substitute to diesel as it significantly reduced harmful exhaust emissions, showed better performance and combustion characteristics compared to other two biodiesels tested.

Keywords: Trans esterification; Biodiesel; Performance; Emissions; Ignition delay.

Abbreviations: TDC- Top Dead Centre; D – Diesel; SRBD - Simarouba neat biodiesel; RSBD - Rubber seed neat Biodiesel; RBBD – Rice Bran neat Biodiesel; BTE- Brake Thermal Efficiency; BSFC - Brake Specific Fuel Consumption; CA - Crank Angle; HRR - Heat Release Rate

1. Introduction

As India is a developing country, energy demands are increasing day by day at alarming rate due to modernization, urbanization, and globalization and population growth. In India, 75% of road transportation depends on vehicles running with diesel. In near future this percentage may further increase and a situation may arise when fossil fuels get depleted and no alternate to diesel. In this direction many researchers are doing inventions to derive a clean, sustainable and energy efficient substitute fuel to diesel, which can be successfully used in an unmodified diesel engine with little compromise in performance. From the literature it reveals that Straight Vegetable Oils (SVOs) derived from tree borne seeds can be used as an alternate to diesel [1]. However, SVOs cannot be directly used in a diesel engine due to their higher viscosity, higher boiling point relative to diesel fuel. The viscosity of SVO is much higher than that of diesel fuel at normal operating temperatures [2]. High fuel viscosity can cause premature wear of the fuel pumps and injectors. It can also dramatically alter the structure of the fuel spray coming out of the injectors: increasing droplet size, decreasing spray angle, and increasing spray penetration. These effects tend to increase wetting of the engine's internal surfaces, thereby diluting the engine lubricant and increasing the tendency for coking and leads the problem of reduced engine life [2]. The carbon buildup doesn't necessarily happen immediately upon use of SVO; it typically takes place over the long term. Diesel engines with vegetable oils offer acceptable engine performance and emissions for short-term operation. Long-term operation results in operational and durability problems [3]. Some investigators have explored modifying vehicles to preheat SVO prior to injection into the engine. Others have examined blends of vegetable oil with conventional diesel [4]. These techniques were mitigating the problems to some degree but did not eliminate them entirely. Studies show that carbon buildup (coking) continues over time, resulting in higher engine maintenance costs and/or shorter engine life [5]. The studies revealed that the tendency to form carbon deposits increases with increasing proportions of vegetable oil blended into the fuel [4]. The above problems can be overcome by reducing viscosity of SVOs by a chemical process called trans esterification [6 - 8], which produces biodiesels. Biodiesel is having similar physical and chemical properties as that of conventional diesel and can be successfully used in an engine either directly or blended form [9]. The present investigation aims in production of SRBD, RSBD and RBBD from their respective seeds[10-13] and accessibility of using in an unmodified single cylinder diesel engine. Very few papers in the literature explain about use of these biodiesels in a diesel engine. As such no literature reveals about performance, emission and combustion analysis of these three potential biodiesels as alternate fuels. This motivated to carry out detailed investigations to analyze performance, exhaust emissions and combustion effect of using SRBD, RSBD and RBBD as alternate fuels.

2. Biodiesel Production

Trans esterification is a chemical process in which triglycerides of straight vegetable oil reacts with ethanol or methanol in the presence of a catalyst (acid or base) to convert triglycerides in to monoesters of ethyl or methyl esters, called as biodiesel. The byproduct will be glycerine. Biodiesels were produced in lab scale model of 5liters capacity consisting of a heater, reaction flask (three necks), magnetic stirrer, condenser to recover methanol. Before the process, free fatty acid (FFA) composition was determined by simple titration process by neutralizing the acid present in the oil to decide, either a single stage (acidtrans esterification) or two stage (acid-base trans esterification) process to produce biodiesel. As FFA was more than 4% in all fuel samples, two stage trans esterification was used to produce biodiesel after optimizing parameters of the process (molar ratio, reaction time and temperature, type of catalyst). In two stage trans esterification process methanol or ethanol is used as reagent along with sulfuric acid and potassium hydroxide as catalysts for acid and base reactions respectively. The trans esterification process with chemical reaction is shown in Figure 1 (a) and (b). The important properties of SRBD, RSBD and RBBD were evaluated as per ASTM standards and compared with conventional diesels are given in Table 1.

