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Performance of Internal Combustion Engine with Combine Effect of Recirculated Exhaust Gas and Variable Compression Ratio

Samkit Shah[1,2] and Nimit Patel[3]*

[1]*The Charutar Vidya Mandal (CVM) University, Anand - 388120, Gujarat, India*

[2]*Automobile Engineering Department, Parul Institute of Technology, Parul University, Vadodara – 391760, Gujarat, India*

[3]*A. D. Patel Institute of Technology, The Charutar Vidya Mandal (CVM) University, Anand - 388121, Gujarat, India; nimit.patel@cvmu.edu.in*

Abstract

NOx conformation in diesel machines depends on temperature and occurs when the combustion chamber temperature exceeds 2000 K, therefore peak combustion temperatures must be controlled to reduce NOx emigrations. For illustration, re-circulating exhaust gas decreases the attention of oxygen in the combustion chamber and results in a hotter input charge, lowering the honey temperature and laterally reducing NOx conformation. It is about compression rate odyssey of direct injection diesel machine the purpose of this study is to experimentally estimate the machine performance and emigrations of a variable contraction rate diesel machine with different situations of incompletely cold EGR in order to tune the exhaust gas temperatures. The current exploration was carried out on single cylinder DI diesel machine with Variable Contraction Rate (VCR) and Exhaust Gas Recirculation (EGR) tested at 1500 rpm with different loads. The effect of Contraction Rate (CR) and EGR for 161, 171 and 181 with E0 (0 EGR), E5 (5 EGR) and E10 (10 EGR) independently on boscage thermal effectiveness, combustion performance and exhaust gas emigrations has been studied and compared. Exhaust gas temperature was reduced with an increase in CR and EGR chance. Electrical Boscage Specific Energy Consumption (BSFC), maximum in- cylinder pressure and Net Heat Release Rate (NHRR) increased with increase of contraction rate and drop in EGR chance. Carbon Monoxide (CO) and Hydrocarbon (HC) emigrations dropped while NOx emigration increased with CR. At a contraction rate of 171, EGR has been determined to help drop NOx emigrations and boost performance characteristics. The advanced EGR rates were more efficient at reducing NOx, but power and boscage specific energy consumption were significantly impacted compared with low EGR rates (i.e., lower than 10), while hydrocarbon and carbon monoxide emigrations increased. As a result, it advocates operating low EGR rates (under 10) for the stylish NOx control and energy frugality.

Major Finding: *The study examines the combined effects of Compression Ratio (CR) and Exhaust Gas Recirculation (EGR) on diesel engine performance and emissions. Increasing CR from 16:1 to 18:1 improved Brake Thermal Efficiency (BTE) by 24.71% and reduced Brake Specific Fuel Consumption (BSFC) by 13.33%. Using EGR effectively lowered NOx emissions, reducing them by 6% at 10% EGR and 18:1 CR, but increased hydrocarbon (HC) and carbon monoxide (CO) emissions due to incomplete combustion. Exhaust gas temperature also decreased with higher CR and EGR. The study suggests keeping EGR rates below 10% to balance NOx control, fuel efficiency, and engine performance.*

Keywords: Brake Thermal Efficiency, Carbon Monoxide, Emission Levels, Hydrocarbon Emissions, Nitrogen Oxides, The Compression Ratio, The Process of Exhaust Gas Recirculation

**Author for correspondence*

1.0 Introduction

Additionally, CI engines use less gasoline than SI engines. However, it emits some dangerous pollutants, including Nitrogen Oxides (NOx) and Particulate Matter (PM). They are widely applicable in the transportation, artillery, and agricultural sectors because of their increased brake thermal efficiency and capacity to operate under high load situations. Finding ways to increase fuel efficiency and adhere to government-imposed emissions limitations is now more important than ever because to the sharp reduction in petroleum storage and stringent emissions rules. To maximize engine performance and satisfy the demands of strict emissions regulations, several test parameters, including injection time, Compression Ratio (CR), and injection pressure, are recalculated. The performance of a diesel-engine using a blend of diesel and biodiesel was assessed using a variable compression ratio at half load and full load[1-3]. Tests of several operational characteristics revealed that when CR increased, so did exhaust gas temperature, peak cylinder pressure, Brake Thermal Efficiency (BTE), and Heat Release Rate (HRR). However, compared to the blended version, plane diesel's mechanical efficiency and Brake Specific Fuel Consumption (BSFC) dropped as CR increased[4].

The combustion, performance features of a multi-cylinder CI engine with a Variable Compression Ratio (VCR) between 14 and 18 were examined by Stone *et al*. It has been seen that when the compression ratio increased, the ignition delay decreased. Early combustion timing with an increase in CR caused the ignition delay to decrease[5,6]. Debnath *et al*. conducted experiments on a variable compression ratio (VCR) engine test rig that ran on diesel and biogas and had three distinct CRs at partial, half, and full load conditions. When CR was adjusted from 16 to 18, it was exposed that the BTE increased by roughly 6%. At part load, there was a greater ignition delay and a lower CR. For blende fuel and plane diesel, EGT fell as the compression ratio increased[7]. The single cylinder, variable compression ratio, direct injection (CI) engine is the subject of the current study. To assess an engine's performance, combustion, and emissions characteristics, three distinct compression ratios-16, 17, and 18- as well as different Exhaust Gas Recirculation (EGR) percentages-5% and 10%- were examined.

Practically speaking, there are some restrictions on the maximum value of the compression ratio[26], although engine output and thermal efficiency often rise as the ratio increases. A too high compression ratio causes the cylinder pressure to rise significantly. Because the engine must be designed strong enough to withstand this high pressure, the benefit of higher efficiency is outweighed by the engine's increased structural weight. At high compression ratios, the combustion process occurs abnormally. A very immediate increase in pressure causes excessive noise and the quick depreciation of several engine components[34]. The relative efficiency benefit is minimal at high compression ratio levels. Furthermore, rather than discussing theoretical efficiency, we will be discussing real efficiency. Every potential loss must be considered. Potential losses include sensible heat loss, incomplete combustion, friction losses, and heat losses through water jackets[39]. High compression ratio values are associated with cooling losses and friction. A higher compression ratio shortens the delay time by lowering temperature and density, and as the compression ratio rises, air temperature rises as well[18,19].

Due to the compressed air's higher density, which causes molecules to come into closer contact and shortens the response time when fuel is injected, the minimum auto-ignition temperature simultaneously drops[23].

2.0 Methodology for Exhaust Gas Recirculation and Variable Compression Ratio

2.1 The Ratio of Variable Compression (VCR)

The fixed compression ratio engine strikes a balance between a variety of driving circumstances, including much city traffic, fast motoring, and interstate motoring at a steady pace. The engine's compression ratio, commonly known as the Variable Compression Ratio (VCR), is constantly changed to provide the optimum value under varied driving conditions[28].

2.2 A 30% Reduction in Fuel Consumption

In addition to offering remarkable performance, the variable compression ratio idea can cut a traditional natural aspirated engine's fuel consumption by up to 30%[28].

2.3 Decreased Heat Loads

The total amount of time that heat is released is shortened when the compression ratio is decreased because the first stage of combustion increases while the second stage decreases. Conversely, when the load is raised, the rate of heat release reduces[26,27].

Additional consequences of a reduced compression ratio include[2]:

The combustion chamber's temperature drops, and the charging efficiency rises. The exhaust temperature has slightly increased.

2.4 Starting Cold and Idling

Since of its higher compression ratio at low loads, the VCR engine performs well while cold starting and idling at low ambient temperatures and load difference[28-30].

2.5 Decreased Emissions

While the CO, HC, and NOx emissions will allow the VCR engine to comply with all pollution laws, the carbon-dioxide emissions are decreased proportionately to the fuel consumption[29,41].

