Performance and Emission Characteristics of Coconut Biodiesel and Diesel Blends on VCR Engine

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ABSTRACT

Many researchers working on the vegetable oil used as alternative fuel in CI engine in last few decades. Some of these researchers have proposed the diesel replace by vegetable oil because of their agricultural origin, lower exhaust emissions and without altering the performance. In the present research paper, an experimental investigation analysis the performance and emission characteristics of single cylinder, 4 stroke, water cooled, variable compression ignition engine runs at constant speed. Coconut biodiesel blends (B10, B20, B30, B40 and B50) with diesel used as fuel. The experimental works have been carried out on VCR engine with varying loads (0 to 12 kg) at different compression ratios (15 to 18). These experiments have been conducted for comparative analysis of engine performances (brake thermal efficiency, brake power, IMEP, engine torque, mechanical efficiency and specific fuel consumption) and exhaust emissions (carbon monoxide, hydrocarbon, nitrogen oxides and carbon dioxide) of coconut biodiesel blends with diesel. In this analysis it was found that BTE increases with load and compression ratio. Higher BTE for B10 as compare to diesel and other blends. Maximum BTE is 40.51 % for B10 at peak load (12 kg) when engine runs at 18 CR. With increasing the compression ratio engine torque also increases. Higher torque for diesel as compared to other blends. As load and compression ratio increases mechanical efficiency also increases. While engine running at peak load B50 shows the maximum specific fuel consumption (0.39 kg/kWh) at CR 17. There is slight reduction in brake power with compression ratio for all the fuel blends. The blend B10 showing comparable brake power with standard diesel. The indicated mean effective pressure increases with increasing both engine load and compression ratio. The Nox emission increases with increasing the compression ratio. There is significant reduction in hydrocarbon emissions (HC) and carbon monoxide (CO) with increasing the load and compression ratio. Higher CO_2 emissions for all blends and at higher CR.

Keywords
Coconut oil and biodiesel, VCR engine, exhaust emission and engine performance.

1. INTRODUCTION

There is rapid depletion of fossil fuel deposits due to its continuous increasing demand [1]. The need of energy from some sources for different sectors like agriculture, industry, domestic etc. These sources are nuclear power, solar, wind, wood, coal, petroleum etc [2–4]. Among of these sources petroleum fuel is primarily used in the world surface transport. Due to overwhelming dependency on petroleum products and related global warming issue have generated anxious condition in the world [5]. Several researchers have been studied and experimental investigation associated with diesel exhaust emissions and its affect on human health [6-9]. Because of the limited petroleum reserves and increase in environmental pollution, it has become a worldwide matter to develop such types of fuel, which are environmental friendly, easily available and technically feasible [10]. Usually, biodiesel has a potential to substitute the petroleum based diesel and it is produced from vegetable plants oil or animal fats by the trans-esterification process. The alternative fuel, biodiesel is biodegradable, renewable, environmentally friendly and oxygenated fuel and it produces lower emissions while using in engine [11]. The various researchers have conducted the experiments and after evaluation of results it has been founded that there is very differences of engine performance like engine torque, power, and BSFC with comparison to diesel fuel. Apart from these results, there is reduction in exhaust emissions like sulphur dioxide, unburn hydrocarbon, carbon monoxide, particulate matter, nitric polycyclic aromatic hydrocarbons and polycyclic aromatic hydrocarbons but increased in nitrogen oxides from most of the experimental results [12-16]. C Carraretto et al. [15] have conducted the experiments on six cylinders direct injection diesel engine. It has been demonstrated that there is little reduction in engine torque and power with increasing the proportion of biodiesel in the blends for whole range of engine speed. Hanbey Hazar et al. [17] have conducted the experiment on direct injection Rainbow–186 diesel for performance and emission characteristics, using preheated raw rapeseed oil diesel blends as a fuel. It was found some positive effects on engine performance and emissions. Significant reduction in Smoke density and CO emissions, increase in NOx emissions and slight reduction in BSFC. There was reduction in viscosity of vegetable and its blends by preheating. H.G. How et al.[18] have conducted the experiment on four stroke (turbocharged) high-pressure common-rail diesel engine and coconut biodiesel used as a fuel. The experiment was conducted for the performance, emissions and combustion characteristics of different biodiesel blends (B10,B20,B30,B50) and with varying load. There was slight increased the BSFC and reduced the BSEC at all load. Increased in brake specific carbon monoxide (BSCO) and reduction in smoke opacity with increasing the proportion of biodiesel in blends. The value BSNOx increased with load. Lengthen the combustion duration and shorten ignition delay with biodiesel blends at all load. Slightly lower peak heat released rate and RMS (root mean square) for biodiesel blends in comparison to diesel. The experiment has been carried out on Ricardo E6 variable compression ratio engine using raw Algae oil and its biodiesel as a fuel and studied the effects of injection timing, compression ratio, engine speed and load output on the combustion noise, engine output torque, maximum pressure and maximum heat release rate. There was slight reduction in engine output torque and increment in combustion noise. By controlling the engine design parameters (injection timing and compression ratio) the above results can be improved [19]. Raheman and Ghadge [20] and Laguitton et al. [21] have been conducted the experiments for study the effect of compression ratios on diesel engine performance and emission characteristics. As increasing the compression ratio the BSFC decreased, exhaust gas temperature increased and improved the brake thermal efficiency. While decreasing the compression ratio cylinder temperature also decreases and hence reduced NOx emission. The CO and HC emission increased when engine operated at lower compression ratio. Therefore main objective of this study is evaluate the performance and emission characteristics of variable compression ratio (VCR) engine using coconut biodiesel (Methyl ester of coconut oil) and its blend with standard diesel as a fuel.

