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Effect of Compression Ratio in a Direct Injection Compression Ignition Engine Fuelled with Methyl Ester of Neem Oil: Experimental Study

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Abstract: The depleting mineral oil reserves, environmental issues and global warming issues have pushed the world towards searching for the alternative renewable energy sources. Future predictions show that the only feasible option is the production of synthetic fuels like "Biodiesel" derived from non-petroleum sources. Biodiesel being a fuel of different origin, the standard design parameters of a diesel engine may not be suitable for methyl ester of neem oil (MENO). This experimental investigation targets the effects of compression ratio (CR) on the performance parameters like brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), and emissions like CO, CO_2, HC, NO and Smoke intensity. The influence of compression ratio (16, 17 & 18) was studied for neat MENO fuel. It was observed that increase in compression ratios (from 16 to 18) improves the performance of the engine as well as reduces the emissions. This is due to the fact that increase in compression ratio ensures more complete combustion due to injection of fuel in higher temperature and pressure, better air–fuel mixing and faster evaporation. The CO, HC and Smoke intensity reduces and NO increases by increasing the CR from 16 to 18. For higher performance and mitigate emission, the compression ratio should be optimized for the neat MENO fuelled CI engine.

Index Terms: Biodiesel, Neem Oil, Compression Ratio, Performance, Emission.

1. INTRODUCTION

The depleting mineral oil reserves and environmental issues in addition to the global warming issues have pushed the world towards searching for the alternative renewable energy sources. Future predictions show that the only feasible option is the production of synthetic fuels derived from non-petroleum sources [1]. For substituting the petroleum fuels used in internal combustion engines, fuels of bio-origin provides a feasible solution to the twin crises of 'fossil fuel depletion' and 'environmental degradation' [2,3]. The fuels of bio-origin may be alcohol, vegetable oils, biomass, and biogas. Some of these fuels can be used directly while others need to be formulated to bring the relevant properties close to conventional mineral fuels. For diesel engines, a significant research effort has been directed towards using vegetable oils and their derivatives as fuels. Non-edible vegetable oils in their natural form called straight vegetable oils (SVO), methyl or ethyl esters known as treated vegetable oils, and esterified vegetable oils referred to as biodiesel fall in the category of bio fuels. Biodiesel is considered as a promising alternative fuel for use in diesel engines, boilers and other combustion equipment. Compared to fossil diesel fuel, biodiesel has several superior combustion characteristics. The fuel properties of biodiesel are approximately close to those of mineral diesel fuel and thus may be used directly as a fuel for diesel engines without any engine modification. They are also biodegradable, can be mixed with diesel in any ratio as blended fuel and are free from sulphur.

Although biodiesel has many advantages over diesel fuel, there are several problems that need to be addressed such as its higher viscosity, lower calorific value, higher flash point, poor cold flow properties,

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poor oxidative stability and produce slightly more oxides of nitrogen (10–13%), which is an ozone depressor [4, 5, 6, 7]. It is found that the lower concentrations of biodiesel blends improve the BTE. Reduction in emission and BSFC is also observed while using upto B20.

Since the introduction of petroleum fuels, the development of compression ignition (CI) engines is being done keeping the properties of diesel fuel in front. The present designs and operating parameters of available engines are standardized for diesel fuel only. For all other fuels, the operating parameters must be optimized to suit the fuel properties. Effect of injection parameters; spray, injection timing and compression ratio have been studied in detail at many places. Most of the research studies concluded that in the existing design of engine and parameters at which engines are operating, a 20% blend of biodiesel with diesel works well. Many researchers indicated the need of research in the areas of engine modifications so as to suit to higher blends and with neat biodiesel also without severe drop in performance so that the renewability advantages along with emission reduction can be harnessed to a greater extent. Effect of variations in these parameters has been studied taking one or more parameters at a time. To sum up the results of these studies, a experimental investigation for varying the compression ratios for a neat neem biodiesel engine is missing. To fill this gap, the experimental investigation was done with an objective of finding the optimum engine design parameters viz. compression ratio, for better performance of neat biodiesel (B100) obtained from Neem oil. The aim was to establish the compression ratio modifications required on a computerized single cylinder, 4-stroke, stationery, water-cooled diesel engine of 3.5 kW rated power.

2. EXPERIMENT AND PROCEDURE

In this experimental investigation, the variable compression ratio engine was run with MENO (B100) at different compression ratios to evaluate the performance with emissions along with the standard settings specified by manufacturer. The results were compared against the diesel fuel with standard compression ratio (17.5) and with neat biodiesel with various CR viz 16, 17 and 18.

