"EXPERIMENTAL INVESTIGATIONS ON THE USE OF TRANSIENT ETHANOL-DIESEL FUEL BLEND IN A DIESEL ENGINE: PERFORMANCE AND EMISSION STUDIES"

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE

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MASTER OF TECHNOLOGY

IN

THERMAL ENGINEERING

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CANDIDATE'S DECLARATION

I, Farhan Khan, 2K21/THE/21 of M. Tech. Thermal Engineering, hereby declare that the project Dissertation titled "Experimental Investigations on the use of transient ethanol-diesel fuel blend in a diesel engine: Performance and emission Studies" which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation . This work has not previously formed the basis for the award of any Degree, Diploma Associateship or other similar title or recognition.

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CERTIFICATE

We hereby certify that the Project Dissertation titled "Experimental Investigations on the use of transient ethanol-diesel fuel blend in a diesel engine: Performance and emission Studies" which is submitted by Mr. Farhan Khan, 2K21/THE/21 of Mechanical Engineering Department, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under our supervision. To the best of our knowledge this work has not been submitted in part or full for the award of any degree or diploma to this University or elsewhere.

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ABSTRACT

The utilization of ethanol as an additive in diesel engines has attracted considerable interest in recent times, owing to its potential to mitigate environmental issues, decrease reliance on fossil fuels, and improve engine performance. This research examines the application of ethanol in diesel engines and investigates its impact on combustion characteristics, engine emissions, and overall efficiency.

This study specifically focuses on the integration of ethanol into diesel engines. Nevertheless, it is essential to acknowledge and address certain limitations associated with the use of ethanol and ethanol-diesel blends. These limitations include a low cetane number, phase separation, as well as low lubricity and viscosity values. To overcome the challenge of phase separation, an inline mixer is employed to ensure thorough blending of ethanol and diesel prior to direct feeding into the engine. Furthermore, a cetane number enhancer is mixed with ethanol to mitigate the impact of its low cetane number. Experimental investigations are conducted on a single-cylinder diesel engine, with variations in the concentration of the cetane number enhancer. Various parameters such as combustion pressure, heat release rate, efficiency, specific fuel combustion, and exhaust emissions are measured and subjected to analysis. The experimental findings are then compared to those obtained using pure diesel fuel, allowing for an assessment of the influence of ethanol on combustion, performance, and emission characteristics in diesel engines.

The results indicate that the addition of ethanol to diesel fuel leads to a retardation of ignition timing and a decrease in peak pressure. Furthermore, the inclusion of ethanol in combination with diesel fuel reduces the duration of combustion due to increased

ignition delay, resulting in an overall reduction in heat release. However, the incorporation of a cetane number enhancer helps to bring these values closer to those observed with pure diesel fuel.

With an increase in load, the Brake Specific Fuel Consumption (BSFC) decreases for all types of fuels. However, when ethanol is added to diesel fuel, the BSFC tends to increase due to the lower calorific value of ethanol. Nonetheless, the introduction of a cetane number enhancer mitigates this increase. On the other hand, the Brake Thermal Efficiency (BTE) demonstrates an increase with increasing load. Similarly, the BTE shows an improvement with the substitution of ethanol and further increases when a cetane number enhancer is incorporated.

As the load on the engine increases, there is a corresponding increase in the emission of Smoke and NOx. However, the addition of ethanol to diesel fuel results in a reduction of Smoke and NOx emissions, and this reduction becomes more pronounced with the inclusion of a cetane number enhancer. It is worth noting that the decrease in Smoke and NOx emissions is more significant at higher load conditions. On the other hand, the emissions of CO and HC decrease as the load increases. Nevertheless, when ethanol is substituted for diesel fuel, there is an increase in CO and HC emissions. However, this increment diminishes as the load increases, and the inclusion of a cetane number enhancer slightly reduces these emissions.

These findings offer valuable insights for future advancements in the application of alternative fuels, aiding in the design and optimization of engines to maximize the benefits of ethanol as a sustainable and renewable fuel option.

CONTENTS

LIST OF FIGURES

LIST OF PLATES AND TABLES

PLATES

TABLES

NOMENCLATURE

MS	Motor Spirit
EJ	Exajoules
b/d	Barrel per day
OPEC	Organization of the Petroleum Exporting Countries
OECD	Organization for Economic Cooperation and Development
bcm	Billion Cubic Meter
tcm	Trillion Cubic Meter
LNG	Liquified Natural Gas
CNG	Compressed Natural Gas
TMT	Thousand Metric Tonnes
FFV	Flex Fuel Vehicles
MoPNG	Ministry of Petroleum and Natural Gas
EBP	Ethanol Blended Fuel Program
°C	Degree Celcius
CV	Calorific Value
CI	Compression Ignition
CO	Carbon Monoxide
CO_2	Carbon Dioxide
NOx	Oxide of Nitrogen
HC	Hydrocarbon
1G Ethanol	First Generation Ethanol
2G Ethanol	Second Generation Ethanol
CV Carburetor	Constant Velocity Carburetor
BSFC	Brake Specific Fuel Consumption
BSEC	Brake Specific Energy Consumption
BTE	Brake Thermal Efficiency
COV	Coefficient of Variance
IMEP	Indicated Mean Effective Pressure
NHRR	Net Heat Release Rate
EGR	Exhaust Gas Recirculation

THF	Tetrahydrofuran
CN Enhancer	Cetane Number Enhancer
RPM	Revolution per Minute
bhp	Brake Horse Power
A.T.D.C.	After Top Dead Center
B.T.D.C.	Before Top Dead Center
A.B.D.C.	After Bottom Dead Center
B.B.D.C.	Before Bottom Dead Center
kW	Kilo-Watt
V_{cc}	Volume of Fuel Consumed
η_{th}	Brake Thermal Efficiency
K_s	Unit constant
HV	Overall Heating Value
ρ	Density of fuel g/mm^3
h_c	convective heat transfer coefficient
T_w	temperature of the wall
E15-D	Blend of 15% Ethanol in 85% Diesel
BMEP	Brake Mean Effective Pressure
BSU	Black Smoke Unit

CHAPTER 1
INTRODUCTION

1.0 Introduction

Today air pollution has become one of the World's most significant health and environmental problems. Air pollution is significantly contributed to by the release of pollutants from the consumption of fuel derived from petroleum. The increasing global population plays a crucial role in the depletion of crude oil reserves, leading to resource scarcity and a sharp rise in the price of petroleum-based fuel. Consequently, researchers are driven to explore and develop sustainable and renewable fuel alternatives for various vehicles and engines.

Biofuels like alcohols and biodiesel have the potential to overcome the above-stated problems. These fuels were produced from plants and animal raw materials and hence are renewable. Biofuels (due to having oxygenated nature) have the ability to reduce exhaust emissions. The oxygen content in biodiesel is about (10-12) %, and for alcohol, it is about 35%. Besides providing better energy security, biofuels also offer a new income source to the agricultural industries.

India ranks as the world's third-largest consumer of oil in terms of volume. In the Financial year 2021-22, India consumes about 76.687 million tonnes of high-speed diesel and 1.0205 million tonnes of light diesel oil (a total of about 77.7075 million tonnes of total diesel). However, the consumption of petrol (Motor Spirit) is about 30.848 million tonnes [1]. Thus the expenditure of diesel is much more remarkable than that of petrol. There is a vast range of applications for diesel engines, such as in heavy trucks, electric generators, farm equipment, city transport buses, underground mines equipment, locomotives, etc. Hence, diesel fuel plays a vital role in the energy sector's economy and has a substantial impact on pollution levels.

Biodiesel is the best-fitted surrogate energy source for diesel engines. But the production cost of biodiesel is very high. Additionally, the production of biodiesel from edible vegetable oil may widen the disparity between food supply and demand. And if the production is from non-edible crops, it will directly impact the edible food crops supply. Hence, alcohol emerges as a highly appealing surrogate energy source due to its abundant availability, convenient storage, and safe handling. Bioethanol as well as methanol are the main alcohols that are commonly used as fuels in automotive applications. Nevertheless, taking into account the reduced energy value and toxic characteristics of methanol, ethanol is currently regarded as the preferred choice for use in diesel engines. Our research focuses specifically on investigating the utilization of bioethanol as a fuel in diesel engines.

1.1 Energy Scenario

People all across the world are becoming more and more aware of the finite supply and worrying rate of consumption of non-renewable petroleum resources. The growing demand for energy and the ongoing exhaustion of fossil fuel reserves will lead to an energy crisis. Oil and coal are the main sources of energy for transportation and industry. Petroleum, a non-renewable energy source, serves as the source of all fuels used in the automotive industry. The 1973 first oil crisis brought the term "energy shortage" into absolute clarity. Since then, more hikes in prices have occurred, affecting the economy of the majority of the countries. There are various categories or classifications of energy based on different factors.

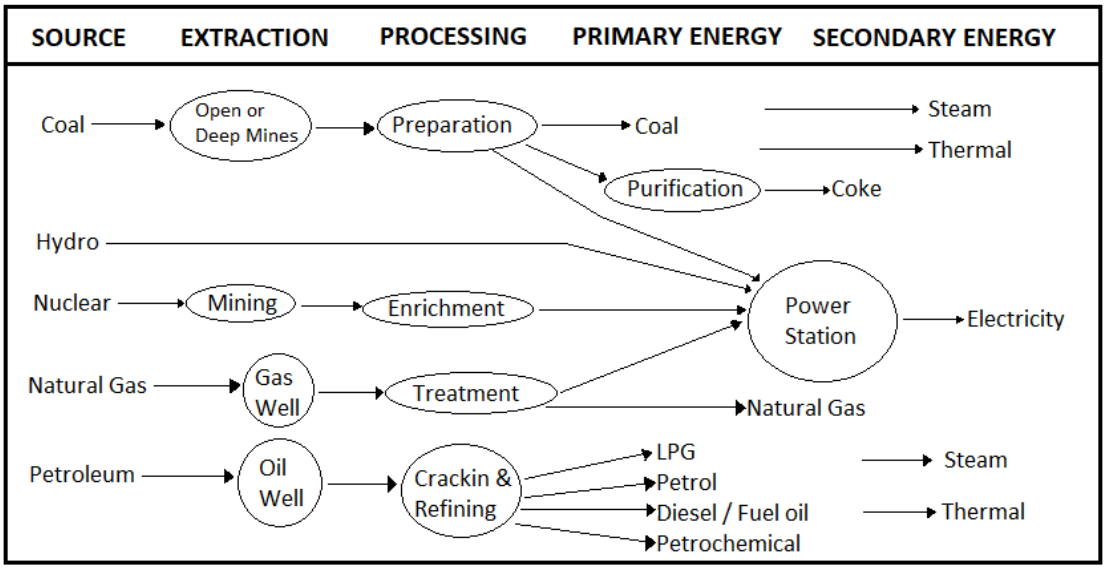

Figure 1.1: Major primary and secondary energy sources [2]

Primary energy sources are those that encompass the naturally existing or stored energy reservoirs present in the surroundings. Illustrations of primary energy sources comprise coal, petroleum, gas, and biomass (like wood). Moreover, there exist alternative primary energy sources such as nuclear energy harnessed from radioactive elements, geothermal energy stored within the Earth's core, and gravitational potential energy. Figure 1.1 provides an illustration of various significant primary and secondary energy sources. It is common for industrial facilities to convert primary energy sources, for example coal, oil, or gas, into secondary energy sources like steam and electricity.

1.1.1 World energy scenario

World Energy reserves

The present state of global energy reserves may be summed up in the following fashion:

Fossil Fuels:

a) **Coal:** The globe has large deposits of coal, mainly in the US, Russia, China, and Australia. Meanwhile, the adverse environmental impacts of coal, especially greenhouse gas emissions, has caused its usage to fall in several locations.

b) **Oil:** Saudi Arabia, Venezuela, Canada, Iran, and Iraq have the greatest concentration of oil repository. The need for crude oil is strong, but worries over the environment and a transition to energy from renewable origin are altering the future prospects for the utilisation of oil.

c) **Natural Gas:** Natural gas repository are ample, with substantial resources located in Russia, Iran, Qatar, and the United States. Natural gas is regarded as an environmentally friendly fossil fuel when correlate to coal and oil, and it is becoming more and more utilised as an alternative fuel in the energy matrix.

Renewable Energy:

a) **Solar and Wind:** Because they depend on Mother Nature's mechanisms, solar and wind energy supplies are virtually limitless. The improvement of technology and the reduction of prices have resulted in considerable increase in both wind and solar power projects across the globe.

b) **Hydroelectric Power:** The presence of sufficient supplies of water determines hydroelectric power repository. Many nations have built significant hydroelectric potential, but further growth may be hampered by issues pertaining to the ecosystem and society.

c) **Other Renewables:** Other sources of sustainable energy, such as geothermal and biomass, plays a role to the balance of energy as well, however their reserves differ by locations.

It is crucial to remember that estimations of energy reserves might alter as time progresses as a result of new findings, developments in mining technology, and changing socioeconomic and ecological considerations. Furthermore, the worldwide energy ecosystem is altering, as countries attempt to expand their energy resources, lowers greenhouse gas emissions, and encourage long term viability.

World Energy Consumption

Figure.1.2 displays the world's primary source of energy utilization during the last past 10 years. As previously stated, fossil fuels dominate the world's energy consumption.

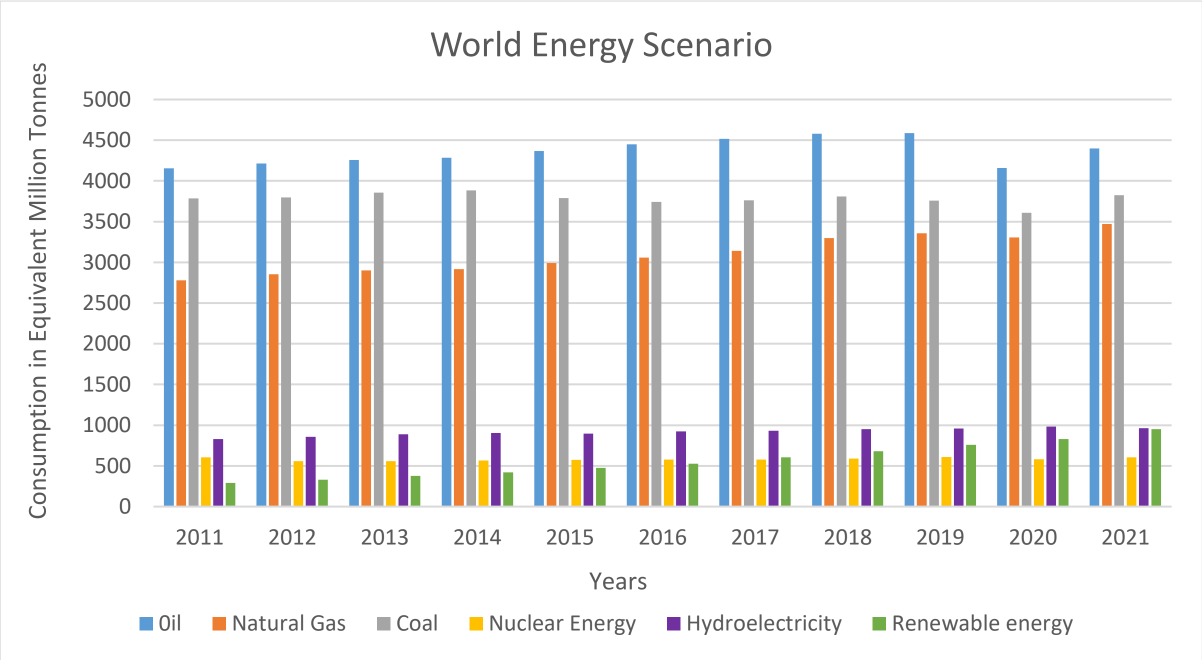

Figure 1.2: World primary energy consumption by fuels in oil equivalent million tonnes [3]

In the year 2021, energy consumption and emissions rebounded to levels seen prior to the COVID-19 pandemic in 2020, nullifying the temporary decline caused by the global health crisis. Primary energy consumption experienced a significant increase of 5.8%, surpassing the levels observed in 2019 by 1.3%. Over the period from 2019 to 2021, renewable energy witnessed a notable growth of more than 8 exajoules (EJ). In contrast, the utilization of fossil fuels remained relatively stable. Fossil fuels constituted 82% of the primary energy consumption in the preceding year, indicating a slight decline from 83% in 2019 and 85% half a decade ago.

