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Research Article

IMPACT OF COMPRESSION RATIO ON PERFORMANCE AND EMISSIONS OF A CI ENGINE

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Abstract: The current study was prompted by the need to improve the CI engine's performance and emission characteristics. It is possible to improve performance by increasing the compression ratio below detonating values. Internal combustion engines' performance characteristics are influenced by the compression ratio. The effect of the compression ratio on the brake power, brake thermal efficiency, brake mean effective pressure, and specific fuel consumption of the variable compression ratio compression ignition engine is investigated experimentally and theoretically in this study. In this study, compression ratios of 12, 14, and 16, were utilized. The comparative results show that as the compression ratio increases, the specific fuel consumption decreases averagely by 5.25%, and improvement was observed in volumetric efficiency of 0.4 %, brake power of 2.30%, brake thermal efficiency of 8.15 %, indicated power of 2.46%, mechanical efficiency of 0.5 %, IMEP of 1.1% and BMEP of 1%. Similarly, as compression ratio increased value of CO and exhaust gas temperature was decreased. While CO_2 and NOx emissions increased.

Keywords: *Pollution, Performance, Compression ratio, Efficiency, CI engine and Emission*

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Introduction

Fossil fuels, namely petroleum-based liquid fuels, natural gas, and coal have been essential in meeting this energy demand during the last few decades. The main consumers of energy are the electricity generation and transportation sectors [1]. The diesel engine forms a vital part of both of these sectors throughout the world. Diesel fuel has versatile applications because of its high fuel efficiency compared to gasoline.

In the present day, several types of engines are available with various power capacities. For better performance of the IC engine, compression ratio plays an important role. Diesel engine available with compression ratios of 14:1 to 21:1, which affect the engine efficiency, and improving efficiency is a prime concern. Many researchers have worked on increasing engine efficiency in order to get more work done with the same amount of fuel burned. Generally, the energy produced by the engine is wasted in the form of heat, in addition to friction losses and losses to the exhaust [2]. Several other operating performance parameters that affect the thermal efficiency like, compression ratio (rc), lower calorific value of fuel (QLV), and ratio of specific heats (γ).

The aim of variable compression ratio (VCR) in IC engines is to improve engine performance, efficiency, and reduce emissions. The higher cylinder pressures and temperatures during the early combustion and the small residual gas fraction owing to the higher compression ratio give faster laminar flame speed. It causes the ignition delay period to be minimised [3].

At higher compression ratio and minimum load of engine shows shorter combustion time as well as time loss also reduce. As a result, it seems probable that at part load, higher compression ratios result in decreased fuel usage. The influence of various compression ratios on diesel engine performance and emission characteristics was investigated in this study, and the optimum compression ratio was identified. For diesel engines, the compression ratios studied ranged from 14 to 18. The purpose of this research is to find a better compression ratio for a variable compression ratio diesel engine operating at variable loads.

Materials and Methods

The performance of a compression ignition engine was studied at different compression ratios and loads. The experiment was conducted in the College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh.

Experimental set up

An engine testing rig with a power measurement device, temperature sensors placed at various locations, and a digital exhaust gas analyzer would make up the setup. On the platform, the engine was placed. Hand drill holes were made in the foundation so that the engine could be fastened with nails or studs. To attenuate the shocks and vibrations, wooden blocks would be placed between the engine and the platform initially. The engine would be properly aligned, and nails/studs would be firmly fastened around the engine to reduce vibration. For cooling, the engine was connected to an overhead water supply [4].

The setup consisted of a single cylinder, four stroke engine connected to a water-cooled eddy current type dynamometer for loading. It provided the necessary instruments for combustion pressure, crank-angle, airflow, fuel flow, water flow, temperatures, and load measurement [Fig-1]. A computer is interfaced with these signals via a high-speed data-collecting device. Data acquisition can be described as the process of sampling signals that measure real world physical conditions, like data signals sent from the sensors of an experimental setup; and then converting the resulting samples into digital numeric values that can be manipulated by an attached computing source based on the relations fed into it or as pre-programmed by the manufacturer [5]. Data acquisition systems (DAS) typically convert analogue waveforms into digital values for processing. DAS products centrally connect all the components together, such as sensors that indicate temperature, flow, performance, combustion parameters etc. The average data of the pressure and crank angle values, occurrence of the peak pressure, maximum rate of pressure rise, and heat release rate were recorded by the DAS and stored in the computer as HTML files. This data acquisition software is developed by Technical Teaching (D) Equipment's Pvt. Ltd.

