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Experimental Investigation of the Effect of Compression Ratio in a Direct Injection Diesel Engine Fueled with Spirulina Algae Biodiesel

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ABSTRACT

Experiments have been carried out on a single cylinder, four stroke, and variable compression ratio diesel engine to investigate the effect of compression ratio on its performance, combustion and emission parameters, when it is fuelled with Spirulina of 20%, 40%, 60% and 80% blend with standard diesel. The parameters that were measured comprised of performance parameters such as Brake Power (BP), Brake Thermal Efficiency (BTHE), Brake Specific Fuel Consumption (BSFC), Mechanical Efficiency, along with Combustion parameters such as Cylinder Pressure and Net Heat Release Rate (HRR). The exhaust gas emission included Carbon Monoxide (CO), Carbon dioxide (CO2), Nitrogen oxides (NOX) and Hydrocarbon (HC). The results obtained for Spirulina at compression ratios (CR) of 15, 16 and 17.5, at different loads have been compared and analyzed to that of standard diesel. After analyzing the data, it is evident that while fuelling the engine with spirulina biodiesel, there is a clear decrease in the emission of Carbon monoxide, Nitrogen oxides and Hydrocarbons. And the performance characteristics of the engine remain unaltered. The optimum engine performance was found at higher compression ratio.

Keywords: Spirulina algae; Compression ratio; Performance; Combustion; Emissions; Diesel engine.

NOMENCLATURE

CO	carbon monoxide	BTE	Brake Thermal Efficiency
CO_2	carbon dioxide	HRR	Heat Release Rate
BP	Brake Power	CR	Compression Ratio
BSFC	Brake Specific Fuel Consumption		

1. INTRODUCTION

For the past century, diesel has been used as a fuel to run internal combustion (IC) engines. IC engines are the main life line of the human race for generating power that is utilized for production of electricity, transportation, locomotives, irrigation, construction, marine, defence, telecom sectors, etc. Despite having various evident merits and applications, IC engines also have their fair share of drawbacks. To highlight a few, the emissions of an IC engine poses an eminent threat to the environment, they are one of the main causes for the release of greenhouse gases that are directly responsible for global warming. This causes a plethora of issues like the melting of ice glaciers increase in the sea water levels, change of weather patterns, shifting of wind currents, changes in the timings of seasonal events and changes in agricultural productivity. IC engine emissions also facilitate the depletion of the ozone layer in our atmosphere.

As per the US department of energy, the world's oil supply will reach its maximum production and midpoint of depletion sometime around the year 2020. The increase in the global population further increases the demand of fossil fuels and also causes a rise in the price of fossil fuels. All of this opens new windows for conduction research on finding a feasible and practical alternate solution for the prominent crisis. Future projections indicate that the only feasible option is the production of synthetic fuels derived from non-petroleum sources said Tashtoush (2007). Based on this belief, more than ample amount of experimental research has and is being done on fuels that can be extracted from non-petroleum sources. 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 bio-diesel fall in the category of bio fuels said Jindal (2010).

Vegetable oils are easily available in rural areas, are renewable, have a reasonably high cetane number can be used in diesel engines with simple modifications and can also be easily blended with diesel in the neat and esterified (Biodiesel) forms. Narayana Reddy (2006), Avinash Kumar Agarwal (2009), Avinash Kumar Agarwal (2013), Dhandapani (2012), Hariram (2013) and M.S. Shehata (2011) reffered that Jatropha oil, Karanji oil, Coconut oil, Sunflower oil, rapeseed oil, neem oil and Algal oil Methyl Ester are some of the vegetable oils that are used as fuels in internal combustion engines. Soha Mostafa *et al*. (2013) evaluated the fuel properties for Microalgae Spirulina Platensis Bio-diesel and its blends with Egyptian Petro-diesel and concluded that, the results of this study indicate microalgae Spirulina platensis is a prime candidate to be used for biodiesel production, for its high growth rate 2.23 g/Ld, sufficient lipid content, requiring just a simple and inexpensive culture medium and producing other valuable byproducts which would decrease the overall cost of biodiesel production. It is worth mentioning that the extreme conditions of salinity and pH in which Spirulina platensis can survive and the easy availability of spirulina algae in rural Indian villages add to its value to be used for production of biodiesel. Motivated by these benefits, many research papers have been published on the effects of using bio-fuels to power IC engines and on the effects of varying engine parameters viz. compression ratio of CI engines powered by biofuels. Muralidharan (2011) examined the Performance, emission and combustion characteristics of biodiesel fuelled variable compression ratio engine and stated that, the experimental result proves that waste cooking oil biodiesel and diesel blends are potentially good alternate fuels for diesel engine. Wail Adaileh (2012) and Ozer Can (2014) also stated that waste cooking oil biodiesel are potentially good alternate fuels for diesel engine. Orkun Ozener (2014) studied the effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics and the results indicate that biodiesel can be used without any modification of the engine and as an alternative and environment friendly fuel. Balajee (2013) investigated the performance and combustion characteristics of CI engine with variable compression ratio fuelled with Pongamia and Jatropha and its blends with diesel and concluded that this biodiesel can be used as an alternate fuel for biodiesel, in the near future.

