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Impact of Compression Ratio on the Performance and Emission Characteristics of a CI Engine Working with Ternary Blended Biodiesel

H. S. Anantha Padmanabha* and Dillip Kumar Mohanty

School of Mechanical Engineering, VIT-AP University, Amaravati - 522237, Andhra Pradesh, India; pavanaputra304@gmail.com

Abstract

The current work investigated the characteristics of a diesel engine working with the ternary biodiesel blend having equal amounts of Jatropha, Karanja, and Cottonseed oils. The biodiesel constitutes 6.67% of each constituent oils and 80% diesel by volume. The impact of compression ratio on various characteristic parameters of a single cylinder diesel engine have been experimentally investigated to achieve enhanced performance and emission parameters. The compression ratio was varied from 15 to 18 and the results for the corresponding parameters were compared with the same parameters of the engine running with pure diesel at nominal compression ratio of 16. The brake thermal efficiency increased by 2.3% while the fuel consumption for unit power output reduced by 0.06 kg/kWh for the biodiesel at compression ratio 18. The hydrocarbon emission at compression ratio 18 with ternary blend biodiesel reduced by 37% than diesel while the carbon monoxide decreased by 42%. The oxides of nitrogen increased for biodiesel compared to pure diesel and it further increased with compression ratio due to better combustion of fuel. Thus, the biodiesel containing of 20% methyl esters of jatropha, karanja and cottonseed oil can be suitably adopted as an alternate fuel for automotive engines at higher compression ratio.

Keywords: *Combustion, Engine Performance, Ternary Biodiesel Blend, Transesterification*

1.0 Introduction

The energy necessity across the world is predominantly satisfied from fossil fuel sources like coal, petroleum and natural gas. The huge requirement in fossil fuels and the rapid rate of increasing demand has led to sharp rise in petroleum prices with the uncertainty of depletion in near future. The diesel engines are utilized in automobiles, household purposes and industries due to better thermal efficiency, consistency and cost-effectiveness. Also, these engines are the major sources of environmental pollution which includes pollutants like unburnt hydrocarbon, oxides of nitrogen, particulate matter, smoke, carbon monoxide and smoke. The emissions from diesel engine cause various greenhouse gases which have detrimental impact on social life, biodiversity, global warming and geographical conditions[1]. Among the various alternative approaches for the issues of petroleum fuel depletion and greenhouse gas emission, the development of biodiesel has been proved to be most promising over the last few decades. The edible and non-edible oils, domestic and industrial wastes have been sources of feedstocks for generation of the non-toxic, biodegradable and less-polluting alternate fuel for diesel engines.

Studies have been accompanied in recent years to study the feasibility of hybrid biofuels, which can completely replace the traditional diesel in automotive engines as primary fuel. Gad *et al.* adopted jatropha oil as

**Author for correspondence*

source for biodiesel production at various concentrations which proved to be a suitable fuel for diesel engines. The engine exhibited comparatively better performance, emissions and combustion parameters at 20% biodiesel concentration compared to pure diesel[2]. Bannikov *et al.* reported the biodiesel extracted from jatropha seeds to possess properties suitable enough for being use as a fuel for automotive engines[3]. The extracted methyl ester on being fueled in a CI engine exhibited much lower greenhouse gas emission at higher engine load. Osman *et al.* carried out the conventional transesterification process with microporous zeolite to produce improve quality jatropha oil biodiesel for engine operations. The produced biodiesel exhibited better fuel characteristics which satisfied all the norms of ASTM[4] (American Society of Testing and Measurement). The properties of jatropha oil biodiesel can be enhanced by inclusion of suitable additives at appropriate concentration. The karanja and jatropha oil has been used as a potential blend for biodiesel preparation to develop an alternate fuel. Ramesh Babu *et al.* evaluated the thermal and emission behavior of CI engines using karanja oil biodiesel as fuel[5]. The exhaust emissions attained remarkable improvement for carbon monoxide, hydrocarbon and nitrogen oxides with karanja oil biodiesel. Kursam *et al.* through an extensive experimental investigation reported that the most optimal biofuel composition for variable compression ratio engine diesel engine is 20% karanja oil methyl ester [6]. Ashok Kumar *et al.* examined the influences of biodiesel from karanja oil on different characteristic parameters of a CI engine concluded the suitability of the biodiesel as a possible candidate for use as fuel in automotive engines[7]. Khatri *et al.* established the karanja oil to be a suitable biodiesel material based on the emission and performance behaviour of a micro level tri-generation system operated by a compression ignition engine[8]. Mehta *et al.* conducted the experiment in compression ignition engines utilizing cottonseed oil mixes with diesel, concluded that declined tendency of BSFC to 12% at 20% blend and also reduction in smoke emissions comparable to diesel fuel[9].

