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Effect of Injection Timing and EGR on the Diverse Attributes of Diesel Engine Powered with Juliflora Methyl Ester Blend

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ABSTRACT

The study examines the efficacy of using a 20% blend of juliflora methyl ester (JFME20) as a diesel fuel alternative, focusing on injection timings of 19°, 23°, and 27° bTDC. At 27° bTDC, JFME20 exhibited a 4.53% increase in brake thermal efficiency (BTE) compared to standard conditions. Emission reductions at full load were notable: smoke decreased by 8%, hydrocarbons (HC) by 17.3%, and carbon monoxide (CO) by 25.45%. However, nitrogen oxide (NOx) emissions increased, necessitating additional mitigation strategies. To address this, exhaust gas recirculation (EGR) was implemented at 10% and 20% with JFME20 at 27° bTDC, resulting in substantial NOx reductions by 16.74% and 33%, respectively, compared to JFME20 without EGR. These findings underscore that JFME20 enhances thermal efficiency, reduces CO, HC, and smoke emissions, and highlights the necessity of managing NOx emissions. EGR emerges as a vital technique for optimizing the environmental performance of biofuels in diesel engines, balancing efficiency and emission control. This study demonstrates the potential of JFME20 as a viable diesel substitute, with EGR playing a critical role in mitigating its environmental impact.

Keywords: Juliflora methyl ester; Injection timing; EGR; Combustion; Emissions.

1. INTRODUCTION

The global automotive industry increasingly focuses on alternative fuels to mitigate environmental impacts, particularly in response to stringent emission regulations. One promising contender in this arena is biodiesel, derived from organic materials like algae, animal fats and vegetable oils. Biodiesel presents itself as a viable supernumerary for conventional diesel because of its comparable qualities and potential environmental benefits, yet it comes with challenges, particularly in terms of its impact on engine efficiency and emissions, notably nitrogen oxides (NO_x). Because of its similar chemical makeup to diesel, diesel engines are capable of using biodiesel that is already in use without requiring many changes. This compatibility has spurred numerous studies to assess its performance and environmental impacts across various feedstocks and blending ratios. Research by Subramaniam *et al*. (2020) highlights that biodiesel extracted from Azolla pinnata algae, despite its ecological promise, exhibited a notable decrease in brake thermal efficiency (BTE) during engine experiments. This reduction in BTE is a common finding across many biodiesel studies. Emiroğlu *et al*. (2018) corroborate this trend, noting that as the concentration of biodiesel increases, BTE tends to decrease. However, they also observed higher cylinder pressures with biodiesel, indicating altered combustion characteristics. Interestingly, studies such as those by Raman *et al*. (2019) and Rajendran and Ganesan (2021) found that a 20% biodiesel blend (B20) can yield acceptable performance, with lower emissions of CO and HC likened to pure diesel. Rathore *et al*. (2019) further supported these findings, reporting improved BTE at all engine loads with a B20 blend. This suggests that optimal blending ratios can balance efficiency and emissions trade-offs. Nevertheless, challenges persist. Khiari *et al*. (2016) noted that higher concentrations of biodiesel can lead to increased viscosity, affecting fuel injection timing and potentially compromising combustion efficiency. Yesilyurt and Aydin (2020) echoed these concerns, reporting decreased BTE when biodiesel content exceeded 20%. Their findings underscore the importance of carefully selecting blending ratios to maintain engine performance. Environmental considerations are pivotal. Temizer *et al*. (2020) emphasized biodiesel's eco-friendly credentials, highlighting higher cylinder pressures and temperatures during combustion, which can enhance thermal efficiency but may also elevate NO_x emissions. Further evidence for this assertion was presented by Uyumaz *et al*. (2020), who noted that while biodiesel derived from poppy oil reduced CO emissions, it marginally increased NO_x emissions compared to diesel. The disparity in results emphasizes how intricately biodiesel characteristics, engine architecture, and operating circumstances interact. Feedstock type, blending percentage, and engine technology influence performance outcomes. Despite efficiency challenges, biodiesel remains an attractive alternative due to its renewability and potential for mitigating greenhouse gas emissions. Continued research into advanced combustion technologies, engine modifications, and novel feedstocks will be crucial in optimizing biodiesel's performance. Addressing NO_x emissions remains a critical focus area, with strategies like Exhaust Gas Recirculation (EGR) showing promise in mitigating environmental impacts without compromising engine efficiency excessively. In conclusion, while biodiesel holds promise as a sustainable alternative fuel, its integration into mainstream use requires careful consideration of its impact on engine efficiency and emissions. Future advancements and policy support will be pivotal in realizing biodiesel's full potential as a key component of a cleaner transportation future.

