Effect of Ethanol Blending on Diesel Engine Performance and Emissions

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Abstract

In India, ethanol is produced from sugarcane juice, Syrup, BH and C molasses. Derived from solar energy-harnessing plants, ethanol is a sustainable and renewable fuel source, offering an eco-friendly alternative to traditional regular fossil fuels. This preaches in line with India's global move towards lowering carbon footprints. India also plans to have 20% ethanol blending in fuel by 2025 to cut vehicle pollution and reduce imports on fossil fuels to help the world's third-biggest emitter of greenhouse gases to reach its net-zero carbon goal by 2070. This study investigates the effects of diesel-ethanol dual-fuel on combustion, engine performance, and emission attributes in a twin-cylinder common rail direct injection (CRDI) diesel engine at various engine loads and injector openings. The study involved testing various proportions of ethanol in a twin-cylinder CRDI engine under different operating conditions. Conventional diesel engine was modified into dual-fuel engine. The study compared performance factors such as power output, pressure, and efficiency when using ethanol and diesel fuel. It also examined the impact of ethanol on engine combustion, including cylinder pressure and heat release rates, to assess its compatibility with the diesel engine. Additionally, the study also analyzed emissions such as nitrogen oxides, carbon monoxide and hydrocarbons to evaluate the environmental impact of ethanol use. The experiments were conducted at 2000 and 2400 RPM under different loads (10, 20, 30, and 40 Nm) and injection openings (0%, 20%, 40%, and 60%) to thoroughly assess how ethanol affects engine performance. The highest ethanol content mixed with diesel reached up to 20% under a 40 Nm load.

Keywords: Ethanol-Diesel Blend, twin-cylinder CRDI Engine, Performance Evaluation, Emission Analysis, Alternative Fuels

INTRODUCTION

India's sugar mills produce valuable by-products like bagasse, molasses, etc., which can be used to generate electricity and ethanol. The Energy Conservation Bill 2022 aims to install 500 GW of non-fossil energy (50% of it by renewable energy) by 2030, reducing carbon intensity by 1 billion metric tons. The bill also aims to achieve zero emissions by 2070. In line with these goals, the Ethanol Blended Petrol Programme (EBP) has been implemented to reduce pollution, conserve foreign exchange, and increase value addition in the sugar industry by blending ethanol with petrol. The sugar industry is uniquely capable of generating steam and power for processing using self-sufficient fuel. The sugar mills are self-sufficient in fuel and energy and typically produce sugar, ethanol, and cogeneration, focusing on exporting excess electricity (Ref no 20)

It's fascinating to learn about the advancements in ethanol production in India, particularly with the EBP that aims to blend ethanol with petrol. Expanding the use of ethanol in diesel engines could potentially bring significant environmental and economic benefits, as ethanol is known to produce fewer emissions compared to traditional fossil fuels. Research into ethanol mixed with diesel engines, such as the study conducted at COEP Technological University in Pune, is an important step in examining the feasibility and effectiveness of this approach. CRDI (Common Rail Direct Injection) diesel engines are widely used in vehicles, and understanding how ethanol-diesel perform in such engines is crucial for potential implementation. This research could lead to a more diverse use of ethanol, reducing reliance on fossil fuels and contributing to India's efforts towards sustainability and energy security. It's exciting to see such innovative initiatives being undertaken and their potential impact on the transportation sector and the environment.

Diesel engines are the preferred choice across multiple economic sectors due to their superior efficiency, durability, and reliability in comparison to their spark-ignited (SI) gasoline engine counterparts. In recent years, with the focus on sustainable energy sources and reducing harmful emissions, ethanol has emerged as a compelling option due to its renewable characteristics, elevated octane rating, and potential to mitigate greenhouse gas emissions. There is growing interest in exploring the combination of ethanol and diesel fuel to leverage the benefits of both fuels while addressing the challenges associated with their individual use. Twin-cylinder, four-stroke CRDI (Common Rail Direct Injection) engines are recognized for their efficiency, power delivery, and compatibility with various fuel mixtures. Primary alcohols like ethanol offer a promising avenue for fueling diesel engines and have the potential to reduce the emission of harmful pollutants.

Table 1: Fuel Properties

FUEL PROPERTIES	ETHANOL	DIESEL
Octane No.	120-135	-
Boiling Point (ºC)	78	149
Density (kg/m³)	789	846
Latent Heat (kJ/kg)	846	267
Calorific Value(kJ/kg)	35500	42600
Auto ignition Temp. (ºC)	363	210

Their unique properties enhance the spray characteristics of 'diesohols', and their inherent oxygen content facilitates more thorough combustion. This oxygen presence alters the oxidation pathways, reducing the formation of higher molecular-weight compounds and consequently mitigating the formation and growth of particulate matter. However, integrating primary alcohols into existing diesel engines presents challenges such as lower cetane numbers and increased corrosiveness. Nonetheless, various techniques such as fumigation, dual-fuel injection, blending, and emulsification can harness the benefits of alcohol fuels in diesel engines.

Understanding the impacts of the ethanol-diesel mixture on these engines' performance, emissions, and combustion attributes is crucial for advancing sustainable transportation technologies.

This research paper aims to delve into the intricacies of ethanol-diesel duel- fuel in twin-cylinder, four-stroke CRDI engines. By synthesizing existing literature, experimental findings, and theoretical frameworks, this study aimed to offer a thorough and encompassing examination of the topic at hand. Through meticulous experimentation conducted at 2000 and 2400 RPM under different loads (10, 20, 30, and 40 NM) and injection openings (0%, 20%, 40%, and 60%), this study meticulously characterizes the multifaceted impacts of ethanol fuel on engine behavior.

Combustion Characteristics: Investigating how ethanol-diesel duel- fuel influence heat release rates, pressure vs. crank angle, and other combustion parameters in CRDI engines.

- Engine Performance: The distinct influence of ethanol-diesel duel- fuel on engine power output, pressure dynamics, and fuel efficiency.
- Emissions Profile: Analyzing the emissions of nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbons (HC), and other pollutants during the utilization of ethanol-diesel mixture.
- Optimization Strategies: Exploring techniques to optimize the fuel percentage ratios of ethanol and diesel fuel for achieving the desired balance between performance, emissions, and overall engine operation.

Table 2: Technical specifications of the test engine and dynamometer

Sr. No.	Description		Specifications
1	Make		Mahindra and Mahindra
2	Engine Capacity	cc	909
3	No. of Cylinders	Nos	2
4	Application		Automotive Multispeed
5	No. of strokes	Nos	4
6	Compression Ratio		16.5:1
7	Bore	mm	83
8	Stroke length	mm	84
9	Ignition		Compression-Ignition
10	Maximum power @ rpm	HP	45 HP @ 3750 RPM
11	Maximum torque @ rpm	NM	90 NM @ 1800 RPM
12	Cooling System		Water Cooled
13	Number of Valves/Cylinder	Nos	2

By synthesizing and critically analyzing existing research findings, this paper aimed to contribute to the body of knowledge surrounding ethanol-diesel duel-fuel in twin-cylinder, four-stroke CRDI engines. Ultimately, the insights gleaned from this exploration can inform future advancements in engine design, fuel formulation, and sustainable transportation initiatives.