In 2021, global oil usage witnessed a surge of 5.3 million b/d, although it remained 3.7 million b/d lower compared to the levels recorded in 2019. The increase in consumption was predominantly fueled by heightened demand for gasoline (1.8 million b/d) and diesel/gasoil (1.3 million b/d). Geographically, the most notable growth in oil consumption was observed in the United States (1.5 million b/d), China (1.3 million b/d), and the European Union (570,000 b/d). On the production front, worldwide crude oil production experienced an uptick of 1.4 million b/d, with OPEC+ countries accounting for over three-quarters of this expansion. Notably, Libya (840,000 b/d), Iran (540,000 b/d), and Canada (300,000 b/d) witnessed substantial increases in oil production. Conversely, Nigeria (-200,000 b/d), the United Kingdom (-170,000 b/d), and Angola (-150,000 b/d) observed the most significant declines in production. Furthermore, refinery capacity witnessed a decrease of approximately 500,000 b/d in 2021, marking the first substantial drop in over three decades. The decline was primarily attributed to a sharp reduction in the refining capacity of the OECD countries (1.1 million b/d). As a result, the OECD's refining capacity in 2021 reached its lowest level since 1998.

In 2021, global natural gas consumption witnessed a growth of 5.3%, reaching pre-pandemic levels and surpassing the threshold of 4 trillion cubic meters (Tcm) for the first time. The share of natural gas in primary energy remained unchanged from the previous year, accounting for 24% in 2021. The supply of liquefied natural gas (LNG) experienced a 5.6% increase, adding 26 billion cubic meters (Bcm) to reach a total of 516 Bcm in 2021. This growth rate was the slowest since 2015, excluding the year 2020. The United States contributed significantly to the rise in LNG supply, with an increase of 34 Bcm, compensating for reductions from other exporters in the Atlantic Basin. Regarding LNG imports, China overtook Japan as the leading global importer of LNG in 2021, representing around 60% of the overall growth in global LNG demand. Among the pipeline deliveries to Europe, Algerian exports exhibited the most significant expansion (+13 Bcm), followed by Azerbaijan (+6 Bcm). While Russian pipeline supplies to Europe remained steady at 167 Bcm in 2021, exports to the European Union (EU) experienced a decline of 8.2% (-12 Bcm).

In the year 2021, global coal consumption saw a significant rise of over 6%, reaching 160 exajoules (EJ), which is slightly higher than the levels observed in 2019 and marks the highest point since 2014. The increased consumption of coal was primarily driven by China and India, which together accounted for over 70% of the overall increase. China's coal consumption grew by 3.7 EJ, while India's consumption rose by 2.7 EJ. With a 440 Mt rise in supply, global output matched to demand. China and India played a significant role in driving the majority of the output growth in coal, with a substantial portion of the increased production being consumed domestically. Additionally, Indonesia also contributed to the growth by expanding its coal exports. It is worth noting that both Europe and North America experienced a departure from the trend of consecutive reductions in coal usage, observing an increase in coal consumption in 2021.

In 2021, renewable primary energy sources, excluding hydro but including biofuels, experienced a notable increase of approximately 5.1 exajoules (EJ). This reflects a significant annual growth rate of 15%, surpassing the previous year's increase of 9% and surpassing all other fuels in terms of growth. The solar and wind energy capacity saw a substantial increase of 226 gigawatts (GW) in 2021, nearing the remarkable growth of 236 GW achieved in the previous year. China remained the primary catalyst for the advancement of solar and wind energy capacity, accounting for approximately 36% and 40% of the global capacity expansions, respectively. However, hydroelectricity generation experienced a decline of approximately 1.4% in 2021, marking the first drop since 2015. On the other hand, nuclear generation witnessed a substantial growth of 4.2%, the highest increase since 2004, mainly due to the efforts in China.

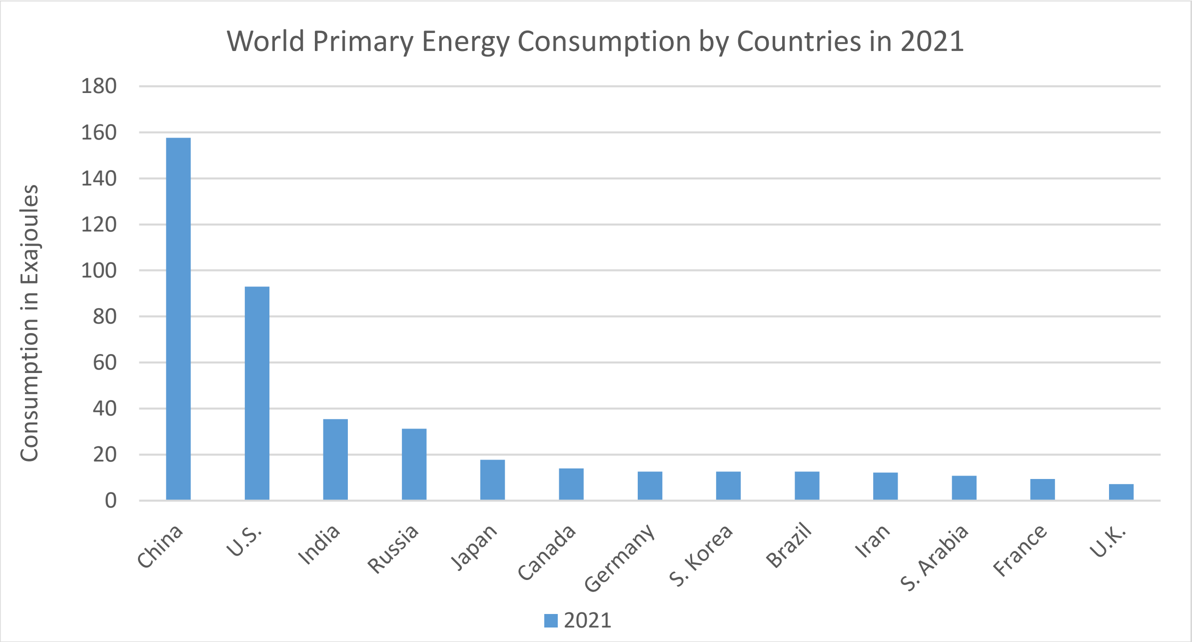

Figure 1.3: World Primary Energy Consumption by countries in 2021 [3]

Figure 1.3 illustrates the aggregate primary-energy usage of nations for the year 2021. China has the highest energy consumption, which is around 157.65 Exajoules, with the United States coming in second with approximately 92.97 Exajoules. The primary energy consumption of India was estimated to be 35.43 Exajoules.

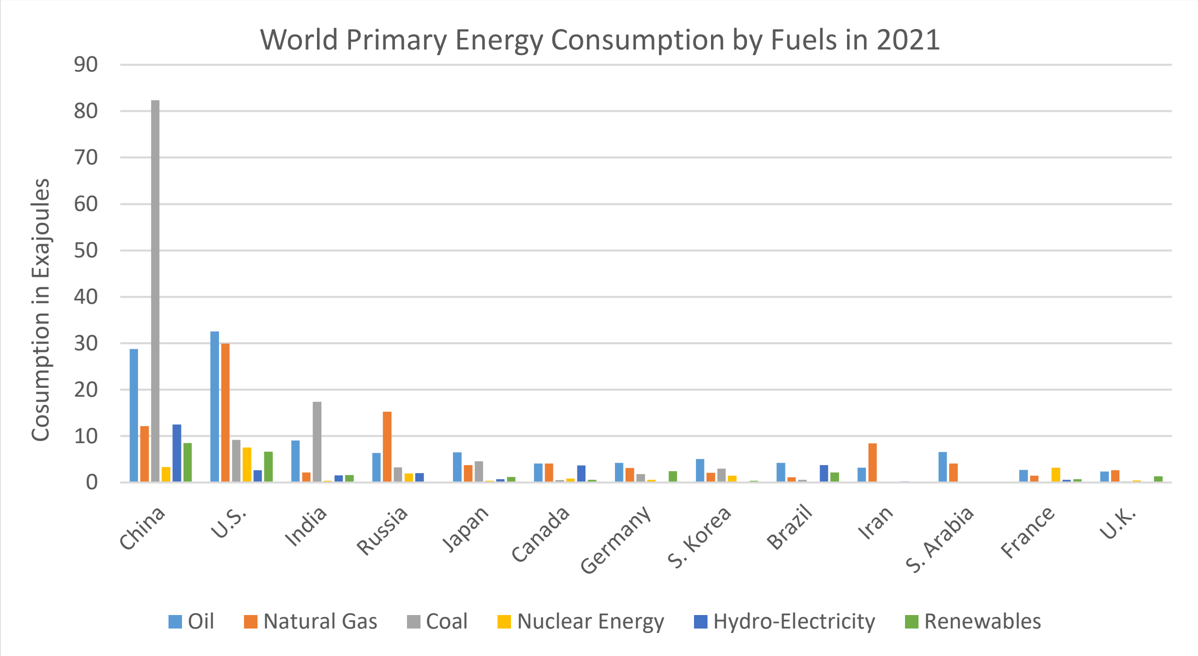

Figure 1.4: World Primary Energy Consumption by Fuels in 2021 [3]

Figure 1.4 presents the fuel-specific breakdown of primary-energy expenditure for different countries in the year 2021. It is evident that coal serves as a crucial energy source for China, and coal is also the key energy source for India. However, in the United States, both petroleum oil and natural gas dominated primary energy consumption. India comes at third position in primary energy consumption.

1.1.2 Indian Energy Scenario

India is significantly reliant on petroleum imports to meet the demands of its auto sector along with other industries. India imports around 277269 TMT crude oil and petroleum products worth Rs. 1187959 crores in the fiscal year 2021-2022 [1].

Indian Energy Consumption

As rapid industrialization drives an increase in per capita income, there has been a significant surge in vehicle ownership, leading to a substantial rise in the demand for crude oil. This will result in a scarcity of our key resources and will cause price hikes. Data indicates that in the period of 2021-22, India's oil consumption reached approximately 224.75 million tonnes, natural gas consumption amounted to 53.50 million tonnes of oil equivalent, and coal consumption stood at 479.84 million tonnes of oil equivalent.

Figure 1.5 depicts a comparison of Indian primary energy consumption

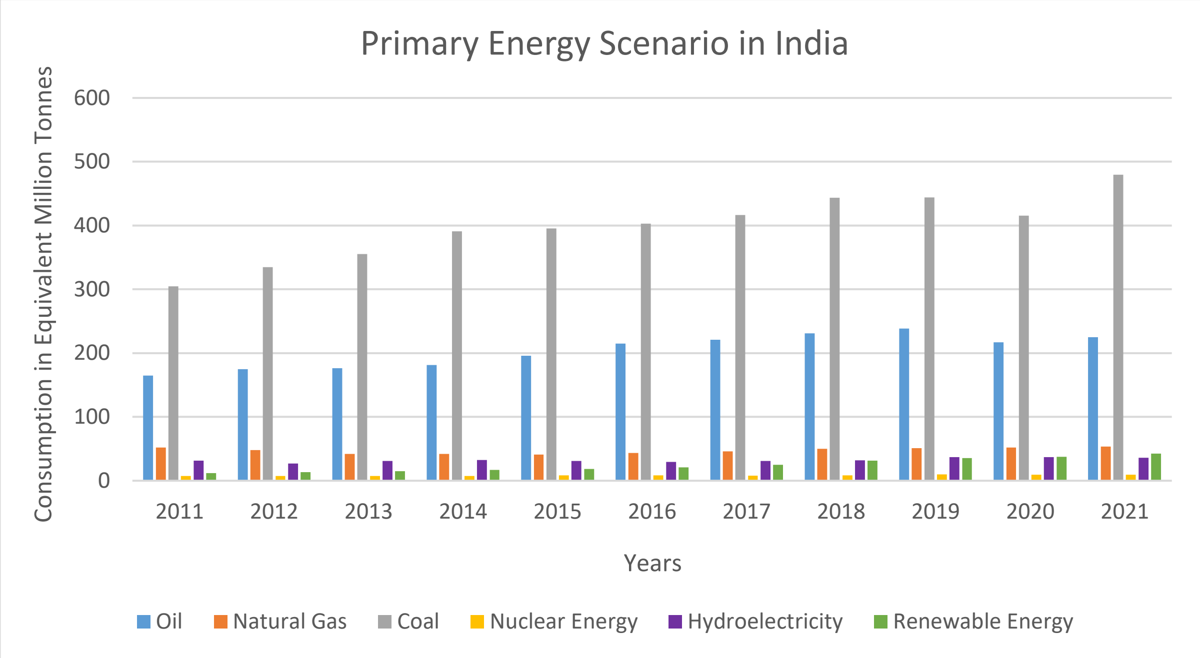

Figure 1.5: Primary Energy Scenario in India by Fuels [3]

Role of Diesel Engines in the Indian Economy

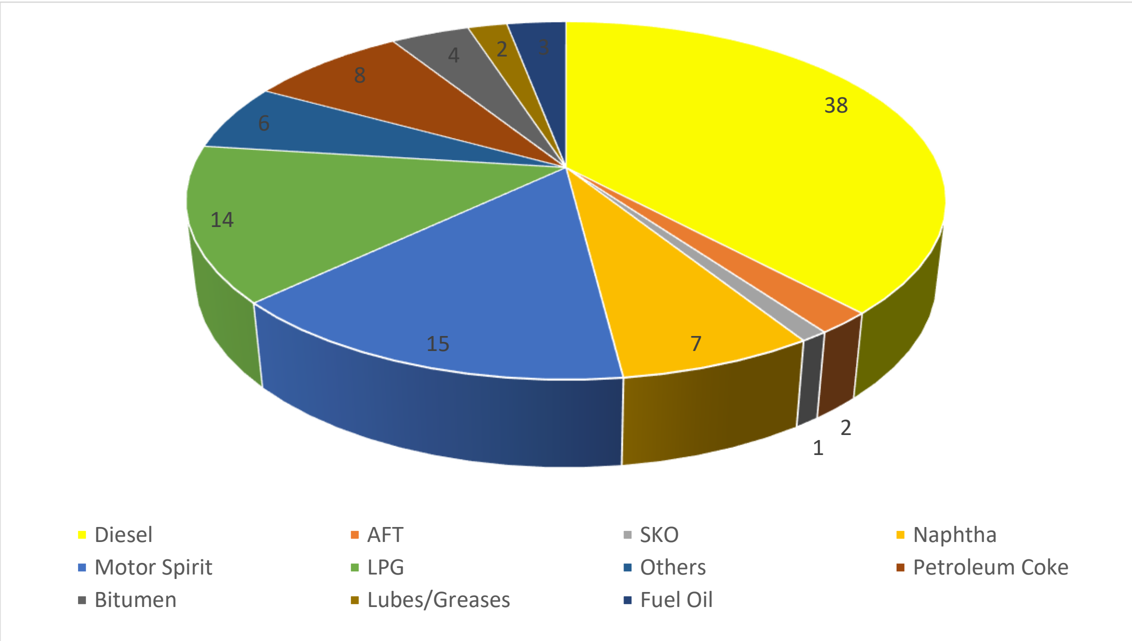

Figure 1.6: Percentage share of different petroleum product in India [1]

In Figure 1.6, the distribution of different petroleum products as a percentage of total petroleum consumption in India for the period of 2021-22 is illustrated. It is evident from the figure that diesel has the highest percentage share (i.e. 38%) followed by gasoline (Motor Sprit) in total petroleum consumption. Therefore, diesel plays a highly significant role in the economy of India.

Figure 1.7 illustrate the expenditure of diesel and petrol in million tonnes for the last six financial years. The figure illustrates a notable disparity in the consumption of diesel and petrol in India, with diesel exhibiting significantly higher usage than petrol. Thus, substituting diesel with some renewable fuels is much more valuable.