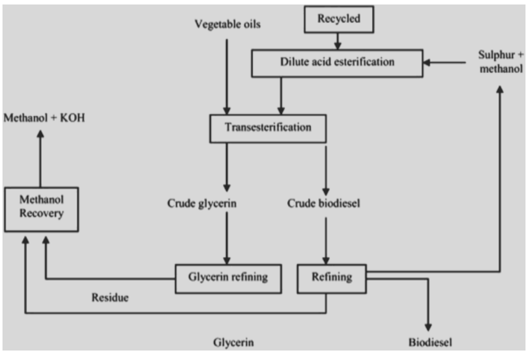

Figure 1a: Block diagram of trans esterification

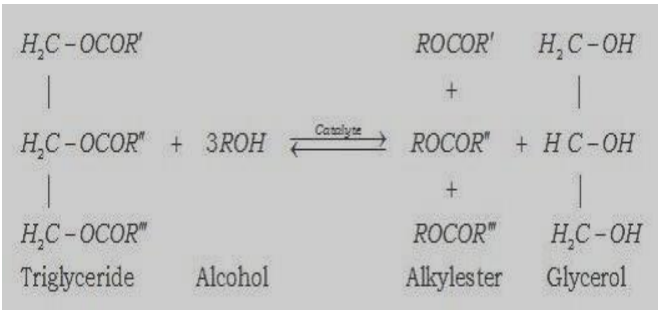

Figure 1b: Chemical reaction of trans esterification process

Table 1: Properties of simarouba, rubber seed and rice bran biodiesels compared with petro-diesel

Property	D	SRBD	RSBD	RBBD
Density (kg/m^3)	840	842	874	877
Calorific Value (MJ/kg)	42.5	38.443	34.66	33.14
Viscosity (mm^2/S) @ 40°C	2.54	4.87	5.81	6.21
Flash Point (°C)	54	162	146	125

3. Experimental Setup and Procedure

A kirloskar make, single cylinder, 4-stroke, air cooled diesel engine was used for conducting the experiment. Engine was coupled to a swing field dynamometer for applying the electric load. Air box fitted with a sharp edge orifice was used to determine airflow rate. Fuel consumption was measured by recording time for 20 cc of fuel flowing in to the engine through burette. Engine cooling water temperatures (inlet and outlet), exhaust gat temperatures were measured using thermocouples. Cylinder pressure was recorded using a piezoelectric pressure transducer incorporated in an engine head. Heat release rates and cylinder pressure variations with respect to crank angle rotation was recorded using AVL indicom mobile software version V2.5 interfaced with a data acquisition system and a computer. AVL 444 DI gas analyzer was used to measure exhaust gases-Carbon monoxide (CO), Carbon dioxide (CO_2), oxides of nitrogen (NO_x), excess oxygen (O_2) and hydrocarbon(HC). Smoke opacity was measured using AVL 415 smoke meter. Schematic of engine used for conducting the test is shown in Figure2. Test engine specifications are given in Table 2.

