

EFFECT OF AMYL ALCOHOL ADDITION IN A CI ENGINE WITH JATROPHA OIL

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Engineering degree in
Mechanical Engineering

By

VISWAJITH B PILLAI (Reg. No. 40150049)

MADESH (Reg. No. 40150023)



DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with grade “A++” by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI – 600119

APRIL 2024



SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited "A++" Grade by NAAC | 12B Status by UGC | Approved by AICTE

www.sathyabama.ac.in

DEPARTMENT OF MECHANICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of MADESH (Reg. No. 40150023) and VISWAJITH B PILLAI (Reg. No. 40150049) who carried out the project entitled "EFFECT OF AMYL ALCOHOL ADDITION IN A CI ENGINE WITH JATHROPA OIL" under our supervision from December 2023 to April 2024.

Internal Guide

Dr. S.P. VENKATESAN., M.E., Ph.D.

Head of the Department

Dr. S. GANESAN., M.E., Ph.D.

Submitted for Viva voce Examination held on 06/04/2024

Internal Examiner
External Examiner

DECLARATION

We MADESH (Reg. No. 40150023) and VISWAJITH B PILLAI (Reg. No. 40150049) hereby declare that the Project Report entitled **"EFFECT OF AMYL ALCOHOL ADDITION IN A CI ENGINE WITH JATHROPA OIL"** done by us under the guidance of **Dr. S.P. VENKATESAN., M.E., Ph.D.,** is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Mechanical Engineering.

1. 

-MADESH

2. 

- VISWAJITH B. PILLAI

DATE: 02/04/24

PLACE: CHENNAI

SIGNATURE OF THE CANDIDATES

ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to Board of Management of **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY** for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

I convey my sincere thanks to **Dr. S. GANESAN, M.E., Ph.D.**, Head of the Department, Department of Mechanical Engineering for providing me necessary support and details at the right time during the progressive reviews.

I would like to express my sincere and deep sense of gratitude to my Project Guide **Dr. S.P. VENKATESAN., M.E., Ph.D.**, for his valuable guidance, suggestions, and constant encouragement paved way for the successful completion of my project work.

I also express my thanks to all Teaching and Non-teaching staff members of the Department of Mechanical Engineering who were helpful in many ways for the completion of the project.

ABSTRACT

The utilization of renewable and sustainable biofuels in internal combustion (IC) engines has gained significant attention in recent years as an environmentally responsible alternative to conventional fossil fuels. Jatropha oil, derived from the seeds of the Jatropha plant, is one such biofuel with potential as a replacement for diesel fuel due to its favourable properties and reduced greenhouse gas emissions. However, Jatropha oil faces challenges related to its combustion characteristics, such as poor ignition, high viscosity, and low cetane number, which can adversely impact engine performance.

This study investigates the potential of amyl alcohol as an additive to enhance the performance and emissions characteristics of a compression-ignition (CI) engine running on Jatropha oil. Amyl alcohol, known for its high cetane number and oxygen content, is expected to improve the combustion efficiency of Jatropha oil, leading to reduced emissions and enhanced engine stability. A series of experiments were conducted in a single-cylinder CI engine, comparing the combustion and emissions behaviour of pure Jatropha oil with Jatropha oil blended with varying proportions of amyl alcohol.

Preliminary results indicate that the addition of amyl alcohol to Jatropha oil has a significant impact on engine performance. The improvement in ignition delay, combustion stability, and reduced emissions of nitrogen oxides (NO_x) and particulate matter (PM) are observed with increasing amyl alcohol content. Additionally, the fuel system and engine modifications required for optimal combustion with the Jatropha oil-amyl alcohol blend are discussed.

This study contributes to the understanding of how amyl alcohol can be used as an effective additive to enhance the combustion properties of Jatropha oil in CI engines, thus making it a more viable and sustainable alternative to conventional diesel fuel. The findings of this research offer valuable insights for the development and utilization of Jatropha oil-based biofuels in CI engines, with the potential to reduce the environmental impact and dependence on fossil fuels.

TABLE OF CONTENTS

CHAPTER NO.	TITLE	PAGE NO.
	ABSTRACT	i
	LIST OF FIGURES	iv
	LIST OF TABLES	v
1	INTRODUCTION	1
	1.1 Fossil Fuels and Biodiesel	1
	1.2 Importance of Alternative Fuels	2
	1.3 Revolution of Biodiesel	3
	1.4 Merits and Demerits of Biodiesel	4
	1.5 Introduction to CI Engine	5
	1.6 Introduction to Jatropha Oil	6
	1.7 Jatropha as a Potential Biodiesel Feedstock	7
2	LITERATURE SURVEY	9
3	AIM AND SCOPE	15
	3.1 Aim of the Project	15
	3.2 Scope of the Project	15
4	MATERIALS AND EXPERIMENTAL METHODS	17
	4.1 Methodology	17
	4.2 Materials Used	17
	4.2.1 Jatropha Seeds	17
	4.2.1.1 Extraction of Oil	19
	4.2.2 Amyl Alcohol	20
	4.3 Experimental Setup	22
	4.3.1 Transesterification Setup	22
	4.3.2 Bomb Calorimeter	22
	4.3.3 Kinematic Viscometer Bath	23
	4.3.4 Pensky Martens Flash Point Apparatus	23
	4.3.5 Bulk Density Test Apparatus	24
	4.3.6 CI Diesel Engine	24
	4.3.7 Engine Testing Software	26

	4.3.8 Smoke Opacity Meter	26
	4.3.9 Exhaust Gas Analyzer	27
5	RESULTS AND DISCUSSION	28
	5.1 Results	28
	5.2 Properties of Jatropha Oil	28
	5.2.1 Kinematic Viscosity	28
	5.2.2 Flash Point	28
	5.2.3 Fire Point	29
	5.2.4 Calorific Value	29
	5.2.5 Acidic Value	29
	5.3 Blend Proportion of Biodiesel	30
	5.4 Performance Characteristics	31
	5.4.1 Variation of BSFC vs BP	31
	5.4.2 Variation of BTE vs BP	33
	5.5 Emission Characteristics	34
	5.5.1 Variation of HC vs BP	34
	5.5.2 Variation of CO vs BP	36
	5.5.3 Variation of NO _x vs BP	37
	5.5.4 Variation of CO ₂ vs BP	39
	5.5.5 Variation of O ₂ vs BP	41
6	SUMMARY AND CONCLUSION	43
	6.1 Summary	43
	6.2 Conclusion	44
	REFERENCES	46
	APPENDIX	