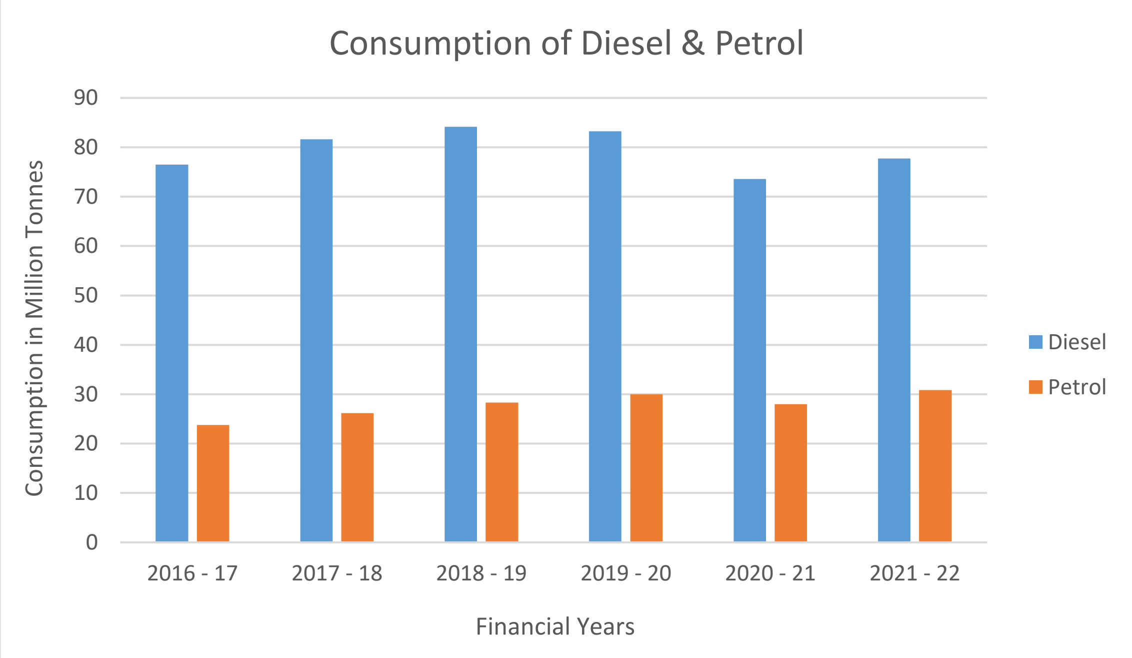

Figure 1.7: Consumption of Petrol and Diesel in India [1]

The environmental contamination stemming from the combustion of gasoline or diesel fuels in vehicles and fixed sources has prompted researchers to prioritize their endeavors in uncovering eco-friendly renewable alternative fuels for automobiles that burn cleanly.

1.2 Necessity of Alternative Fuels

Approximately 80% of the global energy provision is currently derived from finite fossil fuels. However, the main issues linked to their usage encompass the exhaustion of fossil reserves and the adverse environmental effects.

The burning of fossil fuels is widely acknowledged as a significant contributor to the build-up of greenhouse gases (including water vapour, carbon dioxide, methane, ozone, etc.) in the Earth's atmosphere. This increase in greenhouse gases has led to a rise in global temperatures, disrupting vital mechanisms that support life on our planet, including rainfall patterns, weather systems, ocean currents, and the distribution of plant and animal species. Industrial, residential, and transportation sources are responsible for emitting pollutants such as sulphur oxides, nitrogen oxides, particulate matter, carbon monoxide, ozone, hydrocarbons, benzene, 1,3-butadiene, hazardous organic micro-pollutants, lead, and heavy metals. These harmful substances, primarily produced through the burning of fossil fuels, have been recognized as posing risks to both human well-being and the natural environment. It is important to note that air pollution originating from these sources can have far-reaching effects, as pollutants can travel long distances and undergo chemical reactions in the atmosphere, resulting in harmful by-products such as acid rain and ozone.

1.2.1 Alternate Fuels for CI Engine

Due to their remarkable efficiency and durability, compression ignition (CI) engines have gained widespread acceptance in transportation systems. As a result, they are increasingly being adopted in passenger cars and light trucks. In India, a significant number of CI engines are employed across various applications.

Following are the feasible alternate source of energy, which can be used in a diesel engine.

1. Alcohols
2. C.N.G.
3. Oil from vegetables
4. Bio-diesel
5. Hydrogen
6. Bio-gas

Hydrogen has the potential to become a sustainable fuel. There are several issues related to its affordable production, unsafe nature, storage, and handling remain unresolved. If biogas is to be utilized in automobiles then it must be stored at very high pressure. Leakage from the cylinder might be a concern. Hence, the feasible implementation of bio-gas as an alternative fuel for vehicles is currently unfeasible unless suitable storage and handling facilities are developed to ensure convenience and safety.

As mentioned earlier, the demand for diesel in India surpasses that of petrol. Although the ethanol field is firmly established, the biodiesel sector is in its early phases. Presently, biodiesel manufacturing in India mainly revolves around the process of transesterification of oil from vegetabes. To tackle the restricted accessibility of consumable vegetable oil, the government has chosen to utilize non-consumable oil derived from Jatropha curcas seeds as a feedstock for biodiesel. Jatropha offers several advantages, including its ability to thrive with minimal water and fertilizer, its resistance to grazing animals and pests, ease of propagation, short growth cycle, high seed yield and oil content, as well as its production of nutrient-rich organic fertilizer.

The primary hurdle faced in implementing the biodiesel program lies in the establishment of large-scale Jatropha plantations, as farmers do not consider Jatropha farming to be financially viable. To address this challenge, the government must introduce initiatives aimed at instilling confidence among farmers. One such measure is the setting of a minimum support price for Jatropha oilseeds, ensuring farmers receive fair compensation for their produce and providing them with regular reimbursements. These steps are crucial to incentivize and encourage widespread participation in Jatropha cultivation. Ethanol seems to be an attractive substitute fuel in relation to its accessibility, storage, and handling characteristics.

Methanol and ethanol are two alcohols that are frequently investigated for automotive applications. Due to the drawbacks associated with methanol, such as its low energy value and deadly properties, there is a growing focus on utilizing ethanol as a preferred fuel in diesel engines. The benefits of ethanol, such as its increased energy density and comparatively reduced toxicity, render it a compelling substitute for utilization in diesel engines.

1.3 Ethanol

With a distinctive, pleasant scent, ethanol is a clear, transparent liquid. It tastes fairly pleasant when diluted in water, but burns when concentrated. At a temperature of 20°C, ethanol generally exhibits a density of 0.789 g/ml. Its freezing point stands at -114.1°C, while its vaporization point is 78.5°C.

1.3.1 Ethanol as a Fuel

Ethanol serves as a sustainable fuel generated predominantly from resources like maize, sugarcane, and other renewable botanical substances. Its ability to decrease greenhouse gas emissions and reliance on non-renewable resources has earned it acknowledgment as a viable alternative to conventional fossil fuels. With a long history of use as a fuel, especially in the transportation sector, ethanol continues to be explored and utilized as a sustainable energy source [4].

Ethanol presents notable benefits in terms of mitigating greenhouse gas emissions. In comparison to gasoline, ethanol generally yields lower carbon dioxide (CO2) emissions. While the combustion of ethanol releases carbon dioxide, the absorption of carbon dioxide by plants during their growth counterbalances it, thus positioning ethanol as a more environmentally neutral fuel option. Studies conducted by the U.S. Department of Energy suggest that ethanol derived from corn can potentially reduce greenhouse gas emissions by approximately 34% when compared to gasoline. Moreover, cellulosic ethanol, which is derived from non-food plant materials, has the potential to achieve even greater emissions reductions.

Ethanol holds the capability to diminish reliance on fossil fuels and enhance the security of energy supply. Being a renewable fuel, it serves as an alternative to finite petroleum resources, thereby reducing the necessity for oil imports and vulnerability to fluctuations in oil prices. This characteristic of ethanol production holds significant implications for promoting energy sustainability and benefiting national economies [5].

Ethanol is commonly blended with gasoline in different ratios, with E10 (10% ethanol, 90% gasoline) being the prevalent blend in several countries, including the United States. Flex-fuel vehicles (FFVs) are specifically engineered to operate using higher ethanol blends, such as E85 (85% ethanol, 15% gasoline). These vehicles offer consumers increased options and flexibility when it comes to selecting a fuel that aligns with their environmental and energy objectives.

Nevertheless, ethanol as a fuel faces certain challenges. One of the main considerations revolves around its potential influence on the cost of food and the security of food supply. The utilization of crops like corn for ethanol production can result in increased commodity prices and competition for agricultural land, which may have implications for global food supplies. To address these concerns, researchers and policymakers are actively exploring alternative feedstocks such as cellulosic biomass and algae, aiming to mitigate these potential issues and ensure a more sustainable approach to ethanol production [6].

The energy-intensive nature of ethanol production poses another significant challenge. The conversion process of plant materials into ethanol demands substantial energy, especially during activities such as fertilizer production, transportation, and processing. It is imperative to carefully assess the overall energy balance and environmental impact of ethanol production, taking into account the energy inputs and emissions associated with cultivation, harvesting, and conversion processes. This evaluation ensures a comprehensive understanding of the sustainability and efficiency of ethanol production methods.

To overcome these challenges and enhance the sustainability of ethanol, continuous research and development initiatives are dedicated to advancing second-generation biofuels. One notable example is cellulosic ethanol, which utilizes agricultural residues, wood waste, and dedicated energy crops. These feedstock offer higher energy yields and have a reduced impact on food supplies compared to traditional crops like corn. Moreover, advancements in technology and engineering hold the potential to improve the efficiency of ethanol production processes and reduce energy requirements. These ongoing efforts aim to optimize the sustainability and environmental profile of ethanol as a renewable fuel.

1.3.2 World Ethanol Scenario

Figure 1.8 demonstrates global ethanol production by various countries from 2012 to 2022. In general, global production of [specific product or industry] has shown a consistent upward trend over the years. However, the year 2020 witnessed a decline in production levels as a result of the repercussions caused by the COVID-19 pandemic. The pandemic resulted in significant disruptions across various sectors, including [specific industry], leading to a temporary contraction in production worldwide. Despite successive increases, production has yet to approach pre-pandemic levels.

By 2022, the global production of fuel ethanol had reached a significant milestone of 28.16 billion gallons, reflecting a steady average annual growth rate of 4% over the past decade. The production landscape is dominated by key players such as Brazil and the United States, which collectively account for 81% of the global ethanol production. The European Union (EU), China, India, Canada, and Thailand also contribute to the overall production share [5].

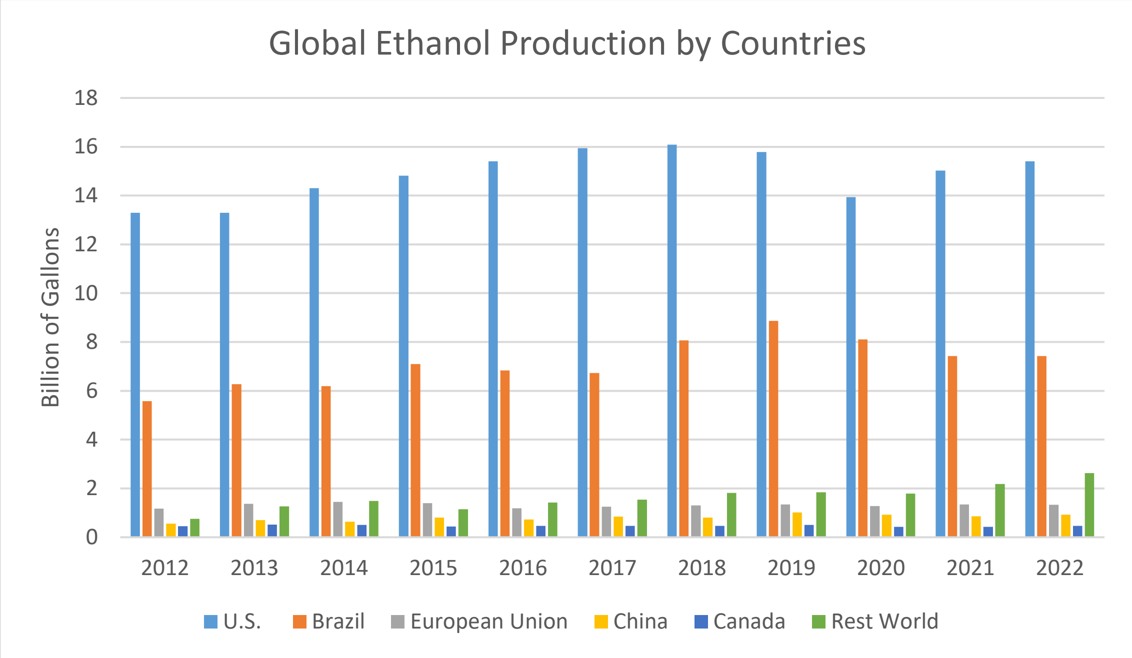

Figure 1.8: Global Ethanol Production by countries [5]

Governments worldwide have undertaken numerous initiatives and projects to bolster the availability of ethanol as an alternative fuel. These efforts aim to promote the adoption of ethanol and capitalize on its environmental advantages. Through such endeavours, governments are actively fostering the growth and sustainability of the ethanol industry, further expanding its role as a viable fuel source.

1.3.3 Indian Ethanol Scenario

Ethanol was introduced as a vehicle fuel in India for the first time in 2003. The Ministry of Petroleum and Natural Gas (MoPNG) made an important announcement in September 2002, stating that a mandatory blend of 5% ethanol with petrol would be implemented starting from 2003. This blending requirement applied to the nine key states in India that were major producers of sugar. The blending mandate was declared optional in October 2004 due to the ethanol scarcity that occurred in 2004–2005. It was then restarted in October 2006 in the following year with a gradual increase to 10% blending.

In 2008, the Ministry of New & Renewable Energy introduced a National Policy on Biofuels with the aim of reducing our carbon footprint and decreasing dependence on imported oil in the future. This strategy was formulated to encourage the adoption of biofuels as a sustainable and eco-conscious substitute for traditional fuels. A target of 20% bioethanol mixing by 2017 was set under this, with the level of 5% bioethanol blending envisaged starting in October 2008. Additionally, a schedule for the program's gradual rollout has been drawn out [1].

Currently, the government is running the Ethanol Blended Fuel (EBP) Program, which allows OMCs to sell fuel that has been up to 10% mixed with ethanol. As a part of the Ethanol Blending Program, the government has set ambitious targets for blending ethanol into petrol and biodiesel into diesel. Initially, the goal was to achieve a 10% ethanol blend in petrol and a 5% biodiesel blend in diesel across the nation by 2022, with a further objective set for 2030 is to achieve a blend of 20% ethanol and 5% biodiesel. However, in December 2020, these targets were revised, and a new aim of achieving a 20% blending of ethanol in petrol by 2025 was set. These objectives demonstrate the government's dedication to fostering the utilization of biofuels and decreasing our dependency on fossil fuels [7].

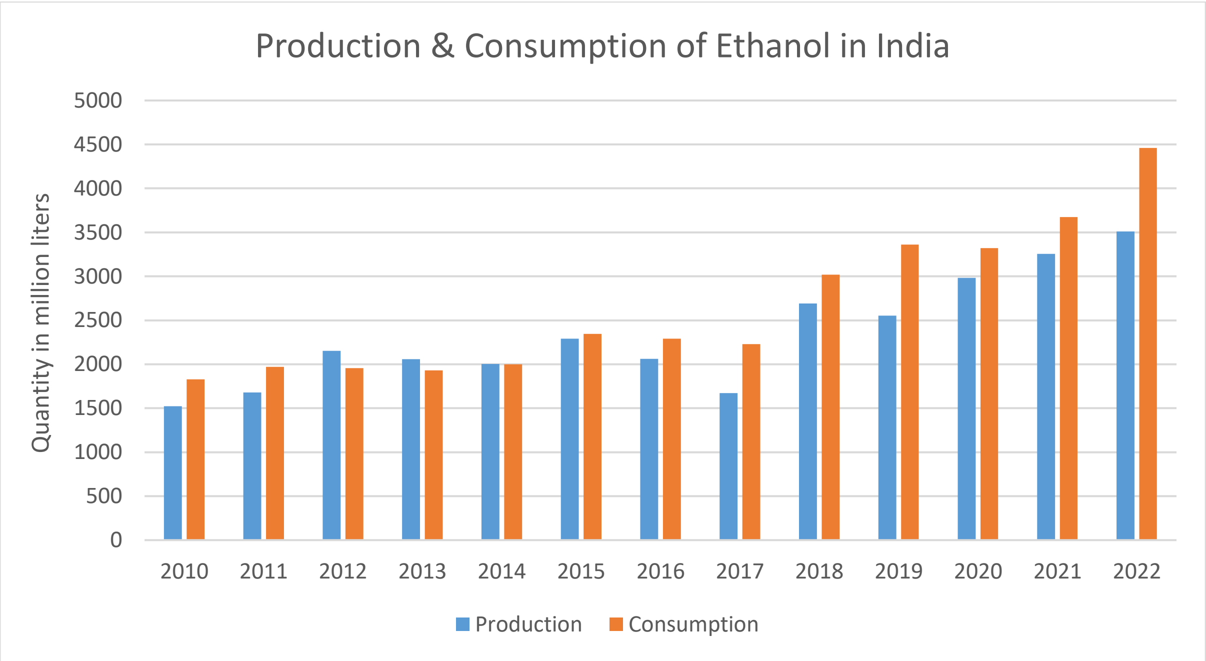

Figure 1.9: Production & Consumption of Ethanol in India [8]

Figure1.9 shows the comparative graph of production vs consumption of ethanol in India. It is evident from the graph that both the production and consumption of ethanol increases year after year. After the launching of the ethanol blending program, the production of ethanol increased at a very faster rate. However, the utilization of ethanol consistently exceeds its production. [8].

