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Evaluating The Impact Of Alternative Liquid Fuels On Internal Combustion Engines

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ABSTRACT

This study evaluates the impact of ethanol and methanol as additives in gasoline for spark ignition (SI) engines, comparing their performance and emissions characteristics to those of a gasoline-only reference case. The results indicate that ethanol-gasoline blends enhance engine power and torque while reducing Brake Specific Fuel Consumption (BSFC). Conversely, methanol-gasoline blends exhibit lower power and torque and higher BSFC compared to pure gasoline. The thermal performance of methanol-gasoline blends was less favorable due to altered combustion properties. However, both ethanol and methanol blends significantly reduced exhaust emissions, particularly carbon monoxide (CO), carbon dioxide (CO_2), and hydrocarbons (HC), across various engine speeds (1,500, 2,000, 2,500, and 3,000 RPM). Ethanol-gasoline blends with 10% ethanol content (E10) are recommended for future applications due to their potential to enhance combustion characteristics and thermal efficiency in internal combustion (IC) engines. The study also highlights a research gap in the storage, distribution, and handling of alternative fuels, as well as their long-term interactions with fuel systems. Future research should focus on the detailed interaction between alternative fuels and fuel system components, including filtering, injector operation, chemical compatibility, and deposit formation. Additionally, a comprehensive examination of the implications of alternative fuels on transport systems, powertrain configurations, and the development of new simulation models is essential. These research directions are crucial for ensuring the efficient integration of alternative fuels into existing automotive systems, ultimately contributing to the advancement of sustainable fuel technologies.

Keywords: spark ignition (SI) engines, additives, gasoline

INTRODUCTION

The transportation sector plays a crucial role in global greenhouse gas emissions, contributing to approximately 14% of total emissions worldwide according to the Intergovernmental Panel on Climate Change (IPCC, 2014). This substantial share is largely due to the widespread use of internal combustion engines (ICEs) in vehicles, which predominantly run on fossil fuels such as gasoline and diesel. As the number of vehicles on the road continues to grow, the emissions from these engines also increase, exacerbating the environmental impact and contributing significantly to climate change. Internal combustion engines release a variety of harmful pollutants during the combustion process. Carbon dioxide (CO_2) is a primary byproduct of burning fossil fuels and is a major contributor to the greenhouse effect, leading to global warming. Alongside CO_2, internal combustion engines emit nitrogen oxides

(NO_x), which are precursors to smog and acid rain, and particulate matter (PM), which consists of tiny particles that can penetrate deep into the lungs and bloodstream. These emissions not only contribute to environmental degradation but also pose serious health risks, including respiratory and cardiovascular diseases, as highlighted by the International Energy Agency (IEA, 2020).

The detrimental effects of ICE emissions on both the environment and human health underscore the urgent need for cleaner and more sustainable transportation solutions. Reducing reliance on fossil fuels and transitioning to alternative energy sources, such as electric vehicles, biofuels, and hydrogen, are critical steps in mitigating the impact of transportation-related emissions.

Oil, as the primary energy source for internal combustion engines (ICEs), faces significant challenges that jeopardize its long-term viability. The rapid depletion of oil reserves is primarily driven by the escalating number of vehicles worldwide, which increases demand for this finite resource. Additionally, the combustion of oil-based fuels generates substantial pollutant emissions, including carbon dioxide (CO_2), nitrogen oxides (NO_x), and particulate matter (PM), contributing to environmental degradation and adverse health effects. Another critical concern is the uneven distribution of global oil reserves, with about half located in the Middle East. This geographical concentration poses risks to energy security and exposes the global economy to geopolitical tensions and supply disruptions.

The swift decline in fossil fuel reserves and the rising cost of crude oil have accelerated the search for alternative energy sources. Researchers and policymakers are increasingly focused on renewable energy resources to meet growing energy demands and mitigate the environmental impacts associated with fossil fuel use. The limited availability of known petroleum reserves underscores the urgency of this transition. Renewable energy sources, such as solar, wind, and hydroelectric power, offer sustainable and abundant alternatives to fossil fuels. These sources are not only more environmentally friendly but also provide a more stable and secure energy supply.

To address the increasing energy demand effectively, leveraging alternative fuels has emerged as the most viable solution. Alternative fuels, including biofuels, alcohol-based fuels, and synthetic fuels, can be produced from renewable resources, ensuring a continuous supply and reducing dependency on finite oil reserves. Biofuels, for instance, are derived from biological materials and can be carbon-neutral, balancing CO_2 emissions with absorption during biomass growth. Alcohol-based fuels like ethanol and methanol offer cleaner combustion properties, potentially lowering harmful emissions. Synthetic fuels, produced through processes such as Fischer-Tropsch synthesis, can be made from various feedstocks, including coal, natural gas, and biomass, providing flexibility and compatibility with existing infrastructure. By adopting these alternative fuels, the transportation sector can significantly reduce its environmental footprint and enhance energy security, paving the way for a more sustainable and resilient energy future.

Gasoline and diesel, traditionally derived from crude oil, can also be synthetically produced through the Fischer-Tropsch (FT) method, a process pioneered by German chemists Franz Fischer and Hans Tropsch in 1923. This technique converts carbon monoxide (CO) and hydrogen (H_2) gases into liquid hydrocarbons, which can be refined into synthetic gasoline and diesel. The Fischer-Tropsch synthesis relies on a range of carbon and hydrogen-based feedstocks, including coal, natural gas, and methane. These feedstocks are first converted into synthesis gas (syngas), a mixture of CO and H_2, which is then processed through the FT reaction to produce liquid fuels. The versatility of this process makes it a valuable alternative to traditional crude oil refining, especially in regions with abundant coal or natural gas resources.

Statement of the Problem

The world is currently grappling with the dual challenges of soaring fuel prices and severe environmental degradation, including air pollution and climate change. Fossil fuels, particularly gasoline and diesel, are the primary energy sources for internal combustion engines (ICEs). However, their widespread use has led to significant environmental issues, including the emission of greenhouse gases (GHGs) such as carbon dioxide (CO_2) and pollutants like nitrogen oxides (NO_x) and particulate matter (PM). These emissions contribute to global warming, deteriorating air quality, and adverse health effects (International

Energy Agency, 2020). Moreover, the finite nature of fossil fuel reserves exacerbates the problem, as these resources are being depleted at an alarming rate (British Petroleum, 2021).

High fuel prices, driven by the scarcity and uneven distribution of petroleum reserves, pose another significant challenge. The transportation sector is heavily dependent on oil, and fluctuations in crude oil prices can lead to economic instability and increased costs for consumers and industries alike (U.S. Energy Information Administration, 2021). This economic strain underscores the urgent need for alternative energy solutions that can provide a stable and affordable supply of fuel for internal combustion engines without compromising environmental integrity.

In light of these issues, alternative fuels have emerged as a crucial component in addressing the current energy crisis. Fuels such as biofuels, ethanol, methanol, and synthetic fuels offer the potential to mitigate the environmental impact of ICEs while providing a more sustainable and renewable energy source (Demirbas, 2008). These alternatives can be produced from a variety of feedstocks, including agricultural residues, waste materials, and renewable resources, thus reducing dependency on depleting fossil fuel reserves and enhancing energy security (Tilman, Hill, & Lehman, 2006).

Despite the promising potential of alternative fuels, there remain significant gaps in understanding their combustion characteristics and overall impact on engine performance and emissions. Comprehensive research is required to evaluate the feasibility and effectiveness of integrating these fuels into conventional ICE applications. Such studies are vital for developing sustainable propulsion technologies that can meet the growing energy demand while minimizing environmental harm (Hansen, Zhang, & Lyne, 2005).

Therefore, this study aims to investigate the combustion characteristics of alternative fuels in internal combustion engines, focusing on their potential to enhance engine performance and reduce emissions. Through rigorous experimental analysis and data collection, this research seeks to provide valuable insights that will inform the development of environmentally conscious and economically viable propulsion technologies for the transportation industry. The findings will contribute to the broader efforts to address the pressing challenges of high fuel prices, air pollution, and climate change, ensuring a sustainable energy future.

Aim and Objectives of the Study

The aim of this study is to investigate the combustion characteristics of alternative fuels in internal combustion engines, with a focus on assessing their potential to enhance engine performance and reduce emissions. The specific objectives of the study include:

i. To analyze the combustion properties of alternative fuels, including ethanol and methanol, when used as additives to traditional gasoline.
ii. To assess the impact of alternative fuel blends on engine performance metrics, including power output, fuel efficiency, and engine durability.
iii. To quantify the reductions in harmful emissions, such as carbon dioxide (CO_2), nitrogen oxides (NOx), and particulate matter (PM), associated with the use of alternative fuels.