The biodiesel extracted from any individual feedstock offers specific advantages in performance and emission characteristics of an automotive engine. Hence, multiple number of feedstocks can be combined to develop a potential alternate fuel with enhanced combustion properties. Venkatesh *et al.,* have done investigation on dual blended biodiesel P50SNB50 (50% pine oil, 50%soapnut oil) showed better performance and reduced emissions as a complete replacement of neat diesel[10]. Kadian *et al.* prepared a fuel using jatropha biodiesel and heptanol at different concentrations for enhancement of performance and mitigation of exhaust emissions from a direct injection CI engine[11]. Dugala *et al.,* utilized a novel dual biofuel blend generated from jatropha and mahua oil at different concentrations which exhibited properties suitable for being use as a fuel in automotive engines[12]. The fuel blend taking 15 and 20% of each biodiesel constituent was observed to possess enhanced cold flow characteristics and physico-chemical properties compared to each individual biodiesel element. Saravanan *et al*., prepared a dual fuel by blending rapseed and mahua oil for use as fuel in a VCR engine. The dual blend biodiesel containing 20% of the biodiesel having equal volume of the rapseed and mahua oil reduced the exhaust emission significantly[13]. The minimum emission was achieved by using the ternary blend biodiesel which indicated the possibility of improved engine characteristics by using multiple biodiesel blends[14].

The biodiesel taken out from a particular feedstock possesses certain properties which improves some specific characteristics of a fuel blend. The current work intends to use biodiesel extracted from three diverse feedstocks to achieve improved combustion properties of the fuel blend and hence improved engine characteristics. The compression ratio being one of the most vital combustion parameters of an automotive engine, its influence has been studied to attain enhanced parameters of a CI engine working with ternary blended biodiesel.

2.0 Materials and Methods

2.1 Biodiesel Preparation

The corresponding methyl esters have been extracted from jatropha, karanja and cottonseed oil through transesterification process. As the FFA content was found to be much higher than 2% for all the oils, two-step transesterification including acid esterification process was adopted in the present work. Initially, the acid esterification was adopted with 99% methanol as alcohol and 98% sulfuric acid. The esterified oil having around 1% of free fatty acid was undergone alkaline base

Table 1. Properties of pure diesel and biodiesel[14]

Properties	Pure Diesel	Jatropha (J)	Karanja (K)	Cottonseed (C)	B20	ASTM Standard
Density (Kg/m^3)	830	901	910	881	842	ASTMD287
Flashpoint (^0C)	53	67	192	156	69	ASTMD93-58T
Viscosity @40^{0}C (cSt)	2.09	5.70	11.15	6.43	3.21	ASTMD445
Cetane number	49	46	54	41	53	ASTMD613
Firepoint (^0C)	56	89	209	164	75	ASTMD93-58T
Calorific Value(KJ/Kg)	42991	36460	37682	40731	41974	ASTMD4809

transesterification process to obtain the corresponding methyl ester. In order to achieve rapid reaction, sodium hydroxide (NaOH) was used as catalyst. After completion of the chemical reaction process, the corresponding methyl ester and glycerin were separated from each other and further purified by warm water to eradicate the remaining drops of catalyst or soap.