Recent research has focused on the impact of biodiesel on engine performance, combustion and emissions to determine whether it might be a viable substitute to traditional diesel fuel. According to Mubarak *et al.*'s (2021) research, biodiesel made from Salvinia Molesta oil has characteristics significantly comparable to diesel fuel. In their study, a 20% biodiesel blend exhibited a Brake Thermal Efficiency (BTE) of 29.51%, reducing CO emissions by 14% and carbon dioxide (CO_2) emissions by 3.36%. However, ISIK *et al.* (2021) found that when they used safflower biodiesel in their studies, there was a rise in BSFC, which they attributed to the fuel's lower calorific value than diesel. Similarly, Selva Babu *et al.* (2020) demonstrated that coriander seed oil-based biodiesel is feasible for diesel engines, indicating promising results for its application. Vijay *et al.* (2018) reported favorable outcomes for a B20 blend, showing improved thermal efficiency and emissions characteristics, albeit with increased nitrogen oxide (NOx) emissions. Szabados and Bereczky (2018) evaluated biodiesel properties and highlighted significant viscosity differences compared to diesel. Praveen *et al.* (2018) recommended EGR as a cost-effective way to reduce NOx emissions. Reddy *et al.* (2021) supported this finding, showing that 5% EGR decreased NOx emissions by 43.3% while slightly reducing BTE and BSFC. Praveena *et al.* (2020) explored grapeseed oil biodiesel with varying EGR rates, concluding that 5% EGR significantly reduced NOx emissions with minimal impact on BTE, whereas 20% EGR reduced BTE by 6.21% and increased BSFC by 31%. Sun *et al.* (2020) highlighted EGR's role in NOx reduction, noting an increase in ignition delay with higher EGR rates, albeit with adverse effects on CO and HC emissions. Saravanan *et al.* (2020) investigated fish oil and jatropha oil biodiesel with 20% EGR and discovered lower exhaust gas temperatures but lower BTE. Overall, biodiesel shows promise as a sustainable alternative to diesel, with varying impacts on engine performance and emissions depending on feedstock and blend ratios. While biodiesel generally improves specific emissions profiles like CO_2 and particulate matter, challenges such as lower calorific value and higher NOx emissions under certain conditions necessitate careful optimization strategies. EGR emerges as a viable technique to mitigate NOx emissions with other emissions and engine efficiency trade-offs. Advanced injection timing increases efficiency due to better premixed combustion and higher peak pressures. Maximizes efficiency by utilizing advanced injection while controlling NOx emissions with EGR. Optimized Timing with Moderate EGR achieves good fuel economy with controlled NOx and minimal impact on other emissions like CO and HC.

It is observed from the literature that ongoing research continues to refine biodiesel formulations and engine optimization techniques to enhance its compatibility with diesel engines, aiming for a balance between performance improvements and environmental benefits. Future studies may focus on addressing remaining challenges to maximize the potential of biodiesel as a sustainable fuel option in the transportation sector.

Table. 1 Variations in biodiesel's impact on diesel engine properties

Biodiesel Used	Results outcomes	References
Cottonseed Biodiesel	↓BTE ↓HC ↓CO ↑NO_X	Kandasamy *et al.* (2019)
Fish oil Methyl Ester	↑BSFC↑NO_X↓HC ↓CO_2	Kattimani *et al.* (2020)
Mexicana Argemone and Mahua	↓BTE ↓HC ↓CO	Kumar and Singh (2019)
Mahua Biodiesel	↓BTE ↓HC ↓SO	Nayak and Pattanaik (2014)
Lal ambari Biodiesel	↓BTE ↑BSFC ↓HC ↓CO	Shrivastava *et al.* (2020)

Table 2 shows how various rates of Exhaust Gas Recirculation (EGR) influence engine characteristics.

