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Effect of Oxygenated Fuel on Performance and Emissions of SI and CI Engines: A Review

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Abstract

The increasing concern for cleaner combustion and reduced emissions has intensified the exploration of oxygenated fuels in internal combustion (IC) engines. This review analyzes the effects of various oxygenated fuels such as ethanol, methanol, butanol, hydrogen, and dimethyl ether on the performance and emissions of spark ignition (SI) and compression ignition (CI) engines, particularly under different compression ratio (CR) configurations. Key findings from comparative studies reveal that blends like E30 at CR 11:1 can enhance engine power output by up to 14% while adding 1-butanol shortens combustion duration and reduces particulate emissions. In CI engines, using PODE blends (P10–P30) reduced smoke emissions by 27.6%, 41.5%, and 47.6%, respectively, compared to diesel. Ethanol and methanol blend improved brake thermal efficiency (BTE) by up to 13.8% and reduced CO emissions by 33.31%. Notably, CO_2, NOx, and CO emissions decreased by 30%, 22%, and 37%, respectively, when methanol was used in SI engines at a CR of 10:1. However, increases in HC emissions were reported with higher CR. The synergistic use of ethanol at 50% blend (E50) with a CR of 10:1 achieved up to 45% reduction in CO emissions compared to gasoline at CR 6:1. The review concludes that oxygenated fuels, especially when optimized with CR variation, offer significant improvements in engine efficiency and emissions control, and hold strong potential as sustainable alternatives for future fuel applications.

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1. Introduction

The increasing global concern over fossil fuel depletion and environmental degradation has stimulated extensive research into alternative fuels for internal combustion engines. Among the most promising alternatives are oxygenated fuels, such as ethanol, methanol, butanol, hydrogen, and dimethyl ether (DME). These have demonstrated significant potential in enhancing combustion efficiency while reducing toxic emissions. These fuels contain inherent oxygen atoms in their molecular structures, facilitating cleaner combustion and lowering carbon-based pollutant formation [1–4]. Numerous studies have reported that blending oxygenated fuels with conventional gasoline or diesel can improve engine thermal efficiency and reduce emissions of carbon monoxide (CO), unburned hydrocarbons (HC), and particulate matter (PM). For instance, ethanol-gasoline blends (E10 to E85) have been shown to increase brake thermal efficiency (BTE) by up to 13.8% and reduce CO emissions by 33.31% under optimized compression ratios [3,5–7]. Similarly, DME and polyoxymethylene dimethyl ethers (PODE) blends have reduced smoke emissions by 27.6% to 47.6%, highlighting their suitability for clean diesel engine applications [8–11].

Engine performance is highly dependent on fuel characteristics such as oxygen content, latent heat of vaporization, cetane number, viscosity, and volatility. Experimental studies have indicated that increasing the compression ratio (CR) enhances the thermal efficiency of engines using oxygenated fuels [12–15]. However, high CR can also increase NOx emissions, requiring careful optimization. For example, methanol at a CR of 10:1 reduced CO_2, NOx, and CO emissions by 30%, 22%, and 37%, respectively, while HC emissions slightly increased [16–19]. The behaviour of oxygenated fuels also varies across different engine types. Spark ignition (SI) engines benefit from the high-octane numbers of alcohols, allowing higher compression without knocking. On the other hand, compression ignition (CI) engines gain from fuels with high cetane numbers and oxygen content, which enhance combustion stability and reduce ignition delay. Blends such as 90B10-E10 (90% biodiesel blend with 10% ethanol) have improved performance and reduced emissions in CI engines under varying load conditions [20–23].

Combustion characteristics, such as heat release rate (ROHR), cylinder pressure (CP), and combustion duration (CD), are also significantly influenced by the presence of oxygen in fuels. Recent studies have shown that adding ethanol or methanol shortens ignition delay, increases CP, and enhances combustion completeness. This is particularly important for variable compression ratio (VCR) engines, where the synergy between fuel type and CR can be utilized to balance power output, efficiency, and emission profiles [24–28]. Despite the growing body of research, a comprehensive comparative review that integrates performance and emission outcomes across both SI and CI engines under variable CR conditions is limited. Most prior works focus on specific fuel blends or engine types in isolation. This review aims to fill that gap by analyzing and synthesizing data from multiple studies to evaluate the overall impact of oxygenated fuels on engine performance and emissions across a broad CR spectrum [29–33].

The primary objective of this review is to identify optimal combinations of oxygenated fuel types, blend ratios, and compression ratios that yield high thermal efficiency and low emissions. By evaluating experimental and simulation-based studies, this paper aims to provide practical insights for engine researchers and manufacturers seeking to develop cleaner, more efficient engines. The novelty of this research lies in its integrated analysis of SI and CI engines using various oxygenated fuels, with a specific focus on the interaction between fuel composition and compression ratio. This review highlights the potential of oxygenated fuels to support sustainable transportation and proposes pathways for optimizing engine performance through fuel-engine matching strategies.

2. Methodology

This study employs a comprehensive review methodology to evaluate the impact of oxygenated fuels on the performance and emissions of spark ignition (SI) and compression ignition (CI) engines. The review is conducted through systematic selection, analysis, and synthesis of previously published experimental and simulation-based studies focusing on oxygenated fuel types, blending ratios, and variable compression ratios (CR). The data sources include peer-reviewed journal articles, technical reports, and conference papers published between 2005 and 2024, emphasising studies indexed in reputable databases and high-impact journals. Keywords such as oxygenated fuels, compression ratio, engine performance, spark ignition engines, and compression ignition engines were used to filter relevant literature. Over 60 references were reviewed, with data extracted from more than 30 primary experimental studies.