EXPERIMENTAL PROCEDURE AND METHODOLOGY:

The diesel engine is widely used in many applications, such as transportation, power generation, agriculture purposes, building construction, and mining, because of its high thermal efficiency due to higher CR and high torque due to higher volumetric efficiency. Along with advantages, it has some disadvantages, like higher NOx, higher CO_2, and high GHG_s. To enhance engine performance and mitigate emissions, transitioning to alternative fuels, such as alcohol, is imperative. Following changes were made:

1 **Selection of Test Engine**: A suitable twin-cylinder CRDI engine representative of contemporary automotive applications was chosen. The engine was set up on a dynamometer test bench equipped with the necessary instrumentation for data acquisition.
2 **Fuel Selection**: Utilizing ethanol with a purity of 99% sourced from various sugar industries represented a significant focus within alternative fuel research due to its relevance and widespread interest in the field of alcohol fuels.
3 **Actual Testing was done as follows:**

- Turn on the engine ignition key, monitor, and cool water supply to the engine.
- Turn on engine scanning software and Medhavi Open ECU software.
- Turn on the engine and let the engine warm. Increase the engine RPM to the experiment-set value and gradually increase the load on the engine.
- Take readings for the pure diesel engine at the set speed (2000 and 2400 RPM), the load (10, 20, 30, and 40 NM), and gradually increase the ethanol injector opening (0, 20, 40, and 60%), and simultaneously record emission data.
- Take each reading after 50 cycles of the engine, and save the files as per format RPM, Load, and Injector Opening for ease of identification.
- Record all the readings as per the design of the experiment and utilize the saved data for further analysis.

▪ **Heat Release Analysis**: Employ in-cylinder pressure data for the computation of heat release rates and investigate the combustion efficiency of alcohol-fueled combustion.
▪ **Gas Sampling:** Collect exhaust gases for detailed analysis of emission components, including NOx, CO, and unburned hydrocarbons.
▪ **Statistical Analysis**: Employed statistical tools to analyze the data obtained from combustion, performance, and emission tests, identifying trends, correlations, and significant differences.
▪ **Comparative Analysis**: Compare the results of alcohol-fueled combustion with baseline diesel tests to quantify the impact on combustion efficiency, engine performance, and emissions.

- **Calibration:** Regularly calibrate instrumentation to ensure accurate and reliable measurements throughout the testing process.

RESULTS AND DISCUSSIONS

Effect of Ethanol Content on BMEP

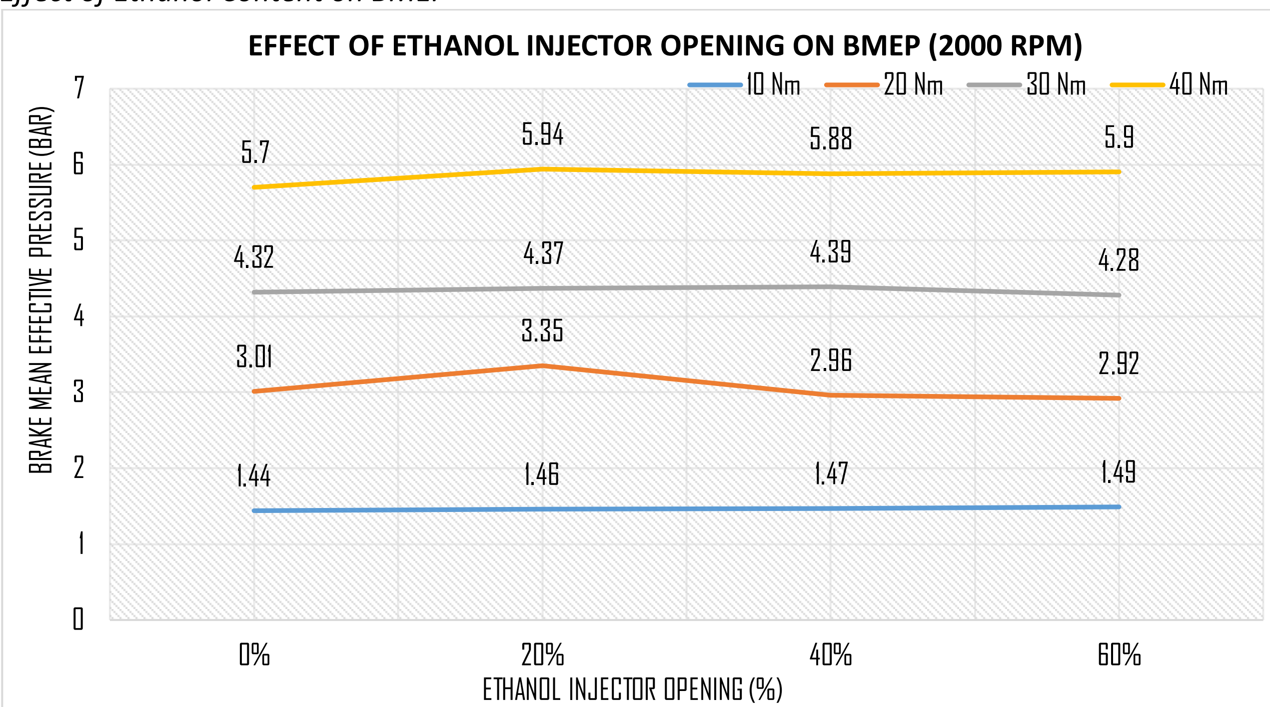


Fig.2: Effect of Ethanol Content on BMEP (BMEP at 2000 RPM)

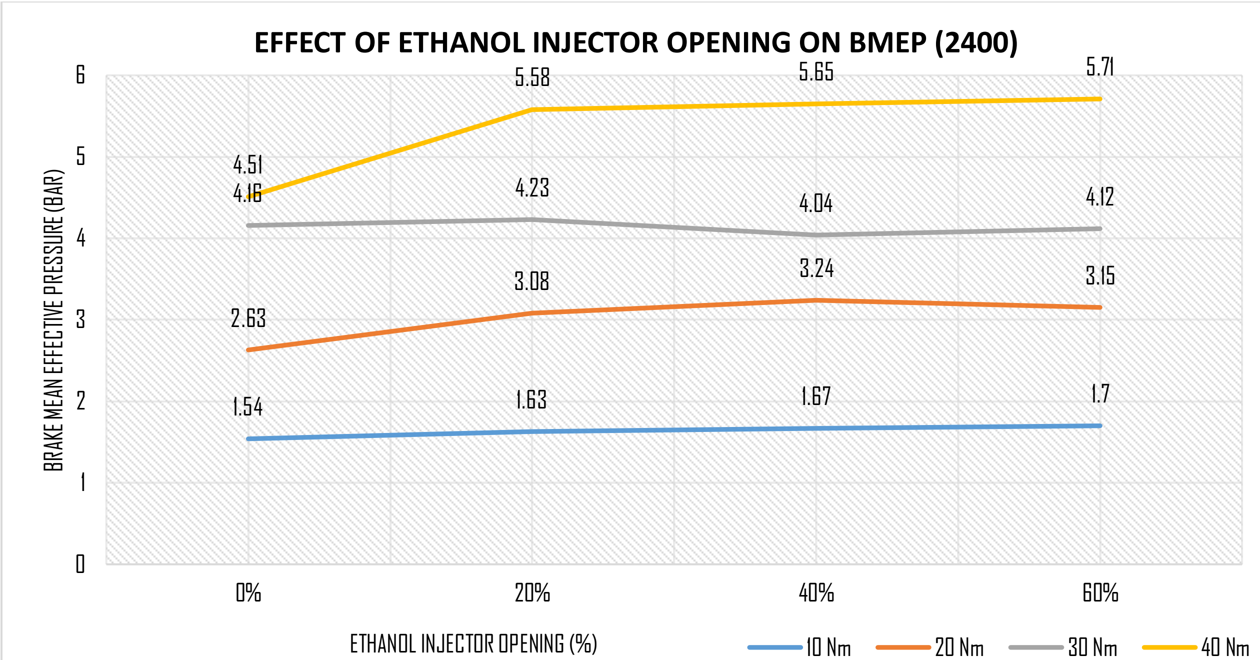


Fig. 2: Effect of Ethanol Content on BMEP (BMEP at 2400RPM)