Significance of the Study

Internal combustion engines (ICEs) are pivotal in transportation and power generation, yet they are also significant contributors to air pollution and greenhouse gas emissions. As the world faces escalating environmental challenges, finding ways to mitigate the ecological impact of ICEs has become increasingly urgent. Alternative fuels present a promising solution to this problem, offering the potential to reduce emissions and improve the environmental performance of ICEs. This study is significant as it aims to provide detailed information on the combustion characteristics of alternative fuels such as ethanol, methanol, biodiesel, and natural gas when used in ICEs. By comparing these with conventional gasoline and diesel fuels, the research will offer insights into how these alternatives can enhance the sustainability of ICE operations.

The findings from this study will be instrumental in developing more efficient and environmentally friendly ICE technologies. Understanding the combustion properties of alternative fuels will enable the design and optimization of engine systems that not only improve performance but also reduce emissions.

This knowledge is crucial for advancing engine technology and ensuring that new developments align with environmental standards and sustainability goals. The research will provide a basis for creating fuel blends that optimize both performance and emissions, thereby facilitating the development of engines that can effectively utilize alternative fuels.

Additionally, the study will contribute to the expanding body of knowledge on alternative fuels and their application in ICEs. This information is invaluable for policymakers and industry leaders working on strategies to reduce the environmental impact of transportation and power generation. The research will support the formulation of policies and regulations that promote the adoption of cleaner fuels and technologies. Potential applications of the study's findings include the development of new fuel blends, innovations in engine technology, and the establishment of regulatory frameworks that encourage the use of alternative fuels. Overall, this study has the potential to drive significant advancements in creating more sustainable and environmentally friendly technologies for both transportation and power generation sectors.

Internal Combustion Engines

Internal combustion engines (ICEs) are a fundamental technology in modern society, driving advancements in transportation, power generation, and industrial processes. These engines operate on the principle of converting the chemical energy stored in fuels into mechanical energy through combustion. The process involves burning a fuel with an oxidizer (typically air) within a combustion chamber. This combustion generates high-temperature, high-pressure gases that expand and exert force on engine components, converting thermal energy into mechanical work (Heywood, 1988).

ICEs are categorized based on their design and the type of combustion process they use. The most common types are piston engines, gas turbines, Wankel engines, and jet engines. Piston engines, including both gasoline and diesel variants, use reciprocating pistons to convert the energy from combustion into rotational motion. Gas turbines, or jet engines, are designed for continuous combustion and use expanding gases to turn turbine blades, generating thrust or mechanical power (Hill & Peterson, 1992). Wankel engines employ a rotary design, with a triangular rotor moving in an elliptical motion within an epitrochoidal housing. Each type of engine has its own unique advantages and applications, from automotive propulsion to aerospace and power generation (Klick, 2000).

Despite their widespread use, ICEs are associated with environmental challenges. The combustion process in ICEs produces a range of emissions, including carbon dioxide (CO_2), nitrogen oxides (NOx), and particulate matter (PM), which contribute to air pollution and climate change (International Energy Agency, 2020). The reliance on fossil fuels also raises concerns about resource depletion and energy security. As a result, there is a growing interest in developing alternative fuels and engine technologies that can reduce the environmental impact of ICEs while maintaining their performance and efficiency (Heywood, 1988; IEA, 2020).

Internal combustion engines (ICEs) are primarily divided into two main categories: reciprocating engines and rotary engines. Reciprocating engines utilize pistons that move up and down within a cylinder to transform the combustion energy into mechanical work. This category is further subdivided into spark-ignition (SI) engines and compression-ignition (CI) engines. SI engines employ a spark plug to ignite the fuel-air mixture within the cylinder. These engines are commonly found in vehicles such as cars and motorcycles that require spark ignition. CI engines rely on the compression of the fuel-air mixture within the cylinder to achieve spontaneous ignition. These engines are predominantly used in diesel-powered vehicles, including trucks and buses. Rotary engines feature a single rotating rotor that converts the energy from combustion into mechanical work. Although less common than reciprocating engines, rotary engines are occasionally used in sports cars and motorcycles.

Internal combustion engines (ICEs) offer several benefits compared to other types of heat engines. They are relatively straightforward and cost-effective to produce, and their lightweight and efficient design makes them ideal for transportation applications. However, ICEs also come with notable drawbacks, including the emission of pollutants such as carbon monoxide, nitrogen oxides, and particulate matter, as well as greenhouse gases like carbon dioxide, which contribute to climate change. Despite these issues,

ICEs are expected to remain a significant component of the energy landscape for the foreseeable future. There is, however, a growing emphasis on enhancing ICEs to be more efficient and environmentally friendly. This shift is driven by factors such as stricter government regulations, increased environmental awareness, and rising fuel costs. One approach to improving ICE efficiency and reducing emissions is the adoption of alternative fuels like biodiesel and ethanol, which are derived from renewable resources and can emit fewer pollutants than traditional fossil fuels. Additionally, advancements in engine technology, such as hybrid electric vehicles that combine ICEs with electric motors, aim to enhance fuel efficiency and lower emissions. Overall, while the future of ICEs is evolving, it is anticipated that they will continue to play a significant role in the energy mix. The focus will likely be on developing technologies that improve their efficiency and environmental performance, aligning with the broader goals of reducing pollution and mitigating climate change.

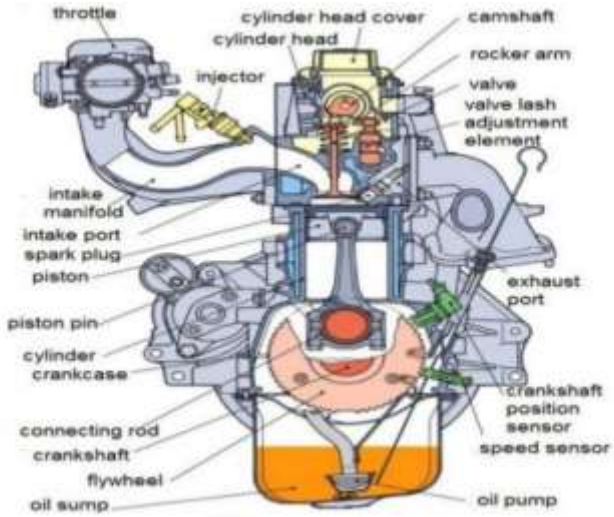

Figure 2.1: Parts of an Internal Combustion Engine

The main components of an IC engine are:

i. Piston: The piston moves up and down in the cylinder to convert the energy of combustion into mechanical work.
ii. Connecting rod: The connecting rod connects the piston to the crankshaft.
iii. Crankshaft: The crankshaft converts the reciprocating motion of the piston into rotary motion.
iv. Cylinder: The cylinder is where the combustion of fuel and air takes place.
v. Cylinder head: The cylinder head seals the top of the cylinder and contains the valves.
vi. Inlet valve: The inlet valve allows air to enter the cylinder.
vii. Exhaust valve: The exhaust valve allows exhaust gases to exit the cylinder.
viii. Spark plug: The spark plug ignites the fuel-air mixture in the cylinder (in spark-ignition engines only).
ix. Fuel injector: The fuel injector injects fuel into the cylinder (in spark-ignition engines only).
x. Combustion chamber: The combustion chamber is where the fuel and air are mixed and ignited.

The operation of an internal combustion (IC) engine involves a sequence of four distinct stages. First, during the **intake stroke**, the inlet valve opens, allowing air to enter the cylinder as the piston moves downward. This process draws air into the cylinder, preparing it for the next stage. Next, in the **compression stroke**, both the inlet and exhaust valves close, and the piston moves upward, compressing the air inside the cylinder. This compression increases the air pressure and temperature, setting the stage for combustion. Following compression, the **power stroke** begins. In spark-ignition engines, fuel is introduced into the cylinder and ignited by a spark plug. In compression-ignition engines, the high

pressure and temperature cause the fuel to ignite spontaneously. The combustion of fuel generates high-pressure gases, which force the piston downward, producing mechanical work. Finally, during the **exhaust stroke**, the exhaust valve opens, and the piston moves upward again. This movement expels the combustion gases from the cylinder, clearing it for the next cycle. The IC engine cycle is repeated many times per second to produce power. IC engines are used in a wide variety of applications, including transportation, power generation, and industrial applications.