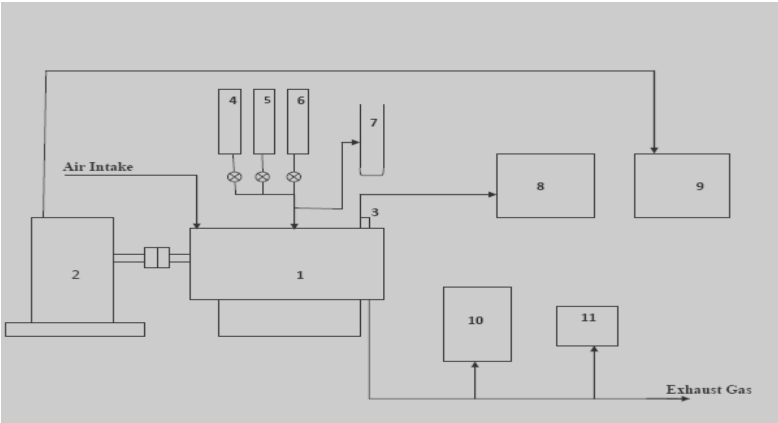

Figure 2: Test Engine setup

1.Test Engine, 2. Swinging field dynamometer, 3. Pressure sensor, 4. Diesel tank, 5. Pure biodiesel tank, 6.Biodiesel-diesel blends tank, 7. Burette, 8. Data acquisition system, 9. Dynamometer controller, 10. AVL DI Gas analyzer, 12. AVL Smoke meter.

Table 2: Test engine specifications

Make:- Kirloskar Oil engine, Single cylinder, four stroke (TAF1)	
Rated power	4.4 kW (6 HP)
Rated speed	1500 rpm
Bore x Stroke	87.5 mm x 110 mm
Compression ratio	17.5:1
Cubic capacity	0.662 ltr
Injection timing	23^{0}bTDC
Nozzle opening pressure	200 bar
Piston bowl	Hemi spherical
Dynamometer specification Swinging Field dynamometer (Make-power stars) KVA-5, PH-1, V-240 Volts, I-21 Amps, RPM-1500	

In the beginning engine was run with conventional diesel with an injection pressure of 200 bars and injection timing of 23° before TDC by applying load ranging from no load to full load in steps of 25% of rated load in five equal parts. The base line data was collected along with exhaust gas emissions, Peak cylinder pressure rise, HRR and calculations were made for BTE and BSFC. Subsequently the engine was run with SRBD, RSBD and RBBD neat biodiesels with the same operating and load conditions as that of conventional diesel. Performance, combustion and exhaust emissions of conventional diesel and engine with neat biodiesel operation were compared and analyzed.

4. Results and Discussions

4.1 Brake Thermal Efficiency

BTE variation with percentage load is shown in Figure 3. BTE was increasing for fuel samples tested from no load to 75% load (maximum) and then falls at full load. The BTE of conventional diesel operation was higher as all load conditions compared to neat biodiesels. The reason for lower BTE would be the lower heating value and higher viscosity of neat biodiesels compared to conventional diesel. Higher viscosity results in poor atomization and increase average droplet size of fuel injected in to the combustion chamber undergoing partial combustion. At the same time in order to maintain constant speed, mass of biodiesel burnt at applied load increases as compared to conventional diesel because of lower heating value and hence BTE decreases. SRBD has showed improved BTE compared to RSBD and RBBD owing to its higher heating value and lower viscosity.BTE of D, SRBD, RSBD and RBBD were 28.2%, 25.8%, 25.1% and 24.2%respectively at 75% load.

4.2 Brake Specific Fuel Consumption

BSFC variation with percentage load is shown in Figure 4. BSFC of fuel samples tested is higher at no load and it goes on decreasing as the load increases and reaches a minimum at 75% load and then increases at full load. BSFC is lower for diesel at all loads compared to biodiesels tested due to lower viscosity and higher heating value. The increase in BSFC values of all biodiesels tested was interrelated with decrease in BTE, and was because of higher viscosity and lower energy content compared to conventional diesel. BSFC of D, SRBD, RSBD and RBBD were 0.29, 0.38, 0.39 and 0.41 kg/kWh respectively at 75% load.