The physico-chemical properties of each individual methyl ester were determined according to the ASTM norms. The properties were found to be within the prescribed limits of ASTM norms for being use as fuel in automotive engines. Further, a ternary blend biodiesel was equipped by combining equal quantity of the three different methyl ester constituents with pure diesel. Considering the optimal composition of the ternary biodiesel in our previous work, the biodiesel JKC20 with 6.67% concentration of each biodiesel and 80% pure diesel has been considered as the test fuel in the present research investigation. The different properties of the individual biodiesel elements and the test fuel JKC20 are summarized in Table 1.

2.2 Experimental Setup

The single cylinder 4 stroke (AV1) Kirloskar oil VCR diesel engine with 1500rpm rating and 3.5KW was used to conduct experiment for finding efficiency and

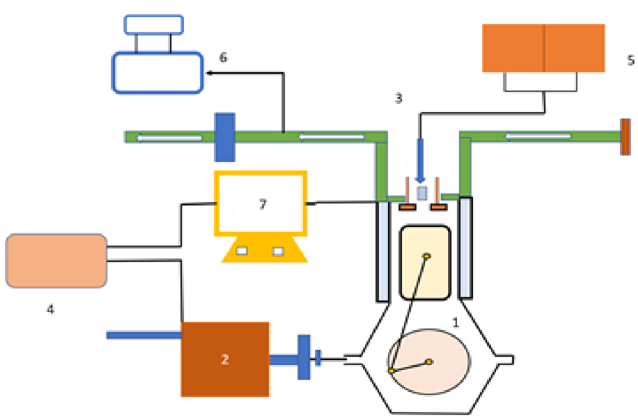

Figure 1. Experimental engine set-up.
1. Test engine, 2. Eddy Current Dynamometer 3. Fuel Injection System, 4. Control Panel 5. Fuel tank, 6. Exhaust gas analyzer 7. Data acquisition system

emissions of various parameters. The graphic diagram of test set-up including the engine and the emission measuring equipment used for experimental investigation is shown in Figure 1. The engine operating specifications are demonstrated in Table 2. The test set-up is equipped with suitable thermocouples, piezo sensor, crank sensor for measurement of the various operating parameters to estimate the engine characteristics. Simultaneously, an AVL gas analyzer has been employed for quantification of the engine exhaust emissions include carbon dioxide, oxides of nitrogen, unburnt hydrocarbon and carbon monoxide.

Table 2. Specifications of engine

Engine	Variable compression ratio with 1-cylinder, 4-stroke diesel engine.
Manufacturer name	Kirloskar
Rating at 1500 rpm	3.7 (5.0) KW (bhp) max rated 5HP
Diameter of Bore	80mm
CC	0.553L
Nominal compression ratio	16.5:1 VCR range 10:1 to 20:1
Stroke value	110mm
Rating at 1800 rpm	4.4 (6.0) kW (bhp)
Dynamometer & Power	Eddy current & 5HP on 1500 RPM

3.0 Results and Discussions

The engine characteristics include brake thermal efficiency (BTE), brake pecific fuel consumption (BSFC), carbon monoxide (CO), hydrocarbon (HC) and oxides of nitrogen (NOx) have been estimated for quantification of the exngine exhaust emissions. The experimental investigation shows that the fuel blend JKC20 consisting of 6.67% of jatropha, karanja and cottonseed oil with 80% of pure diesel exhibits optimal performance and emission characteristics[14]. As a result, the current experimental analysis was accomplished to assess the impact of compression ratio on the VCR engine characteristics using JKC20 as test fuel. The engine characteristics of the above mentioned test set-up for the test fuel biodiesel at compression ratios of 15, 16, 17 and 18 were estimated and associated with those of pure diesel at compression ratio of 16.

3.1 Effect of Compression Ratio

3.1.1 Brake Thermal Efficiency (BTE)

The fluctuation of BTE with load for diesel and JKC20 fuel at several compression ratios (CR) are presented in Figure 2. The BTE for both diesel and the test fuel at different compression ratios increase with engine load. The test results of the experimental observation exhibit lower BTE for JKC20 blend biodiesel than petroleum diesel for entire engine loads for compression ratio of 16. The lower BTE for the biodiesel at same compression ratio is primarily ascribed to lower calorific value, poor volatility and higher viscosity of the biodiesel blend. However, the BTE for the biofuel rises as the CR is increased. The engine was observed to attain BTE of 24.4, 26.3 and 28.3% for the biodiesel JKC20 corresponding to compression ratio 16, 17 and 18 respectively. The BTE for the same engine was observed to be 26.1% for pure diesel fuel at a CR 16. The rate of reaction during combustion process of the fuel-air mixture increases rapidly with surge in compression ratio as the temperature and pressure attains higher peak at high CR. The higher magnitude of combustion temperature and pressure inside the chamber causes much better droplet atomization and hence resulting in