The reviewed studies were categorized based on engine type (SI or CI), type of oxygenated fuel used (e.g., ethanol, methanol, butanol, DME, PODE, hydrogen), blending volume (e.g., E10, M30, B10), and the range of compression ratios applied (from 6:1 to 22:1). Performance parameters analyzed include specific fuel consumption (SFC), brake thermal efficiency (BTE), torque, and power output. Emission parameters include CO, CO_2, NOx, HC, and smoke. Quantitative findings such as reductions in CO emissions by up to 45% with E50 at CR 10:1 and improvements in thermal efficiency by up to 13.8% with carbinol blends were recorded and compared across studies. Tabular data from the original studies were extracted, reorganized, and interpreted to highlight consistent patterns and performance trends. This methodological approach allows for a cross-comparative analysis of how different oxygenated fuel formulations and compression ratios affect engine combustion behaviour, performance efficiency, and pollutant formation, supporting evidence-based conclusions and recommendations.

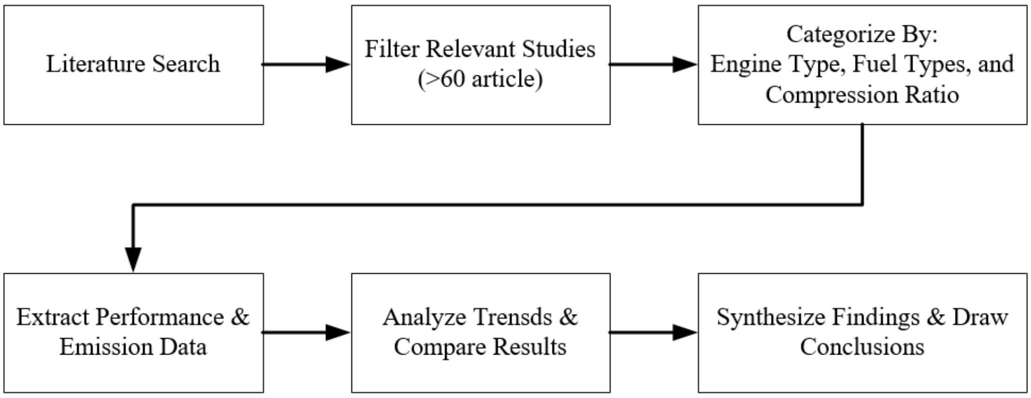

Figure 1: Flowchart of the Review Methodology for Evaluating Oxygenated Fuels in SI and CI Engines

Figure 1 illustrates the flowchart of the review methodology used in this study to evaluate the effects of oxygenated fuels on the performance and emissions of spark ignition (SI) and compression ignition (CI) engines. The process begins with a comprehensive literature search covering 2005 to 2024 to capture a wide range of experimental and simulation-based studies. The next stage involves filtering relevant studies, with more than 60 selected based on specific inclusion criteria such as relevance to oxygenated fuels, engine type, and the presence of performance or emission data. The selected studies are then categorized by engine type (SI or CI), type of oxygenated fuel (e.g., ethanol, methanol, butanol, hydrogen, DME), fuel blending ratios, and compression ratio (CR) range used in the tests.

In the data extraction phase, quantitative values are obtained for key performance indicators such as brake thermal efficiency (BTE), specific fuel consumption (SFC), torque (T), and power (P), along with emission data including CO, CO_2, NOx, and HC. Subsequently, the data is subjected to a comparative analysis, identifying trends, synergies, or trade-offs between fuel types, blend levels, and compression ratios. This step also helps highlight consistent patterns across different studies and engine configurations. Finally, the findings are synthesized to conclude the optimal fuel types and CR level combinations that enhance engine performance while minimizing emissions. This structured approach ensures a thorough and objective evaluation of existing literature and helps identify research gaps and future opportunities in sustainable combustion engine technologies.

3. Result & Discussion

Other fuel specifications

Performance on engines, emissions and cultivators can be affected by chemical and physical properties parameters. The oxygen content of oxygen fuel is one of the most critical features in which molecular compounds can significantly reduce HC and CO emissions. Still, otherwise, NOx emissions will allow for worse outcomes [13,34–37]. The fuel viscosity associated with an oxygen-fueled SI engine can produce quantities of octane and more critical properties during combustion. The ability of IC to influence widespread evaporation and volumetric efficiency can be increased, resulting in lower temperatures in the intake manifold [12,38]. The DME has a high cetane amount of oxygen fuel and has significantly improved engine performance to adjust the load on a cylinder [5,20,39]. However, the consumption of some oxygen-rich fuels, such as 37%-40% alcohol, can be decreased compared to fossil fuels, which must be used more (1.2-1.4) to produce the same power [40–42]. Then, the oxygen, carbon and hydrogen ratios and moisture content can influence the oxygen-fueled enrichment as it affects the fatty acid ash content [43–46].

Table 1. The performance of the SI engine and compression ratio affects the blending of oxygenated fuels.

