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Performance, Combustion and Emission Characteristics of Variable Compression Ratio Engine Fuelled with Biodiesel

P.Navaneetha Krishnan[1]*, D. Vasudevan[2]

[1]Department of Mechanical Engineering, Bharathidasan Institute of Technology, Anna University Tiruchirappalli 620024, India
[2]Department of Mechanical Engineering, PSNA College of Engineering & Technology, Dindigul 624622, India

Abstract: In the present investigation experimental work has been carried out to estimate the performance, combustion and emission characteristics of a single cylinder, four stroke variable compression ratio multi fuel engine fuelled with tamanu oil methyl ester blended with standard diesel. Tests has been conducted using the biodiesel blends of 10%, 20%, 40% and 60% biodiesel with standard diesel, with fixed compression ratio 19, and an engine speed of 1500 rpm at different loading conditions. The performance parameters includes brake thermal efficiency (BTE), specific fuel consumption (SFC), brake power (BP), indicated mean effective pressure (IMEP), mechanical efficiency and exhaust gas temperature. The exhaust gas emission is found to contain carbon monoxide (CO), hydrocarbon (HC), nitrogen oxides (NO_x) and carbon dioxide (CO_2). The result of the experimental works has been compared with standard diesel and it concludes considerable improvement in the performance parameters, heat release rate as well as exhaust emissions. From the result the emission rate of carbon monoxide, hydrocarbon and carbon dioxide are reduced with the increase of nitrogen oxides emissions. The combustion characteristics of tamanu oil methyl ester and its diesel blends are closely follows the standard diesel.
Keywords: Biodiesel, Tamanu oil methyl ester, VCR engine, Performance, Combustion, Emission.

1. Introduction

Increasing number of automobiles has led to increase in demand of fossil fuels (petroleum). The increasing cost of petroleum is another concern for developing countries as it will increase their import bill. The world is also presently confronted with the problem of fossil fuel depletion and environmental degradation. Fossil fuels have limited life and the ever increasing cost of these fuels has led to the search of alternative renewable fuels for ensuring energy security and environmental protection. One hundred years ago, Rudolf Diesel tested vegetable oils as a fuel for his engine [1]. Biodiesel as a vegetable oil, biodegradable and non-toxic, has low emission profiles and so is environmentally beneficial [2]. Biodiesel is a chemically produced vegetable oil to replace the traditional Diesel fuel. The chemical process is known as transesterfication and consists of treating vegetable oils, like soybean, sunflower and rapeseed, with reactants (methanol or ethanol) to obtain a methyl or ethyl ester and glycerine. In transesterfication, one ester is converted to another. The reaction is catalysed by a reaction with either an acid or base and involves a reaction with an alcohol, typically methanol if a biodiesel fuel is the desired product [3].

The aim of the study was to investigate the effect of tamanu oil biodiesel fuels on engine performance and to investigate the effect of emission in tamanu oil on engine performance. A single cylinder, 4 stroke, direct injection diesel engine has been used to measure the general performance of biodiesel and traditional Diesel. Diesel engines are used in agriculture, transportation, and industries. The known petroleum reserves are predicted to become depleted in the near future. Emissions from petroleum diesel exert negative effects on the environment. The drive towards clean energy economy is therefore both indispensable and inevitable. Vegetable oils in this regard provide an opportunity to replace a proportion of the petroleum diesel usage in compression ignition (CI) engines in order to achieve significant emission reduction. In addition to emission reduction, vegetable oils are available locally, with the potential of creating jobs and providing energy security.

Sanjib Kumar Karmee *et al*., [4] have prepared biodiesel of Pongamia with a yield of 95% using methanol and potassium hydroxide as a catalyst. The viscosity of the oil decreases on transesterification and the flash point was 150°C. Both these properties meet the ASTM and German biodiesel standards. Suresh Kumar *et al*., [5] have investigated that the performance and emission characteristics on a single cylinder diesel engine is decrease in NOx and HC emissions. A 40% blend of biodiesel in diesel has been recommended by the authors.

Recep Altin *et al*., [6] have studied the potential of using vegetable oils and their methyl esters in a single cylinder diesel engine. Their result indicates a reduction in NO_x emission and methyl esters are better than pure oil due to their inherent property of high density, higher viscosity, gumming and lower cetane number. Banapurmath *et al*., [7] have reported tests on a single cylinder C.I. engine with 3 different biodiesels viz methyl esters of honge, jatropha and sesame. All the fuels gave a slightly lower efficiency. HC and CO emissions were slightly higher and NO_x emission decreased by about 10%. They have reported that these oils can be used without any major engine modifications.