Table 2. Effects of varying EGR rates on engine characteristics

Type of fuel and EGR	Inferences	References
Calophyllum inophyllum biodiesel, EGR 10%	↓BTE ,↓NO_X	Ashok *et al.* (2017)
Ethanol-fueled diesel, 20% EGR	↓BTE,↓NO_X	Sathiyamoorthi *et al.* (2019)
Palm biodiesel, 20% EGR	↓BTE,↓NO_X,↓HC, ↓CO	Venu *et al.* (2019)
Biogas, 5% EGR	↓NO_X ,↓HC ,↓CO	Verma *et al.* (2019)
Fish biodiesel, EGR 20%	↓NO_X	Bhaskar *et al.* (2013)

Exhaust Gas Recirculation (EGR) is a technique used in internal combustion engines to reduce nitrogen oxides (NO_x) emissions by recirculating a portion of the exhaust gases back into the engine's intake manifold. The EGR rate, defined as the percentage of exhaust gas recirculated, significantly affects engine performance, particularly in terms of power output and fuel consumption. Higher EGR rates are favorable for NO_x reduction but come at the cost of power and fuel economy. Modern engines optimize EGR rates through advanced control systems to strike a balance between emission standards, performance, and fuel economy. The literature widely advocates transesterification for producing biodiesel, which closely matches conventional fossil fuels in their properties. Many researchers have demonstrated that biodiesel is compatible with CI engines without requiring engine modifications. Research continuously shows that motors fueled by biodiesel produce less pollution than regular diesel-powered ones. Juliflora biodiesel (JFME20) is emerging as a promising alternative fuel, boosting properties rivaling diesel fuel. The current study uses a JFME20 blended diesel. The study varies injection timings and EGR rates to assess their impact, comparing results directly with standard diesel to draw meaningful conclusions.

2. MATERIALS AND METHODOLOGY

2.1 Juliflora

Juliflora trees are endemic to South America and Caribbean towns. It is a dry land tree, which gives it more advantages in terms of availability throughout the year. Julliflora will be found in all regions of India, making seed availability very easy. It is grown for different reasons, such as construction work, fuel, and charcoal. The trees can be grown in tonnes and seeds can be collected in any season. Fig. 1 shows a fully grown Julliflora tree, Fig. 2 Shows Julliflora dry seeds.

Fig. 1: Julliflora tree

Fig. 2: Julliflora dry seeds

2.2 Biodiesel Preparation and Experimental Setup

Julliflora seeds are harvested and dried before undergoing cold press extraction to obtain their oil. The oil is then carefully filtered to produce pure Julliflora oil.

The literature revealed that transesterification is a proven process for producing biodiesel. The transesterification process reduces the oil's fat content, thus improving oil properties for combustion. The Juliflora are dryland trees, which means they are independent of water availability, giving Juliflora oil production an advantage. India has a large area of dry land which provides more availability of Juliflora seeds.

Transesterification breaks down large triglyceride molecules from Juliflora oil into smaller molecules resembling diesel molecules. The process includes heating the Juliflora oil with alcohol, aided by a catalyst to accelerate the chemical reaction. After heating, the mixture is left to cool and settle: the fat separates and settles at the bottom, while the biodiesel forms a layer on top.

Once the biodiesel is obtained the different blends are prepared. The qualities of Juliflora biodiesel and its blends are shown in Table 3.

Table 3. Fuel properties of diesel and juliflora biofuel

Properties of Fuel	Diesel	JFME	JFME20
Heating value (MJ/kg)	42.6	39.08	41.25
Flashpoint (˚C)	51	161	73
Viscosity (cSt)	3.31	6.12	3.74
Density(kg/m^3)	830	889	841
Cetane index	48	51	49
Viscosity (cSt)	3.31	6.12	3.74
Fire point (˚C)	57	166	78

The use of JFME20 (20% Juliflora Methyl Ester and 80% diesel) for commercial and industrial applications is promising but faces challenges. Juliflora, a hardy and invasive species, is widely available and offers a sustainable feedstock for biodiesel. Also, the cost of biodiesel production, including feedstock collection, processing, and transesterification, is lower than fossil diesel. Long-term engine performance with JFME20 has shown reduced wear due to better lubrication, but challenges include managing deposits and ensuring fuel consistency. Scaling requires policy incentives, technology improvements, and logistics to make JFME cost-competitive and ensure consistent supply. The cost analysis for Juliflora biodiesel per liter production is shown in below table 4.

