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An Experimental Study Aimed at Determining the Effects of Blending Synthetic Kerosene (SK) with Diesel on the Performance and Combustion of CI Engines

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IN

THERMAL ENGINEERING

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CANDIDATE'S DECLARATION

I, AMAN KHARB, 2K21/THE/03, of M. Tech (Thermal Engineering), hereby declare that the project Dissertation titled "An Experimental Study Aimed at Determining the Effects of Blending Synthetic Kerosene (SK) with Diesel on the Performance and Combustion of CI Engines" 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, Fellowship, or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled "An Experimental Study Aimed at Determining the Effects of Blending Synthetic Kerosene (SK) with Diesel on the Performance and Combustion of CI Engines" which is submitted by AMAN KHARB, 2K21/THE/03, 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 a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

The current energy crisis is disrupting long-standing demand trends. Due to the enormous instability in the energy markets caused by Russia's invasion of Ukraine, the human race has moved quickly towards alternative fuel sources to become independent of other countries. This experimental investigation's goal is to learn more about how a single-cylinder CI engine responds to the combination of Synthetic Kerosene (SK) and diesel fuel. The behavior of the CI engine was experimentally examined utilizing different SK and conventional diesel fuel mixtures. Under various load situations, SK blends in the ratios of 10%, 20%, 30%, and 40% by volume are created and studied in a constant speed engine. Data were compared with diesel fuel to determine various characteristics, including BTE, BSFC, exhaust gas temperature; HRR (J/°CA), peak pressure, and cylinder mean gas temperature. Minimum BSFC is observed at load of 60% - 70% engine load. SK20 blend achieved minimum BSFC which is approximately 7.5% lower than the diesel fuel. For blends of SK10, SK30 it is in between of SK20 and diesel fuel. For SK40 there is increase of 3% at minimum BSFC load condition which is range of 60% - 70%. Maximum brake thermal efficiency is observed in range of 60% - 70% of engine for all blends. SK20 is having maximum BTE, approximately 5.5% higher than diesel reference fuel. For blends S10, SK30 it is in-between SK20 and diesel. For SK40 blends there is drop in BTE in comparison to diesel fuel and a drop of nearly 4% is observed. In comparison to the trend for diesel alone, the plot for SK10, SK20 and SK30 of the synthetic kerosene blends is seen to be slightly higher because of better combustion due to presence of oxygenates. Further blending of SK leads to lower exhaust temperature due to lower calorific value of SK fuel. Maximum peak pressure is achieved in case of SK20 blend, approximately 3.5% higher than diesel for the idle condition and 1.75% higher for 100% loading condition. The percentage change for

SK10, SK30 is in-between to SK20 and diesel fuel. For SK40 blend, drop of 1.7% for idle and 0.5% for 100% loading condition is observed with respect to base line diesel fuel. Maximum rate of pressure rise (RPP) is observed in case of SK20 blending which is approximately 7%, 6.5% higher than the diesel reference fuel data for idle and 100% loading conditions. Higher percentage blending of synthetic kerosene results in drop of rate of pressure rise for all loading conditions and drop of 9%, 3.5% is observed for idle and maximum loading condition in present study. The maximum temperature is observed in case of SK20, which nearly 3% and 2% higher is for idle and 100% loading condition respectively in comparison of diesel reference fuel. The SK40 blend is having drop of approximately 2% and 0.8% for idle and 100% load respectively. The mean gas temperature of SK10 and SK30 is between to that of SK20 and diesel reference fuel.

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AMAN KHARB

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Table of Contents

List of Figures

List of Tables

List of Symbols and Abbreviations

Abbreviations/Symbols	Descriptions
IEA	International Energy Agency
CO2	Carbon Dioxide
CI	Compression Ignition
COVID	Coronavirus Disease
SAF	Sustainable Aviation Fuel
SK	Synthetic Kerosene
FAME	Fatty Acid Methyl Ester
ASTM	American Society for Testing and Materials
RP-3	Rocket Propellant 3
BTL	Biomass to Liquid
ICE	Internal Combustion Engine
ID	Ignition Delay
CD	Combustion Delay
IMEP	Indicated Mean Effective Pressure
HRR	Heat Release Rate
RPR	Rate of Pressure Rise
BP	Brake Power
BMEP	Brake Mean Effective Pressure
BTE	Brake Thermal Efficiency
BSFC	Brake Specific Fuel Consumption

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Long-standing demand trends are changing as a result of the present energy crisis. The incursion of Russia into Ukraine has caused a phase of exceptional instability in the energy sector, particularly concerning the natural gas market.[1] Industries that are subject to fluctuating pricing are reducing their output due to the genuine possibility of restrictions. Because of the high cost of energy and urgent demand reduction initiatives, consumers are changing their consumption habits for energy. Many policy solutions are made, but they frequently involve steadfast efforts to speed up the investment in clean energy. In the energy sector, this calls for a stronger push for sources of clean energy and a quicker electrification of heating, transportation, and industrial activities. Since many of the answers to the current crisis are also necessary to achieve the world's climate goals, the crisis may ultimately be considered in hindsight as having marked a crucial turning point in the movement for both securities of energy supply and emissions mitigation.

1.2 FUTURE ENERGY DEMAND

The International Energy Agency (IEA) forecasts that global energy consumption will rise and majority of the energy demand will be fulfilled by the use of fossil fuel as per data released in its recently issued International Energy Outlook 2022.[1] The majority of this expansion comes from developing nation where demand is being driven by rapid economic growth, particularly in Asia.

The future energy demand is high specifically in Asia due to large scale development in India, China and fellow nation. The government and policy makers should also think about the source of the energy. The majority of developed nations, including India, have committed to net zero goals to achieve this feat clean burning fuels should be adopted. Aviation industry is also using jet fuel based on hydrocarbons originated from fossil fuel which also contributing to large amount of CO_2 emissions. The previous data and forecast of CO_2 emission due to aviation industry is released by the IEA report 2022[1].

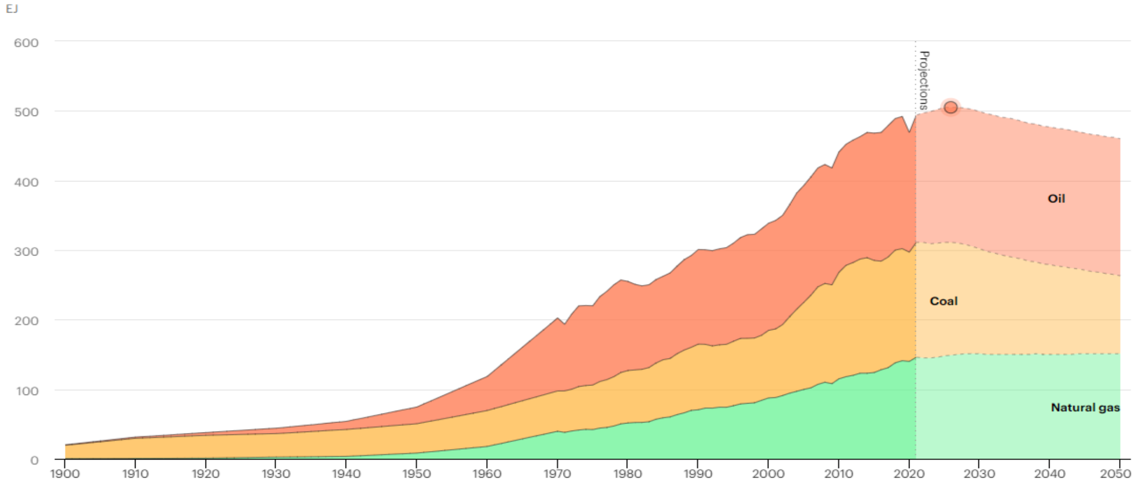

Figure 1.2.1 Fossil Fuel Demand

Source: IEA, Fossil fuel demand in the Stated Policies Scenario, 1900-2050, IEA, Paris

IEA, Fossil fuel demand in the Stated Policies Scenario, 1900-2050, IEA, Paris 4.0

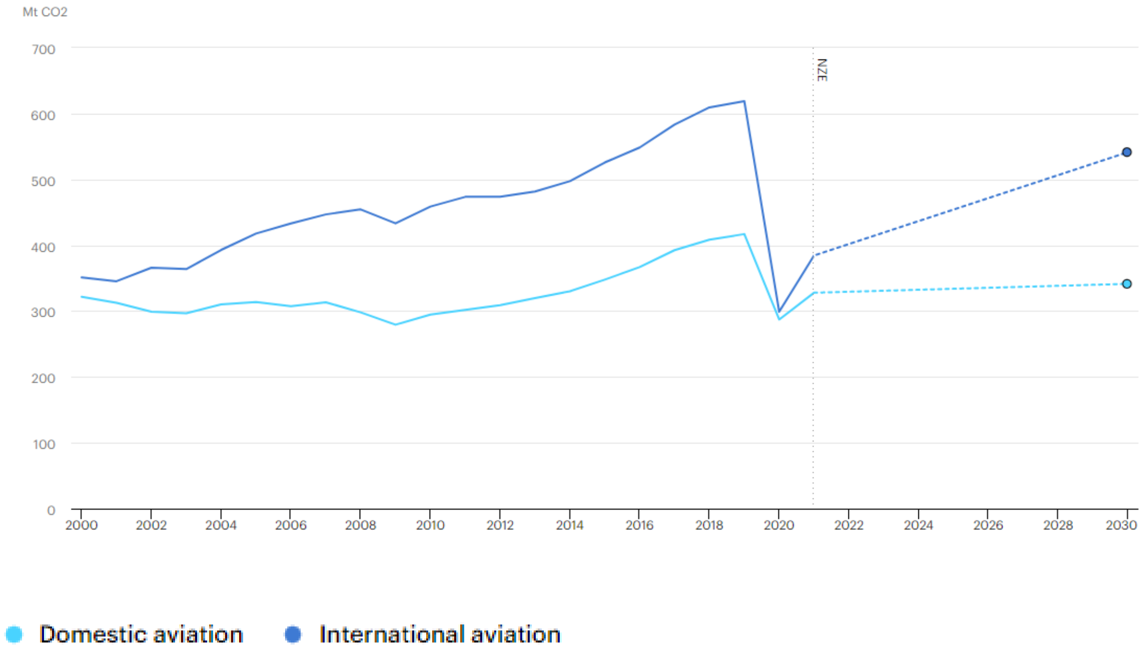

Figure 1.2.2 CO_2 Emissions from Aviation

Source: IEA, Direct CO2 emissions from aviation in the Net Zero Scenario, 2000-2030, IEA, Paris https://www.iea.org/data-and-statistics/charts/direct-co2-emissions-from-aviation-in-the-net-zero-scenario-2000-2030, IEA. Licence: CC BY 4.0

The rapid drop in curve due to COVID 19 pandemic, but soon after the vaccination and precautions, the aviation industry is again rising and thus the CO_2 emission curve is also increasing and will soon supress the pre pandemic emissions.

1.3 DIESEL DEMAND & EFFECT ON INDIAN ECONOMY

India has been a major consumer of diesel fuel due to its widespread use in various sectors of the economy. In 2020, diesel emerged as the most widely consumed fuel in India, reaching approximately 88.2 billion liters annually in volume. Following closely behind was gasoline, also known as petrol, with a consumption volume of around 37.2 billion liters during the same year.[2] Diesel is commonly used in transportation, agriculture, manufacturing, and power generation, among other sectors. The demand for diesel fuel in India has been influenced by several factors, including economic growth, population growth, industrial development, and government policies. Diesel consumption has traditionally been driven by the transportation sector, which includes commercial vehicles such as trucks, buses, and railways.