Table 1.1: Ethanol Production Projection and Capacity Requirement [7]

Financial Year	Ethanol Production Projections			Capacity Requirement		
	Grains	**Sugar**	**Total**	**Grains**	**Sugar**	**Total**
2022-23	2930	5350	8280	3500	6250	9750
2023-24	3880	6000	9880	4500	7250	11750
2024-25	6280	6600	12880	7000	7300	14300
2025-26	6660	6840	13500	7400	7600	15000

All the values are in Million Liters.

Ethanol blending program estimates some projections related to ethanol production and requirement, which can be seen in the table. It can be seen from the table that the projected requirement of ethanol is always greater than the projected production. In the coming years, the production of ethanol from grain sources is expected to play a crucial role in meeting the ethanol demand of the country. This highlights the significance of utilizing grain-based ethanol as a key source to fulfill the ethanol requirements in India. In addition to this 2G ethanol plant also contribute in fulling the ethanol requirement of the country.

CHAPTER 2

LITERATURE SURVEY

2.1 Ethanol as an Alternate Fuel in Diesel Engine

The utilisation of bioethanol as an energy source for internal combustion engines for a considerable period, dating back to the 19th century. One notable advantage of ethanol is its comparatively lower production cost when compared to petroleum products. This puts ethanol in an excellent position to significantly serve India's future energy needs since petroleum prices are predicted to continue rising. Ethanol offers several significant advantages, including reducing hazardous gas emissions and greenhouse gases, better employment opportunities in the agriculture sector, energy security, and a reduction in dependence on imported oil. It can be regarded as a renewable fuel due to its agricultural roots.

Ethanol offers numerous advantages compared to diesel fuel when utilised as an energy source for compression ignition (CI) engines. These advantages include reduced emissions of soot, carbon monoxide (CO), nitrogen oxides, and unburned hydrocarbons (HC). Ethanol has the potential to be utilized as an ethanol infused diesel mixture in compression ignition (CI) engines. Diesel fuel consists of hydrocarbons ranging from C3 to C25, giving it a wider range of transitional properties compared to bioethanol (C_2H_5OH), which is a single hydrocarbon. Due to the presence of an oxygen atom, ethanol can be regarded as a hydrocarbon undergoing partial oxidation. Furthermore, bioethanol exhibits complete miscibility with aqua molecule (water). This could potentially lead to the presence of moisture in the mixed fuel, which would cause the mechanical parts to corrode, especially those constructed of copper, brass, and aluminium. These materials should be avoided to reduce the aforementioned issue. Most types of rubber can react with ethanol, causing a blockage in the fuel stream. Fluorocarbon rubber is therefore suggested as an alternative to natural rubber. Ethanol is safer to transport and store since, it possesses a higher temperature at which it can auto-ignite compared to diesel fuel. Nonetheless, one disadvantage of ethanol is its lower flash point when compared to diesel fuel, which can be considered a safety concern.

Ethanol has gained recognition as a high-quality motor fuel due to its excellent anti detonation properties, as measured by the "octane rating," and its excellent proficiency as denoted by energy release and thermal efficiency. Because of their low cetane value, which indicates poor ignition quality, ethanol poses significant challenges in terms of combustion in CI engines [9]. In the field of diesel-alcohol technology, the main focus of study was to identify methods and techniques to enable alcohol to ignite through compression in diesel engines. This was particularly important because high-octane fuels, which are suitable for gasoline engines, generally have low cetane values, which is not desirable for diesel engines.

The growing demand for light-duty diesel engines highlights the necessity of exploring alternative energy source like ethanol for CI engine. This enables them to serve as viable replacements for petroleum-based fuels and make a significant contribution to meeting energy needs. Nonetheless, incorporating ethanol into diesel engines has encountered numerous challenges and obstacles. The main difficulties are:

- ❖ Because of low calorific value of ethanol, a greater quantity of fuel is necessary compared to diesel.
- ❖ The feasibility of utilizing ethanol infused diesel mixture is hampered by the limited ability to mix significant volumes of bioethanol with diesel fuel. Moreover, the stability of the blend is compromised, resulting in phase separation even with minimal water content [10].
- ❖ Diesel engines typically benefit from fuels with high cetane numbers, which facilitate rapid auto-ignition and have shorter ignition delays. However, ethanol exhibits notably low cetane numbers, which is a limitation when considering its use in diesel engines [11].
- ❖ For diesel engines, diesel fuels act as lubricants. Alcohol fuels don't have the same lubricating properties [12].
- ❖ Due to the ethanol's poor auto-ignition ability, a large quantity of vaporized ethanol gets collected in the cylinder, which gets ignited at once and causes a considerable knock [12].
- ❖ Ethanol have corrosive nature due to which it is not compatible with Copper, Zinc, Lead, Aluminum, Rubber gaskets etc. [13].
- ❖ Ethanol has low value of viscosity which leads to pump and fuel injector leakage [14].
- ❖ Ethanol's minimal lubricity value poses a challenge as it can cause wear and tear on fuel injectors [14].

While completely replacing diesel fuel with ethanol presents significant challenges, there has been a growing interest in recent years to utilize ethanol in diesel engines through various approaches and in different proportions. This includes exploring dual fuel operation, where ethanol is used alongside diesel fuel.

The following table presents the physiochemical properties of ethanol as well as diesel: [15], [16]

Properties	**Ethanol**	**Diesel**
Formula	C_2H_5OH	$C_{14}H_{30}$
Molecular weight, (grams per mole)	46.07	198.4
Boiling point, (°C)	78	125–400
Calorific value, (MJ per kg)	26.7	42.6
Density, (kg per m^3, at 20 °C)	785	856
Flash point temperature, (°C)	13	52
Auto-ignition temperature, (°C)	425	300–340
Lower heating value, (MJ per kg)	26.8	41.66
Cetane number	5–8	45–50
Vapor Pressure, (kPa, at 38 °C)	17	0.34
Stoichiometric ratio, (air : fuel)	8.96	14.7
Latent heat of vaporization, (kJ/kg)	921.1	620
Carbon content, (by wt.%)	52.2	87
Hydrogen content, (by wt.%)	13	13
Oxygen content, (by wt.%)	34.8	0
Sulphur content, (Mass %)	0	<50

Table 2.1: Various Physio-chemical properties of Ethanol and Diesel

2.2 Methods of Ethanol Production

Based on the feedstock, there are two techniques which are extensively used in producing ethanol commercially: First Generation (1G) Ethanol and Second Generation (2G) Ethanol.

2.2.1 First Generation (1G) Ethanol Production

- ❖ Ethanol derived from food-based raw materials, such as starch and sugar, are commonly referred to as first-generation ethanol.
- ❖ This type of ethanol is made by the fermentation of sugar and starches with the aid of enzymes and microbes.
- ❖ The majority of ethanol produced fall within this category.
- ❖ Glucose, fructose, and sucrose are employed as the primary constituents derived from sugar crops like sugarcane, sugar beet, and sweet sorghum.
- ❖ Grinding or crushing is carried out to obtain these fermentable sugars, which are then fermented to ethanol.
- ❖ Distillation, subsequently followed by dehydration, is used to extract ethanol from the by-product.
- ❖ Crops such as maize and wheat contain starch, a polysaccharide composed of glucose units connected by (1-4) and (1-6) glycosidic linkages.
- ❖ Yeast does not ferment starch immediately.
- ❖ Starch is obtained by grinding the grains.
- ❖ α-amylase and glucoamylase are used to hydrolyzed the starch into glucose.
- ❖ The glucose is subsequently fermented to produce ethanol.
- ❖ The financial viability of manufacturing ethanol from food-based ingredients, as well as the effects on land use change, have been condemn.
- ❖ Because of the challenges associated with the manufacturing of first generation ethanol, the demand for ethanol synthesis from other than food based raw materials such as biomass arose.
- ❖ Figure 2.1 depicts the manufacturing of first generation (1G) bioethanol [17].

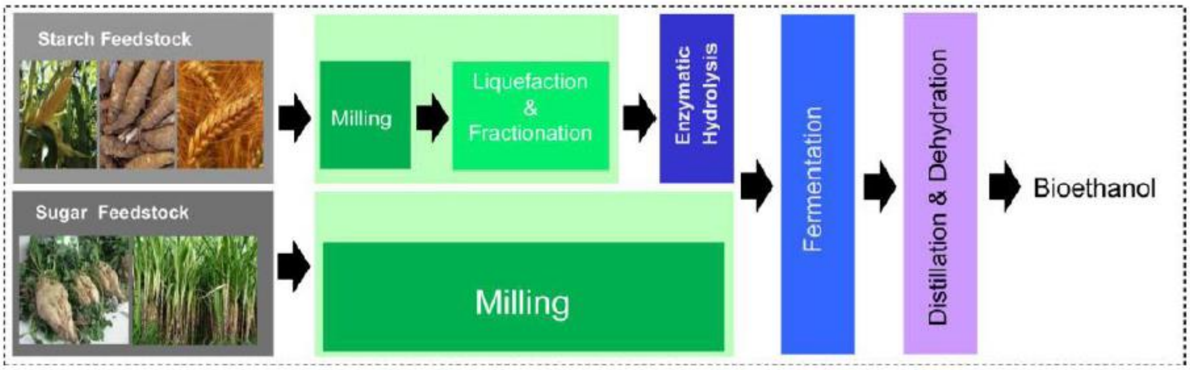

Figure 2.1: Ethanol production from first generation biomass [17]

2.2.2 Second Generation (2G) Ethanol Production

- Second generation ethanol are manufactured from other than food raw materials.
- Because second generation ethanol are sourced from different raw materials, they tend to be manufactured using alternative technologies.
- Cellulosic materials such as certain energy crops (e.g., switchgrass, miscanthus) and agro and wood wastes (e.g., woodchips, cornstover, sugarcane bagasse, and sawdust) are among the non-food items based raw materials utilised in the manufacturing of second generation ethanol.
- Cellulosic material primarily consists of cellulose, hemicellulose, and lignin polymers that are interconnected within a heterogeneous matrix.
- Cellulose is a straight polysaccharide made up of many (1-4) connected D-glucose units.
- Hemicellulose is a polymer composed of xylose, mannose, galactose, rhamnose, and arabinose.
- Lignin is an intricate polymer composed of interconnected aromatic molecules.
- Lignin works as a shield, preventing cellulose and hemicellulose from depolymerizing to fermentable sugars.
- The process of converting cellulosic biomass to ethanol is more complicated than that of first generation ethanol manufacturing.

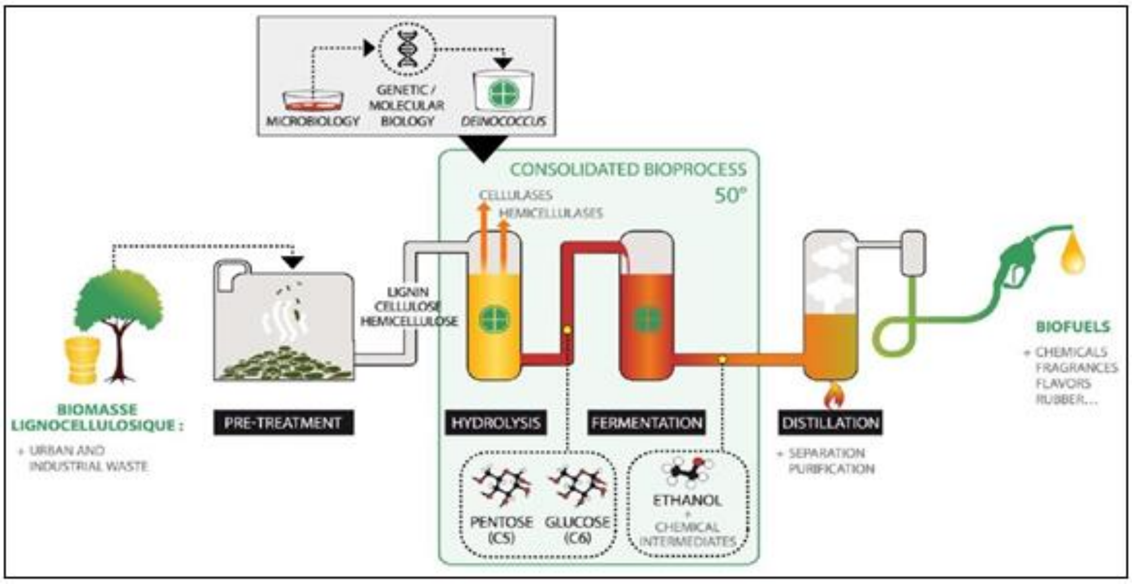

Figure 2.2: Production of the second generation (2G) ethanol from non-food feed-stocks [17]

- Cellulosic biomass is first processed, either by chemicals or enzymes, to break down the polymeric units and enhance the reach of C5-C6 sugars for the fermenting process of microbial compounds to create ethanol.
- While the commercial production of second generation ethanol facilities appears exciting, the viability of such facilities will rely heavily on a supply of raw materials at acceptable costs in the market.
- Figure 2.2 depicts a simplified structured diagram for producing the second (2G) ethanol [17].

2.3 Method of Injecting Ethanol in CI Engine

Ethanol-diesel bi-fuel functioning can be achieved through various methods. The natural propensity of diesel fuel to undergo auto-ignition enables the ignition of ethanol in bi-fuel vehicles. The following techniques are commonly employed for dual fuel operation:

2.3.1 Ethanol diesel fuel blend

Ethanol has the ability to form both macro and micro emulsions with diesel fuel, and these emulsions do not require any engine modifications. The solutions of bioethanol without water in diesel, and the emulsions of bioethanol in diesel with a translucent appearance, are recognized as being stable. Dry bioethanol can be readily dissolved in diesel fuel, forming a transparent mixture, without the need for a surfactant or emulsifying agent. However, these bioethanol-diesel solutions have limited tolerance for water content, typically up to 0.5%. In practical applications, the formation of a non-transparent macro-emulsion using non-dry bioethanol requires the presence of an emulsifying agent. However, over time, these emulsions may separate into two phases if left undisturbed. From an engine durability perspective, blends of bioethanol in diesel fuel up to 20% (by volume) are generally considered to be reasonably safe. Several properties which impact the characteristics of ethanol infused diesel mixtures.

Blend stability

The dissolution of bioethanol in diesel is primarily influenced by two key parameters: temperature and the water content in the blend. Dry ethanol and diesel fuel combine easily in warm environments. The two fuels do, however, separate at temperatures below around 10°C, which is easily exceeded over much of the earth for a significant time of the year. To prevent separation, two approaches can be employed when combining ethanol and diesel fuel. One approach includes the use of an emulsifier, which aids in the dispersion of tiny ethanol droplets within the diesel fuel. The alternative method entails employing a co-solvent or surfactant, which functions as a linking agent, fostering molecular coherence and bonding to achieve a uniform and homogeneous solution. Both approaches are effective in preventing the separation of bioethanol and diesel [18].

The ability of bioethanol to dissolve in diesel fuel is affected by the concentration of aromatic compounds in the diesel. Ethanol, being a polar substance, induces a dipole in the aromatic molecules found in diesel fuel, leading to stronger interactions between them. However, despite these interactions, aromatic molecules can still maintain compatibility with other hydrocarbons present in diesel fuel. This means that aromatics can partially act as bridging agents and co-solvents. Consequently, reducing the amount of aromatic compounds in diesel fuels can impact both the miscibility of ethanol in diesel fuel and the quantity of additive needed to attain a stable blend [19].

Viscosity and Lubricity

Fuel injection systems depends on the fuel to lubricate the high-pressure pumping arrangement. The viscosity and lubricating properties of the fuel play a crucial role in providing lubrication to these systems. Fuel injection systems, specifically those that employ rotating injector pumps totally depend on the fuel for lubricating purposes. There are some places in the fuel injection system that requires less lubrication by fuel like in inline pimp and unit injector but some places highly depend on it like plunger and barrel. Lower fuel viscosities cause more pump and injector leakage, which lowers the amount of fuel that can be delivered at once and, ultimately, reduces power output. Inadequate fuel may be introduced at cranking speed if there is a leakage of fuel in the pumps because of the minimal viscosity of fuel at high temperatures which can lead to hot restart challenges [20], [21].

Material compatibility

Numerous material compatibility tests carried out in the early 1980s, primarily focused on ethanol's use in gasoline engines, can provide valuable insights into the effects of ethanol infused diesel mixture in diesel engines. These tests hold significance, especially in relation to understanding the potential impact on the fuel injection system. The degree to which ethanol is corrosive depends significantly on its quality [22].

Corrosion caused by ethanol-diesel fuel blends can be categorized into normal corrosion, dry and wet corrosion. Ionic contaminants, particularly chloride ions and acetic acid, were responsible for general corrosion. The polarity and structure of the ethanol molecule can contribute to the occurrence of dry corrosion [23]. Azeotropic water oxidizes most metals, which leads to wet corrosion. It can be presumed that recently prepared blends containing anhydrous bioethanol would have a relatively low corrosive effect. The fuel injection system may find that a blend is more corrosive if it has been let to remain in a tank for long enough for the ethanol to accumulate water vapour from the environment. Furthermore, in certain situations such as in engines used for combine harvesters, the fuel may reside in the fuel injection pump for an extended duration, allowing for potential corrosion of internal pump components. To address this issue, certain additive packages employed for ethanol-diesel blends include corrosion inhibitors [24].