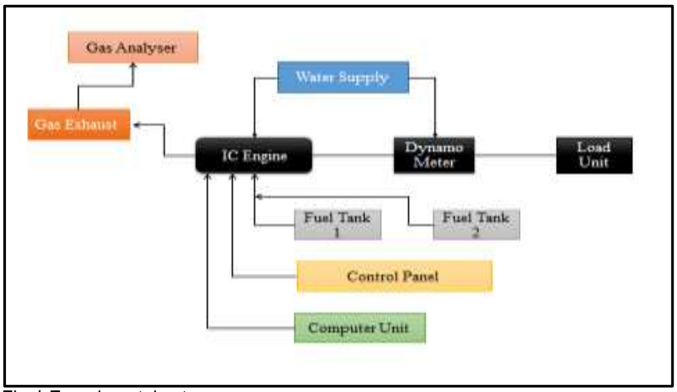

Fig-1 Experimental set up

Diesel fuel has been used in the engine performance and emission tests for three comparison ratios and the load demand. Through a valve attched to the tank, diesel fuel was permitted to flow down to the burette. The engine was started by turning on the starter motor and allowing a set amount of water to circulate through the cooling system. At no load, the engine was allowed to warm up and reach its operational temperature [6]. Temperature sensors placed on the water jacket will be used to monitor the operational temperature. The engine was equipped with its full load as soon as the working temperature was reached. The observations for the key parameters for performance and emissions were recorded by using the performance measurement unit and the exhaust gas analyser, respectively.

Measurement of fuel flow range

The Rate of Fuel flow is measured using two capacitive sensors with a glass burred and a Solenoid valve [Fig-2]. The solenoid valve is controlled from the digital output of the NI6210 card. When the solenoid stops the fuel inside the burette will start reducing as the fuel goes just below the top sensor timer is started. When the fuel decreases below the bottom sensor the timer stops. The fuel flow rate is calculated using the time required for the volume of fuel consumed between the top and the bottom sensor.

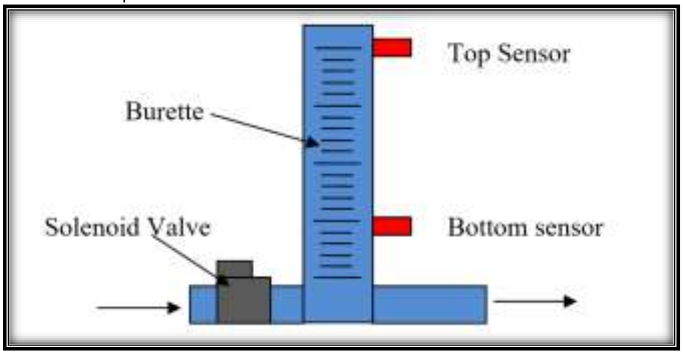

Fig-2 Arrangement for Fuel Flow Rate Measurement

Load measurement using eddy-current dynamometer

The engine is coupled to a water cooled Eddy current dynamometer for loading the Engine. The Loading End of the shaft of the Dynamometer is mounted with a load cell and Arm [Fig-3]. As the Dynamometer is loaded the load cell senses the load in Kg. Multiplying with the arm length the Load applied to the engine can be calculated.

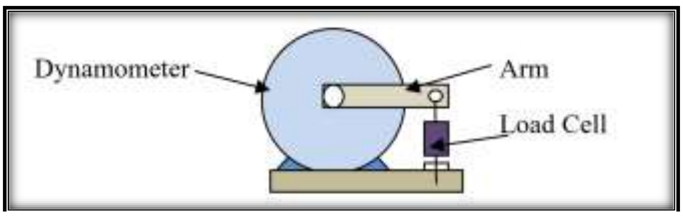

Fig-3 Eddy Current Dynamometer with Load Cell

Measurement of air flow rate

Air Flow Rate is measured by using Orifice with Differential Pressure Transmitter. The Orifice is fitted to a 2ft x 2ft metal enclosure. As the Engine starts it starts sucking the air from the chamber. The vacuum created in the chamber will start sucking the air through the Orifice. The Differential pressure built due to the suction of air inside the chamber is measured and Air flow rate is calculated based on the CD and Diameter of the orifice.