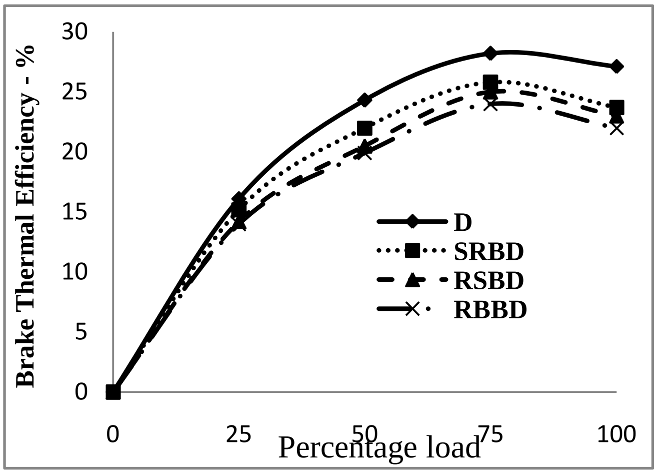

Figure 3: Variation brake thermal efficiency with load

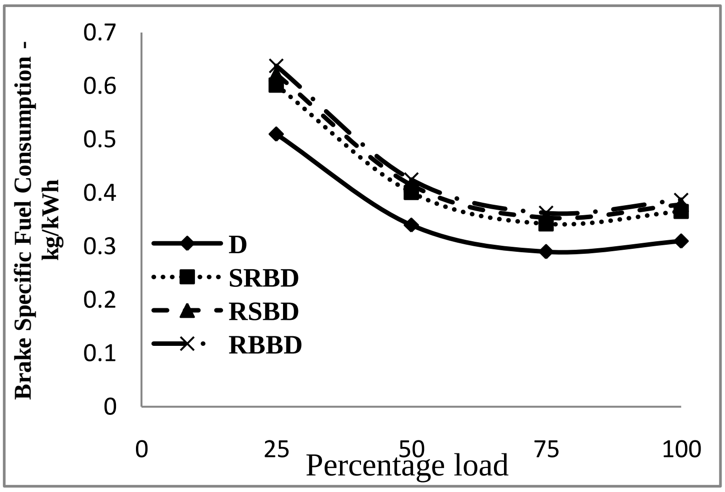

Figure 4: Variation of brake specific fuel consumption with load

4.3 Carbon Monoxide Emission

CO emission with percentage load is shown in Figure 5. CO emission increases due to incomplete or partial combustion of the fuel. CO emission of biodiesels tested was significantly reduced at all load conditions compared to conventional diesel. This is an indication of clean and complete burning of biodiesels. Biodiesels tested shows reduced CO because of oxygen molecules present in biodiesels which helps in complete combustion of the mix at the later part of diffusion phase. The percentage decrease in CO emission for SRBD, RSBD and RBBD was 48.23%, 38.34% and 23.12% respectively as compared to conventional diesel at 75% load.

4.4 Hydro Carbon Emission

HC emission with percentage load is shown in Figure 6. Emission of HC increases with load for fuel samples tested. As the load increases, more mass of fuel is added and burnt to achieve the constant speed and this may results in partial combustion and hence increases HC emission. HC emission with biodiesels was greatly reduced at all load conditions compared to conventional diesel for the reason mentioned in case of CO emission. The percentage reduction in HC emission of SRBD, RSBD and RBBD was 46.43%, 35.71% and 28.57% respectively as compared to conventional diesel at 75% load.