A. Test Fuels

Neem oil is light to dark brown in color, bitter in taste and has a strong odor. Neem oil can be obtained from solvent extraction of the neem seed, fruit, oil-cake or kernel. A large industry in India extracts the oil remaining in the seed cake using hexane [8]. The neem tree is native to India and Burma [9] and almost the whole tree is usable for various purposes such as medicines, pesticides and organic fertilizer. Neem can be grown on very marginal soils that may be very rocky, shallow, dry, or pan forming. Neem tree can tolerate some extreme conditions like temperature of 45°C and rainfall less than 35 cm per year [10]. Neem tree gets full maturity in just 10 years and gives an average seed yield of around 5.25 tonnes per hectare and has an oil content of 45%. As the energy ratio of neem biodiesel is around 1.64, it is considered as one of the best renewable fuels in view of environmental inputs. Azadirachtin is the main constituent of neem seed oil, which varies from 300 to 2500 ppm depending on the extraction technology and quality of the neem seeds crushed [11]. The oil contains sulfurous compounds, which gives it a pungent odor and a less clean burn than other vegetable oils. It comprises of Triglyceride and Triterpenoid compounds.

B. Methyl Ester of Neem Oil

The biodiesel produced from neem oil is prepared by a method of two step process. The first step acid, catalyzed esterification reduces the FFA value of the oil to about 1%. The second step, alkaline catalyzed transesterification process converts the products of the first step to its monoesters and glycerol. In acid esterification, 1000 ml neem oil is heated to about 55°C, 250 ml methanol is added and stirred for a few minutes. With this mixture 2% H_2SO_4 is also added and stirred at a constant rate with 60°C for 1 h. After the reaction is over, the solution is allowed to settle for 24 h in a separating funnel. The excess alcohol along with sulfuric acid and impurities floats at the top surface and is removed. The lower layer is separated for further processing (alkaline esterification). In alkaline catalyzed esterification, the products of the first step are again heated to about 55°C. To this mixture, 2 % KOH dissolved in 250 ml methanol is added and stirred for 60 min. After the reaction is over, the solution is again allowed to settle for 24 h [12]. The glycerin settles at the bottom and esterified neem oil rises to the top. This esterified neem oil (biodiesel) is separated and purified with warm water. The higher percentage of esters alkanes and absence of phosphorous and sulfur make this esterified neem oil, the future candidate for alternative environment friendly diesel fuel. The measured properties of diesel fuel, neem oil and methyl ester of neem are given in Table 1.

Table 1
Comparisons of important properties of test fuels

Properties	*Standard Method*	*Diesel*	*Neem Oil*	*MENO*
Density (g/cm^3)	ASTM D941	0.8359	0.944	0.890
Calorific Value (kJ/kg)	ASTM D240	44500	39742	40678
Kinematic Viscosity (cSt)	ASTM D613	2-3	38.2	4.27
Flash Point (°C)	ASTM D445	75	201	180
Cetane Index	ASTM D93	51	55	53

C. Experimental set-up

Table 2
Specifications of the engine

Make & Model	*Kirloskar & TV1*
Power	3.5 KW @ 1500 rpm
Type	Multi Fuel
Speed	1500 rpm
Compression ratio	12:1 to 18:1
Bore	87.5 mm
Stroke	110 mm
Injection Variation	0-25 Deg BTDC
Capacity	661 cc
Method of loading	Electrical Load
Method of cooling	Water
Type of ignition	Compression Ignition

The study was carried out in the laboratory on an advanced, fully computerized experimental engine test rig comprising of a single cylinder, water cooled, four stroke, VCR diesel engine connected to eddy current type dynamometer for loading, Figure 1. The setup includes necessary instruments for online measurement of cylinder pressure, injection pressure and crank-angle. One Piezo sensor is mounted on engine head through a sleeve and other mounted on fuel line near the injector for measurement of pressures. The setup has transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement. Provision is also made for online measurement of temperature of the exhaust and cooling water inlet and outlet and load on the engine. These signals are interfaced to computer through a data acquisition system and the software displays the P–H and P–V diagrams. Windows based Engine Performance Analysis software package ‘‘Enginesoft” is used for online performance evaluation and to acquire data for combustion characteristics. The setup enables study of engine performance for power, mean effective pressure, thermal efficiency, specific fuel consumption and A/F ratio. The specifications of the engine used for this experimental investigation are given in Table 2.