2. EXPERIMENTAL SETUP

The experiments have been conducted for engine performance and exhaust emission on variable compression ratio research engine fuelled with diesel and coconut biodiesel blends (B00 to B50). Specification of the VCR research engines is as follows: Single cylinder four stroke multi-fuel water cooled, stroke 110 mm, bore 87.5 mm. Capacity 661 cc. Diesel Power 3.5 kW, Speed 1500 rpm, CR range 12:1-18:1. Injection variation: 0-25 Deg BTDC. For loading engine is connected to current type dynamometer. The VCR engine specifications have been listed in table 1. The engine was started by using starter motor. The test has performed at varying compression ratio from 15 to 18 on constant speed (1500 rpm) VCR engine. "Engine soft" is the software used for analysis of engine performance. It is independent panel box comprises digital speed indicator, manometer, fuel tank, air box, digital temperature indicator and fuel measuring unit. There is tree type of sensor PT100, RTD and thermocouple. Strain gauge type load sensor used for measuring the load and it ranges 0-50 kg. Digital voltmeter used for measuring the voltage (0-20 V). The type K used to measure temperature at different zone. Air flow rate was measured by air box method. At each one degree increment of crank angle the cylinder pressure was measured and it recorded. The water flow rate in engine and calorimeter were measured. Its range for water 40-400 LPH and for calorimeter 25-250 LPH. Circulation of water in engine and calrimeter by using self-priming pump. The tail pipe emissions were measured with portable AVL digas 444 gas analyser. The specification of AVL gas analyser has been listed in table 2. The gas analyser shows the different emissions like carbon monoxide CO (vol%) and carbon dioxide CO_2 (vol%), nitrogen oxides NO_X (ppm), unconsumed oxygen O_2 (vol%) and unburned hydrocarbons HC(ppm) in the exhaust. The starting of AVL gas analyser with conducting the leakage test and hydrocarbon residue test. The leakage test performs for ensuring there is no leakage in pipe line and HC residue test for checking any HC residue is present in the analyser. If any of these tests are failed, changes the filters and whole test are conducted again.

Table 1. Engine Specification

General details	4 stroke, water cooled ,compressed ignition , VCR
Product code	240PE
Rated power	3.5kW at 1500rpm
Number of cylinder	Single cylinder
Compression ratio	12:1-18:1 (variable)
Bore	87.5 mm.
Stroke	110 mm,
Dynamometer	Type eddy current type, water cooled, with loading unit
Temperature sensor	Type RTD, PT100 and Thermocouple, Type K
Calorimeter	Pipe in pipe
Rota meter	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH
Air flow transmitter	Pressure transmitter, Range (-) 250 mm WC
Piezo sensor	Combustion: Range 5000 PSI, with low noise cable Diesel line: Range 5000 PSI, with low noise cable

Table 2. Technical specifications of AVL gas analyser

Measurement quality	Measuring range	Accuracy
CO	0-10% vol	< 0.6%: ± 0.03 %
		≥ 0.6%: ± 5 % of ind. val.
CO_2	0-20% vol	< 10% vol: ± 0.5 vol
		≥10% vol: ± 5 % vol
HC	0-20000 ppm vol	< 200 ppm vol: ± 10 ppm vol
		≥ 200 ppm vol: ± 5 % of ind. val
O_2	0-22 % vol	< 2 % vol: ± 0.1 % vol
		≥2 % vol: ± 5 % vol
NO	0-5000 ppm vol	< 500 ppm vol: ± 50 ppm vol
		≥ 500 ppm vol: ± 10 % ind. val