The figure 1 and 2 shows the BMEP readings for the different ethanol openings at 2000 and 2400 RPM. BMEP is the measure of pressure or work that the engine can produce independently of engine displacement as load increases, BMEP also increases. From the figure 1 , it is clear that for 2000 RPM at only diesel, the highest BMEP was 5.7 bar at 40 N-m Load and 20%, 40%, and 60% openings of ethanol fuel, the highest BMEP was 5.94 bar, 5.88 bar, and 5.9 bar at 40 N-m load, respectively. From the figure 2 for 2400 RPM at only diesel, the highest BMEP was recorded 4.51 bar at 40 N-m Load. For 20%, 40%, and 60% openings of ethanol fuel, the highest BMEP was 5.58 bar, 5.65 bar, and 5.71 bar at 40 N-m load, respectively. Generally, all three openings produced balanced BMEP, but from average data 60% ethanol opening produced the highest BMEP, slightly over 20%, and 40% ethanol opening.

Effect of Ethanol Content on Brake Power:

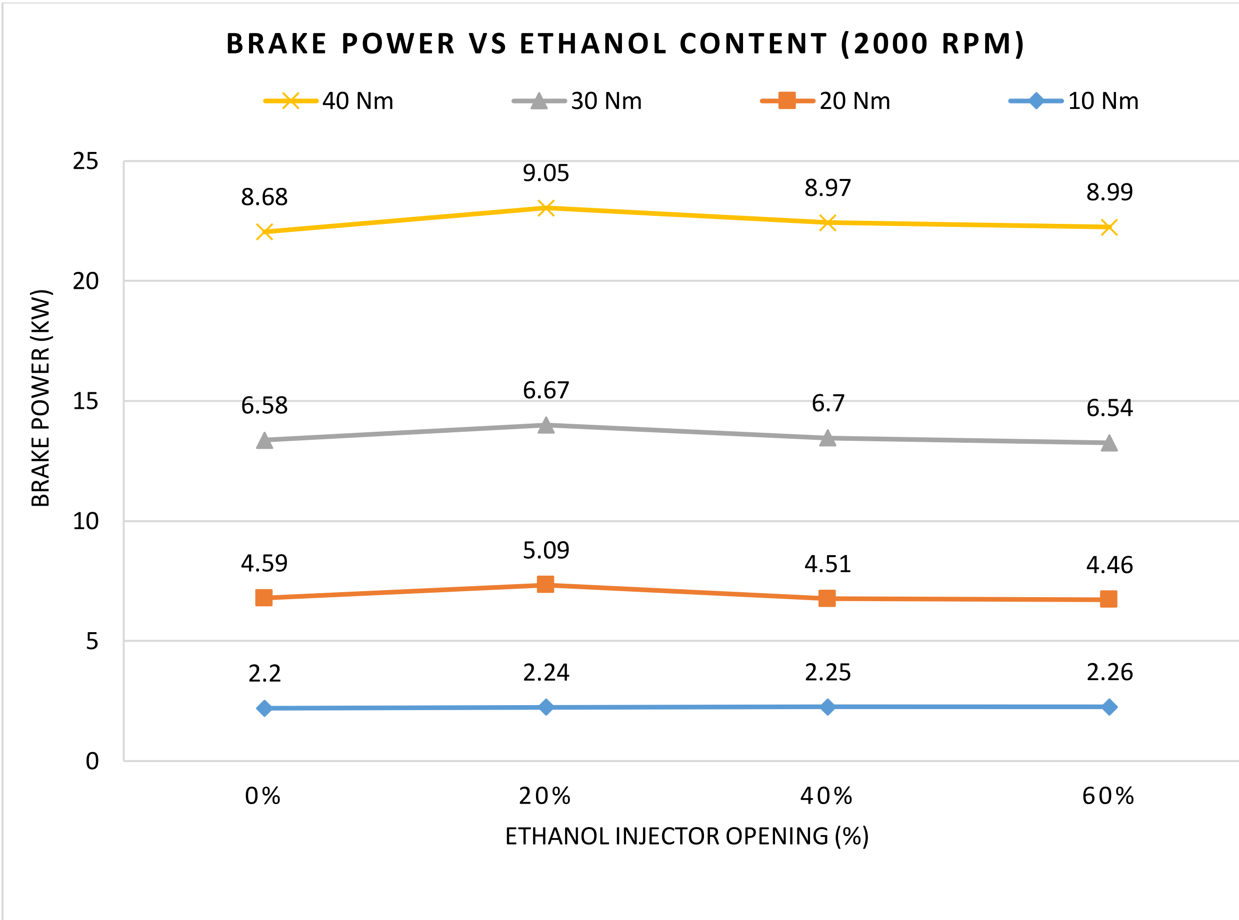


Fig. 3: Brake Power at 2000RPM

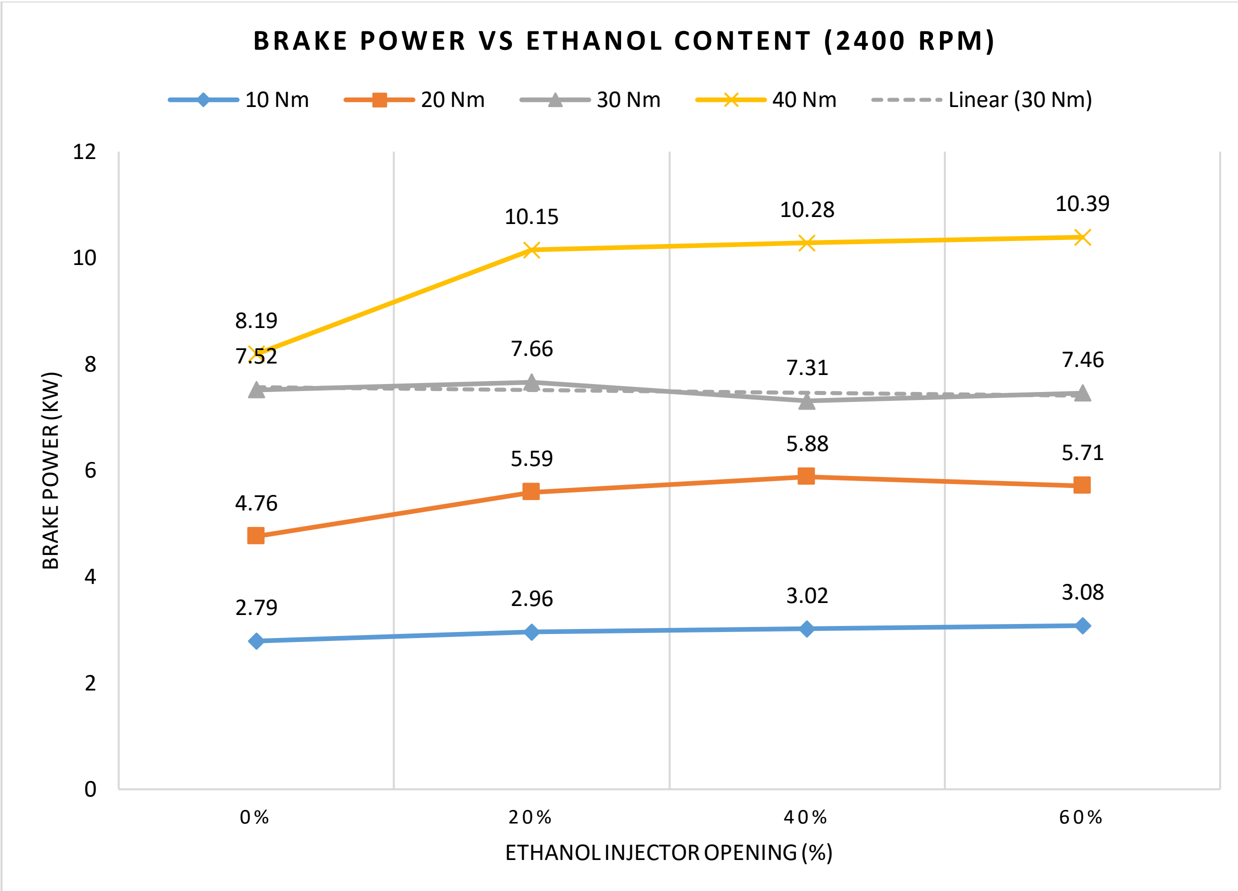


Fig. 4: Brake Power at 2400RPM

Brake power is the measure of power output at the crankshaft of an engine, without considering any power losses due to components such as the transmission, gearbox, and other auxiliary systems. It represents the maximum power that an engine can deliver under ideal conditions. Figure 3 and 4 shows the BP produced by the engine at 2000 and 2400 RPM, respectively. By comparison, for all RPM 20% opening showed the lower brake power and 60% ethanol opening showed the higher brake power.

Pressure vs Crank Angle (ϑ)

