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Evaluation of CI Engine Performance Using Compression Ratio for Palm Oil Biodiesel

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The experiment explores vegetable oils as potential future fuels for internal combustion engines, particularly compression ignition engines designed for diesel. However, these oils have distinct properties from diesel, requiring modifications for direct use. Integration approaches include adjusting oil properties or adapting engines. Commonly, transesterification aligns oil properties, but using biodiesel often affects engine performance. In this study palm oil biodiesel as a diesel

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substitute, evaluating engine performance and emissions. In a short-term test, engine performance and emission traits by employing biodiesel compression ratio of 12:1, 14:1 and 18:1 with diesel at full load. Findings indicated that 14:1 and 18:1 exhibited 1.01 % and 1.02 % higher brake power than pure diesel. Volumetric efficiency percentages were 82.33 for 14:1, 82.36 for 18:1, and 82.30 for 12:1. Notably, 14:1 and 18:1 showed 5.44% and 10.90 % increased brake thermal efficiency compared to diesel. Interestingly, 14:1 and 18:1 displayed 2.35 % and 2.61 % higher mechanical efficiency than diesel. The exhaust gas temperature was notably decreased in 12:1 to 18:1 compression ratio. Nitric oxide concentrations were 65.07 ppm for 12:1, 124.44 ppm for 14:1, and 126.48 ppm for 18:1. Carbon dioxide levels increased by 9.79 % for 14:1 and 62.47 % for 18:1 relative to diesel. Carbon monoxide concentrations were 0.07 % for 14:1 and 0.05% for 18:1, in contrast to diesel's 0.12%.

Keywords: Palm oil; bio diesel; performance; emission; compression ratio; transesterification; CI (Compression ignition) engine.

1. INTRODUCTION

“The demand for petroleum products has expanded because of the world's rising industrialization and motorization in recent years. The world's population uses more petroleum than any other single energy source, including natural gas, coal, nuclear energy, and renewable energy sources. Petroleum fuels account for almost 90% of the world's energy usage. Petroleum-based fuels come from finite stocks and are only expected to be used for a few more decades” [1]. However, it is anticipated that these fossil fuels may run out soon due to their non-renewable nature. The transportation and electricity generation industries are the biggest consumers of energy. Around the world, the diesel engine plays a crucial role in both industries” [2].

“The development of alternative fuels like biodiesels has been accelerated by rising fossil fuel prices, depleting fossil fuel supplies, and environmental concerns. Additionally, the ecosystem has been contaminated by the burning of these fuels. The relevance of alternative energy sources has increased due to the depletion of fossil fuels and their detrimental effects on the environment. The finest alternative fuel, considered both technically and environmentally acceptable, and widely accessible, is biodiesel. Biodiesel is the methyl or ethyl ester of a fatty acid made from fresh or spent vegetable oil and animal fats. Like how rapeseed oil methyl ester (RME) is used in Europe, palm oil bio-diesel ester is commonly used in India as a synonym for biodiesel due to its unique properties” [3]. Straight vegetable oil used as fuel results in a number of issues, including the coking of injector nozzles, piston ring sticking, dilution of the crankcase oil, contamination of the lubricating oil, and more. "Using clean and renewable fuels may be the key to meeting pollution regulations without materially altering engine efficiency and fuel economy. Without modifying the engine, compression ignition (CI) diesel engines have been used with both pure biodiesel fuel (oxygenated fuel derived from esters) and biodiesel/diesel fuel blends. Biodiesel fuel is produced from renewable resources, such as vegetables or animal fat, and is less polluting from engine exhaust than diesel fuel. Groundnut shells are also used as biofuel” [4]. “Blends of biodiesel, which are both domestic and renewable resources, are said to offer nearly equivalent engine performance and fuel economy to conventional fuels, but at a significant reduction in emissions. Regarding exhaust emission, the use of biodiesel results in lower emissions of unburnt hydrocarbons; carbon monoxide, smoke and particulate matter with some increase in emissions of NO_x” [2].

2. MATERIALS AND METHODS

The efficiency of a compression ignition engine was examined using biodiesel compression ratios. The experiment was carried out at the Department of Farm Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh.