Ref	Fuel	Blend	Volume	Type Engine	Range	SFC	P	TE	T	Finding
[5]	Diesel fuel	Methanol and Ethanol	DM10-DM15-DM20, DM25-DM30-DM35-DM40	SC, Four-stroke compression ignition	17:1	▲	▼	▲	▼	Adding and increasing wood alcohol content up to 30% mixed with diesel-methanol produced a positive result in thermal potency.
[47]	Gasoline	Ethanol	E0-E10-E20-E30	The four-cylinder four-stroke spark ignition engine	8.8:1	▲	▼	▲	▼	Experiments and theoretical calculations showed that fermentation alcohol side fuels show a discount in (CO), (CO_2) and (NOx) emissions.
[48]	Gasoline	n-Butane	40 CAD-42 CAD	SC, DISI (direct injection spark ignition)	12:1	X	X	X	X	n-Butane required a shorter mixture formation time. However, the variety of appropriate mixture formation times was narrower than gasoline.
[49]	Gasoline	Alcohol	T10-T50	Spark ignition, double overhead cam, 4 V	10.5:1	X	▲	▲	X	The Reid pressure, T10, T50 and warmth of vaporization recommend an essential result of mixture formation and fuel metering within the combustion development.
[24]	Gasoline	Methanol	iBE10-iBE7-iBE3-G	Four-stroke, spark-ignition, single cylinder	7:1	▲	▲	▼	▲	By increasing the mix rate price (>10 Vol%), the engine performance would exceed that of the clean gasoline fuel.
[50]	Natural Gas	Hydrogen		Kirloskar TAF1, air-	17.5:1	▲	▲	▲	▲	Hydrogen addition showed a discount on

Ref	Fuel	Blend	Volume	Type Engine	Range	SFC	P	TE	T	Finding
				cooled, single cylinder CI engine						organic compound emissions from sixty-five g/kWh to six.9 g/kWh at associate degree equivalence magnitude relation of zero.5 aboard monoxide and greenhouse gas reduction.

Influences of oxygenated fuel with CR on engine SI

The significant impact of fuel on engine combustion and emission performance is the high heat energy evaporation in LHOV, fuel content, high hydrocarbon content and flammable heat temperature within the SI engine by creating the quantitative compression relation (CR) to adore engine combustion. The effect of CR fuel on SI combustion engine performance is as concluded in **Table 1** and **Table 2**. The discussion thoroughly proceeds from the study results of previous research.

Influences on engine performance and efficiency

Ethanol fuel has a lower evaporation and heat rate than octane evaporation rate, and the high engine combustion strength is highly suited for the co-production ratio of fuels such as methanol and butanol. This is because alcohol and MTBE contain very high-octane values; hence, it is very suitable with a significantly increased compression ratio [50]. The experimental results performed by [5,24,47–50] showed that specific fuel consumption (SFC) and TE increased considerably with an increase in CR with oxygen fuel use, but for power (P) and torque (T) decreased in the combustion engine, as shown and described in **Table 1**. The LME heat peak rate was not very sensitive to the compression ratio and combustion duration of 10%-90%. Torque power was increased by 9.5%, while BSFC was reduced by 10.9%. Then, the NOx emissions were increased as the compression ratio increased. With the undesirable parameters, the LME compression ratio can be increased to 15.6% or without the tap, indicating an excellent performance increase for the LME [51,52]. Experimental work by Jamrozik [4] discussed the effect of compression ratio between methanol fuel and pure gasoline used in combustion engines, with compression ratio (17:1), which positively impacted thermal efficiency but was unchanged at constant pressure. The increase caused a substantial reduction in carbon monoxide emissions but showed significant effects on hydrocarbon and carbon dioxide emissions. Diesel-ethanol blends showed reduced CO emissions, but THC and CO_2 emissions did not change. Adding alcohol injures nitrogen oxide emissions from the engine, with a 30% alcohol content up to 10% of the COVIMEP coefficient.

Table 2. The emissions of SI engines and the effects of compression ratio on blending oxygenated fuels.

Fuel	Oxygenated Fuel	Volume	Type Engine	Range	CO2	HC	NOx	CO	Finding	Ref
Diesel fuel	Methanol and Ethanol	DM40	SC, 4S	17:1	▲	X	X	▲	The addition of wood alcohol up to time unit caused the increase in compound emissions by 146%.	[5]
Gasoline	n-Butane	40 CAD-42 CAD	SC, DISI (direct injection spark ignition)	12:1	X	X	X	▼	Particulate remember emission of n-butane was nearly zero while	[48]

Fuel	Oxygenated Fuel	Volume	Type Engine	Range	CO2	HC	NOx	CO	Finding	Ref
									(NOx) emissions were much like those of gas.	
Gasoline	Alcohol	T10-T50	Spark ignition, double overhead cam, 4-V	10.5:1	▼	▼	▲	▼	Oxygen contents and relative density are directly related to CO and CO_2 and reciprocally connected with NOx emissions.	[49]
Gasoline	Methanol	iBE10-iBE7-iBE3-G	Four-stroke, spark-ignition, single-cylinder	7:1	▼	▼	X	▼	By 10 vol%, ternary blends bestowed a slight drop in engine performance, compared to regular petrol, by 2, 3.8 and 1.7%.	[24]
Natural Gas	Hydrogen		Kirloskar TAF1, air-cooled, single-cylinder CI engine	17.5:1	▼	X	▲	▼	Adding hydrogen can significantly enhance performance and reduce HC and NOx.	[50]
Gasoline	Ethanol	E0-E10-E50-E85	4-stroke, 4-cylinder, GDI wall-guided turbocharged	9.5:1	▲	X	▲	▲	In addition, E85 and E50 showed higher values of the integral flame physical property within the initial part of combustion because of the upper flame speed regarding hydrocarbon.	[54]

During engine execution, the tap on the engine should be avoided to increase the compression ratio. The effect of high octane fuel value with a bit low below the variable compression ratio on the DISI engine was experimentally studied by Thomas et al. [29,53]; experiments were tested with volume compression ratio (VCR) between 10.7 and 11.5 at 8.5 bar engine load, with mixed fuel (Bu1020% 1-butanol with gasoline) and (E2020% ethanol with gas). Adding 1-butanol and ethanol to gasoline was very useful at the point of MFB50 and can shorten the combustion duration. At the same time, adding 1-butanol to gas was proper to scale back the PM emission, whereas Night is often reduced by exploitation of ethyl alcohol. With the experimental results, the synergy between compression ratio and the addition of alcohol to gasoline enabled the simultaneous control of gas and particle emissions, increasing savings on fuel usage in the engine.