The effects of diesel fuel demand on the Indian economy can be significant. Here are some key points to consider:

- Energy Costs: Diesel fuel constitutes a significant portion of the energy costs for industries and transportation companies. Fluctuations in diesel prices can directly impact operational costs, affecting profit margins and overall competitiveness.
- Inflation: The widespread use of diesel in transportation makes it susceptible to influencing higher transportation costs when diesel prices rise, thereby impacting the prices of commodities.and services throughout the economy. This can contribute to inflationary pressures.
- Public Finances: Diesel fuel subsidies provided by the government can strain public finances. Subsidies are commonly utilized as a measure to alleviate the consequences of elevated diesel prices on consumers especially in essential

sectors like agriculture and transportation. However, these subsidies can create fiscal deficits if not managed effectively.

- Environmental Impact: The combustion of diesel fuel contributes to the pollution of air and the emission of greenhouse gases, which can have detrimental effects on public health and the environment.India has been making efforts to reduce diesel consumption and promote cleaner alternatives to mitigate these effects.
- Energy Security: India is heavily dependent on oil imports to meet its energy needs, including diesel fuel. Fluctuations in global oil prices and geopolitical developments in oil-producing regions can affect the country's energy security and trade balance.

1.4 ALTERNATIVE FUELS

The extraction and excessive utilization of fossil fuels have led to a decline in the availability of underground carbon resources. Several nations must quickly transition to other energy sources due to the fluctuating price and supply, as well as the resource management by western nations. It is crucial to create alternatives to conventional diesel because the energy utilised in the transportation and agriculture sectors is primarily based on diesel fuel.[3]

In today's context, there is a significant need for an alternative fuel that aligns with sustainable development, effective energy management, efficiency, and the preservation of the environment, reflecting the growing demand in this regard. Biofuels can offer a workable answer to the dilemma for the emerging nations of the world. Alcohol, vegetable oils, biomass, and biogas are all examples of fuels with a bio-origin.[4] While some of these fuels can be utilised right away, others need to be specially manufactured to have qualities that are comparable to those of conventional fuels.

Aviation industry jet fuel is also based on hydrocarbons originated from fossil fuel which also contributing to large amount of CO_2 emissions as well as depleting rapidly. There is strong need in moving towards cleaner aviation fuel, called sustainable aviation fuel (SAF) or synthetic kerosene (SK).

1.5 EV’S AND FUTURE

Due to tailpipe emissions, internal combustion engines (IC) are now considered to be bad for the climate and are out of favor. Although EVs have the potential to drastically decrease the releases of greenhouse gases in the automotive industry, it's crucial to take into account all of the emissions that occur over the course of their entire lifecycle to properly gauge their environmental impact.

Electric vehicles (EVs) have emissions throughout their entire lifetime, from manufacturing to disposal.[5] The production of the vehicle and its parts, the creation of the energy used to charge the vehicle, the disposal of the vehicle and its parts at the end of their useful lives are some of the sources of these emissions.

The production of EVs and their batteries uses a lot of energy and resources, which can leave a big carbon impact. Depending on where the energy comes from, the electrical power used to charge an EV may also increase its carbon footprint. The carbon impact of the EV is very small if the electricity is produced using green energy, such as solar, wind, or hydropower. But if the energy is produced using fossil fuels instead, like coal, oil, or natural gas, the carbon footprint of the EV grows because these fuels produce greenhouse gases when they are burned. Footprint of the EV increases, as these sources emit greenhouse gases during their operation.

An EV must be appropriately disposed of when its life cycle is over, which may produce emissions. The EV and its battery's materials can be recycled or put to other uses, but some parts might wind up in landfills, which can increase pollution.[6]

The future transport system is expected to feature a combination of electric cars (EVs) and IC engine powered by biofuels, as the two offer potential approaches for lowering the release of greenhouse gases and reliance on fossil fuels.

1.6 SYNTHETIC KEROSENE

Synthetic Kerosene (SK) or Sustainable aviation fuel (SAF), is a type of aviation fuel that is processed using sustainable and renewable sources like biomass, waste cooking oils, and algae.[7] Its purpose is to serve as a direct substitute for traditional jet fuel without requiring any modifications, with the aim of reducing the aviation industry's greenhouse gas emissions. SAF is typically blended with conventional jet fuel (kerosene with additives) and can be used in existing aircraft without any modifications.

The production process of Synthetic Kerosene, SK can vary depending on the feedstock used and the specific technology employed. However, here is a general overview of the process:

- Feedstock sourcing: The first step is to source the feedstock for the production of SAF. This can include various types of waste materials, non-food crops, and other sustainable sources such as algae.
- Pre-treatment: The feedstock undergoes pre-treatment to eliminate any impurities or contaminants that may hinder the conversion process.
- Conversion: Subsequently, the pre-treated feedstock is transformed into a fuel through a range of processes. such as Fischer-Tropsch synthesis, pyrolysis, or fermentation. These processes can involve high temperatures, pressure, and chemical reactions to convert the feedstock into a liquid fuel.
- Upgrading: The fuel produced in the previous step is then further processed to remove any remaining impurities and increase its energy density.
- Blending: The final step is to blend the SK with conventional jet fuel to create a drop-in replacement that can be used in existing aircraft.

It's important to note that the production process of SK is still evolving, and there are many different approaches and technologies being developed to produce SK more efficiently and sustainably.[8]

1.7 SK VS. BIODIESEL

Synthetic Kerosene, SK and biodiesel are both renewable fuels, but their production methods are different.

Biodiesel is typically processed using vegetable oils, animal fats and waste cooking oil. The production method of biodiesel involves a chemical reaction called transesterification, which involves reacting the feedstock with an alcohol, such as methanol or ethanol, to produce a fatty acid methyl ester (FAME). The FAME is then separated from the glycerol and purified before being used as a fuel.[9] With certain modifications, biodiesel can serve as a viable replacement for diesel fuel in diesel engines.[10]

On the other hand, SK is typically produced from sustainable and renewable sources such as biomass, waste oils, and algae.[11] The production process for SK varies depending on the feedstock and technology used, but generally involves converting the feedstock into a fuel through processes such as Fischer-Tropsch synthesis, pyrolysis, or fermentation. The fuel is then further processed to remove impurities and increase its energy density before being blended with conventional jet fuel. SK is designed to be a drop-in replacement for conventional jet fuel, with the aim of reducing the aviation industry's greenhouse gas emissions.[12]

In general, biodiesel and SK (a type of fuel) are produced using distinct methods. However, both fuels are renewable and contribute to the reduction of greenhouse gas emissions in the transportation sector.

1.8 SYNTHETIC KEROSENE PRODUCTION

The production of synthetic kerosene involves several steps, primarily using the Fischer-Tropsch (FT) synthesis process [7], [8], [13]. Here is a more detailed overview of the synthetic kerosene production process:

1. Feedstock Preparation: Various carbon-based feedstock's can be used for synthetic kerosene production, such as natural gas, biomass, coal, or even waste materials. The feedstock is typically processed to remove impurities and convert it into a suitable form for subsequent steps. For example, biomass may undergo pre-treatment to break down complex organic molecules into simpler components.
2. Gasification: The feedstock is subjected to high temperatures in a gasifier, which converts it into synthesis gas or syngas. The gasifier operates in a controlled environment, either with oxygen or steam, to react with the feedstock. Gasification can be done through various methods, such as entrained flow, fluidized bed, or partial oxidation, depending on the feedstock and process requirements.
3. Gas Cleaning: The syngas produced in the gasifier contains impurities like sulfur, nitrogen compounds, and particulate matter. These impurities need to be removed to prevent catalyst deactivation and ensure the quality of the final product. The gas goes through a series of cleaning processes, including

desulfurization, desulphurization, and removal of other contaminants, using various techniques like scrubbing, absorption, or catalytic conversion.

4. Syngas Conditioning: The cleaned syngas then undergoes further conditioning to optimize its composition for the Fischer-Tropsch synthesis. This may involve adjusting the ratio of hydrogen to carbon monoxide, controlling the temperature, or removing any remaining impurities.
5. Fischer-Tropsch Synthesis: The conditioned syngas is introduced into a reactor vessel containing a catalyst, typically based on iron or cobalt. The Fischer-Tropsch synthesis occurs at high temperatures (around 200-300 degrees Celsius) and pressures, facilitating a series of chemical reactions. The syngas components, mainly hydrogen and carbon monoxide, are transformed into longer-chain hydrocarbon molecules through polymerization.
6. Hydroprocessing: The resulting hydrocarbon product from the Fischer-Tropsch synthesis contains a mixture of hydrocarbons, including waxes and heavier compounds. This product goes through a hydroprocessing step, which involves hydrotreating and hydrocracking. Hydrotreating removes impurities like sulfur, nitrogen, and metals, while hydrocracking breaks down larger molecules into smaller ones to improve the product's properties and achieve the desired boiling range.
7. Fractionation and Distillation: The hydroprocessed product is then fractionated to separate different hydrocarbon fractions based on their boiling points. Fractionation may involve distillation, where the product is heated, and various fractions are collected as they vaporize at different temperatures. This process helps obtain the desired boiling range and properties for synthetic kerosene.
8. Blending and Additives: The obtained synthetic kerosene fraction may undergo further blending with other components or additives to meet specific fuel specifications. These additives can enhance properties like lubricity, stability, or anti-icing characteristics. The blending ensures the synthetic kerosene meets the required quality standards for use in aviation.
9. Quality Testing: The final synthetic kerosene product goes through rigorous quality testing to ensure it meets the necessary specifications for use in aviation. This includes testing for parameters such as energy density, flash point, viscosity, sulfur content, and other relevant properties.

It's important to note that the synthetic kerosene production process can vary depending on factors such as the feedstock used, catalysts employed, and desired product specifications. Ongoing research and development efforts continue to refine and optimize the process to improve efficiency, reduce costs, and enhance sustainability.

1.9 ASTM CERTIFIED METHOD OF PRODUCTION.

The major certified method of production by ASTM (American Society for Testing and Materials) is discussed below with their respective blending limit approved by ASTM.[14][15]

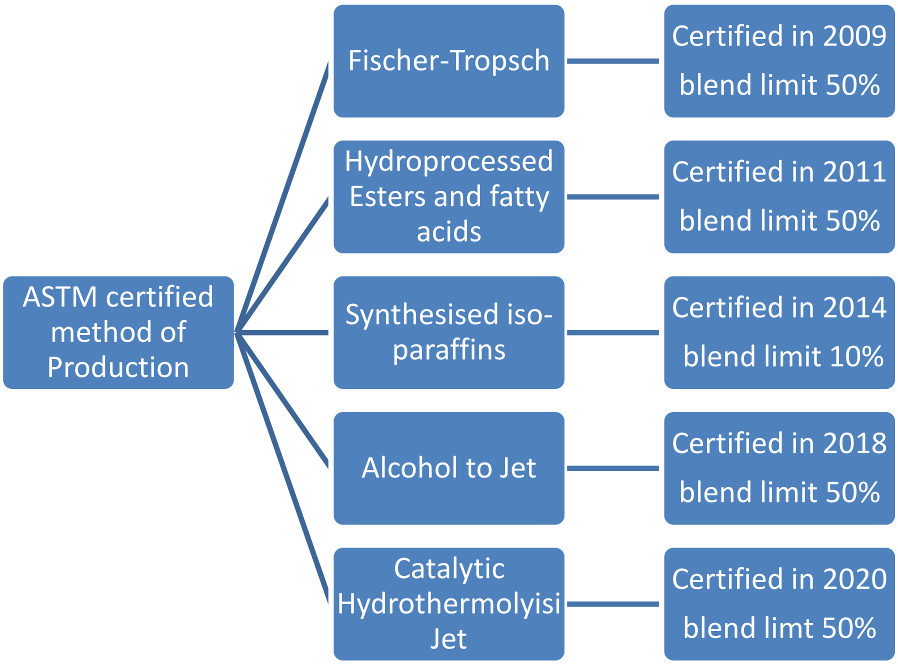

Figure 1.9.1ASTM Certified Methods

1.10 SINGLE FUEL FOR AVIATION AND TRANSPORTATION

A single fuel concept that can be used for both aviation and transportation would ideally need to meet the specific requirements and challenges of both sectors. While it is challenging to develop a single fuel that can fulfill all the diverse needs, here is a concept that could potentially address the requirements of aviation and transportation:

Synthetic Fuel: One possible approach is to develop a synthetic fuel that can be used across both aviation and transportation. Synthetic fuels, also known as synthetic hydrocarbons or synfuels, are produced through chemical processes using renewable or carbon-neutral sources. These fuels can be tailored to meet specific requirements and offer potential advantages such as lower carbon emissions and compatibility with existing infrastructure.