Energy content

The engine's power output is directly influenced by the energy content of the fuel it consumes. As stated by Wrage and Goering [25], for producing adequate power by the engine, the mixture of ethyl alcohol and diesel should possess at least 90% energy content of neat diesel. It is assumed that all the additives in the blend possess an energy content equivalent to diesel. The incorporation of 5% bioethanol into the fuel mixture reduces the energy content of the mixture by 2%.

Cetane number

According to ASTM Standard, fuel for diesel engines requires at least a 40 cetane rating. Because the octane and cetane numbers are inversely correlated, ethanol possesses a small value of cetane rating. As on increasing the percentage of bioethanol in the fuel blend, the cetane rating reduces simultaneously. Because of differences in the methods used to determine cetane values below 30, utilizing cetane rating to evaluate the combustion characteristics of the bioethanol and diesel combination was revealed ineffective. The cetane value of ethanol, however, was considered to lie in the range of 5 to 15. Longer ignition delays caused by lower cetane levels allow a bit longer time to fuel to vaporise before initiating ignition. More heat is released at constant volume due to faster initial burn rates, which leads in a more efficient transformation of energy to work. However, it is advisable to add a combustion booster to bioethanol and diesel mixture to increase their cetane rating so that they fall within a desirable range comparable to what is anticipated of diesel fuel [26], [27].

2.3.2 Ethanol Fumigation

Ethanol fumigation is one of the most popular techniques for obtaining dual fuel functioning in Diesel engines. The process of adding ethanol to the intake air to achieve a homogeneous mixture while injecting diesel fuel from the fuel pump is known as ethanol fumigation. Ethanol is introduced into the intake manifold through a constant velocity (CV) carburetor, where it is mixed with air before entering the cylinder along with the intake air. By adjusting the throttle, the ethanol mixing ratio can be varied between 3 to 48 percent by fully closing or opening the throttle [28]. The following are some benefits of fumigation:

- Because the ethanol-injecting device is placed near the inlet air manifold, the engine must be somewhat modified. Additionally, a fuel supply system and a simplified device may also control the fuel flow.
- Here, two fuel systems are present, one is for diesel and another is for bioethanol. Diesel engines with a fumigation system may be able to run only on diesel fuel due to their versatility. The engine may run on both fuel or only on diesel fuel by cutting away and rejoining the ethanol supply to the injector, and vice versa.
- Fumigated ethanol may boost an engine's power production if smoke emissions constrain it since alcohol tends to lessen smoke. This is due to the alcohol and injected charge being well mixed.
- Ethyl alcohol may be employed to substitute diesel through fumigation. Fumigation of ethyl alcohol can give up to 50% of fuel energy [29].

2.3.3 Inline Mixing

Mechanical stirrers are used in traditional chemical reactors to create blends. Generally, a stirred tank reactor of this nature comprises a vessel equipped with baffles on the sides, enabling the fluid to be agitated by an impeller. The fluid is restrained from rotating with the impeller by the use of the baffles. This configuration has been used for centuries for mixing.

Inline mixing is a technique for blending ethanol with diesel in which the two substances are blended mechanically or using a static mixer before the fuel pump. A static mixer is a tool that combines fluids without the need of an emulsifier or surfactant. This approach efficiently generates a uniform blend of ethanol and diesel after the mixing device, resulting in a homogeneous mixture. Conventional shear, reverse flow, and collision may mix ethanol and diesel in a pipeline effectively and with little net pressure loss. Since static mixers don't have moving parts, the maintenance is minimal. By harnessing the energy from the fluid in the pipeline and determining the appropriate number of mixing elements, it is feasible to achieve complete mixing of liquids at the outlet of the mixer. The static mixer goes through 4 steps of mixing.

1. Splitting the main stream.
2. The streams are directed to exert force in the opposite direction of the external walls.
3. A mixing vortex is formed along the centerline of the second element.
4. The first step of the mixing vortex shears repeats in the opposite spin [30], [31].

Figure 9 illustrates the helix static mixer carrying out the function described above.

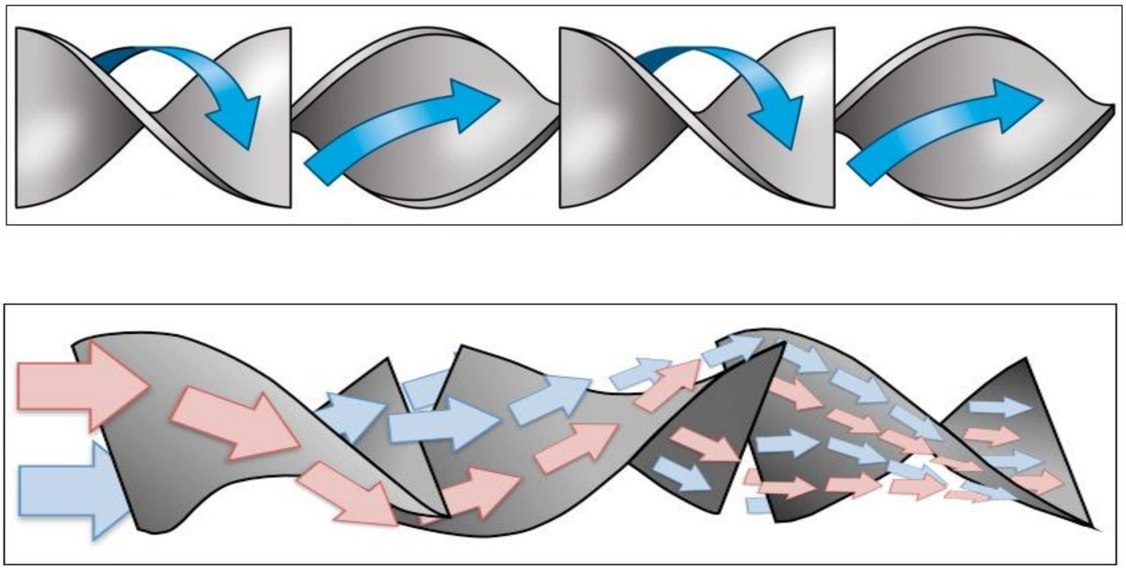

Figure 2.3: Helix Static Mixer [32]

2.4 Literature Survey

Kim et al. [33] conducted the experiment to analyse exhaust gases emission of bioethanol and diesel blended fuel at no load condition. A 40 Nm engine load was added at 750 rpm. The number of samples of fuel that were used is four from 0% to 10% bioethanol (by vol.%). Upon adding bioethanol the pressure rise was found to be 4.1% and heat release is increased by 13.5%. The specific fuel consumption rise by 5.9%, but the thermal efficiency stand stable at 23.8%. The ignition delay is raised by a 1.7-degree CA and the combustion duration is decreased by a 0.7-degree CA when 10% ethanol is blended with diesel. The fusion of bioethanol reduced nitrogen oxides (NOx) by 6.5%, increased carbon monoxide emissions by 27.4%, and lowered opacity by 2.3%. On adding ethanol, the hydrocarbon emission decreases up to a value of 50% of the pure diesel, but further addition of ethanol further increases the emission of hydrocarbon. When bioethanol is fused with diesel, the hydrocarbon emission drops to a level of 50%, but subsequent bioethanol additions cause the hydrocarbon emission to rise. The soot particles' average size decreased by 26.7%.

Jamuwa et al. [34] study the combustion behaviour, exhaust emissions, and thermal performance of small-capacity diesel engines employing fumigated ethanol. An efficient, inexpensive ethanol fueling system is used to provide fumigated ethanol to the combustion chamber during suction at various flow rates. During low loads, the BTE (brake thermal efficiency) decreases to 11.2% as a result of inefficient combustion, whereas it improves to 6% under heavier loads when compared to pure diesel. When comparing various levels of ethanol fumigation with pure diesel operation, the study revealed significant reductions in NOx, smoke, and CO_2 emissions, reaching a maximum of 22%, 41%, and 27% respectively. However, there was a concurrent rise in HC and CO emissions, with an increase of up to 144% and 139% respectively. Furthermore, as the levels of ethanol fumigation increased, an increase in the maximum rate of pressure rise by 0.3 to 0.5 bar/crank angle was observed, along with a shift in the crank angle after the top dead center (where peak pressure occurs) ranging from 1-4 crank angle units. Additionally, in comparison to the standard diesel operation, the maximum rate of energy emission exhibited a rise of 2-9 J/crank angle.

Pandey et al. [35] conducted an experiment involving a compression ignition engine to investigate the effects of partially premixed charge with diesel and fumigated ethanol. The study utilized a single-cylinder diesel engine rated at 3.5 kW. During lower engine loads, the high value of enthalpy of vaporization of bioethanol results in a drop of net heat release rate (NHRR) and the peak pressure value, resulting in increased CO and HC emissions. However, as NHRR and peak pressure inside the cylinder rises at larger loads, CO emissions decreased. The inclusion of additional premixed bioethanol at all engine loads led to a decrease in NOx emissions. Furthermore, there was a decrease in smoke emissions as the proportion of premixed bioethanol increased across all loads.

Considering the continuous combustion, overall performance, and emissions of the engine, the study concluded that using ethanol in different proportions instead of pure diesel is a favourable choice.

Saravanan et al. [36] conducted an experiment in which they built an arrangement utilising ethanol diesel blend incorporated with the exhaust gas recirculation (EGR) technology. In EGR technology, some portion of exhaust gas is utilized for limiting the maximum temperature of the engine by feeding it back into the engine. At full load, brake thermal efficiency for ethanol was 2.32% and 6.32% higher than the efficiency with 10% and 20% EGR. With an increase in EGR rates, the engine's BTE falls. With the use of EGR at 10% and 20% rates, the BSEC gets reduced by 2.49% and 6.92%, respectively, than without EGR. The carbon monoxide emission increased by 28.57% and 55.84% and the unburnt hydrocarbon emission increased by 7.14% and 14.28% with the use of EGR at 10% and 20% rates, respectively. This is because of the reduction in oxygen levels in the combustible mixtures. NOx emission decreases by 34.02% and 42.26%, with EGR at 10% and 20% rates. The drop in combustion temperatures of the mixture is the main reason behind this. The maximum heat release rate is 6.58% and 13.6% higher for a system without EGR than with EGR at 10% and 20%, respectively.

Vali et al. [37] studied the influence of nano-particles on the functioning and exhaust parameters of a CI engine fueled with ethyl alcohol and diesel. Using ultrasonic agitation, he added nano-additions Al_2O_3 and TiO_2 to the mixture at concentrations of 50 and 100 ppm, respectively, in the presence of a surfactant. Because nanoparticles have a bigger area of contact and high catalytic action, hence they boost the air-fuel mixture and combustion processes, improving BTE and lowering BSFC. The introduction of nano-additives in the blend was shown to reduce the emissions of CO and UBHC because the increased catalytic activity of nanoparticles improves oxidation. The increased catalytic activity is because of a large area of contact of nano-particles (due to their very small size). By introducing nanoparticles, a reduction in NOx was seen in the emission. Nano-additives increased Carbon Dioxide emission because of an increase in combustion rate.

Liang et al. [38] performed an investigation to analyse the effect of EGR levels and Tetrahydrofuran (THF) as ethanol and diesel co-solvents on ignition and emissions parameters. On increasing the THF concentration in the blend at a low EGR rate, the pressure rise increases. When the EGR rate is less than 30%, plain diesel has a lower efficiency than blended fuel. On increasing the content of ethanol and THF in the blend, the hydrocarbon emission increases but CO emission reduces because of the higher oxygen percentage in the fuel. Blends' soot emissions significantly decline as ethanol and THF fractions rise. At low EGR rates, the emission of oxides of nitrogen increases, with a rise in ethanol and THF ratio; however, at high EGR rates, the pattern of oxides of nitrogen emissions is inverted.

Han et al. [39], in their experiment explored the use of a diesel engine operating on a combination of ethanol infused diesel mixtures. In the study, ethanol was injected into the intake port while diesel was directly injected into the cylinder. The findings revealed that bioethanol mass ratios of up to 80% could be achieved without encountering misfires, particularly at low to medium loads. The addition of bioethanol resulted in reduced soot emissions, although its impact on NOx emissions was unpredictable. With higher ethanol mass ratios, partial combustion occurred during dual-fuel operation. Moreover, at high loads, increased hydrocarbon and carbon monoxide emissions were believed to be controlled by a diesel oxidation catalyst. By adding ethanol, thermal and combustion efficiency drop at low load. Due to inadequate combustion phasing at high ethanol mass ratios, thermal efficiency rises for medium to high loads and declines afterward. At medium to high loads, limitations on the ethanol ratio to less than 40% may arise due to constraints such as pressure increase rate and maximum pressure. However, these limitations can be overcome by adjusting the timing of diesel injection and appropriately timing the combustion process.

Gnanamoorthi et al. [40] conducted a study to investigate the impact of compression ratio on the performance, combustion characteristics, and emissions of a diesel engine. They achieved different compression ratios by modifying the size of the bowl of the piston while maintaining a fixed length of stroke. The researchers utilized five different ethanol blends from 0% to 40% in their experimental tests. To ensure the homogeneity of the bioethanol infused diesel mixture and avoid the separation of phase, they introduced 1% ethyl acetate and 1% diethyl carbonate as additives. The results showed that an increased proportion of ethanol and a higher compression ratio improved the BTE. The presence of bioethanol in the fuel blend, along with a higher compression ratio, led to increase in percentage of oxygen, which had a positive impact on reducing carbon monoxide and hydrocarbon emissions. Moreover, compared to neat diesel, a higher proportion of ethanol in the blend, particularly at a high compression ratio, resulted in a more pronounced sharp heat release rate during combustion. Consequently, this led to an increase in the adiabatic flame temperature. This finally increases Nitrogen oxides (NOx). With a rise in ethanol concentration at a smaller load and an excessively lengthy ignition delay, combustion that occurs at the late diffusive stage produces more smoke. However, at higher compression ratios, the reduction in latent heat of vaporization and ignition delay contributes to a decrease in smoke formation, particularly at higher loads.

Surawski et al. [41] investigate the influence of ethyl alcohol fumigation on the levels of exhaust emissions. In this analysis, a 4-cylinder engine was utilized. Four load levels were used throughout testing, and ethanol substituting ratios ranged from 10% to 40% (by energy). It was found that ethyl alcohol fumigation lowers the engine's surplus air, resulting in increased CO and HC emissions but decreased NOx emissions. Due to ethanol's relatively low sooting tendency, ethanol fumigation lowered PM2.5 emissions. Because of a greater hydrogen-to-carbon ratio and the minute value of aromatic content in the fuel, ethanol has a reduced sooting aptitude. A rise in particle number emission was observed with ethanol fumigation because of the presence of volatile organic compounds.

Rakopoulos et al. [42] study the influence of ethyl alcohol mixed with diesel fuel on the emission levels and performance of a diesel engine. The ethyl alcohol was taken at concentrations of 5% and 10%. The engine was run at two speeds and three loads during the testing, which uses each of the aforementioned fuel samples. The increase in ethyl alcohol percentage in the sample resulted in somewhat greater fuel consumption and a very low enhancement in thermal efficiency. The NOx and CO emissions were either unchanged or hardly decreased, HC emissions rose with the diesel and ethyl alcohol blended fuel. The smoke emission get decreases with the utilization of ethyl alcohol in diesel but this reduction further increases on increasing the percentage of ethyl alcohol in the diesel.

He et al. [43] investigate the influence of ethyl alcohol blended diesel on the emissions of the engine. The amount of ethanol is 10% and 30% by volume in the blend. Some additives are used to maintain uniformity and stability and improve the blend's cetane number. Under heavy load conditions, ethanol mixed with diesel fuel has a significant impact on smoke, oxide of nitrogen, acetaldehyde, and HC emissions. In most operating situations, as ethanol consumption rises, emissions of smoke, Nitrogen oxide, and CO2 drop while CO, acetaldehyde, and unburned hydrocarbon rise. The blend hardly affects smoke reduction at low loads. The use of additives and ignition improvers can somewhat reduce CO, and acetaldehyde emissions while also greatly reducing THC emissions to levels that are even smaller than those of pure diesel at low load.