2.6 Reasons for the Production of NOx

The fact that diesel engine combustion is extremely variable, and transient presents a significant challenge to comprehending the mechanism of formation and managing its emission[34]. Although NO and $N0_2$ are grouped together as NOx, these two pollutants differ in a few keyways. N02 is a reddish-brown gas with a strong smell, whereas NO is colorless and odorless. Although both gases are regarded as hazardous, $N0_2$ is five times more toxic than NO[35,36].

In an area with high temperatures, NO is created during the post-flame combustion process. Zeldovich proposed the most often recognized mechanism (Heywood 1988)[37]. The oxidation of nitrogen in atmospheric air is the main cause of NO production. Atomic oxygen, which is created when oxygen molecules dissociate at the high temperatures achieved during combustion, starts the chain reactions that lead to the creation of nitric oxide[38].

N_2+O

NO+N N+O_2 are the main processes that control the production of NO from molecular nitrogen.

NO+0 N+OH NO+H

N02INO ratios for burnt gases at normal flame temperatures should be extremely low, according to chemical equilibrium considerations. NO_2 can account for 10–30 % of the total exhaust emissions of nitrogen oxides in diesel engines, however investigational data indicates that this is true for SI engines. The following is a tenable explanation for NO_2's persistence[39]. Through reactions like

NO+H0_2—N0_2+0H,

NO generated in the flame zone can be quickly transformed into NO_2.

This NO_2 is subsequently converted to NO via **NO_2+O—NO+O_2**.

Unless the NO_2 generated in the flame is combined with a cooler fluid to extinguish it. This hypothesis aligns with the fact that diesels have the largest NO_2/NO ratio at high loads, when chiller regions that could quench the conversion back to NO are prevalent (Wood 1988). Both native temperatures and molecular oxygen absorption affect the local atomic oxygen concentration. NOx formation is nearly nonexistent at temperatures lower than 2000 K[40]. Therefore, any method that may lower the combustion chamber's instantaneous local temperature below 2000 K will be able to lessen the production of NOx.

2.7 NOx Reduction Using the EGR Technique

One effective method for lowering NOx production in the combustion chamber is EGR. CO_2, N_2, and water vapors make up most of the exhaust. A portion of this exhaust gas serves as a diluent to the combusting mixture when it is returned to the cylinder. Additionally, this lowers the combustion chamber's O_2 content. Since EGR has a significantly higher specific heat than fresh air, it raises the intake charge's heat capacity (specific heat), this reduces the temperature increase for equivalent heat release in the combustion chamber[41],

$$\%\mathbf{EGR} = \frac{\mathbf{Volume\ of\ EGR} * 100}{\mathbf{Total\ intake\ Charge\ of\ Cylinder}}$$

The EGR ratio can also be defined using the concentration of CO_2,

$$\text{EGR ratio} = \frac{\text{Co}_2\ \text{Intake} - \text{CO2 Ambient}}{\text{Co}_2\ \text{Exhaust} - \text{CO2 Ambient}}$$

Increasing ignition delay, increasing heat capacity, and diluting the intake charge with inert gases are the three most common theories for how EGR affects NOx reduction. The ignition delay hypothesis states that EGR has the same effect as delaying injection timing because it increases ignition delay. The heat capacity theory suggests that the non-reacting matter present during combustion has a higher heat capacity (specific heat) when inert exhaust gas is added to the intake. The peak combustion temperature is lowered because of the improved heat capacity[18,26]. The dilution theory states that the increase in inert gas concentrations in the mixture lowers the adiabatic flame temperature, which is what causes EGR's influence on NOx. EGR is challenging to be used at high loads because diffusion combustion deteriorates, which could lead to an unnecessarily high rise in smoke and particulate emissions.

Unburned hydrocarbons in the EGR may re-burn in the mixture under low loads, reducing the amount of unburned fuel in the exhaust and improving brake thermal efficiency. In addition, heated EGR would influence combustion and exhaust emissions by increasing the intake charge temperature[31-33]. There is a trade-off between lowering CO, NOx and raising soot along with unburned hydrocarbons when using EGR.

Numerous investigations have been carried out to investigate this. The use of a particle trap is advised since it has been shown that particulate emissions rise sharply above SO% EGR[21-25]. The structure of the flame is altered by the change in oxygen content, which also alters the combustion time. It is proposed that the primary factor affecting NO production is the decrease in flame temperature[42].

Higher fuel injection pressure, supercharging, and repeated injections are other techniques for lowering diesel engine particle emissions. Two self-regenerating systems are now receiving the most attention: a Continuous Regeneration Trap (CRT) that uses sulfur-free diesel fuel and fuel additive-supported regeneration that uses additives based on cerium or iron. EGR and its impacts on engine performance in terms of fuel efficiency, volumetric efficiency, power output, etc., have been the subject of extensive research over the past 20 years[43].

3.0 Materials and Methodology

In the exploration of engine performance under controlled conditions with different rate of Exhaust Gas Recirculation as E0, E5, E10 with Variable Compression Ratio of 16, 17 and 18, series of experiments were conducted, maintaining consistent parameters: A constant 1500 rpm, Fuel as diesel, and varying loads from 0% to 100% intervals. This systematic approach was designed to clarify the influence of various loads on EGR rate with VCR level, examining their performance parameters, combustion and Brake-Specific Emission (BSE) characteristics through the experimental analysis.

4.0 Experimental Set up

4.1 Engine Test Rig Setup

Single-cylinder, four-stroke, water-cooled, variable compression ratio direct injection diesel engines with exhaust gas recirculation were utilized for the research. Table 1 provides an engine's complete specifications. The engine ran on a variable compression ratio between 16:1 and 18:1. When the engine was operating at 0% load, the compression ratio modification was accomplished. The engine's tilting block cylinder design allowed for a change in the engine cylinder's clearance volume, which in turn led to a change in the CR.

The different engine loads were measured using the AG Series eddy current water-cooled dynamometer. A rotameter was employed to control the water flow rate to keep the engine and calorimeter at their ideal temperatures. Figure 1 displays the engine test setup's schematic line diagram. Figure 1(a) displays the test rig's line diagram in conjunction with the Data Acquisition System (DAS) that was utilized to obtain the engine parameters. To equip the water-cooled EGR, the intake manifold underwent the necessary modifications. Water-cooled EGR was designed to reduce the temperature of the in-cylinder and intake charge during combustion.

A mechanical system was used to regulate the EGR percentage. The included hand wheel sets the compression ratio at 16:1. Cranking is how the engine gets started. The

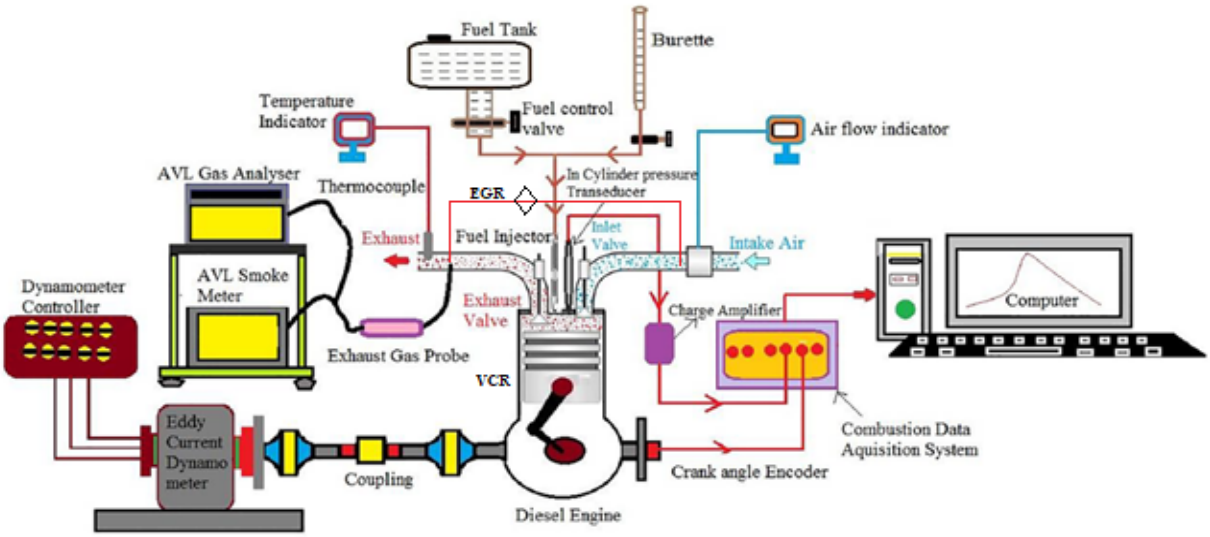


Figure 1. Schematic diagram of the test engine.