The concept involves producing a synthetic fuel using sustainable feedstock, such as biomass, agricultural waste, or renewable electricity. The feedstock would undergo a conversion process, such as gasification or biomass-to-liquid (BTL) technology, to produce synthetic hydrocarbons. These hydrocarbons can be refined to create a fuel suitable for both aviation and transportation.

The synthetic fuel must fulfill the following set of requirements:

- Energy Density - The synthetic fuel should possess a substantial energy density, meeting the performance demands of aviation while offering an ample range for transportation vehicles.
- Compatibility: The fuel should be compatible with existing aircraft and vehicle engines without requiring major modifications. This ensures that it can be easily adopted without significant infrastructure changes.
- Environmental ImpactThe synthetic fuel is expected to exhibit decreased levels of greenhouse gas emissions in comparison to conventional fossil fuels, resulting in a diminished carbon footprint and enhanced air quality.[16]
- Safety and Stability: The fuel should possess stability and safety characteristics suitable for aviation and transportation, including appropriate flashpoint, stability over a wide range of temperatures, and compatibility with existing fuel storage and distribution systems.

It's important to note that while this concept presents a potential solution, the practical implementation and widespread adoption of a single fuel for aviation and transportation would require overcoming numerous technical, economic, and logistical challenges. Collaboration between governments, research institutions, and private industries would be crucial to drive advancements in synthetic fuel production. Nonetheless, ongoing efforts to develop sustainable and low-emission fuels are promising steps toward achieving a more environmentally friendly and efficient future for both aviation and transportation.[17]

CHAPTER 2

LITERATURE REVIEW

In this chapter, fuel properties of synthetic kerosene, kerosene based on crude oil, diesel are reviewed from different renowned sources. The production process and use of blend of kerosene with diesel as well as biodiesel in CI engine is also discussed in this chapter.

Some research also done by the researchers to use ternary blends of kerosene (based on crude oil), diesel and biodiesel from various feed sources. Little to no work of use of synthetic kerosene is done so far for use of synthetic kerosene in CI engine with blend with diesel fuel.

2.1 FUEL PROPERTIES

The table 2.1 shows the collected data of fuel properties from renowned sources [18]–[21]and some important fuel properties are discussed below. The properties of synthetic kerosene will depend upon the quality of feedstock, the method of production as well as the fuel additives used.

Table 2.1.1Fuel Properties

Property	Synthetic Kerosene	Kerosene	Diesel Fuel
Energy density (MJ/kg)	34.8 - 44.8	43.1 - 45.8	42.6 - 45.8
Mass density (kg/L)	0.78 - 0.81	0.78 - 0.82	0.82 - 0.85
Viscosity (cSt)	2.8 - 8.0	2.9 - 4.1	2.6 - 4.1
Auto ignition temperature (°C)	220 – 325	210 - 300	210 - 350
Flash point (°C)	>38	>38	>52
Pour point (°C)	-47	-47	-40 to -15
Adiabatic flame temperature (K)	2075 - 2200	2000 - 2100	2100 - 2200

Cetane Number	-	42-46	45-55
Oxygenates %	5 -20	-	-
Production cost ($/gallon)	4.00 - 7.50	2.50 - 3.00	2.50 - 3.50

2.1.1 Energy Density

Energy density pertains to the quantity of energy stored in a specific volume or mass of a substance and is typically denoted in units of joules per kilogram (J/kg). or mega joules per liter (MJ/L). For fuels, energy density is a key factor in determining their usefulness for various applications, particularly in transportation where higher energy density fuels allow for greater range or more efficient use of space. The Energy density in MJ/kg is given in table 2.1, fossil fuel based kerosene and diesel is having almost same energy density with kerosene having slightly high.

The energy density of SK (34.8 - 44.8 MJ/kg) can vary depending on the feedstock and the process used to produce it. In general, SK has a slightly lower energy density than traditional jet fuel due to the oxygen content in the fuel molecules, which reduces the energy content per unit volume. Nevertheless, SK offers additional advantages, such as decreased greenhouse gas emissions and reduced reliance on fossil fuels, establishing it as a significant alternative for the aviation sector.

2.1.2 Viscosity

Viscosity represents the degree of resistance to flow exhibited by a fluid. It is important in determining the fluid's ability to move through pipes and machinery. In the context of kerosene, diesel, and sustainable aviation fuel (SK), viscosity plays an important role in their performance as fuels.

Kerosene and diesel have similar viscosities, with kerosene having a slightly lower viscosity than diesel. This means that kerosene flows more easily than diesel, which makes it a preferred fuel for use in colder temperatures, as it is less likely to thicken and become difficult to pump.

SK, on the other hand, can have a wide range of viscosities depending on the feedstock used to produce it. However, in general, SK has a lower viscosity than both kerosene and diesel. This means that it flows more easily and can potentially lead to improved fuel efficiency in aircraft engines.

It is worth noting that while viscosity is an important factor in fuel performance, it is not the only consideration. Other factors such as energy density, flash point, and freezing point also play important roles in determining the suitability of a fuel for a particular application.

2.1.3 Flash Point

The Flash Point is characterized as the minimum temperature at which a liquid can generate sufficient vapor to form a flammable mixture with air in close proximity to its surface. Essentially, it indicates the temperature at which a fuel can ignite in the presence of a spark or flame. The Flash Point holds significant importance as a safety parameter in fuel-related contexts and handling as it indicates the fuel's volatility and the risk of fire or explosion during storage, transportation, and use.

When it comes to kerosene, diesel, and SK, the Flash Point values vary due to differences in their chemical composition and properties. Specifically, the Flash Point of diesel fuel is higher compared to that of kerosene and SK.

2.1.4 Pour Point

The Pour Point is the minimum temperature at which a liquid fuel, such as kerosene, diesel, or SK, maintains its ability to flow. It is an important property for liquid fuels because it determines their ability to be pumped and transported in cold weather conditions.

The pour point for kerosene ranges from -40°C to -47°C, while for diesel it ranges from -30°C to -45°C. In comparison, the pour point for sustainable aviation fuel can vary depending on the feedstock and the production process, but it typically falls within the range of -40°C to -60°C.

Due to its lower pour point, kerosene is better suited for utilization in cold weather conditions compared to diesel. However, the pour point of SK is similar to that of kerosene, which makes it a viable alternative to conventional aviation fuels in terms of cold weather performance.

Overall, pour point is an important property for liquid fuels as it affects their handling and performance in cold weather conditions. While kerosene has a lower pour point than diesel, SK can match the pour point of kerosene and provide a sustainable alternative for aviation fuel.

2.1.5 Cetane Number

The Cetane number serves as an indicator of the ignition characteristics of diesel fuels, representing their capacity to combust smoothly and efficiently within a diesel engine. Higher cetane numbers generally indicate better ignition quality and smoother combustion.

Diesel fuels have cetane numbers typically ranging from 45 to 55, while for conventional fossil fuel based kerosene it is in-between 42 to 46. An elevated cetane number in diesel fuel leads to enhanced ignition properties, facilitating faster and more thorough combustion, along with reduced emissions. Diesel fuels with higher cetane numbers typically demonstrate improved engine performance, smoother operation, and decreased emissions of pollutants like nitrogen oxides (NOx) and particulate matter (PM).

Synthetic Kerosene does not have a cetane number because it is primarily used in aviation turbine engines, which operate differently from diesel engines.

2.2 USE IN CI ENGINE

Chen et al. [22] investigated, the combustion and emission characteristics of diesel, aviation kerosene rocket propellant 3 (RP-3), and RP-3-pentanol blends were investigated in a single-cylinder CI engine. The objective was to analyse the HRR, ITE, ID, CD, and coefficient of variation (COV) of IMEP as key parameters reflecting the engine's combustion performance. The results indicated that the use of RP-3 and its mild pentanol blend (20% by volume) in modern CI engines is feasible. However, if a higher pentanol ratio (40%) is employed, further optimization of the injection strategy is necessary. Compared to diesel, RP-3 demonstrated an improvement in stated thermal efficiency ranging from 1.4% to 12.4%, while the addition of pentanol resulted in a decrease ranging from 1% to 6.5%. While RP-3 and its pentanol blends exhibited higher levels of carbon monoxide (CO) and total hydrocarbon (THC) pollutants at low loads, there was a slight decrease in CO emissions at high loads. Notably, soot emissions were significantly reduced at higher engine loads compared to diesel, without any notable impact on nitrogen oxide (NOx) emissions.

Ashoura et al. [23] examines he study investigated the impact of blending diesel and diesel-biodiesel mixtures with 2 kerosene fuels, named J100 (100% jet fuel) and P100 (paraffinic solvent) on the performance, combustion parameters, and emissions of CI engine. The trials were performed at a uniform speed of 2000 rpm, covering a range of loads. A single-cylinder, air-cooled, four-stroke, direct-injection CI engine was employed for the trials. Different v/v blending ratios of 5 percent, 10 percent, and 15percent of the additives were mixed with B30 (70% diesel & 30% biodiesel) and plain diesel. The results showed an average reduction in BSFC of 8.4% and 5.6%. Ternary blends exhibited BSFC similar to that of pure diesel. However, binary blends required an increase of up to 10% in P100 or J100 content to achieve stable engine performance. Stable performance was achieved for ternary blends with P100 up to 10% and J100 up to 15%. The maximum drop in NOx pollutant was 38.7% for D95-P5 blend, and B30-J15 blend resulted in a maximum reduction of 50.3% in CO emissions.

Kadhim et al. [24] examine the effects of varying the volume of kerosene added to diesel fuel on the engine's performance and emissions across different loads (torques) in the experiment, a single-cylinder, four stroke, air-cooled, DI compression ignition diesel engine. The baseline was pure diesel (designated as D), and two blend levels were introduced: 10% kerosene blending labeled as K10, and 20% kerosene blending labeled as K20. The experiment included a constant engine speed of 1500 rpm, three load levels (torques) of 2 N.m, 6 N.m, and 10 N.m, and three fuel types: D, K10, and K20. Performance metrics such as BSFC, BTE, and exhaust temperature were examined. Additionally, the emissions of nitrogen oxides (NOx) and carbon dioxide (CO2) resulting from specific fuel mixes were examined. The results demonstrated that engines fueled with K10 or K20 experienced reductions in BSFC of 14.1% and 20.1% respectively, compared to pure diesel, particularly under low load conditions, the exhaust gas temperature, BTE, CO_2, and NOx content all rise. These findings suggested that kerosene and diesel fuel might be mixed at levels of 10% and 20% by volume without requiring any engine modifications.

Anjum et al. [25] performed the experimental examination to ascertain the impact of the combination of conventional fuel and an experimental analysis was conducted using a single-cylinder diesel engine connected to an eddy current dynamometer to evaluate the impact of kerosene oil. Various blends of kerosene and mineral diesel were employed to investigate the performance of the diesel engine. The experimental tests involved testing different ratios of kerosene oil and diesel mixtures (5%, 10%, and 15% by volume) in a compression ignition (CI) engine under varying load conditions. The findings suggested that the performance parameters under different conditions were quite comparable to those observed with diesel fuel alone.