Many researchers have used Methyl esters of *Pongamia pinnata* [8], mahua oil [9], rapeseed oil [10], linseed oil [11], soybean [12], jatropha [13], cottonseed [14], and palm oil [15] reported the performance and emission characteristics in diesel engines. Barnwal *et al*., [16] have discussed about prospects of biodiesel production from vegetable oils in India. The methyl esters of non-edible oil are cheaper than petroleum diesel. The purpose of this paper is to investigate the performance and emission characteristics of a single cylinder, 4 stroke, constant speed, variable compression ratio, water cooled diesel engine with standard diesel and its biodiesel blends

2. Experimental Methodology

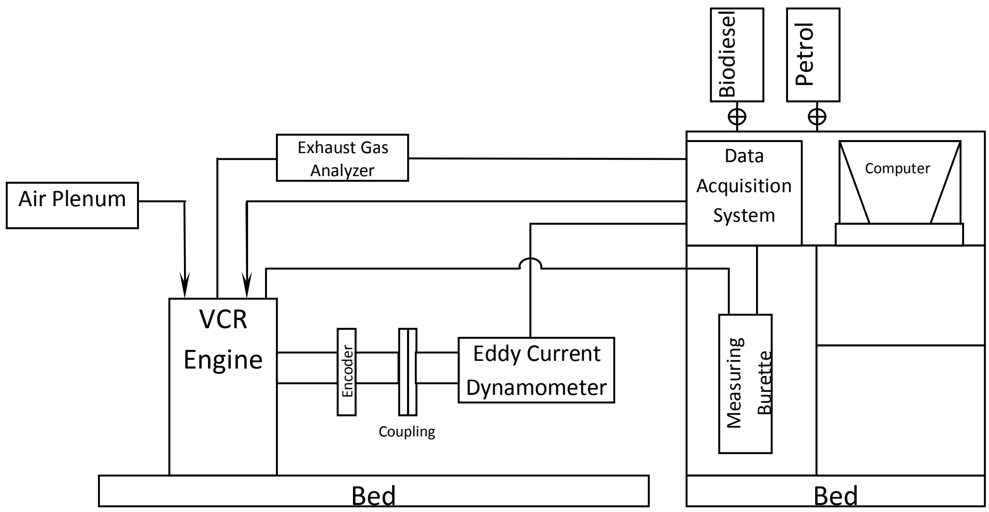

Fig 1. Schematic diagram of the experimental setup

The experimental set up for this study is shown in Fig 1. The set up consists of single cylinder, four stroke, and variable compression ratio multi fuel engine coupled with eddy current dynamometer for loading. Engine performance analysis software package "Engine Test Express V5.76" is used for performance analysis. The detailed specification of the engine is shown in Table 1. The tests have been carried out at the rated speed of 1500 rpm at different loads. Standard diesel is used to start the engine and is allowed to warm up till cooling water temperature reaches 60°C. Then the engine operating parameters such as Brake thermal efficiency (BTE), Brake power (BP), Indicated mean effective pressure (IMEP), Specific fuel consumption (SFC) and Mechanical efficiency and exhaust gas temperature with respect to different loads for different blends are measured and recorded. The exhaust emissions by combustion of biodiesel were measured by AVL DIGAS 2200 five exhaust gas analyzer. In this analyzer the zero setting function sets the sensor to zero using fresh air. On a timed basis the analyzer first being turned ON a zero will be requested. Subsequent request will be every 25 minutes. The zero key on the keyboard enables to set zero for CO, CO_2 and NOx values to zero with ambient air and is calibrated to 20.9% oxygen by volume. Table 2 shows the accuracy of the measurements and the uncertainty of the calculated results of the different parameters.

Table 1: Specification of the variable compression ratio engine.

General details	4 - stroke, VCR engine
Rated power	3 – 5 HP
Speed	1450 - 1600 rpm
Number of Cylinder	Single cylinder
Compression ratio	5:1 to 20:1 (variable)
Bore	80 mm
Stroke	110 mm
Ignition	Compression ignition
Loading	Eddy current dynamometer
Load sensor	Strain gauge load cell
Temperature Sensor	Type K – thermocouples
Starting	Manual crank start
Cooling	Water

Table 2: The accuracies of the measurements and the uncertainty of the calculated results.

Measurements	Accuracy
Engine speed	±2 rpm
Temperatures	±1 °C
Time	±0.5%
Carbon dioxide	±0.5%
Nitrogen oxides	±15 ppm
Carbon monoxide	±0.02%
Hydrocarbon	±10 ppm
Calculated Results	Uncertainty
Specific fuel consumption	±2%
Power	±1%
Crank angle encoder	±0.5 °CA

Table 3: Fuel properties of diesel and biodiesel blends.

Properties	Diesel	B10	B20	B40	B60	Bio diesel	Standards [a,b]	
							ASTM D 6751-02	DIN EN 14214
Calculated Cetane Index	45-50[c]	55	52	49	45	31	41 min	51 min
Gross Calorific Value (kJ/kg)	45240[c]	44,070	42,793	42,295	40,608	40,055	-	-
Density (kg/m^3)	0.835	0.8413	0.8527	0.8676	0.8906	0.9322	0.86	0.90
Viscosity at 40 °C (mm^2/s)	1.382	1.407	2.970	3.670	4.560	5.720	1.9-6.0	3.5-5.0
Flash Point	42°C	42°C	42°C	46°C	54°C	204°C	>130°C	>120°C
Fire Point	68°C	50°C	50°C	54°C	62°C	212°C	-	-
Water Content, %	0.02	0.02	0.025	0.03	0.03	0.04	<0.03	<0.05

[a] Reference [20], [b] Reference [21], [c] Reference [22].

Table 4: Indian standards used for emission analysis [17].

Elements	Standards
Carbon dioxide	IS 13270:1992 (reaffirmed 1999)
Carbon monoxide	IS 11293:1992
Nitrogen oxides	IS 11255 - (PART 7) – 2005
Hydrocarbon	-

Various sensors are utilized during the experiment to collect, store and analyze the data by computerized data acquisition system. Then for the different blends of tamanu oil methyl ester same procedures were repeated. The properties of the biodiesel blends and the diesel fuel are summarized in Table 3. The representative values taken from the different references mentioned. The fire point, water content, actual density, flash point, viscosity and gross calorific value were measured in the laboratory. The different Indian standards used for emission analysis are specified in Table 4 [17]. The outcome of tamanu oil methyl ester and blends of biodiesel are within the acceptable limits.