Sukumar (2005) investigated the Performance and emission study of Mahua oil (madhuca indica oil) ethyl ester in a 4-stroke natural aspirated direct injection diesel engine and based on this study it was concluded that Mahua oil ethyl ester can be used a substitute for diesel in diesel engine. Balajee (2015) studied the optimization of a stationary VCR–CI engine fuelled with Dunaliella Salina oil and corn oil using Taguchi approach and concluded that the emission of CO was lower than that of diesel, whereas CO_2 emission for biodiesel was found to be higher than diesel due to improved combustion. Murat Karabektas (2008) investigated the effects of preheated cottonseed oil methyl ester on the performance and exhaust emissions of a diesel engine and concluded that the use of preheated Cottonseed oil methyl ester (COME) usually yielded a significant decrease in CO emissions, while NOx emissions were increased due to higher combustion temperatures caused by preheating and oxygen content of COME. Vallinayagam (2013) studied the combustion performance and emission characteristics study of pine oil in a diesel engine and it was agreed that the current experimental investigation indicates that pine oil can be directly used in diesel engine without trans-esterification due to its unique properties. 100% pine oil shows better thermal efficiency and specific fuel consumption than diesel. Cenk Sayin (2011) examined the impact of compression ratio and injection parameters on the performance and emissions of a DI diesel engine fueled with biodiesel-blended diesel fuel. Based on the results, they drew a conclusion that for all CRs, the emissions of HC, OP and CO with biodiesel blends are lower than that of diesel fuel. With the increase in CR, the temperature reached is also high and so less OP, CO and HC emissions are exhausted in engine.

Bhaskor Bora (2014) investigated the effect of compression ratio on performance, combustion and emission characteristics of a dual fuel diesel engine run on raw biogas. Based on the results of this study, it can be concluded that the performance parameters and emissions of a biogas run DFDE are found to be a function of CR. At higher CR, biodiesel releases lesser emission than standard diesel. Kassaby (2013) studied the effect of compression ratio on an engine fueled with waste oil produced biodiesel/diesel fuel and concluded that increasing the compression ratio improved the performance and cylinder pressure of the engine and had more benefits with biodiesel than with high pure diesel. Lakshmanan (2017) analysed about the usage of chicken fat oil blended with diesel fuel in a compression ignition engine.

2. EXPERIMENTAL SETUP

The setup, as shown in Fig. 1, consists of single cylinder, four strokes, VCR (Variable Compression Ratio) dual fuel engine. Engine is connected to eddy current type dynamometer for loading. The compression ratio can be changed without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. Setup is provided with necessary instruments for measuring the combustion pressure and crank-angle. These signals are interfaced to computer through engine indicator for Pθ-PV diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The set-up has stand-alone panel box consisting of air box, two fuel tanks for dual fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement. The setup enables study of VCR engine performance for Brake power, Indicated power, Frictional power, Brake mean effective pressure (BMEP), Indicated mean effective pressure (IMEP), Brake thermal efficiency, Indicated thermal efficiency, Mechanical efficiency, Volumetric efficiency, Specific fuel consumption, A/F ratio and Heat balance. Lab view based engine Performance Analysis software package “Enginesoft” is provided for on line performance evaluation. Engine Soft is Lab view based software package developed by Apex Innovations Pvt. Ltd. for engine performance monitoring system. Engine Soft can serve most of the engine testing application needs including monitoring, reporting, data entry, data logging. The software evaluates power, efficiencies, fuel consumption and heat release. The standard available engine (with fixed compression ratio) can be modified to VCR by providing additional variable combustion space. There are different arrangements by which this can be achieved. Tilting cylinder block method is one of the arrangements where the compression ratio can be changed without changing the combustion geometry. With this method the compression ratio can be changed within designed range without stopping the engine. The clearance volume of the combustion chamber is changed by tilting the cylinder block. As the clearance volume is changed and swept volume is constant the CR changes. Using 100 % diesel and B20 (20% of spirulina in 80% of diesel), B40, B60 and B80 blends of biodiesel (spirulina) in the variable compression ratio CI engine at 1500rpm, the performance evaluation of the engine is carried out at various loads (4kg, 8kg, 12kg) and the performance such as mechanical efficiency, brake thermal efficiency, specific fuel consumption, brake power, cylinder pressure are calculated and recorded. The engine specifications and the measurement range and accuracy of delta 1600S gas analyzer used is specified in table 1.