3. RESULTS AND DISCUSSION

3.1 Performance

3.1.1 Brake Thermal Efficiency (BTE)

Brake thermal efficiency of engine is very essential parameter and it indicates how efficient combustion of any engine. The proper and efficient utilization of fuel and lower fuel consumption for same power output indicates the higher BTE. If the BTE of engine is lower the overall efficiency of the engine decreases due to inefficient utilization of fuel, improper combustion and higher fuel consumption and this leads to more unburned particles exhausted from tail pipe. Fig. 1 and 2 shows the variation of brake thermal efficiency (BTE) for different blends (B10, B20, B30, B40 and B50) of coconut biodiesel and diesel (B00) for different loading condition at compression ratio 15 and 18. From the figure it has been observed that value of brake thermal efficiency is lower at low engine load. This is due to higher air-fuel ratio which leads to incomplete flame propagation and most of the fresh charge remains unburnt. At higher engine loads brake thermal efficiency increases. This is because of complete combustion of fuel takes place while fuel-air ratio increases [22]. There is lesser losses are encountered at higher load and consequently BTE increases with load [23]. Higher brake thermal efficiency for B10 compared to diesel and others blends. Brake thermal efficiency of the blends B10, B20, B30, B40, B50 and standard diesel (B00) at peak load for compression ratio 18 are 40.51%, 37.69%, 36.12%, 34.36%, 33.29% and 26.02% respectively. Brake thermal efficiency increases with increasing the compression ratio. As the compression ratio increases the cylinder temperature and the pressure also increases and result of this more amount of fuel undergo complete the combustion. But it is clear from fig. 3 at peak load there is little variation with compression ratio in BTE for all tested fuel.

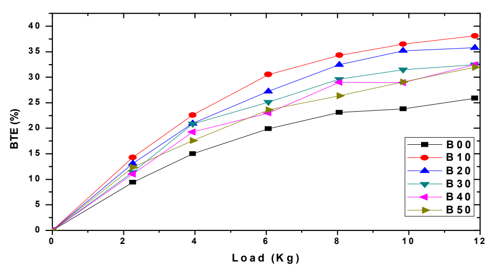

Fig .1 BTE vs. Load at CR 15

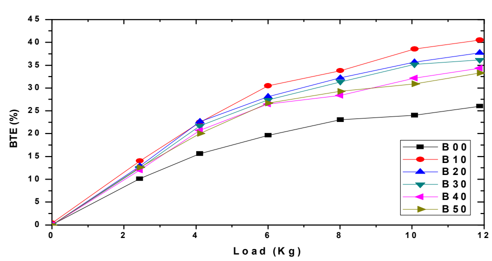

Fig .2 BTE vs. Load at CR 18

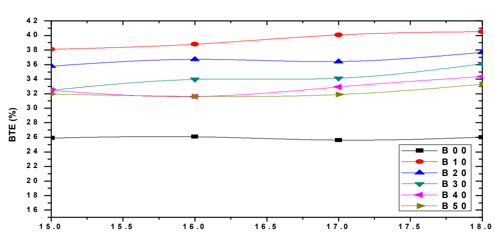

Fig.3 Variation of BTE with compression ratio at different blending

3.1.2 Engine Torque

The variation of engine torque with compression ratio for different blends has been shown in fig. 4. It has been observed that the engine torque increases with increasing the compression ratio for all the blends. This is because the development of high pressure inside cylinder which leads to increase the indicated power and as result of that engine torque will be increased. On other hand at lower compression ratio biodiesel not performing well. This is may be due to their higher viscosity and lower volatility causes reduced cylinder pressure and temperature. The engine torque at 18 CR is for diesel and all blends (B10, B20, B30, B40, B50) are 21.6 nm, 21.29 nm, 21.28 nm, 21.26 nm, 21.24 nm, 21.2 nm respectively. It is clear that maximum torque value of diesel higher than all biodiesel blends at compression ratio 18. This is because the lower heating value of biodiesel. At higher compression ratio temperature and pressure inside the combustion chamber increases result of this atomization of fuel and combustion is better and hence engine performing relatively better. The similar result has been obtained by Mohammed EL Kassaby et al. [24] and Y.C. Bhatt [25].

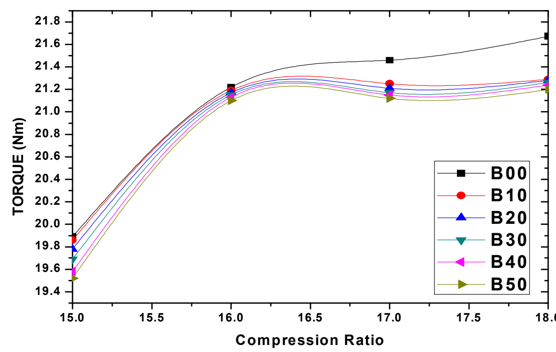

Fig.4 Variation of Torque with compression ratio at different blending

3.1.3 Specific fuel consumption

Specific fuel consumption of biodiesel blends and diesel with varying load at CR 15 and 18 showed in figure fig 5 & 6. It is easily perceived from figure, higher maximum specific fuel consumption (SFC) at lower load and its value decreases with increasing the engine load. The specific fuel consumption increases with increasing the proportion of biodiesel in the blends. It might be due the lower heating value and higher viscosity and density of biodiesel as compared to diesel. Generally, it is well known due to containing oxygen in biodiesel causes the lower heating value [26]. Therefore, it needed more mass of fuel for same output from the engine, due to which to compensate the decrease the chemical energy increases the fuel consumption [26.27]. The specific fuel consumption of diesel (B00) and biodiesel blends (B10,B20,B30,B40,B50) for 18 compression ratio are 0.33,0.33,0,34,0.36,0.37,0.38 kg/kWh respectively at peak load. The maximum SFC is 0.39 kg/kWh for B50 at compression ratio 17. The blend B50 shows the higher SFC than other blends and diesel. Variation of these results may be due the decreases the calorific value with increasing the proportion of biodiesel in fuel blends. Lower specific fuel consumption is desirable for any engine [28, 29**]**. Lower heat value of biodiesel as compare to diesel more biodiesel consumed to maintain same the power output [23]. As compression ratio increases specific fuel consumption slightly decreases (fig.7). Specific fuel consumption is higher for higher blends at all compression ratios. This is because the improvement in combustion of fuel at higher compression ratio.