Research on the effect of compression ratio variables (7:1 to 13:1) was done by Elfasakhany [24,55,56] with different mixtures of fuels (iBE10, iBE7, iBE3, and G) on performance and emissions of combustion engines. Experimental results showed that the throttle was wide open (WOT), and the stoichiometric fuel and air ratio between 2000, 3500, and 5000 rpm were tested for the best MBT torque at minimum timing temperature on a single-cylinder engine. The best compression ratio (13:1 and 8:1) to increase fuel consumption should be 14% by using E40 and E60. With a 2000 rpm engine speed, the expenditure for BSFC brake fuels should be 15% with the E40 blend fuel usage. Furthermore, speeds below 3,500 and 5,000 rpm can improve the higher BSFC by using a fuel ratio of E60 between 14.5% and 17%; hence, the CR was raised at 11:1, with gasoline used to build engine torque when the engine speed was at 2000 rpm. There was an increase in the 8% ratio compared to CR 8:1. As for comparing the CR 13:1 volume with the CR 8:1, an increase was obtained up to 14% of E40 and E60 fuels with higher CR. The engine torque was not apparent. A compression ratio of 7:1, 9:1 and 11:1 was tested on all fuels (E10, E30, E85) with different engine speeds. The experimental results and analysis showed increased CR and a rise in output. Overall, a 3500 rpm engine can generate high engine power at full load when the E30 compression ratio was used with CR 11:1. Further, engine power was increased with CR for fuel, thus saving on the engine power [57–59]. In his research, he used a variable compression ratio using fuel from carbinol with pure gasoline used in SI engines. J. Pradeep Bhasker et al. [55] compared to gasoline, lower torque BTE carbinol with the same CR, with increasing CR, will increase torque power and BTE. However, increasing CR will lower SFC, but gasoline is still higher. Output and BTE increased by 13.8% and 35%, respectively, with an increased CR 10/1 from carbinol.

Influences on the combustion engine

The fuel in the combustion engine is very advantageous, one of which is obtained from oxygen fuel that can be generally used on SI engines [12,60–63]. This fuel is suitable for SI engines with high compression values that can replace gasoline in the coming era. The tap on the engine should be avoided to increase the compression ratio on the SI engine [64–68]. The combustion characteristics of the engine with the rate of heat velocity (ROHR), the pressure rate (ROPR) of combustion (CT), combustion (CP), combustion (CD), anti-knocking (AK) and combustion (FMB) on the SI and CI engines are strongly influenced by the amount of fuel compression ratio used. Ftwi Y. Hagos et al. [69] reviewed fuel improvements by not modifying the engine body to the best, commonly by using oxygen fuels, such as water, alcohol, biodiesel, or a combination of the two are well suited from the results of the study, with emulsification techniques, and followed by mixed materials combustion at varying heat temperatures for micro-explosions in automated fuel emulsions and fuel oxygenation, is responsible for increased combustion emissions, performance and emissions of CO and PM and evaporation found in NOx emissions.

Ethyl tert-butyl ether (ETBE) fuel containing oxygen has future fuel potential and is vital as an alternate biofuel replacement for gasoline [8,70,71]. Schifter et al. [65] researched variable compression ratios on SI engines by increasing CR and switching boundary to TDC and 10% EBB Butyl Ether (ETBE) combustion effect with 90% petrol fuel (ETBE10) as well as pure octane and 5% ethanol, 95% gasoline (E5). Press caused the phenomenon of a stop tap on the in-cylinder with a maximum compression ratio. Among the three fuels, the largest anti-tap is obtained from octane values. ETBE10 and two deg-CA can determine splash time at the knocked limit after moving about one deg-CA compared to iso-octane. The higher tap on the combustion engine was due to the high CR value at the engine combustion. The ETBE fuel mixture was smaller than the more massive E5, which means the anti-knock was much better on high-CR engines with high CR and anti-knock properties and better features.

Table 3. The combustion of ICE and effects of compression ratio with blending oxygenate fuels.

Ref	Fuel	Blend	Volume	Type test engine	Range	ROPR	ROHR	CD	FMB	CP	ID	CT
[48]	Gasoline	N-butanol	40 CAD-42 CAD	SC, DISI (direct injection spark ignition)		▲	▲	X	X	X	X	▲
[72]	Gasoline	N-butanol	GNDI, G-NxDI, N-GxDI	Four cylinders; dual injection; Naturally Aspirated; Spark ignited	9.6	▲	▲	▲	X	X	X	▼
[73]	Gasoline	Methanol	D100, D70G30,	Four-cylinder, four-stroke,	17.5	▲	▲	▲		▲	▲	▲