2.1 Experimental Set Up and Performance Measurement

One engine testing rig with a power measurement device, many exhaust gas temperature sensors installed, and a single digital exhaust gas analyzer would make up the setup. The platform had the engine attached. To allow the engine to be fixed with nails or studs, holes were made in the foundation using a hand drill. To reduce noise and vibration, a wooden block should initially be placed between the engine and the platform. The engine will be properly positioned and fastened with nails or studs all around to minimize vibration. The engine was attached to an above-ground water supply tank for cooling.

The system included a single-cylinder, four-stroke engine coupled to a loading dynamometer using an eddy current that was water-cooled. It offered the tools required to measure load, temperatures, airflow, fuel flow, crank-angle, fuel flow, and combustion pressure. These signals are interfaced to the computer via a fast data acquisition device. The process of taking samples of signals that correspond to real physical conditions—for example, data signals from sensors in an experimental setup—and translating those samples into digital numerical values is known as data collection. An associated computer source can subsequently change these digital numeric values based on the inputs or in accordance with manufacturer-programmed instructions. Analog waves are usually converted into digital values for processing by data acquisition systems (DAS). All the parts, including sensors that provide temperature, flow, performance, combustion parameters, etc., are centrally connected by DAS products. The maximum rate of pressure rise, rate of heat emission, peak pressure occurrence, and average pressure and crank angle values were all recorded and stored as HTML files by the DAS. Technical Teaching (D) Equipment's Pvt. Ltd. is the developer of this data collecting program.

Fig. 1. Experimental set up

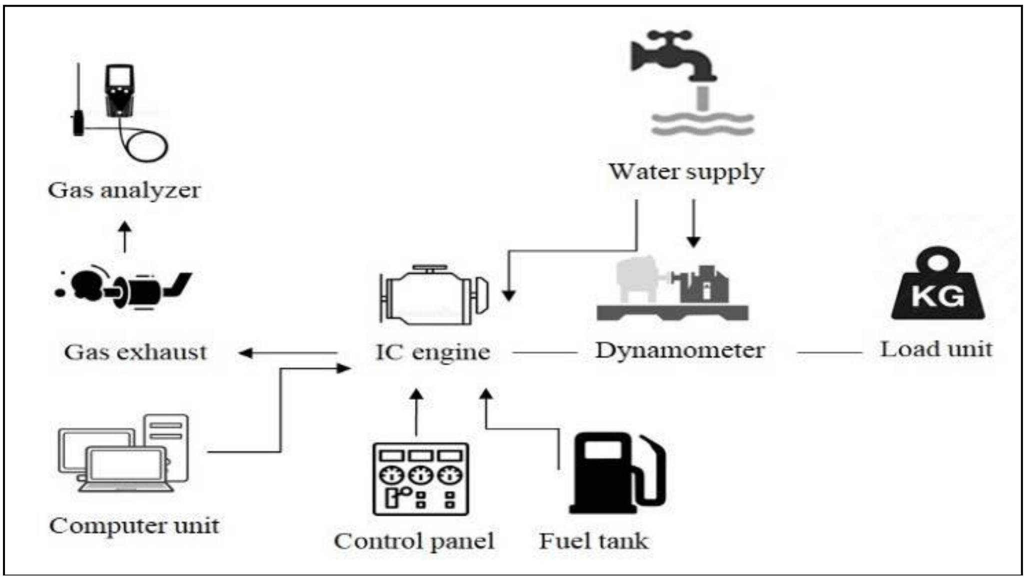

Fig. 2. Layout of experimental set up

"The engine was carefully hand-cranked and started while a certain amount of water was running through its cooling system. Without any load, the engine was allowed to warm up and reach its operating temperature, which would be monitored with the help of temperature sensors mounted at the water jacket outlet. As the operating temperature was achieved, the engine was loaded with full load. "Diesel fuel was used to assess engine performance and emissions in comparison to mixtures of methyl and ethyl esters of Jatropha oil," the study states" [5]. However, the warm-up period would be provided once the load had reached operating temperature and all the heaters designated for it were shining brightly. Then, using the designated instruments, such as the performance measuring unit and exhaust gas analyzer, the observations for the dependent performance and emission parameters were recorded. The increasing awareness of the depletion of fossil fuel resources and the environmental benefits of biodiesel fuel has made it more attractive in recent times".