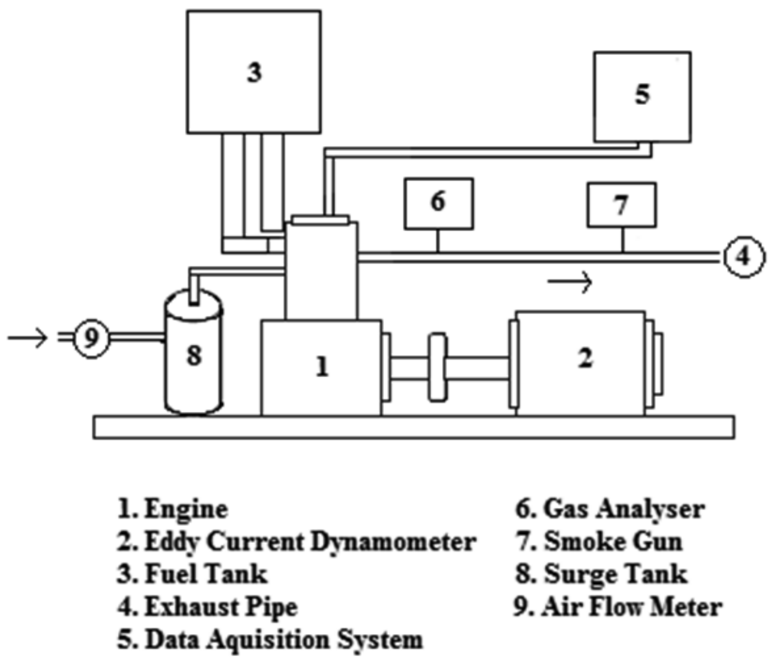

Figure 1: Layout of engine test rig and data acquisition system

D. Emission Measurement

The exhaust gases were analyzed using an AVL DiGas 444 gas analyzer. It measures carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC) and nitric oxide (NO). Model 114 smoke meter was used to measure the smoke intensity which works based on the British standard institution BS AU 141:1967 testing procedures.

E. Experimental Procedure

The performance test of the engine was conducted as per IS: 10,000 [P: 5]:1980. The engine was tested at no load and at 25%, 50%, 75% and 100% loads. For each load condition, the engine was run for at least 3 min after which data were collected. For diesel the performance tests were conducted with 17.5 CR, 210 bar injection pressure and 23 degree BTDC fuel injection angle was maintained at rated speed of 1500 rpm. For 100% biodiesel, in addition to the above settings, performance and emission tests were carried out at three CRs (16, 17 and 18). The performance of the engine at different loads and settings was evaluated in terms of BSFC, BTE and emissions of CO, CO_2, HC, NO and smoke intensity with exhaust gas temperature.

3. RESULTS AND DISCUSSION

The effect of various compression ratios on performance and emissions with MENO are investigated in this experimental study. The performance and emission measurements are taken repeatedly for 3 times. The analysis is done for the average of the readings. Further the error analysis is done for BTE at full load conditions. The percentage error at 90 % confidence limit for neat biodiesel comes around ±0.158 %.

A. Performance and Combustion Parameters

Figure 2, shows the variation of BTE, BSFC, ignition delay period and exhaust gas temperatures at full load conditions. The BTE is lower for MENO at all loads compared with diesel fuel. This may be due to its high viscosity and poor mixture formation [13]. For CR16, CR17 and CR18 the BTE were 26.95%, 27.78% and 28.62% respectively. The increase in CR increases the BTE. This is due to the fact that increase in CR ensures more complete combustion due to injection of fuel at higher temperature and pressure, better air–fuel mixing and faster evaporation.

It is observed that the BSFC for neat biodiesel is more than diesel fuel at all loads. This may be due to higher viscosity and lower calorific value of biodiesel. For CR16, CR17 and CR18 the BSFC were 0.42, 0.41 and 0.395 kg/kWhr respectively. The increase in CR decreases the BSFC. This is due to reduction in dilution of charge by residual gases, which results in lower BSFC.

The exhaust gas temperature increased with the increase in load because more fuel was burnt to meet the power requirement. MENO contains constitutes of poor volatility, which burn during the late combustion phase and which would have resulted in higher exhaust gas temperature compared to that of mineral diesel. For CR16, CR17 and CR18 the exhaust gas temperature was 358.5°C, 365.8°C and 373.11°C respectively. The increase in CR decreases the BSFC. Exhaust gas temperature increases with an increase in CR since the operating temperature is higher when engine operates at a higher CR [14].