Measurement of water flow rate

The water Flow rate is measured using a Flow sensor which has Flow formers at the inlet of the cylinder generate a controlled and constant swirl that causes the rotor to float in the flow stream of the metered fluid. This free rotation is almost without friction and proportionate to the fluid throughput. The rotation interrupts an infrared signal that provides a direct pulse output. The infrared beam is generated by a diode and detected by a phototransistor on integrated electronics. Based on the frequency flow rate is calculated.

Measurement of temperature

Temperature at four different places like Inlet water temperature, Outlet water temperature, Room temperature, Exhaust temperature are measured using K-Type Thermocouple.

Measurement of engine speed

The Engine Speed is measured using Encoder fitted to measure the angle position of the Piston inside the Cylinder. The Encoder pulse frequency is measured and RPM of the engine is calculated.

Measurement of cylinder pressure

Quadrature Encoder is fitted to the Shaft of the Engine. The Encoder gives 360 pulse per revolution in A and also in B. Z pulse is matched to the TDC of the Engine. M/s Kistler Instrument or equivalent make Combustion Pressure sensor is used to measure the pressure inside the cylinder. The system start taking the Pressure reading when the TDC is detected. The readings are taken for every 0.250 of rotation of the engine upto 7200 (*i.e.* around 2880 readings for 2 rotation of the engine).

Engine performance parameters

Volumetric efficiency (%)

It is the proportion of the weight of air that the engine actually introduces during the suction stroke to the weight of air that would have been introduced if air had been poured into the piston displacement volume at room temperature and atmospheric pressure.

Specific fuel consumption (kg/kW-h)

Specific fuel consumption designated as SFC is the quantity of fuel consumed per kW h in an engine [7].

Specific fuel consumption = Total fuel consumption / Power output

SFC = TFC/P

Where,

SFC - Specific fuel consumption (kg/kW-h)

TFC - Total fuel consumption (kg/h)

P - Power output (kW)

Brake power (kW)

Power developed by the engine using the diesel fuel and blend fuels under test was calculated from the observed values of current and voltage developed by the generator attached to the engine.

Bp - (V×I)/1000

Where,

V - Voltage (V) and

I - Current (A)

Brake thermal efficiency (%)

Brake thermal efficiency (%) = [(brake power (kW))/(power value of fuel (kW))] ×100

Indicated power (kW)

Indicated power (ip) = [PLAn/(60×10¹²)] × [x/2]

Where,
P - Mean effective pressure (Pa)
L - Length of stroke (mm)
A - Cross sectional area of piston (mm2)
n - Engine speed (rev/min)
x - Number of cylinder

Mechanical efficiency (%)

Mechanical efficiency (ηmech) = (bp/ip)×100

Where,
bp - Brake power (kW)
ip - Indicated power (kW)

Indicated mean effective pressure (IMEP)

IMEP = ((Avg.pressure during @power stroke (Pa)))- ((Avg.pressure during @other stroke (Pa)))

Brake mean effective pressure (BMEP)

BMEP (Pa) = (bp×60×10¹²) / ((L×A×n×(x/2))

Where,
bp - Brake power (kW)
L - Length of stroke (mm)
A - Cross sectional area of piston (mm2)
n - Engine speed (rev/min)
x - Number of cylinders

Exhaust gas analyser and Emission measurement

Exhaust gas analyser (PRIMA FEM-55), which measures the concentration of the exhaust gases in parts per million (ppm) or percentage and temperature in °C. They are microprocessor based and can store real time data with which can later be either printed or copied to a computer disk for long time storage. The measurements were made under all the selected load conditions and different biodiesel blends. The heart of the instrument is an electrochemical sensor, which converts the concentration of gas encountered around it into an electrical signal, which was sensed by the instrument, amplified, compensated, and displayed in terms of percentage on the LCD. Temperature of exhaust gas was measured by a thermocouple.