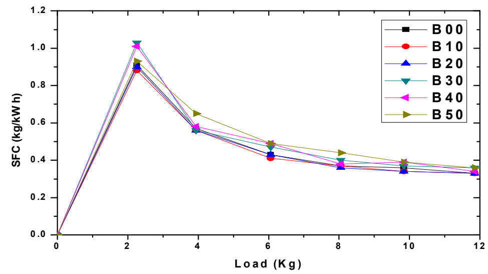

Fig .5 at CR 15

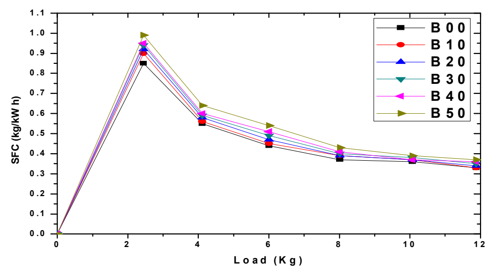

Fig .6 at CR 18

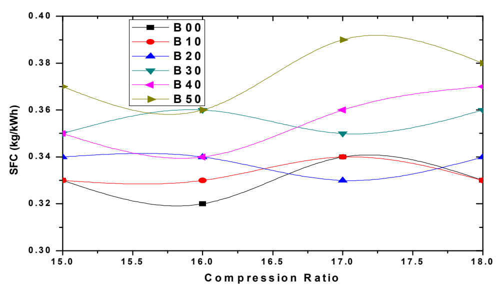

Fig.7 Variation of SFC with compression ratio at different blending

3.1.4 Brake power (BP)

Fig.8 shows the variation of brake power with load for different blends at CR 18. It is clear from brake power value increases with increasing the load and maximum at peak load. Approximately identical value at peak load for all the blends. The diesel and B10 shows the maximum brake power at compression ratio 18. It has been observed from fig. 9 the brake power decreases with increasing the compression ratio. It may happen due to chemical energy of fuel converted into mechanical energy. The brake power for diesel and biodiesel blends (B10, B20, B30, B40 and B50) is 3.31, 3.29, 3.29, 3.28, 3.25 and 3.26 kW respectively at 18 CR. The biodiesel blends shows lower brake power due to its lower heating value than diesel [26]. Additionally, this is because the improper combustion and lower heating value of biodiesel [28].

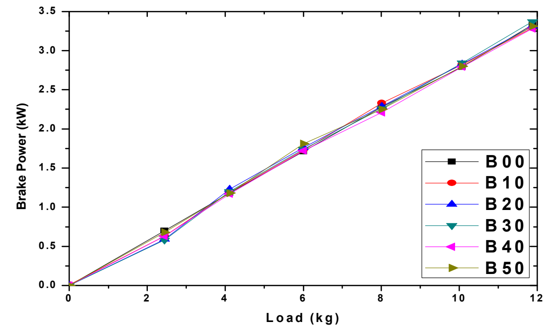

Fig.8 Brake power vs. Load

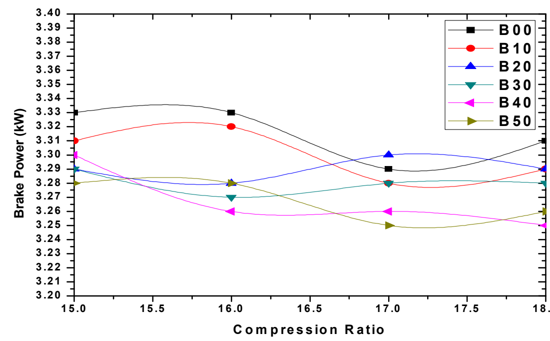

Fig.9 Variation of Brake Power with compression ratio at different blending

3.1.5 Indicated mean effective pressure (IMEP)

The fig. 10 shows the variation of indicated mean effective pressure with load for different blends. It has been observed from figure that indicated mean effective pressure increases with increasing the load. At lower load diesel shows higher indicated mean effective pressure than biodiesel blends but opposite results at peak load. The indicated mean effective pressure increases with increasing the proportion of biodiesel in blends. The blends B10 and diesel follows similar variation with load. Blends B40 shows the maximum IMEP (8.19 bar) for 18 compression ratio at peak load. It is observed from fig.11 the IMEP increases with increasing the compression ratio. The blend B10 closely follows diesel at compression ratio 16 and 17.