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE NO.
4.1	Methodology	17
4.2	Jatropha Seeds	18
4.3	Wood Press Oil Machine	19
4.4	Amyl Alcohol	21
4.5	CI Diesel Engine	25
4.6	Smoke Opacity Meter	27
4.7	Exhaust Gas Analyser	27
5.1	Biodiesel Blends B15, B20, B25	31
5.2	Specific Fuel Consumption (SFC) of Biodiesel blends and diesel	32
5.3	Brake thermal Efficiency of Biodiesel blends and diesel	34
5.4	Hydrocarbon Emissions of Biodiesel blends and diesel	35
5.5	Carbon Monoxide (CO) emission of Biodiesel blends and diesel	37
5.6	NO _x Emission of Biodiesel blends and diesel	39
5.7	CO ₂ Emission of Biodiesel blends and diesel	40
5.8	Variation of O ₂ vs BP values of Biodiesel blends and diesel	42

LIST OF TABLES

TABLE NO.	TITLE	PAGE NO.
5.1	Transesterification of Jatropha Oil	28
5.2	Properties of Jatropha Biodiesel	30
5.3	Blend Proportions of Biodiesels	30
5.4	BSFC Values of Biodiesel blends and diesel	32
5.5	Brake Thermal Efficiency (BTE) values of Biodiesel blends and diesel	33
5.6	Hydrocarbon Emissions of Biodiesel blends and diesel	35
5.7	Carbon Monoxide (CO) emission of Biodiesel blends and diesel	36
5.8	NO _x Emissions of Biodiesel blends and diesel	38
5.9	Carbon Dioxide (CO ₂) Emissions of Biodiesel blends and diesel	40
5.10	Variation of O ₂ vs BP Values	41

CHAPTER 1

INTRODUCTION

1.1 FOSSIL FUELS AND BIODIESEL

Two different but related facets of the global energy scene are fossil fuels and biodiesel. Fossil fuels, including coal, oil, and natural gas, have long been the main energy sources used for home, commercial, and transportation applications. However, using them has serious negative effects on the environment, including as contributing to climate change, air and water pollution, and greenhouse gas emissions. Fossil fuels are still the most popular source of energy in the world because of their accessibility, low cost, and well-established infrastructure, even with these disadvantages. However, there is a need to find alternative energy sources, and biodiesel is one of them, due to rising worries about climate change and the limited nature of fossil fuel stocks.

An environmentally friendly fuel made from organic elements like algae, animal fats, and vegetable oils is called biodiesel. It is made by reacting these feedstocks with alcohol in a procedure known as transesterification, which yields glycerin and biodiesel. With less emissions of sulfur oxides, carbon monoxide, and particulate matter, biodiesel is a cleaner fuel that may be used either alone or in combination with regular diesel.

The ability of biodiesel to reduce greenhouse gas emissions is one of its main benefits. A closed carbon cycle is created when carbon dioxide is taken up by the plants that generate the feedstocks through photosynthesis, while burning biodiesel releases carbon dioxide into the environment. This contrasts with fossil fuels, which contribute to the greenhouse effect by releasing carbon into the atmosphere after burning that has been stored underground for millions of years.

Additionally, by creating new markets for agricultural products and lowering reliance on imported oil, the manufacturing of biodiesel can boost rural economies. Additionally, by lowering reliance on limited fossil fuel supplies, which are vulnerable to price volatility and geopolitical uncertainty, it can aid in diversifying energy sources and improving energy security.

1.2 IMPORTANCE OF ALTERNATIVE FUELS

To solve urgent global issues including environmental degradation, climate change, energy security, and economic stability, alternative fuels are essential. When compared to conventional fossil fuels, these fuels—which include a wide range of renewable and low-carbon options—offer several advantages that spur innovation, sustainability, and resilience in the energy industry.

Above all, compared to traditional fossil fuels, alternative fuels drastically cut down on air pollution and greenhouse gas emissions. Renewable resources including sunshine, wind, water, biomass, and geothermal heat are used to create alternative fuels, which provide more sustainable and clean energy sources. By lowering the emission of dangerous pollutants including carbon dioxide, nitrogen oxides, sulfur dioxide, and particulate matter, this helps to mitigate climate change, improve air quality, and safeguard human health.

Furthermore, by lowering reliance on limited and politically sensitive fossil fuel deposits, alternative fuels improve energy security and diversity. Countries can lessen their susceptibility to supply interruptions, price volatility, and geopolitical conflicts related to the mining and transportation of fossil fuels by utilizing locally accessible renewable resources. This supports national security and economic stability by improving energy independence and resilience.

In addition, the production and uptake of alternative fuels stimulate economic expansion and technical advancement, which in turn promotes investment, entrepreneurship, and the creation of jobs in a variety of industries. The renewable energy sector, which includes hydrogen, solar, wind, bioenergy, and bioenergy, has grown quickly and seen cost reductions, making it more and more competitive with traditional fossil fuels. This increases industrial competitiveness, boosts economic development, draws investment, and produces job possibilities.

Because they preserve ecosystems, limit environmental damage from fossil fuel extraction, processing, and burning, and save natural resources, alternative fuels

also support sustainable development and environmental stewardship. Societies may move toward more resilient and regenerative energy systems that fulfil present requirements without jeopardizing the ability of future generations to meet their own needs by utilizing renewable energy sources and sustainable behaviours.

1.3 REVOLUTION OF BIODIESEL

The biodiesel revolution is a game-changer for the global energy scene because it provides a sustainable substitute for fossil fuels while tackling social, economic, and environmental issues. Produced from organic renewable resources including algae, vegetable and animal fats, and oils, biodiesel has shown great promise in reducing greenhouse gas emissions, improving energy security, and fostering rural development.

The promise of biodiesel to reduce greenhouse gas emissions and combat climate change has driven the revolution in the fuel industry. In contrast to fossil fuels, which release carbon dioxide that has been stored underground for millions of years, biodiesel closes the carbon cycle. The plants used to make biodiesel efficiently offset the emissions emitted while burning by taking up CO₂ from the atmosphere during growing. for the reason that it is carbon neutral.