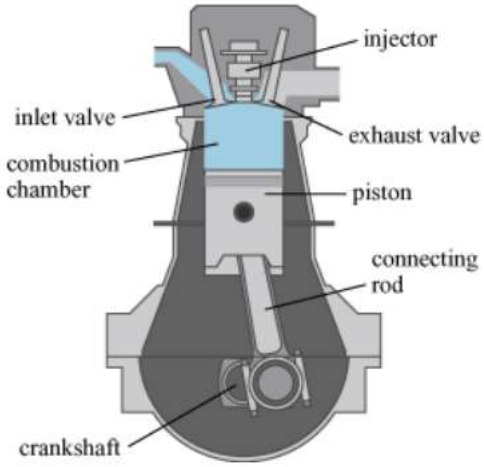

Figure 2.2: Diagram of a compression-ignition (CI) engine, also known as a diesel engine

The main components of a CI engine are:

i. Piston: The piston moves up and down in the cylinder to convert the energy of combustion into mechanical work.
ii. Connecting rod: The connecting rod connects the piston to the crankshaft.
iii. Crankshaft: The crankshaft converts the reciprocating motion of the piston into rotary motion.
iv. Cylinder: The cylinder is where the combustion of fuel and air takes place.
v. Cylinder head: The cylinder head seals the top of the cylinder and contains the valves.
vi. Inlet valve: The inlet valve allows air to enter the cylinder.
vii. Exhaust valve: The exhaust valve allows exhaust gases to exit the cylinder.
viii. Fuel injector: The fuel injector injects fuel into the cylinder at high pressure.
ix. Combustion chamber: The combustion chamber is where the fuel and air are mixed and ignited.

The operation of a compression-ignition (CI) engine unfolds through a series of four key stages. Initially, during the intake stroke, the inlet valve opens, allowing air to enter the cylinder as the piston moves downward. This inflow of air prepares the cylinder for the next phase. In the compression stroke, both the inlet and exhaust valves are closed while the piston moves upward, compressing the air inside the cylinder. This compression increases the air's pressure and temperature, setting the stage for ignition. During the power stroke, fuel is injected into the cylinder at high pressure by the fuel injector. The intense heat from the compressed air ignites the fuel-air mixture, causing combustion. This explosion generates a force that drives the piston downward, producing mechanical power. Finally, in the exhaust stroke, the exhaust valve opens, and the piston moves upward to push the exhaust gases out of the cylinder. This completes the cycle, which repeats rapidly to maintain engine power. CI engines are known for their efficiency and durability compared to spark-ignition (SI) engines, though they tend to produce higher levels of emissions such as nitrogen oxides and particulate matter.

2.1.2 Combustion Characteristics of Different Fuels

Table 2.1: Fuel Characteristics: Physical and Combustion Properties

Properties	**Acetylene**	**Hydrogen**	**CNG**	**Ethanol**	**Gasoline**	**Diesel**
Formula	C_2H_2	H_2	CH_4	C_2H_5OH	C_4–C_{12}	C_8–C_{20}
Density (1 atm, 20°C (kg/m^3))	1.092	0.08	0.65	809.9	720–780	820–860
Autoignition Temperature (°C)	305	572	540	363	257	254
Stoichiometric ratio(kg/kg)	13.2	34.3	17.2	9	14.7	14.5
Motor Octane Number	45 - 50	130	105	89.7	95 - 97	-
Flammability Limits in air (%Vol.)	2.5 - 81	4 - 74.5	5.3 - 15	3 - 19	1.4 - 7.6	0.6 - 5.5
Adiabatic Flame Temperature (K)	2500	2400	2320	2193	2300	2200
Min. quenching diameter (mm)	0.85	0.9	3.53	2.97	2.97	-
Min. ignition energy (MJ)	0.019	0.02	0.29	0.23	0.23	-
Maximum flame speed (m/s)	1.5	3.5	0.42	0.61	0.5	0.3
Lower heating value(kJ/kg)	48.225	120	49.990	26.700	43.000	42.500

Table 2.1 highlights that different fuels have distinct properties that affect their suitability for various applications. The density of fuels varies significantly. Hydrogen is the least dense at 0.08 kg/m³, followed by acetylene at 1.092 kg/m³. In contrast, ethanol has a much higher density of 809.9 kg/m³, and gasoline and diesel are denser still, ranging between 720–780 kg/m³ and 820–860 kg/m³, respectively. Lower density fuels like hydrogen and acetylene are more prone to dispersion and may require more advanced storage solutions compared to denser fuels like ethanol and diesel.

The autoignition temperature reflects the temperature at which a fuel ignites without an external spark. Hydrogen has the highest autoignition temperature at 572°C, making it less prone to accidental ignition. Acetylene and ethanol have lower autoignition temperatures (305°C and 363°C respectively), which can make them more susceptible to ignition under high temperature conditions. Gasoline and diesel have even lower autoignition temperatures, with diesel being slightly lower (254°C), indicating their higher risk of premature ignition.

Stoichiometric ratio indicates the amount of air required for complete combustion of a fuel. Hydrogen has the highest stoichiometric ratio at 34.3 kg/kg, meaning it requires a lot of air relative to its fuel weight. Conversely, ethanol has a stoichiometric ratio of 9 kg/kg, indicating a more fuel-efficient combustion process. Fuels with lower stoichiometric ratios, such as ethanol and gasoline, typically have a higher energy yield per unit of air.

Motor Octane Number is a measure of fuel's resistance to knocking shows that hydrogen has the highest octane number (130), making it less likely to cause knocking in engines. Gasoline ranges from 95 to 97, while ethanol has an octane number of approximately 89.7. Lower octane numbers, such as those of ethanol and gasoline, suggest that these fuels are more prone to engine knocking compared to hydrogen.

Flammability Limits in Air describe the range of fuel-air mixtures that can ignite. Hydrogen has the broadest flammability range (4–74.5% by volume), indicating it can ignite over a wide range of conditions. Acetylene also has a wide range (2.5–81%), while fuels like gasoline and diesel have narrower flammability limits, which restrict their use under certain conditions.

Adiabatic Flame Temperature shows the theoretical maximum temperature of the flame produced by the combustion of the fuel. Acetylene has the highest adiabatic flame temperature (2500 K), followed closely by hydrogen (2400 K). Ethanol and gasoline have lower temperatures (2193 K and 2300 K, respectively), which can influence the engine design requirements for heat dissipation and performance.

Minimum Quenching Diameter and Ignition Energy indicate the minimum size of a fuel-air mixture that can sustain a flame and the energy required to ignite the fuel. Hydrogen has a slightly larger minimum quenching diameter (0.9 mm) compared to acetylene (0.85 mm), making it somewhat more challenging to maintain a flame. Hydrogen also requires a lower ignition energy (0.02 MJ) than fuels like CNG (0.29 MJ) and ethanol (0.23 MJ).

Maximum Flame Speed and Lower Heating Value impacts how rapidly a fuel burns. Hydrogen has the highest flame speed (3.5 m/s), which affects combustion dynamics. In terms of heating value, hydrogen has the highest lower heating value (120,000 kJ/kg), followed by acetylene (48,225 kJ/kg) and CNG (49,990 kJ/kg). Fuels with higher heating values generally offer better energy efficiency.

Hydrogen and acetylene, with their high energy densities and broad flammability ranges, offer significant potential for high-efficiency applications, while ethanol and gasoline, with their lower stoichiometric ratios and octane numbers, are well-suited for conventional engine designs.

Table 2.2: Energy and Greenhouse Gas Assessment in Well-to-Tank Analyses for the EU (2010 - 2020+)

Fuels	**Resource**	**Expended energy [MJ/MJ fuel]**	**Greenhouse emissions [g CO_2/MJ]**
Gasoline	Crude oil	0.18	13.8
Diesel	Crude oil	0.20	15.4
Natural gas	EU-mix NG	0.17	13.0
	Imported NG 7000 km	0.29	22.6
	Imported NG 4000 km	0.21	16.1
	LNG*	0.28	19.9
	Shale gas	0.10	7.8
	Synthetic from wind electricity	1.05	3.3
Ethanol	Sugar*	1.20	28.4
	Wheat*	1.31	55.6
	Other*	1.66	41.4
Hydrogen	Natural Gas*	1.10	118
	Coal*	1.45	237
	Biomass*	1.05	14.6
	Electricity*	3.11	190

*Average value.

Table 2.2 presents an overview of the energy expenditure and greenhouse gas emissions associated with various fuels. It compares the efficiency and environmental impact of different fuel sources, offering insights into their sustainability and ecological footprint. Energy Expenditure indicates the amount of energy required to produce one megajoule (MJ) of fuel, expressed in MJ per MJ of fuel. It provides a measure of the energy input needed for fuel production relative to the energy content of the fuel itself. Greenhouse Gas Emissions shows the amount of carbon dioxide (CO_2) emitted per megajoule of fuel consumed, expressed in grams of CO_2 per MJ. It provides an indication of the fuel's environmental impact in terms of contributing to global warming. Table 2.2 highlights that while fossil fuels like gasoline and

diesel have relatively moderate energy expenditures and emissions, alternative fuels such as synthetic natural gas and hydrogen from renewable sources offer significant potential for reducing greenhouse gas emissions. However, these benefits must be weighed against the energy costs and practicalities of their production processes.