Engine emission parameters

The engine emission parameters Exhaust gas component and exhaust gas temperature were measured using exhaust gas analyzer. In which CO_2 and CO were measured in percentages. While NO and exhaust gas temperature was measured in ppm and °C respectively.

Results and Discussion

Performance of CI Engine Using Different Compression Ratios

Effect of different compression ratios on volumetric efficiency of CI engine

From [Fig-4] it is clear that, as compression ratio was increased volumetric efficiency was found to be increasing successively. The progressive trend was like [8]. Increase of 0.03 % and 0.33 % in volumetric efficiency for 14:1 and 16:1 compression ratio ware observed as compared to 12:1 respectively.

Effect of different compression ratios on specific fuel consumption of CI engine

As compression ratio is increased from 12:1 to 16:1, values of SFC were found to be decreasing continuously [Fig-5]. This may be due to improved combustion at higher compression ratios [9, 10]. A decrease of 1.17 % and 5.12 % in specific fuel consumption for 14:1 and 16:1 compression ratio was observed as compared to 12:1 respectively.

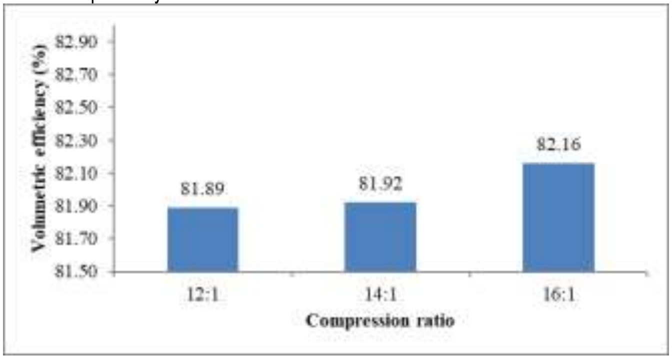

Fig-4 Effect of various compression ratios on volumetric efficiency

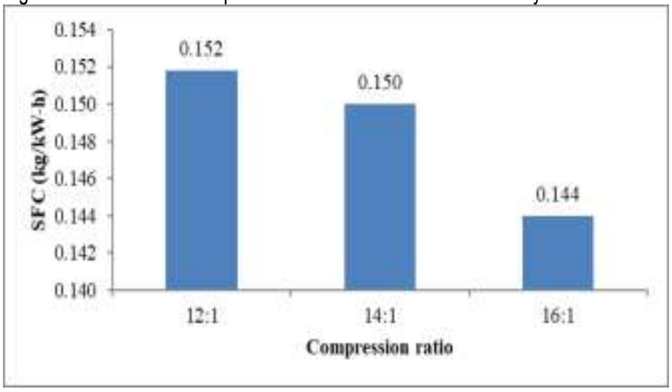

Fig-5 Effect of various compression ratios on specific fuel consumption

Effect of different compression ratios on brake power of CI engine

[Fig-6] reveals effects of variation in compression ratio from 12:1 to 16:1, values of brake power were increased continuously. This may be due to improved combustion at higher compression ratios [11]. Increase of 1.20 % and 2.77 % in brake power for compression ratios of 14:1 and 16:1 respectively, as compared to 12:1 compression ratio.