Zangana et al. [26] investigated the effect of mixing kerosene and diesel on engine efficiency and fuel economy. Additionally, the research objective to determine the optimal blending ratio that does not significantly compromise engine performance. To assess engine efficiency, tests were conducted using blended diesel fuel containing kerosene at varying volume percentages ranging from 7% to 20%. The tests were carried out at a constant speed of 2000 rpm and three different torques (2 N m, 4 N m, and 6 N m). Several operational characteristics were calculated, including engine effective power (Ne kW), noise intensity (measured in dB), brake thermal efficiency (BTE), and brake-specific fuel consumption (BSFC Kg/kW.h).and brake-specific energy consumption (BSEC MJ/kW.h). The findings indicate that tiny volume percentages (up to 14%) have little effect on engine performance and fuel usage. Specifically, blending ratios of 7% and 14% result in only minor increases in brake-specific fuel consumption (BSFC) of 3.8% and 9.6%, respectively. Adding kerosene and diesel can reduce engine noise intensity and minimize pollution emissions. The study concludes that a combination of kerosene and diesel fuel up to 14% can be achieved without significantly impacting engine performance or fuel efficiency.

Elsharkawy et al. [27] the combustion characteristics, performance parameters, and emission attributes of a CI engine were evaluated using a range of nine distinct fuels. These fuels encompassed variations such as diesel fuel, blends of biodiesel with diesel, and blends of biodiesel with kerosene, are examined and compared in this study. The percentages of 10%, 20%, and 30% used in biodiesel blends with diesel and kerosene

(CD10, CD20, CD30, CK10, CK20, and CK30) are considered common. Through the transesterification process, castor oil is transformed into biodiesel fuel. Test fuels derived from this process are utilized in a DI CI engine with a single cylinder, operating at a constant speed of 2000 rpm across various load conditions (0%, 20%, 40%, 60%, and 80%). The research findings indicate that the cylinder pressure for blends of diesel and biodiesel is slightly higher compared to blends of kerosene and biodiesel. Moreover, both kerosene-biodiesel and diesel-biodiesel blends exhibit lower maximum pressure values than base diesel across all engine load settings. Maximum pressures of diesel-biodiesel blends are also somewhat greater than kerosene-biodiesel blends. In contrast, CK30 observed a 20% reduction in NOx levels when compared to pure diesel, whereas CD20 recorded an increase in emissions levels of 19.5% when compared to pure diesel. Both kerosene diesel & diesel-biodiesel blends have been shown to have close BSFC and BTE values. This study suggests replacing diesel with a blend of 70% kerosene and 30% biodiesel, rather than using the biodiesel only as an additive, especially when the biodiesel is highly viscous, as in the case of castor oil biodiesel.

Tay et al. [28] The introduction of the Single Fuel Concept initiated the utilization of kerosene in DI - CI engines, which impacts engine performance and emissions due to the dissimilar fuel characteristics between kerosene and diesel. Since standard diesel engines are designed specifically for diesel fuel, understanding kerosene's properties, auto-ignition and combustion characteristics, and emission formation behavior under diesel engine conditions is crucial for its effective and efficient use in diesel engines. Additionally, exploring viable alternatives to kerosene for engine applications is advantageous for developing reliable chemical reaction processes for numerical simulations. This comprehensive review systematically examines the characteristics and behavior of kerosene in direct injection compression ignition engines. The review article outlines the fuel qualities of kerosene and investigates its auto-ignition studies conducted in various experimental setups such as shock tubes, rapid compression machines, fuel ignition testers, ignition quality testers, constant volume combustion chambers, and engines. Furthermore, it discusses experimental studies on kerosene combustion and emissions in direct injection compression ignition engines. The development of kerosene substitutes, their chemical reaction methods, and modelling of kerosene combustion in DI-CI engines are also examined. Finally, the review highlights the areas where further research is needed to address the existing gaps in knowledge.

Roy et al. [29] evaluated the performance parameters and emissions attributes of a direct injection (DI) diesel engine are investigated using different fuel combinations, including kerosene-biodiesel, biodiesel-diesel-additive, and diesel-biodiesel. Biodiesel is produced from canola oil, and a new biodiesel additive called Wintron XC 30 (2 vol. %) is introduced to assess its impact on engine performance and emissions. A systematic testing approach is employed, involving various fuel blends such as kerosene-biodiesel with different volume percentages of kerosene (0, 5, 10, 20, 50, and 100) and biodiesel (0, 5, 10, 20, 50, and 100). The engine's performance parameters and emissions are evaluated under varying load conditions at the rated speed of 1800 rpm.

Mustak et al. [30] Air pollution is severely impacted when fuels with a petroleum base are used. Humanity searches for new alternative fuel sources in an effort to reduce this impact on the environment. To find a reliable alternative supply, a lot of testing has been done. Vegetable oils can be a good replacement for diesel fuel, according to the studies that have already been done. Vegetable oils have a high viscosity and low volatility, therefore putting them directly in an engine is not an option. In order to replace diesel in engines, mixtures of vegetable oils are employed. The impact of mixing kerosene and palm oil with diesel fuel is demonstrated in this experiment. Diverse mixtures of kerosene, palm oil, and diesel are used in experiments. First, several ratios of kerosene alone and diesel are blended, and the effects of the blending are noted. The outcome of mixing palm oil alone with diesel in various ratios was then assessed. Finally, equal amounts of palm oil, kerosene, and diesel fuel were blended together to evaluate how various fuel qualities changed. Comparisons are made between the effects of mixing palm oil and kerosene separately from diesel and the combined effects. A variety of fuel qualities were evaluated to compare the impacts. For various comparisons, this study focuses mostly on density and lower heating value (LHV) or lower calorific value (LCV).

Patil et al. [31] The impact of using kerosene as an additive to diesel fuel on the combustion, performance, and emission characteristics of a direct-injection diesel engine, commonly found in gensets and agricultural pumps, was investigated through experimental analysis. Engine tests were conducted using base diesel fuel and three blend fuels at various engine loads, following the ISO 8178-D2 five-mode test cycle procedure. The blends consisted of diesel mixed with 5%, 10%, and 15% kerosene (by volume), referred to as K5D, K10D, and K15D, respectively. Laboratory fuel experiments indicated that when the kerosene blend exceeded 15%, the viscosity and density of the blended fuel decreased below the permitted limits, potentially compromising lubricity and causing wear issues in fuel-injection pumps and injectors. The experimental tests revealed that the K5D blend exhibited lower smoke, lower NOx emissions, higher brake thermal efficiency, and lower brake-specific fuel consumption compared to the K10D and K15D blends. The analysis of the results suggests that, in terms of performance and emission characteristics, the K5D blend is the most favorable among the three blends (K5D, K10D, and K15D).

2.3 RESEARCH GAP

The application of synthetic kerosene in internal combustion engines (ICE) is a relatively understudied field with limited research conducted thus far. While synthetic fuels have been investigated and utilized in aviation applications, their potential use in ICEs is relatively less explored. Here are a few research gaps that could be addressed regarding the use of synthetic kerosene in ICEs:

- Combustion Characteristics: There is a need for a comprehensive investigation into the combustion characteristics of synthetic kerosene in ICEs. This includes studying ignition delays, flame propagation, combustion stability, and emissions formation. Comparisons with conventional kerosene or other alternative fuels can provide insights into the differences and advantages of synthetic kerosene.
- Performance and Efficiency: Assessing the performance and efficiency of ICEs using synthetic kerosene is crucial. Studies should evaluate factors such as power output, torque, fuel consumption, and thermal efficiency when compared to conventional kerosene or other fuels. Understanding the potential benefits and drawbacks of using synthetic kerosene can guide engine optimization and design considerations.
- Emissions and Environmental Impact: Investigating the emissions profile and environmental impact of synthetic kerosene in ICEs is essential. Research should focus on measuring and analyzing the emissions of pollutants such as nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO), and unburned hydrocarbons (HC). Comparisons with conventional fuels can provide insights

into the potential emission reductions or changes associated with synthetic kerosene.

- Engine Compatibility and Modifications: Understanding the compatibility of synthetic kerosene with existing engine technologies is crucial. Research should explore the need for any engine modifications or adaptations to accommodate the specific characteristics of synthetic kerosene. This includes evaluating the effects on fuel injection systems, combustion chamber design, and exhaust after treatment systems.

Addressing these research gaps can provide valuable insights into the feasibility, performance, and environmental impacts of using synthetic kerosene in ICEs. This knowledge can guide future developments and help determine the potential for synthetic kerosene as a sustainable and efficient fuel option for transportation.

2.4 OBJECTIVE

The aim of the present research is to investigate the performance and efficiency of a compression ignition (CI) engine using blends of synthetic kerosene and diesel fuel based on volume proportions. Evaluation of different factors such as power output, torque, fuel consumption, and thermal efficiency, comparing them to those of conventional diesel fuel and alternative fuels. Combustion parameters such as P-Q diagram, HRR, mean gas temp., RPR are utilized to validate the changes in performance and efficiency of the CI engine when operated with different fuel blends.

CHAPTER 3

EXPERIMENTAL SETUP AND METHODOLOGY

3.1 TEST SETUP

A single-cylinder, water-cooled, direct-injection diesel engine with 3.5kW of output at the rated speed of 1500 rpm was employed in the current study, as illustrated in Fig. 3.1.1.

Figure 3.1.1 Engine Photo

Table 3.1.1 displays the engine specifications. These engines are a common sight in India's rural areas, where they are mostly employed for power backup and agricultural purposes.

Table 3.1.1 Test Engine Specifications

Make	Kirloskar
Number of Cylinder	1
Brake Power (kW)	3.5
Rated speed (rpm)	1500
Compression ratio	17.5:1
Stroke x Bore (mm)	110 x 87.5
Connection rod length (mm)	234
Cooling type	Liquid Cooled
Inlet valve opens at	4.5 degrees BTDC
Inlet valve closes at	35.5 degrees ATDC
Exhaust valve opens at	35.5 degrees BBDC
Exhaust valve closes at	4.5 degrees ATDC
Injection starts at	23 degrees BTDC
No. of injector holes	3
Nozzle diameter (mm)	0.148

The data provided by the data acquisition system were read using ICEnginesoft software (version 9.0) by Apex Innovations, and additional analysis was done using the data. The control panel depicted in Fig. 3.1.3 contained the data collecting system, the engine loading system, the fuel measuring system, and the air and fuel flow measurement system.

The crank angle encoder was attached to the end of the engine-loading eddy current dynamometer, and the piezoelectric transducer was mounted in the cylinder head surface to measure the in-cylinder pressure. With the aid of a data collecting system (NI USB 6210 (Fig. 3.1.2)), these sensors transmit the signal to a personal computer.

The engine and eddy current dynamometer were cooled by a centralized water cooling system. The water flow rate to the engine was kept at 150 l/h, while it was kept at 75 l/h for the dynamometer and the flow is maintained using the rotameter as shown in Fig. 3.1.4. Rotameters are straightforward, trustworthy, and reasonably priced flow measurement devices. A float rises when fluid fed into a flow tube with a uniform taper, with the weight of the fluid moving beneath it, until the complete volume of fluid can pass the float. An indicator of the fluid's flow rate can be obtained from the float's location, which correlates to a point on the tube's measurement scale.

Calorimeters are used to measure the amount of heat that exhaust gases carry with them. It is a kind of heat exchanger where the heat balance, water inlet and outlet temperatures, and exhaust inlet temperatures are utilized to calculate how much heat the exhaust gases are transferring.