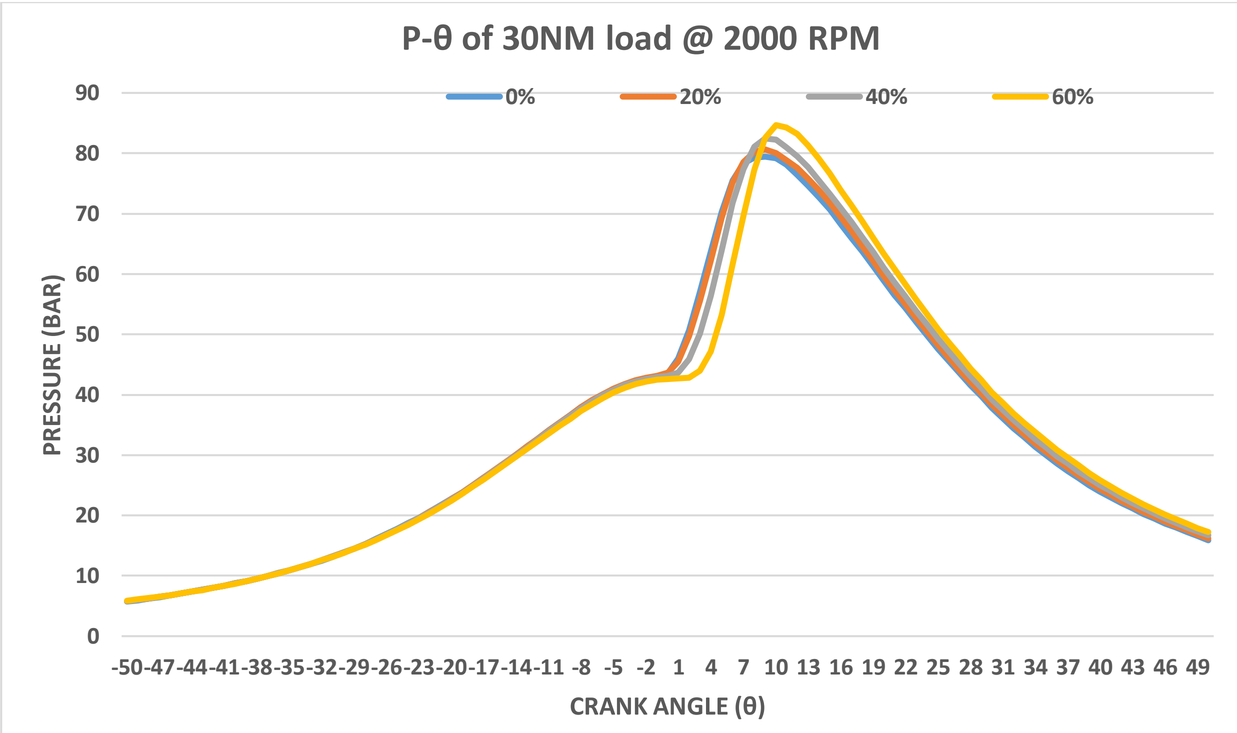


Fig. 5: P-θ at 2000 RPM

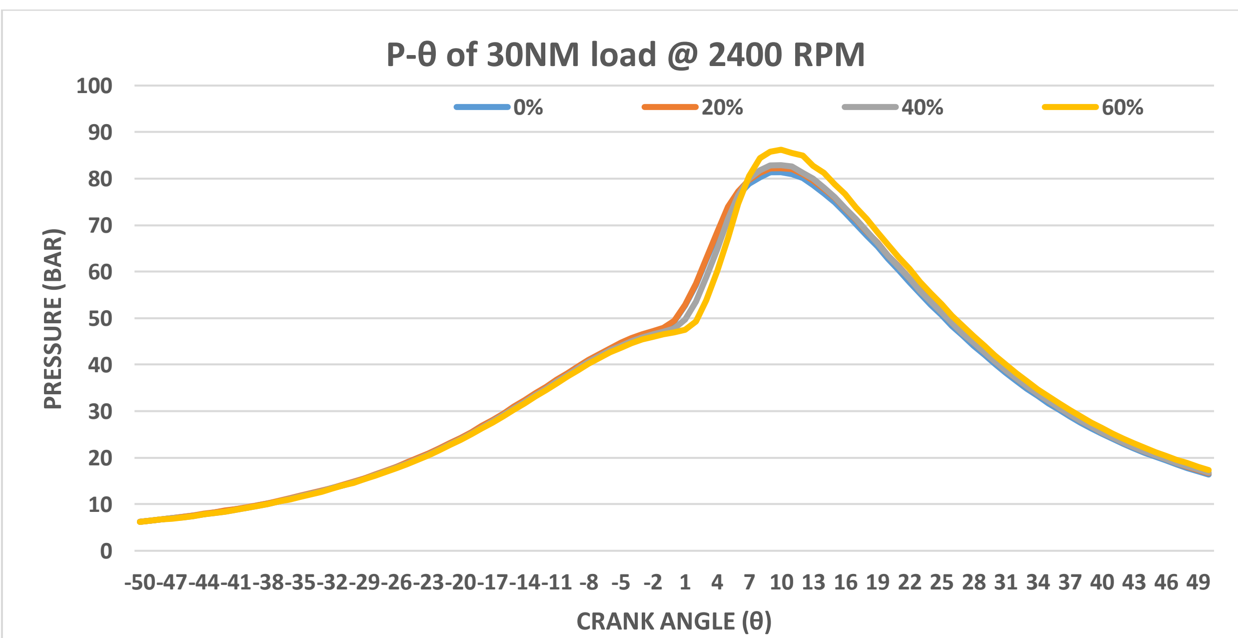


Fig. 6: P-θ at 2400 RPM

The pressure versus crank angle analysis conducted for twin-cylinder CRDI engines operating at 2000 and 2400 RPM offers valuable insights into the engine's performance characteristics. By comparing the pressure profiles at different RPM levels, it becomes evident that how engine speed affects combustion dynamics. Higher RPM typically resulted in more rapid pressure rise and combustion events due to shorter cycle durations (Fig. 6). A consistent and smooth pressure curve indicates stable combustion, while irregularities may suggest issues such as misfires or incomplete combustion. One significant observation was the higher pressure observed at 60% opening for both RPM settings, ranging from 80 to 90 bar. This finding underscores the critical role of this crank angle position in the combustion process, indicating intense pressure buildup during this phase.