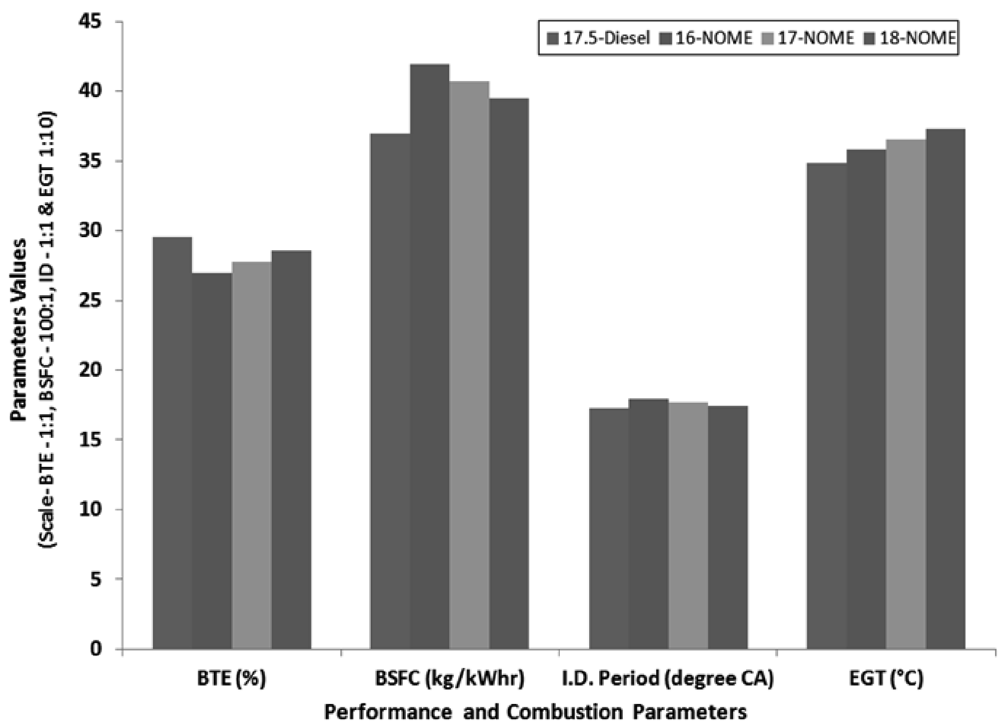

Figure 2: Variation of Performance and Combustion Parameters at full load

Ignition delay is the period between the start of fuel injection into the combustion chamber and the start of combustion. It was computed by calculating the change in slope of the pressure crank angle diagram, and from a heat release analysis of the pressure crank angle data. The ignition delay period of the tested fuel decreases with the increasing load. It is observed that the ignition delay period for neat biodiesel is more than diesel fuel at all loads. For CR16, CR17 and CR18 the ignition delay period was 17.91°CA, 17.65°CA and 17.47°CA respectively. The increase in CR decreases the ignition delay period.

B. Comparisons of Emissions

Figure 3, shows the variation of NO, HC, CO_2, CO and smoke emissions at full load conditions. The results show that NO emission increases with the increase of engine load due to more fuel combustion temperature. Neat biodiesel emits more NO emission than diesel because of its oxygen content in the fuel.

For CR16, CR17 and CR18 the NO emissions were 1262, 1343 and 1383 ppm respectively. The increase in CR increases the NO emissions. This may be due to the fact that increase in CR, increases the combustion pressure and temperature which accelerates the oxidation of nitrogen to form oxides of nitrogen. At lower CR, the combustion takes place during expansion stroke which results in lower combustion temperature and pressure which leads to lower NO emission.

Unburned HC come under different forms such as vapour, drops of fuel, or products of fuel after thermal degradation. HC emissions contribute to the formation of smog and may include photochemically reactive species as well as carcinogens. For CR16, CR17 and CR18 the HC emissions were 129, 125 and 118 ppm respectively. The increase in CR decreases the HC emissions. This may be due to the increase in the air temperature at the end of compression stroke, enhancement in combustion temperature and reduction in charge dilution which leads to better combustion and reduction in HC emissions. Increase in HC emission is observed with reduction in CR which is due to slow combustion process.