2.2 Engine Performance Parameters

2.2.1 Volumetric efficiency (%)

The proportion of the weight of air that the engine sucked in during the suction stroke to the weight of air that, under ideal conditions, the piston displacement volume would have filled with air at room temperature and atmospheric pressure.

2.2.2 Specific fuel consumption (kg/kW-h)

The amount of fuel consumed per kW hour in an engine is known as specific fuel consumption, or SFC.

Specific fuel consumption(kg/kWh)=(Total Fuel Consumption(kh/h))/(Power output(kW))

2.2.3 Brake power (kW)

The measured values of current and voltage created by the generator attached to the engine were used to determine the power developed by the engine using the diesel fuel and the compression ratios of the fuels under test.

$$\mathrm{Bp} = \frac{\mathrm{Voltage} \times \mathrm{current}}{1000}$$

2.2.4 Brake thermal efficiency (%):

Brake thermal efficiency (%)=(Brake power (kw))/(Power value of fuel (kw))×100

2.2.5 Indicated power (kW)

$$\text{Indicated power (ip)} = \frac{\mathrm{PLAn}}{60 \times 10^{12}} \times \frac{x}{2}$$

Where,

P = Mean effective pressure (Pa)
L = Length of stroke (mm)
A = Cross sectional area of piston (mm^2)
n = Engine speed (rev/min)
x = Number of cylinders

2.2.6 Mechanical efficiency (%)

Mechanical efficiency (%)= (Brake power (kW))/ (Indicated power(kW))×100

2.2.7 Indicated mean effective pressure (IMEP)

$$\mathrm{IMEP} = \left(\begin{matrix}\text{Avg pressure during} \\ \text{power stroke (Pa)}\end{matrix}\right) - \left(\begin{matrix}\text{Avg pressure during} \\ \text{other stroke (Pa)}\end{matrix}\right)$$

2.2.8 Brake mean effective pressure (BMEP)

$$\mathrm{BMEP\ (Pa)} = \frac{\mathrm{bp} \times 60 \times 10^{12}}{\mathrm{L} \times \mathrm{A} \times \mathrm{n} \times \frac{x}{2}}$$

Where,

bp = Brake power (kW)
L = Length of stroke (mm)
A= Cross sectional area of piston (mm^2)
n = Engine speed (rev/min)
x = Number of cylinders

2.3 Exhaust Gas Analyser and Emission Measurement

Exhaust gas analyzer (PRIMA FEM-55), which measures the percentage or parts per million (ppm) of exhaust gas concentration in addition to the temperature in degrees Celsius. They are microprocessor-based and have the ability to save real-time data that may be printed or copied to a computer disc for long-term archiving. Several biodiesel compression ratios and all of the selected load situations were used throughout the experiments. The device's electrochemical sensor senses the gas concentrations surrounding it and converts them into an electrical signal, which is then detected by the instrument, amplified, adjusted, and displayed on the LCD as a percentage. The exhaust gas temperature was measured with a thermocouple.

2.3.1 Engine emission parameters

Standards for engine emissions the temperature and component of the exhaust gas were analyzed using an exhaust gas analyzer. which measured CO2 and CO in percentage terms. The NO and exhaust gas temperatures were recorded in degrees Celsius and parts per million, respectively.

3. RESULTS AND DISCUSSION

3.1 Performance of CI Engine Using Biodiesel Compression Ratio

3.1.1 Effect of various compression ratios on volumetric efficiency of CI engine

Impact of different compression ratios on the CI engine's volumetric efficiency: Fig. 3 shows that the volumetric efficiency was found to rise progressively as the percentage of biodiesel in the compression ratio rose. These findings closely aligned with the results reported by Gaadhe and Mehta [2].

3.1.2 Effect of various compression ratios on specific fuel consumption of CI engine

The impact of different fuel compression ratios on a given fuel's consumption is seen in Fig. 4. With an increase in the percentage of biodiesel compression ratio, it was found that specific fuel consumption was falling in comparison to diesel fuel.

"The specific fuel consumption of biodiesel is higher than that of diesel fuel due to the lower calorific values of Jatropha biodiesel." Diesel engines require more fuel to produce the same amount of power when using biodiesel and its diesel fuel blends [6].