3. Results and Discussion

3.1. Brake Thermal Efficiency and Specific Fuel Consumption

The variation of brake thermal efficiency (BTE) with load for different blends is shown in Fig. 2. It has been observed that as the applied load increases, the brake thermal efficiency of the fuel blends also increases. It is due to increase in power developed and reduction in heat loss with increase in load [18]. The maximum brake thermal efficiency at full load is 41.72% for B40. Then the brake thermal efficiency of B20 and standard diesel are 39.68% and 36.49% respectively and while comparing the values fuel blend B40 is 5.2% higher than standard diesel. Tests on all fuel type shows that the brake thermal efficiency of fuels increases when the load of the engine increases. Due to lower heating value and increased fuel consumption the brake thermal efficiency for higher blends decreases [19]. Fig. 3 shows the variation of specific fuel consumption with respect to different loading condition. From the figure it is concluded that when load increases the specific fuel consumption of the fuel will maintain a gradual decrease. The specific fuel consumption values are 0.2234 kg/ kWh, 0.2268 kg/ kWh and 0.2201 kg/ kWh for the fuel blends B20, B40 and standard diesel respectively. The specific fuel consumption values increases only for the higher percentage of blends. It is due to heating value, density and viscosity of the fuels. Lesser value of specific fuel consumption value is also an undesirable one. Fuel blend B40 has lower energy content than standard diesel, but higher energy content than blends B10, B20 and B60.

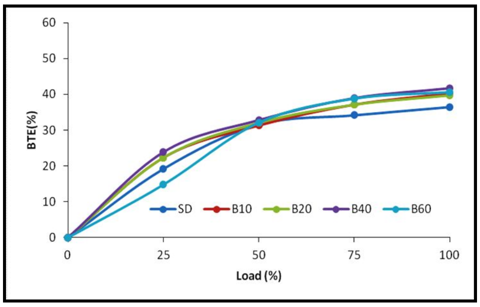

Fig. 2. Variation of brake thermal efficiency with load for different blends.

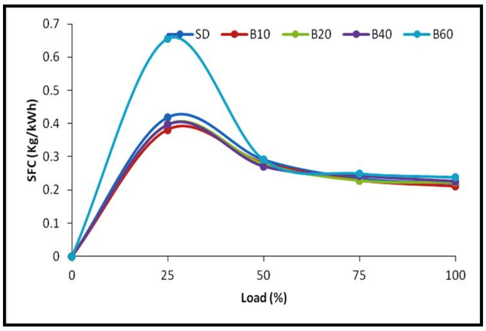

Fig. 3. Variation of specific fuel consumption with load for different blends.

3.2. Brake Power and Indicated Mean Effective Pressure

Fig.4 shows the variation of brake power values for different blends at different load. The fuels blends B10, B20, B40 and B60 have decreased brake power while comparing with standard diesel. At higher compression ratio the conversion of chemical energy into mechanical energy leads to decrease in brake power. In addition to that uneven combustion and lower heating value of the fuel blends leads to decreased brake power. The maximum brake power obtained for B40 and standard diesel while the other blends having a reduction in brake power with load due to lower heating value. The brake power values are 3.7149 kW and 3.6973 kW for B40 and standard diesel respectively. At lesser load condition the indicated mean effective pressure for blend B40 increases but lower at higher load while comparing with standard diesel. Fig. 5 shows the variation of indicated mean effective pressure with load for different blends. At 50% and 75% loading conditions the blend B40 closely follows standard diesel values. The indicated mean effective pressure for blend B40 and standard diesel at 50% load is 1.908 bar, 1.919 bar and for 75% load is 2.834 bar and 2.841 bar respectively.

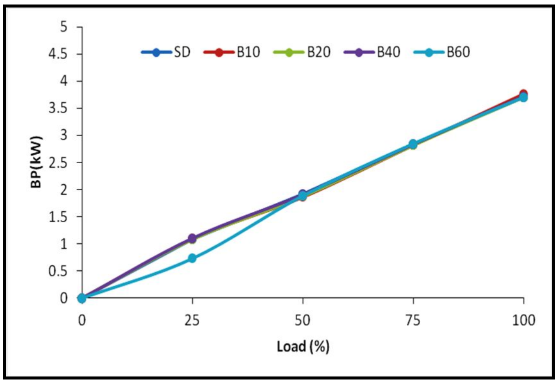

Fig. 4. Variation of brake power with load for different blends.

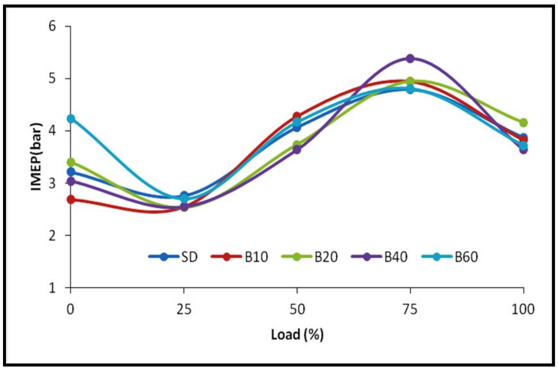

Fig. 5. Variation of indicated mean effective pressure with load for different blends.