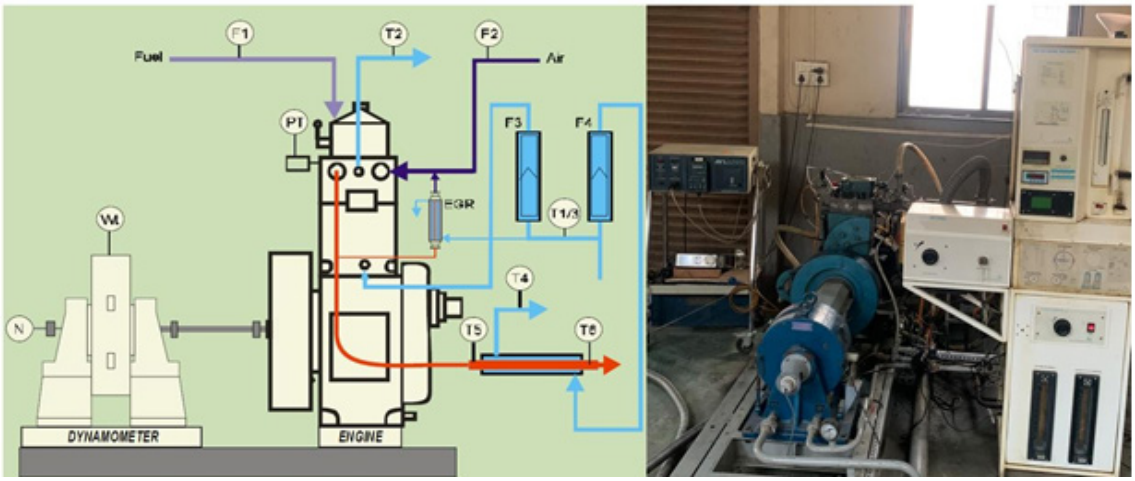


Figure 1. **(a)** Experimental set up.

Table 1. Engine specifications

Manufacturer: Kirloskar -TV1-Computerized CRDI VCR, 661 CC cubic capacity
Engine Type: Single cylinder, direct injection, water-cooled, diesel, 3.7 kW of engine power
1500 rpm (constant rpm) is the engine speed.
87.5 mm/110 mm cylinder bore/stroke, **12:1–18:1** compression ratio,
Chamber of combustion (default)Chamber for **Hemispherical Combustion**

engine is permitted to run at 1500 rpm and with no load. Under load of 2 kg circumstances, the fuel consumption time (10 cc) and monomeric deflection are recorded. The AVL automotive gas analyzer is used to record the emission parameters (CO, CO_2, and NOx). After that, the fuel consumption time is measured by progressively increasing the load using the eddy current dynamometer in increments of 4 kg to 12 kg.

For experiments, average operating procedures have been used. Diesel tests were performed at different loads, and the results served as baseline information for the uncertainty estimations. Next, 3 compression ratios (16:1, 17:1, and up to 18:1) were tested at different engine loads using diesel and 5% and 10% EGR.

After the engine stabilized, data was taken at each load. To ensure the reproducibility of the findings, the experiments were carried out on two different instances. Table 2 displays the uncertainties% of different metrics[8].

4.2 Uncertainty Analysis

Significant errors and uncertainties in experiments may occur from factors such as the selection, condition, calibration, and environment of the instruments used, as well as the observation, reading, and planning of the tests.

Verifying the accuracy of the experimental results requires performing uncertainty analysis. The error is the discrepancy between the outcome and the true value, which is known.

The easiest way to gauge the size of the known inaccuracy is to use uncertainty. R ± ΔR is a representation of the error limitations for the computed result and the measured variables or parameters.

Holman used the root-mean-square approach to calculate the error to establish precise error bounds for the computed result[17]. We will still combine the uncertainties in a quadrature if the calculation's result, R, depends on several measurements. If

$R = R(x_1, x_2, x_3, ..)$

And the uncertainty in the calculated value ***R*** due to the uncertainty in x_1 is,

$$u_{R_{x_1}} = R(x_1 + u_{x_1}, x_2, \dots) - R(x_1, x_2, \dots) \approx u_{x_1} \frac{\partial R}{\partial x_1}$$

Where, the approximation arises from taking only the first term in a Taylor Series expansion around ***x1***, reasonably accurate as long as ***ux1*** is small.

The sum of the contributions from all of the measurements will be the overall uncertainty in the calculated quantity.

Or, utilizing the previously mentioned estimate,

$$u_R = \sqrt{\left(u_{x_1} \frac{\partial R}{\partial x_1}\right)^2 + \left(u_{x_2} \frac{\partial R}{\partial x_2}\right)^2 + \left(u_{x_3} \frac{\partial R}{\partial x_3}\right)^2 + \dots}$$

Using the above equation, the uncertainty in the computed values such as BP, BTE and fuel flow measurements were estimated. The % uncertainties of parameters such as load, BTE, and BSFC were determined

Table 2. Equipment list including manufacturer, range, accuracy, and uncertainty

Equipment	Make	Range	Accuracy	Uncertainty (%)
Gas Analyzer	AVL	CO: 0–10% HC : 0–20,000 ppm NO_x: 0–5000 ppm	±0.01 ±1ppm ±1ppm	±0.5 ±5.0 ±10.0
Crank angle sensor	Kubler	0-360°	±1° CA	±0.2
Load cell	Sensortronics	0-50Kg	±0.1 kg	±0.1
Load Indicator	ABUS Technologies	0-100 kg	±0.2%	±0.2
RPM indicator with Speed sensor	Selectron process control	4-9999 rpm	±0.05%	±2.0
Pressure Transducer	PCB Piezotronics	5000 psi	±0.1 psi	±0.2
BP	-	-	-	±0.008
BTE	-	-	-	±2.38
BSFC	-	-	-	±0.005

by utilizing the percentage uncertainties of several instruments. Given in Table 3.

The observed data, including voltage, current, fuel duration, and speed were calculated using their respective uncertainties according to the Gaussian distribution equation[44].

The errors in the observed parameters, RPM (N) and load (Kg) found using the Gaussian technique, are ±2 RPM and ±0.05 torque respectively. Fuel consumption, the uncertainties are taken as ± 0.1 Kg/h (ΔFC)[44].

5.0 Results and Discussions

To examine the impact on engine performance, emissions, and combustion characteristics, the engine was run at 1500 rpm with a range of loads and three different compression ratios (like 16:1, 17:1, and 18:1) along with EGR E0 (without EGR), 5% EGR (E5), and 10% EGR (E10). The Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC), Exhaust Gas Temperature (EGT), volumetric efficiency, in-cylinder combustion pressure, Net Heat Release Rate (NHRR), CO, HC, NOx, and emissions were all evaluated and analyzed for the engine.