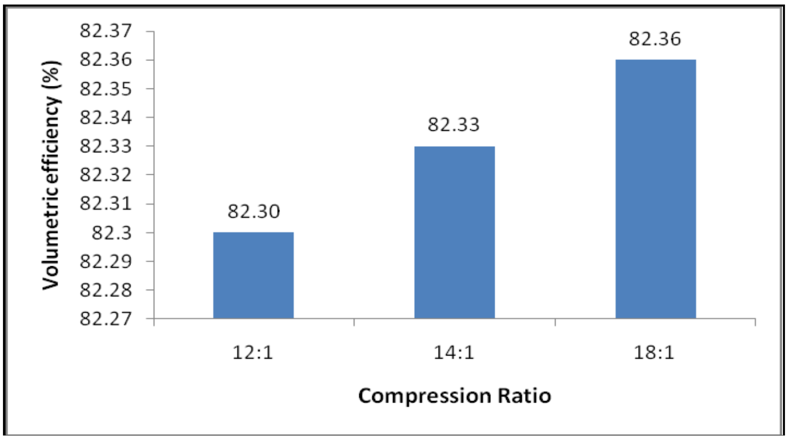

Fig. 3. Effect of different compression ratio on volumetric efficiency

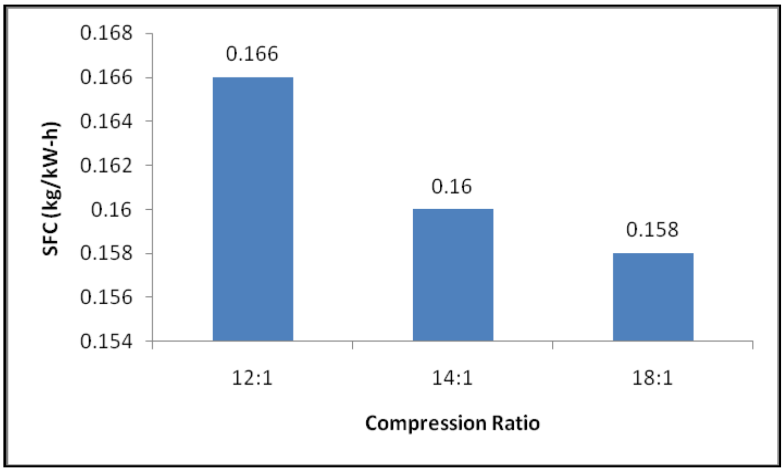

Fig. 4. Effect of different compression ratio on specific fuel consumption

3.1.3 Effect of various compression ratio on brake power of CI engine

The effects of different biodiesel compression ratios on brake power are shown in Fig. 5. “Braking performance was discovered to be more than that of pure diesel fuel as the percentage of biodiesel in the compression ratios rise. This may be because, compared to pure diesel (B0), biodiesel blends have weaker spray characteristics, inappropriate fuel-air mixing, and incomplete combustion due to their higher density [7].

3.1.4 Effect of various compression ratios on brake thermal efficiency of CI engine

Compared to compression ratios 12:1, brake thermal efficiency for biodiesel compression ratio 14:1 and 18:1 is somewhat higher in Fig. 6. "Biodiesel compression ratio braking thermal efficiency enhanced as compared to diesel fuel due to biodiesel's poor combustion properties—lower calorific value, higher density, higher viscosity, and reduced volatility” [8].

3.1.5 Effect of various compression ratios on indicated power of CI engine

Fig. 7 shows that the power was found to be higher than that of pure diesel fuel as the percentage of biodiesel increases. This might be as a result of the fuel's reduced spray characteristics, inappropriate fuel-air mixing, and incomplete combustion brought on by the biodiesel compression ratios higher density than pure diesel [7].