Meta et al. [44] conducted an experiment to examine the impact of ethanol-diesel blends on pollutant emissions. His research examines how two distinct fuels (ethanol and diesel) affect nitrogen oxide levels and particle size distributions during accelerated driving scenarios. The investigation was carried out using two types of comparable buses, each of which operated in cities with varying altitudes. The results indicate that using an ethanol-diesel combination decreases the particle concentration and average geometric diameters. At high altitudes, ethanol-diesel fuel blends reduce NOx, while at low altitudes, emissions rise. In the end, he concluded that the results were likely influenced more by the altitude of the cities than by the vehicle model itself.

Murat et al. [45] studied the effect of 2-ethylhexyl nitrate (EN) substitution to ethanol blended diesel fuel as a cetane rating enhancer and tested the performance parameter. Four alternative fuels were evaluated, including an ethanol blended diesel fuel with 10% ethanol and the inclusion of the CN enhancer to this mixture through boosting its level from 2% to 6%. The results demonstrate that the cetane rating of the mixture rises by 5%, 11%, and 16% for the mixture including CN enhancer against the mixture without it. The use of this cetane number (CN) improver also leads to a decrease in the kinematic viscosity and heating value, while simultaneously increasing the density of the mixture. The inclusion of CN enhancer decreases NOx and CO discharge as well as braking power, while increasing CO_2 discharge and brake specific fuel consumption.

Liu et al. [46] examined the impact of ethyl alcohol and a cetane number booster on the ignition characteristics of a direct injection (DI) diesel engine. To make-up for the drop in CN caused by the incorporation of ethyl alcohol, isoamyl nitrite is utilised as a cetane number booster in the mixture. The incorporation of ethyl alcohol alters the ignition lag chemically. According to the chemical kinetic approach, ethyl alcohol absorbs OH radicals via hydrogen-atom intake processes, resulting in a decrease in OH radicals throughout the minimum temperature oxidation phase. This may cause the lower temperatures oxidation to be delayed, and hence the extreme temperatures oxidation to be delayed. The incorporation of isoamyl nitrite accelerates the lower temperatures oxidation reaction. Isoamyl nitrite disintegration produces two energetic radicals: NO and i-$C_5H_{11}O$, both of which can yield OH radicals throughout the minimal temp reactivity phase. Furthermore, the chemical reactions of i-$C_5H_{11}O$ produce warmth, making it a more efficient for minimizing the ignition lag. The formation of OH radicals via NO and i-$C_5H_{11}O$ reactions speeds up the lower temperatures reactions of n-heptane and minimises the ignition lag.

2.5 STATEMENT OF THE PROBLEM

Previous research has identified several common methods of utilizing bioethanol in diesel engines, which include bioethanol fumigation, bioethanol-diesel blends, and the formation of both macro as well as micro emulsions of bioethanol in diesel. The application of a static mixer to prepare a mixture of ethanol and diesel is a highly appealing field with little research. Low cetane number of ethanol also creates many technical problems while utilising it in diesel engine therefore it is essential to investigate the impact of some cetane number enhancing additives. Therefore, it is crucial to explore the development of a static mixer that facilitates the infusion of bioethanol in diesel, allowing for the addition of varying quantities of cetane number enhancer to the ethanol. This methodology allows for the assessment of the impacts of ethanol infusion and the use of a cetane number enhancer on combustion, engine performance, and emissions characteristics in a diesel engine. Ultimately, a comparison will be made between these parameters for an engine fueled with pure diesel, ethanol-infused diesel, and ethanol-infused diesel with the cetane number enhancer.

As a result, the following goals were established for the current study project:

1. Through an extensive review of the existing literature.
2. The development of a static mixer for inline mixing of ethanol and diesel fuel was pursued.
3. Preparing the fuel by incorporating ethanol and different quantities of cetane number enhancer in diesel.
4. An experimental diesel engine test rig was designed and developed specifically for conducting studies on inline mixing.
5. A number of experiment is being carried out.
6. Evaluation of the experimental outcomes.

CHAPTER 3

SYSTEM DEVELOPMENT AND EXPERIMENTAL PROCEDURE

3.1 Selection of the Engine

India confronts a notable peril of confronting a substantial fuel crisis in the future as a result of the upsurge in fuel consumption in critical sectors, particularly in transportation and agriculture. With the increasing reliance on diesel engines in these sectors, the requirement for diesel is expected to skyrocket in the upcoming years. When comparing spark ignition engines to diesel engines, the latter continue to dominate the agricultural industry in our country and have always been favoured for their power generation, specific fuel consumption, and durability. While providing an intricate elucidation of the combustion process in diesel engines exceeds the purview of this investigation, it is crucial to acknowledge that diesel fuel spontaneously ignites at elevated temperatures and pressures, commonly around 600°C and 40 bars. The fuel is entered inside the cylinder of the diesel engine after the compression stroke is completed, followed by a predetermined ignition delay, during which it burns to produce the driving power. In India, the usage of diesel engines is widespread across various applications, encompassing irrigation pump-sets, tractors, automated agriculture equipment, and high-load transportation vehicles. Given the extensive adoption of low-power diesel engines, which hold a dominant position in the agricultural sector of India, a comparable engine was selected for this study to ensure meaningful investigation.

With a proper arrangement supplied in the engines, the governing parameters might be adjusted. For the ongoing research project, a Kirloskar-manufactured diesel engine with a single cylinder, air-cooling, and direct injection, as shown in Plate 3.1, was specifically selected. The diesel engine finds extensive use in agriculture, numerous small and medium enterprises, and households in India, serving as a reliable source of emergency power generation. This particular engine is a naturally aspirated, single-cylinder, air-cooled, four-stroke vertical design. It is equipped with electrical loading capabilities, achieved through its connection to a single-phase alternator via a flexible coupling. The engine possesses the capability of being initiated manually through the utilization of the decompression lever, and it is additionally outfitted with a centrifugal speed regulator.

Plate 3.1: Engine for the Experiment

The comprehensive technical description of the engine can be found in Table 3.1.

Manufactured by	**Kirloskar**
Specimen	D.A.F. 8
Brake Power, (bhp per kW)	8/5.9
Speed, (in rpm)	1500
Cylinder (Quantity)	1
Bore & Stroke (in mm)	95 & 110
Compression Ratio,	17.5:1
Cooling Arrangement	Cooled by air
Lubrication Mechanism	Feed by Force
Volume (Cubic Capacity)	0.78 Litres
Opening of inlet valve (in Degree)	4.5 B.T.D.C.
Closing of inlet valve (in Degree)	35.5 A.B.D.C.
Opening of Exhaust Valve (in Degree)	35.5 B.B.D.C.
Closing of Exhaust Valve (in Degrees)	4.5 A.T.D.C.
Timing of Fuel Injection (in Degrees)	26 B.T.D.C.

Table 3.1: Description of the Diesel Engine

The engine underwent an initial start using diesel fuel, followed by a conversion to an inline mixing mode of ethanol and diesel, both with and without cetane enhancing additives. Prior to gathering the actual data ranging from no load to full load, the engine underwent a part load operation for a duration surpassing thirty minutes. The engine cylinder is fabricated utilizing cast iron material and integrates a hardened cast iron coating enriched with a high phosphorus composition. A lubrication system with a wet sump design is employed, where oil is supplied to the crankshaft and big end via a pump positioned on the engine's front cover. This pump is actuated by the crankshaft. The opening and closing of the inlet and exhaust valves are regulated by an overhead camshaft, which is driven by the crankshaft through two sets of bevel gears. In contrast, the fuel pump is driven by the camshaft's end.

As previously stated, the objective of the present investigation was to combine ethanol and diesel fuel using an inline static mixer and analyze the effect of cetane-enhancing additives. The setup used for inline mixing is explained below:

3.2 Fuel used in the Experiment

During this experiment, a total of five distinct fuels were employed to assess the combustion, performance, and emission traits of a diesel engine. These fuels encompassed pure diesel and ethanol-infused diesel blends with a 15% (v/v) ethanol concentration. The ethanol blends incorporated varying composition of cetane number enhancer: 0%, 0.2%, 0.4%, and 0.6%. The cetane number-enhancing additive employed in this study was 2-ethyl hexyl nitrate.

3.3 Setup for Inline Mixing

For this study, an ethanol-diesel blend is generated through in-line mixing while the engine is in operation. Static mixers are employed for inline mixing. Considering the cost-effectiveness and the absence of space constraints, the Kenics static mixer is deemed suitable for this study and is thus the focus of investigation. The Kenics static mixer is characterized by a geometry comprising multiple blending elements. Every component comprises of a compact spiral, extending 1.5 times the length of the tube's diameter. These helices are arranged at a 90-degree angle to each other, with one helix rotating clockwise and the other rotating counter clockwise at an angle of 180 degrees.

The arrangement of the static mixer employed in the inline blending of ethanol and diesel can be seen in 3.2. This static mixer possesses a diameter of 1.5 cm and is outfitted with 10 blending components, extending over a length of 30 cm. Considering the available pressure, the flow velocity inside the static mixer can achieve a maximum of 1 m/s, facilitating effective blending. The flow of ethanol and diesel inside the static mixer is controlled by a regulating valves. These valve controls the flow rate of ethanol in accordance with the desired level of mixing. A burette is connected to both the ethanol tank and the diesel tank to accurately measure the flow rates of ethanol and diesel.

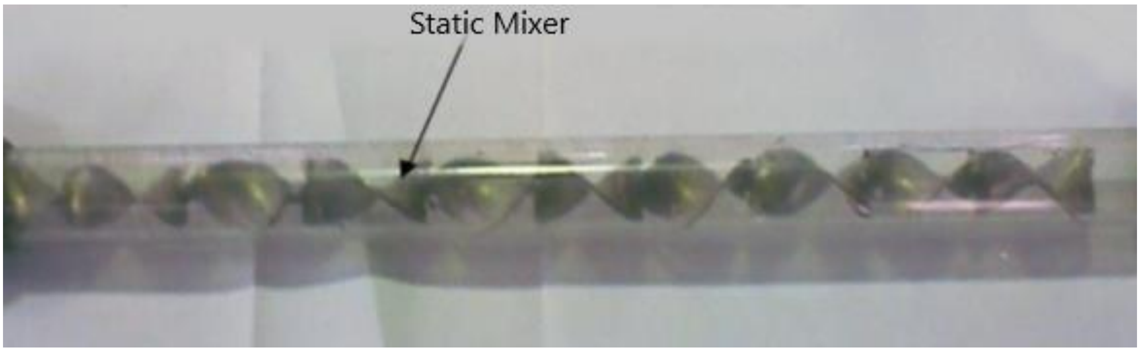

Plate 3.2 Static Mixer

3.4 Fuel Consumption Measurement

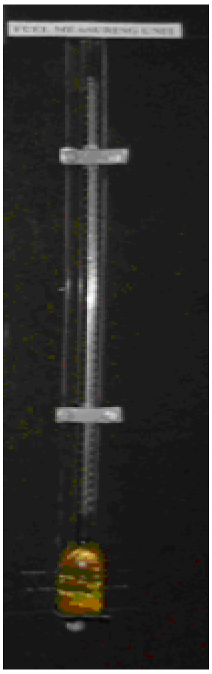

Plate 3.3: Unit for Measuring Fuel Consumption

Two 50ml burette is used to measure the fuels. It is made up of glass. The stop valve is attached to one side of the burette, while the engine fuel filter is connected to the other side. To measure fuel expenditure, a stopwatch is employed to record the duration required for a 10 ml droplet. The amount of time needed to consume a certain volume of fuel is used to calculate an engine's fuel consumption. The volumetric flow rate is determined by dividing the volume of fuel consumed by the corresponding time. To ascertain the fuel mass consumed, the volume of fuel consumed is multiplied by the fuel density.

Here, BSFC = Brake specific fuel consumption, g per kW-h

vol. = Volume of fuel consumed, cc

ρ = Density of fuel, g/cc

HP = Brake horsepower, kW

t = Time taken to consume, cc of fuel, sec.

The computation of the engine's brake thermal efficiency for different fuel blends and operational circumstances was achieved utilizing the subsequent equation:

$$\eta_{th} = Ks / (HV \times BSFC)$$

Here, η_{th} = Brake thermal efficiency, (in %)

Ks = Constant Factor, 3600

HV = Overall Heating Value, kJ per kg

3.5 Measurement of RPM

Plate 3.4: Monitoring of RPM

The engine's RPM is measured using an "NPN-NO" brand RPM sensor and a proximetric switch that converts one RPM into a pulse before transmitting it to the RPM indicator, which provides the reading in digital format. It is capable of measuring speeds ranging from 0 to 9999 rpm.

3.6 Fuel Supply System

A setup comprising of two tanks has been arranged, one for ethanol and the other for diesel. These fuel reservoirs were situated at the elevated locations on the back portion of the panel. Please refer to Plate 3.9 for an illustration of the Fuel Tank Arrangement.

Plate 3.5: Fuel Tank Configuration

3.7 Measurement of Temperature

Plate 3.6: Temperature Measuring Unit

To ensure precise temperature measurement and monitoring, a J-Type thermocouple and a temperature gauge capable of measuring temperatures from 0 to 600°C were utilized.

3.8 Control Panel & Load Bank

Upon concluding the data collection procedures and obtaining the essential instruments, they were arranged on a specially designed panel. The panel featured a fabricated stand supporting a 102 cm×85 cm bakelite sheet with a thickness of 0.3 cm. On the fore side of the control-panel, several devices such as a RPM Indicator, ammeter, a digital temperature display with six channels, and a voltmeter were positioned (refer to Plate 3.7). Meanwhile, on the posterior side of the control panel, twelve 500-watt bulbs were installed as electrical load banks (refer to Plate 3.11). The switches controlling these load banks were thoughtfully located on the fore side of the control-panel to facilitate easy access and control.

Plate 3.7: Control Panel & Load Bank

3.9 Combustion and Emission Measurement:

The opacity of the exhaust smoke, HC, CO, and NOx were all examined in the exhaust gas analysis. The measurement of smoke opacity was conducted using an AVL 437 smoke analyzer. This device provided readings expressed as a percentage of opacity. A fraction of the luminosity emitted by a light beam directed through an exhaust gas stream is either absorbed or dispersed by the particulate matter (soot) existing in the exhaust. The remaining light subsequently reaches the photocell, producing a photoelectric current that can be employed to quantify the density of smoke.

The measurements of UBHC, CO, and NOx were conducted using an AVL4000 Light Di-Gas Analyzer. Plate 3.8 provides a visual representation of both the AVL 437 Smoke Meter and the AVL Di-Gas Analyzer.

The study of combustion is done by Kistler KiBox combustion analyser. Pressure sensor will take the value of in-cylinder pressure and send these values to the Kistler KiBox which gives us the combustion characteristics of the engine. Plate 3.9 shows the Kistler Kibox Combustion Analyzer.

Plate 3.8: Smoke Meter and Di Gas Analyzer

Plate 3.9: Combustion Analyzer

The AVL DIGAS analyzer, which can detect CO, NOx, unburned hydrocarbon, smoke opacity, smoke absorbency, and exhaust temperature, is used to measure emissions.

3.10 Schematic Diagram of Experimental test rig

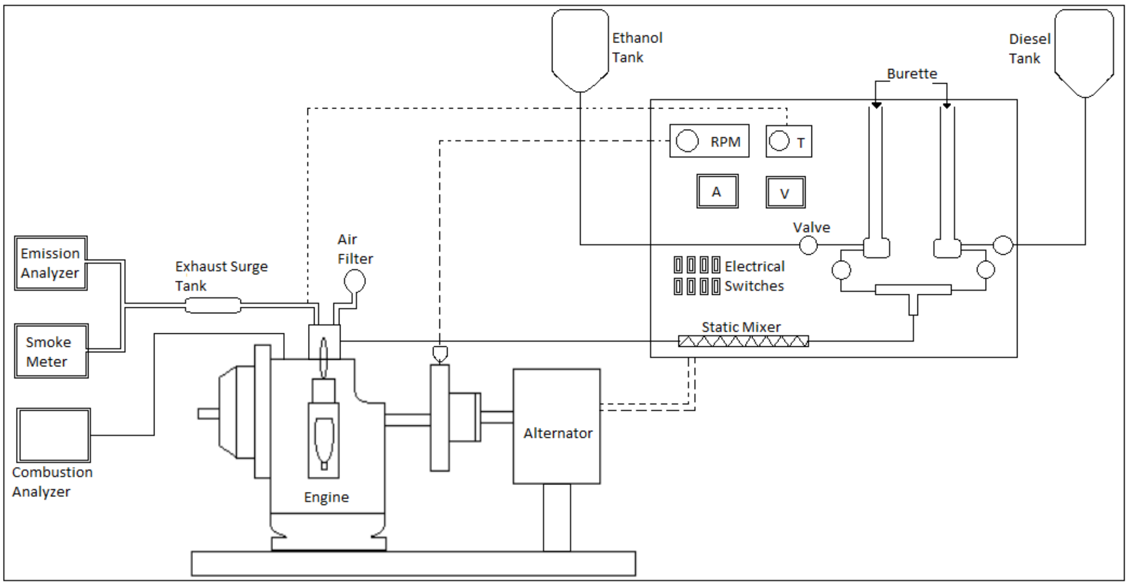

Figure 3.3 Schematic diagram of the Experimental Test Rig

3.11 Selection of Testing Parameters

For the precise assessment of engine performance, the choice of operating parameters was very crucial, hence attention was given when making these choices. The following list contains the parameters that must be observed.