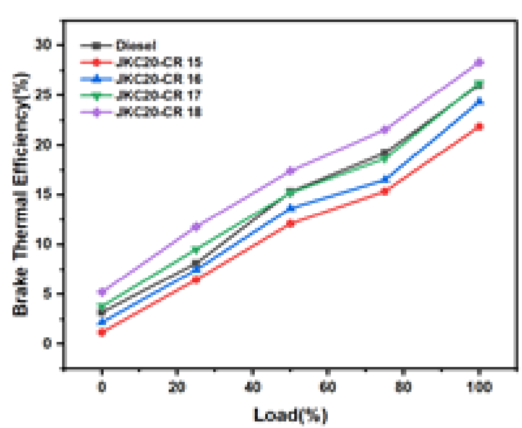

Figure 2. Effect of CR on BTE for JKC20 biodiesel blend.

improved combustion of the fuel. The higher temperature difference facilitates conversion of high grade of heat into increased output work and better BTE is achieved. Besides, the increased cylinder pressure and temperature gives rise to higher brake mean effective pressure ensuring improved combustion which causes to higher BTE.

3.1.2 Brake Specific Fuel Consumption (BSFC)

The BSFC denotes the consumption of fuel for unit power output of the automotive engine. The difference of BSFC with engine load depicted in Figure 3 indicates that the BSFC declines as the load surges irrespective of the fuel used in the engine. The test engine fueled with pure diesel at compression ratio of 16 consumes 0.41 kg of fuel to produce 1kWh power output. The same engine exhibits BSFC of 0.4, 0.39 and 0.35 kg/kWh for the biodiesel JKC20 at compression ratio of 16, 17 and 18 respectively. It can also be noticed that the BSFC attains a significantly higher value of 0.48 kg/kWh for the JKC20 biodiesel at lower compression ratio of 15. The BSFC for the biodiesel fuel at same compression ratio was observed to higher than of diesel over complete range of engine load due to higher density and lower heating value. Besides, higher fuel density of biodiesel blend causes poor fuel atomization which consequences in poor combustion and hence lower output power. However, the BSFC for all the fuel blends decreases with increase in load due to increased brake mean effective pressure at higher load. In a similar manner, the increased compression ratio results in higher pressure and cylinder temperature which causes to proper combustion of fuel producing higher power output for same amount of fuel. The increase in compression ratio from conventional value of 16 to 18 resulted in decrease of BSFC by 12.5% for the test engine operating with JKC20 biodiesel.

3.1.3 Hydrocarbon (HC) Emissions

The variation of hydrocarbon emission from the test engine setup fueled with the ternary biodiesel blend at dissimilar compression ratios are illustrated in Figure 4. The primary reason behind the formation of unburnt hydrocarbon in the exhaust emissions of an automotive engine is due to improper combustion of the air fuel mixture because of improper mixing. However, the emissions of HC rises sharply with increase in engine load irrespective of fuel and compression ratio. On the other hand, the hydrocarbon content in the exhaust emission decreases as the biodiesel concentration increases in the automotive fuel. The biodiesel being highly oxygenated fuel facilitates the oxidation of the unburnt hydrocarbon leading to lower HC emission from the locally over-rich fuel air mixture. The larger oxygen content in the biodiesel element enhances the quality of combustion leading to efficient combustion and less emission of hydrocarbon. For the same compression ratio of 16, the HC emission for biodiesel blend JKC20 reduces to 25ppm compared to 30 ppm for pure diesel. The HC emission from the engine can be further reduced by increase in the compression ratio. The HC emission for JKC20 attains 28, 25, 22 and 19 ppm for compression ratio 15, 16, 17 and 18 respectively.