T_1 - Jacket water inlet temperature,

T_2 - Jacket water outlet temperature,

T_3 - Inlet water temperature at calorimeter,

T_4 - Outlet water temperature at calorimeter,

T_5 - Exhaust gas temperature before calorimeter,

T_6 - Exhaust gas temperature after calorimeter.

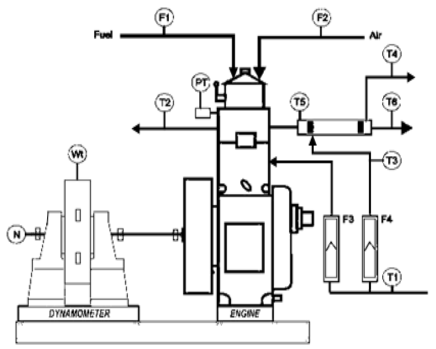


Fig. 1. Layout of VCR-CI engine coupled with dynamometer

Table 1 Combustion Properties of the sample

Sample	Calorific value (KJ/kg)	Kinematic viscosity (at 40°C)	Cetane Number
DIESEL	45240	1.382	45
B20	43061.6	2.106	47.78
B40	41977.2	2.862	48.63
B60	41169.4	3.374	49.12
B80	40553.8	3.618	50.28

Table 2 Combustion Properties of the sample

Sample	Flash Point (°C)	Fire Point (°C)	Density (kg/m^3)	Specific Gravity
D	68	127	0.864	0.84
B20	85.2	135.2	0.858	0.8488
B40	102.4	143.4	0.866	0.8576
B60	119.6	161.6	0.875	0.8664
B80	136.8	179.8	0.883	0.8752

3. EXPERIMENTAL PROCEDURE

The performance test of the engine was conducted as per IS: 10,000 [P: 5]:1980. Initially the engine was run on no load condition and its speed was adjusted to 1500 ± 10 rpm. After warming up the engine, it was tested at no load and at 4kg, 8kg and 12kg loads. As per the test rig specifications, at full load (100%), the eddy current dynamometer is to be loaded with 12 kg load for given arm length. For each load condition, the engine was run for at least 3 minutes before collecting the experimental data for both the fuel types. The process was replicated thrice. For diesel the performance tests were conducted with 17.5 compression ratio, injection pressure of 210 bar and at the rated speed of 1500 rpm. For spirulina blends with standard diesel, in addition to the above settings, performance tests were carried out at compression ratios of 15, 16 and 17.5 (as per the standards set by the manufacturer). The compression ratios below 15 lead to poor power output and above 18 were not possible due to engine structural constraints. For all settings, the emission values were recorded thrice and an average of these was taken for comparison. The performance of the engine at different loads and settings was evaluated in terms of brake specific fuel consumption (BSFC), brake thermal efficiency (BTE) and emissions of carbon monoxide, carbon dioxide, un-burnt hydrocarbon and oxides of nitrogen with exhaust gas opacity and temperature. The BSFC is evaluated by the software on the basis of fuel flow and brake power developed by the engine using the expression BSFC = (volumetric fuel flow in 1 h X fuel density/brake power). Similarly, BTE is also evaluated by software using the expression BTE = (brake power X 3600 X 100/volumetric fuel flow in 1 h X fuel density X calorific value of fuel).