Additionally, the production of biodiesel supports energy security and independence by diversifying the energy mix and reducing reliance on foreign oil. By utilizing locally available feedstocks, biodiesel reduces vulnerability to supply disruptions, price volatility, and geopolitical issues associated with the importation of fossil fuels. This supports economic stability and security by strengthening national energy sovereignty and resilience.

Furthermore, by opening new markets for commodities and agricultural waste, the biodiesel revolution boosts the agricultural and rural economies. Producing biodiesel gives farmers the chance to increase agricultural output, optimize land usage, and diversify their sources of revenue. Additionally, by encouraging

entrepreneurship and value-added agricultural practices, it revitalizes rural areas, creates jobs, and lowers poverty.

In addition, the biodiesel business has experienced rapid expansion due to regulatory backing and technological improvements, which has increased its competitiveness with traditional diesel fuel. Biodiesel manufacturing is now more efficient, affordable, and scalable because to advancements in feedstock production, conversion technology, and distribution infrastructure. Furthermore, market incentives and regulatory certainty for biodiesel adoption have been provided by government mandates, incentives, and sustainability requirements. In summary, the biodiesel revolution signifies a paradigm change toward a future in energy that is more robust, sustainable, and equal. Biodiesel provides a multidimensional response to the intricate problems confronting the global energy sector by lowering greenhouse gas emissions, improving energy security, encouraging rural development, and spurring technical advancement.

1.4 MERITS AND DEMERITS OF BIODIESEL

Compared to traditional diesel fuel, biodiesel is a cleaner and more sustainable fuel with several advantages. First and foremost, as compared to conventional diesel, biodiesel produces much fewer greenhouse gas emissions, contributing to the mitigation of climate change and improvement of air quality. By broadening the energy mix and lowering reliance on imported fossil fuels, its production from renewable organic sources also improves resilience against supply interruptions and price changes, so contributing to energy security. Furthermore, biodiesel promotes rural development by expanding the markets for agricultural byproducts and wastes, producing jobs, and enhancing living standards in farming communities. Furthermore, the fact that it is non-toxic and biodegradable helps to lessen the negative effects of gasoline spills on soil and water ecosystems as well as environmental pollution. Finally, the compatibility of biodiesel with current diesel engines, requiring little to no change.

Not with standing its advantages, biodiesel has several drawbacks that should be considered. The development of feedstock crops for biodiesel may put food

production in competition, which might result in habitat damage, deforestation, and volatile food prices. Energy intensity can be a result of intensive agricultural techniques and a dependence on fossil fuels for transportation, processing, and production. This lowers total energy efficiency. Furthermore, if food crops are utilized as fuel in underdeveloped nations, the rising demand for biodiesel feedstocks might take resources away from food production, worsening food insecurity and inequality. Furthermore, biodiesel may function less well in cold weather than traditional diesel due to its higher cloud point and gelling problems; in these cases, additives or blending with petroleum diesel may be necessary.

1.5 INTRODUCTION TO CI ENGINE

An internal combustion engine that runs on the theory of compressing air to a high enough temperature to ignite fuel without the need for an external spark is called a compression ignition (CI) engine, also referred to as a diesel engine. The main distinction that sets CI engines apart from Spark Ignition (SI) engines—like gasoline engines—is this basic difference.

Air is pulled into the combustion chamber during the intake stroke, which starts a CI engine's functioning. CI engines just intake air during this stage, in contrast to SI engines, which combine fuel and air before to intake. The compression stroke causes the piston to rise, compressing the air to a high temperature and pressure. Fuel injectors enable the direct injection of fuel into the combustion chamber in the form of a finely atomized mist at the peak of the compression stroke. The power stroke is started when the fuel ignites on its own because to the high temperature and pressure of the compressed air. Gases expand quickly, pushing the piston down and producing mechanical work that turns the crankshaft.

Compared to SI engines, CI engines have several benefits. Because of their greater compression ratios, which enable more thorough fuel burning, they are usually more fuel-efficient. Because of their increased efficiency, CI engines consume less gasoline and have a better thermal efficiency, which makes them ideal for heavy-duty vehicles like trucks, buses, and industrial machines. Furthermore, CI engines have a higher torque output at lower speeds, which makes them ideal for tasks needing a lot of pulling force, such hauling and towing.

CI engines do, however, also come with certain restrictions and difficulties. Compared to SI engines, they often create greater amounts of nitrogen oxides (NO_x) and particulate matter, necessitating the use of extra pollution control systems such as diesel particulate filters (DPF) and exhaust gas recirculation (EGR). Furthermore, because CI engines operate at greater pressures and temperatures, they can be more complicated, costly to construct, and require more frequent maintenance. Notwithstanding these difficulties, CI engines continue to be an essential and popular technology that power a broad variety of cars and machinery in several sectors.

1.6 INTRODUCTION TO JATROPHA OIL

Originating from the seeds of the *Jatropha curcas* plant, jatropha oil is a useful and adaptable vegetable oil with a wide range of industrial, agricultural, and biofuel uses. *Jatropha curcas* is a robust, drought-resistant shrub that is native to Central America. It is a potential option for cultivation in semi-arid areas where conventional crops struggle to grow since it thrives in dry and marginal environments.

The seeds of the *Jatropha curcas* plant, which contain between 30 and 40 percent oil by weight, are used to produce jatropha oil. Good-quality, pale yellow oil with a little nutty taste is produced by the usual solvent extraction or mechanical pressing procedures used in the oil extraction process. Due to its high triglyceride content, which mostly consists of oleic, linoleic, and palmitic acid, this oil may be used in a wide range of commercial and industrial settings.

Jatropha oil is primarily used as a feedstock for the manufacturing of biodiesel. With less greenhouse gas emissions and less reliance on fossil fuels, biodiesel made from Jatropha oil provides a sustainable and greener fuel option than regular diesel. Jatropha biodiesel is a practical and affordable solution for lowering carbon emissions in the transportation industry and other fields since it can be used as a drop-in substitute for diesel fuel in current engines with little to no modification.

Because of its high fatty acid content and superior emollient qualities, Jatropha oil is used in the manufacturing of soaps, detergents, cosmetics, and lubricants in addition to biodiesel. Additionally, Jatropha oil cake, a byproduct of oil extraction, is rich in protein and other elements and works well as an organic fertilizer and animal feed additive. By giving farmers new revenue streams and enhancing soil fertility and crop yield in agroecosystems, this dual-use strategy optimizes the economic feasibility and sustainability of Jatropha farming.