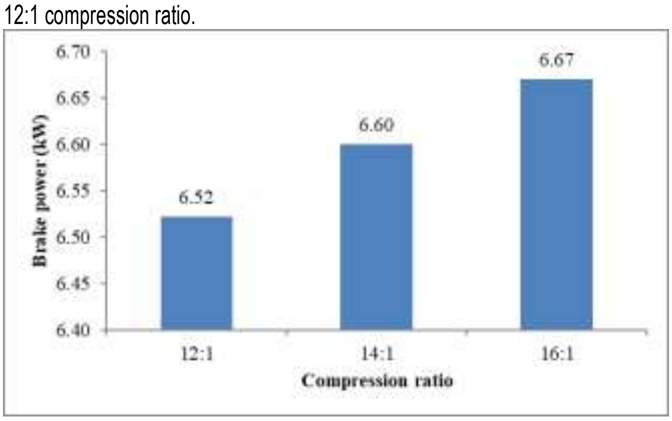

Fig-6 Effect of various compression ratios on brake power

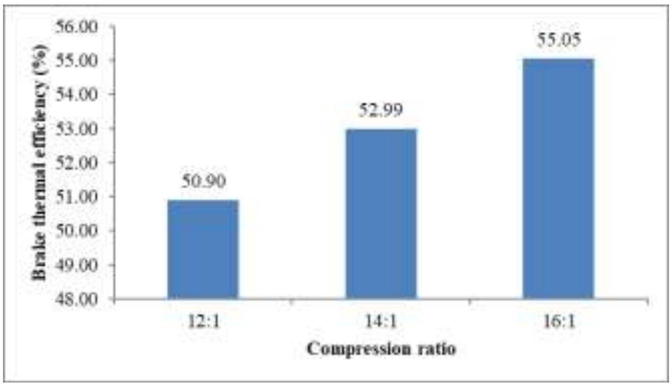

Fig-7 Effect of various compression ratios on brake thermal efficiency

Effect of different compression ratios on brake thermal efficiency of CI engine

As the compression ratio increases, the fuel mixture is sufficiently compressed thereby increasing thermal efficiency [Fig-7], so that less fuel is required to produce the same amount of energy [12]. Increase of 4.11 % and 8.16 % in brake thermal efficiency for 14:1 and 16:1 compression ratio was observed as compared to 12:1 respectively.

Effect of different compression ratios on indicated power of CI engine

As compression ratio is increased from 12:1 to 16:1, values of indicated power ware increased continuously [Fig-8]. This may be due to improved combustion at higher compression ratios. Increase of 1.14 % and 2.49 % in indicated power for 14:1 and 16:1 compression ratio was observed as compared to 12:1 respectively, which was relatable to [Abinay, A., Sandeep, M. and Pratap, N., 2018)].

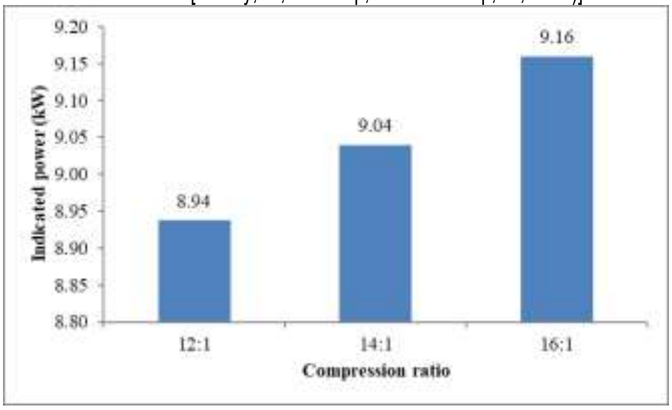

Fig-8 Effect of various compression ratios on indicated power

Effect of different compression ratios on mechanical efficiency of CI engine

The effect of various compression ratios on mechanical efficiency is presented in [Fig-9]. The compression ratio of 16:1 gave the highest mechanical efficiency of 72.12 % which was near to [13,14], whereas mechanical efficiency of 71.76 and 72.01 % were observed for 12:1 and 14:1 compression ratios, respectively.