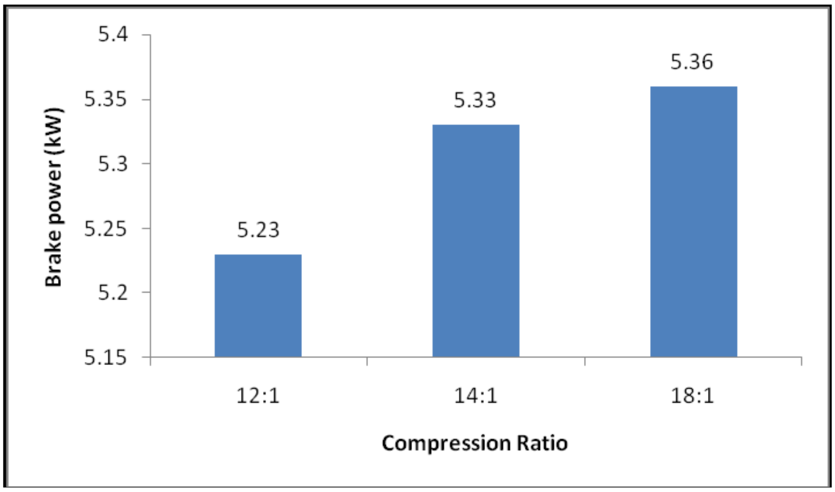

Fig. 5. Effect of different compression ratio on brake power

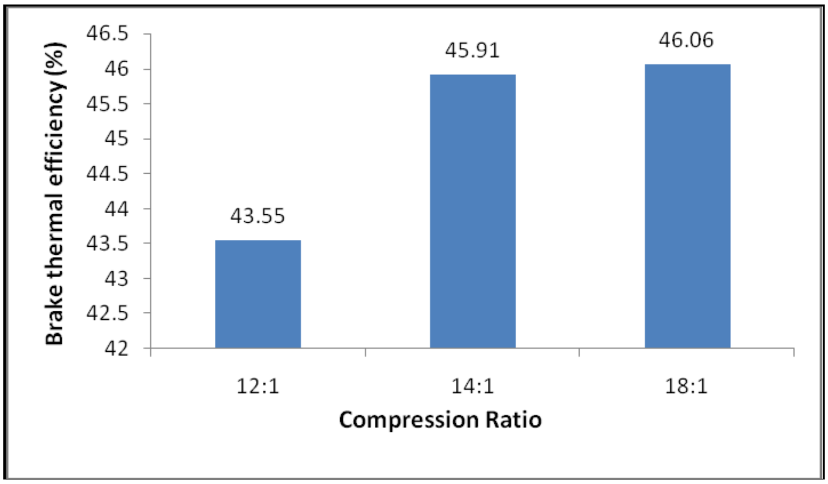

Fig. 6. Effect of different compression ratio on brake thermal efficiency

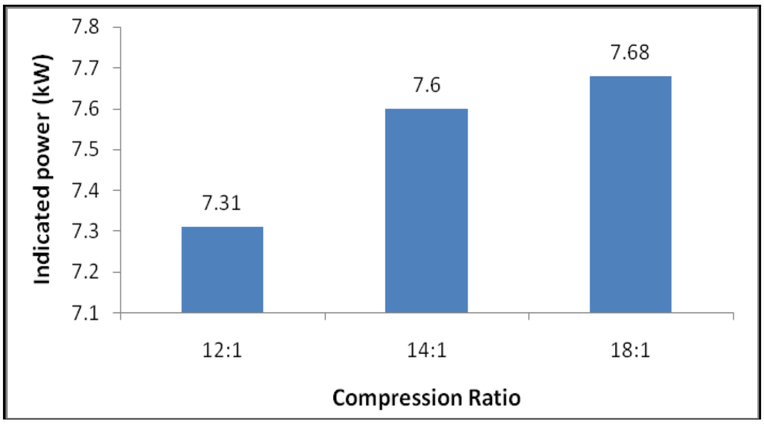

Fig. 7. Effect of different compression ratio on indicated power

3.1.6 Effect of various compression ratios on mechanical efficiency of CI engine

Mechanical efficiency was seen to be growing steadily as the percentage of biodiesel in the compression ratios rise, as shown in Fig. 8. The increase in mechanical efficiency was caused by the lubricating effect brought on by biodiesel's higher glycerol content than diesel fuel.

3.1.7 Effect of various compression ratios on indicated mean effective pressure (IMEP) of CI engine

Due to biodiesel's lower volatility than pure diesel, suggested mean effective pressure constantly rise as the percentage of biodiesel in compression ratios grew [9].

3.1.8 Effect of various compression ratios on brake mean effective pressure (BMEP) of CI engine

Diesel fuel's brake mean effective pressure (BMEP) is lower than biodiesel compression ratios because of its greater combustion characteristics and higher volatility (Fig. 10). [9].