The results show that CO_2 emission increases with the increase of engine load. For CR16, CR17 and CR18 the CO_2 emissions were 7.64%, 7.96% and 8.27% respectively. The increase in CR, increases the CO_2 emissions. This may also due to better combustion, and less dilution of charge by residual gases accelerates the carbon oxidation to form carbon dioxide.

Low flame temperature and too rich fuel air ratio are the major causes of CO emissions from engine. Higher CO emissions results in loss of power in engine. The higher density and viscosity of neat MENO cause poor mixture formation, which results in high partial burning during combustion process. So CO emissions for neat MENO are more than diesel at all loads. For CR16, CR17 and CR18 the CO emissions were 0.263%, 0.251% and 0.233% respectively. The increase in CR, decreases the CO emissions. CO emission reduction may be due to short ignition delay and the improved ignition characteristics in the combustion chamber. This may also due to better combustion, and less dilution of charge by residual gases accelerates the carbon oxidation to form carbon dioxide. At lower CR, the carbon monoxide emissions are increased due to more dilution of fresh air with residual gases, lower compression temperature and poor mixing of fuel and air [15].

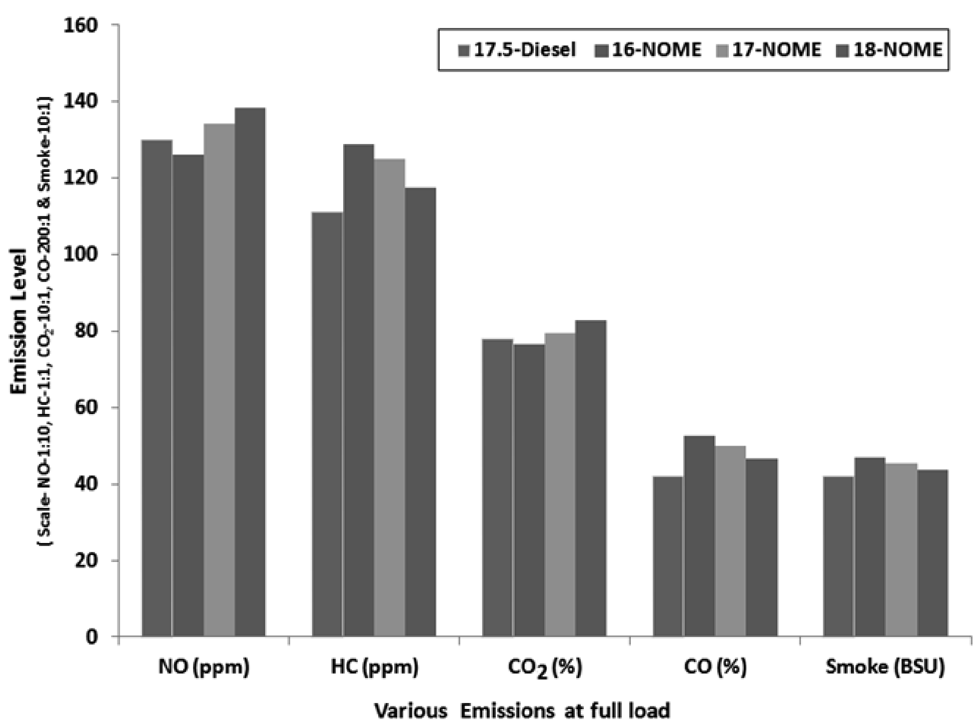

Figure 3: Variation of Emissions at full load

The results show that smoke intensity increases for all fuels with the increase of engine load. Neat MENO gives more smoke than diesel as the higher viscosity of oil leads to poor mixture formation. For CR16, CR17 and CR18 the smoke intensity was 4.69 BSU, 4.56 BSU and 4.38 BSU respectively. The increase in CR, decreases the smoke intensity. This may be due to more complete combustion because of fuel injected at higher temperature and pressure, better air–fuel mixing and faster evaporation.

4. CONCLUSIONS

In the current experimental investigation is done to evaluate the effects of engine parameter values (CR) while working with MENO as fuel. Trials with three values of compression ratios (16, 17 & 18) as against the standard values set by manufacturer for diesel as fuel (17.5) has demonstrated that increase in CR improves the performance of the engine as well as reduces the emissions.

1. The BTE increases and BSFC decreases by increasing the CR from 16 to 18.
2. The CO, HC and Smoke intensity reduces by increasing the CR from 16 to 18.
3. NO emission increases by increasing the CR from 16 to 18.
4. For better performance and emission reduction, the CR should be optimized (increased to 18) for the neat MENO fuelled CI engine.

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