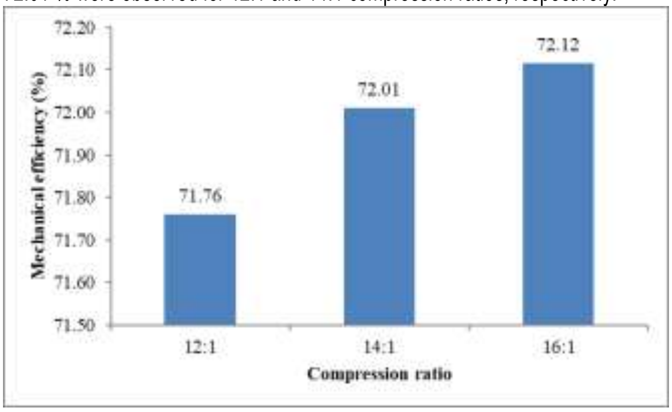

Fig-9 Effect of various compression ratios on mechanical efficiency

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

Different compression ratios effect on indicated mean effective pressure (IMEP) is graphically represented in [Fig-10]. Compression ratio of 12:1 gave minimum indicated mean effective pressure (IMEP) of 68.72 bar, whereas indicated mean effective pressure (IMEP) of 69.13 bar and 69.48 bar were observed for 14:1 and 16:1 compression ratio, respectively. As compression ratio increase indicated mean effective pressure (IMEP) also increases successively. Increase of 0.60 % and 1.11 % in indicated mean effective pressure (IMEP) for 14:1 and 16:1 compression ratio was observed as compared to 12:1 respectively.

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

As compression ratio is increased, values of brake mean effective pressure (BMEP) were increased successively [Fig-11]. Increase of 0.36 % in brake mean effective pressure (BMEP) for 14:1 compression ratio was observed as compared to 12:1. Similarly brake mean effective pressure (BMEP) for 16:1 compression ratio was observed to be 1.02 % more than 12:1.

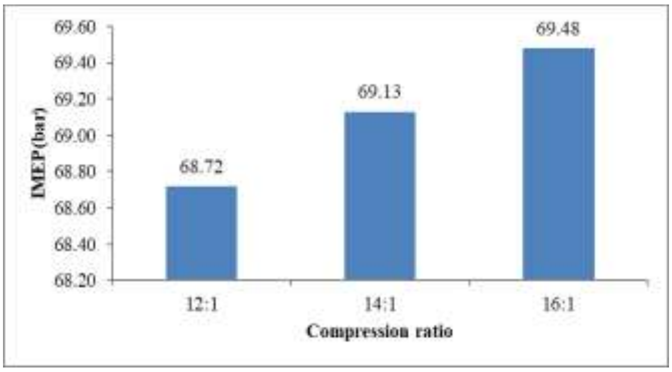

Fig-10 Effect of various compression ratios on IMEP

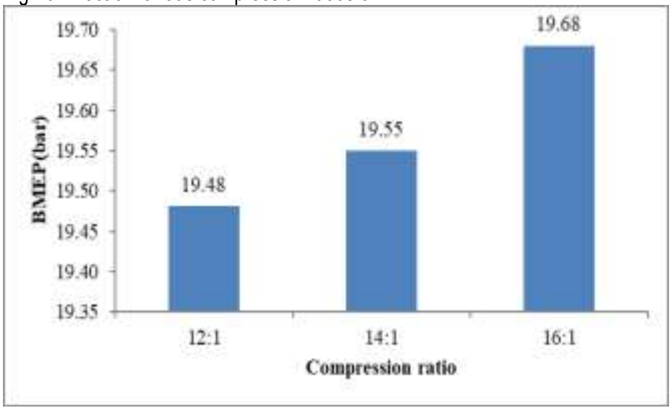

Fig-11 Effect of various compression ratios on BMEP

Emission Characteristics of CI Engine Using Various Compression Ratios

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

As compression ratios are increased, values of carbon dioxide (CO_2) emission were found to be increasing consecutively [Fig-12]. This may be due to improved combustion at higher compression ratios. Increase of 4.52 % in carbon dioxide (CO_2) emission for 14:1 compression ratio was observed as compared to 12:1. Carbon dioxide (CO_2) emission for 16:1 compression ratio was observed to be 44.80 % more than 12:1 which is reveal with [15].