In addition to analyzing combustion characteristics, it's crucial to assess how alternative fuels affect various engine systems. One of the primary considerations is the fuel delivery system, which needs to ensure consistent and efficient fuel supply to the engine. For example, biodiesel may necessitate adjustments in the fuel delivery system to accommodate its properties. Another critical aspect is the fuel injection system, which injects fuel into the engine cylinder. Fuels such as methanol may require modifications to the injection system to ensure optimal performance.

The combustion chamber, where fuel combustion occurs, also needs attention. Fuels like natural gas might require alterations to the combustion chamber to handle their distinct combustion characteristics. Additionally, the after-treatment system, responsible for reducing emissions, may need adjustments depending on the alternative fuel used. For instance, hydrogen fuel could necessitate changes to the after-treatment system to manage its unique emissions profile effectively.

When evaluating alternative fuels for transportation, it's essential to consider their impact on engine systems alongside their combustion properties. Factors such as overall cost and availability are also crucial. While hydrogen remains relatively expensive and less accessible, biodiesel is more readily available and can be produced from renewable sources. A comprehensive evaluation that includes these aspects will help in developing alternative fuel vehicles that are both efficient and environmentally friendly.

MATERIALS AND METHOD

The experimental study was conducted using a single-cylinder, four-stroke diesel engine with an 11 kW power output capability. The engine was fitted with a dynamometer for measuring torque and power output. The test setup included sensors and data acquisition systems to capture real-time data on engine performance and emissions. The study evaluated various fuel blends, including pure gasoline as a baseline and several alternative fuel blends. Each fuel blend was prepared and thoroughly mixed to ensure homogeneity before being introduced into the engine.

Engine Setup and Configuration

In this experiment, the TBMC12 engine investigation bench, was utilized as the training equipment to test internal combustion engines with a power output capacity of up to 11 kW. The engine featured an 81 mm bore and a 64 mm stroke. It was a single-cylinder engine with a compression ratio of 8.3:1 and utilized air as the cooling medium. The engine was operated within a speed range of 1,500 to 3,000 RPM under a load of 8 N. Figures 3.1 and 3.2 provide visual representations of the setup, while Table 3.1 details the engine specifications used in this investigation.

The engine investigation bench is an advanced piece of equipment designed for educational and experimental purposes, allowing for comprehensive testing and analysis of internal combustion engines. With the ability to handle engines up to 11 kW, this bench is well-suited for examining various performance and emission characteristics under controlled conditions. The one-cylinder engine employed in this study, characterized by its specific bore, stroke, and compression ratio, was selected to provide a representative model for evaluating the impact of different fuel blends. The specified speed range and load conditions ensure a thorough assessment of engine behavior across typical operating scenarios, facilitating a detailed understanding of how alternative fuels perform compared to conventional options.

Table 3.1: Specification of Test Engine

Engine kind	**Spark ignition, Four strokes**
Number of cylinders	Single cylinder
Bore * stroke	81 mm*64 mm
Swept volume	0.000239 m^3
Cooling	Air
Compression ratio	8.3:1
Output Power	11 kW

Instrumentation Flow Chart

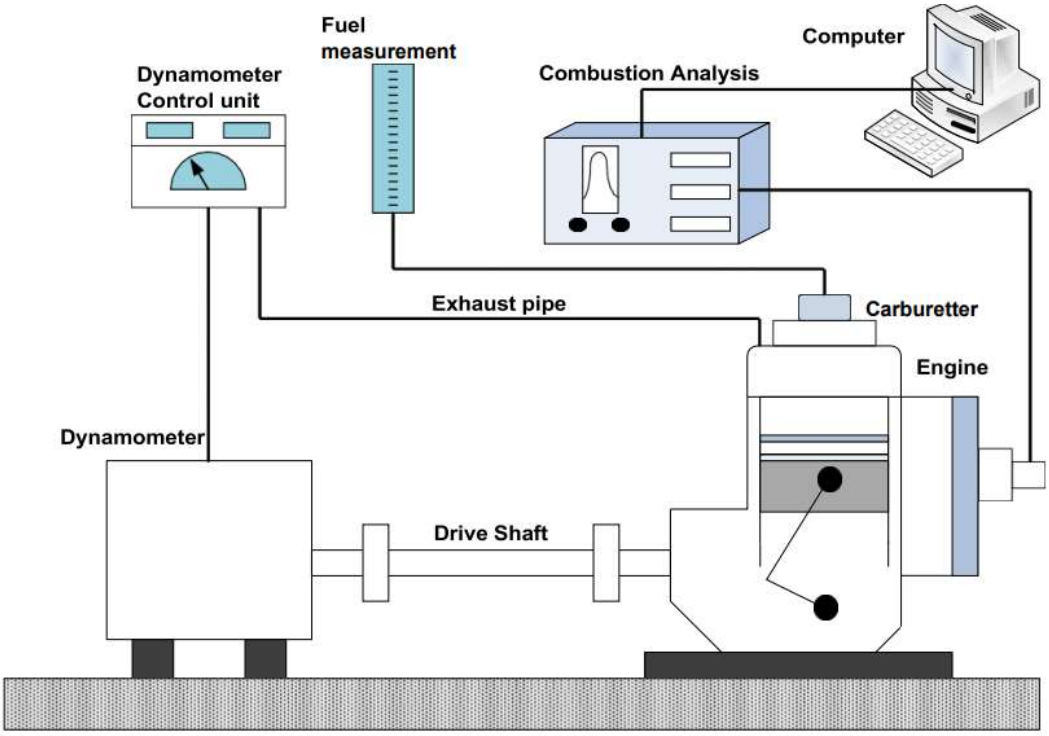

Figure 3.2: Diagram Illustrating the Experimental Setup

3.3 Fuel Characteristics

This study utilizes three distinct types of fuel, each mixed in varying proportions. The primary fuel is gasoline, mainly composed of C_6H_6, widely used in automotive engines globally. The composition of gasoline can vary significantly depending on the crude oils used, typically including 2 to 5% alkenes, 4 to 8% alkanes, 25 to 40% isoalkanes, 3 to 7% cycloalkanes, and 20 to 50% total aromatics. Ethanol, represented by C_2H_5OH, is another fuel examined in different ratios. Ethanol is notable for its hydroxyl group in its molecular structure, with a density of 0.789 g/mL at 293 K and a melting point of 158.9 K.
Gasoline generally has a higher heating value than ethanol. The third fuel type is methanol, designated as CH_3OH, which is also used in varying proportions. Methanol has an ignition temperature of 740 K, higher than gasoline's 495 K, due to its high octane number. Conventional gasoline typically has an octane number ranging from 90 to 100. Although methanol may not be the most cost-effective option, its chemical properties make it a viable alternative to other automotive fuels. Table 3.2 summarizes the chemical and physical properties of the three fuels used in this study.

Table 3.2: Fuel Properties Used In the Experiments

Property	Ethanol	Methanol	Gasoline
Molecular formula	C_2H_5OH	CH_3OH	C_6H_6
Molecular weight (kg/k.mol)	46.07	32.04	114.15
Density(kg/m^3)	789	792	765
Latent heat of vapor. At 20(°C) (kJ/kg)	840	1103	305
Stoichiometric A/F ratio	9.00	6.47	15.13
Boiling point (°C)	78	64	38-204
Auto-ignition temperature (°C)	425	465	228-470
LHV (kJ/kg)	26900	20000	44000

3.4 Procedure and Mathematical Models

The engine was initially warmed up gradually, and experimental tests were conducted at engine speeds of 1,500, 2,000, 2,500, and 3,000 RPM. Before each new test, the engine was given sufficient time to consume any residual fuel from the previous experiment. The performance of the internal combustion engine was evaluated with ethanol (E) and methanol (M) blends ranging from 10% to 30% (10E, 10M to 30E, 30M) at speeds from 1,500 RPM to 3,000 RPM. This was done to assess each key variable under investigation while keeping other variables constant. The same procedures were followed for all fuel blends, as illustrated in Figure 3.5, which shows a sample of the experimental method with a constant load of 8 N and variable proportions of ethanol and methanol.