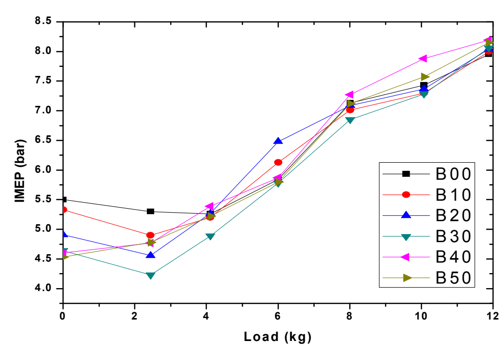

Fig. 10 Variation of IMEP with load

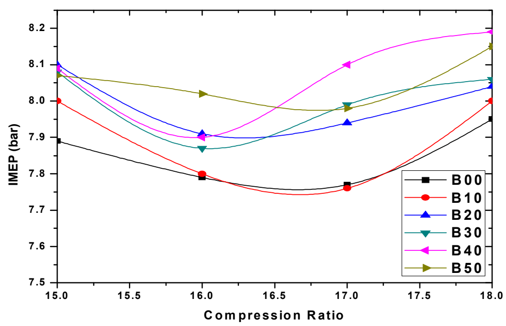

Fig.11 Variation of Brake Power with compression ratio at different blending

3.1.6 Mechanical efficiency

Fig. 12 and 13 shows the variation of mechanical efficiency with load for different blends at compression ratio 15 and 18. It is evident from figure that mechanical efficiency increases with load for all the blends (B10, B20, B30, B40 and B50). The value mechanical efficiency for blend B10 closely follows the diesel (B00). The mechanical efficiency for diesel and all blends is 54.92%, 53.83% 51.09%, 48.71%, 47.21%, 41.41% respectively for compression ratio 18 at peak load. Mechanical efficiency decreases as the proportion of biodiesel increases in blends. It has been observed from fig.14 that the mechanical efficiency increases with increasing the compression ratio for all the blends. The blend B10 shows the comparable result as compared to diesel.

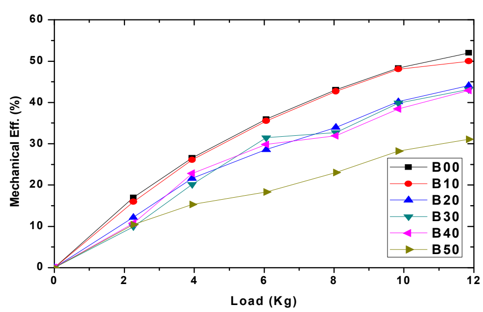

Fig .12 Mechanical Eff. vs. Load at CR 15

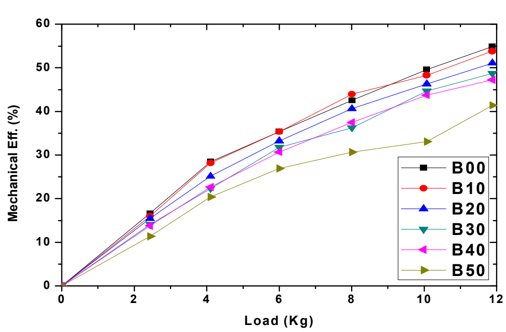

Fig .13 Mechanical Eff. vs. Load at CR 18

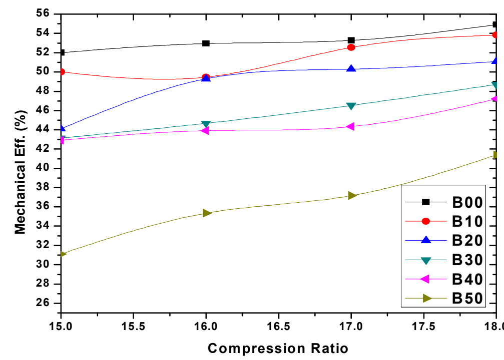

Fig.14 Variation of Mechanical Efficiency with compression ratio at different blending

3.2 Emissions

3.2.1 Carbon monoxide (CO)

The formation of CO is mainly due to incomplete combustion and it forms during the intermediate stage of combustion of fuel. The CO is converted into CO_2, when completion of combustion takes place [26]. Fig 15 and 16 shows the variation of carbon monoxide emission with load at different compression ratio (15 to 18) for biodiesel blends (B10 and B50). It is obvious from figure that reduction in CO emission as load is increases. Maximum and minimum CO formation at no load and peak load respectively. This is because the absence of air or lower temperature when engine running at no lower load due to which combustion is incomplete hence more CO will be formed. CO emission increases with increasing the proportion of biodiesel in blends. This is because of the biodiesel contains higher proportion of oxygen in biodiesel as compared to diesel. Additionally, it might be due to biodiesel has less C/H ratio than that of diesel [30, 31]. There is difficulty in atomization of biodiesel while using as a fuel in diesel engine due to its higher viscosity, which affects the air–fuel mixing process. Moreover, increases the production of CO emissions in locally rich mixtures of biodiesel. Additionally, more complete combustion due to presence of higher proportion of oxygen in biodiesel [30]. It has been observed from fig. 17 the CO emissions decrease with increasing the compression ratio for all biodiesel blends. While compression ratio increases temperature of combustion chamber also increases as result of this complete combustion takes place and hence lower formation of CO. Another reason, as compression ratio the production of CO is increases due to increases temperature of combustion chamber, properties of biodiesel, lack of oxygen at higher speed causes less time available for completion of combustion [32]. The temperature and pressure of air inside of cylinder increases with increasing the compression ratio consequently size of fuel droplets increases during injection due to which ignition lag increased and hence level of CO increases [33]. At lower compression ratio higher level of CO. This is because the increases temperature of combustion chamber, properties of biodiesel, lack of oxygen at higher speed causes less time available for completion of combustion.