Heat Release Rate

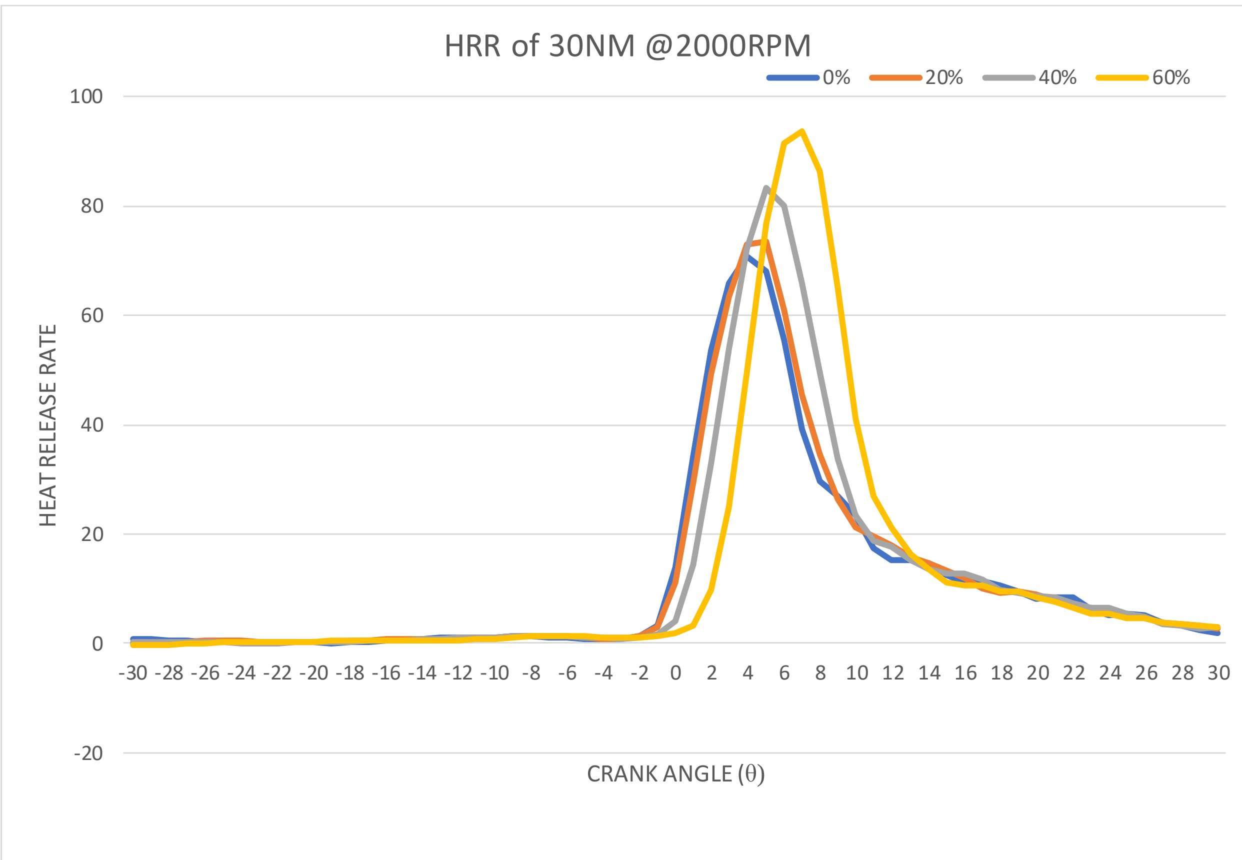


Fig. 7: HRR at 2000 RPM

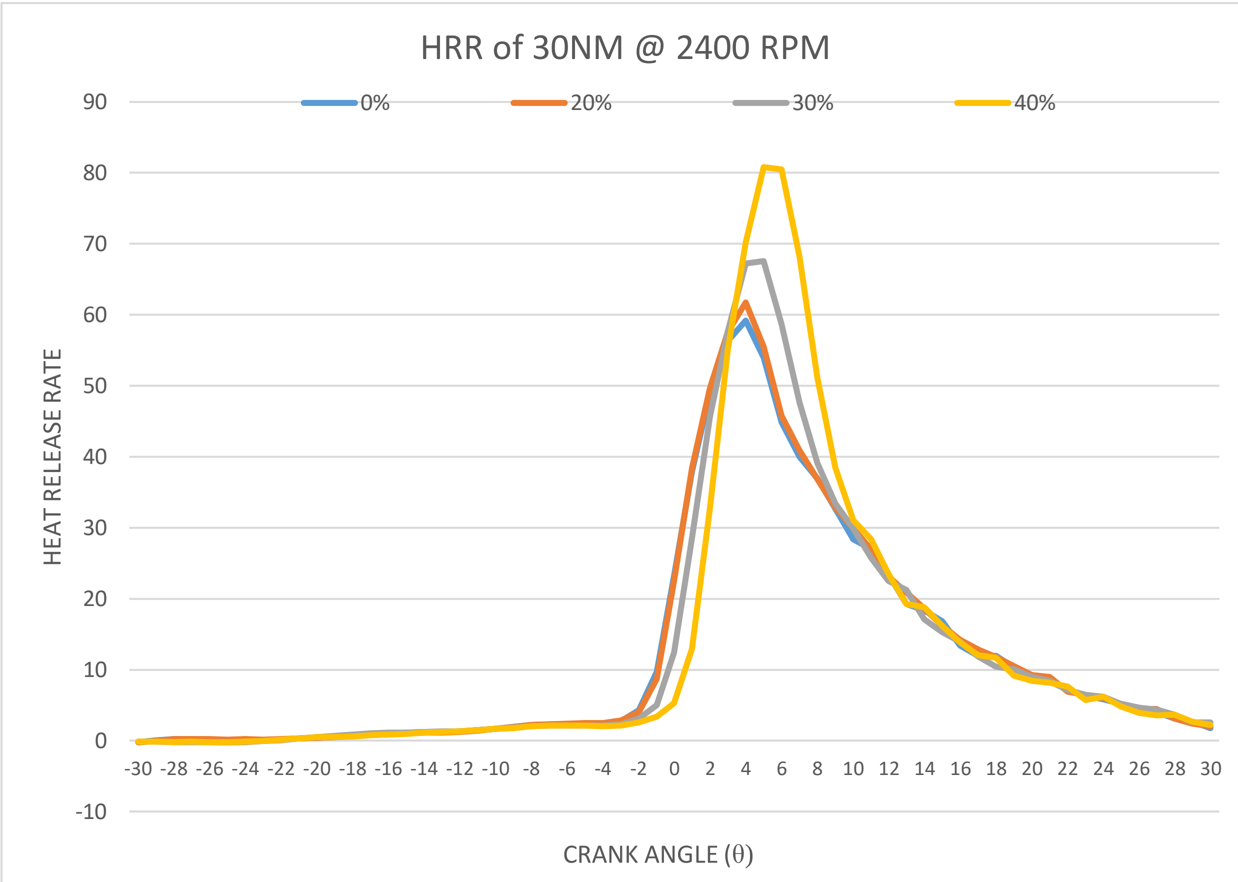


Fig. 8: HRR at 2400 RPM

At 2000 RPM, the heat release rate tended to exhibit a more gradual increase with ethanol diesel duel-fuel, indicating improved combustion efficiency and potentially reduced emissions (Fig. 7). On the other