5.1 Assessment of Engine Performance

5.1.1 Heat Efficiency of Brakes (BTE)

BTE must be known to assess how effectively fuel is being used to power the engine. Because more power is generated at increasing engine loads, BTE grew gradually as loads climbed. As CR declined from 18:1 to 16:1, an engine's BTE decreased because of lower combustion pressure and temperature, which slowed combustion. In contrast, brake thermal efficiency increased with increasing CR because of improved combustion and a

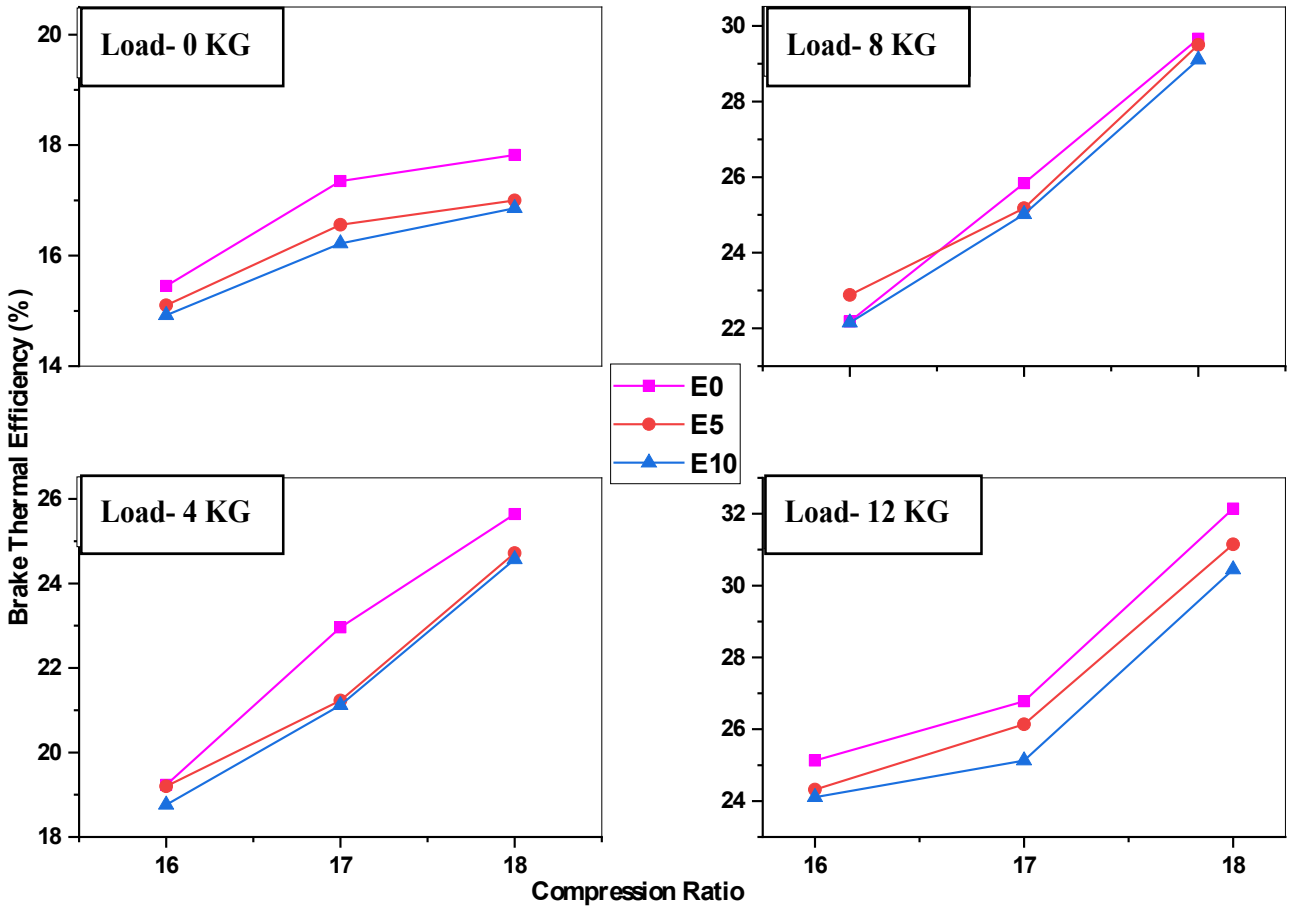


Figure 2. EGR %, compression ratio, and brake thermal efficiency at varied loads.

faster rate of fuel evaporation. When CR was raised from 16 to 18, the BTE increased by about 9% at half and full engine load. BTE was less than 3% at E10 than E0 at full load and at greater compression ratios. The observed decrease in BTE with EGR was brought on by the dilution of air-fuel mixture.

5.1.2 Efficiency of Volumetric

As the engine load and EGR percentage increased, it was discovered that the air intake to the cylinder significantly decreased, as seen in Figure 3, which resulted in a decrease in the gas's oxygen availability. Changes in the air temperature intake produce these variations in the volumetric efficiency at different EGR rates and loads[9]. The intake air mass flow rate decreases as engine load increases because the heat release rate rises along with the intake air temperatures.

5.1.3 Temperature of Exhaust Gases

It is evident from Figure 4 that EGT increased gradually as the load increased because more fuel is needed for combustion at the same engine rpm. Because of improved combustion and a shorter ignition delay, EGT was shown to decrease as CR increased. EGT significantly dropped as the EGR percentage rose. EGT decreases when EGR increases because the air-fuel combination is diluted with exhaust gas, which lowers the rate of heat release in the cylinder during combustion. When comparing E0 and E10 at maximum engine load, EGT dropped by over 9% at 18 CR.

5.2 Engine Emissions

5.2.1 NO_x emissions

High combustion temperatures cause NOx emissions

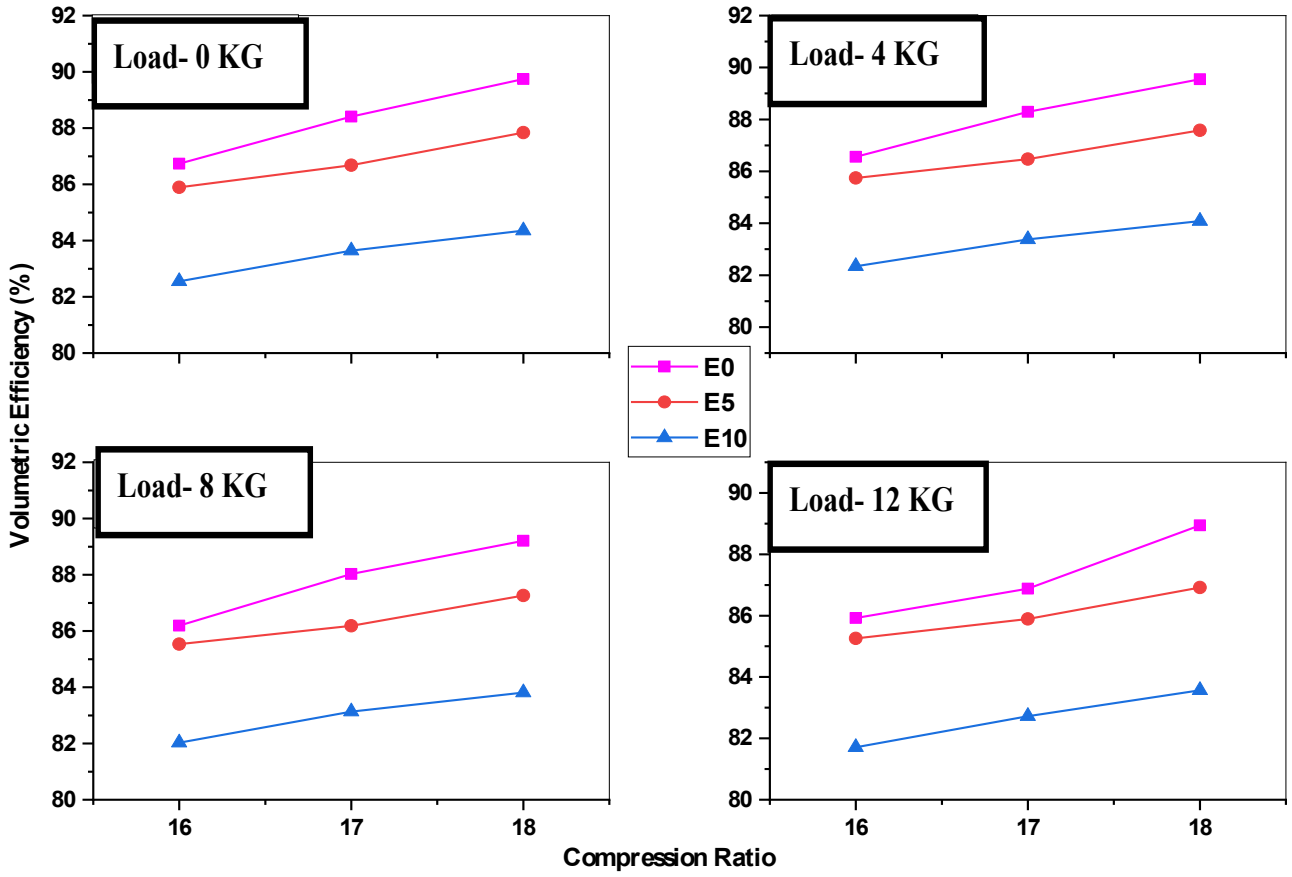


Figure 3. EGR %, compression ratios, and volumetric efficiency at different loads.