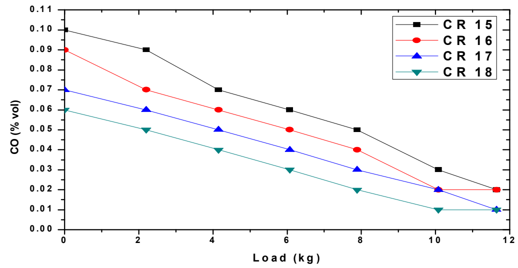

Fig .15 CO variations with load at B10

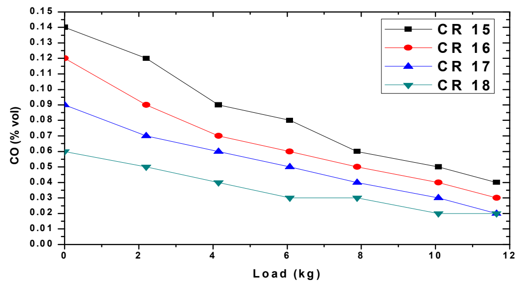

Fig .16 CO variations with load at B50

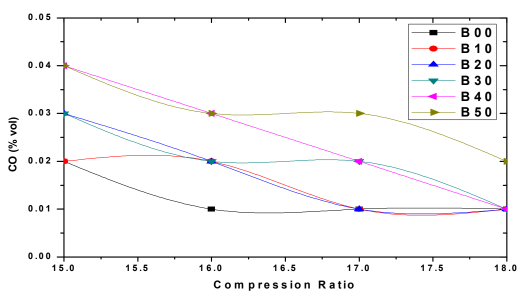

Fig.17 Variation of CO with CR

3.2.2 Hydrocarbon (HC)

Fig. 18 and 19 shows the variation of hydrocarbon emissions with load at varying compression ratio for biodiesel blends (B10 and B50). It has been observed from figure, there is reduction in HC emissions with increasing the load for all the fuel blends. With increasing the load fuel consumption decreases due to this more fuel injected into combustion chamber, causes increases the temperature and complete combustion take place. The proportion of biodiesel increases in blends HC emissions decreases. This is mainly due to presence of oxygen in coconut biodiesel causes high combustion temperature and complete combustion and hence it promoted the oxidation of hydrocarbon emissions. It has been demonstrated that improvement in fuel oxidation due to presence of oxygenated compounds in biodiesel and hence it reduces HC emissions [26, 34]. Additionally, reduction in HC emissions also due to higher cetane number of biodiesel blends which reduces the combustion delay [26, 35-37]. It is evident from fig. 20, with increasing compression ratio from 15 to 18 hydrocarbon emission decreases. While engine running at higher compression ratio the cylinder temperature increases which promotes more complete combustion and hence reduction of hydrocarbon emission.