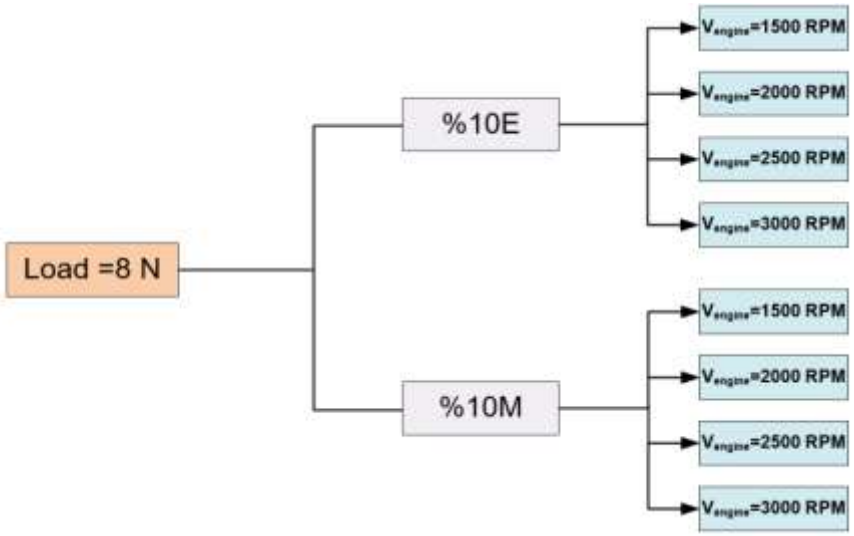

Figure 3.5: Experimental protocols at 8 N load with 10% ethanol and 10% methanol

3.5 Formulas

The study employed the following mathematical models to calculate the engine's thermal performance:

1. The equation representing the brake torque is given by:

$$T = \frac{v_d \times P}{4\pi}$$

T = Torque (N.m)

v_d = Displacement volume (m3) or swept volume of engine (m3)

P = atmospheric pressure, (Pa)

2. The brake power is presented as:

$$BP = T \times \left(\frac{2\pi \times N}{60}\right) \times 10^{-5}$$

N = speed of engine (RPM)

3. The consumption of the brake specific fuel is given by:

$$BSFC = \frac{\dot{m}_j}{BP}$$

$\dot{m}_j$ = rate of mass flow for fuel, (kg /m3)

4. The brake thermal efficiency of the fuel combustion is:

$$\eta_{BTH} = \left(\frac{3600}{BSFC \times LHV_{bl}}\right) \times 100$$

$$\rho_b = \sum \rho_i \times v$$

$$LHV_{bl} = \sum \frac{\rho_i \times v_i}{\rho_b} \times LHV$$

ρ_b = density of fuel blend (kg/m3)

ρ_i = density of given component (kg/m3)

v_i = volume fraction of given component in fuel blend (%)

LHV_i = lower heating value of given component (KJ/kg)

LHV_{bl} = lower heating value of blend (KJ/kg)

RESULTS AND DISCUSSION

Results on Torque Characteristics

Figure 4.1 illustrates the effects of various ethanol-gasoline fuel blends on engine torque. The results show a notable increase in engine torque with lower ethanol-gasoline ratios (E10). In contrast, blends of E20 and E30 yield a modest torque improvement compared to pure gasoline, especially at lower engine speeds. This improvement can be attributed to the higher octane rating of ethanol, which reduces knocking and enhances combustion pressure, thereby increasing brake torque output.

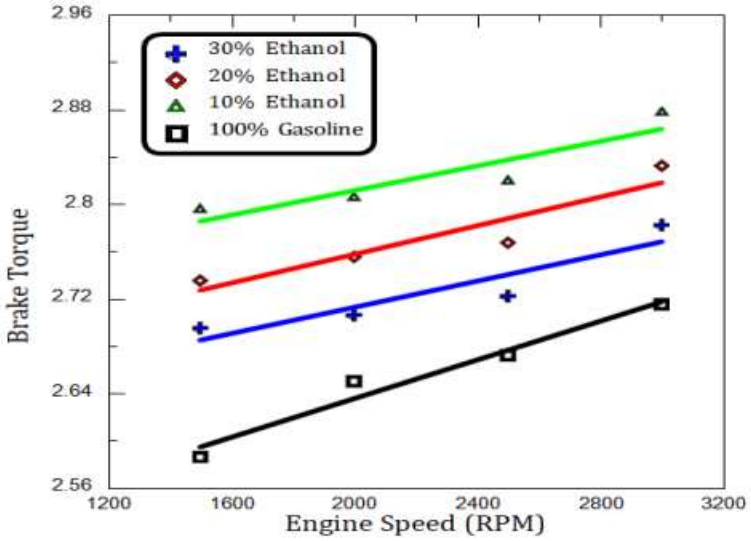

Figure 4.1: Experimental Findings of Engine Performance in Terms of Brake Torque using Different Ethanol-Gasoline Blends at Varied Engine Speeds

Figure 4.2 displays the impact of methanol-gasoline fuel blends on engine torque at various speeds, presenting a distinct contrast to the trends observed with ethanol-gasoline blends in Figure 4.1. Notably, the engine's torque slightly decreases with higher methanol concentrations in the fuel mixture. However, the brake torque value for M10 is nearly comparable to that of pure gasoline, unlike the results seen with M20 and M30 blends.

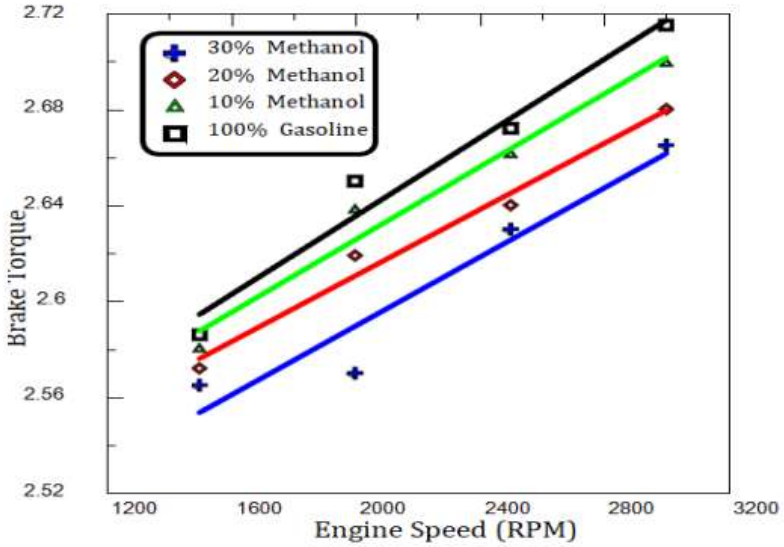

Figure 4.2: Experimental Findings of Engine Performance in Terms of Brake Torque using Different Methanol-Gasoline Blends at Varied Engine Speeds

4.2 Results on Brake Horsepower

Figure 4.3 demonstrates the effect of ethanol-gasoline blends on engine brake horsepower at different speeds. It shows that higher ethanol concentrations in the fuel mixture consistently lead to increased engine brake power across all speeds. Specifically, the brake power of E10 exceeds that of both E20 and E30 blends. This increase can be attributed to the higher density and efficiency of the blend as ethanol content rises, which boosts brake power. These results are consistent with previous experimental studies conducted under various operational conditions.

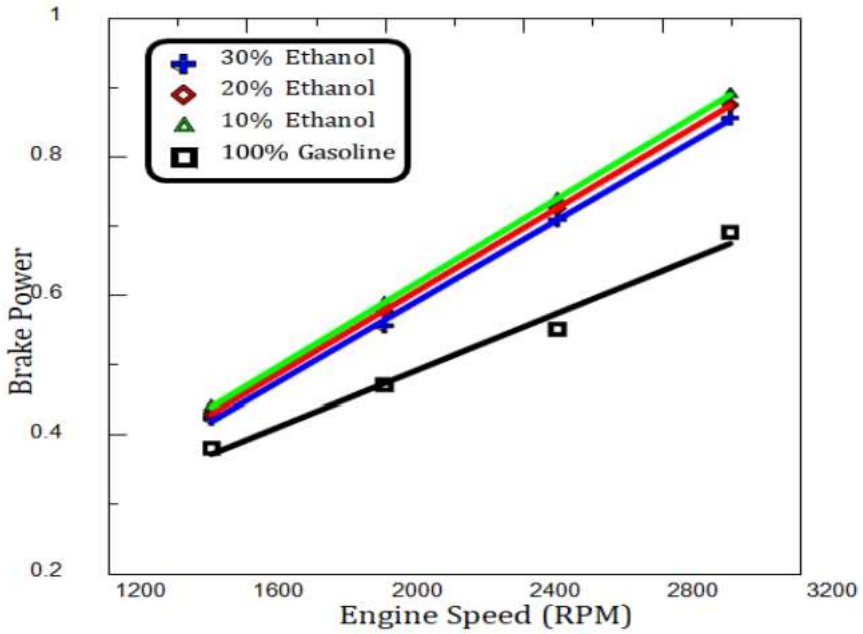

Figure 4.3: Experimental Findings of Engine Brake Power using Various Ethanol-Gasoline Blends at Different Engine Speeds

Figure 4.4 illustrates the effects of methanol-gasoline fuel blends (M10, M20, and M30) on engine brake power. As the methanol proportion in the fuel mixture increases, there is a slight decrease in power across all tested speeds. Notably, the power output is higher with pure gasoline, especially at an engine speed of 2,000 RPM. Additionally, M10 demonstrates greater brake power compared to both M20 and M30, which is due to similar factors affecting performance.