3.3. Mechanical Efficiency

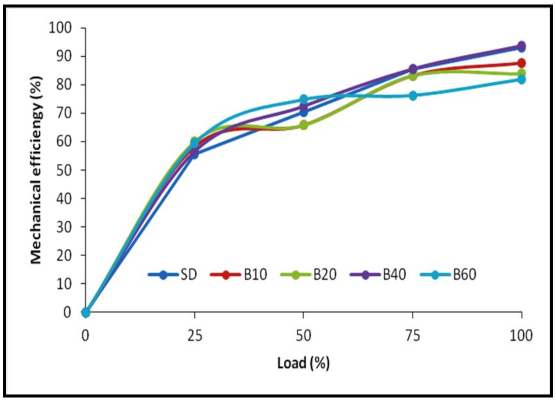

Fig. 6. Variation of mechanical efficiency with load for different blends.

The variation of mechanical efficiency with load ratio for various blends is shown in Fig 6. It has been observed that as the load increases, mechanical efficiency for all the blends are also increases in a steady rate. From results, blends B40 and B10 at full load are having maximum mechanical efficiency and it is 93.77% and 87.62 % respectively. Due to difference in fuel properties such as viscosity and density, negligible difference among the curve may be accounted. The mechanical efficiency of the fuel blends is in general very close to that of diesel. While compared to diesel, fuel blends have improved quality of spray, high reaction activity in the fuel rich zone and decreases in heat loss due to lower flame temperature will be the cause for efficiency increases. Mechanical efficiency increases with increasing load for all the blends [23].

3.4. Exhaust Gas Temperature

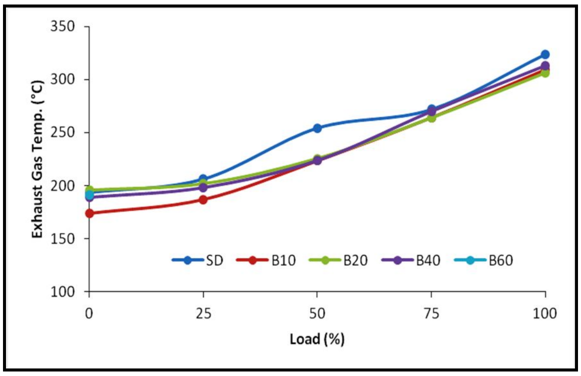

Fig. 7. Variation of exhaust gas temperature with load for different blends.

The variation of exhaust gas temperature with applied load for different blends is shown in Fig 7. It has been observed that exhaust gas temperature decreases for different blends when compared to that of diesel. The result indicates that standard diesel having highest exhaust gas temperature and it is 323.97 °C, whereas the blends B20 and B40 are having lower temperature 306.23 °C and 312.93 °C respectively. Blended fuels are having lower calorific value that leads to reduction in exhaust gas temperature as compared to the standard diesel and lesser temperature, at the end of compression [24]. Higher performance is due to lower exhaust loss [25].

4. Combustion Analysis

4.1. Maximum Combustion Pressure

The variation of maximum combustion pressure with crank angle for different loads and for different blends is shown in Fig 8. It has been observed that the tamanu oil blend B40 gives higher combustion pressure due to longer ignition delay of tamanu oil [26]. Longer ignition delay occurs due to the fuel absorbs more heat from the cylinder immediately after injection. The peak pressure value for standard diesel and tamanu oil blends B10, B20, B40, B60 are 72.89 bar, 73.07 bar, 70.76 bar, 71.30 bar and 69.16 bar respectively at full load. The higher combustion pressure obtained due to the rapid and complete combustion of fuel inside the combustion chamber.

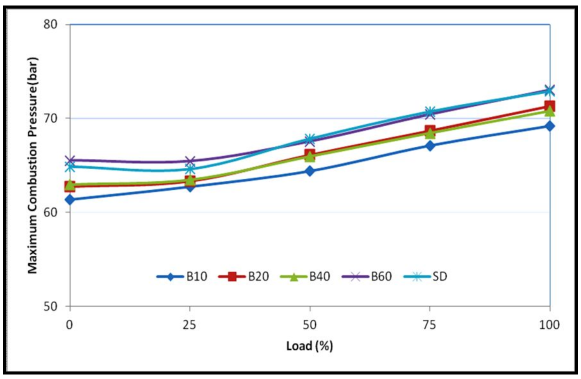

Fig. 8. Variation of maximum combustion pressure with load for different blends.

4.2. Combustion Duration

The variations of the total duration of combustion for different blends with different loads are shown in Fig 9. The time duration measured from the beginning of the heat release to the end of heat release. While comparing with standard diesel, the total duration of combustion is shorter for biodiesel and diesel blends. Due to lower calorific value, a higher quantity of fuel is required to keep the engine speed stable at different loads for biodiesel blends. The combustion duration for the fuel blends B10, B20, B40, B60 and diesel at full load condition are 36.37, 35.38, 34.17, 29.85 and 38.94°CA respectively. Due to the efficient combustion of the injected fuel, the combustion duration for fuels gets decreased.