Ref	Fuel	Blend	Volume	Type test engine	Range	ROPR	ROHR	CD	FMB	CP	ID	CT
			D70B30, D70G15B15	turbocharged, water-cooling, common-rail diesel engine								
[74]	Baseline	Method	ASTM D4814-ASTM D5453-ASTM D4953-ASTM D6729-ASTM D240-ASTM D129-ASTM D2699-ASTM D2700	Single cylinder	10.5:1 (10:1–11:1)	X	X	X	▼	X	X	X
[75]	Diesel	Polyoxymethylene dimethyl ethers	P10-P20-P30	4-cylinder, in-line, turbocharged, intercooling	17.5	▲	▼	▼	X	▲	▼	▼
[76]	Diesel	Ethanol-Methanol	PD-BT50-BT70-BT90-BT	Single-cylinder, four-stroke, water-cooled, constant speed, direct injection, compression ignition engine	17.5:1	X	▲	▲	X	X	▲	X
[5]	Diesel	Methanol-Ethanol	DM10-DM15-DM20-DM25-DM30-DM35-DM40	SC, 4-stroke CI	7.35–22.38	X	▼	▼	X	X	▲	X
[77]	Diesel	Ethanol	ASTM D4052-ASTM D445-ASTM D240-ASTM D93	Direct injection, turbocharged, intercooled, four strokes, water-cooled, common-rail	18.45:1	X	▲	▼	▼	▲	▲	▲
[78]	Diesel	Methanol	M30-M50-M70	SC, 4S, water-cooled, stratified-charge DISI stratified-charge	16:1 to 14:1	▼	▲	▼	X	▼		▲
[79]	Biodiesel	Diesel	M10-M20-M30	SC, DI-Diesel engine	18:1	X	▲	▲	X	▼		▼

Fuel use in diesel engines has a higher value during heat evaporation in the presence of oxygen content in fuels, such as ethanol and methanol [80–83]. The fuel potency is not up to the combustion potency exploitation alcohol (methanol with ethanol) in the slightest degree compression ratios because the fuel contains chemical elements. Therefore, it is additionally ignitable. Methanol with CR 8.5:1 has a better efficiency value during maximum combustion at 99.4%. Compared to gasoline, ethanol and methanol increased by up to 1.73% to 1.92% and are more efficient during engine combustion. The highest engine combustion pressure using alcohol fuels is higher than gasoline, while ethanol and methanol rise first at the start of combustion pressure (CP). The ROHR value is reduced due to a lower boiling point in alcohol than gasoline. The heat release rate of ROHR also decreased with alcohol lower than gasoline. Some studies conclude that using alcohol fuels can increase combustion pressure (CP) [73,84–87]. Of the many reviews, the use of ethanol fuel with gasoline in combustion engines and cycle generation on the SI engine will be discussed. The experimental evaluation showed that the amount of ethanol fuel was increased, which caused less fuel and the burning of the engine due to the oxygen content. Therefore, the combustion pressure and temperature on the cylinder were increased when the combustion volume became reduced due to the engine burning speed.

Influences on Emissions Engine

Based on the experimental results, several previous studies suggested that when the compression ratio increases, CO_2, NOx and CO of oxygen fuel use decreases. At the same time, HC increases with CR [5,24,57,88,89], as shown in **Table 2**. The compression ratio of 6:1 to 10:1 with methanol fuel can reduce CO_2, NOx and CO emissions by 30%, 22% and 37%, respectively, while emissions in HC increases with increasing CR [16]. Subsequent studies for the use of ethanol fuel compression ratios include (E0, E25, E50, E75 and E100) tested on SI engines with a tiny cylinder, modified cylinder head and compression ratio changed from 6 1 to (6:1 to 10:1). This executed modelling showed better results [54]. The modified results will be used on E50 fuel and pure gasoline engines, explicitly focusing on emissions, engine speeds (between 1500 and 4000), and engine performance when the load is below average. The oxygen content will increase with increased ethanol concentration and CO emissions due to improved engine combustion caused by oxygen content. Gas emissions are slightly higher than CO emissions at CR 6:1 with E50 lower 45%, while there is a maximum CO emission reduction at CR 10:1 with E50 compared to pure petrol fuel with CR 6:1.

Meanwhile, gasoline fuel is only reduced by 10% with CR 6:1 compared to the highest CO emission reduction at CR 10: with E50. The same emission reduction is as much as 26% at CR 6:1, with E50 slightly more gasoline than HC emissions. Subsequently, reductions also occurred in HC emissions of 12% with E50 at CR 10:1. In contrast, with gasoline, it did not decrease in CR 6:1. While the 30% reduction in atomic number 24 10:1 is capable nineteen happens in Roman deity. In contrast, automatic number 24 6:1 by victimisation hydrocarbon additionally doesn't disagree considerably. From the results of the review, it can be concluded that the reduction of NOx, CO and CO_2 emissions by 12%, 10%, 3% and 19% is obtained from E50 when CR increased from gasoline. The greenhouse effect is non-toxic in the presence of CO_2 contributions. Ethanol has more lace carbon atoms than gasoline, so CO_2 is less productive [75].

The performance of oxygenated fuel for CI engine

Substantially, the compression in the combustion engine (CI) is very efficient compared to the combustion engine (SI) [90]. The ratio of the compression engine applied to a diesel engine is usually between 14:1 and 18:1, but on some engines. There is a higher CR until it reaches 22:1. Oxygenated fuels have properties such as the heating value found in total cetane, LHOV, oxygen, viscosity, carbon, fatty acids, and significant oxygen content for CI engines [74,76,89]. The varying compression ratios applied to diesel engines can substantially increase engine performance and emissions [77,78]. The effect of CR applied to CI engines, as formulated in **Tables 3, 4**, and **5** is comprehensively reviewed.