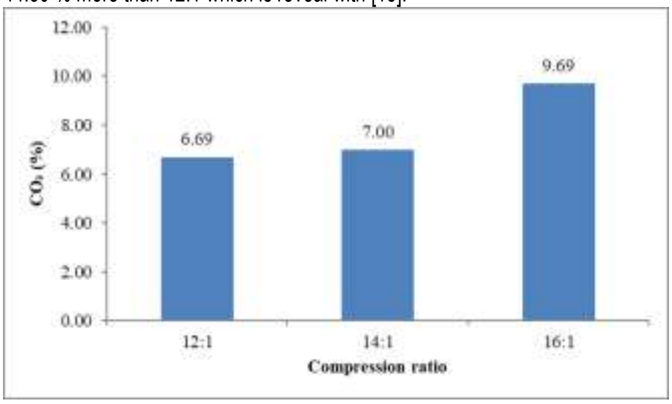

Fig-12 Effect of various compression ratios on CO_2 emission

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

Effect of various compression ratios on carbon monoxide (CO) emission is graphically represented in [Fig-13]. Compression ratio of 12:1 gave maximum carbon monoxide (CO) emission of 0.12 %, whereas carbon monoxide (CO) emission of 0.07 % and 0.05 % were observed for 14:1 and 16:1 compression ratio, respectively. Which is close enough to Nagraja study [16].

Decrease of 43.9 % in carbon monoxide (CO) emission for 14:1 compression ratio was observed as compared to 12:1. On other hand, carbon monoxide (CO) emission for 16:1 compression ratio was observed to be 59.9 % less than 12:1.

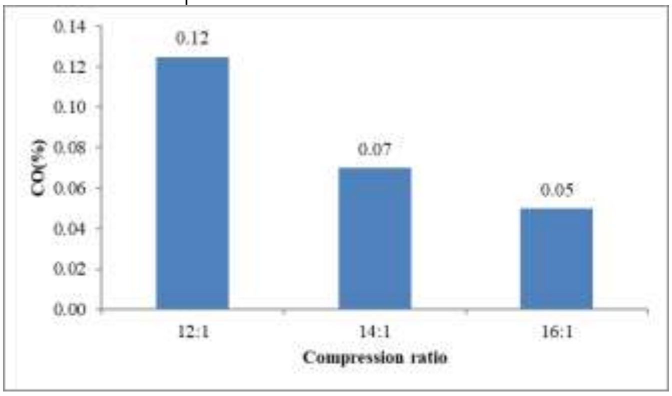

Fig-13 Effect of various compression ratios on CO emission

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

From [Fig-14] it is clear that compression ratio of 16:1 gave maximum nitric oxide (NO) emission of 158.0 ppm, whereas nitric oxide (NO) emission of 88.19 ppm and 142.48 ppm were observed for 12:1 and 14:1 compression ratio, respectively. An increase of 61.56 % in nitric oxide (NO) emission for 14:1 compression ratio was observed as compared to 12:1. Nitric oxide (NO) emission for 16:1 compression ratio was observed to be 79.16 % more than 12:1. The higher temperatures of combustion and the presence of fuel oxygen with the blend combustion caused higher NO emissions, especially at medium engine speed (around engine speed of 1500 rpm) [17].