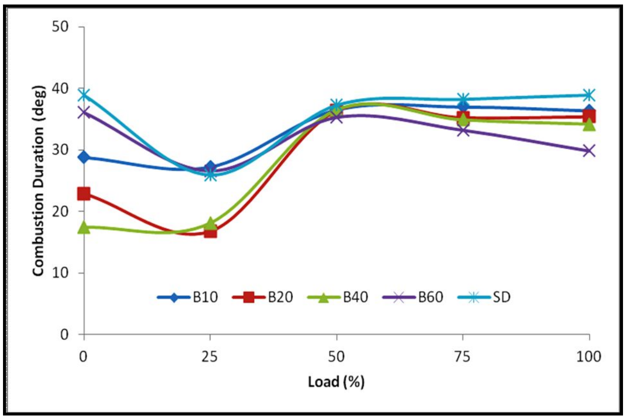

Fig. 9. Variation of combustion duration with load for different bends.

4.3. Heat Release Rate and Cylinder Pressure

The heat release rate at 100% load with crank angle for different tamanu oil blends is given in Fig. 10. The maximum heat release rate for fuel blends B10, B20, B40, B60 and standard diesel has been measures to be 17.23, 17.61, 17.45, 16.10, 17.92 J/°CA. Based on the changes in crank angle variation of the cylinder, the heat release rate is analyzed. From the results, it has been confirmed that the heat release rate decrease at the start of combustion and increase further. This variation is due to the air entrainment combined with lower air/fuel mixing rate and effect of viscosity of the fuel blends. While comparing the results obtained the heat release rate for B20 blends quite similar to that of standard diesel, whereas other blends deviates more from that of standard diesel. The heat release rate of tamanu oil blends decreases compared to that of diesel at full load. The heat release rate of standard diesel is higher than oil blends due to its reduced viscosity and better spray formation [27].

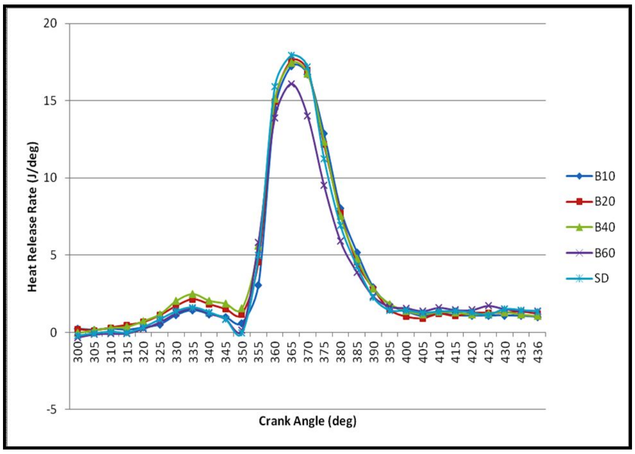

Fig. 10. Variation of heat release rate with crank angle at full load.

The variation of cylinder pressure with crank angle for diesel, tamanu oil and its blends at full load condition is shown in Fig 11. It had been concluded from figure that, the peak cylinder pressure decreases at the start of combustion and increases further. The pressure rise is due to the combustion rate in initial stages, which is influenced by the fuel intake component in the uncontrolled heat release phase [27]. The peak pressure recorded for standard diesel, B10, B20, B40 and B60 are 64.12 bar, 66.03 bar, 67.03 bar, 65.52 bar, 67.68 bar respectively. Due to the high viscosity and low volatility of biodiesel, the cylinder peak pressure is lower that of standard diesel [28].

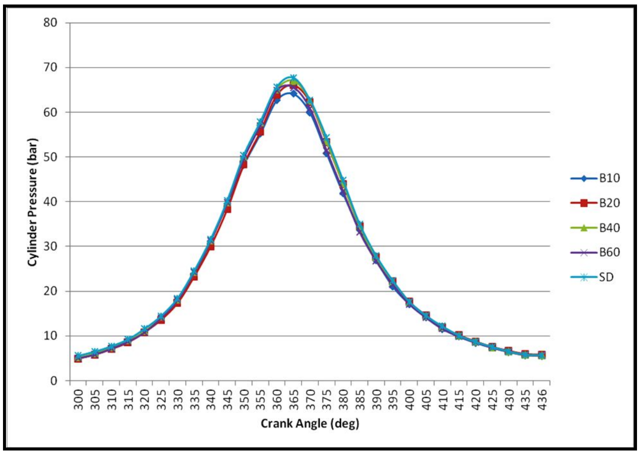

Fig. 11. Variation of cylinder pressure with crank angle at full load.

4.4. Mass Fraction Burnt and Ignition Delay

The variation of the mass fraction burnt for tamanu oil blends and standard diesel with the crank angle at full load is given in Fig 12. At full load conditions the mass fraction burnt of blends is slightly higher than that of standard diesel. Due to the oxygen content of the fuel blends the combustion is sustained in the diffusive combustion phase [24]. At crank angle 340°-360°, the mass fraction burnt for the fuel blend B40 is higher than the standard diesel. But at crank angle 360°-390°, the mass fraction burnt is slightly closer to each other. The efficient rate of combustion is shown by the highest rate of burning. The engine reaches stoichiometric region at higher compression ratio and it operates efficiently only at rich mixture. Rapid heat release is in the combustion phase due to more fuel is accumulated in the combustion [24].