Table 4. Cost analysis for Juliflora biodiesel production per liter

S. No.	Cost Component	Estimated Cost (Rs)
1	Feedstock Collection	12
2	Processing (Crushing/Extracting)	10
3	Transesterification Process	15
4	Labor and Maintenance	12
5	Transportation and Storage	6
	Total cost	55

3. EXPERIMENTAL SETUP

Experiments on a diesel engine utilizing blends of diesel and biodiesel aimed to investigate various engine parameters under different conditions. The engine was tested at a constant speed of 1500 rpm with load increments of 25%, from 0% to 100%. Three injection timings were employed: standard (SIT-23° bTDC), advanced (AIT-27° bTDC), and retarded (RIT-19° bTDC). Additionally, exhaust gas recirculation (EGR) experiments were conducted using a JFME20 biodiesel blend, applying 10% and 20% EGR levels under advanced injection timing.

A multi-gas analyzer measured engine exhaust emissions, while a smoke meter assessed smoke emissions. A comprehensive data collection system was used to gather detailed combustion data. Each experimental test was repeated three times to ensure the reliability of the results. The data on engine parameters are detailed in Table 5, and Figure 3 provides a experimental setup of the diesel engine.

This thorough experimental setup allowed for the assessment of the effects of varying load conditions, injection timings, and EGR levels on engine performance and emissions. The systematic repetition of tests ensured robust and reliable data, facilitating a comprehensive understanding of how biodiesel blends and different engine settings influence overall engine behavior.

Table 5. Technical standards for diesel engines used for the current study

Model/Make	TV1/Kirloskar
Compression ratio	17.5
Stroke length	110 mm
Nozzle size	0.3 mm
Cylinder Dia	87.5 mm
Swept volume	661 cm^3
Rated speed/power	1500 rpm/4.4 kW
Number of nozzles	3

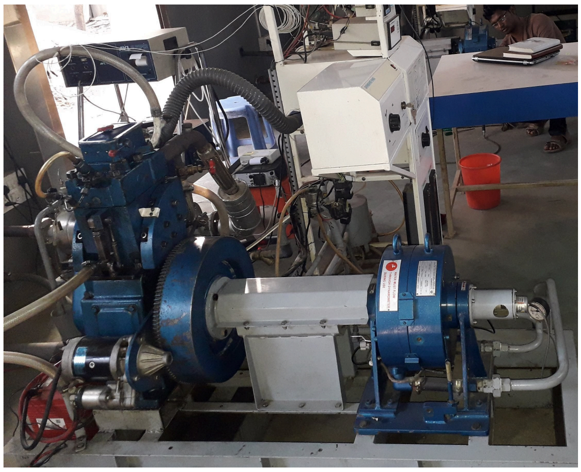

Fig. 3: Experimental setup of diesel engine

4. RESULTS AND DISCUSSIONS

4.1 Brake Specific Fuel Consumption

Figure 4 illustrates that all tested fuel samples exhibit a similar trend where the Brake Specific Fuel Consumption (BSFC) decreases with increasing engine load, reaching a minimum at the entire load operation. At peak load, the BSFC values for the fuels are as follows: diesel at 0.24 kg/kWh, JFME20 at 19˚bTDC at 0.27 kg/kWh, JFME20 at 23˚bTDC at 0.26 kg/kWh, JFME20 at 27˚bTDC at 0.28 kg/kWh, JFME20 at 23˚bTDC with 5% EGR at 0.29 kg/kWh, and JFME20 at 23˚bTDC with 10% EGR at 0.305 kg/kWh. The data reveals that advanced injection timing leads to a lower BSFC for JFME20 at peak load, indicating improved fuel efficiency. Conversely, introducing Exhaust Gas Recirculation (EGR) slightly increases the BSFC, reflecting a minor reduction in fuel efficiency. These findings align with previous research by Kumar *et al.* (2019), reinforcing the understanding that optimizing injection timing can enhance engine performance while using EGR, although beneficial for emissions control, may compromise fuel efficiency. This balance between performance and emissions remains critical in engine research and development. These results were close conformity with the results reported by Prasada and Prasad (2022) and Kumar *et al*. (2022).