The jatropha oil is a flexible and sustainable resource that has a great deal of potential to support environmental sustainability, economic growth, and energy security. Jatropha oil presents a possible route towards a more robust and sustainable energy future through its usage in the manufacturing of biodiesel as well as several industrial and agricultural uses. To fully realize the potential of Jatropha oil and encourage its broad use.

1.7 JATROPHA AS A POTENTIAL BIODIESEL FEEDSTOCK

Jatropha (*Jatropha curcas*) is a highly promising feedstock for biodiesel because of its exceptional qualities and capacity to adapt to a wide range of environmental circumstances. Jatropha seeds have a high oil content of between 30% and 40%, making them a promising crop for large-scale biodiesel manufacturing. Because of its availability, oil is a renewable and ecologically friendly answer to today's energy problems, making it a desirable substitute for traditional diesel made from fossil fuels. Jatropha is unique in that it can grow on marginal places where typical food crops cannot, such as desert and semi-arid climates. This feature not only reduces rivalry with food production but also makes it possible to grow Jatropha in regions where agricultural activity is normally restricted, so helping to the utilization of underutilized land resources for energy production.

Furthermore, jatropha is a hardy and low-maintenance crop that needs little in the way of pesticides, fertilizer, and water. Because of its hardiness and resilience to adverse weather, it is a good choice for cultivation in areas with little infrastructure and resources. Additionally, by encouraging soil protection, reforestation, and

biodiversity preservation in degraded or marginal sites, jatropha farming can offer additional environmental advantages. Jatropha farming supports environmentally sound land management techniques by improving soil fertility and restoring ecosystem services.

While jatropha has great potential as a feedstock for biodiesel, there are a number of issues that need to be resolved in order to realize this potential, including poor seed yields, variable oil quality, and the need for better cultivation and processing methods. The key to overcoming these obstacles and increasing Jatropha production for biodiesel on a commercial scale is research, investment, and legislative backing. Notwithstanding these obstacles, Jatropha continues to be a feasible and encouraging choice for improving energy security, diversifying the energy mix, and reducing the negative environmental effects of using fossil fuels.

CHAPTER 2

LITERATURE SURVEY

(Vallinayagam et. al., 2014) In an effort to maximize the renewable energy source from plant-based bio-oil, pine oil, this study has started, with the goal of optimizing its usage in a diesel engine. Because the feedstock is made from the oleoresins of pine trees, it has a lower boiling point and viscosity, which allows it to burn without affecting the engine performance characteristics caused by ignition promoters. Brake specific fuel consumption, or BSFC, is (a). (b) Brake Thermal Efficiency, or BTE. Engine emission metrics impacted by ignition promoters. (a) Nitrogen oxides, or NOX. (b) Tobacco. (c) Carbon monoxide, or CO. (d) Hydrocarbons (HC) more thoroughly and with less emissions.

In a diesel engine, the experimental examination of 50D:50B shows that the BTE and peak heat release rate are greater than in diesel, and there is a noticeable decrease in the emissions of CO, HC, and smoke. However, because of the lower cetane number of 50D:50B, it was noticed that the NOX emission was greater than that of diesel. Ignition enhancers (IAN and DTBP) have been used to boost ignition in a diesel engine without any changes in order to lower NOX emission and shorten the ignition delay. Better ignition has resulted from the inclusion of IAN and DTBP, and as a result of the decreased peak heat release rate, the NOX emissions for 50D:50B-IAN and 50D:50B-DTBP were, respectively, 12.8% and 19.2% lower than those for 50D:50B. Apart from NOX emissions, the final disposition also included reductions of 40% and 34% in CO and HC emissions for 50D:50B-DTBP compared to 50D:50B, and an improvement in BTE and BSFC under full load conditions. Overall, the experimental research using additives that promote ignition has amply demonstrated the potential of pine oil biofuel as one of the alternative fuel sources.

(Alpaslan Atmanli, 2016) Engine characteristics were assessed for the microemulsion fuels with EHN and compared to the baseline microemulsion fuels (DnBH and DPnH). Engine characteristics included change in braking power, BSFC, BTE, NOx, HC, and CO with regard to 0%, 30%, 60%, 90%, and 100% load at a constant engine speed of 2200 rpm. In terms of engine performance and emission

characteristics, the test findings from this study were compared and discussed for diesel microemulsion fuels with and without EHN. Because of the reduced in-cylinder temperature, decreased oxygen concentration, and fuel-rich zones inside the cylinder, there was a decrease in the oxidation of carbon atoms and oxygen molecules, resulting in an increase in CO emissions. Oxygenated fuels such as vegetable oil and biodiesel often reduce greenhouse gas emissions.

Fuels with a lower heating value and BSFC work together to determine BTE. Lower heating values in microemulsion blends are caused by higher oxygen levels. Because microemulsion fuels include more oxygen, they have a lower calorific value. The breakdown of nitrate molecules in EHN during combustion can be used to explain the rise in cetane number. This process produces free radicals, which accelerate fuel degradation.

(Omar et. al.,2016) An investigation and comparison between pure diesel and fusel oil diesel F20 (20%vol ÷ 80%vol diesel) blend was conducted on the performance, emissions, and combustion of a CI engine. Consequently, it was shown that the physicochemical characteristics of the blends, including density, calorific value, cetane number, water content, C/H ratio, and oxygen content, were altered when fusel oil was added to diesel fuel. Based on the findings of the above investigation, the subsequent deductions were made. The high moisture content and low cetane number of F20 caused a modest loss in engine power and torque at low speeds when compared to pure diesel.

When comparing pure diesel to F20, the ISFC improved by 8% on average. Fusel oil was used, which resulted in a modest drop in in-cylinder temperatures and pressures. The oxygen and moisture levels in fusel oil may be to blame for this. Compared to diesel, F20 had a greater energy release rate. The energy release rate peak locations for F20 were found at 2400 rpm and 75% load. F20 had a longer ignition delay at all speeds and loads than pure diesel because of its lower cetane number and greater latent heat of vaporization.

At all loads and speeds, the NO_x emission fell; at 1500 rpm, the highest reductions were 20% and 25% at 50% and 75% engine loads, respectively. As engine loads and speeds increased, so did the CO₂ emissions. Moreover, an increase in CO₂

emissions of around 3e10% for F20 compared to diesel was seen at an average speed of 1800 rpm. When F20 was employed, there was an increase in CO emissions; on average, there was an increase of 35% and 20% at 50% and 75% engine loads, respectively.