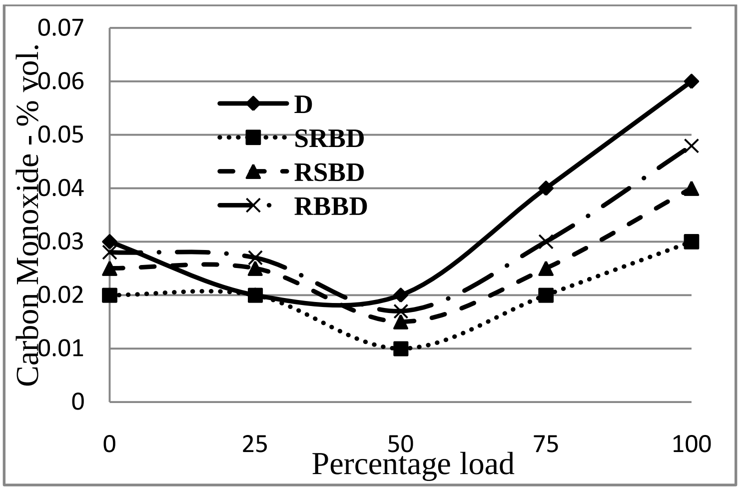

Figure 5: Variation of carbon monoxide with load

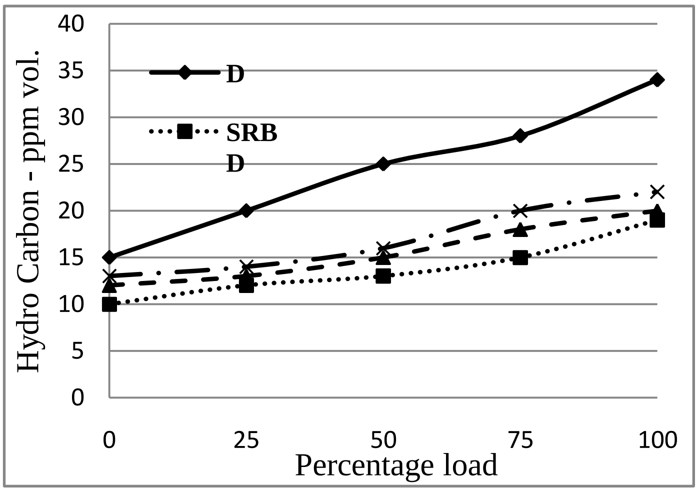

Figure 6: Variation of hydrocarbon emission with load

4.5 Carbon Dioxide Emission

CO_2 emission with percentage load is shown in Figure 7. Emission of CO_2 increases as the load increases for fuel samples tested. CO_2 emission is higher as a result of complete combustion of the mix. The trend of more CO_2 emission with biodiesels tested at all load conditions is an indication of complete combustion compared to conventional diesel. Oxidation reaction of CO enhance due to the oxygen molecule present in the biodiesel and results in higher CO_2.Emission of CO_2 by biodiesels was absorbed by crops and maintains balance of it on the earth surface and hence no risk of global warming.

4.6 Oxides of Nitrogen

NO_x emission increases with load as shown in Figure 8 for fuel samples tested. Biodiesels tested shown higher NO_x at all load conditions compared to conventional diesel. SRBD has shown highest NO_x at all loads compared to other two biodiesels tested, indicating that it undergoes clean and complete combustion due to lower viscosity and higher heating value. Other possible reason for higher NO_x with biodiesels as fuel is presence of oxygen molecule which supports in combustion. No_x emission can be controlled by many modern techniques such as exhaust gas recirculation, advancing injection timing, water injection on to combustion chamber head etc.