Effect of performance and efficiency on the engine

Most studies conducted by [5,20,75,76,78,91] showed that specific fuel consumption (SFC) can be reduced, but the strength (P), thermal efficiency (TE), and torque (T) will be increased, as shown in Table 4. An in-depth description will be provided in this section. A study by Gong et al. [90] at a low-speed of 1000 rpm reported that GCR showed the most suitable result of 13.5%. As the GCR increases, it will improve thermal efficiency (TE). The cause of the increase in pressure and temperature in cylinder combustion was perfect due to the presence of high oxygen, and reduced heat during CR was diminished. Further research on terner jojoba methyl ester-diesel-ethanol is needed to evaluate the impact of effects on engine performance and exhaust emissions [76]. The B10 mix (10% JME + 90% diesel fuel) was the best combination of diesel fuel with a constant speed of 1500 rpm. The three tests were performed for mixed B10 on two loads to improve engine performance and exhaust emissions by adopting various ethanol proportions. The results of this study showed that the ternary mixture 90B10-E10, with volume (10% grain alcohol and ninetieth B10 mix), showed the most effective engine performance and increased exhaust emissions from diesel engines as compared to pure fuel. Moreover, the analysis of the mixture of polyoxymethylene dimethyl ethers (PODE) with volume (10%, two hundredth and 30%) is going to be with PODE-diesel (marked with P10, P20 and P30). Also, to work out the result of PODE-diesel blends on performance, combustion and emission characteristics were performed on diesel-rail turbocharged 4-cylinder diesel [92]. The mixture results of P10, P20, and P30 stay stable at temperature, and additionally, the kinematic consistency of the PODE-diesel mixture decreases with the increasing magnitude relation and temperature of the PODE mixture. This enhanced PODE mix quantitative relation will increase most in-cylinder pressure and improve the thermal potency of brakes.

Furthermore, Roman deity emissions will considerably increase HC, CO, and smoke emissions. Compared with pure diesel oil, the smoke emissions of P10, P20 and P30 at complete load area unit are severally minus twenty-seven. 6%, 41.5% and 47.6%, peak concentration of accumulated mode particles (50 nm <Dp <1000 nm) P10, P20 and P30 severally decreased fifteen.97%, 32.28% and 43.79% severally. This indicated that PODE, collectively of the different rising fuels, has the potential to supply economical and clean combustion for diesel engines.

Table 4. The performance of the CI engine and effects of compression ratio with oxygenated fuels.

Ref	Fuel	Oxygenated Fuel	Ratio Blending Fuel	Type Engine CI	Range	T	SFC	P	TE	Finding
[75]	Diesel	Polyoxymethylene dimethyl ethers	P10-P20-P30	4-cylinder, in-line, turbocharged, intercooling	17.5	X	▲	X	▲	The blended fuel has little impact on NOx emissions. However, it can significantly improve HC, CO and smoke emissions.
[76]	Diesel	Ethanol, Methanol	PD-BT50-BT70-BT90-BT	Single cylinder, four strokes, water-cooled, constant speed, direct injection, compression ignition engine	17.5:1	X	▲	▲	▼	Dual fuel blends are the most effective substitute for traditional fuel in aspects like performance and emissions. With a mixture of BT 50 yielding full load conditions, 2.9% reduction, 4.72%, 4.56%, 42.5% and 29.16% on BTE, NOx, HC, CO and several smoke CO_2 emissions increased by 10.7%.
[5]	Diesel	Methanol, Ethanol	DM10-DM15-DM20-DM25-DM30-DM35-DM40	SC, Four-stroke compression ignition	7.35–22.38	X	▲	▼	▲	The addition of alcohol harmed NOx emissions from the engine fueled with diesel methanol and diesel-ethanol blends.
[78]	Diesel	Methanol	M30-M50-M70	SC, 4S, water-cooled, stratified-charge DISI stratified-charge	16:1 to 14:1	▼	X	▼	▼	With a decreasing compression ratio from 16 to 14, the BTE of the methanol engine increases by 18% at low load, the BTE decreases by 6%,

Ref	Fuel	Oxygenated Fuel	Ratio Blending Fuel	Type Engine CI	Range	T	SFC	P	TE	Finding
										and the PRR decreases by 60%.
[20]	Diesel	Method	B5-B10-B15-B20-B25	SC, Air cooling, Naturally Aspirated, Direct injection	5:1, 7:1, 9:1	X	▲	▲	▲	The blend of 90B10-E10 (10% ethanol and 90% B10 blend) by volume showed the best engine performance and improved diesel engine exhaust emissions compared with pure diesel fuel.
[91]	Diesel	Gasoline, Methanol, Ethanol	B45M10D45-B40M20D40-B45E10D45-B40E20D40							Based on the results of a review from previous research, the engine's performance and emissions are different from those of alcohol fuel, and other studies of alcohol can provide better results than those of diesel fuel.

The increased heat levels can be seen during LCR but can reduce high CR. This is due to the mixing speed, air entertainment, and low fuel consumption, which affect the mixture's viscosity. Then, it can also be found that a higher compression ratio was not favourable for DEM because of the low octane, low ignition, and high cetane in DEM [6,93–95]. Furthermore, the use of DME fuels with low compression ratios on DICI engines sought to identify combustion regimes and high thermal efficiency. So, the brake efficiency against BTE remains hot. Still, DME remains stable, with a compression ratio of (18:1 to 12:1). Lowering the compression ratio can reduce the pressure on the in-cylinder [96].
The hot fuel is the most critical parameter to choose as fuel, especially alcohol fuel with a relatively low heating value, as compared to fossil oil relief, so the engine's fuel consumption can be affected. Also, the compression ratio consideration solution becomes a problem against fuel consumption. The effect of the methanol mix ratio was studied by Jamrozik A [5] with volume (DE10, DE15, DE20, DE25, DE30, DE35, and DE40) under CR 17:1 at engine performance and emissions in ASTM-CFR in a single position. A directly correlated yeast power can be calculated as the PV curve zone closes and increases CR. Due to less heat and ethanol than diesel and engines, a mixture of ethanol-diesel strengths can be reduced. However, when the CR is on the rise, mixed and pure diesel can increase torque power. As the CR increases, the efficiency of the engine thermal increases and fuel consumption and specific brakes are lowered.