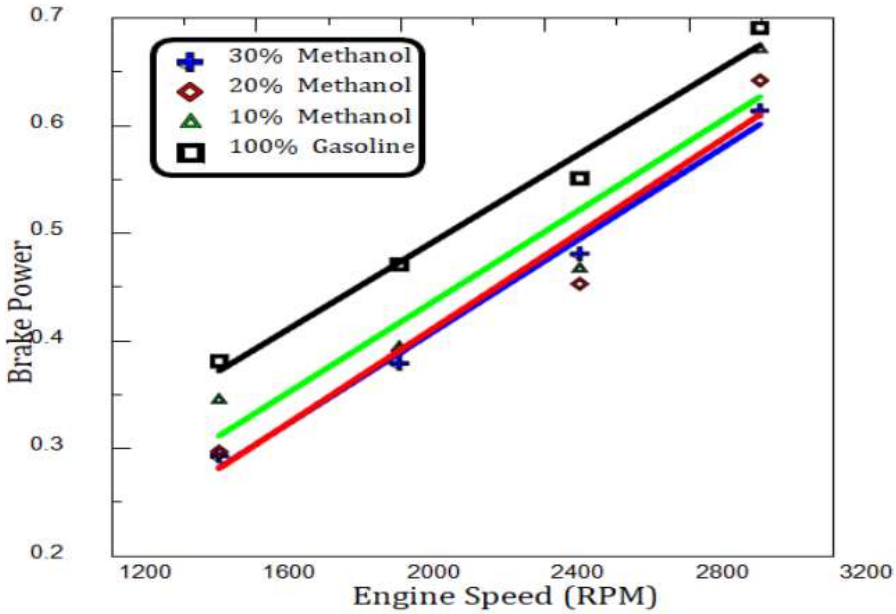

Figure 4.4: Experimental Findings of Engine Brake Power using Various Methanol-Gasoline Blended Fuels at Different Engine Speeds

4.3 Results on Brake Specific Fuel Consumption (BSFC)

Figure 4.5 shows the variations in Brake Specific Fuel Consumption (BSFC) for different ethanol-gasoline blends at various engine speeds. The data indicate that BSFC decreases with a higher proportion of ethanol in the fuel mixture. There is a noticeable difference in BSFC between pure gasoline and the E10, E20, and E30 blends. Specifically, as engine speed increases, particularly reaching around 3,000 RPM, the BSFC tends to decrease. This trend can be attributed to improved thermal efficiency, as previously discussed.

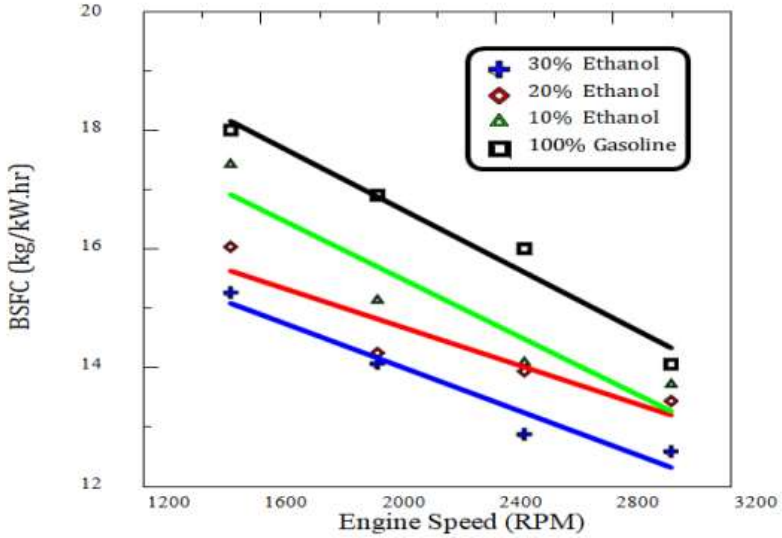

Figure 4.5: Experimental Findings of Brake Specific Fuel Consumption using Various Ethanol-Gasoline Blended Fuels at Different Engine Speeds

Figure 4.6 illustrates the changes in Brake Specific Fuel Consumption (BSFC) for methanol-gasoline blends at various engine speeds. The data show that BSFC increases as the methanol ratio in the blend rises. Additionally, there is a minor difference between the BSFC of pure gasoline and the methanol-gasoline blends. Interestingly, the lowest BSFC value is observed as the engine speed approaches around 3,000 RPM.

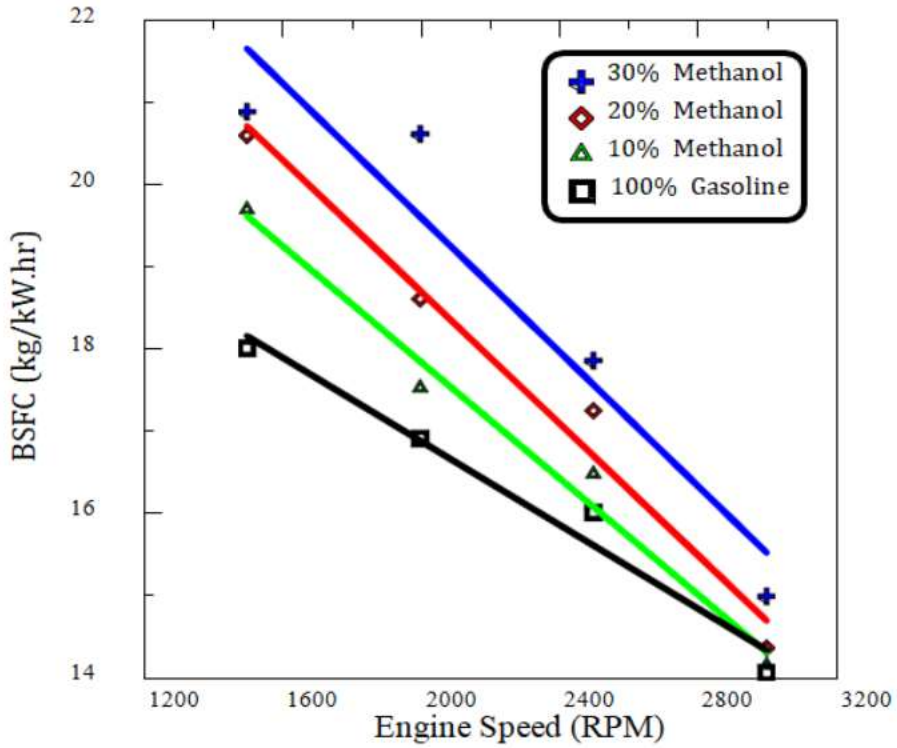

Figure 4.6: Experimental Findings of Brake Specific Fuel Consumption using Various Methanol-Gasoline Blended Fuels at Different Engine Speeds

4.4 Results on Brake Thermal Efficiency

Figures 4.7 and 4.8 display the Brake Thermal Efficiency (BTE) values for various fuel blends at different engine speeds. In Figure 4.7, BTE improves with the use of ethanol-blended fuels compared to pure gasoline, and this improvement continues as engine speed increases. In contrast, Figure 4.8 shows a reduction in BTE when using methanol-blended fuels relative to pure gasoline. This decline is due to the lower latent heat content in the fuel mixtures with higher methanol concentrations. Consequently, among the ethanol blends, E10 exhibits better BTE than E20 and E30, as outlined in Equation 4 of the study.