hand, at 2400 RPM, the heat release rate displayed a more pronounced peak, particularly at higher ethanol blending ratios (Fig. 8). This suggests a more rapid combustion process, possibly due to enhanced ignitability and shorter ignition delay associated with ethanol.

NOx Emission

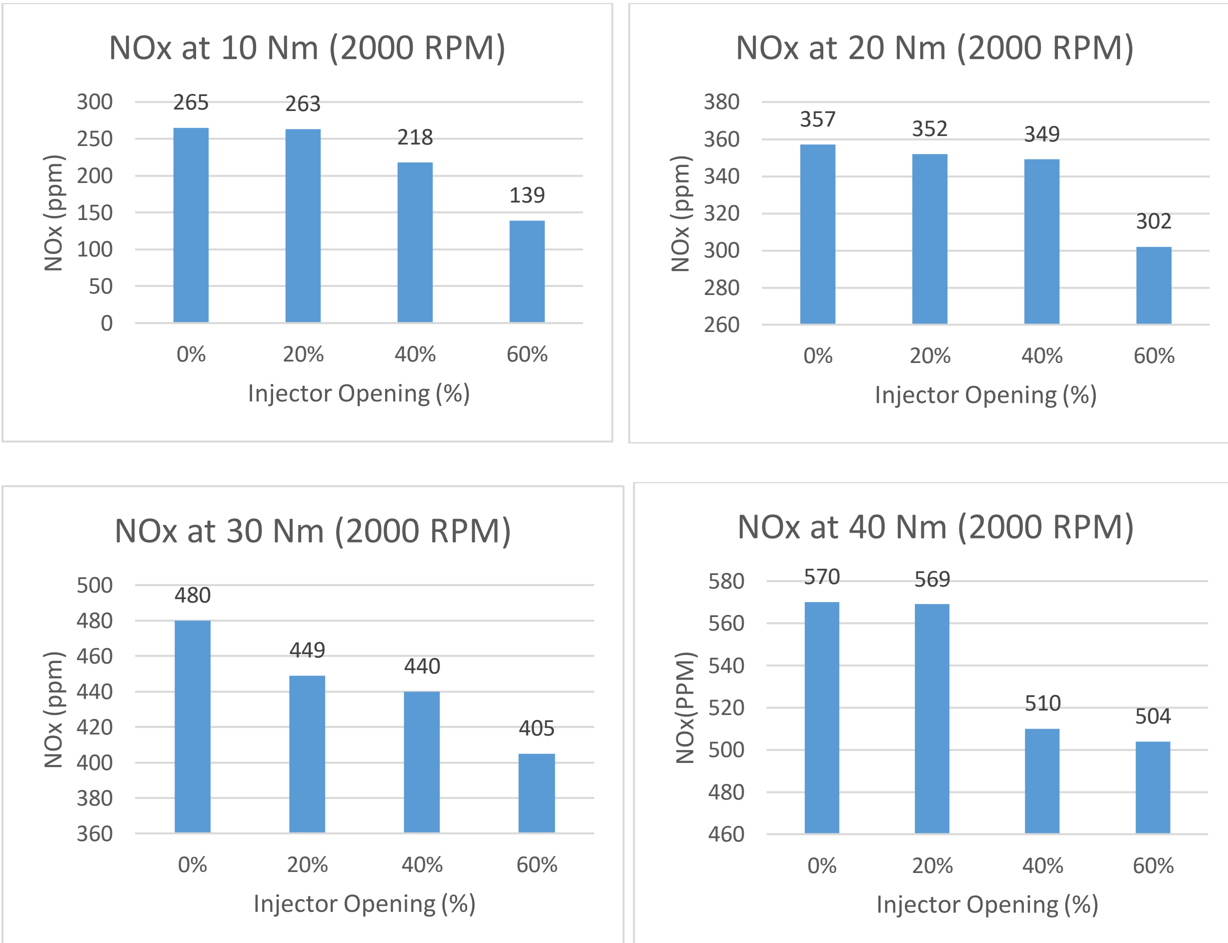
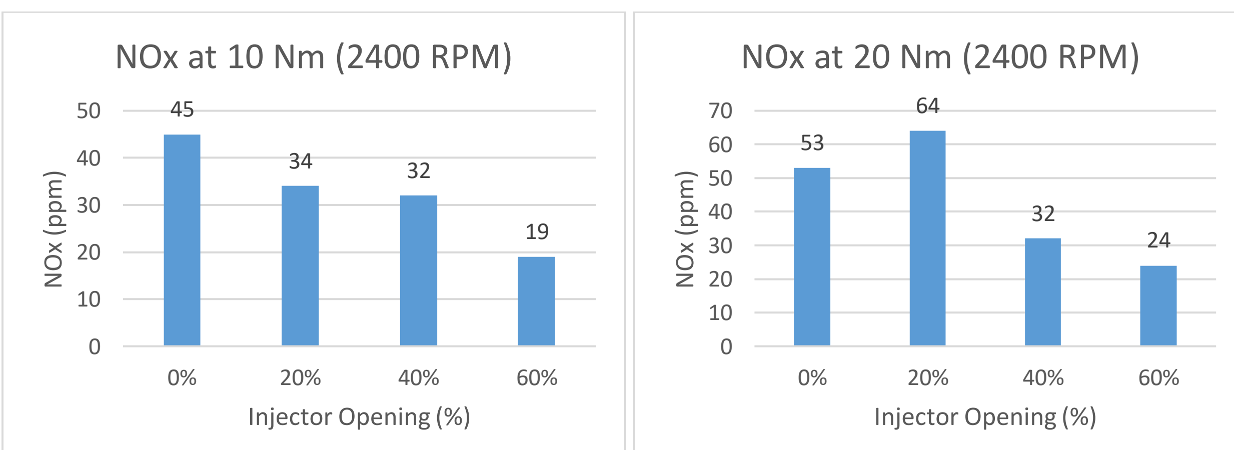