3.2 Emission Characteristics of CI Engine Using Biodiesel Compression Ratio

3.2.1 Effect of various compression ratios on carbon dioxide (CO_2) emission of CI engine

Fig. 11 shows that carbon dioxide (CO_2) output gradually increases as the amount of biodiesel in the compression ratio increases. How well fuel is burned in a diesel engine's combustion chamber is shown by CO_2 emissions. Since the biodiesel compression ratio efficiently than diesel due to higher oxygen content in biodiesel [10].

3.2.2 Effect of different compression ratios on carbon monoxide (CO) emission of CI engine

Because there is more oxygen available for full oxidation in biodiesel than in diesel, lower carbon monoxide emissions from biodiesel compression ratios may result from this. The carbon monoxide generated during the biodiesel compression ratio combustion process may have been lessened by absorbing the additional oxygen molecule present and converting it into CO2 [11].

3.2.3 Effect of various compression ratios on nitric oxide (NO) emission of CI engine

Fig. 13 shows how different fuel compression ratios affect the amount of nitric oxide (NO) released. It was shown that when the percentage of biodiesel increased in the compression ratio, the amount of nitric oxide (NO) emissions increased relative to diesel fuel. Higher combustion temperatures and the presence of fuel oxygen in the mix combustion resulted in higher NO emissions, especially at medium engine speeds (about 1500 rpm) [11].

3.2.4 Effect of various compression ratios on exhaust gas temperature of CI engine

Fig. 14 makes it clear that when the proportion of biodiesel in compression ratios rose, the temperature of the exhaust gas dropped relative to diesel fuel. Because to the poor combustion properties, a lower exhaust gas temperature was found for biodiesel compression ratios than for fossil diesel under the full engine load. This might be the result of burning less gasoline to meet the increased load requirement, which lowers the engine cylinder's internal temperature [12].

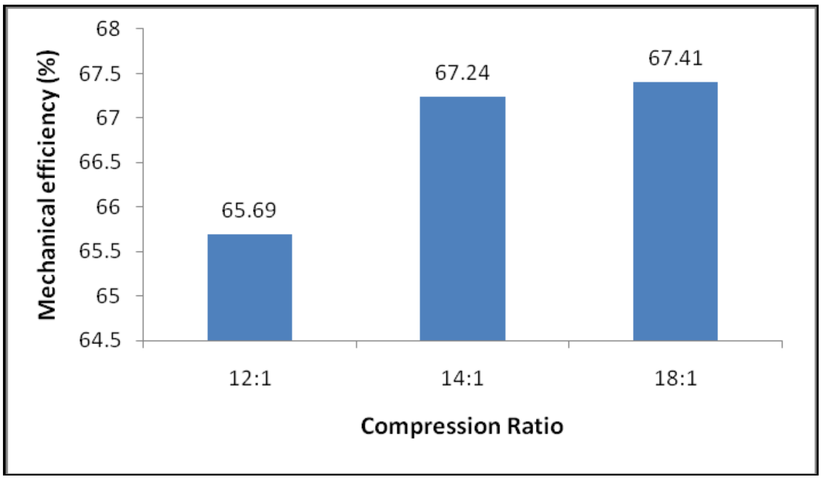

Fig. 8. Effect of different compression ratio on mechanical efficiency

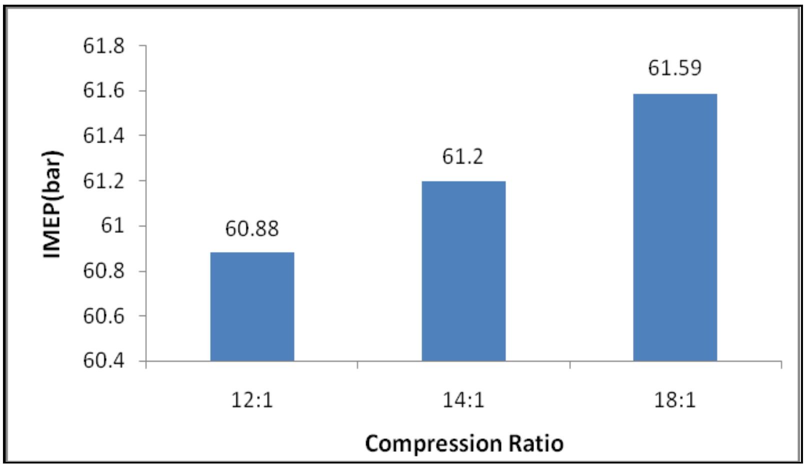

Fig. 9. Effect of different compression ratio on indicated mean effective pressure