(Sunil Kumar et. al.,2012) With JME blended diesel, the experimental study demonstrates reduced BTE, greater BSFC, and exhaust temperature. The enhanced heat release rate resulting from higher SFC is responsible for the higher exhaust temperature of JME blends. The combustion chamber may get heated as a result of the elevated exhaust gas temperature, adding stress to the engine's cooling and lubricating systems. This might increase the engine's need for coolant and lubrication oil. Fuel injection may explode as a result of elevated combustion chamber temperature. Therefore, more field testing in warm climates is needed to validate the efficacy of JME mixes containing petro-diesel. Lower JME calorific value relative to diesel fuel is the cause of higher BSFC for fuels B5, B10, B20, B50, and B100.

Reduced emissions of HC, CO₂, and CO₂ while using JME mixed with diesel is a benefit associated with reduced regulatory emissions. Adoption of biodiesel may be hampered by smoke opacity given strict emission standards. The maximum amount of JME to diesel mix should be limited to 20% based on the equivalent BSFC and BTE of B20 compared to diesel, lower regulatory emissions, and less noise and vibrations found for B20 fuel. When compared to diesel, biodiesel emits a considerable fraction of less greenhouse gases. The primary causes have been identified as the increased oxygen content, advancements in biodiesel injection and combustion, and a decrease in aromatic chemicals. When utilizing biodiesel, NO_x emissions rise mostly because to the increased cetane number for biodiesel and oxygen concentration.

(Narayana Reddy and Ramesh, 2005) To make up for the longer ignition delay in the case of Jatropha oil, the injection timing must be advanced in comparison to base diesel operation. More advanced injection timing results in a longer ignition delay and a more noticeable premixed portion, which is the first stage of combustion. At full load, advancing the injection time by 31 crank angle (to 33.51bTDC) produced

the following benefits: J Brake thermal efficiency rises to 27.3% from 25.7%. J decrease in HC concentration from 2350 to 2068 ppm J Smoke level dropped from 3.9BSU to 3.3BSU. Performance and emissions were significantly improved by raising the injector opening pressure (IOP) from the rated value for diesel (205 bar) to 220 bar. BMEP (bar) Pressure Rise Rate (bar/degree) 7 mm, 8 mm, and 9 mm diesel fluctuation in the pressure rising rate. BMEP (bar) Maximum Pressure in Bars 8 mm, 9 mm, and 7 mm Diesel. peak pressure variation.

Jatropha oil since it forms sprays more effectively. At full output, the following modifications were observed at a static injection time of 321bTDC: J Brake heat efficiency rises to 28.9% from 26.2% J HC falls to 1638 ppm J. Smoke level dropped to 2.1 BSU from 3.6 BSU. An increase in the IOP was also associated with improvements in the heat release characteristics and a decrease in the ignition delay. When the IOP changes from 205 to 220 bar, the peak heat release rate rises from 39 to 62 J/ 1CA.

(Saaho et al., 2005) Transterification, or methanolysis, and mixing methyl ester with diesel reduced the high viscosity of the Jatropha curcas oil, which has been explored as a possible substitute fuel for the diesel engine. Three test fuels of neat diesel were created, examined, and contrasted with diesel fuel. These fuels included blends of 20% volume (B20) of jatropha oil methyl ester (JOME) with diesel and plain JOME (B100). The engine's performance and exhaust emissions while utilizing a 20% JOME mix In a single-cylinder C.I. engine, JOME was tested with diesel and neat, and the results were compared with the diesel's performance. When engine performance was compared to biodiesel alone, a notable improvement was seen.

The decrease in the viscosity of the biodiesel led to a drop in both the specific fuel consumption and the exhaust gas temperature. With tidy JOME (100% volume of JOME), the engine's thermal efficiency were achieved to an acceptable level. The behavior of exhaust emissions was environmentally beneficial. It has been determined from the characteristics and engine test results that diesel can be completely replaced with 100% jatropha oil methyl ester without modifying the engine.

(Pradhan et al., 2014) By heating CJO (crude Jatropha oil) with the heat from exhaust gas from a diesel engine and a specially made helical coil heat exchanger, the oil's viscosity and density were decreased. Using PJO (preheated Jatropha oil), experiments were carried out to assess the combustion characteristics of a DI (direct injection) diesel engine. For all engine loadings, it showed slightly greater cylinder gas pressure, pressure increase rate, and heat release rate in the early phases of combustion than HSD (high speed diesel). The PJO had a lower ignition delay than the HSD. Additionally, according to the data, while comparing PJO to HSD, BSFC (brake specific fuel consumption) and EGT (exhaust gas temperature) increased while BTE (brake thermal efficiency) declined. PJO was shown to have higher CO (carbon monoxide) emissions in comparison to HSD, coupled with decreases in CO₂, HC (hydrocarbon), and NO_x (nitrous oxide) emissions.

(Mustafa and Samet, 2020) The effects of gasoline/i-amyl alcohol fuel mixes on the performance and emissions of spark ignition (SI) engines were examined experimentally, forecasted by an artificial neural network (ANN), and optimized using response surface methodology (RSM). Fuel mixtures including gasoline and isoamyl alcohol (iso-pentanol) in varying proportions were used to run the test engine at varied engine speeds and compression ratios (CR). An artificial neural network (ANN) model, an application of artificial intelligence (AI), has been designed to estimate outputs such as braking the engine speed (rpm), fuel blending ratio (by vol.%), mean effective pressure (BMEP), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), nitrogen oxides (NO_x), hydrocarbon emission (HC), and carbon monoxide (CO) based on CR. RSM was also used to determine the best engine operating conditions.

The results show that the engine performance and emission parameters may be estimated by the ANN model using a correlation coefficient (R²) between 0.94 and 0.99. When compared to test results, the maximum mean relative error (MRE) is seen to be less than 7%. The RSM investigation showed that the ideal engine operating conditions are an i-AA ratio of 15% at 8.31 CR and 2957.58 rpm engine speed. It was discovered that the ANN model with RSM assistance was a useful tool for forecasting and improving engine outputs with the least amount of testing.