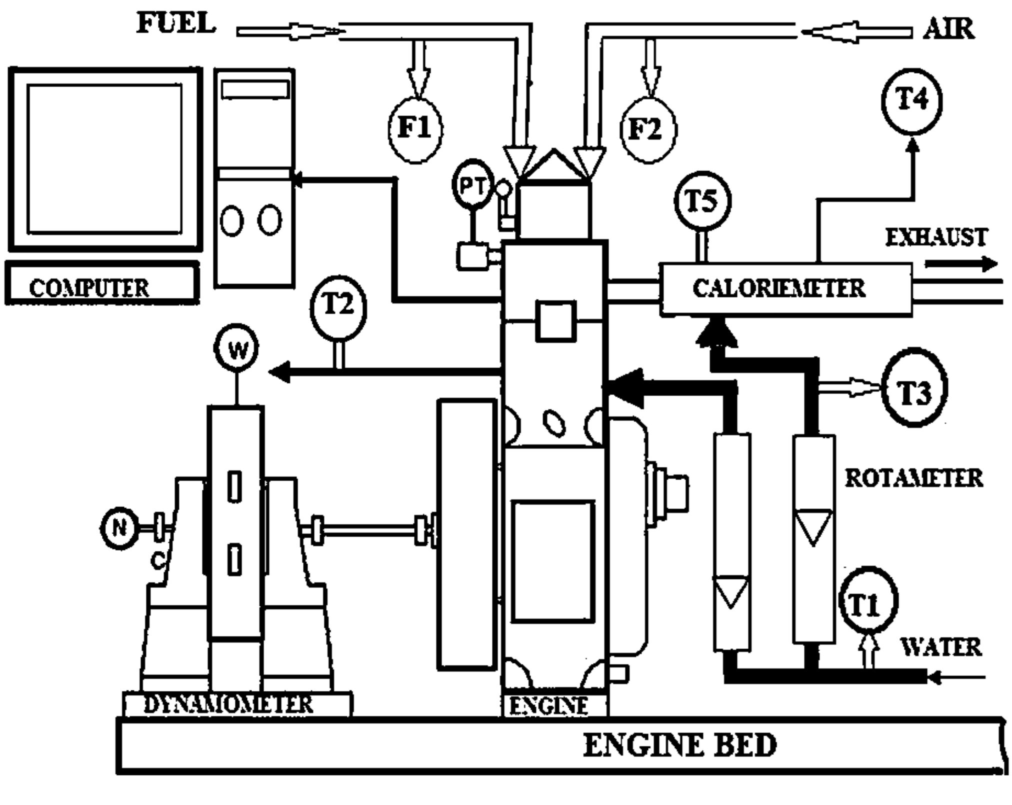

Figure 3.1.2 Schematic Layout of Setup

The notations in the schematic layout have following meanings

T1 – Temperature, Cooling water Inlet

T2 – Temperature, Cooling water Outlet

T3 – Temperature, Calorimeter Inlet

T4 – Temperature, Calorimeter Outlet

T5 – Temperature, Exhaust gas at calorimeter inlet

F1 – Flow meter, Air flow meter

F2 – Flowmeter, fuel flow meter

PT – Pressure Transducer

N – Engine speed measurement device

W – Load on engine using dynamometer.

Figure 3.1.3 NI Data Acquisition System

Figure 3.1.4 Control Panel

Figure 3.1.5 Rotameters

3.2 ENGINE TEST PARAMETERS

For the purpose of testing of the engine, choosing the proper test parameters is crucial, and in this study, the parameters were carefully chosen.

The various observed parameters are engine load, engine speed, air flow rate, fuel consumption rate, temperature at various location, in-cylinder pressure and crank angle using encoder

The parameters that were calculated are brake thermal efficiency (BTE), Brake specific fuel consumption (BSFC), pressure rise rate, heat release rate, mean cylinder gas temperature.

3.2.1 Measurement of Brake Power

Brake power (BP) is the most crucial factor when evaluating an internal combustion engine. Through a flexible link, the engine was connected to an eddy current dynamometer. The engine was loaded on the water cooled eddy current dynamometer, which is seen in Fig. 3.2.2, and the brake power was measured at each load. The stator and rotor of an eddy current dynamometer make up the device. The stator contains permanent electromagnets, whereas the rotor is made up of a copper or steel disc.

Through the coupling, the rotor is linked to the engine shaft. The electromagnets are energized by running the current through them while the engine is being loaded. Eddy current is created in the electromagnets while the rotor turns. The magnetic field created by this eddy current opposes the rotation of the rotor, loading the engine. The water flowing through the dynamometer dissipates the heat produced during the loading.

The arm length of the dynamometer was 0.185, and it was used to apply force to a load cell in order to apply a moment to measure the load. Kg were used to measure the load. Equation 3.2.1.1 was used to determine the brake power.

$$BP\ (kW) = \frac{2*\pi*N(rpm)*Load(kg)*9.81*Dynamometer\ arm\ length\ (m)}{60*1000} \qquad 3.2.1.1$$

3.2.2 Measurement of Engine Speed

A disc with teeth was attached to the shaft's end closest to the dynamometer. A magnetic pickup type rpm sensor, as seen in Fig. 3.2.2.1, was positioned near to the toothed disc. A permanent magnet, a yoke, and a coil make up the sensor. A pulse was created in the coil as each tooth passed the sensor. More pulses were generated by the sensor as the speed increased. These pulses were transmitted to the system of digital acquisition, which computed the engine rpm. The software installed on the personal computer and the control panel both showed the engine rpm.

3.2.3 Measurement of fuel flow

A differential pressure transmitter (Yokogawa, Japan-made brand) that utilises the hydrostatic head theory was used to measure the amount of gasoline the engine used at each load. According to Fig. 3.2.3.1, the transmitter, which was installed at the end of the burette, generated an output voltage that was proportionate to the weight of the fuel in the column.

By monitoring the change in transmitter output at certain intervals and multiplying it by the fuel factor, the fuel flow rate was estimated. The fuel factor is the quantity of fuel (in kilogrammes) that leaves the burette for every unit change in the transmitter's output voltage (kg/V). Equation 3.2.3.1 provides the fuel factor.

$$\text{Fuel Factor} = \rho * g * h * A \qquad (3.2.3.1)$$

Figure 3.2.1 Eddy Current Dynanometer

Figure 3.2.2 Load Cell

The data collecting system received a direct signal from the sensor, which it used to calculate the fuel flow rate. By simultaneously collecting manual readings from the burette, the sensor data was determined. The engine's brake thermal efficiency and brake specific energy consumption (BSEC) at a given load may be computed from the fuel flow rate.

The efficiency with which heat stored in the fuel is converted into usable work available at the axles is known as the brake thermal efficiency. Equation 3.2.3.1 contains the brake thermal efficiency formula. Similar to this, BSEC is the amount of fuel energy used to create a unit of shaft power. Equation 3.2.3.2 is used to compute it.

$$\text{BTE (\%)} = \frac{BP\ (kW) * 100}{\text{mass flow rate (kg/s)} * \text{Calorific value(kJ/kg)}} \qquad (3.2.3.2)$$

$$\text{BSEC (MJ/kWh)} = \frac{\text{mass flow rate } \left(\frac{\text{kg}}{\text{s}}\right) * \text{Calorific value}\left(\frac{\text{kJ}}{\text{kg}}\right) * 3600}{\text{BP (kW)}} \qquad (3.2.3.2)$$

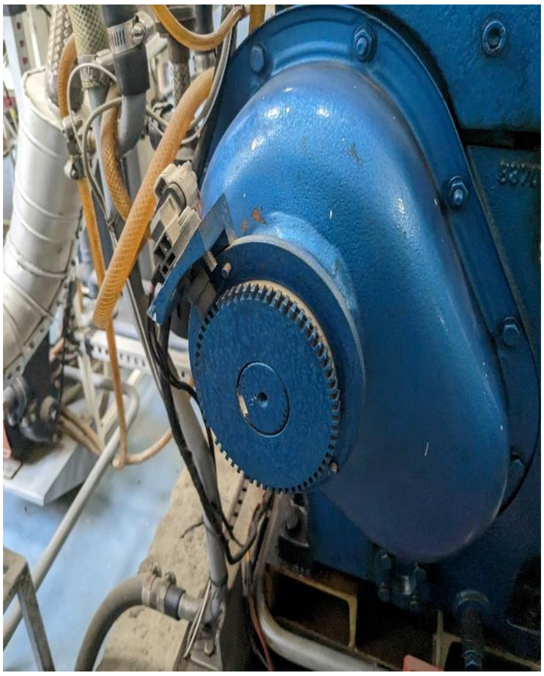

Figure 3.2.3 Engine speed measurement device

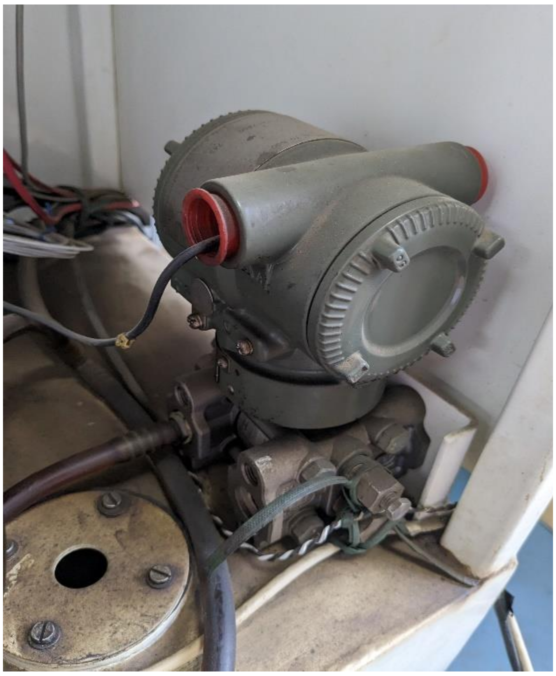

Figure 3.2.4 Fuel Flowmeter

3.2.4 Measurement of air flow

Since air flows once every two crankshaft rotations and is also compressible, measuring the exact quantity of air flow required by an engine is difficult. As a result, it is not practical to use the induction pipe's orifice alone because the results won't be accurate. In order to measure the air flow, a suitable-sized air box with a circular opening with sharp edges was employed. The U-tube manometer seen in Fig. 3.2.4.1 was used to determine the pressure difference between the atmosphere and the air box. Using equation 3.2.4.1, the mass flow rate of air was computed.

$$\text{Mass of air } \left(\frac{kg}{h}\right) = C_d * A * \sqrt[2]{2 * g * \text{hw} * \rho\text{w}/\rho\text{a}} \qquad (3.2.4.1)$$

Where C_d = coefficient of discharge (0.6), A = orifice area,

g= acceleration due to Gravity, h_w = height of water column,

$\rho_w/\rho a$ = density of water/density of air.

To monitor the air flow rate, an air sensor was additionally put in the air box (see Fig. 3.2.4.1). A rotor with blades attached to it makes up the air sensor. Since each blade has a bit of metal implanted in it, a pulse is produced when the blades begin to rotate and are thus magnetically detected. The transmitter analyses the signal to calculate the airflow rate. The computer's software had the data readily available.

Figure 3.2.5 Air Flow Sensor

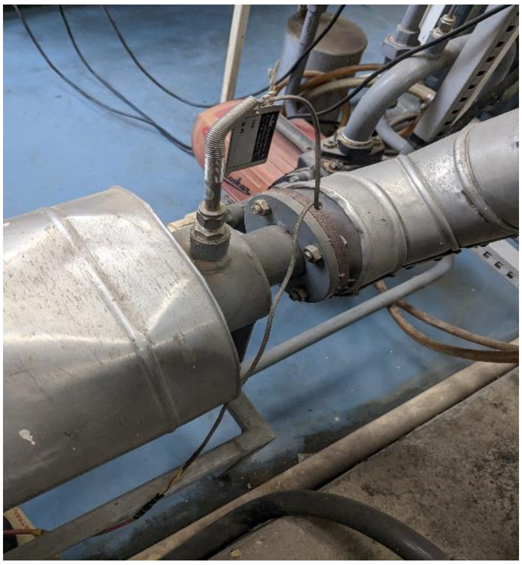

Figure 3.2.6 K-Type Thermometer

3.2.5 Measurement of temperature

In the current study, intake air, exhaust gas, coolant water in and out, and calorimeter water input and outlet temperatures were all measured using K-type thermocouples linked to a six-channel digital panel meter. Fig. 3.2.5.1 depicts the thermocouple attached to the calorimeter's inlet.