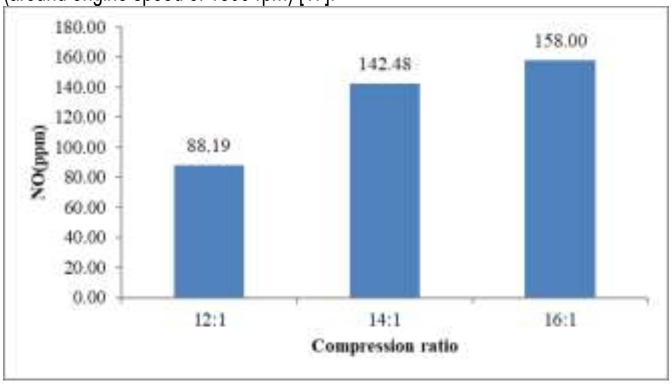

Fig-14 Effect of various compression ratios on CO emission

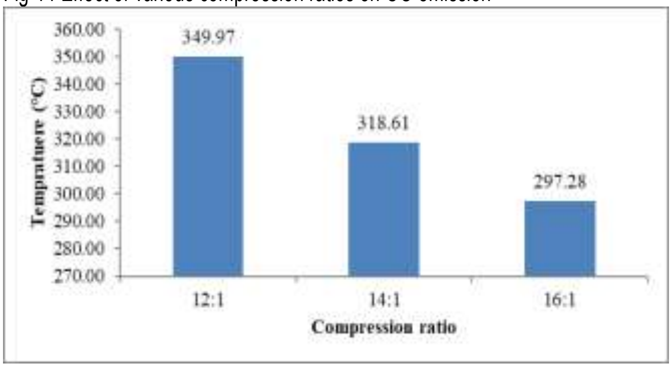

Fig-15 Effect of various compression ratios on exhaust gas temperature

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

As compression ratio is increased, exhaust gas temperature was found to decrease continuously due to improved combustion at higher compression ratios [Fig-15]. A decrease of 8.96 % in exhaust gas temperature for 14:1 compression ratio was observed as compared to 12:1. Similarly exhaust gas temperature for 16:1 compression ratio was observed to be 15.05 % less than 12:1. Because of the poor combustion characteristics, a higher exhaust gas temperature was recorded for biodiesel blends compared to fossil diesel for the entire engine load [18]. This may be due to higher temperature inside the engine cylinder as more fuel is burnt to meet the higher load demand [29, 20].

Summery

The CI engine used in experiment is a four stroke, single cylinder, water cooled diesel engine with an arrangement for varying the compression ratio and the setup is fully computerized with data acquisition system and analysis software for performance evaluation. The engine is mounted with an eddy current dynamometer for loading. The exhaust emissions of the engine were analyzed using a multi gas analyzer. Short-term tests were conducted on the test engine using diesel in different ratios. A statistical analysis was carried out using complete randomized design (Factorial) on SPSS statistical package for social sciences software.

Engine performance parameters studied were Power developed in kW, indicated power in kW, Specific fuel consumption in kg/kW-h, Brake thermal efficiency in percentage, Mechanical efficiency in percentage, Volumetric efficiency in percentage, indicated mean effective pressure (IMEP) in bar and Brake mean effective pressure (BMEP) in bar. Similarly, the emission parameters under the study were Oxides of nitrogen in ppm, Carbon dioxide in percentage, Carbon monoxide in percentage, and Exhaust gas temperature in °C.

Conclusion

In this study, engine performance and pollutant emissions from different compression ratios in types (12:1, 14:1 and 16:1) have been investigated experimentally. The test results indicated that as the compression ratio of the engine is increased, BSFC decreases (improves). Because of partial fuel combustion, fuel consumption is higher at lower compression ratios. It was also noticed that by the compression ratio of the engine is increased indicated brake power, brake power, indicated mean effective pressure and brake mean effective pressure was increased 2.49%, 2.77%, 1.11 % and 1.02% respectively as compared to lower compression ratio. In numbers, maximum volumetric efficiency 82.16%, maximum brake thermal efficiency 55.05% and maximum mechanical efficiency 72.12% were observed at 16:1 compression ratio. 12:1 compression ratio shows lower CO_2 and NOx emissions. While the value of CO and exhaust gas temperature was minimum at 16:1 compression ratio.

Finally, this study demonstrate that if we aim to get less emissions of CO_2 and NOx from CI engines we should use 12:1 compression ratio; however, if we interested in getting a higher output power with a bit low CO and exhaust gas temperature, we should use 16:1 compression ratio; to get a low moderate emissions as well as a high moderate volumetric efficiency, mechanical efficiency and power, we should use 14:1 compression ratio.

Application of research: This research has the potential to revolutionize agricultural practices by offering more efficient, environmentally friendly, and cost-effective solutions for powering agricultural machinery

Research Category: Agricultural Engineering

Abbreviations: CO_2-Carbon Dioxide, CO-Carbon Monoxide
NOx-Nitrogen Oxide, kW- Kilo watt
BMEP-Brake mean effective pressure, IMEP-Indicated mean effective pressure

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University: Tamil Nadu Agricultural University, Coimbatore, 641003, India
Research project name or number: M.Tech Thesis

Author Contributions: All authors equally contributed

Author statement: All authors read, reviewed, agreed and approved the final manuscript. Note-All authors agreed that- Written informed consent was obtained from all participants prior to publish / enrolment

Study area / Sample Collection: College of Agricultural Engineering & Technology, Junagadh

Cultivar / Variety / Breed name: Nil

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.
Ethical Committee Approval Number: Nil

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