Fig. 9: NOx at 2000 RPM



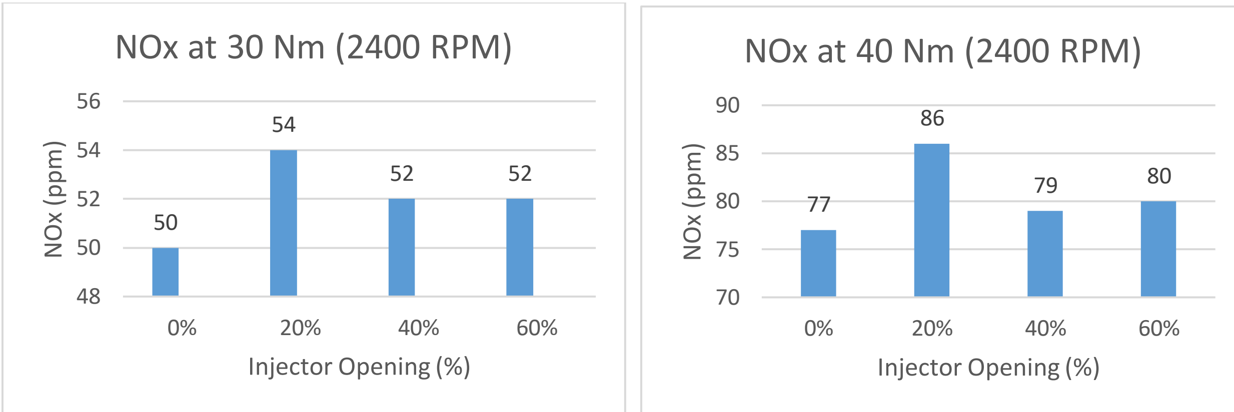
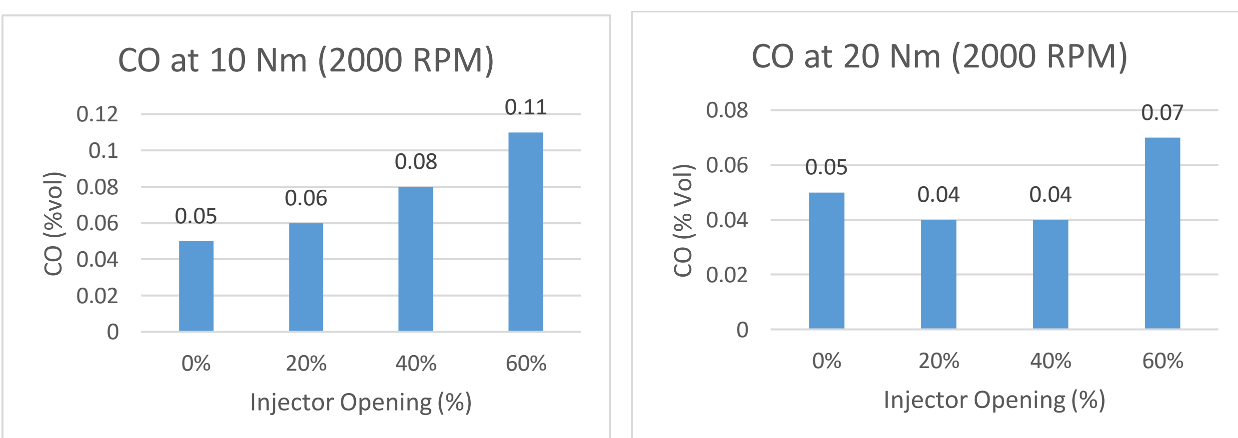


Fig. 10: NOx at 2400 RPM

At 2000 RPM, the NOx emissions exhibited a trend of reduction with increasing ethanol fuel percentage ratio (Fig. 9). This phenomenon suggests that ethanol, with its higher oxygen content and cleaner combustion properties, promotes more complete combustion, thereby mitigating the formation of nitrogen oxides. Conversely, at 2400 RPM, the NOx emissions demonstrated a more complex behavior, possibly influenced by factors such as increased combustion temperature and shorter residence time due to higher engine speed (Fig. 10). While ethanol blending still tends to mitigate NOx emissions compared to pure diesel, the rate of reduction may be less pronounced compared to lower engine speeds.