Influence on the combustion engine

The study discussed the effect of variable compression ratio (VCR) [77,79], as shown in Table 3, and the combustion characteristics by using oxygen fuel for heat release including (ROHR) combustion temperature and pressure velocity (ROPR), combustion pressure (CP), torque pressure (CT), mass of combustion fraction (FMB), and duration of combustion (CD) on CI engine. Dubey et al. [88] researched variable compression ratios applied to SCDI combustion engines between CR (17.5:1) with (ethanol, methanol, and diesel) used as a mixture of fuel. From these results, it's seen that the pressure on the cylinder (CP) increases at maximum load (ROPR), and the rate of heat release at (ROHR) in the presence of too long delay in (ID) can increase the ethanol ratio higher. Then, the increase in peak pressure was due to the very high rise of CR and BMEP, but the peak pressure on the cylinder gas was obtained from 104 in BMEP 5.5 by using a BT mixture with CR 17.5:1. The maximum heat dissipation rate was 120/CA with the same mixture ratio CR. Ignition can be reduced based on CR and mixed fuel with higher fuel quantities. The ignition delay was on BT50 less than when using pure diesel fuel. The long ignition delay made the fire grow faster, and the whole achievement was obtained from oxygen fuel, such as biodiesel and ethanol, with the engine temperature lowered.

Research was conducted by [81] on the use of methanol fuel with pure gasoline fuel intended for combustion testing on engines with unequal CR between 14:1 and 16:1 by modifying the diesel engine with CR 16:1. To be ready to make the most of the prevailing plugs, the plate must be adjusted. Furthermore, research is needed on speed and load on other engines. From the analysis of pure methanol with diesel combustion with CR, the speed resulted in differentiation. The cause of the increase in CR is that the maximum pressure will increase, and BTE will be lowered when the load is low. Ignition (ID) was delayed because the methanol fuel at CR 14:1 was 30% less than CR 16:1 found on much lower engine load. By increasing CR, the burning duration (CD) can be decreased to 16.7%, 25.8% and 45% engine loads, respectively, to 0.15 MPa, 0.67 MPa and 0.38Mpa. The high number of injections will be adjusted to the amount of fuel so that it has higher combustion, faster operation, and combustion pressure. With the engine's high seminal load, CR will shorten the combustion duration. The high number of fuel injections should be adjusted to the height at the combustion temperature, rapid propagation and the combustion pressure. The burning period can increase the load engine and CR if the burning period is less. The maximum number of ROHR contained in CR 14 was almost the same as that of the CR 15 to 16 engine, whereas the CR maximum on the ROHR was close to the height of the TDC rather than CR when the load on the engine was full.

The effect of emissions on the engine

Based on some studies [5,76,78,97,98] described in Table 5, the use of oxygenated root materials can increase NOx when the CI engine's compression ratio also increases. Oxygenated fuel applications like ethanol can reduce CO, HC and NOx emissions when CR is rising. Research on emission specifications on brakes from use other than methanol and diesel fuel Jamrozik [5]. The high compression ratio (CR) in methanol resulted in the emission of NOx and HC, while the increased CR will reduce CO emissions. A low 50% methanol amount, compared to diesel, can reduce NOx emissions but increase emissions of HC and CO, which are slightly lower. LHOV higher than methanol can cause a reduction in the combustion temperature of methanol. Research on the use of DME fuels on a DICI engine was conducted with lower CR to seek the identification of combustion regimes [77]. Noise on DME engines with carbon monoxide, CO emissions, and carbon hydrocarbons was relatively constant when using CR (12:1 to 18). A higher compression ratio can reduce NOx emissions.

Perfect and cleaner combustion can be achieved on diesel in the presence of oxygen. On the other hand, the absence of oxygen in conventional diesel will produce incomplete combustion, emitting black smoke when it starts to burn. Liu J et al. [75] reported that the Polyoxymethylene dimethyl ether (PODE) mixed with diesel fuel had a small impact on NOx emissions. Still, HC, CO and smoke emissions could be significantly increased. Compared with pure diesel fuel, smoke emissions P10, P20 and P30 at complete load are minus 27.6%, 41.5% and 47.6%, respectively. Therefore, the PODE-diesel mixture will cut back particle concentration and particle mass concentration within the diesel exhaust, shifting the height of the distribution to a small particle size. Compared with pure diesel oil, the height concentration of accumulated mode particles (50 nm < Dp < 1000 nm) P10, P20, and P30 slashed fifteen.97%, 32.28% and 43.79%, severally. This indicated that PODE, together with the different rising fuels, has the potential to supply economical and clean combustion for diesel engines.