(Ching et. al., 2011) The future renewable supply of non-edible oil for the manufacturing of biodiesel is jatropha oil. For the generation of biodiesel, an alkaline catalyst—like RDJO—is more suited if the jatropha oil's FFA level is less than 1%. A two-step transesterification procedure is a preferable option if the FFA concentration is greater than 1%. Nevertheless, there is an additional step needed, which would raise the cost of producing biodiesel. An excellent substitute for any chemically catalyzed transesterification of jatropha oil is the enzymatic method. However, for it to become a green and economically feasible process, it has to be optimized in a solvent-free system.

(Kywe and Mya, 2009) In a lab setting, biodiesel was made using jatropha oil, methanol, and ethanol. It was discovered that employing the following ideal process parameters—methanol to oil molar ratio of 6:1, NaOH 1%, reaction temperature at 65°C, and reaction duration of 60 minutes—maximum biodiesel yield of 76% was produced from FFA 22.6% in raw jatropha oil. By employing the ideal process parameters, such as an ethanol to oil molar ratio of 8:1, KOH 1%, a reaction temperature of room temperature, and a reaction duration of 5 hours, the highest biodiesel production of 73% from FFA 8.8% in raw jatropha oil was achieved. The molar ratios of ethanol to oil (8:1) and methanol to oil (6:1) were the ideal process conditions.

It is determined that because methanol is more reactive than ethanol, methanol must be added in greater amounts. The physical characteristics of biodiesel made from jatropha oil in the laboratory using methanol and ethanol were determined to be within the ASTM-specified limits. Chemical characteristics such as combined, free, and total glycerol were marginally over the ASTM-specified limit. The engine performance test yielded identical findings about the fuel consumption of petrodiesel and biodiesel derived from jatropha oil in a lab setting. The engine was run at 2240 rpm, producing 11.1 kW of power. The engine exhaust temperature when running on biodiesel was 469°C, whereas the engine exhaust temperature when running on petrodiesel was 473°C.

CHAPTER 3

AIM AND SCOPE

3.1 AIM OF THE PROJECT

This experimental study's objective is to assess the biodiesel made from Jatropha seed oil's performance and emission characteristics using a VCR diesel engine. The primary goal of this study is to use a combination of Jatropha oil and diesel to lower the emissions of the CI diesel engine. Utilizing alternative fuels lessens both the environmental effect and reliance on the import of crude oil. That is the project's goal.

3.2 SCOPE OF THE PROJECT

As the availability of petroleum products is steadily declining, there is an increasing need to produce biodiesel. Because petroleum products are not available everywhere, you can turn home oils into biodiesel. Additionally, biodiesel emits less pollutants than diesel, which lessens the climate effect—currently the biggest worldwide issue. Biodiesel has garnered significant attention and acclaim in recent times as a sustainable and eco-friendly substitute for traditional diesel fuel. Owing to its extensive uses across several sectors, it is a great subject for a project report. Researchers studying biofuels are now experimenting with different mixing ratios and how single-chamber diesel engines work. Diesel and Jatropha oil are combined in one of the tests.

Three different oil blends are being tested: B15, B20, and B25. Fillers are being employed to lessen the need on fuel. Worldwide, vehicles and transportation systems consume a lot of vegetable oils. The depletion of petroleum supplies, rising energy needs, and growing concern about emissions that damage the ozone layer make biodiesel a viable option to consider. Certain places may not have easy access to conventional diesel fuel, thus nations are looking for conveniently accessible oils to utilize as biofuel. Vegetable, animal, or used cooking oil is combined with spirits (often methanol) to create biodiesel.

Diesel fuel is frequently replaced with bioenergy in engines, or it can be added to vehicles to cut emissions by 20% or more. Every step of the bioenergy production process must be optimized as the world's energy needs change and increase. This entails creating biotreatment facilities that are more effective and investigating biohydrogen as a potential energy source. It will be necessary to update and modify the current energy infrastructure for biomass power production to live up to its potential. In addition to articles on audits, cutting-edge research, analysis, and news pertaining to the bioenergy industry, Bio Energies provides a forum for conversation.

By replacing petroleum-based diesel with biodiesel, which is made from domestically generated plant oils or waste fats, one may lessen their reliance on foreign oil, cut their net greenhouse gas emissions, and boost the domestic economy in real ways. National, state, and municipal governments have adopted laws requiring the production and use of biodiesel or making it financially advantageous to do so due to the potential advantages of biodiesel. Future requirements and incentives seem inevitable given the finite supply of fossil fuels and the rising worldwide awareness of environmental issues. Production and consumption are the two primary areas into which biodiesel incentive schemes may be divided. The cost of biodiesel is reduced by both kinds of incentives, decreasing the price difference that presently prohibits its broad use. It seems likely that biodiesel will soon experience a major push in public policy that blends municipal, state, and federal regulations and incentives into a viable commercial opportunity.

CHAPTER 4

MATERIALS AND EXPERIMENTAL METHODS

4.1 METHODOLOGY

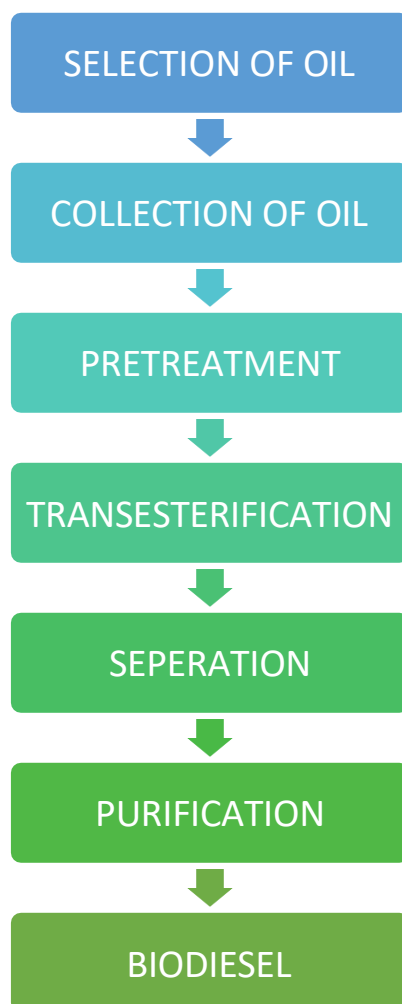


Fig. 4.1 Methodology

4.2 MATERIALS USED

4.2.1 Jatropha Seeds

The main source of Jatropha oil, an important and adaptable resource with a range of industrial, agricultural, and biofuel applications, is Jatropha seeds, which are derived from the Jatropha curcas plant. These seeds have a high oil content, usually between 30% and 40% by weight, which makes them a good feedstock for the generation of biodiesel. The oil-rich kernel inside of jatropha seeds is protected by

a tough outer shell. The seeds are smooth, oval or kidney-shaped, with an average length of 2 to 3 cm. Their sizes and shapes vary.