4. RESULTS AND DISCUSSION

4.1 Brake Power

From Fig.2 it can be witnessed that the Brake Power (BP) of the engine increases as the Compression Ratio (CR) increases. This is due to the improved conversion from chemical energy to mechanical energy, when bio diesel is used. This can be attributed to the low volatility and high cetane number of spirulina blended with standard diesel. From the experimental values (Fig.2(a)), it is clear that the highest brake power is obtained while using a 20% blend of spirulina biofuel at a compression ratio of 17.5.

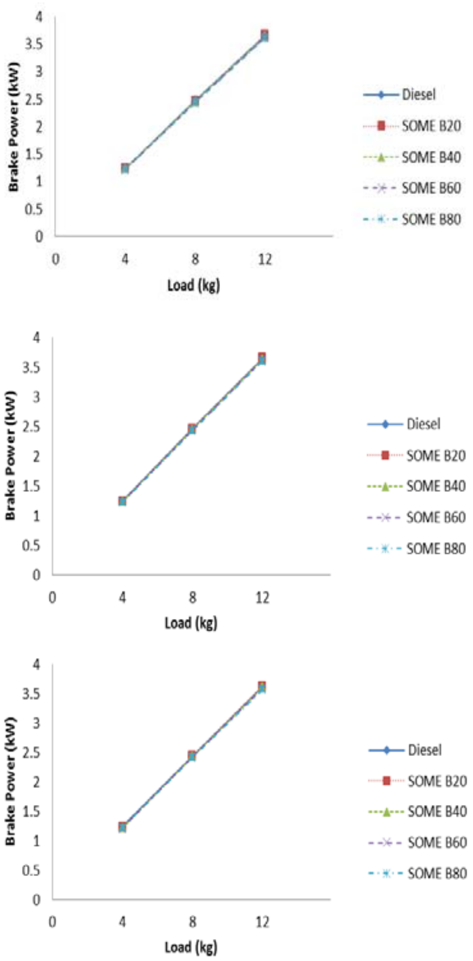


Fig. 2. Brake power for various compression ratio

4.2 Brake Specific Fuel Consumption

From Fig.3 it can be seen that the Brake Specific Fuel Consumption (BSFC) decreases as the load increases. This is due to the fact that the power output per unit fuel increases at higher loads. Moreover, the BSFC improves as the CR increases. This is due to the fact that, at higher CR the BP increases. The BSFC also increases as the percentage of spirulina in the biodiesel increases, as more biofuel is needed to maintain the same output produced by standard diesel.

At a compression ratio of 15 (Fig.3(c)), the BSFC improves from a value of 0.69 kg/kwWhr (B80 blend), at a load of 4kg to 0.28 kg/kwWhr (B20 blend), at a load of 12kg. Similarly, at a compression ratio of 16 (Fig.3(b)), the BSFC improves from a value of 0.56 kg/kWhr (B60 blend), at a load of 4kg to 0.27 kg/kwWhr (B20 blend), at a load of 12kg. The least value of BSFC (Fig.3(a)) is observed while using a B20 blend of spirulina biodiesel, at a compression ratio of 17.5

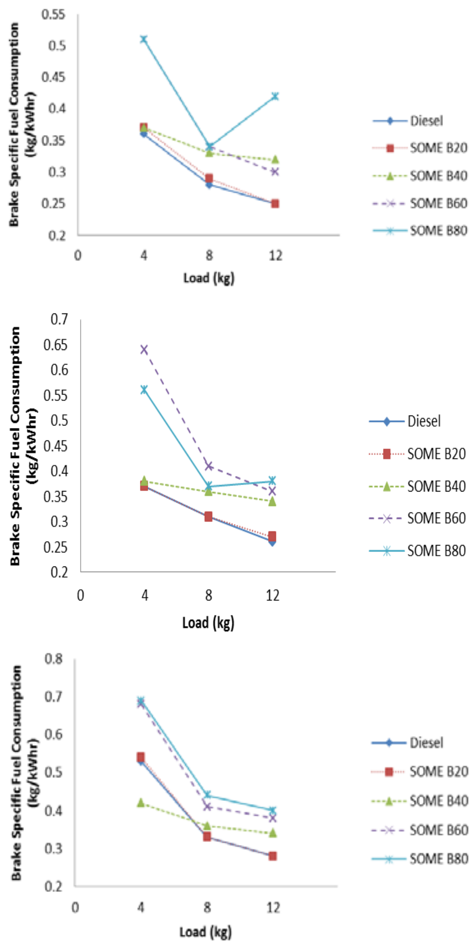


Fig. 3. Brake Specific Fuel Consumption for various compression ratio

4.3 Brake Thermal Efficiency

From Fig.4 it can be observed that the Brake Thermal Efficiency (BTE) increases as the CR increases. This is due to the better combustion of biodiesel and also the higher lubricity of biodiesel. Also, the BTE increases as the load increases. This is because, there are lesser heat losses encountered at higher loads. The lower heating value for biodiesels can also be an additional factor for the increase in BTE.