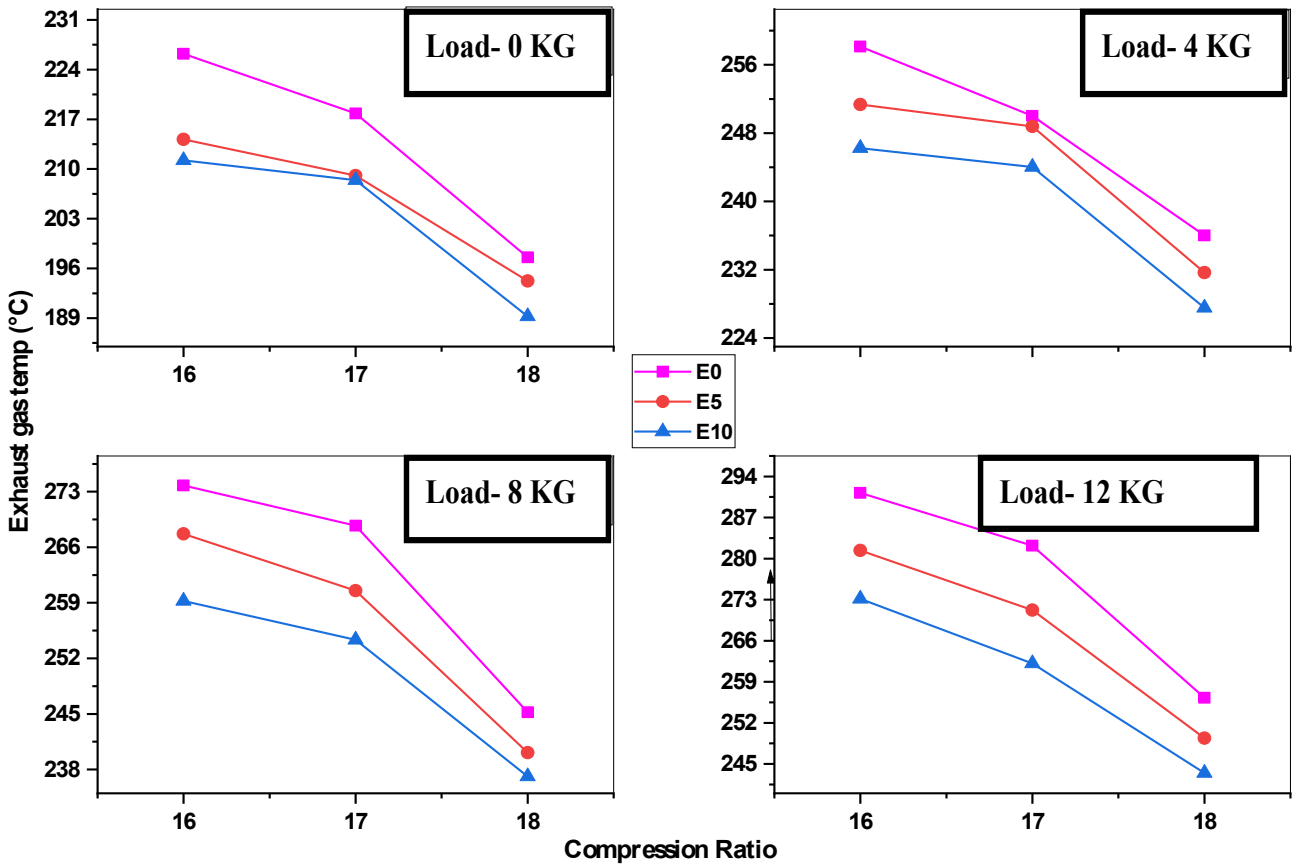


Figure 4. EGR %, compression ratio, and exhaust gas temperature at different loads.

, which are influenced by a number of engine factors like as the compression ratio, equivalency ratio, and piston bowl shape. Figure 5 shows that, across the whole range of engine loads, NOx emissions are declining as the EGR percentage rises.

Approximately of the oxygen in the fresh opening air charge gets mixed with recirculated gas, there is a decrease in O_2 availability, which is the reason for this trend[10,11]. Because of the flame's spatial broadening brought on by the decrease in oxygen, this lowers the local flame temperature[12]. Ultimately, the dissociation of H_2O and CO_2 and other endothermic chemical reactions resulted in a drop in the overall flame temperature during burning[13]. NOx emissions were 645 ppm at full engine load (18 E0), however they dropped by nearly 6% at 18 E10.

It was observed that when engine load and CR increased, NOx emissions increased gradually. NOx emissions at 18E10 were 287 ppm at part load and 637 ppm at full engine load.

As CR rises, NOx emissions rise because of a decrease in delay in ignition and an increase in peak pressure, which raises the temperature of combustion.

5.2.2 Emissions of Hydrocarbons

The HC emissions at different compression ratios and EGR percentages at different engine loads are displayed in Figure 6. It has been noted that as the compression ratio rises, the HC emissions gradually decline. This occurs as a result of the opening air temperature rising at the conclusion of the compression stroke, which raises the combustion temperature and lowers charge reduction, both of which improve combustion and lower HC emissions. It was observed that HC emissions rose as the EGR % increased and that load had little effect on the HC emissions.

The fuel quantity injected at each specific engine load remains constant, regardless of the presence of EGR. Recirculated exhaust gas limits the O_2 availability for combustion which leads to rise in HC emissions[14]. The highest recorded HC emissions at 16 E5 at partial engine load were 50 ppm.