Furthermore, Sathiyamoorthi et al. [98] reported that the combined result of the DEE additional that EGR blended LGO25 resulted in a significant reduction in Night and smoke emissions of thirty.72% and 11.2% severally as compared to LGO25. Furthermore, HC and CO emissions were reduced by 18% and 33.31% severally compared to LGO25. A pair enhanced the thermal brake potency and specific fuel consumption of brakes., 4% and 10.8%, respectively, compared to LGO25. Combustion characteristics improved by four, such as cylinder pressure and warmth unleash rate. 46% and 3.29%, respectively, compared to LGO25. Combustion length and progressive ignition delay on LGO25 nano-pinned with

DEE and EGR modes however down for LGO25 nano-emulsion fuel. The diesel-ethanol mixture, the performance of the look at the engine was determined for all alcohol content values. The engine potency will increase to take care of the constant level of sufficient pressure shown. CO emissions area unit reduced, whereas psychoactive substance and greenhouse emission emissions stay unchanged. The addition of alcohol hurts pollutant emissions from engines triggered by a mix of diesel-methanol and diesel-ethanol. When extraordinary the half-hour alcohol content, non-repetitive work as mirrored within the COVIMEP constant hyperbolic to quite 10% [5]. Dubey P et al. [88] rumoured combining twin fuels was the best substitute for conventional dead fuel in aspects like performance and emissions. Furthermore, the BT fifty produced a complete load condition, 2.9% reduction, 4.72%, 4.56%, 42.5% and 29.16% on the thermal potency of brakes, NOx, HC, CO and several smokes, whereas carbonic acid gas emissions augmented 10.7%. Sharudin et al. [97] reported that the lower ratio of the methanol-gasoline mixture (M5) was mixed with the iso-butanol additives 5 to 15%, with a 5% increase compared to gasoline. The test was carried out at a constant load (100%) with variable speed of low engine speed from 1000 rpm to 2,500 rpm. The results showed that engine performance, M5B15, improved engine brake power, BTE (thermal efficiency brake), and EGT (exhaust gas temperature) compared to other mixed fuels. Furthermore, engine emissions, M5B15, provide significant CO and HC emissions reductions. However, an increasing trend was projected by the emissions of NOx and CO_2.

Table 5. The emissions of CI engines and the effects of compression ratio with oxygenated fuels.

Ref	Fuel	Blend	Volume	Type Engine CI	Range	CO2	HC	NOx	CO	Finding
[75]	Diesel	Polyoxymethylene dimethyl ethers	P10-P20-P30	4-cylinder, in-line, turbocharge, intercooling	17.5	X	X	X	X	The results show that P10, P20, and P30 have excellent stability at room temperature, and the kinematic viscosity of PODE-diesel blends gradually decreases with increasing PODE blending ratio and temperature.
[76]	Diesel	Ethanol, Methanol	PD-BT50-BT70-BT90-BT	Single-cylinder, 4-strokes, water-cooled, constant speed, direct injection, CI-engine	17.5:1	▲	▼	▼	▼	Regarding dual fuel blend, BT50 has lower NOx, CO, HC, and smoke emissions than mineral diesel fuel.
[5]	Diesel	Methanol, Ethanol	DM10-DM15-DM20-DM25-DM30-DM35-DM40	SC, 4-stroke CI engine	7.35–22.38	▲	X	X	▲	The addition and increase within the methyl alcohol content of up to a half-hour in diesel-methanol blends had a positive effect on the thermal potency of the engine. In contrast, no necessary changes

Ref	Fuel	Blend	Volume	Type Engine CI	Range	CO2	HC	NOx	CO	Finding
										were found within the indicated mean adequate pressure values.
[78]	Diesel	Methanol	M30-M50-M70	SC, 4S, water-cooled, stratified-charge DISI stratified-charge	16:1 - 14:1	X	▲	▲	▲	The torque and power of the methanol engine decrease not more than 3.5% when the compression ratio decreases from 16 to 14.
[20]	Diesel	Methanol	B5-B10-B15-B20-B25	SC, Air cooling, Naturally Aspirated, DI	5:1, 7:1, 9:1	X	X	X	X	B10 blend (10% JME+90% diesel fuel) was the best blend, substituting diesel fuel under variable load operating conditions and at a constant speed of 1500 rpm.
[97]	Gasoline	Methanol, Ethanol	ASTM D4052-ASTM D7042-ASTM D445-ASTM D240-ASTM D5191	4S, Multipoint electric port fuel system	10:1	▲	▼	▲	▼	The M5B15 mixture showed improvements in engine BP, BTE, and EGT compared to other mixed fuels.
[98]	Diesel	lemongrass oil (LGO)	DEE-LGO25	Single Cylinder, 4-stroke, DI	17.5	▼	▼	▼	▲	The merging result between DEE and LGO25 with EGR can reduce NOx emission significantly between 30,72% and 11,2% compared to pure LGO25.

4. Conclusion

The application of oxygenated fuels in internal combustion (IC) engines has shown significant potential in enhancing engine performance and reducing harmful emissions in both spark ignition (SI) and compression ignition (CI) systems. Studies reveal that ethanol blends such as E30 at a compression ratio (CR) of 11:1 can improve engine power by up to 14%, while blends containing 1-butanol or methanol effectively reduce particulate and hydrocarbon (HC) emissions. In CI engines, the use of polyoxymethylene dimethyl ether (PODE) at P10, P20, and P30 concentrations resulted in smoke emission reductions of 27.6%, 41.5%, and 47.6%, respectively, compared to pure diesel fuel. Furthermore, brake thermal efficiency (BTE) increased by up to 13.8%, and CO emissions were reduced by 33.31% when using dual-fuel blends such as BT50 (a 50% blend of ethanol or methanol with diesel). On the SI side, methanol fuel at a CR of 10:1 reduced CO_2, NOx, and CO emissions by 30%, 22%, and

37%, respectively. A blend of E50 fuel at the same CR reduced CO emissions by up to 45% compared to gasoline at CR 6:1. However, increased HC emissions were noted at higher CR levels. Overall, integrating oxygenated fuels with optimal compression ratios improves fuel combustion and efficiency and significantly contributes to cleaner engine operation, supporting the transition towards sustainable and low-emission transportation technologies.

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