At a compression ratio of 15, (Fig.4(c)) the least value of BTE is observed at a load of 4kgs, while using a B80 blend and the maximum value is observed at a load of 12kgs, while using a B20 blend. At a compression ratio of 16, (Fig 4(b)) the BTE improves from 14.31% at a load of 4kgs (B60 blend) to 32.35% at a load of 12kgs (B20 blend). The maximum BTE of 34.33% is obtained while using a B20 blend of spirulina at a compression ratio of 17.5 and a load of 12 kgs, which is 0.25% higher than the BTE value obtained for standard diesel, under the same conditions.

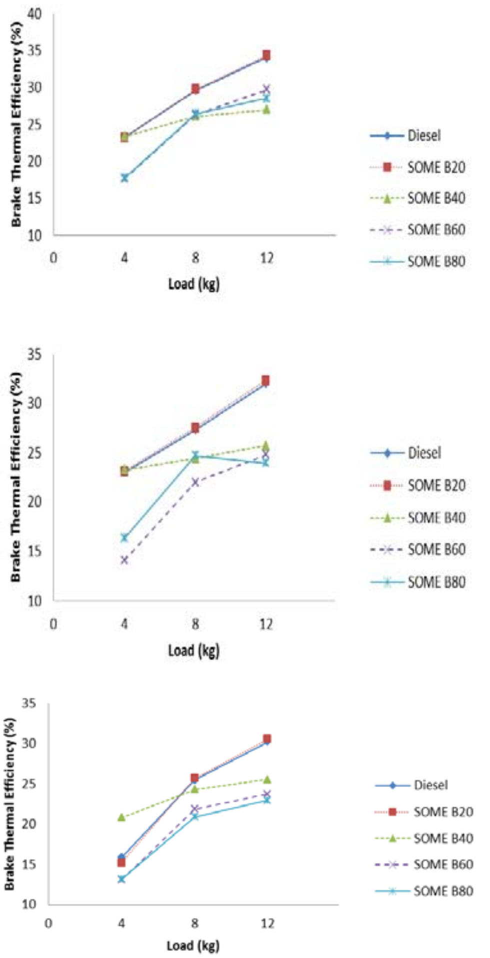


Fig. 4. Brake Thermal Efficiency for various compression ratio

4.4 Mechanical Efficiency

From Fig.5 it can be interpreted that the Mechanical Efficiency of the engine increases with the simultaneous increase in the engine load and also due to the increase in thec ompression ratio. This is because of lower heat loss and higher reaction in fuel rich zone at higher loads and CR for biofuels.

At a compression ratio of 15, (Fig.5(c)) the highest value of mechanical efficiency for biodiesel (B80 blend at 12kg load) is 65.99%, whereas, the highest value of mechanical efficiency for diesel is only 62.45%. Likewise, at a compression ratio of 16, (Fig.5(b)) the highest value of mechanical efficiency for biodiesel (B80 blend at 12kg load) is 70.53%, whereas, the highest value of mechanical efficiency for diesel is only 63.84%. Finally, the maximum value of Mechanical Efficiency (Fig.5(a)) .ie. 70.6% is witnessed at the compression ratio of 17.5, while using a B80 blend of spirulina biodiesel at a load of 12kgs, which is 4.91% greater than the value witnessed for diesel. (under the same conditions).