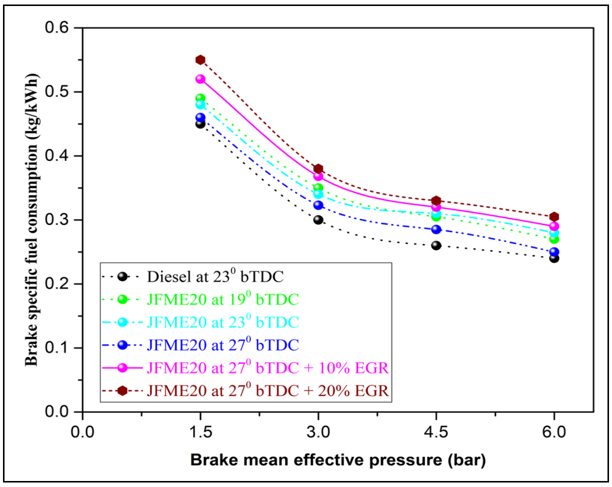

Fig. 4: Variation of BSFC with BMEP

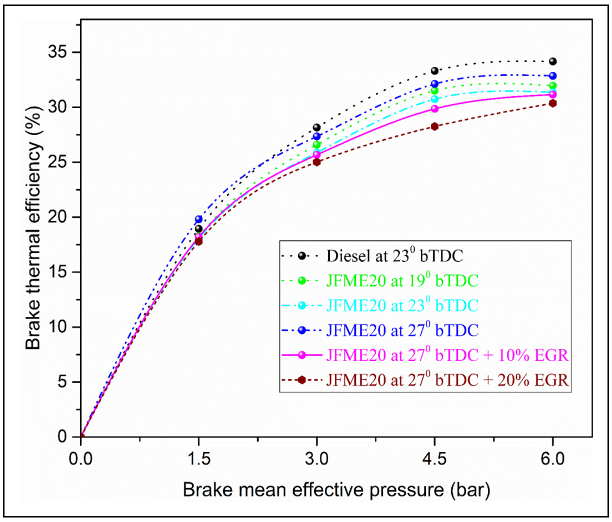

Fig. 5: BTE variation with BMEP

4.2 Brake Thermal Efficiency

Figure 5 shows the variation in BTE with BMEP for different injection timings and conditions. Among the various injection timings for the JFME 20 blend, 27˚bTDC yields the highest BTE, outperforming 19˚bTDC and 23˚bTDC. The fuels examined—diesel, JFME20 at 19˚bTDC, JFME20 at 23˚bTDC, JFME20 at 27˚bTDC, JFME20 at 27˚bTDC with 10% EGR, and JFME20 at 27˚bTDC with 20% EGR—demonstrate BTEs of 34.2%, 31.92%, 31.95%, 31.36%, 31.15%, and 29.32%, respectively. Reddy *et al*. (2021) reported that incorporating exhaust gas recirculation (EGR) at 27˚bTDC leads to a decline in BTE as EGR levels increase. This decrease is attributed to the diluting effect of the recirculated exhaust gas on the fuel/air mixture, which hinders efficient combustion. Particularly, at full load with 20% EGR, the drop in BTE is more pronounced. BTE is a critical metric for assessing an engine's efficiency in converting heat into useful work. The findings highlight the impact of injection timing and EGR on engine performance, emphasizing the trade-off between reducing emissions and maintaining high thermal efficiency. The use of biodiesel was shown slight lower BTE when compared to diesel and these results were close agreement with the results presented by Harish venu *et al*. (2019) and Bala Prasad *et al*. (2021).

4.3 Hydrocarbon Emissions

Incomplete combustion is a key contributor to elevated HC emissions. Figure 6 demonstrates the variations in HC emissions with BMEP, significantly affected by factors like energy content and cetane index. The analysis of HC emissions for diesel and various JFME20 engine configurations—measured at different degrees before top dead center (BTDC), with and without EGR—yielded the following values: 42 ppm for diesel, and 47 ppm, 52 ppm, 43 ppm, 57 ppm, and 64 ppm for JFME20 respectively.

These findings reveal that HC emissions are minimized when the JFME20 engine operates with advanced injection timings, indicating more efficient combustion. On the other hand, because the fuel/air combination is diluted when the EGR is activated at full load, the amount of HC emissions increases. This dilution impairs the combustion process, leading to higher unburnt hydrocarbons. According to Venu *et al*. (2019), this pattern supports their findings and emphasizes the intricate relationship between injection timing and EGR in determining HC emissions. While EGR is good for reducing NOx emissions, it can sometimes worsen incomplete combustion, increasing HC emissions. In contrast, advanced injection timing encourages complete combustion, which lowers HC emissions.