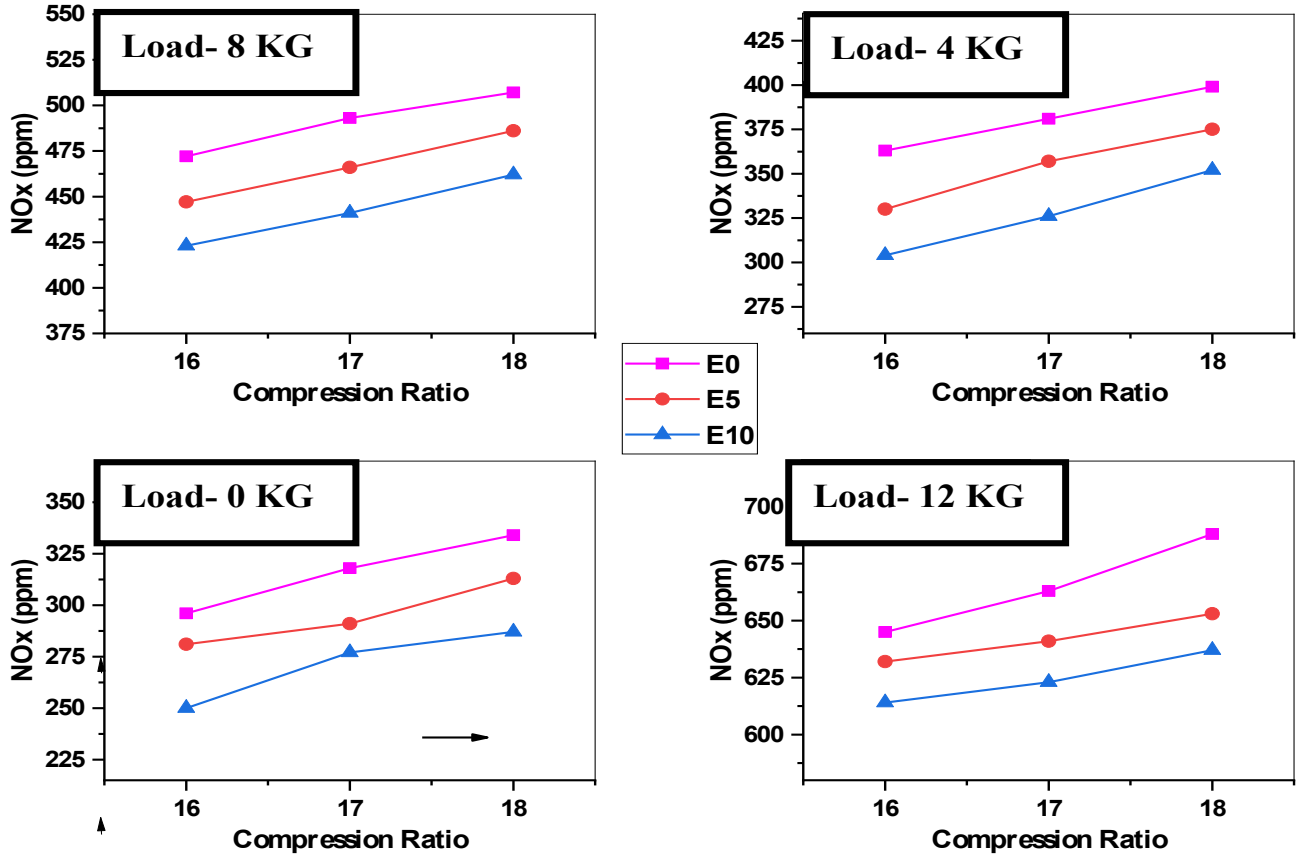
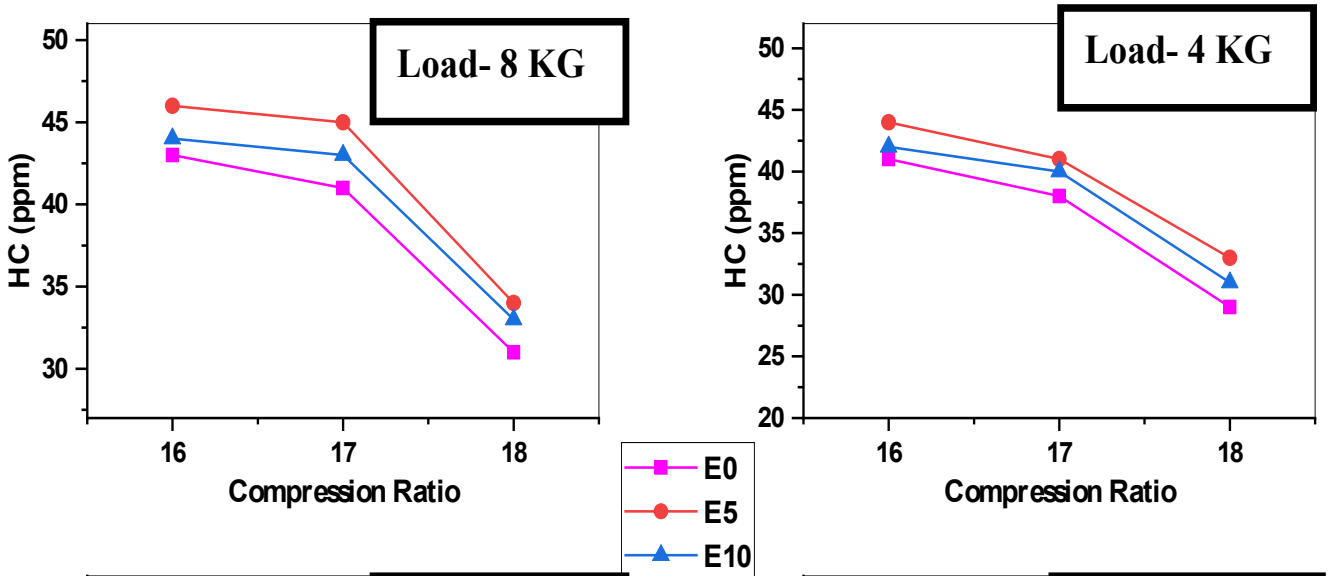


Figure 5. Emissions of NOx at different EGR percentages and compression ratios.



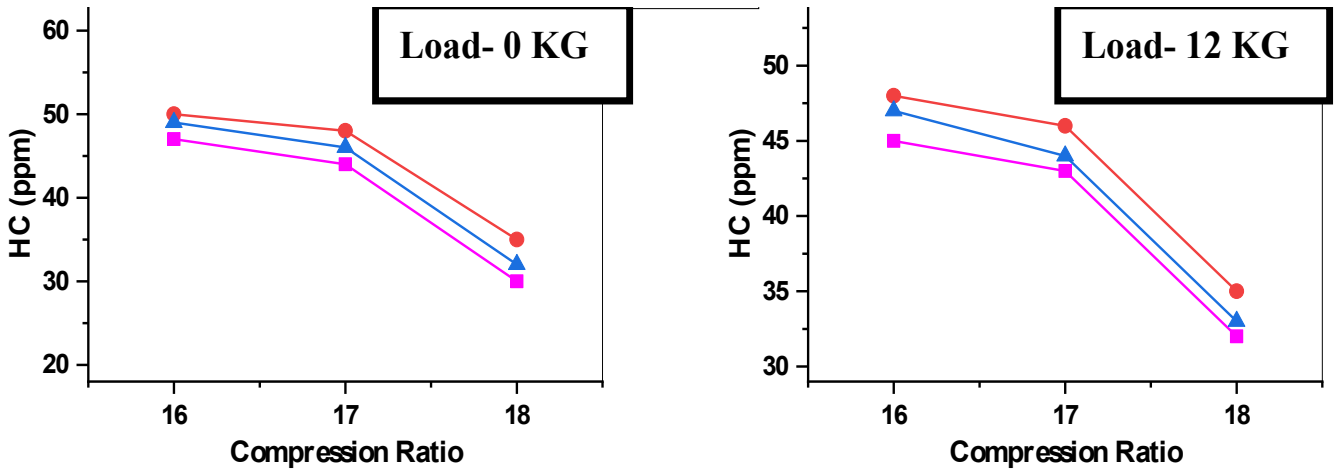


Figure 6. HC emissions at different EGR percentages and compression ratios.

5.2.3 CO Emissions

Incomplete combustion results in CO emissions, which mostly rely on the A/F ratio. Lower temperatures result from the increase in EGR % because it slows down the air-fuel mixture's response rates and reduces the amount of O_2 available in the cylinder during combustion[10].