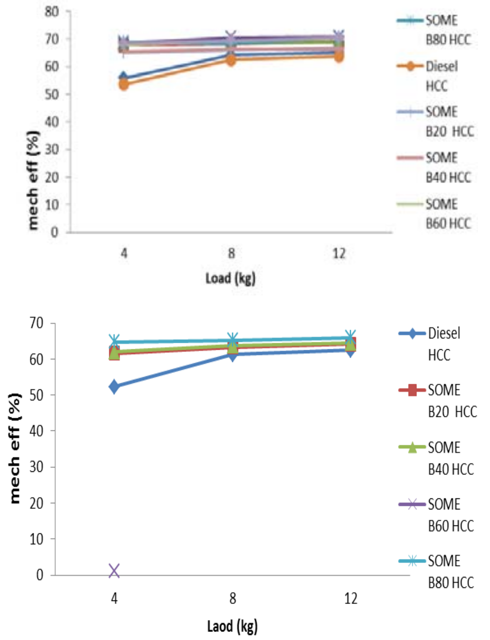


Fig. 5. Mechanical Efficiency for various compression ratio

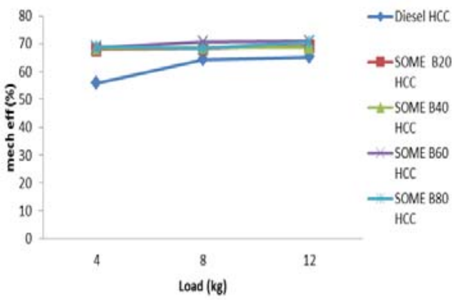
4.5 Heat Release Rate

Figure 6 represents the variation of Heat Release Rate (HRR) with the Crank angle variation. It is noticed that the HRR is decreases at the start and then gradually increases. Initially, the decrease of the HRR is due to air entrainment combined with the lower air to fuel ratio. The net heat release rate is low for spirulina biodiesel when compared with standard diesel; this is attributed to its higher viscosity, resulting in a poor spray of the fuel by the injector.

From the figure shown below, it's evident that the HRR decreases as the blend percentage of the biodiesel increases. The minimum value of heat release rate is observed for the B80 blend of spirulina biodiesel at compression ratio of 17.5.

4.6 Cylinder Pressure

Figure7 represents the variation of the cylinder pressure with the variation of crank angle. It is clear that the cylinder pressure decreases at the start and then gradually increases. The cylinder pressure value is lesser for biodiesel, when compared with standard diesel; this is because of the higher viscosity and low volatility of biodiesel. It is clear that as the blend percentage increases, the cylinder pressure decreases. The least value of cylinder pressure is observed while using B80 blend spirulina biodiesel at a compression ratio of 16.



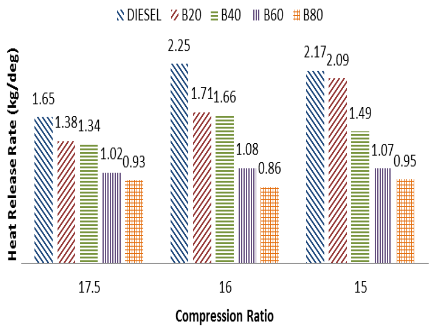


Fig. 6. Heat release rate for various samples at different compression ratio

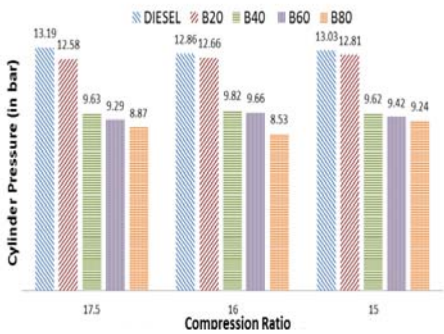


Fig. 7. Cylinder pressure for various samples at different compression ratio

4.7 Hydrocarbon Emission

Figure 8 depicts the variation of Hydrocarbon (HC) emission with load at a CR of 17.5. For B40 blend, the HC emission increases with the increase in load. This is due to longer ignition delay, which causes higher accumulation of fuel. For the other blends, it decreases with the increase in load. This is because, biodiesel has 10-11% more Oxygen which helps combustion. At the other two compression ratios of 16 and 15, the HC emissions decrease with the increase in load; for all the blends. The least value of HC emission is found while using a B60 blend of spirulina biodiesel at a CR of 17.5.

4.8 Carbon dioxide Emission

Figure 9 portrays the variation of Carbon dioxide (CO_2) emission with load at a CR of 17.5. The CO_2 emissions increase with the increase in load. This indicates better combustion of the fuel. The minimum value for CO_2 emission is viewed while using B20 blend of spirulina biodiesel at a CR of 17.5. The accrual of CO2 in the atmosphere leads to several environmental problems like ozone depletion and global warming. The CO2 emission from the combustion of bio fuels can be riveted by the plants and the carbon dioxide level and is kept constant in the atmosphere.