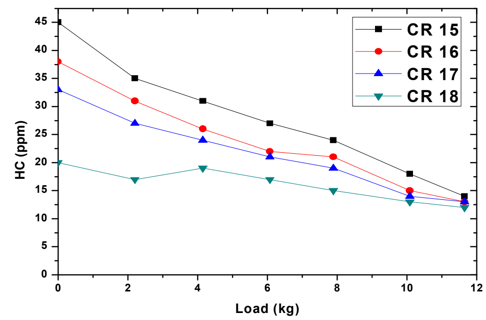

Fig .18 HC variations with load at B10

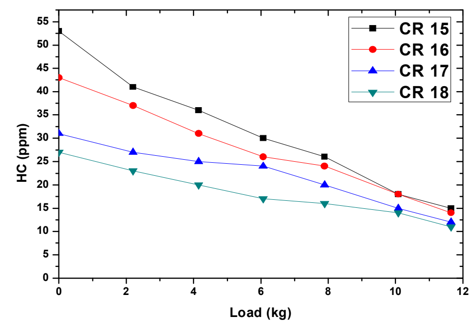

Fig .19 HC variations with load at B50

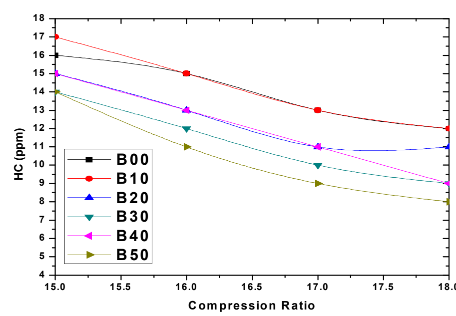

Fig.20 variations of HC with CR

3.2.3 Nitrous Oxide (NOx)

The formation of NOx is highly depends on the temperature and due to which reaction involved in combustion needed high activation energy. The concentration of oxygen, equivalence ratio and combustion temperature are used in determining these reactions. The fuel injection and combustion behaviour is affected by chemical and physical properties of fuel such as viscosity, density, cetane number and bulk modulus [38-41]. Fig 21 and 22 shows the variations of nitrogen oxides (NOx) emission with respect to load at varying compression ratio for biodiesel blends (B10 and B50). It is clear from figure, the NOx emission for all the blends increases with load but at peak load its value decreased. The biodiesel blends shows higher NOx emissions than diesel fuel. It has been demonstrated that the equivalence ratio, oxygen concentration and burned gas temperature are strongly influences the formation of NOx [26]. In another study, it has been reported that the formation of NOx increases by increasing the maximum temperature during the combustion and it will be due to increased the oxygen levels in fuel [42,43].The inherently oxygen concentration in fuel having more potential to produce NOx than the external oxygen supplied with the air [44].

From the fig. 23, it is obvious that NOx emission increases with compression ratio for all the fuel. This is due to NOx formation is mainly depends on high peak temperatures and availability of oxygen in the combustion chamber. At elevated temperature N_2 converts in to NOx in presence oxygen. From the results, it has founded that the increases the percentage of neem biodiesel in blends increases the NOx formation. The Highest value NOx at compression ratio 18 and lowest at compression ratio 15. The NOx emission at 18 compression ratio for diesel (B00) and biodiesel blends (B10, B20, B30, B40 and B50) are 98,182,188,237,166 and 195 ppm respectively when engine running at peak. The blends B30 shows higher value than other blend and diesel also.

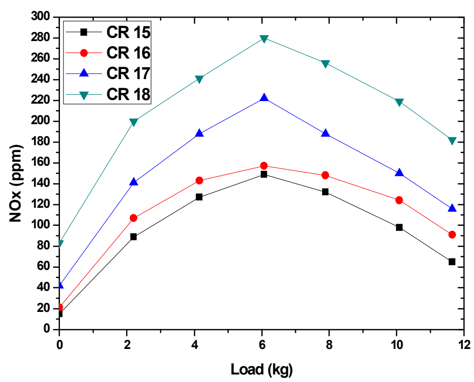

Fig .21 NOx variations with load at B10

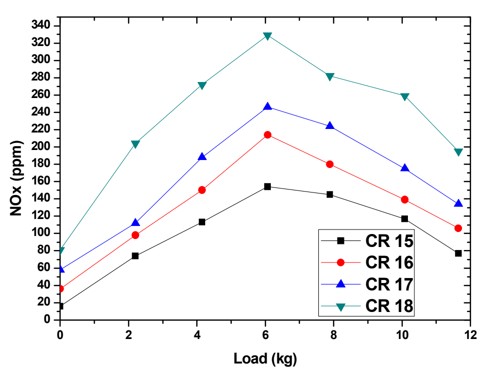

Fig .22 NOx variations with load at B50

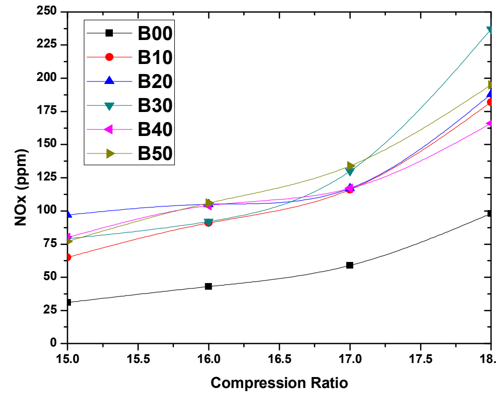

Fig.23 variations of NOx with CR

3.2.4 *Carbon dioxide (CO_2)*

The global warming and ozone depletion of environment due to periodically accumulation of CO_2 in the atmosphere. The various environmental problems like ozone depletion and global warming due periodically accumulation of CO_2 in the atmosphere. The CO_2 emissions from diesel engine can play role in serious public health problems and most important in formation of ozone layer [38, 44]. The complete combustion of fuel is indicated by the excess amount of CO_2 exhausted from tail pipe. The variation of carbon dioxide emission with load at varying compression ratio (15 CR-18 CR) for biodiesel blends (B10 and B50) has been shown in figure 24 and 25. It is clear from figure that CO_2 emission increases at lower load but its value decreases at higher load. CR 18 shows the maximum CO_2 emission and minimum for 15 CR for all the blends. Fig. 26 shows the variation of CO_2 emissions with compression ratio for different biodiesel blends at peak load. As compression ratio increases CO_2 emission also increases. This is because the higher engine performance at higher compression ratio. As the compression ratios increases temperature inside the combustion chamber also increases which leads to complete combustion of fuel and hence more formation CO_2. In order to keep constant amount of CO_2 in the atmosphere by the utilization of plant origin bio fuels. The CO_2 emission from the combustion of bio fuels can be utilized by the plants and the carbon dioxide level and is kept constant in the atmosphere [45]. There is more production of CO_2 when the proportion of biodiesel increases in the blends with comparison to diesel fuel. It may be happen due presence of oxygen in biodiesel. During the combustion these oxygen reacts with unburned carbon and promotes more formation of CO_2. If the amount of CO_2 is more in the exhaust emission means complete combustion of fuel in engine cylinder [26,46].Maximum production of CO_2 with B50 at all compression ratios.