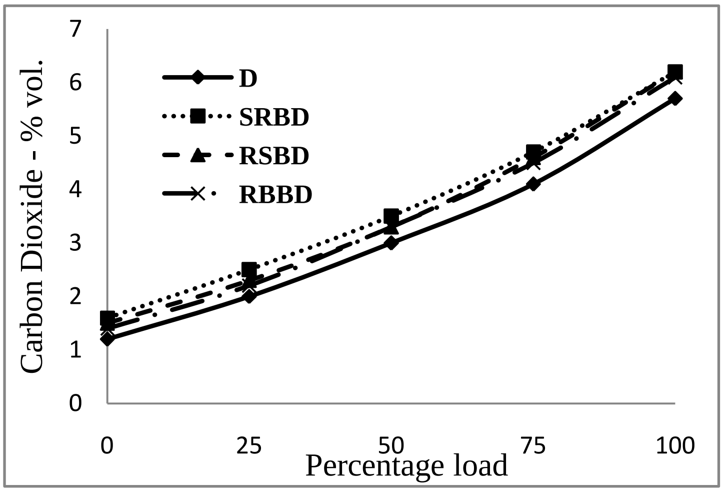

Figure 7: Variation of carbon dioxide with load

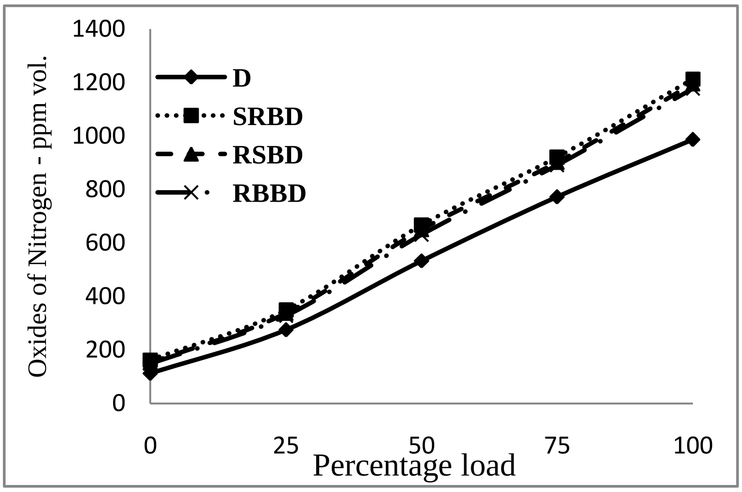

Figure 8: Variation of oxides of nitrogen with load

4.7 Smoke Opacity

Smoke opacity (in percentage) increases with increase in load is shown in Figure 9. A Lower CO and HC emission tends to reduce smoke opacity. As biodiesels tested undergo complete combustion due to the presence of oxygen molecule, smoke opacity was considerably reduced at all load conditions compared to conventional diesel. The percentage decrease in smoke opacity of SRBD, RSBD and RBBD was 33.62%, 22.5% and 17.1% respectively at 75% load.

4.8 Effect of Ignition Delay

Figure10 shows variation of ignition delay with percentage load. Ignition delay is longer at no load condition and goes on decreasing for fuel samples tested as the load increases. Diesel is having longer ignition delay at all load conditions as compared with neat biodiesels tested. Delay period of neat biodiesels is shorter, as chemical delay reduces due to the presence of oxygen molecule which prepares the mixture well before piston reaches top dead center and combustion starts. The other factor on which delay period depends is cetane number. As cetane number of biodiesels tested is more that diesel and hence delay period reduces. The total ignition delay period for D, SRBD, RSBD and RBBD was 8, 4, 5 and 4 degrees of CA respectively at 75% load. The overall decrease in delay for biodiesels was 2-6 degrees of CA as compared to conventional diesel.