CO Emission



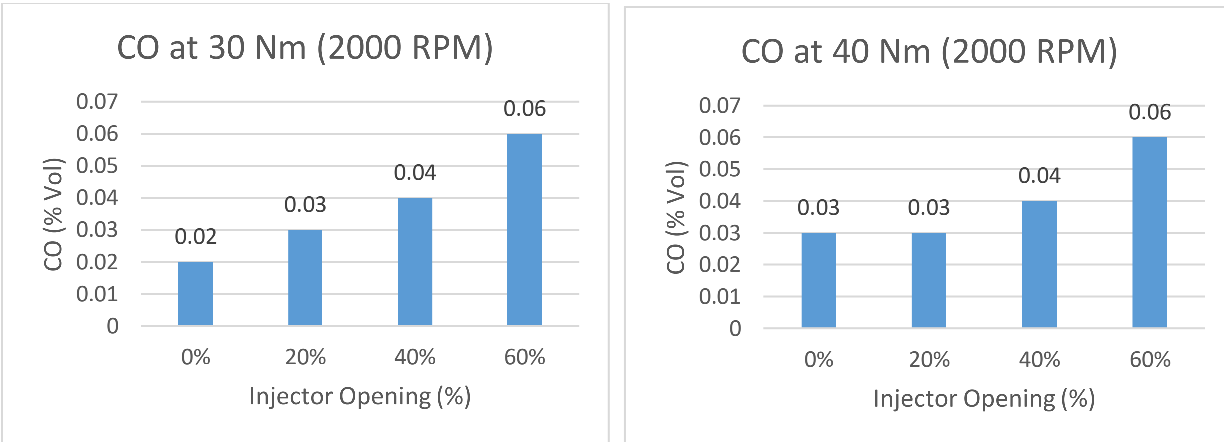


Fig. 11**: CO at 2000 RPM**

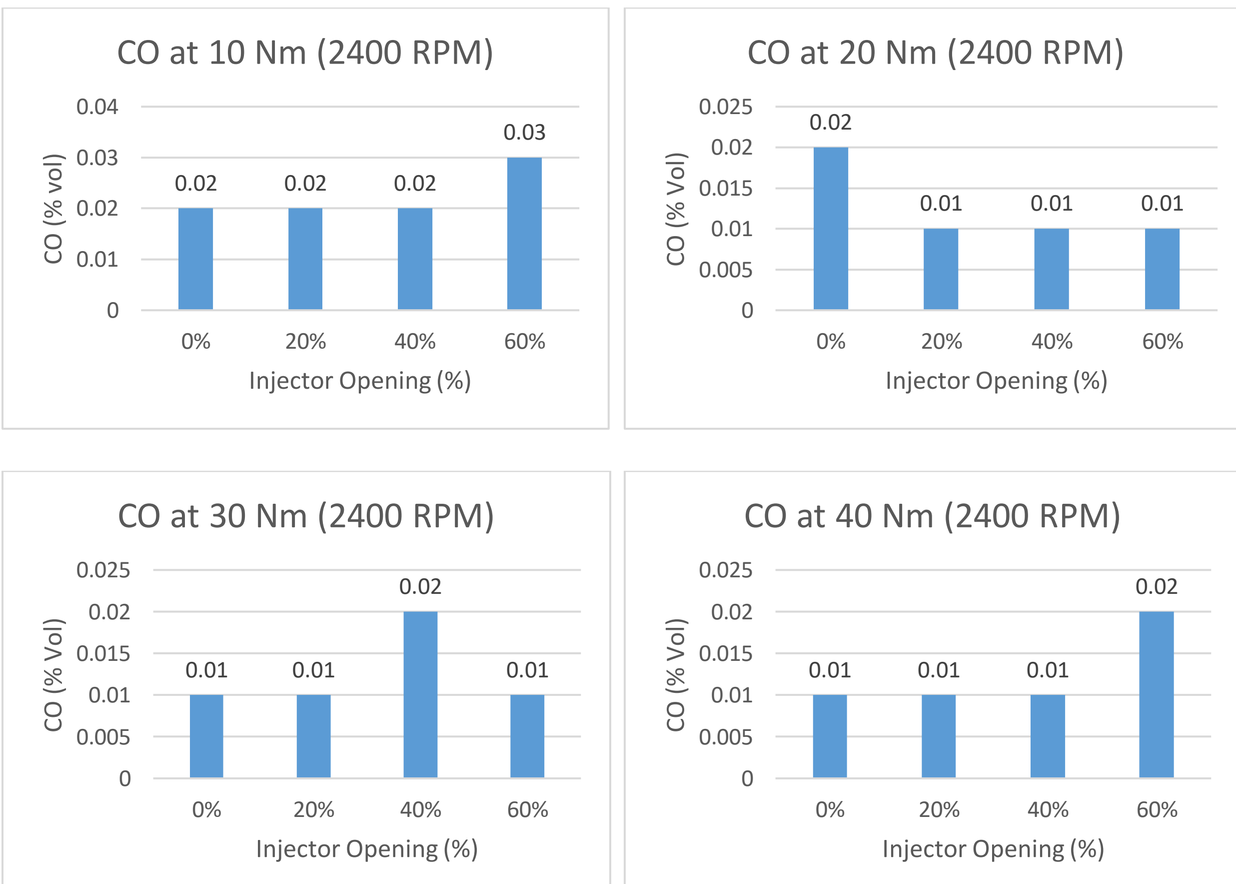


Fig.12**: CO at 2400 RPM**

For low loads, the CO emission increases as the ethanol fraction increases, while for high loads, the CO emission is almost the same for all ethanol fractions (Fig. 11 and 12).

HC Emission

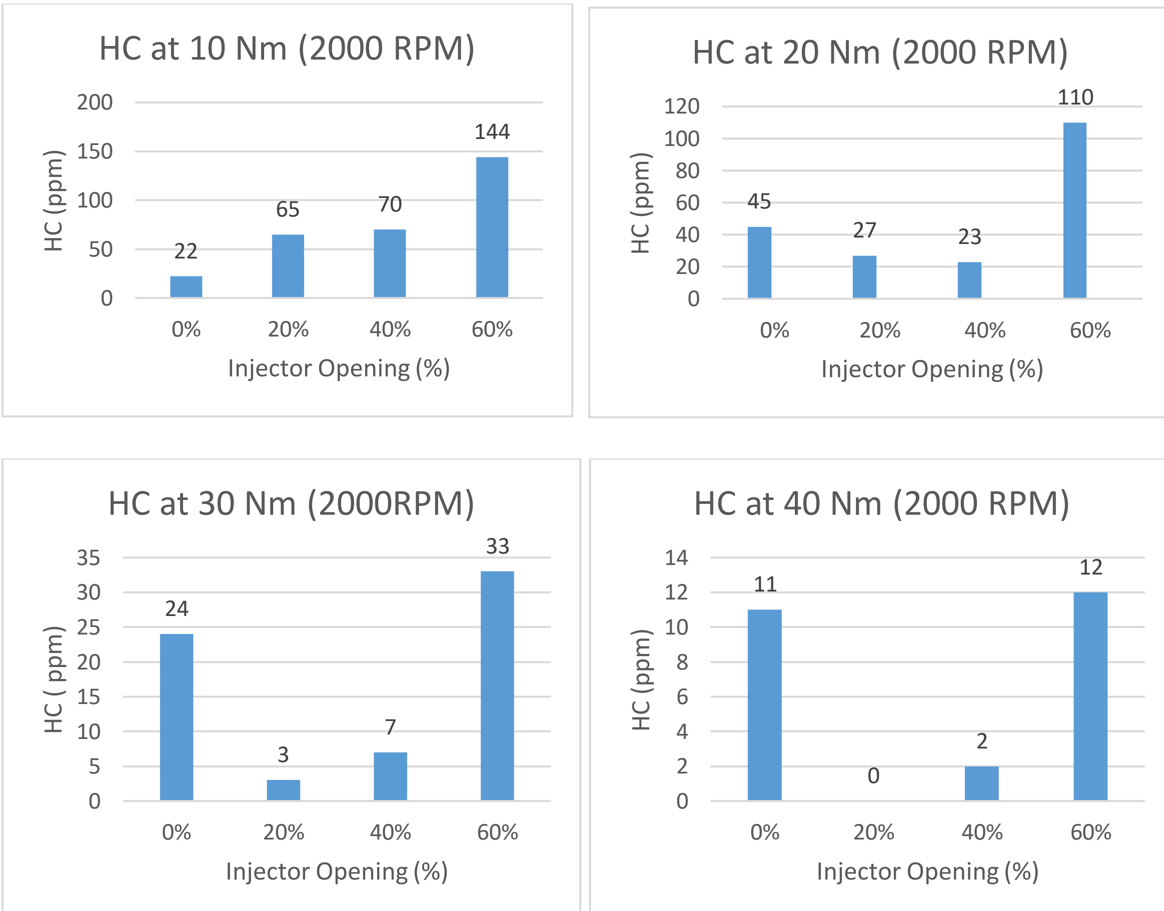


Fig. 13: HC at 2000 RPM

The observed decrease in HC emissions with increasing load and injector opening duration can be attributed to several factors. At higher loads, the engine operates closer to its optimal combustion conditions, promoting more complete fuel combustion and minimizing the formation of unburned hydrocarbons (Fig. 13). Similarly, longer injector opening durations allow for better fuel atomization and mixing, facilitating more uniform combustion and reducing HC emissions. The addition of ethanol to diesel blends may further enhance combustion efficiency by improving fuel vaporization and increasing the oxygen content, thereby aiding in the reduction of HC emissions.

<u>CONCLUSION:</u>

- At 2000 RPM, the maximum ethanol–diesel fuel percentage was found up to 20% at a 40 Nm load.
- For 2000 and 2400, when the load increases, NOx emissions also increase, but increasing the openings leads to a decrease in NOx emissions.

- The brake power is produced by the engine at 2000 and 2400 RPM, respectively. By comparison, for all RPM, a 20% opening shows lower brake power. And the 60% ethanol opening shows the higher brake power.
- One significant observation of the P-θ curve is the higher pressure observed at 60% opening for both RPM settings, ranging from 80 to 90 bar.
- For 2000 and 2400 RPM, the heat release rate displays a more pronounced peak, particularly at higher ethanol blending ratios.
- For low loads, the CO emission increases as the ethanol fraction increases, while for high loads, the CO emission is almost the same for all ethanol fractions.
- HC emissions decrease as the load increases and the opening increases.
- Optimization strategies for improving engine efficiency and emission control with alcohol fuels.

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