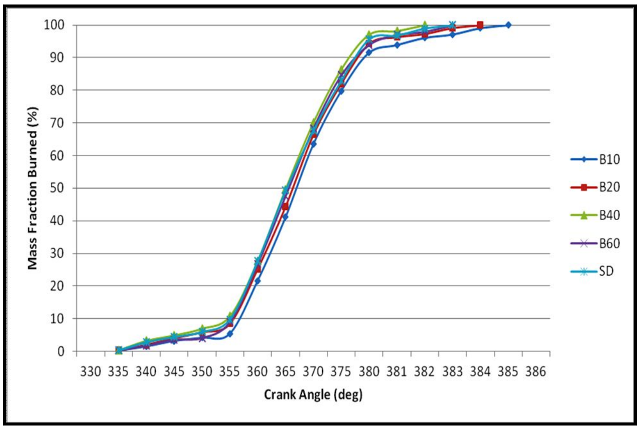

Fig. 12. Variation of mass fraction burned with crank angle at full load.

Ignition delay is the most important parameter in the combustion analysis. Ignition delay is influenced by a group of parameters such as engine speed, intake air temperature and pressure, fuel type, air-fuel ratio, fuel quantity, quality fuel atomization. The type of fuel plays the important role for ignition delay [29]. The variation of ignition delay with load is shown in Fig 13. It has been observed that the ignition delay decreases with biodiesel in the diesel blends with increase in load. The ignition delay period for B10, B20, B40 and B60 at full load condition are 5.34, 1.61, 3.68and 3.39/°CA respectively that are higher than diesel. It is mainly due to maximum cylinder pressure higher temperature and higher cetane number [29].

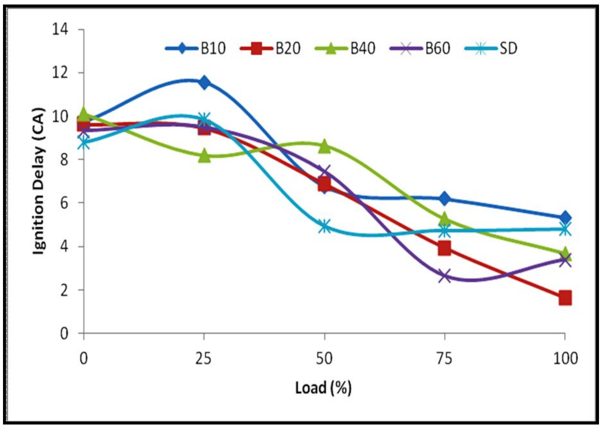

Fig. 13. Variation of ignition delay with loads for different blends.

5. Emission Analysis

5.1. Hydrocarbon Emission

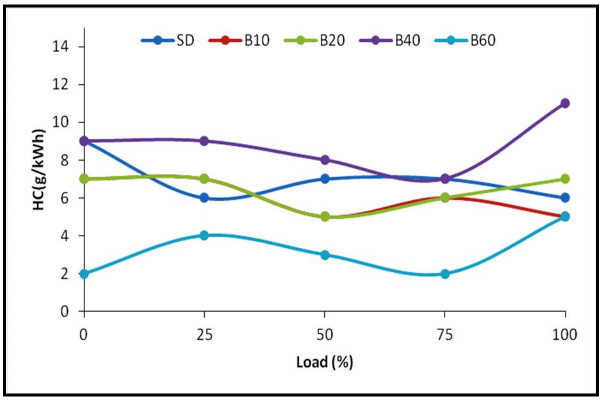

Fig. 14. Variation of hydro carbon with loads for different blends.

The variation of hydrocarbon emission with load for different blends is shown in Fig. 14. At higher load condition the hydrocarbon emission of various blends are higher except the blend B20. In vegetable oil fuels, the effect of fuel viscosity and the fuel spray quality has been expected to produce some increase in hydrocarbon content in emission [27]. In this work for blend B40 increase in load increase the hydrocarbon emission. The other blends B10, B20 and B60 produce lesser hydrocarbon emission at 50% and 75% load while comparing with standard diesel. Higher hydrocarbon emission is due to the longer ignition delay that leads to the accumulation of fuel in the combustion chamber.

5.2. Nitrogen Oxide Emission

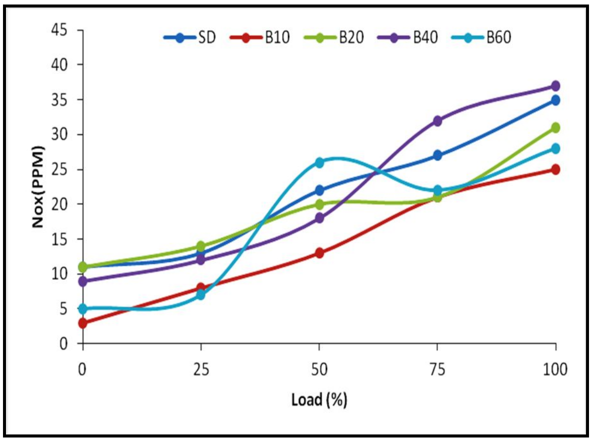

Fig. 15. Variation of NOx with compression ratio for different blends.

The variation of nitrogen oxide (NOx) emission with load for different blends is shown in Fig. 15. The nitrogen oxide emission for standard diesel is lower than that of biodiesel and its blends except B40 at lower loads. Usually vegetable based fuel contains a small amount of nitrogen. This leads to the nitrogen oxide production [18]. From the graph it is concluded that for 50% load, nitrogen oxide emission from the tamanu oil blend B40 is slightly lower than that of standard diesel. But in case of 100% load condition the nitrogen oxide emission from the B40 blend is higher than that of standard diesel, while the other blends close follows the standard diesel. Due to the higher peak temperature higher nitrogen oxide emission for fuel blends will occur. The reduction of nitrogen oxide emission is the important aim of researchers. The nitrogen oxide emission for fuel blend B40 and standard diesel for 50% load is 18 ppm and 22 ppm respectively.