3.2.6 Measurement of in-cylinder pressure

The in-cylinder pressure was measured using a piezoelectric transducer of "Kubeler" brand. The charge amplifier enhanced the signals after they were sent from the transducer and lessened signal noise. The signals were then transmitted to the data acquisition system, where they were combined with the signals from the crank angle encoder to create the pressure versus crank angle graph using personal computer software. For each rotational crank angle, pressure data was generated. For the purpose of obtaining the in-cylinder pressure vs crank angle data in the current investigation, an average of fifty continuous cycles was used. The pressure sensor mounted on the engine head is shown in Fig. 3.2.6.1, and the crank angle encoder is shown in Fig. 3.2.6.2.

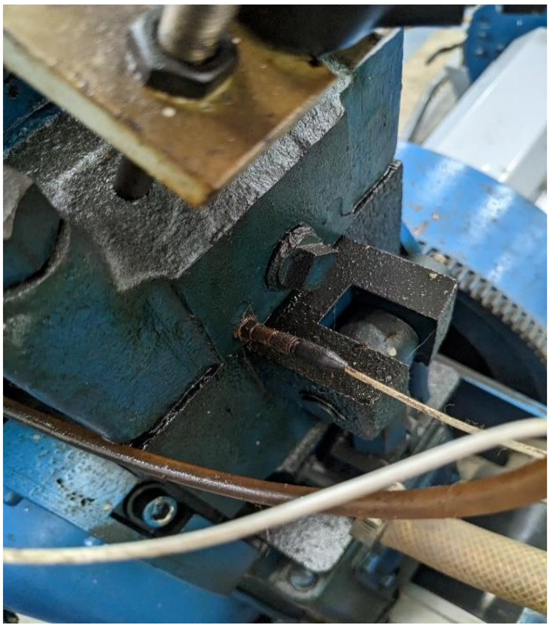

Figure 3.2.7 Pressure Sensor

Figure 3.2.8 Angle Encorder

3.3 ENGINE TRIAL PROCEDURE

Before starting the test, the drained system is filled using unadulterated diesel fuel to ensure that any air bubbles that could have accumulated in the fuel delivery system are removed. The engine then operates without additionally load for 15 minutes to warm up and stabilize the system. The constancy of the exhaust temperature was used to gauge engine stability. Then, with the aid of the control panel's knob, a load of 2 kg was introduced and progressively raised until the engine's maximum capacity, or about 12 kg of weight, was attained. The fuel supply valve was then closed to disconnect the fuel reservoir from the diesel engine and enable the fuel to be ingested from the pipette after 2 minutes with the same load and consistent rpm. As a result, fuel consumed was calculated using a fuel flow calculating integral equipment in addition to tracked by noting the amount of time the engine required to burn a certain amount of fuel; throughout the procedure, all data were recorded. To improve accuracy, each test was repeated, and both the final outcome and the mean value were taken into account.

CHAPTER 4

RESULT AND DISCUSSION

In the present work, synthetic kerosene and diesel blend mixture with diesel as base fuel and kerosene blending fuel with 10%, 20%, 30%, 40% v/v ratio was used in the compression ignition engine. The performance and combustion characteristics of each blend ratio are compared with baseline diesel operation at constant speed of 1500 rpm by varying the load on the engine.

4.1 BSFC (Brake Specific Fuel Consumption)

The relationship between brake-specific fuel consumption and load percent is shown in Fig. 4.1.1. Brake fuel consumption decreases exponentially as load increases because of high fuel air ratio when increases the cylinder gas temperature owing to better combustion and hence better utilization of fuel energy.

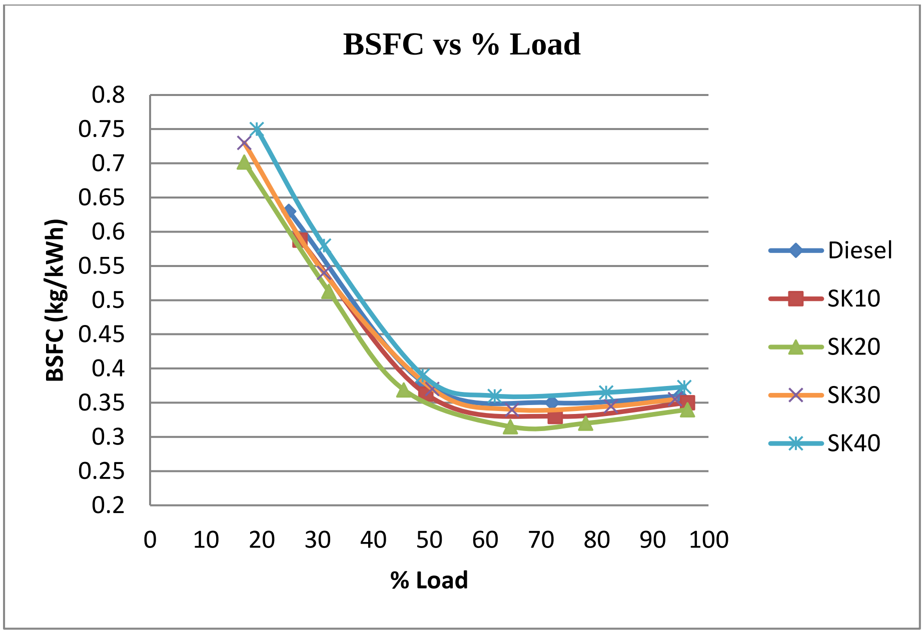

Figure 4.1.1 BSFC as function of Load %

The BSFC for SK10, SK20 and SK30 were observed lower than the diesel base fuel for all loading conditions. For SK20 the lowest BSFC is obtained. With blending of synthetic kerosene near to complete oxidation of fuel charge is obtained due to presence of oxygen content in synthetic kerosene as well as high volatility of kerosene fuel in comparison to diesel fuel. Further blending of SK increases the BSFC because of lower heating value of SK fuel which was observed in SK30 and SK40 trends, while SK40 having lower BSFC then diesel fuel.

Minimum BSFC is observed at load of 60% - 70% engine load. SK20 blend achieved minimum BSFC which is approximately 7.5% lower than the diesel fuel. For blends of SK10, SK30 it is in between of SK20 and diesel fuel. For SK40 there is increase of 3% at minimum BSFC load condition which is range of 60% - 70%.

At loads percentage higher than 70%, slightly increase in specific fuel consumption is observed for all blends due to richer fuel mixture at higher loads, leading to incomplete combustion of some portion of charge.

4.2 BRAKE THERMAL EFFICIENCY

The graphical representation of brake thermal efficiency and load is shown in Fig. 4.2.1. According to the graph, the efficiency of the SK blend is comparable to that of diesel baseline fuel. As the load increases, brake thermal efficiency rises, because of better charge combustion at higher loads.

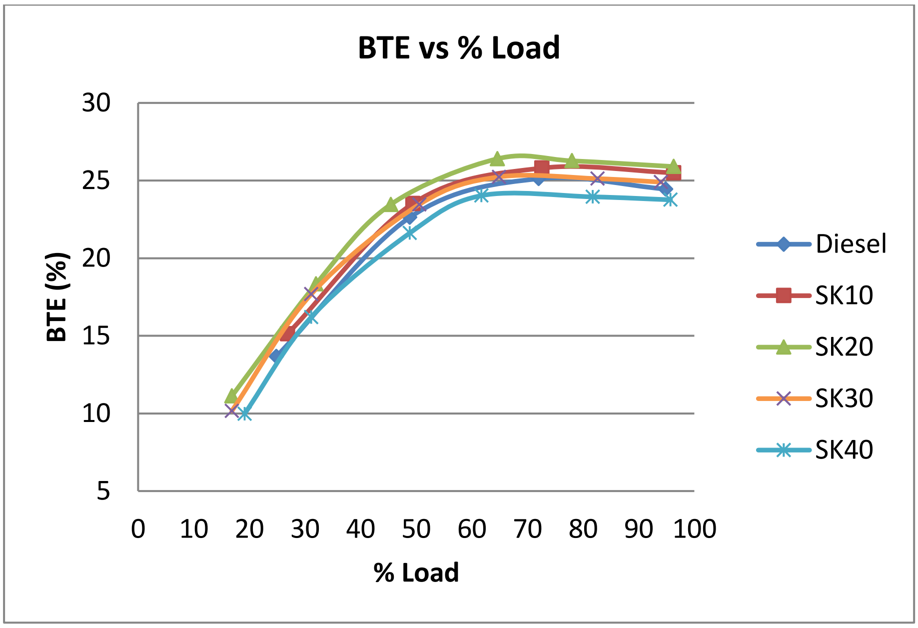

Figure 4.2.1 Brake thermal efficiency in correlation with load%

The brake thermal efficiency of blends are comparable to the base fuel observations. The BTE of SK10, SK20 and SK30 were higher than diesel fuel due to better combustion of charge because of presence of oxygen content, high volatility of SK. Further blending of SK were resulting in lower BTE than diesel fuel due to lower calorific value to SK fuel.

Maximum brake thermal efficiency is observed in range of 60% - 70% of engine for all blends. SK20 is having maximum BTE, approximately 5.5% higher than diesel reference fuel. For blends S10, SK30 it is in-between SK20 and diesel. For SK40 blends there is drop in BTE in comparison to diesel fuel and a drop of nearly 4% is observed.

At loads percentage higher than 70%, slightly drop in brake thermal efficiency is observed for all blends due to richer fuel mixture at higher loads, leading to incomplete combustion of some portion of charge.

4.3 EXHAUST TEMPERATURE

The curve relating the temperature of the exhaust gases and load percentage is shown in Fig. 4.3.1. Exhaust gas temperature rises as load rises, and as, bigger loads require more fuel, which must be burned in order to provide more power. The temperature of the exhaust gas is therefore higher.

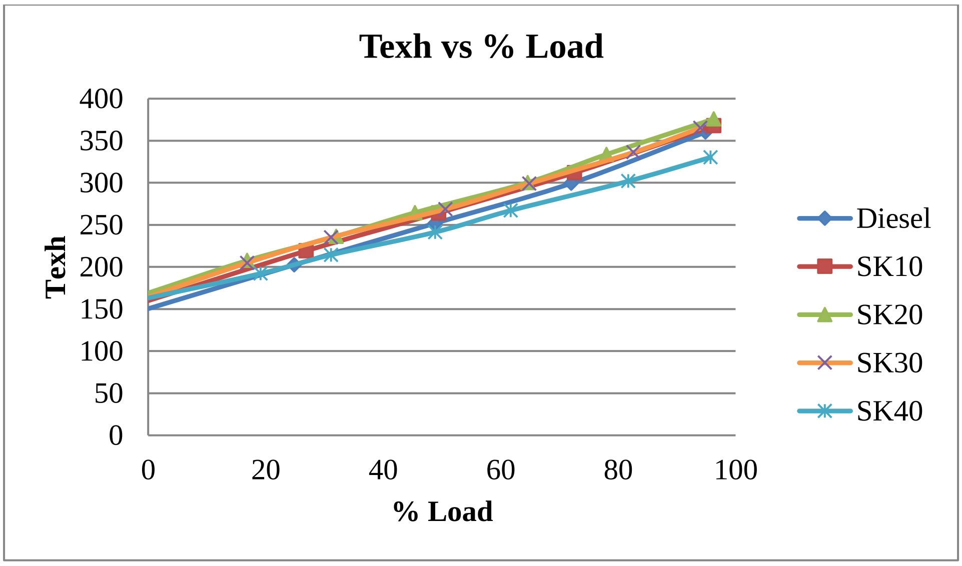

Figure 4.3.1 Exhaust gas temperature in correlation with load%

In comparison to the trend for diesel alone, the plot for SK10, SK20 and SK30 of the synthetic kerosene blends is seen to be slightly higher because of better combustion due to presence of oxygenates. Further blending of SK leads to lower exhaust temperature due to lower calorific value of SK fuel.