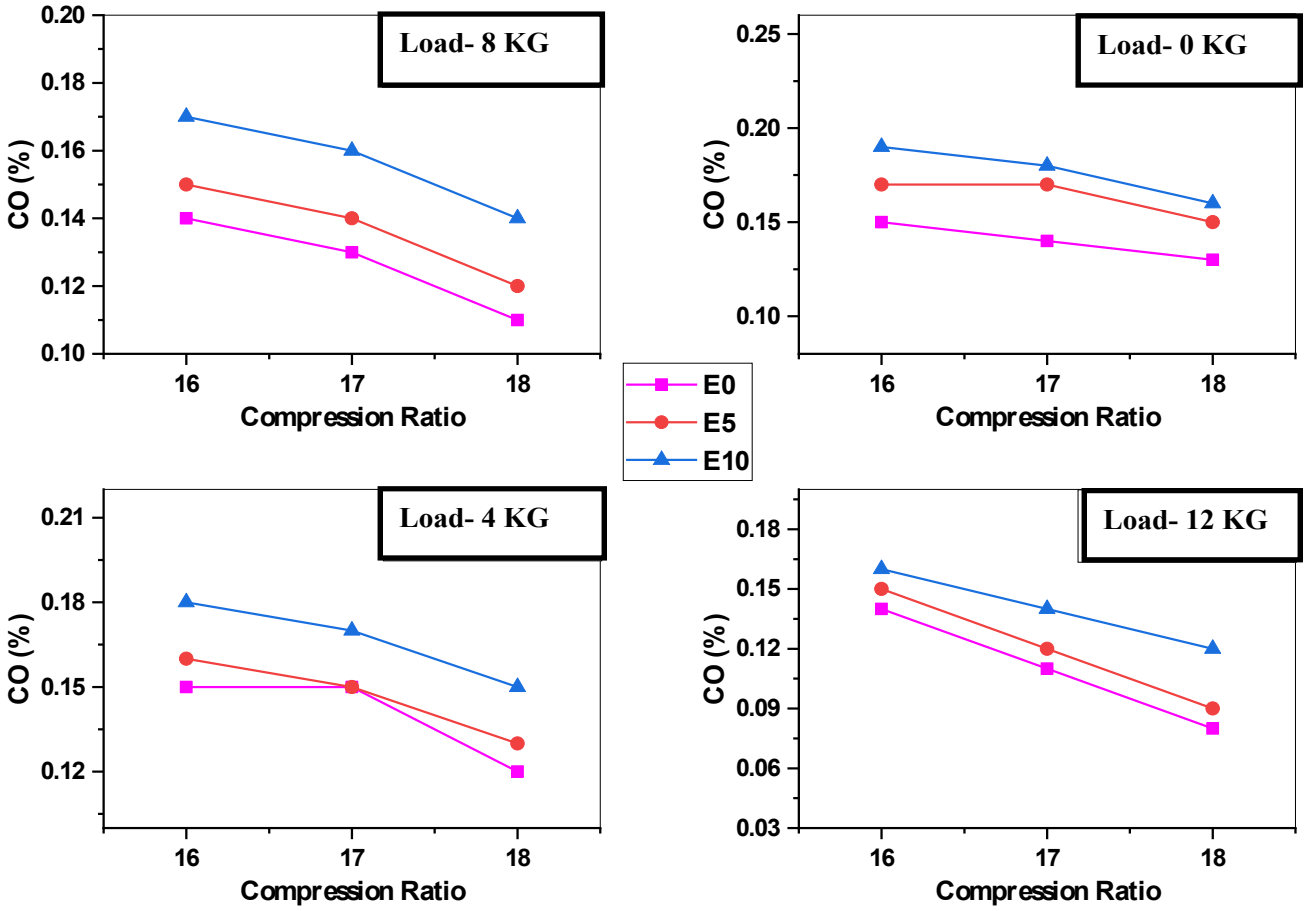


Figure 7. CO emissions at different EGR percentages and compression ratios.

Lean mixtures were unable to sustain the flame front growth at such a temperature.

As a result, as seen in Figure 7, the A/F combination does not burn entirely, leading to increased CO emissions[15].

Because of full combustion, CO emissions were shown to decrease as the compression ratio increased. Peak CO emissions were seen when the EGR fraction in the fresh A/F mixture rose, which is consistent with the references[14,16].

6.0 Conclusions

The following conclusions were drawn from this experimental investigation of the effects of Exhaust Gas Recirculation (EGR) and Compression Ratio (CR) on engine parameters under several loading scenarios.

When CR was raised from 16:1 to 18:1, there was a decrease in BSFC of roughly 13.33% and an improvement in BTE of 24.71% at maximum engine load. Out of all the compression ratios taken into consideration, 18 CR has demonstrated the highest efficiency. Regardless of compression ratios, an increase in EGR percentage resulted in a rise in BSFC and a fall in BTE.

When the CR and EGR percentages were raised since 16:1 toward 18:1 and E0 to E10, respectively, the exhaust gas temperature decreased.

Without EGR, maximum NOx emissions were recorded at 18E0 full engine load; with 10% EGR, however, they were reduced by about 6%. As CR and engine load grew and EGR decreased, NOx emissions rose as well.

When the engine was partially loaded, the maximum HC emissions of 50 ppm were recorded at 16E5. It grew gradually as engine load decreased, CR decreased, and EGR increased. The trend for HC and CO emissions has been consistent across CR, EGR, and engine load.

7.0 Acknowledgement

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8.0 Author Designation

Samkit Jayeshbhai Shah- Research Scholar
Dr. Nimit Patel- Assistant Professor

9.0 References

1. Raheman H, Kumari S. Combustion characteristics and emissions of a compression ignition engine using emulsified jatropha biodiesel blend. Biosyst Eng. 2014; 123:29-39. https://doi.org/10.1016/j.biosystemseng.2014.05.001
2. Hariram V, Kumar GM. The effect of injection timing on combustion, performance, and emission parameters with AOME blends as a fuel for compression ignition engine. Eur J Sci Res. 2012; 79(4):653-65.
3. Hariram V, Vagesh Shangar R. Influence of compression ratio on combustion and performance characteristics of direct injection compression ignition engine. Alex Eng J. 2015; 54(4):807-14. https://doi.org/10.1016/j.aej.2015.06.007
4. Gowthaman S, Sathiyagnanam AP. Performance and emission characteristics of homogeneous charge compression ignition engine: A review. Int J Ambient Energy. 2016; 38(7):672-84. https://doi.org/10.1080/01430750.2016.1155491
5. Muralidharan K, Vasudevan D. Performance, emission, and combustion characteristics of a variable compression ratio engine using methyl esters of waste cooking oil and diesel blends. Appl Energy. 2011; 88(11):3959-68. https://doi.org/10.1016/j.apenergy.2011.04.014
6. Stone R. Introduction to internal combustion engines; 1999. https://doi.org/10.1007/978-1-349-14916-2.
7. Debnath BK, Sahoo N, Saha UK. Thermodynamic analysis of a variable compression ratio diesel engine running with palm oil methyl ester. Energy Convers Manag. 2013; 65:147-54. https://doi.org/10.1016/j.enconman.2012.07.016
8. Moffat RJ. Using uncertainty analysis in the planning of an experiment. J Fluids Eng. 1985; 107(2):173-8. https://doi.org/10.1115/1.3242452
9. De Oliveira A, *et al*. Combustion, performance, and emissions of a diesel power generator with direct injection of B7 and port injection of ethanol. J Braz Soc Mech Sci Eng. 2017; 39(4):1087-96. https://doi.org/10.1007/s40430-016-0667-7
10. Agarwal D, Singh SK, Agarwal AK. Effect of Exhaust Gas Recirculation (EGR) on performance, emissions, deposits, and durability of a constant speed compression ignition engine. Appl Energy. 2011; 88(8):2900-7. https://doi.org/10.1016/j.apenergy.2011.01.066
11. Guo M, *et al*. A short review of treatment methods of marine diesel engine exhaust gases. Procedia Eng. 2015; 121:938-43. https://doi.org/10.1016/j.proeng.2015.09.059