5.3. Carbon Monoxide Emission

The variation of carbon monoxide emission of the blends and diesel for various loads is shown Fig. 16. The carbon monoxide emission of the blend B40 is found to be higher for light and medium loads and closer to that of standard diesel. Due to rising temperature in the combustion chamber, air fuel ratio, lack of oxygen at high speed, physical and chemical properties of fuel and smaller amount of time available for complete combustion, the proportion of carbon monoxide emission increases [21]. The carbon monoxide emission increases for vegetable oil fuels due to the effect of fuel viscosity on the fuel spray quality [26].

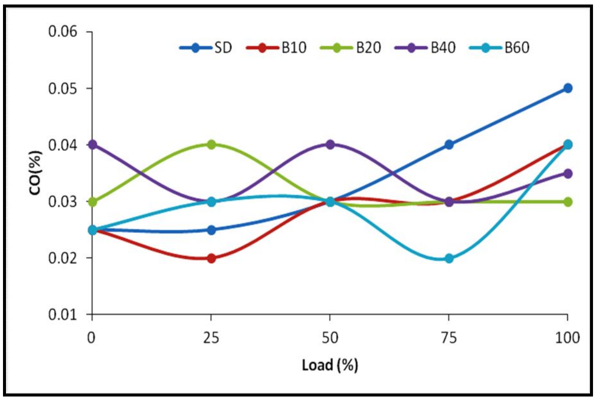

Fig. 16. Variation of carbon monoxide with loads for different blends.

5.4. Carbon Dioxide Emission

Fig. 17 shows that the variation of carbon dioxide emission with different loads. The complete combustion of fuel in the combustion chamber leads to increased emission of carbon dioxide. The carbon dioxide emission changes with exhaust gas temperature. Due to incomplete combustion and inadequate supply of oxygen carbon dioxide emission of the fuel blends B40 at full load decreases. The increased emission of carbon dioxide in the atmosphere leads to several environmental problems like global warming and ozone layer depletion. The carbon dioxide emission from the combustion of bio fuel blends can be intake by the plants and so the carbon dioxide level is kept constant in the atmosphere

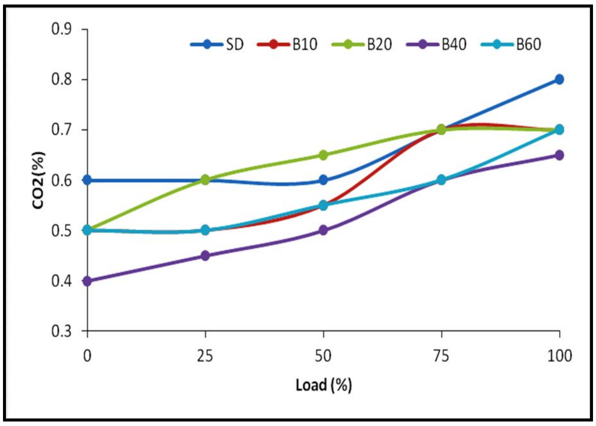

Fig. 17. Variation of CO_2 with loads for different blends.

Conclusion

A detailed experimental study was conducted to evaluate and analyze the performance, exhaust emission level and combustion of tamanu oil biodiesel and diesel blends in a fully instrumented single cylinder, variable compression ratio multi fuel engine. The conclusions are summarized as follow:

- As load applied to the engine increases brake thermal efficiency of the fuel blends also increases. The maximum brake thermal efficiency is 41.72% for B40 at full load, which is 5.2% higher than standard diesel. As the load increases specific fuel consumption of the engine decreases gradually. At full load conditions the specific fuel consumption for the blends B20 and B40 is 0.2234 kg/ kWh, 0.2268 kg/ kWh respectively whereas for standard diesel it is 0.2201 kg/ kWh
- As load applied increases exhaust gas temperature get decreased. Lower calorific value of the blended fuel than standard diesel and lower temperature at the end of compression leads to reduction in exhaust gas temperature. As load increases mechanical efficiency of the blended fuel shows steady increase. At full load condition the maximum mechanical efficiency obtained from blend B20 and B40 is 93.77% and 87.62 % respectively
- From the analysis of exhaust emission of the blends, it has found that at higher load condition except B20 all other blends having higher hydrocarbon emission. At lower loads except B40 all other blended fuel having higher NOx emission than standard diesel. The carbon monoxide emission is closer to standard diesel at full load and it is higher for light and medium loads.
- Due to longer ignition delay of the blended fuel B40, it gives higher combustion pressure. The heat release rate the blended fuel decreases at the start of combustion and increases further gradually. This may be due to effect of viscosity of the blends and the air entrainment combined with lower air/fuel mixing rate. At full load condition, the mass fraction burnt for blends is slightly higher than that of diesel