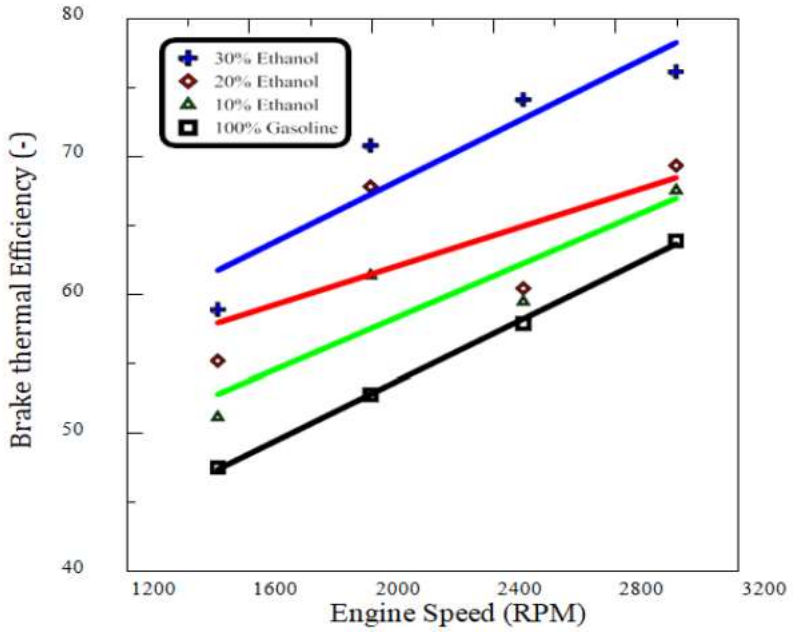

Figure 4.7: Experimental Findings of Engine Performance in Terms of Brake Thermal Efficiency using Different Ethanol-Gasoline Blends at Varied Engine Speeds

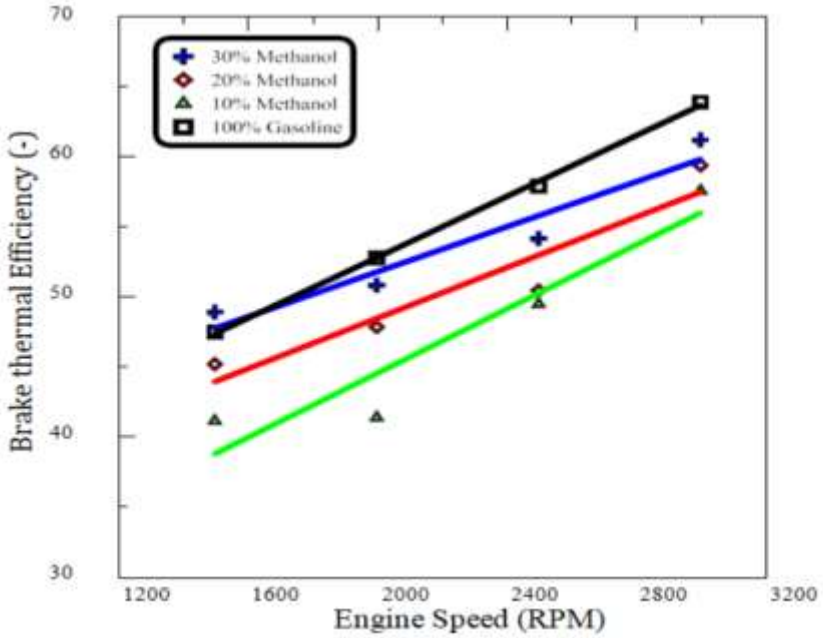

Figure 4.8: Experimental Findings of Engine Performance in Terms of Brake Thermal Efficiency using Different Methanol-Gasoline Blends at Varied Engine Speed

4.5 Emissions Analysis

4.5.1 Pollutant Emissions (CO, NOx, HC)

To evaluate the effects of various ethanol- and methanol-gasoline fuel blends on exhaust emissions, the experimental data collected at 2,500 RPM were analyzed, as depicted in Figure 4.9. Incomplete combustion typically leads to higher levels of CO in the exhaust gases. Since both ethanol and methanol contain oxygen, their addition to the gasoline mixture improves combustion efficiency, thereby lowering

CO concentrations. Figure 4.9 shows that CO levels decrease by 35% with increasing ethanol content and by 36% with rising methanol content.

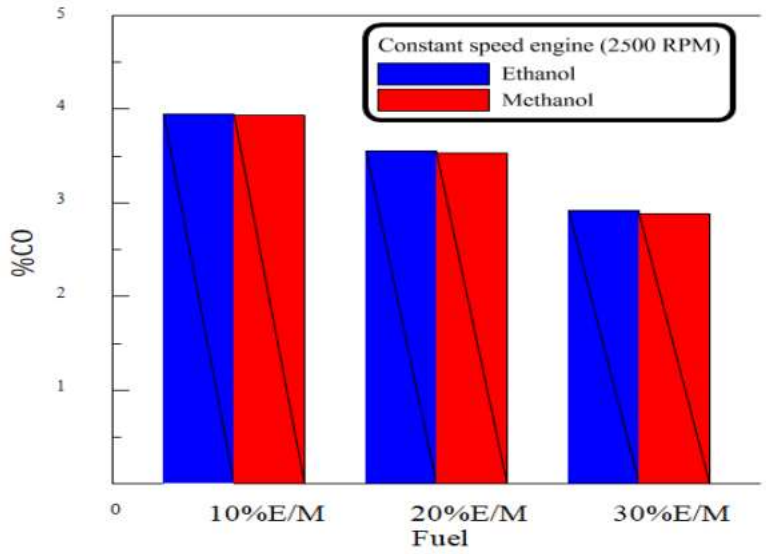

Figure 4.9: Carbon Monoxide (CO) Concentrations for Various Blended Fuels at 2,500 RPM Engine Speed

At an engine speed of 2,500 RPM, the levels of carbon monoxide (CO) are significantly lower when using ethanol- and methanol-gasoline blends compared to pure gasoline. This reduction is due to ethanol and methanol having fewer carbon atoms than gasoline, which leads to lower CO_2 production. Overall, the observed reductions in CO and CO_2 are consistent with trends reported in prior experimental studies, as shown in Figure 4.9.

4.5.2 Particulate Matter Emissions

Particulate matter (PM) consists of solid particles and liquid droplets suspended in the air. While some PM originates from natural sources like wildfires, dust storms, and pollen, the majority comes from human activities, particularly the burning of fossil fuels. Vehicle emissions are a significant source of PM, which can adversely affect human health and the environment. PM exposure can irritate the respiratory system, exacerbating conditions like asthma and bronchitis, and may also lead to heart disease, stroke, and lung cancer.

Blended fuels, such as ethanol and biodiesel, offer the potential to reduce PM emissions from vehicles. These fuels burn cleaner than traditional gasoline and diesel, potentially lowering PM emissions. Additionally, blended fuels can decrease engine knocking, which may further reduce PM output. Research has shown that blended fuels can have a positive impact on PM emissions. For instance, the National Renewable Energy Laboratory (NREL) reported that a 20% ethanol blend (E20) cut PM emissions from gasoline engines by 17%. Similarly, the University of California, Berkeley, found that a 20% biodiesel blend (B20) reduced PM emissions from diesel engines by 20%. However, the effect of blended fuels on PM emissions can vary based on the fuel type, engine specifications, and operating conditions. For example, a study by the European Commission indicated that a 15% ethanol blend (E15) did not significantly affect PM emissions from gasoline engines. Research suggests that blended fuels could reduce PM emissions, further studies are needed to fully understand how different blends perform across various engines and operating conditions.

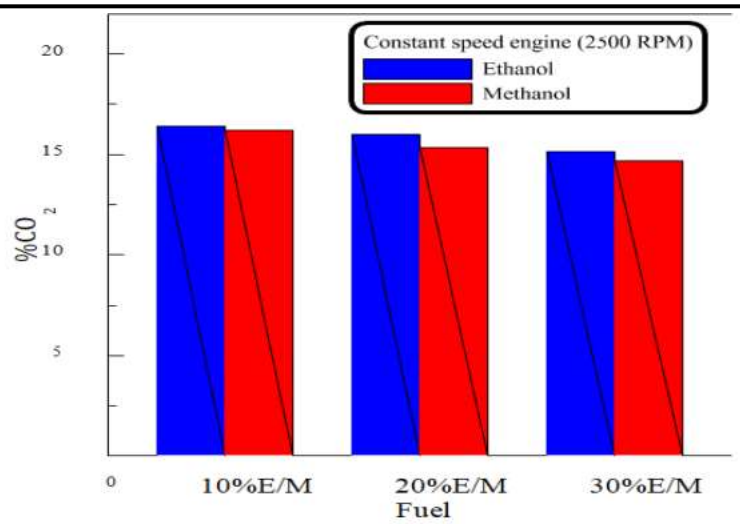

Figure 4.10: Carbon Dioxide (CO_2) Concentrations for Various Blended Fuels at 2,500 RPM Engine Speed

Figure 4.11 illustrates the levels of hydrocarbons (HC) in the exhaust gases at 2,500 RPM with the throttle fully open. The data show that the addition of ethanol and methanol, which can be considered partially oxidized hydrocarbons, leads to a significant decrease in HC concentrations when these additives are mixed with gasoline.