The seeds of the *Jatropha curcas* plant, which contain between 30 and 40 percent oil by weight, are used to produce jatropha oil. An excellent light-yellow oil with a little nutty taste is produced by the usual solvent extraction or mechanical pressing procedures used in the oil extraction process. Due to its high triglyceride content, which mostly consists of oleic acid, linoleic acid, and palmitic acid, this oil may be used in a wide range of commercial and industrial settings.

Jatropha oil is primarily used as a feedstock for the manufacturing of biodiesel. With less greenhouse gas emissions and less reliance on fossil fuels, biodiesel made from Jatropha oil provides a sustainable and greener fuel option than regular diesel. Jatropha biodiesel is a practical and affordable solution for lowering carbon emissions in the transportation industry and other fields since it can be used as a drop-in substitute for diesel fuel in current engines with little to no modification.



Fig. 4.2: Jatropha Seeds

Because of its high fatty acid content and superior emollient qualities, Jatropha oil is used in the manufacturing of soaps, detergents, cosmetics, and lubricants in addition to biodiesel. Additionally, Jatropha oil cake, a byproduct of oil extraction, is rich in protein and other elements and works well as an organic fertilizer and animal feed additive. By giving farmers new revenue streams and enhancing soil fertility

and crop yield in agroecosystems, this dual-use strategy optimizes the economic feasibility and sustainability of Jatropha farming.

The jatropha oil is a flexible and sustainable resource that has a great deal of potential to support environmental sustainability, economic growth, and energy security. Jatropha oil presents a possible route towards a more robust and sustainable energy future through its usage in the manufacturing of biodiesel as well as several industrial and agricultural uses. To fully realize the promise of jatropha oil and encourage its wider acceptance as a competitive substitute for fossil fuels, more research, funding, and legislative backing are needed.

4.2.1.1 Extraction of Oil

We remove contaminants like dirt, trash, and tiny twigs from the seeds once we have collected them. The seeds are meticulously picked apart from undesirable elements by hand. The seeds were cleaned, and then we spread them thinly on a clean surface to dry them out in the sun and lower their moisture content. We ground and pressed the seeds using a wooden press to obtain the oil when they had dried. Following the extraction of the oil, we use filter material to remove any suspended particles or contaminants, resulting in a high-quality product that may be used to make biodiesel. There are various phases involved in extracting oil from Jatropha seeds, which are typically carried out by hand or with the use of machinery.



Fig. 4.3: Wood Press Oil Machine

There are various procedures involved in getting *Jatropha* seeds ready for oil extraction. First, the seeds are hand- or machine-washed to get rid of debris and branches. Sieves and screens are also used for this purpose. The seeds are dried after washing to lower the moisture content and improve extraction effectiveness. Mechanical drying and solar drying are two types of drying techniques. The hard outer shell of the seeds is broken and the oil-containing kernel is released by crushing or grinding them after they have dried. Traditional mortar and pestle methods or more recent mechanical techniques like crushers can be used to accomplish this. The oil-bearing kernels are then subjected to pressing with mechanical presses in order to press out the oil. To increase clarity and shelf life, suspended particles and contaminants are filtered out of the extracted oil. Following filtering, the oil settles to remove any last bits of particles or water before being preserved in hygienic, dry containers under the right circumstances.

4.2.2 Amyl Alcohol

Pentanol, or amyl alcohol, is a kind of alcohol distinguished by its molecular structure of five carbons. It may be found in several isomeric forms, such as tert-amyl alcohol (2-methyl-2-butanol), isoamyl alcohol (2-methyl-1-butanol), and n-amyl alcohol (1-pentanol), each having unique characteristics and uses. Although amyl alcohol is frequently found in nature in the form of several fruits, flowers, and alcoholic drinks, it is also produced industrially for a variety of purposes.

Amyl alcohol is mostly used as a solvent in chemical reactions, especially in the fragrance, cosmetic, and pharmaceutical sectors. It is useful for extracting, dissolving, and synthesizing different chemicals, such as medications, tastes, and perfumes, due to its broad dissolution range. Amyl alcohol is also utilized as a solvent in paint, varnish, and coating manufacturing, where it aids in the dissolution of resinous compounds and enhances flow characteristics.

Because of its pleasant taste and smell, isoamyl alcohol in particular is frequently used as a flavoring component in food and beverages. It frequently appears in fruit-flavored alcoholic drinks and banana flavorings, adding to their distinctive flavor and scent profiles. In order to discourage alcohol addiction and retain its value for

industrial and commercial applications, isoamyl alcohol is also utilized as a denaturant in ethanol. This makes ethanol unsuitable for human consumption.

Amyl alcohol is a versatile reagent used in organic synthesis activities in the laboratory. It may be used in a variety of chemical processes, including as oxidation reactions, esterification, and etherification, thanks to its special structure and characteristics. Furthermore, amyl alcohol can be used as a starting point for the synthesis of various compounds, including medicinal intermediates, surfactants, and plasticizers.



Fig.4.4 Amyl Alcohol

Moreover, amyl alcohol is used in the fermentation of renewable biomass sources such as sugars, starches, and cellulosic materials to produce biofuels. Its high energy density and compatibility with current fuel infrastructure make it a viable feedstock for biofuels and a feasible substitute for fossil fuels in the search for renewable energy sources.

All things considered, amyl alcohol is a useful and adaptable chemical molecule that finds use in a wide range of industries and applications, from flavorings and solvents to laboratory reagents and biofuels.

4.3 EXPERIMENTAL SETUP

4.3.1 Transesterification Setup

The transesterification setup includes a heater, circular bottom, three neck flask, and separation flask, among other items. The lemongrass oil is heated to 60°C in a round-bottom, three-neck flask before being mixed with methanol and sodium hydroxide. Glycerol is extracted from lemongrass oil using a separating flask with the addition of sodium hydroxide and methanol. In addition, the separating flask is used to wash the glycerol-free lemon grass oil until it reaches a neutral pH. The heater is used to dry the oil made from lemon grass, removing any remaining water.