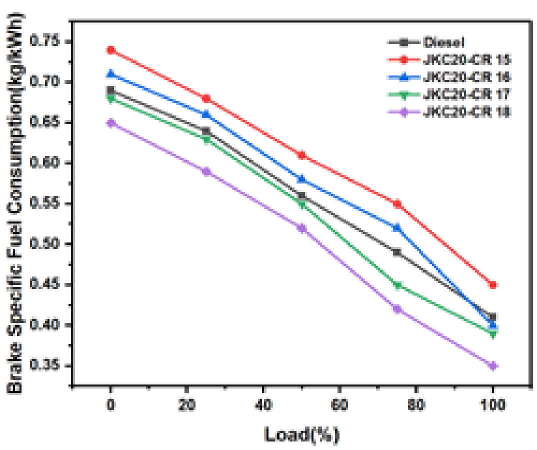

Figure 3. Effect of CR on BSFC for JKC20 biodiesel blend.

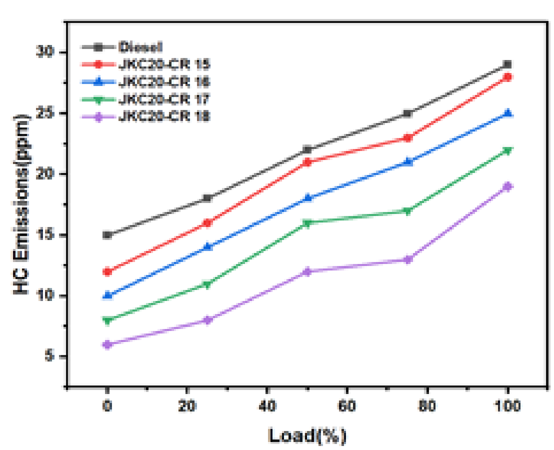

Figure 4. Effect of CR on HC for JKC6.66D80 blend.

Compared to pure diesel at conventional compression ratio 16, the JKC 20 fuel exhibits 16.7, 26.7 and 34.5% lower HC emission as the compression ratio increases to 16, 17 and 18 respectively. The lower HC emission can be ascribed to well mixing of the fuel-air mixture as a result of enhanced swirl motion at higher compression ratio. Thus, combustion process gets improved and more effective and consequently much lower hydrocarbon in the exhaust emission.

3.1.4 Carbon Monoxide (CO) Emissions

The carbon monoxide (CO) emissions occur in automotive engine primarily ascribed to inefficient combustion of fuel. The CO emission of the test engine set-up for pure diesel and JKC20 biodiesel at different compression ratios are presented in Figure 5. For any particular compression ratio, the CO emissions were found to be lower for the JKC20 biodiesel associated to pure diesel. The lower CO emission for biodiesel associated to pure diesel occurs due to high oxygen content of the biofuel which facilitates complete and improved combustion of fuel. As observed in the experimental results, the engine emits 22.5% lower carbon monoxide for JKC20 biodiesel compared to pure diesel at nominal CR 16. On the other hand, the CO emission of the engine reduces further as the CR is increased. The CO emissions of the engine fueled with JKC20 biodiesel were found to be 0.27, 0.24, 0.22 and 0.18% at compression ratios of 15, 16, 17 and 18 respectively. The higher compression ratio causes high cylinder temperature which leads to better fuel combustion resulting in lower emissions of CO. As observed in the results, the CO emission was found to be 11.2% higher for same biodiesel fuel at compression ratio 15 compared to nominal compression ratio 16. The higher CO emission occurs at lower CR value as the ignition gets delayed because lower heat of compression which is insufficient for full combustion. Additionally, the ignition lag reduces ascribed to higher in-cylinder temperature at higher CR causing proper combustion of fuel resulting in lower emissions of carbon monoxide.