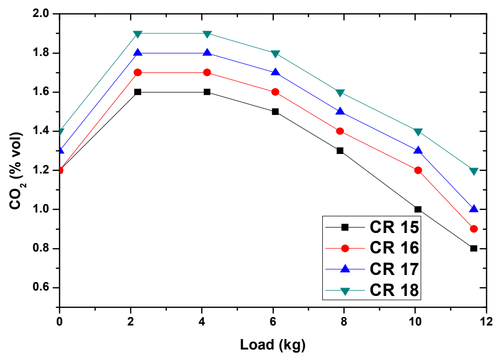

Fig .24 CO_2 variations with load at B10

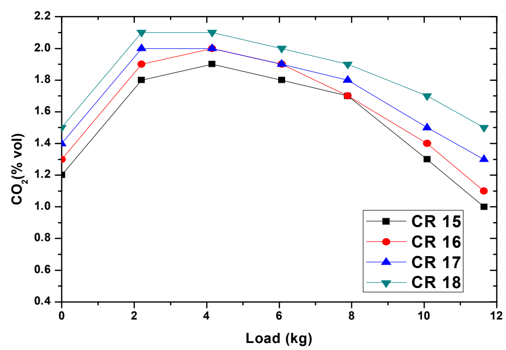

Fig .25 CO_2 variations with load at B50

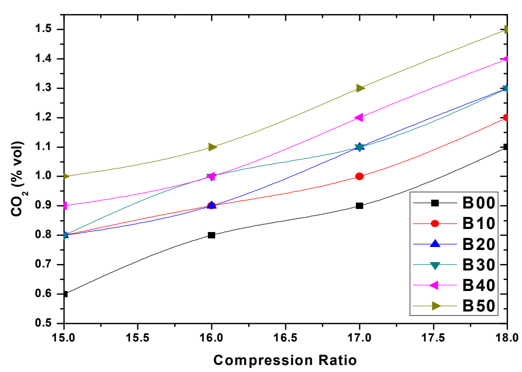

Fig.26 Variation of CO_2 with compression ratio for different blending

4. CONCLUSION

The experimental investigation has been carried out on variable compression ratio research engine fuelled with coconut biodiesel blends. In this experimentation studied the engine performance and emission characteristics at different compression ratio (15 to 18) and load (0 to 12 kg). These are the following conclusions from experimental results.

1. The Brake thermal efficiency increases with load. Higher BTE for Coconut biodiesel blends as compared to standard diesel. The blend B10 shows maximum BTE at compression ratio 18. Very little variation with compression ratio.
2. Engine torque increases with compression ratio. Lower torque for all coconut biodiesel blends as compared to standard diesel.
3. Due lower heating value of coconut biodiesel higher SFC for biodiesel. There is slight variation in SFC with compression ratio.
4. Brake power gradually increases with load. The B10 shows comparable brake power with standard diesel. Brake power slightly reduces with increasing the compression ratio for all the fuel blends.
5. Indicated mean effective pressure (IMEP) increases with load for biodiesel blends. The maximum IMEP for blends B40 at compression ratio 18. IMEP increases with compression ratio.
6. Mechanical efficiency increases with increasing the load for all fuel. Lower mechanical efficiency for biodiesel blends than diesel. The blend B10 and diesel show comparable results at all compression ratio. Mechanical efficiency increases with compression ratio for all the biodiesel blends and standard diesel.
7. Significant Reduction in CO and HC emissions with increasing the engine load at all compression for all the biodiesel blends. Both CO and HC emissions reduces with increasing the compression ratio for all the fuel. The CO emission increases with increasing the proportion of biodiesel in the blends and opposite trend for HC emissions.
8. The NOx emissions increases with increasing the load but its value decreases after certain load. Higher NOx formation at higher compression ratio. For higher biodiesel blends NOx formation also higher.
9. Higher CO_2 emissions for higher biodiesel blends. CO_2 level increases with increasing the compression ratio.

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Nomenclature

NOx	nitrous oxides	CO_2	carbon dioxide
CO	carbon monoxides	HC	hydrocarbons
B0	pure diesel	B10	10% biodiesel
B20	20% biodiesel	B30	30% biodiesel
B40	40% biodiesel	B50	50% biodiesel
CR	compression ratio		

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