12. Hussain J, *et al*. Retracted: Effect of Exhaust Gas Recirculation (EGR) on performance and emission characteristics of a three-cylinder direct injection compression ignition engine. Alex Eng J. 2012. https://doi.org/10.1016/j.aej.2012.09.004
13. Maiboom A, Tauzia X, Hétet JF. Experimental study of various effects of exhaust gas recirculation (EGR) on combustion and emissions of an automotive direct injection diesel engine. Energy. 2008; 33(1):22-34. https://doi.org/10.1016/j.energy.2007.08.010
14. De Serio D, De Oliveira A, Sodré JR. Effects of EGR rate on performance and emissions of a diesel power generator fueled by B7. J Braz Soc Mech Sci Eng. 2017; 39(6):1919-27. https://doi.org/10.1007/s40430-017-0777-x
15. Park SH, Youn IM, Lee CS. Influence of two-stage injection and exhaust gas recirculation on the emissions reduction in an ethanol-blended diesel-fueled four-cylinder diesel engine. Fuel Process Technol. 2010; 91(11):1753-60. https://doi.org/10.1016/j.fuproc.2010.07.016
16. Kumar BR, *et al*. Effect of a sustainable biofuel-n-octanol on the combustion, performance, and emissions of a DI diesel engine under naturally aspirated and Exhaust Gas Recirculation (EGR) modes. Energy Convers Manag. 2016; 118:275-86. https://doi.org/10.1016/j.enconman.2016.04.001
17. Anderson AM. Experimental methods for engineers. Exp Therm Fluid Sci. 1994; 250. https://doi.org/10.1016/0894-1777(94)90118-X
18. Agarwal D, Singh SK, Agarwal AK. Effect of exhaust gas recirculation (EGR) on performance, emissions, deposits, and durability of a constant speed compression ignition engine. Appl Energy. 2011; 88(8):2900-7. https://doi.org/10.1016/j.apenergy.2011.01.066
19. Ahamad Shaik A, Rami Reddy S, Dhana Raju V, Govindarajan M. Combined influence of compression ratio and EGR on diverse characteristics of a research diesel engine fueled with waste mango seed biodiesel blend. Energy Sources Part A: Recovery, Utilization, and Environmental Effects. 2024; 46(1):1-24
20. Boretti A, Scalzo J. Exploring the advantages of Atkinson effects in variable compression ratio turbo GDI engines. SAE 2011 World Congress and Exhibition. 2011. https://doi.org/10.4271/2011-01-0367
21. Bozza F, De Bellis V, Teodosio L. EGR systems employment to reduce the fuel consumption of a downsized turbocharged engine at high-load operations. Energy Procedia. 2015; 81:866-73. https://doi.org/10.1016/j.egypro.2015.12.134
22. Cairns A, Fraser N, Blaxill H. Pre versus post compressor supply of cooled EGR for full load fuel economy in turbocharged gasoline engines. SAE Tech Pap. 2008; 2008(724):776-90. https://doi.org/10.4271/2008-01-0425
23. Chaudhari AJ, Hotta SK, Sahoo N, Kulkarni V. Combined impact of compression ratio and re-circulated exhaust gas on the performance of a biogas fueled spark ignition engine. J Renew Sustain Energy. 2019; 11(1). https://doi.org/10.1063/1.5045742
24. Deepan G. Experimental investigation of performance and emission characteristics in a variable compression ratio diesel engine using partly cold Exhaust Gas Recirculation (EGR) method. 2013 Int Conf Energy Eff Technol Sustain (ICEETS). 2013; 727-39. https://doi.org/10.1109/ICEETS.2013.6533475
25. Fischer M, Kreutziger P, Sun Y, Kotrba A. Clean EGR for gasoline engines - innovative approach to efficiency improvement and emissions reduction simultaneously. SAE Tech Pap. 2017. https://doi.org/10.4271/2017-01-0683
26. Galindo J, Dolz V, Monsalve-Serrano J, Bernal MA, Odillard L. Impacts of the Exhaust Gas Recirculation (EGR) combined with the regeneration mode in a compression ignition diesel engine operating at cold conditions. Int J Engine Res. 2021; 22(12):3548-57. https://doi.org/10.1177/14680874211013986
27. Galloni E, Fontana G, Palmaccio R. Numerical analyses of EGR techniques in a turbocharged spark-ignition engine. Appl Therm Eng. 2012; 39:95-104. https://doi.org/10.1016/j.applthermaleng.2012.01.040
28. Ghazal O. Effect of exhaust gas recirculation on SI engine performance and emissions. ARPN J Eng Appl Sci. 2019; 14(5):1089-92.
29. Gondhane S, Goyal K, Shinde A. Exhaust gas recirculation and variable compression ratio effect for rape seed oil methyl ester powered by diesel engine. Int Conf Ideas Impact Innov Mech Eng ICIIIME. 2017; 5(June):1324–9.
30. Gowtham R, Bathusha AHM, Ganapathy RS, Mohanraj K, Venkatasubramanian N. Performance and emission characterization of adjustable cylinder head type variable compression ratio in two-stroke SI engine. IOP Conf Ser Mater Sci Eng. 2020; 995(1). https://doi.org/10.1088/1757-899X/995/1/012005
31. Grandin B, Denbratt I, Bood J, Brackmann C, Bengtsson PE, Gogan A, *et al*. Heat release in the end-gas prior to knock in lean, rich and stoichiometric mixtures with and without EGR. SAE Tech Pap. 2002. https://doi.org/10.4271/2002-01-0239

32. Khan IR. Study of Variable Compression Ratio engine (VCR) and different innovations to achieve VCR. Int J Res Appl Sci Eng Technol. 2017; V(XI):1473–8. https://doi.org/10.22214/ijraset.2017.11213
33. Khoa NX, Lim O. A review of the external and internal residual exhaust gas in the internal combustion engine. Energies. 2022; 15(3). https://doi.org/10.3390/en15031208
34. Kumar R, Dixit AK. Combustion and emission characteristics of variable compression ignition engine fueled with Jatropha curcas ethyl ester blends at different compression ratio. J Renew Energy. 2014; 2014:1–12. https://doi.org/10.1155/2014/872923
35. Lee TYK, Hwang SH. Combustion and emission characteristics of wood pyrolysis oil-butanol blended fuels in a DI diesel engine. Int J Automot Technol. 2012; 13(2):293–300. https://doi.org/10.1007/s12239
36. Lou D, Ren Y, Zhang Y, Sun X. Study on the effects of EGR and spark timing on the combustion, performance, and emissions of a stoichiometric natural gas engine. ACS Omega. 2020; 5(41):26763–75. https://doi.org/10.1021/acsomega.0c03859
37. Marchitto L, Tornatore C, Valentino G, Teodosio L. Impact of cooled EGR on performance and emissions of a turbocharged spark-ignition engine under low-full load conditions. SAE Tech Pap. 2019. https://doi.org/10.4271/2019-24-0021
38. Mishra RK, Soota T, Singh R. Effect of variable compression ratio on performance of a diesel engine fueled with karanja biodiesel and its blends. IOP Conf Ser Mater Sci Eng. 2017; 225:012064. https://doi.org/10.1088/1757-899X/225/1/012064
39. Mo YK, Shim JK, Lim DJ. Kinematic structure analysis of variable compression ratio engine mechanisms. Trans Korean Soc Automot Eng. 2018; 26(2):159–66. https://doi.org/10.7467/KSAE.2018.26.2.159
40. Mohiuddin K, Kwon H, Choi M, Park S. Effect of engine compression ratio, injection timing, and exhaust gas recirculation on gaseous and particle number emissions in a light-duty diesel engine. Fuel. 2021; 294(March):120547. https://doi.org/10.1016/j.fuel.2021.120547
41. Piqueras P, Morena JD la, Sanchis EJ, Pitarch R. Impact of exhaust gas recirculation on gaseous emissions of turbocharged spark-ignition engines. Appl Sci (Switz). 2020; 10(21):1–17. https://doi.org/10.3390/app10217634
42. Pohjalainen T, Larmi M. Novel crank mechanism increasing engine efficiency and reducing CO_2 emissions. SAE Tech Pap. 2015; 2015. https://doi.org/10.4271/2015-01-1259
43. Rao SVU, Raj A, Narayana KS, Rao TVH, Naik RT. Effect of variable compression ratio on performance and emissions characteristics of IC engine. Int J Eng Trends Technol. 2016; 37(6):317–26. https://doi.org/10.14445/22315381/IJETT-V37P256
44. Shelat SJ, Patel SM. Performance characteristics of a Compression Ignition (CI) engine using an environmentally friendly waste plastic fuel. J Mines Met Fuels. 2024; 5572(9):923–36. https://doi.org/10.18311/jmmf/2024/45074