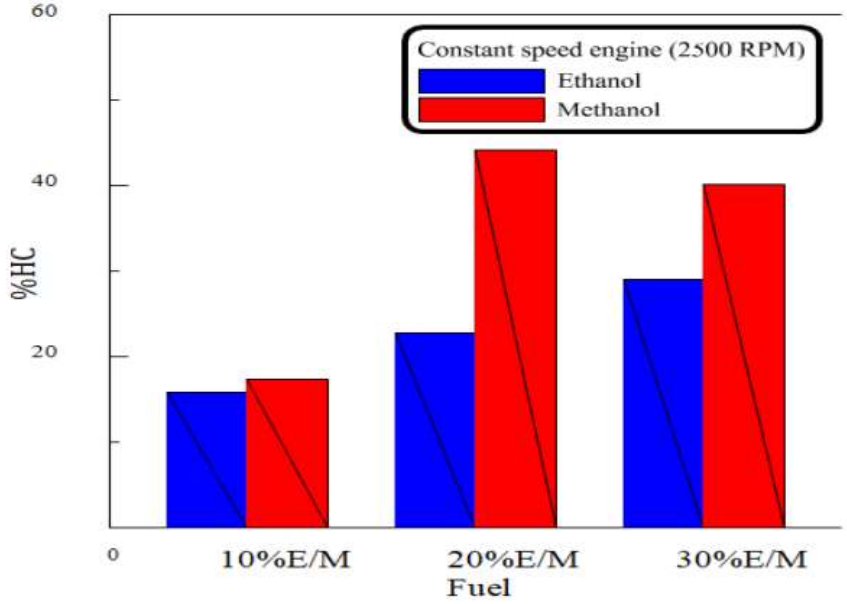

Figure 4.11: Concentrations of Oxidized Hydrocarbons (HC) for Various Blended Fuels at 2,500 RPM Engine Speed

4.5.3 Comparison with Conventional Fuels

To enhance the confidence in the experimental findings, an error analysis has been conducted for the combustion cases of E10, M10, and pure gasoline. The results are summarized in Table 4.1.

Table 4.1: Error Analysis for Experimental Accuracy.

Independent variables	Variable errors		
	E10	**M10**	**100% Gasoline**
Brake torque	2.644±0.07	2.8±0.04	2.65±0.08
Brake power	0.66±0.11	0.46±0.061	2.65±0.08
Brake Specific Fuel Consumption	1.6±2.306	1.5±2.15	2.65±0.08
Brake thermal efficiency	1.54±1.87	2.113±0.48	2.65±0.08
CO emission	3.47±0.53	3.44±0.56	
CO_2 emission	5.84±0.80	4.6±1.19	
HC emission	2.52±0.852	2.52±0.418	

4.5.4 Comparative Analysis of Blended Fuels

Blended fuels are created by combining two or more different types of fuel, aiming to enhance performance, reduce emissions, or lower costs. There are several common blended fuels used for vehicle propulsion:

i. Ethanol-Gasoline Blends: These blends mix ethanol, a renewable fuel derived from crops like corn and sugarcane, with gasoline. Common blends include E10, E15, and E20, where the number represents the percentage of ethanol. Ethanol-gasoline blends generally improve the octane rating of the fuel, which can enhance engine performance and reduce knocking.
ii. Biodiesel-Diesel Blends: By mixing biodiesel, which is produced from vegetable oils or animal fats, with diesel fuel, these blends, such as B2, B5, and B20, aim to provide a renewable alternative to pure diesel. Biodiesel-diesel blends can improve engine performance and reduce wear, though they may also affect power output.
iii. Natural Gas-Gasoline Blends: Combining natural gas with gasoline results in blends like CNG (compressed natural gas) and LNG (liquefied natural gas). Natural gas is a cleaner-burning fuel that can help lower emissions, making it a viable alternative to conventional gasoline.
iv. Hydrogen-Gasoline Blends: Mixing hydrogen with gasoline is a more experimental approach, as hydrogen is a clean-burning fuel that can potentially produce zero emissions. Though still in early development stages, hydrogen-gasoline blends promise significant emission reductions in the future.

Blended fuels offer several benefits over conventional fuels. They can enhance vehicle performance by improving combustion efficiency and reducing engine knocking. For instance, ethanol-gasoline blends can boost the octane rating and improve performance, while biodiesel-diesel blends help reduce engine wear. Blended fuels also have the potential to reduce emissions, with ethanol and biodiesel blends lowering pollutants like carbon monoxide (CO) and particulate matter (PM), and natural gas blends reducing multiple emissions. Hydrogen blends, being emissions-free, represent the cleanest option.

Additionally, blended fuels can be more cost-effective. For example, ethanol-gasoline blends are often cheaper than gasoline, and biodiesel-diesel blends can be more affordable than pure diesel, depending on biodiesel prices. Natural gas blends can also be less costly, especially when natural gas prices are low. Hydrogen blends, while currently more expensive, are expected to become more economical as technology advances. However, several factors should be considered when using blended fuels:

i. Compatibility: Not all vehicles are compatible with every type of blended fuel, so checking with the vehicle manufacturer is essential.
ii. Availability: Blended fuels might not be available everywhere, so it's important to verify local availability.
iii. Infrastructure: Some blended fuels, particularly hydrogen-gasoline blends, may require specific infrastructure, like specialized refueling stations and storage tanks.

Blended fuels can offer significant advantages in terms of performance, efficiency, and environmental impact. While their benefits are evident, it is crucial to consider compatibility, availability, and

infrastructure needs before adopting them. The impact of blended fuels on combustion and emissions varies with the fuel type and engine conditions, but generally, they improve combustion efficiency, reduce emissions, and lower knocking.

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study aimed to evaluate the impact of ethanol and methanol blends with gasoline on the performance and emissions of a spark ignition (SI) engine. The research focused on comparing these blended fuels against pure gasoline to determine their effects on engine power, torque, fuel consumption, and exhaust emissions. Ethanol-gasoline blends were found to enhance engine power and torque while reducing Brake Specific Fuel Consumption (BSFC). On the other hand, methanol-gasoline blends showed lower power and torque, and higher BSFC relative to pure gasoline. The thermal performance of methanol blends was less favorable due to changes in combustion properties. Notably, fuel mixtures with higher ethanol and methanol content led to significant reductions in exhaust emissions, particularly for CO, CO_2, and HC, across various engine speeds (1,500, 2,000, 2,500, and 3,000 RPM). Based on these results, it is recommended to consider ethanol-gasoline blends with 10% ethanol for future applications, as they offer improved combustion characteristics and thermal efficiency.

The primary objective was to investigate how different proportions of ethanol and methanol in gasoline affect engine performance and exhaust emissions. The study sought to identify which fuel blends offer improvements in power, efficiency, and emissions, and to highlight any potential drawbacks. The findings revealed that ethanol-gasoline blends significantly improved engine power and torque while reducing Brake Specific Fuel Consumption (BSFC) compared to pure gasoline. Specifically, blends with up to 10% ethanol (E10) demonstrated enhanced combustion efficiency and lower emissions of carbon monoxide (CO), carbon dioxide (CO2), and hydrocarbons (HC). In contrast, methanol-gasoline blends resulted in reduced engine power and torque and higher BSFC. The thermal performance of methanol blends was less favorable due to changes in combustion properties, though they still contributed to lower emissions of CO, CO_2, and HC at various engine speeds.

The study concluded that ethanol-gasoline blends, particularly with 10% ethanol, offer notable advantages in terms of enhanced combustion characteristics and thermal efficiency. These blends are recommended for future applications due to their improved performance and reduced emissions. Conversely, methanol-gasoline blends, despite reducing emissions, showed less favorable effects on engine performance and efficiency.

The study also identified a significant research gap in the areas of fuel storage, distribution, and handling, as well as the interaction of blended fuels with fuel systems. Further research is needed to explore these aspects and their impact on the efficiency and adoption of alternative fuels in automotive systems.

5.2 Recommendations for Future Research

Recommendations for future research on the combustion characteristics of alternative fuels in internal combustion engines include:

i. **Examine Combustion Under Various Conditions:** Study how alternative fuels perform under different engine speeds, loads, and temperatures to understand their combustion characteristics better.
ii. **Investigate Fuel-Engine Interactions:** Explore the effects of alternative fuels on engine components, including potential wear and tear, and how these fuels impact the performance of emissions control systems.
iii. **Develop Advanced Combustion Technologies:** Focus on creating new combustion strategies and technologies, such as innovative injection methods, ignition systems, and combustion chamber designs, to optimize the use of alternative fuels.
iv. **Study Fuel Blends:** Research the use of alternative fuels in combination with conventional fuels to reduce the need for significant engine modifications and enhance compatibility with existing infrastructure.

v. **Enhance Predictive Models:** Develop advanced models and simulations to better predict the combustion characteristics of alternative fuels, which can facilitate the rapid development of new engine technologies and fuels.

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