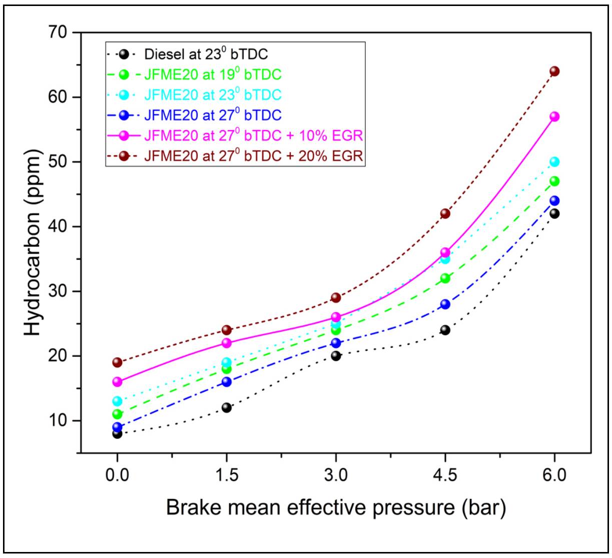

Fig. 6: Variation in HC emissions with engine load

4.4 Carbon Monoxide Emissions

CO emissions in diesel engines primarily result from improper ignition. Figure 7 illustrates the variation in CO emissions for various fuels. Specifically, the CO emissions for diesel, JFME20 19˚bTDC, JFME20 23˚bTDC, JFME20 27˚bTDC, JFME20 23˚bTDC with 5% EGR, and JFME20 23˚bTDC with 10% EGR are recorded at 0.132%, 0.278%, 0.165%, 0.123%, 0.321%, and 0.41%, respectively. Implementing 5% and 10% EGR with JFME20 at 27˚bTDC significantly reduces CO emissions at peak load compared to other injection timings. This indicates that EGR effectively mitigates CO emissions by enhancing combustion efficiency. Therefore, optimizing EGR and injection timing is crucial for lowering CO emissions in diesel engines using JFME20 fuel blends, contributing to better engine performance and reduced environmental impact Gopidesi *et al*. (2024).

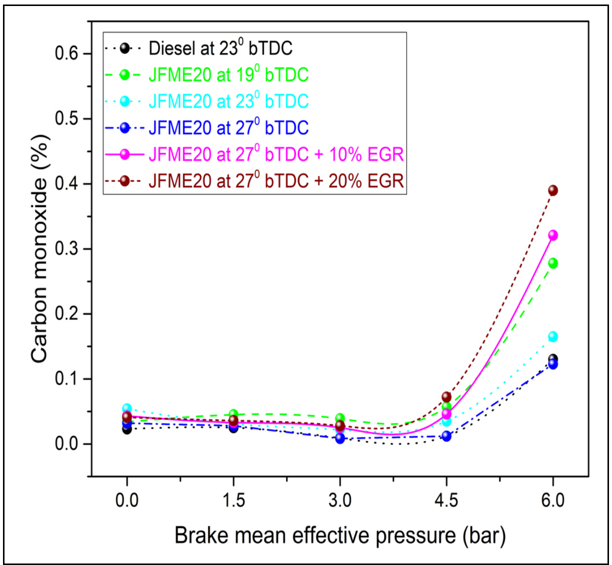

Fig. 7: Variation in CO emissions with BMEP

4.5 Nitrogen Oxides

The deviation of NOx emissions with BMEP for a diesel engine operating on biofuel is primarily due to the higher availability of oxygen and increased in-cylinder temperatures. Oxygen molecules are particularly reactive with NO_x at temperatures above 1500 ˚C. Measurements of NO_x emissions for various conditions showed in figure 8: 1922 ppm for diesel, 2087 ppm for JFME20 at 19˚ bTDC, 2112 ppm at 23˚ bTDC, 2198 ppm at 27˚ bTDC, 1830 ppm for JFME20 at 23˚ bTDC with 5% EGR, and 1475 ppm with 10% EGR. These results indicate that NOx emissions increase when biofuel is used due to more available oxygen and higher combustion temperatures. However, employing exhaust gas recirculation (EGR) significantly reduces NO_x emissions. The significant reduction in NO_x emissions with 10% EGR underscores its role in mitigating the environmental impact of using biofuels in diesel engines. The use of EGR and changing the injection timing have shown promising engine attributes reported by Kishore *et al*. (2018) and Ramakrishna Reddy *et al*. (2020).