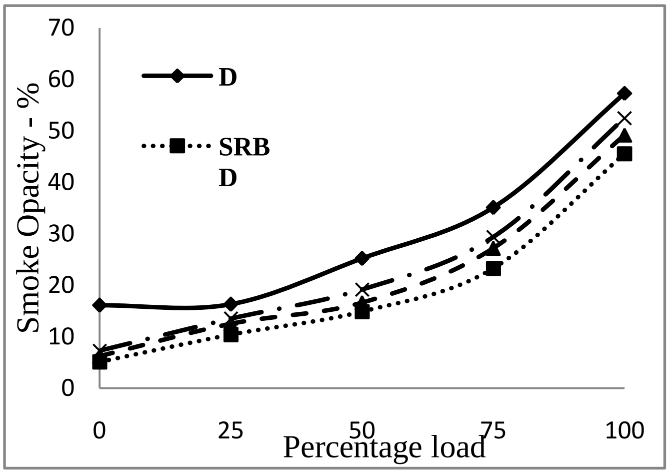

Figure 9: Variation of smoke opacity with load

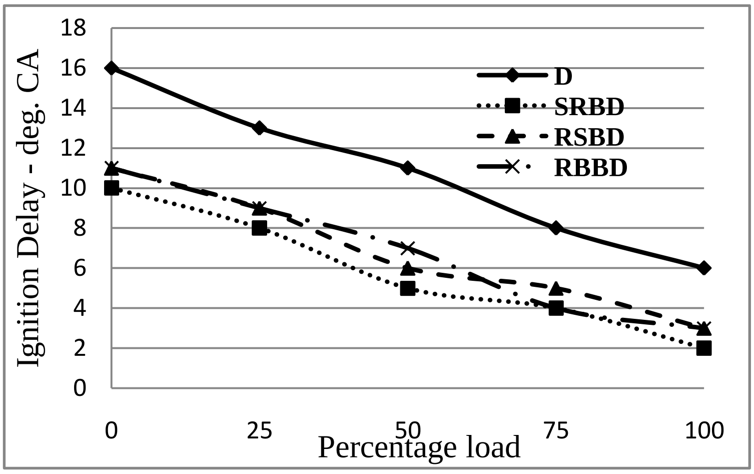

Figure 10: Variation of ignition delay (°CA) with load

4.9 Heat Release Rate

Figure 11 shows variation of HRR with degrees of CA for fuel samples tested at 75% load. Peak HRR for conventional diesel was highest because of its higher heating value and lower viscosity. As calorific value of biodiesels was lower than diesel and delay periods were shorter, peak HRR gets reduced and shifts away from TDC. The values of peak HRR for D, SRBD, RSBD and RBBD was 89.89, 80.53, 75.69 and 71.91 kJ/m^3 before 2-4 degrees of CA before TDC.

4.10 Cylinder Pressure Rise

Variation of cylinder pressure rise with degrees of CA for fuel samples tested is shown in Figure 12 at 75% load. Conventional diesel releases higher peak pressure at all load conditions as compared to neat biodiesels because of its higher heating value and lower viscosity It is observed from the graph that, the peak cylinder pressure for D, SRBD, RSBD and RBBD was 65.19, 63.65, 61.76 and 60.52 bar respectively after TDC by 6-8 degrees of CA.