3.1.5 Oxides of Nitrogen (NOx) Emissions

Figure 6 illustrates NOx emissions for diesel and JKC20 ternary blend biodiesel for the test engine at different compression ratios (CR) over the total load condition ranging from 0 to 100%. In CI engines, the NOx content of the engine exhaust gas mostly depends on the adiabatic flame temperature, which is very much associated to the peak temperature of the cylinder. As observed in Figure 6, the emissions of NOx increase with increase in load irrespective of the fuel used. This was due to the large quantity of fuel burned at higher BP, leading to an increased peak cylinder temperature during the fuel combustion process. The NOx values decreased from 1625 to 1556 ppm with decrease in the compression ratio 16 to 15 for the biodiesel at full load conditions. The engine emission was found to constitute 1694 and 1763 ppm of NOx compared to 1625ppm for JKC20 biodiesel corresponding to full load condition. The NOx content was observed to be 1402 ppm for pure diesel

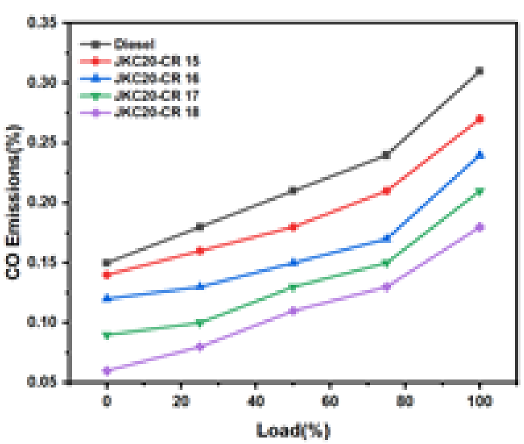

Figure 5. Effect of CR on CO for JKC20 biodiesel blend.

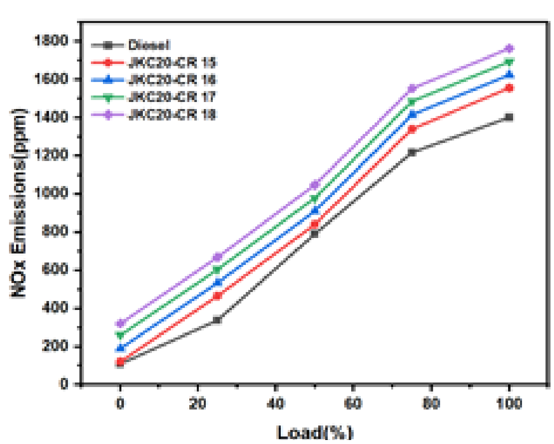

Figure 6. Effect of CR on NOx for JKC20 biodiesel blend.

corresponding to similar operating conditions. The excess content of oxygen in the biofuel causes higher temperature of the gas inside the engine cylinder which consequences in better combustion leading to extra oxides of nitrogen. At lower compression ratio, the cylinder temperature and hence the flame temperature reduces during the fuel combustion which suppresses the NOx emission.

4.0 Conclusion

The present research studies a comprehensive investigation on the characteristic of VCR diesel engine working with different blends of biodiesel extracted from jatropha, karanja and cottonseed oil. Furthermore, the influence of engine compression ratio has been studied in detail to achieve lower emissions and better efficiency. The experimental investigations were conducted with the VCR engine to estimate the performance, combustion and emission characteristics for pure diesel at conventional compression ratio of 16 and the optimum ternary biodiesel blend JKC20 at compression ratio ranging from 15 to 18. As observed from the test results, the engine fuelled with JKC20 blended biodiesel fuel at CR 18 attains brake thermal efficiency 2.3% higher than that for pure diesel at conventional compression ratio of the engine. Similarly, the fuel economy represented as BSFC declines by 0.06 kg/kWh for the biodiesel blend at higher CR of 18 as compared to pure diesel with CR 16. On comparing the emission results corresponding to pure diesel, the JKC20 blend achieved lower HC emissions by 37% and CO emission by 42% at enhanced compression ratio of 18. However, the NOx content of the engine exhaust was found to be increased by adopting the alternate fuel which further adversely increased for higher compression ratio. The undesirable increase in NOx emission can be controlled by adopting exhaust gas recirculation approach which can be studied further. Based on the consequences of improved compression ratio on characteristics of a CI engine, it can be concluded that JKC20 biodiesel blend is a suitable substitute for diesel in vehicles with a higher compression ratio.

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