References

1. Shay, E.G., Diesel Fuel from Vegetable Oils: Status and Opportunities" Biomass and Bioenergy,1993, 4, 227-242,
2. Krawezyk, T., Biodiesel Alternative Fuels Makes Inroads But Hurdles Remain". Inform, 1996, 7, 801-829.
3. Graboski, M.S. and McCormick, R.L., Combustion of Fat and Vegetable Oil Derived Fuels in Diesel Engines", Prog. Energy Combust. Sci., 1998, 24, 125-164.
4. Sanjib Kumar Karmee *et al*.. Preparation of Biodiesel from Crude Oil of *Pongamia pinnata*. Bioresource Technology. 2005, 96: 1425-1429.
5. K. Sureshkumar *et al*.. Performance and exhaust emission characteristics of a CI engine fueled with Pongamia pinnata methyl ester (PPME) and its blends with diesel. Renewable Energy. 2008 33: 2294 - 2302.
6. Recep Altin *et al*.. The Potential of Using Vegetable Oil Fuel as Fuel for Diesel Engine. Energy Conversion and Management. 2001, 42: 529-538.
7. N.R. Banapurmath *et al*.. Performance and emission characteristics of Compression Ignition engine operated on Honge, Jatropha and sesame oil methyl esters. Renewable Energy. 2008, 33: 1982-1988.
8. S.K. Haldar *et al*.. Studies on the comparison of performance and emission characteristics of a diesel engine using three degummed non-edible vegetable oils. Biomass and Bioenergy 2008: 1013 – 1018.
9. Sukumar Puhan *et al*. Performance and Emission Study of Mahua Oil (*Madhuca indica* oil) Ethyl ester in a 4-Stroke Natural Aspirated Direct injection Diesel Engine. Renewable Energy, 2005, 30: 1269-1278.
10. Gvidonas Labeckas *et al*. The Effect of Rapeseed Oil Methyl Ester on Direct Injection Diesel Engine Performance and Exhaust. Energy Conversion and Management, 2006, 47: 1954-1967.
11. Deepak Agarwal *et al*. Performance Evaluation of a Vegetable Oil Fuelled Compression Ignition Engine. Renewable Energy, 2007, 30: 1147–1156.
12. A.J. Kinney *et al*. Modifying Soybean Oil for Enhanced Performance in Biodiesel Blends. Fuel Processing Technology, 2005, 86: 1137-1147.
13. Pramanik. Properties and Use of Jatropha Curcas Oil and Diesel Fuel Blends in Compression Ignition engine. Renewable Energy, 2003, 28: 2339-2348.
14. Ali Keskin *et al*. Using of Cotton Oil Soapstock Bio-Diesel Fuel Blends as an Alternative Diesel Fuel. Renewable Energy, 2008, 33: 553-557.

15. M.A. Kalam, H.H. Masjuki. Biodiesel from palm oil-an analysis of its properties and potential. Biomass and Bioenergy, 2002, 23: 471-479.
16. B.K. Barnwal, M.P. Sharma. Prospects of Bio-diesel Production from Vegetable Oils in India. Renewable and Sustainable Energy Reviews, 2005, 9: 363-378.
17. Hirkude Jagannath Balasaheb, Padalkar Atul S. Performance and emission analysis of a compression ignition engine operated on waste fried oil methyl esters. Applied Energy; 2010, doi:10.1016/j.apenergy.2010.11.028.
18. Panwar NL, Shrirame Hemant Y, Rathore NS, Jindal Sudhakar, Kurchania AK. Performance evaluation of a diesel engine fueled with methyl ester of castor seed oil. Applied Thermal Engineering 2010;30:245-249.
19. Ramdhas AS, Muraleedharan C, Jayaraj S. Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. Renewable Energy 2005;30:1789-1800.
20. Raheman H, Ghadge SV. Performance of diesel engine with biodiesel at varying compression ratio and ignition timings. Fuel 2008;87:2659-2666.
21. Arpa Orhan, Yumrutas Recep, Argunhan Zeki. Experimental investigation of the effects of diesel e like fuel obtained from waste lubrication oil on engine performance and exhaust emission. Fuel Processing Technology 2010;91:1241-1249.
22. Murugesan A, Umarani C, Subramanian R, Nedunchezhian N. Bio-diesel as an alternative fuel for diesel engines dA review. Renewable and Sustainable Energy Reviews 2009;13:653-662.
23. Singh Pranil J, Khurma Jagjit, Singh Anirudh. Preparation, characterization, engine performance and emission characteristics of coconut oil based hybrid fuels. Renewable Energy 2010;35:2065-2070.
24. Arul Mozhi Selvan V, Anand RB, Udayakumar M. Combustion characteristics of Diesohol using bio diesel as an additive in a direct injection ignition engine under various compression ratios. Energy & Fuels 2009;23:5413-5422.
25. Hebbal OD, Vijayakumar Reddy K, Rajagopal K. Performance characteristics of a diesel engine with deccan hemp oil. Fuel 2006;85:2187-2194.
26. Devan PK, Mahalakshmi NV. Performance, emission and combustion characteristics of poon oil and its diesel blends in a DI diesel engine. Fuel 2009;88:861-867.
27. Devan PK, Mahalakshmi NV. A study of Performance, emission and combustion characteristics of a compression ignition engine using methyl ester of paradise oil e eucalyptus oil blends. Applied Energy 2009;86:675-680.
28. buyukkaya Ekrem. Effects of biodiesel on a diesel engine performance, emission and combustion characteristics. Fuel 2010;89:3099-3105.
29. Gumus MA. Comprehensive experimental investigation of combustion and heat release characteristics of a biodiesel (hazelnut kernel oil methyl ester) fueled direct injection compression ignition engine. Fuel 2010;89:2802-2814.

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