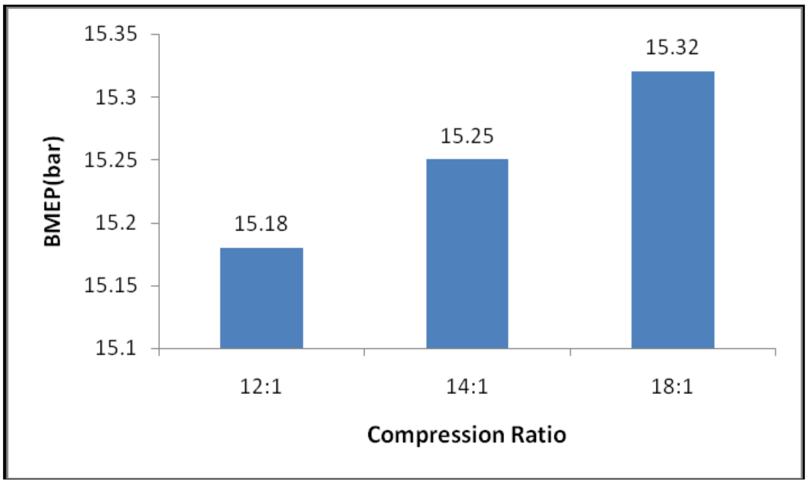

Fig. 10. Effect of different compression ratio on brake mean effective pressure

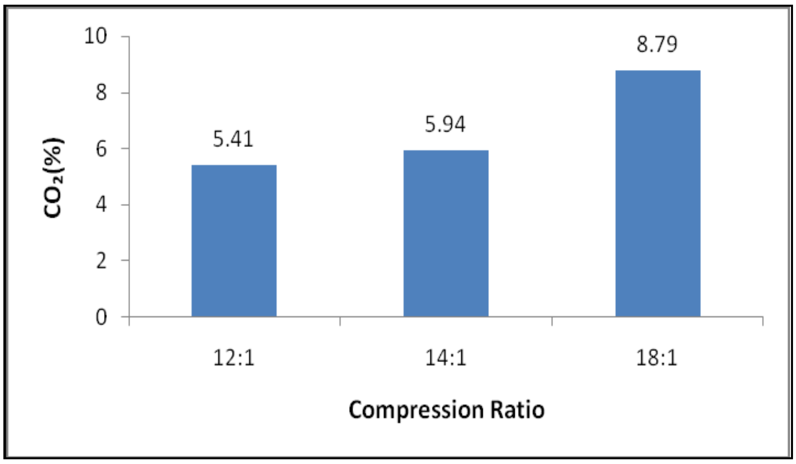

Fig. 11. Effect of different compression ratio on carbon dioxide

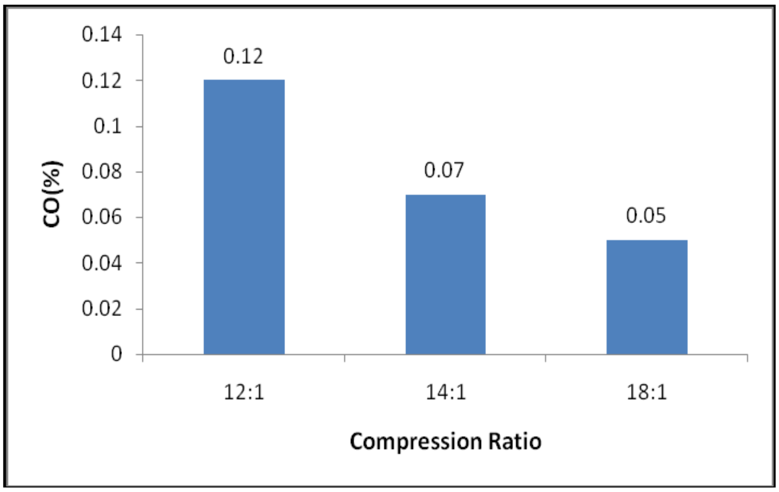

Fig. 12. Effect of different compression ratio on carbon monoxide

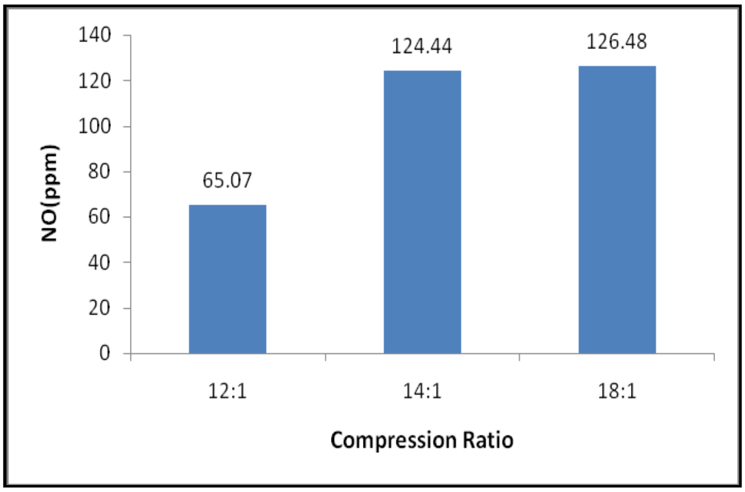

Fig. 13. Effect of different compression ratio on nitric oxide

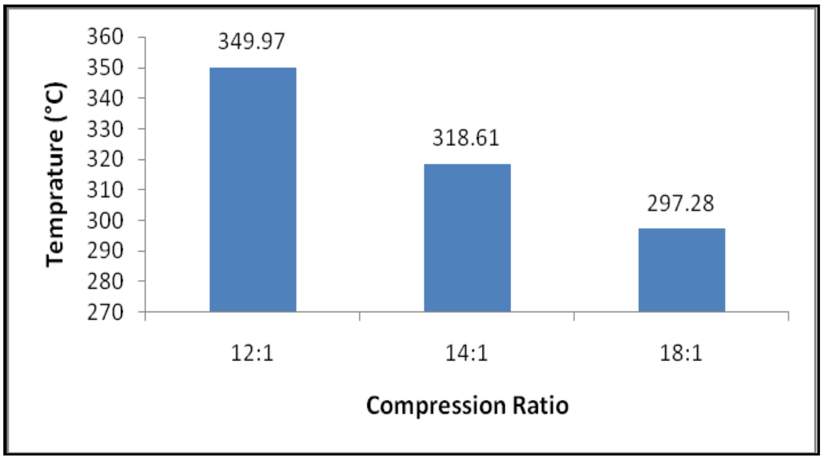

Fig. 14. Effect of different compression ratio on exhaust gas temperature

4. CONCLUSIONS

The Experiment produced important findings in a number of areas. Significantly, the compression ratio of 12:1 resulted in the lowest emissions of carbon dioxide (CO2) and nitric oxide (NO), with values of 5.41 percent and 65.07 parts per million, respectively. However, when using an 18:1 compression ratio at full load, the highest brake mean effective pressure of 15.32 bar was recorded. Impressive metrics were recorded by the experiment when there was an 18:1 compression ratio and full load operation: a minimum specific fuel consumption of 0.158 kg/kW-h, a maximum indicated power of 46.06 kW, a peak brake thermal efficiency of 63.52%, and a maximum brake power of 5.36 kW.

In terms of mechanical efficiency and energy consumption, the highest figures of 67.41 % and 80.52 MJ/h, respectively, were achieved under employing an 18:1 compression ratio, and operating at full load. Moreover, the experiment established that employing 12:1 compression ratio resulted in the lowest fuel cost, amounting to ₹71.34 per hour.

This study revealed that the brake thermal efficiency and brake specific fuel consumption of compression ratio were higher and lower, respectively, in comparison to diesel. This can be attributed to the compression ratio higher viscosity and lower calorific value. Additionally, the compression ratios demonstrated a lower presence of CO_2 and higher presence of CO emissions than diesel due to more efficient fuel combustion within the cylinder. As a conclusion, the findings highlight that a compression ratio of 18:1 for CO_2 and 12:1 for CO provides optimal values for both performance and emission characteristics.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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