1. The generated power output of the engines
2. Speed of the Engine (Rev. per min.)
3. Consumption of Fuel
4. Temperature
5. Engine Speed
6. Emissions of Exhaust Gas (NOx, CO, HC, and smoke opacity)
7. Combustion Pressure

The following signals have to be captured from the test setup in order to determine the parameters indicated above.

1. The electric potential generated by the alternator
2. The electric current generated by the alternator
3. Revolution per Minute of the engine
4. Rate of Fuel Consumption
5. AVL-437 smoke meter
6. AVL Di-Gas analyzer

7. Kistler Kibox Combustion Analyzer

The necessary equipment needed for determining these parameters was put at the proper positions in the experimental set-up once the parameters had been chosen.

3.12 Experimental Procedure

Diesel was used to start the engine, and a time of 30 minutes was allotted to obtain the steady state condition. Emission measurement is done for the specified load, and the results were recorded. The first reading is carried out with no load, followed by readings done with increasing the load. While conducting the diesel engine test run, a number of precautions must be taken. The readings should be taken only when the engine reaches a steady state condition. Despite the engine maintaining a consistent speed, a digital RPM sensor and display were utilized to monitor any deviations in speed from idle to full load and their influence on various parameters. The load could be adjusted by modifying the power output of the alternator, which was interconnected with the load bank. Digital ammeters and voltmeters were employed throughout the test to facilitate its implementation.

The temperature at critical locations of the diesel engine was assessed during operational conditions by utilizing thermocouples. A digital temperature indicator with adjustable junction received the thermocouple output and presented the temperature values. The thermocouples were carefully installed on the engine assembly using customized setups. To ensure maximum accuracy, hardware optimization is necessary for diesel engines to minimize energy loss.

With the help of inlet valves ethanol and diesel is filled in the measuring burette from their respective tank. And with the help of outlet valves quantity of ethanol and diesel can be controlled which are going to form a blend. Now, these two fuels combine inside the tee and together enters the static mixer. A burette is employed for quantifying the rate of flow of ethanol and diesel. The static mixer thoroughly mixes these two fuels and fed the blend inside the engine.

CHAPTER 4

EXPERIMENTAL RESULT AND DISCUSSION

This chapter focuses on presenting the outcomes of conducted experiments, which will be thoroughly examined and discussed in subsequent sections. The study's major goal was to evaluate the combustion, performance, and emission attributes of ethanol-infused diesel engines and correlate outcomes with reference data on pure diesel.

4.1 Combustion Characteristics

The combustion properties of the experimental engine using diesel and ethanol-blended diesel combinations are outlined as follows:

4.1.1 In-cylinder Pressure

The figure 4.1 illustrates the in-cylinder pressures of a diesel engine operating with different fuel compositions, specifically ethanol infused diesel mixture with and without cetane number enhancer and pure diesel, while operating under identical conditions.

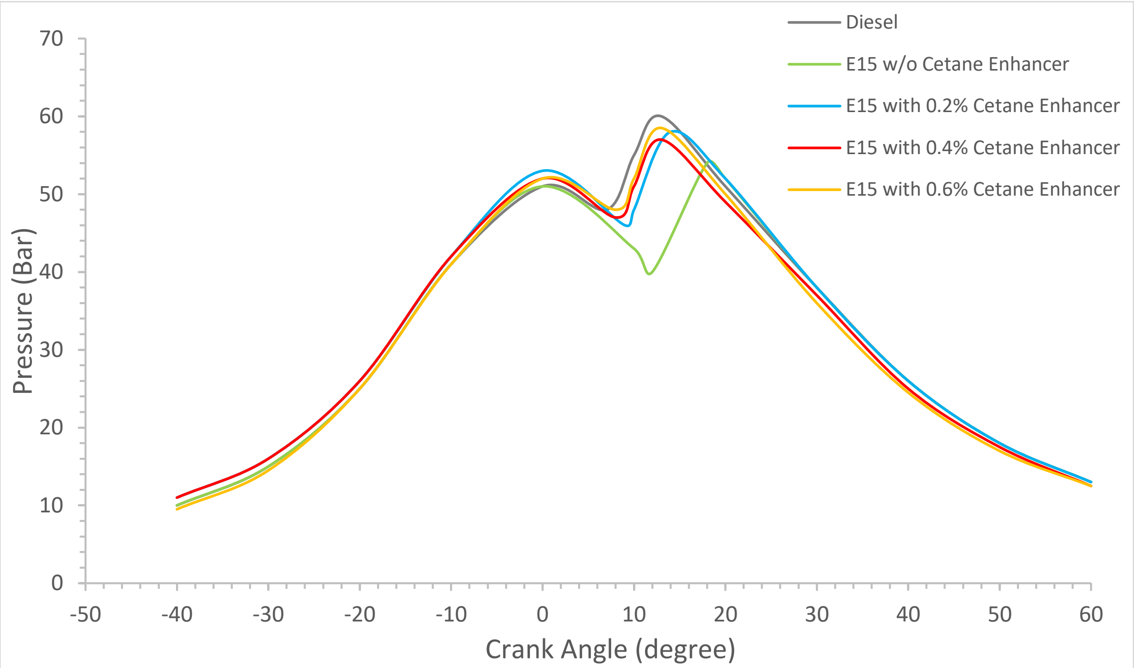

Figure 4.1: Pressure V/s Crank Angle

It is evident from the Figure that whenever the diesel engine is supplied with ethanol-diesel blends, the ignition point is postponed and the peak cylinder pressure is diminished. However, when the concentration of the CN enhancer in the blend is increased, it leads to a minimisation in the ignition delay and also the value of maximum pressure increases. As the concentration of a cetane enhancer in the blend increases, the pressure value approaches that of pure diesel fuel.

4.1.2 Rate of Heat Release

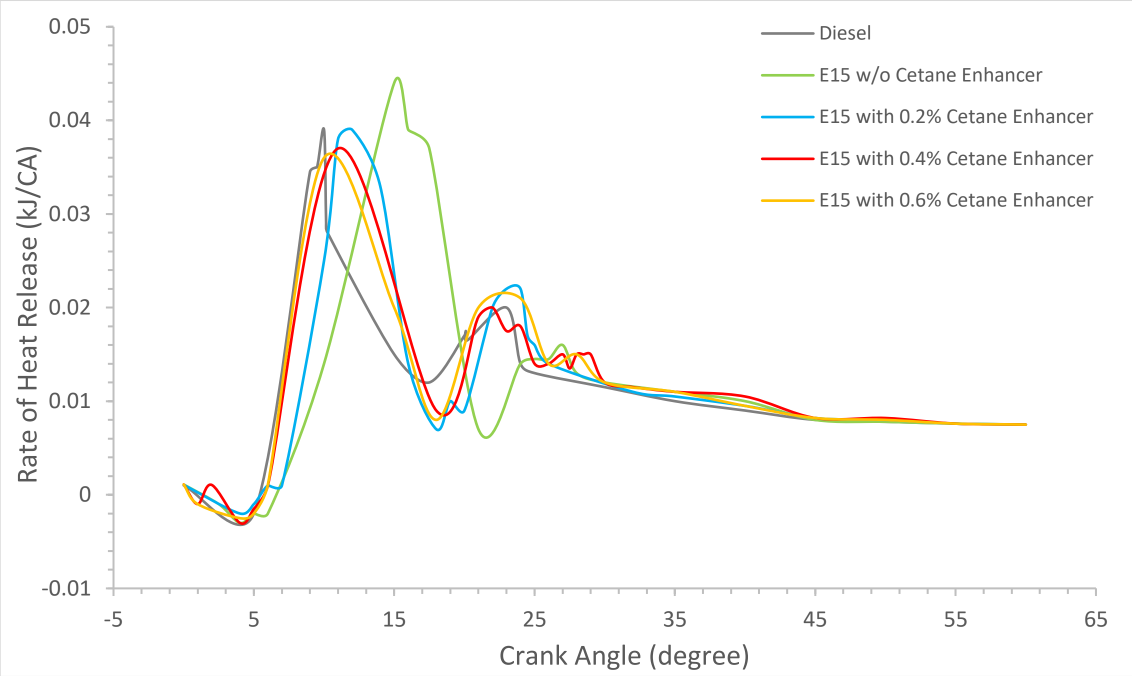

Figure 4.2: Rate of Heat Release V/s Crank Angle

Figure 4.2 depicts the rate at which heat emission of various ethanol infused diesel mixture and plain diesel fuel at various working configurations. According to the rate of heat emission at certain BMEP, the combustion duration before ignition for all ethanol infused diesel mixture is extended as relative to plain diesel fuel, but the combustion duration before ignition steadily reduces as the CN enhancer amount in mixture fuel increases.

This phenomenon is hypothesized to transpire due to alterations in the ignition delay. Ethanol fuel, with its diminished cetane number, contributes to a decrease in the overall cetane number when blended with diesel. By incorporating a cetane number booster, the ignition timing of ethanol-diesel blends can be approximated to that of pure diesel fuel under high load conditions. However, substantial disparities in ignition timing persist at low loads. This can be ascribed to the higher enthalpy of ethanol vaporization, leading to a more pronounced temperature reduction during compression at lower loads. As a result, the gas temperature within the cylinder at the end of the compression stroke is lower. Consequently, when operating at lower loads, relying solely on a cetane number enhancer is insufficient to fully restore the ignition delay of ethanol-diesel mixtures.

The entire combustion length for ethanol infused diesel mixture is clearly shorter in comparison to neat diesel fuel, and displays a significant variation with increasing the CN enhancer application. When the CN enhancer was introduced to the fuels mixture for a given BMEP, the overall combustion length rose and eventually came closed to neat diesel fuel. This phenomenon is thought to be associated with an alteration in the ignition delay. While the initial rate of heat emission is slowed for ethanol infused diesel mixture, but the final rate of heat emission remains relatively consistent compared to pure diesel regardless of the amount of CN improver added.

4.2 Performance Characteristics

The performance attributes of the experimental engine using diesel and ethanol-blended diesel combinations are summarized as follows:

4.2.1 Brake Specific Fuel Consumption

The BSFC v/s BMEP for various ethanol-diesel blends with and without a cetane number enhancer, as well as pure diesel fuel are shown in Figure 4.3.

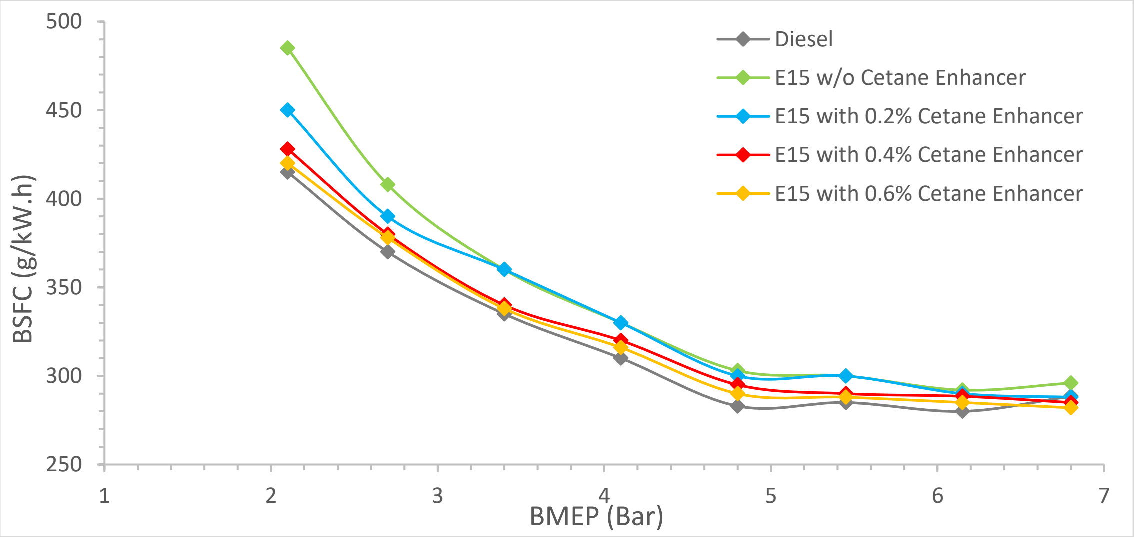

Figure 4.3: BSFC V/s BMEP

Brake specific fuel consumption (BSFC) serves as an indicator of the fuel efficiency of an engine, denoting the quantity of fuel necessary to generate a unit of brake power at the crankshaft. It provides insight into how effectively the fuel is utilized to generate power. The graph clearly shows that the BSFC for all fuels decreases as the load rises. Additionally, it has been observed that adding ethanol causes the BSFC to rise. The BSFC for a certain BMEP shows a decline with rising CN enhancer concentration. These actions are understandable, considering that the engine would need more fuel when using ethanol infused diesel mixture than when using pure diesel to yield an equivalent power output. This is a result of the diminished calorific value of ethanol, which consequently reduces the overall calorific value of the blend. On the other hand, the cetane number enhancer enhances the combustion duration of ethanol-diesel mixtures, thereby slightly decreasing the BSFC.

4.2.2 Brake Thermal Efficiency

Figure 4.4 showcases the thermal efficiency of the engine running on both diesel fuel and various combinations of ethanol-infused diesel fuel. Brake thermal efficiency, a gauge of engine thermal efficiency, signifies the proportion of the brake power attained at the engine's crankshaft to the power generated by fuel combustion.

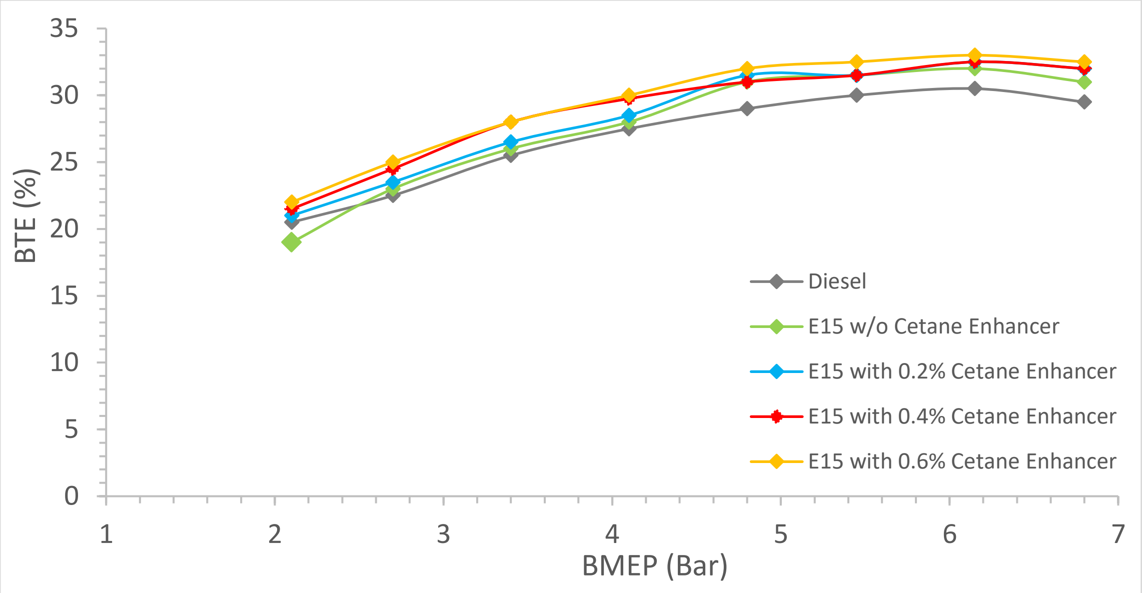

Figure 4.4: Brake Thermal Efficiency V/s BMEP

The graph reveals that the brake thermal efficiency (BTE) for all fuels rises as the load increases. The incorporation of ethanol into the diesel fuel led to a marginal enhancement in the brake thermal efficiency. Moreover, when a cetane number enhancer was introduced to the ethanol-diesel blend, the brake thermal efficiency experienced further improvement. The reason behind increasing thermal efficiency upon adding ethanol is the rise in ignition lag because of which duration of combustion decreases due to which heat generated inside the engine does not escape because there is not enough time for this. Upon adding the cetane number enhancer, the combustion quality (combustion duration) of the mixture gets improved which further results in increase in thermal efficiency.