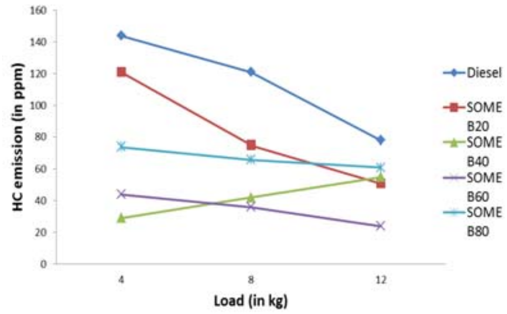


Fig. 8. Hydrocarbon emission for various samples at different loads

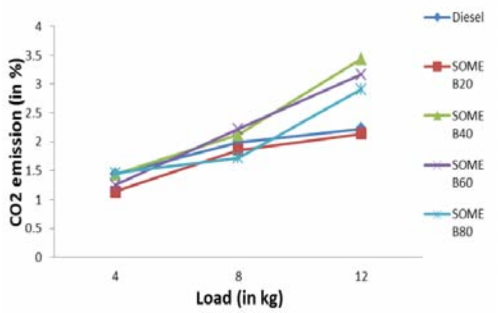


Fig. 9. Carbon dioxide emission for various samples at different loads

4.9 Carbon monoxide Emission

Figure10 depicts the variation of CO emission with the variation in load, at a compression ratio of 17.5. The CO emission decreases with the increase in load. The proportion of CO decreases due to rising temperature in the combustion chamber, physical and chemical properties of the fuel and air-fuel ratio. For B80 blend, the CO emission first increases and then sharply decreases. It indicates good primary combustion of the fuel. The minimum value for CO emission is viewed while using B80 blend of spirulina biodiesel at a CR of 17.5.

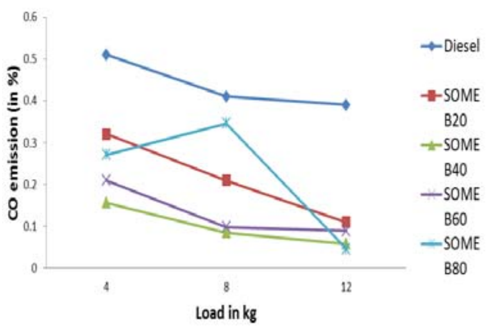


Fig. 10. Carbon Monoxide emission for various samples at different loads

4.10 Nitrogen Oxide Emission

Figure 11 shows that the variations of Nitrogen oxides (NOx) emission with load for different blends. It is well known that the vegetable based fuel contains a small amount of nitrogen. This contributes towards NOx production. The diminution of NOx is the main aim of the engine researchers. The NOx emission values decrease with the increase in compression ratio. The reason for NOx emission is due to the higher peak temperature and higher combustion temperature. The minimum value of NOx emission is seen while using B80 blend of spirulina biodiesel at a CR of 17.5.

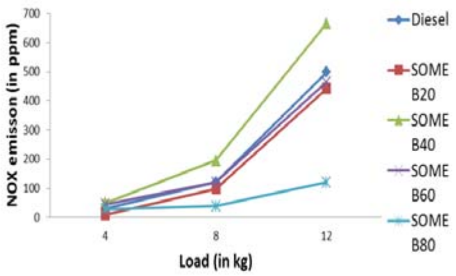


Fig 11. Nitrous oxides emission for various samples at different loads

5. CONCLUSION

In this study, the effect of compression ratio on the diesel engine parameters while working with Spirulina as the fuel was evaluated. Experimental values taken for the three different compression ratios (15, 16, and 17.5) set by the manufacturer, has depicted that the increase in compression ratio improves the performance of the engine in terms of BSFC and BTE. The maximum performance is delivered by the engine while using a B20 blend of spirulina biodiesel at a compression ratio of 17.5, at which the BSFC improves by 15% and BTE improves by 10%. With respect to emission parameters, increase in compression ratio leads to increase in emission of HC, whereas, CO emission reduces. For all compression ratios, the emissions of HC, NO_x and CO are lower with spirulina biodiesel versus that of standard.

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