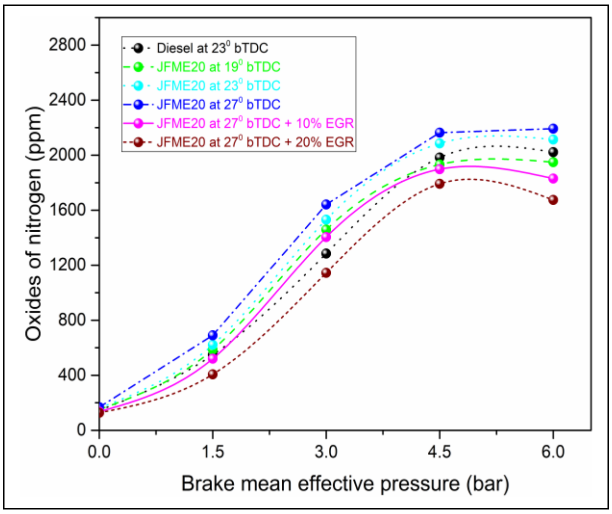

Fig. 8: Changes in NOx emissions according to engine load

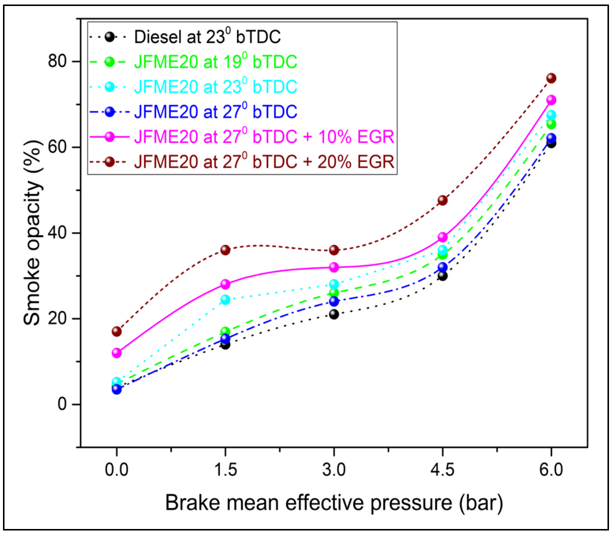

Fig. 9: Variation of smoke opacity with BMEP

4.6 Smoke Opacity

Figure 9 shows the variations in smoke emissions for diesel and Juliflora biodiesel fuels under different loads. The engine's incomplete combustion is the leading cause of smoke emissions. Diesel, JFME20 19˚bTDC, JFME20 23˚bTDC, JFME20 27˚bTDC, JFME20 23^bTDC with 5% EGR, and JFME20 23˚bTDC with 10% EGR have smoke opacity ratings of 69%, 65%, 67.5%, 62%, 72%, and 76% at full load, respectively. Interestingly, the smoke opacity decreases with the biodiesel blends compared to diesel, with JFME20 27˚bTDC having the lowest value at 62%. However, introducing 5% and 10% EGR to the JFME20 23˚bTDC blend leads to higher smoke opacity values of

72% and 76%, respectively, indicating that EGR increases smoke emissions. This trend suggests that while biodiesel blends can reduce smoke emissions, using EGR in these blends may counteract this benefit Gopidesi *et al*. (2019).

4.7 Cylinder Pressure

Figure 10 shows the fluctuation of cylinder pressure with crank angle, influenced by various phases of the combustion process, such as after-burning, regulated combustion, and rapid combustion. Among the fuels tested, diesel exhibits the highest cylinder pressure, reaching 75.2 bar at peak load, followed by JFME20 at 23˚bTDC with 71 bar. Introducing exhaust gas recirculation (EGR) significantly reduces cylinder pressure under all load conditions and slows the rate of pressure increase. Specifically, for JFME20 at different timing settings, the cylinder pressures at peak load are recorded as follows: JFME20 at 19˚bTDC reaches 68.2 bar, at 23˚bTDC it reaches 71 bar, and at 27˚bTDC it reaches 70.12 bar. When EGR is applied at 23˚bTDC, the pressure decreases further; with 5% EGR, the pressure is 72.52 bar, and with 10% EGR, it drops to 69 bar and finally to 65 bar. The data indicate that increasing EGR levels can effectively reduce peak cylinder pressures, demonstrating its potential for controlling combustion dynamics and improving engine performance while reducing emissions Gopidesi *et al*. (2020).