4.3 EMISSION CHARACTERISTICS

The emission traits of the experimental engine operating on diesel and ethanol-infused diesel mixtures are outlined as follows:

4.3.1 Smoke Emission

Figure 4.5 illustrates the relationship between the smoke emission and BMEP (Brake Mean Effective Pressure) for different ethanol-infused diesel mixtures and pure diesel. BSU stands for "Black Smoke Unit," which is a unit of measurement used to quantify the level of black smoke emissions in internal combustion engines. The BSU scale typically ranges from 0 to 10, with 0 representing no visible black smoke and 10 indicating extremely high levels of black smoke emissions. The scale is subjective and relies on visual observation or the use of smoke meters to assess the opacity of the exhaust gas.

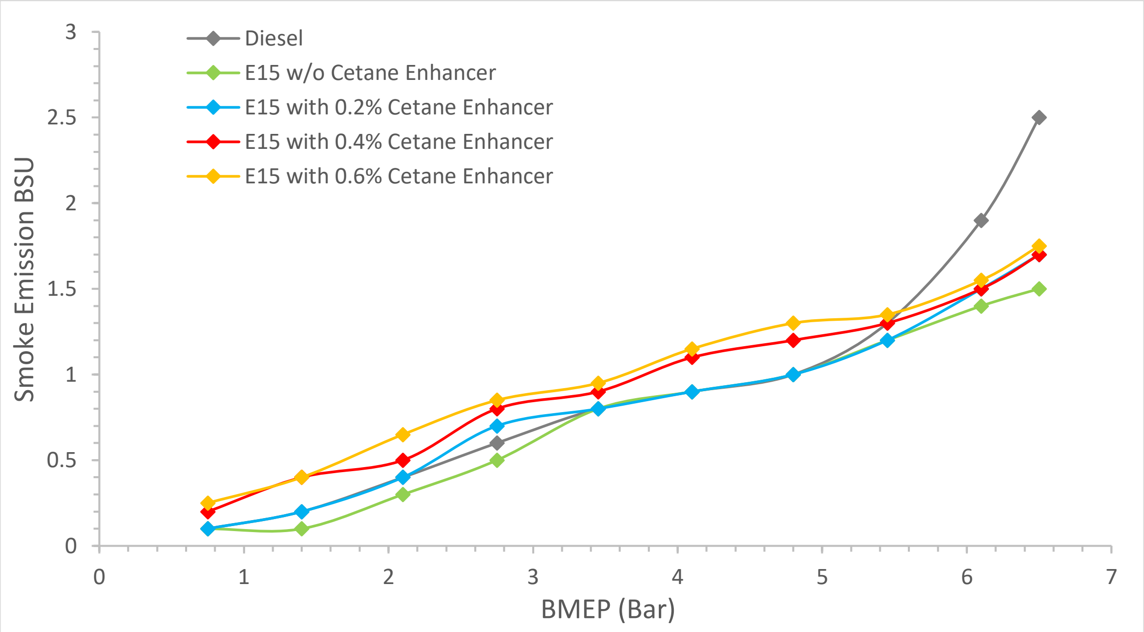

Figure 4.5: Smoke Emission V/s BMEP

The smoke level tends to escalate as the load intensifies for all fuel combinations. This is attributed to the additional fuel being supplied, leading to the formation of a richer mixture at higher loads. For blended fuels, it was discovered that smoke decreased substantially more during high loads than in low load. This makes sense because there are more fuels available for the heavy load and there isn't much time to prepare the air/fuel mixture for high speed. In comparison to diesel fuels, this factor results in an improvement in the quality of combustion for blends. Furthermore, it has been discovered that CN improver has a very slight impact on smoke emission.

4.3.2 NOx Emissions

Figure 4.6 presents the NOx emissions of diesel engines operating on both diesel fuel and ethanol-infused diesel mixtures under various operating conditions. The graph reveals that as the engine load (or BMEP) rises, the NOx emissions also increase. Furthermore, the inclusion of ethanol in the fuel blend leads to a reduction in NOx emissions across all loads. Moreover, at medium and heavy loads, augmenting the substitution of the cetane number enhancer results in decreased NOx emissions for a given engine BMEP.

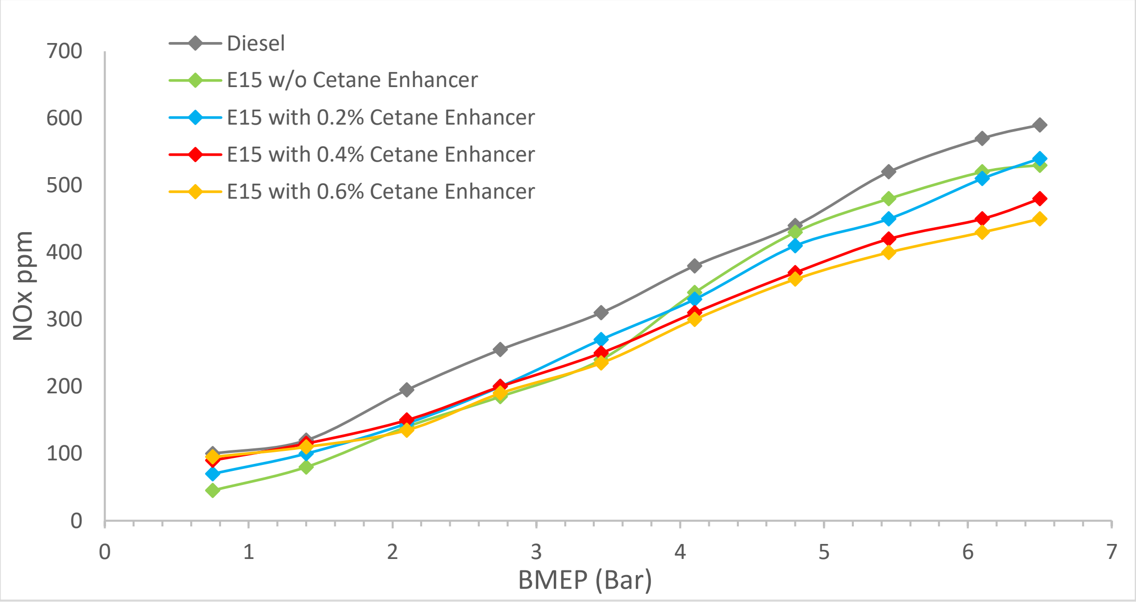

Figure 4.6: NOx Emission V/s BMEP

In theoretical terms, the NOx emission is primarily affected by factors such as the oxygen level in the mixture, the maximum temperature attained during combustion, and the duration of elevated temperature. The analysis conducted indicates that the introduction of ethanol to diesel fuel prolongs the ignition delay and diminishes the combustion duration. Consequently, the peak in-cylinder temperature is lowered, resulting in a decline in NOx emissions. Therefore, the ethanol-blended fuel showcases a decrease in NOx emissions in comparison to pure diesel.

4.3.3 CO Emissions

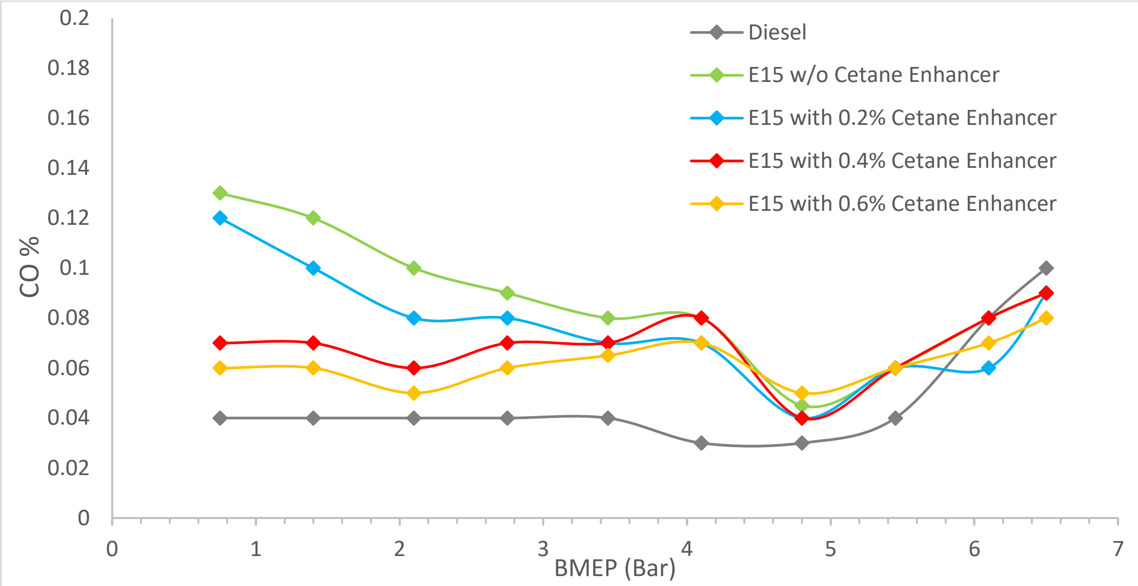

Figure 4.7: CO Emission V/s BMEP

The CO emissions for different ethanol infused diesel mixture and diesel are indicated in Fig. 4.7 in relation to engine BMEP. When using ethanol infused diesel mixture, CO emission rises noticeably at light and medium loads. However, it is important to note that the level of carbon monoxide (CO) emissions, which tends to increase over time, decreases when the level of CN enhancer additive is increased. The incomplete combustion of the air-fuel mixture is the underlying cause of CO emissions. This incomplete combustion is attributed to the shortened combustion duration brought about by the presence of ethanol. Additionally, the high latent heat of evaporation plays a role in the elevation of carbon monoxide (CO) emissions. The high latent heat of evaporation reduces the combustion temperature, thereby influencing the combustion quality at low and medium loads.

On the other hand, while using blended fuels at high load, CO emissions somewhat decline. This may be understood by the oxygen enhancement brought on by the incorporation of ethanol, as doing so will encourage the engine exhaust to process's further oxidation of CO.

4.3.4 Hydrocarbon Emission

Figure 4.8 depicts the relation between emissions of Hydrocarbon and BMEP of diesel and various ethanol infused diesel mixtures.

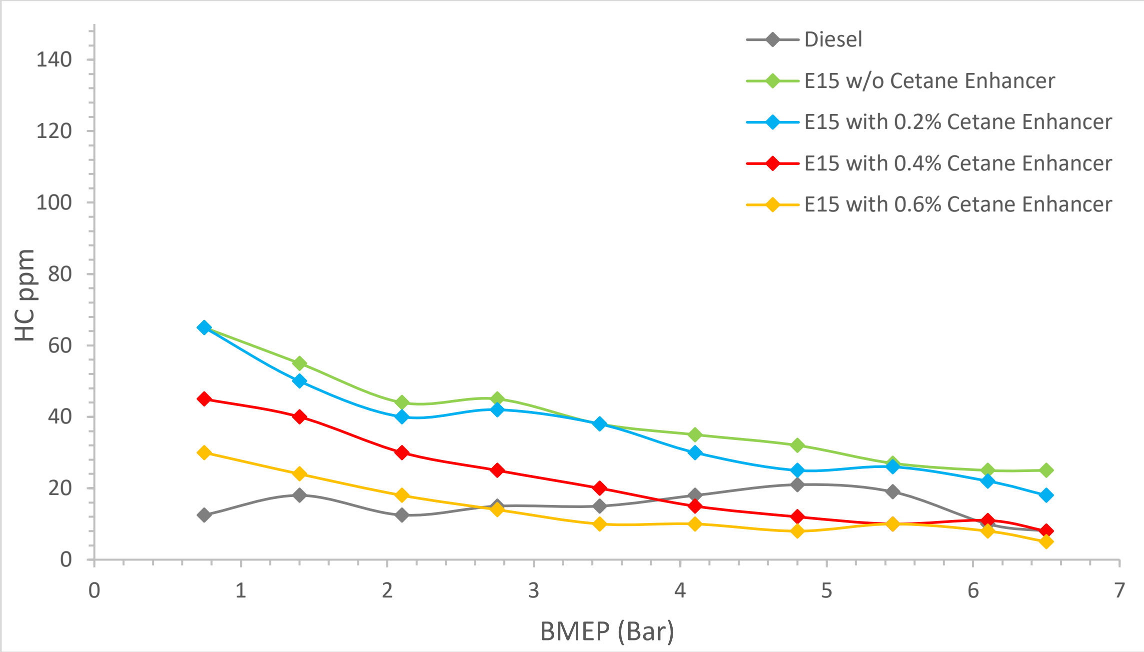

Figure 4.8: HC Emission V/s BMEP

At small to medium load, upon adding ethanol in diesel the hydrocarbon emission increases considerably but at higher load this increment reduces significantly. Upon adding the cetane number enhancer in the mixture, the hydrocarbon emission reduces and this reduction increases further on increasing the concentration of cetane enhancer. According to Fig., both E15 with 0.2% CN enhancer and E15 with no CN enhancer exhibit a marginal rise in hydrocarbon (HC) emissions can be observed across all engine operating conditions. The reason behind this is incomplete combustion due small combustion duration because of low value of the cetane number of ethanol. However, when the concentration of the cetane number (CN) enhancer is increased (specifically, to 0.6%), the emission level of hydrocarbons (HC) becomes comparable to that of pure diesel.

CHAPTER 5

CONCLUSION & FUTURE SCOPE

In ethanol, has emerged as a promising substitute for diesel engines, presenting a wide range of advantages and prospects in the quest for sustainable diesel engine operations. Ethanol is recognized as a low-emission fuel due to its derivation from renewable sources like corn, sugarcane, or cellulosic feed-stocks. By incorporating ethanol into diesel fuel blends, the overall carbon footprint of the engine can be reduced, thereby helping to mitigate climate change.

Nevertheless, there are specific challenges and considerations associated with the practical application of ethanol in diesel engines. The primary limitations of ethanol in diesel engines include its relatively low energy content, lower cetane number, potential phase separation issues, as well as lower lubricity and viscosity properties. However, there are strategies available to overcome these challenges. One approach involves the implementation of an inline static mixer, which helps prevent phase separation and ensures a more homogeneous mixture of ethanol infused diesel blend. Additionally, a cetane number enhancer can be utilized to effectively manage and improve the cetane value of the ethanol infused diesel mixture, addressing the issue of lower cetane number.

The experimental results demonstrate that the incorporation of ethanol inside the diesel fuel leads to a retardation in the ignition timing of the blend and a reduction in peak pressure values. This is attributed to the elevated enthalpy of vaporization of ethanol, which diminishes the temperature of the blend, consequently leading to a delay in ignition. However, when a cetane number enhancer is added to the blend, both the ignition timing and pressure values approach those of pure diesel fuel. This phenomenon can be ascribed to the capacity of the cetane number booster to decrease the ignition delay of the blend. Conversely, when ethanol is introduced to the diesel without a cetane number enhancer, the ignition delay is prolonged, leading to a reduction in the duration of combustion and, subsequently, a decrease in heat release. However, with the addition of the cetane number enhancer, the rate of heat release becomes closer to that of pure diesel because of increase in combustion duration.

The incorporation of ethanol into diesel fuel leads to a rise in the brake specific fuel consumption of the mixture. This can be primarily attributed to the lower energy content of ethanol. However, by escalating the proportion of the cetane number booster in the mixture, this value can be decreased because of the improved combustion duration. Similarly, the incorporation of ethanol into diesel results in an elevation in the brake thermal efficiency, and this value further improves with rising the proportion of cetane number enhancer. This enhancement can be credited to the delay in ignition caused by the substitution of ethanol, which reduces the available time for heat loss.

At lower loads, the incorporation of ethanol in diesel results in increased emissions of hydrocarbon (HC) and carbon monoxide (CO). However, as the load increases, this increment in emissions diminishes. The possible explanation for this phenomenon lies in the high value enthalpy of vaporization of ethanol, which generates a cooling effect during the combustion process. This cooling effect can lead to incomplete combustion, thereby increasing the emissions of HC and CO. Ignition delay may also contribute to this effect. However, when a cetane number enhancer is added to the blend, these emissions tend to decrease.

As the load increases, the emission of nitrogen oxides (NOx) also tends to increase. However, when ethanol is added to diesel, this emission is reduced. The significant enthalpy of vaporization of ethanol contributes to lowering the peak temperature inside the cylinder, thereby resulting in a decrease in NOx emissions. Furthermore, when a cetane number enhancer is introduced to the blend, the NOx emissions are comparatively reduced, particularly at higher loads. As the load increases, the emission of smoke exhibits a parallel pattern, indicating a corresponding increase. However, the addition of ethanol slightly reduces the smoke emission at higher loads. On the other hand, the impact of the cetane number enhancer on smoke emission is minimal, with only a slight effect observed.

Future Scope

Future research should focus on comparing the impact of various cetane number enhancers in the blend and determining the most effective one. Additionally, studies should be conducted to explore additives that can mitigate the corrosive nature of ethanol.

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