4.4 IN-CYLINDER PRESSURE

The relationship between cylinder pressures versus crank angle is shown in Figs. 4.4.1 and 4.4.2, respectively, at idle and 100% load, with the crank angle changing from start of fuel injection to just before the exhaust valve opens. The table 4.4.1 shows the peak pressure with respect to crank angle for various blends of fuel.

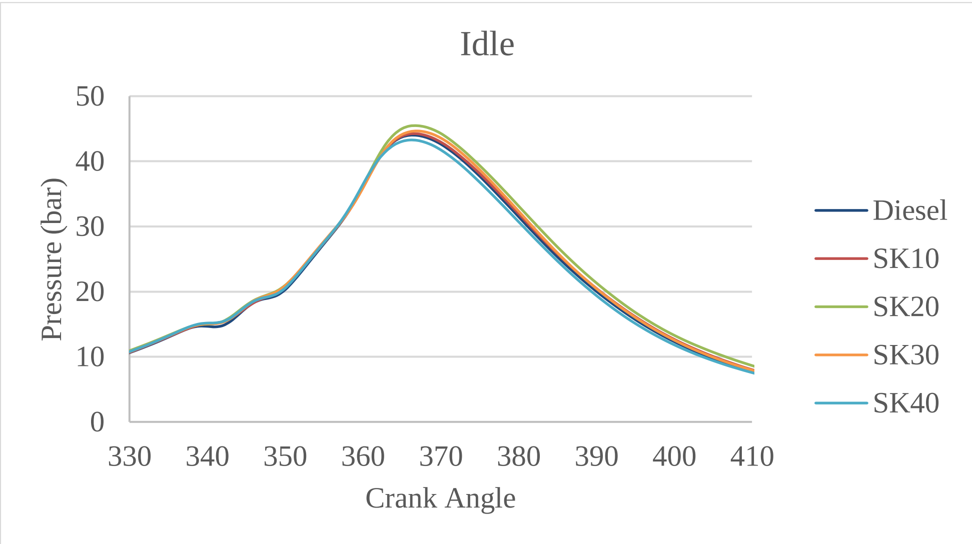

Figure 4.4.1 Pressure vs. Crank angle for idle condition

The peak pressure for 100% load is achieved at 8 to 9 degrees ATDC, which is close to 6-7 degrees ATDC under idle running conditions. There is delay of 2-3 °CA in peak pressure with increasing load is observed reason may be due to more fuel injection which takes more time to atomize as well as longer combustion period. Better combustion of SK10, SK20, and SK30 blends then diesel shows the variation in pressure angle which justify the increase in brake thermal efficiency and drop in the brake specific fuel consumption.

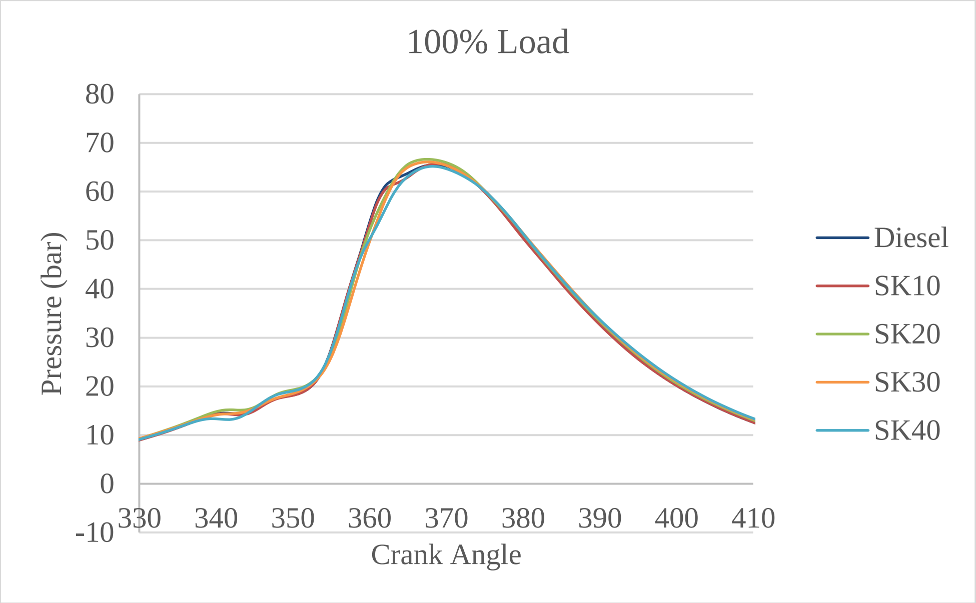

Figure 4.4.2 Pressure vs. Crank angle for 100% Load

Table 4.4.1 Peak Pressure of blends with CA

	Idle					100% Load				
Fuel	Diesel	SK10	SK20	SK30	SK40	Diesel	SK10	SK20	SK30	SK40
P_{max} CA	366	367	367	367	366	369	369	367	368	368
P_{max}	44	44.23	45.47	44.66	43.27	65.5	65.68	66.6	66.06	65.17

Maximum peak pressure is achieved in case of SK20 blend, approximately 3.5% higher than diesel for the idle condition and 1.75% higher for 100% loading condition. The percentage change for SK10, SK30 is in-between to SK20 and diesel fuel. For SK40 blend, drop of 1.7% for idle and 0.5% for 100% loading condition is observed with respect to base line diesel fuel.

4.5 RATE OF PRESSURE RISE

Fig 4.5.1, 4.5.2 plots the rate of pressure rise with respect to crank angle from start of injection to opening of exhaust valve for different blends.

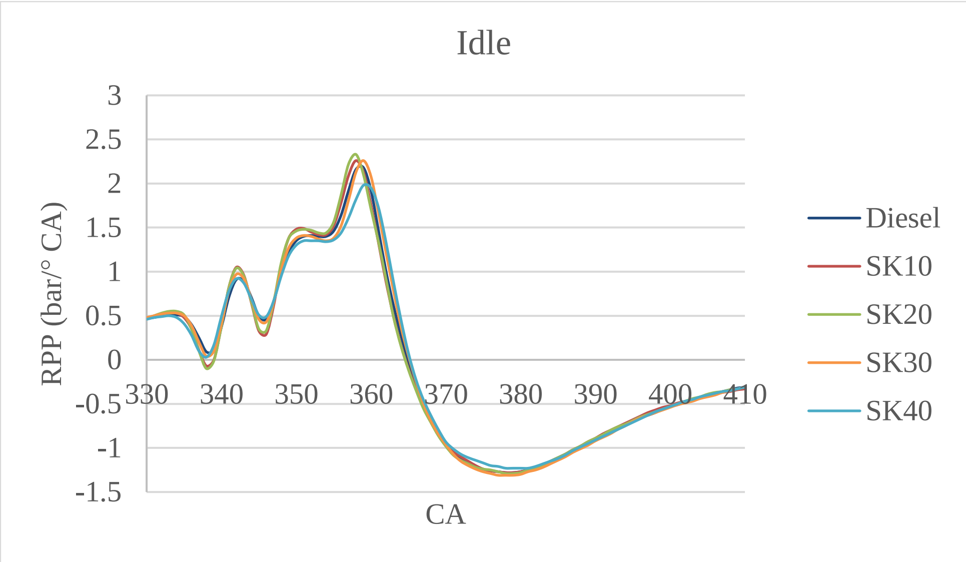

Figure 4.5.1 Rate of pressure rise vs. Crank angle for idle condition

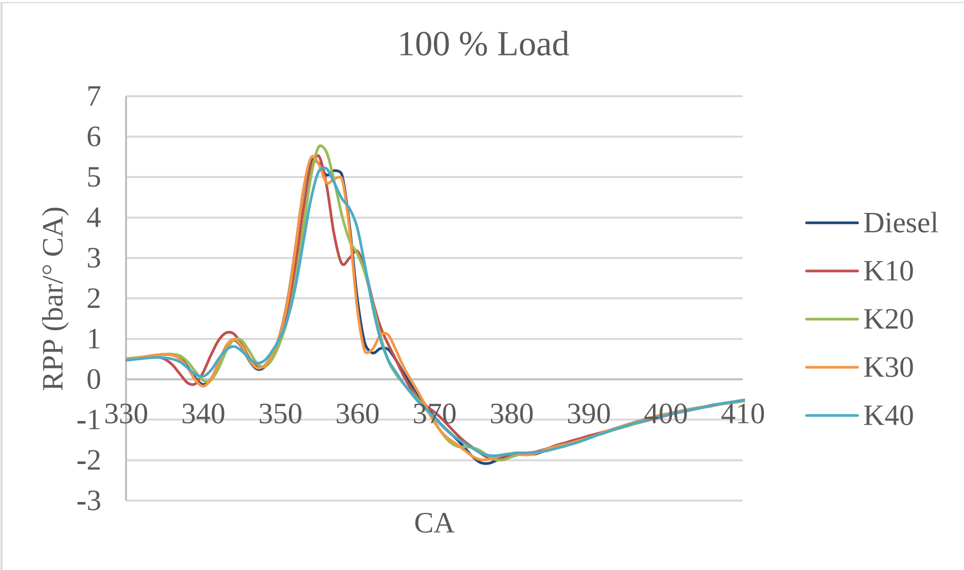

Figure 4.5.2 Rate of pressure rise vs. Crank angle for 100% Load

The pressure rise is due to two reasons; one is due to compression of charge due to piston movement and other being the pressure rise due to combustion of charge. The combine effect is maximum at piston position of 6-8 degree before reaching top dead center. Higher RPP is observed for SK10, SK20 and SK30 blends then diesel base fuel, with maximum rise for SK20 blending. When blending ratio increased further to SK40, drop in max RPP is observed resulting due to lower energy density of blend. The table 4.5.1 shows the maximum rate of pressure rise with respect to crank angle for various blends of fuel.

Maximum rate of pressure rise (RPP) is observed in case of SK20 blending which is approximately 7%, 6.5% higher than the diesel reference fuel data for idle and 100% loading conditions. Higher percentage blending of synthetic kerosene results in drop of rate of pressure rise for all loading conditions and drop of 9%, 3.5% is observed for idle and maximum loading condition in present study.

Table 4.5.1 Max RPP of various blend with CA

	Idle					Full Load				
Fuel	Diesel	SK10	SK20	SK30	SK40	Diesel	SK10	SK20	SK30	SK40
Crank Angle for Max RPP	359	358	358	359	359	354	355	355	354	356
Max RPP	2.18	2.26	2.33	2.26	1.98	5.4	5.52	5.75	5.48	5.21

4.6 CYLINDER MEAN GAS TEMPERATURE

Fig 4.6.1, 4.6.1 demonstrate the cylinder mean gas temperature change in comparison to crank angle with effect due to various blending ratios. The maximum temperature is achieved to nearly about 15-20 degrees ATDC. When the load % on engine increases, the mean gas temperature also increases due to more burning of fuel.to maintain the required speed and torque.

Similar variation of mean gas temperature for blends of SK10, SK20 and SK30 is obtained in plots of both idle and 100% load condition. Increased temperature of above blends then base diesel fuel, SK20 being highest. Drop in temperature for higher blends due to lower energy content in charge. The table 4.6.1 shows the maximum gas temperature with respect to crank angle for various blends of fuel.