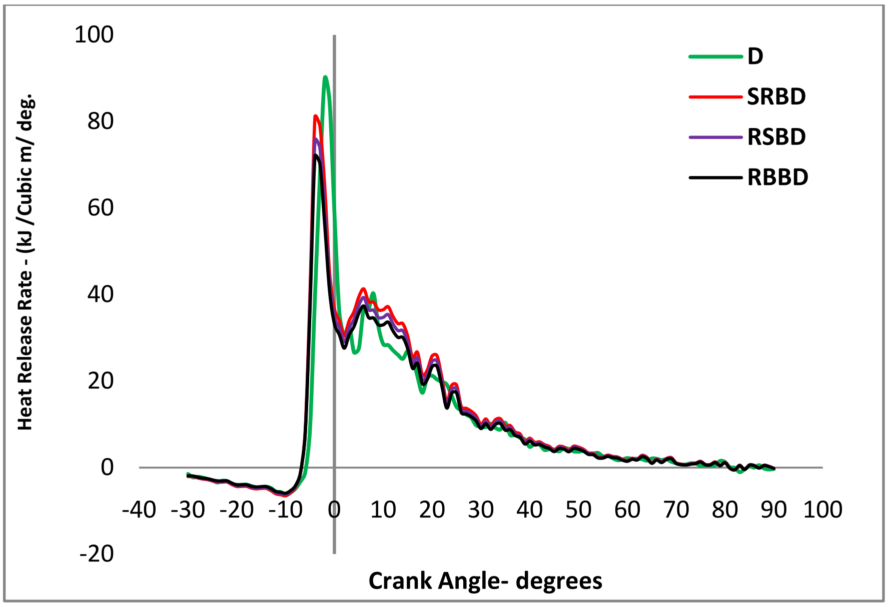

Figure 11: Heat release rate with crank angle in degrees at 75% load

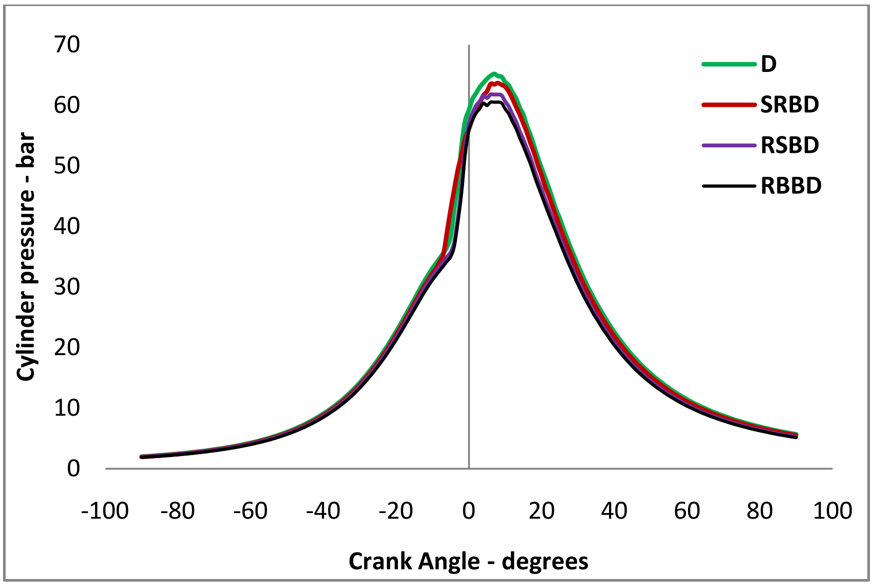

Figure 12: Cylinder pressure rise with crank angle in degrees at 75% load

Conclusions

Experiments were conducted on single cylinder, 4-stroke air cooled diesel engine, at an injection pressure of 200 bar and injection timing of 23°before TDC with diesel, SRBD, RSBD and RBBD as fuels. The performance, exhaust emissions and combustion parameters for biodiesels tested were analyzed and were compared with conventional diesel. After detailed analysis of the results following conclusions were drawn.

1. The neat biodiesels of SRBD, RSBD and RBBD can be successfully used in a diesel engine without any modifications of base engine design as an alternate to diesel.
2. The performance of engine was dropped with biodiesels operation due to their higher viscosity and lower heating value as compared to conventional diesel. The BTE was lower and BSFC was higher for biodiesels tested at all load conditions as compared to conventional diesel.
3. Exhaust emissions i.e. CO, HC and smoke opacity for biodiesels tested were significantly reduced (except NO_x) at all load conditions as compared to conventional dieseland is mentioned below (75% load)
    - The percentage decrease in CO emission for SRBD, RSBD and RBBD was 48.23%, 38.34% and 23.12% respectively.

- The percentage decrease in HC emission for SRBD, RSBD and RBBD was 46.43%, 35.71% and 28.57% respectively
- The percentage decrease in smoke opacity for SRBD, RSBD and RBBD was 33.62%, 22.5% and 17.1% respectively

4. The cylinder peak pressure rise and heat release rate were reduced with biodiesel operations at all load conditions as compared to conventional diesel. The higher viscosity and lower heating values are the reason for this.
5. Combustion analysis revealed that, ignition delay of biodiesels tested was shorter at all load conditions as compared to conventional diesel and was shorter in the range of 3-6 degrees of CA.
6. Among three biodiesels tested, SRBD has showed better results in terms of improved performance, significant reduction in exhaust emissions (except NO_x),and higher peak cylinder pressure and heat release rate. Thus we can conclude that SRBD can be a better choice as a potential alternate to diesel.

However, further through investigations may be required in order to measure additional fuel properties, long run engine effects, wear and tear analysis of engine parts fuelled with biodiesels, optimization of injection pressure and injection timings for better combustion of biodiesel and its blends in an unmodified diesel engine.

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