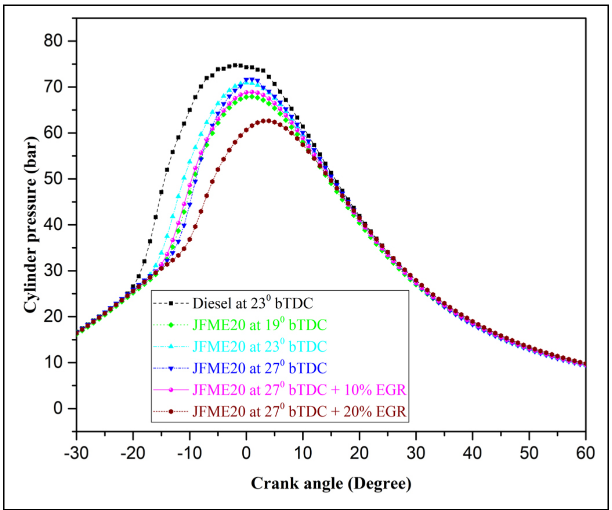

Fig. 10: Cylinder pressure variation at various crank degrees

4.8 Heat Release Rate (HRR)

HRR, or the quantity of heat released during combustion, as depicted in Figure 11. The combustion's diffusive phase dramatically impacts it. Some factors that significantly affect HRR rate are the fuel's heating value, optimal air/fuel ratio, and cetane number. Equation (1) represents the rate of heat release during burning.

$$\left(\frac{dQn}{d\theta}\right) = \left(\frac{\gamma}{\gamma-1}P\frac{dV}{d\theta}\right)+\left(\frac{1}{\gamma-1}V\frac{dP}{d\theta}\right)+ Q_{lw} \quad \ldots (1)$$

At maximum load, the heat release rates for diesel, JFME20 19^bTDC, JFME20 23^bTDC, JFME20 27˚bTDC, JFME20 23^bTDC 5% EGR, and JFME20 23^bTDC 10% EGR are 61.5 kJ/^ CA, 55.98 kJ/˚CA, 56.86 kJ/^ CA, 58.8 kJ/˚ CA, 54 kJ/- CA, and 51 kJ/- CA, respectively. Additionally, a noteworthy decrease in HRR is observed when a higher EGR application is used.

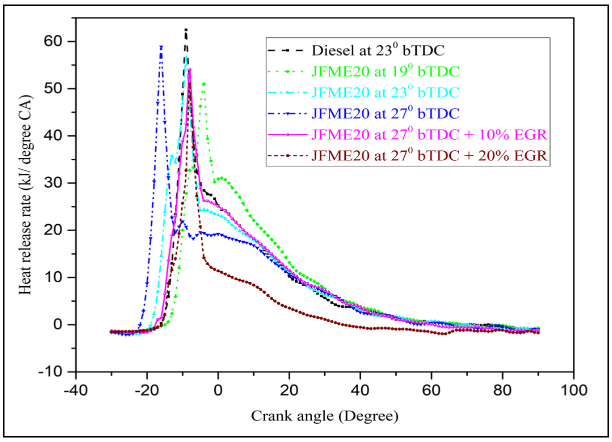

Fig. 11: HRR variation with engine crank angle

5. CONCLUSION

The current experimental study studies the impact of EGR and injection timing on various aspects of a diesel engine. The key findings from these experiments are summarized below:

- Among different injection timings (19˚bTDC, 23˚bTDC, and 27˚bTDC) for the JFME 20 blend, the highest Brake Thermal Efficiency (BTE) was observed at 27˚bTDC compared to other settings. Specifically, a 4.53% increase in BTE was noted for JFME 20 at 27˚bTDC compared to standard operating conditions.

- Combustion characteristics such as HRR (58.82 J/deg CA) and cylinder pressure (72.52 bar) showed improvement with the advanced injection timing of JFME 20, particularly at 27˚bTDC.

- In comparison to conventional injection time at full load, significant reductions in key exhaust emissions—HC, CO, and smoke emissions—of 17.3%, 25.45%, and 8%, respectively, were seen with the JFME 20 blend at 27˚bTDC.

- NOx emissions were notably reduced when using EGR at 10% and 20% with the JFME 20 blend at 27˚bTDC. Specifically, 16.74% and 33% reductions in NOx emissions were achieved with 10% and 20% EGR, respectively, compared to the same operating conditions without EGR at maximum load.

In conclusion, the study recommends operating the JFME 20 biodiesel blend with 10% EGR at 27˚bTDC to achieve promising engine attributes, including significant reductions in exhaust emissions.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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