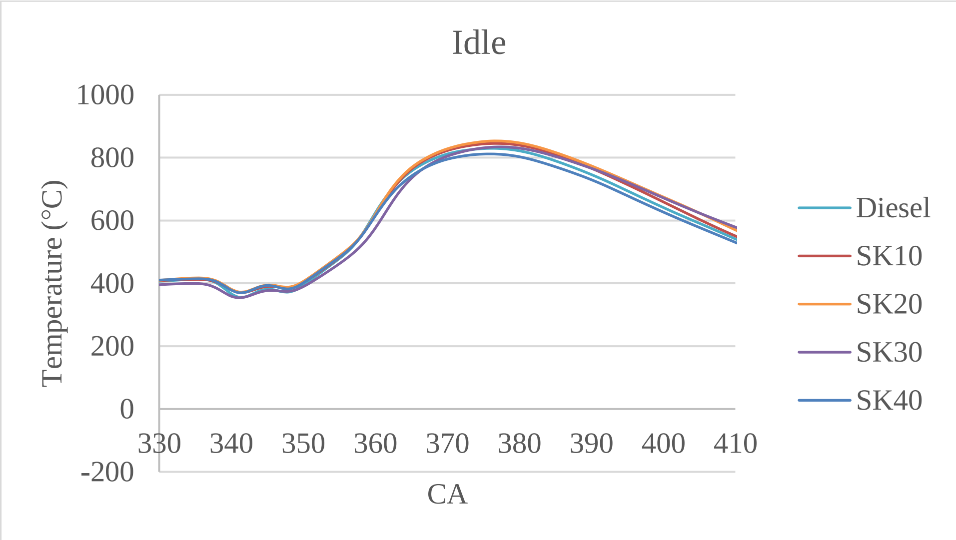

Figure 4.6.1 Cylinder gas temperature Vs. Crank angle for idle condition

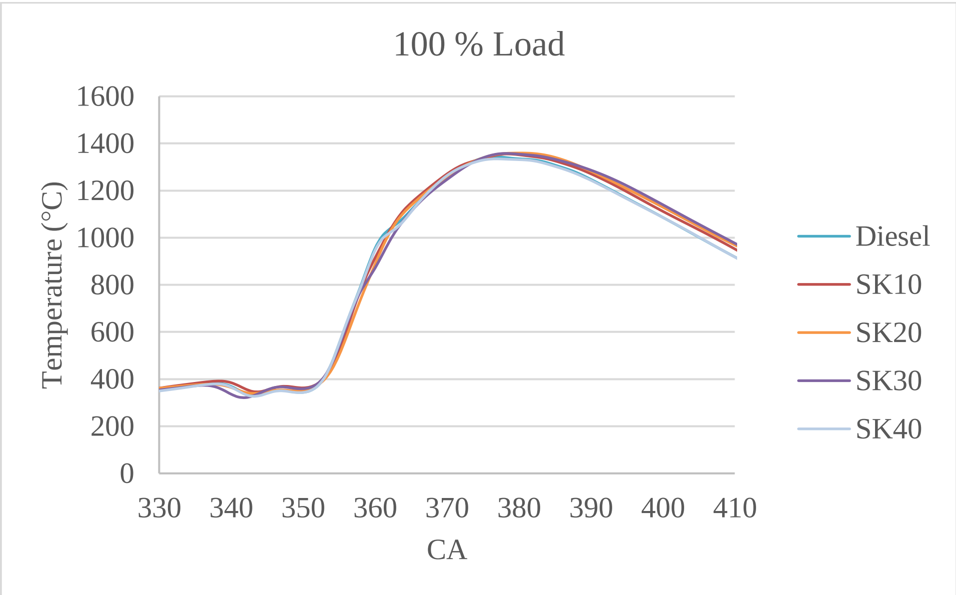

Figure 4.6.2 Cylinder mean gas temperature Vs. Crank angle for 100% Load

The maximum gas temperature is calculated by the integrated ICEngine Software based on in-cylinder pressure and rate of pressure rise data. The maximum temperature is observed in case of SK20, which nearly 3% and 2% higher is for idle and 100% loading condition respectively in comparison of diesel reference fuel. The SK40 blend is having drop of approximately 2% and 0.8% for idle and 100% load respectively. The mean gas temperature of SK10 and SK30 is between to that of SK20 and diesel reference fuel

Table 4.6.1 Maximum gas temperature of various blend with CA

	Idle					Full Load				
Fuel	Diesel	SK10	SK20	SK30	SK40	Diesel	SK10	SK20	SK30	SK40
CA for Max. Temp.	3767	377	377	377	376	377	378	380	378	377
Max Temp. (Degree C)	829	845	853	834	811	1343	1355	1359	1357	1334

4.7 NET HEAT RELEASE RATE

Fig 4.7.1, 4.7.2 represents the change for rate of heat release with respect to crank angle position and effect due to blending. The maximum heat release in J/deg of crank angle is observed few degrees before reaching top dead center. For increasing the load percentage on the engine the maximum heat release rate also increases due to burning of more charge as well as the peak location is observed few more degrees before reaching the top dead center.

The table 4.5.2 shows the maximum heat release rate with respect to crank angle for various blends of fuel. The maximum HRR (J/°C) is observed in case of SK20 blend with 7% and 6% higher HRR for idle and 100% loading condition respectively than the base reference diesel fuel. SK10 and SK30 variation is in-between the SK20 and diesel observations. The SK40 is having drop of nearly 0.2% and 5% for idle and 100% load condition.

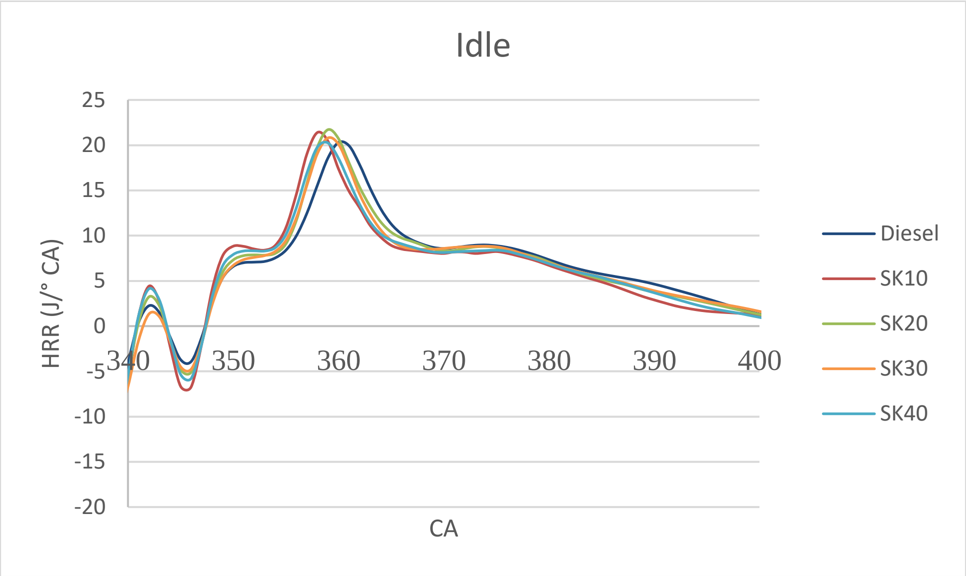

Figure 4.7.1 Net Heat Release rate Vs. Crank angle for idle condition

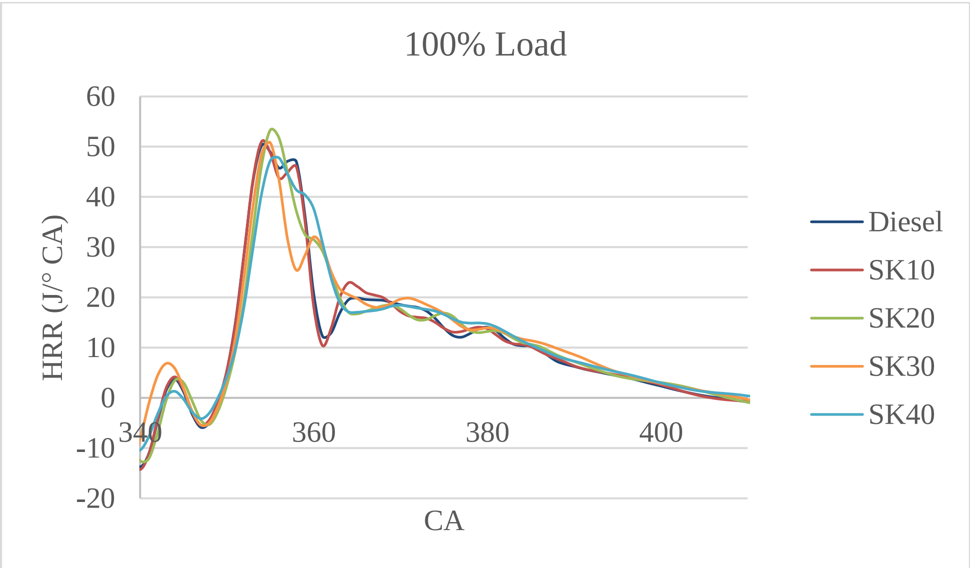

Figure 4.7.2 Net Heat Release rate Vs. Crank angle for 100% load

Table 4.7.1 Max HRR of various blend with CA

	Idle					Full Load				
Fuel	Diesel	SK10	SK20	SK30	SK40	Diesel	SK10	SK20	SK30	SK40
Crank Angle for Max HRR	360	358	359	359	359	354	354	355	355	356
Max HRR (J/deg)	20.29	21.4	21.71	20.8	20.25	50.22	51.01	53.32	50.77	47.76

CHAPTER 5

CONCLUSION

The following findings were from an experimental investigation of four-stroke single-cylinder diesel engines fitted with an eddy current dynamometer and running on several synthetic kerosene blends at rated 1500 rpm and under various load circumstances ranging from 0% to 100%.

- Minimum BSFC is observed at load of 60% - 70% engine load. SK20 blend achieved minimum BSFC which is approximately 7.5% lower than the diesel fuel. For blends of SK10, SK30 it is in between of SK20 and diesel fuel. For SK40 there is increase of 3% at minimum BSFC load condition which is range of 60% - 70%
- At loads percentage higher than 70%, slightly increase in specific fuel consumption is observed for all blends due to richer fuel mixture at higher loads, leading to incomplete combustion of some portion of charge
- Maximum brake thermal efficiency is observed in range of 60% - 70% of engine for all blends. SK20 is having maximum BTE, approximately 5.5% higher than diesel reference fuel. For blends S10, SK30 it is in-between SK20 and diesel. For SK40 blends there is drop in BTE in comparison to diesel fuel and a drop of nearly 4% is observed.
- At loads percentage higher than 70%, slightly drop in brake thermal efficiency is observed for all blends due to richer fuel mixture at higher loads, leading to incomplete combustion of some portion of charge.
- . Exhaust gas temperature rises as load rises, and as, bigger loads require more fuel, which must be burned in order to provide more power synthetic kerosene blends is seen to be slightly higher because of better combustion due to presence of oxygenates. Further blending of SK leads to lower exhaust temperature due to lower calorific value of SK fuel.
- Maximum peak pressure is achieved in case of SK20 blend, approximately 3.5% higher than diesel for the idle condition and 1.75% higher for 100% loading condition. The percentage change for SK10, SK30 is in-between to SK20 and diesel fuel. For SK40 blend, drop of 1.7% for idle and 0.5% for 100% loading condition is observed with respect to base line diesel fuel.

- Maximum rate of pressure rise (RPP) is observed in case of SK20 blending which is approximately 7%, 6.5% higher than the diesel reference fuel data for idle and 100% loading conditions. Higher percentage blending of synthetic kerosene results in drop of rate of pressure rise for all loading conditions and drop of 9%, 3.5% is observed for idle and maximum loading condition in present study.
- The maximum gas temperature is observed in case of SK20, which nearly 3% and 2% higher is for idle and 100% loading condition respectively in comparison of diesel reference fuel. The SK40 blend is having drop of approximately 2% and 0.8% for idle and 100% load respectively. The mean gas temperature of SK10 and SK30 is between to that of SK20 and diesel reference fuel
- The maximum HRR (J/°C) is observed in case of SK20 blend with 7% and 6% higher HRR for idle and 100% loading condition respectively than the base reference diesel fuel. SK10 and SK30 variation is in-between the SK20 and diesel observations. The SK40 is having drop of nearly 0.2% and 5% for idle and 100% load condition.

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