4.3.2 Bomb Calorimeter

A bomb calorimeter is an experimental device used to determine the calorific value of a material or fuel. It is a closed system in which a sample of the material is burnt completely in a controlled environment before the quantity of heat generated is measured. The thermometer, pressure gauge, and ignition wires are all attached to the metal calorimeter. The sample for analysis and oxygen are placed into the calorimeter vessel.

The vessel is then sealed and submerged in water. The sample is ignited by running an electric current via the ignition wires. The heat generated during combustion is absorbed by the water bath, increasing the temperature of the water. It is computed how much heat is emitted via monitoring the water's temperature change and the calorimeter vessel's heat capacity. Direct calorimetry is the name given to this technique of detecting heat output. To ascertain the calorific value of the lemongrass oil, a bomb calorimeter is utilized. Bomb calorimeters are extremely precise, reliable, and trustworthy. They may be used to determine the calorific value of a material to within 0.1%. But they cost a lot of money to run and take a lot of work. Moreover, they simply measure the quantity of heat a substance releases; they don't tell anything about its chemical composition or other properties.

4.3.3 Kinematic Viscometer Bath

A kinematic viscometer bath is a scientific instrument used to measure the viscosity of a liquid. Viscosity is the property of a fluid that regulates its resistance to flow. The kinematic viscometer bath determines how long it takes a liquid to go through a capillary tube under specific conditions.

The apparatus consists of a glass capillary tube with a predetermined diameter hung vertically in a temperature-controlled bath. The bath's temperature is set to a predetermined level before the liquid to be analyzed is added. Subsequently, the liquid is introduced into the capillary tube using a syringe, and the duration of the liquid's passage through the tube is measured using a timer.

The kinematic viscometer bath operates on the premise of Stokes' Law, which says that a particle's rate of sedimentation in a fluid is proportional to its size, density, and fluid viscosity. The viscosity of a liquid may be calculated using a Stokes' Law-based formula by measuring the amount of time it takes for it to flow through a capillary tube. The kinematic viscosity of the lemongrass oil is measured using a kinematic viscometer bath.

4.3.4 Pensky Martens Flash Point Apparatus

The Pensky-Martens flash point apparatus is a laboratory instrument used to determine the flash point of liquids, especially petroleum-based products. The term "flash point" refers to the temperature at which a liquid emits sufficient vapor in the presence of a flame or spark to ignite it. The apparatus consists of a metal cup with a cover that is fastened to a gas burner and a thermometer. After inserting the sample to be studied, the cup's lid is closed.

The cup is then heated to a certain temperature using a gas burner, and the temperature is recorded at regular intervals. The flash point of a sample is reached when a little amount of flame momentarily appears at its surface when the sample is exposed to a test flame. The temperature at which this occurs is known as the

flash point. Lemongrass oil's flash and fire points are found using Pensky Martens flash point equipment.

4.3.5 Bulk Density test Apparatus

The bulk density test device is a scientific instrument used to determine the bulk density of powders and other dry materials. Bulk density is the weight of a material in its uncompacted or natural form per unit volume. It is an important characteristic in the characterisation of powders and other materials since it greatly affects how they behave during processing, storage, and transportation.

The apparatus consists of a funnel that is attached to the top of a known-volume cylindrical container. The item to be inspected is poured into the container using the funnel, and any excess is scraped off using a straight edge. The weight of the substance and the container is then ascertained using a balance.

4.3.6 CI Diesel Engine

A single-cylinder, constant speed Direct Injection engine was used to evaluate the engine performance and emission characteristics of lemongrass biodiesel. The diesel runs at a constant 1500 rpm and 3.5 kW of power with different blend ratios under different load conditions. The diesel engine was directly connected to an eddy current dynamometer, which allowed for load fluctuations ranging from 0% to 100%. There are many engine load conditions: 0%, 25%, 50%, 75%, and 100% at maximum load, depending on the engine's power. The engine loads are manually regulated using an eddy current dynamo meter.



Fig. 4.5: CI Diesel Engine

The volumetric calibrated burette method was used to measure the fuel flow, and an air drum with a calibrated aperture was used to measure the air flow rate. To evaluate fuel flow, two fuel tanks were used: one had pure diesel and the other, transesterified lemongrass biodiesel. Using a mounted AVL smoke meter, the temperatures of the exhaust gases and the opacity of the smoke were measured. The test rig was equipped with AVL Indi small software, which was designed to gather several readings and observations throughout operation.

The emission characteristics of the exhaust gas, including the concentrations of HC, CO, CO₂, O₂, and NO_x, were tested using a five-gas analyzer. For the performance and emissions tests, rated power and a 17.5% compression ratio were employed.

Testing was done on brake thermal efficiency (BTE), specific fuel consumption (SFC), and various mixes of lemongrass biofuel and pure diesel fuel. The engine performance investigation showed that the engine's rated power varied based on emissions factors (HC, CO, CO₂, O₂, and NO_x).

4.3.7 Engine Testing Software

EngineSoft is a suite of LabVIEW-based software for engine performance monitoring systems produced by Apex Innovations Pvt. Ltd. EngineSoft may be able to meet most engine testing application requirements, such as monitoring, reporting, data entry, and data recording. The software evaluates fuel usage, power, efficiency, and heat emission. It may be set up in accordance with the engine configuration. Under various operating conditions, different graphs are produced. Identify, record, and plot the signals required for online engine testing in the run mode. Tabular and graphical representations of the data are possible with access to the stored data file. Printing of the results and graphs is possible. Additional research may be conducted using the excel formatted data.

4.3.8 Smoke Opacity Meter

The density or opacity of smoke emitted by combustion engines, particularly diesel engines, is measured using a device known as a smoke meter. It works by focusing a laser beam onto the exhaust gas plume, utilizing light absorption. The quantity of light absorbed by the smoke particles determines the gas's opacity, which can be stated as a percentage or a numerical number. Smoke meters are vital tools for assessing the environmental impact of vehicle emissions and ensuring that air quality and pollution regulations are adhered to. By precisely measuring the opacity of smoke, this equipment helps authorities monitor vehicle performance and enforce emission regulations.



Fig. 4.6: Smoke Opacity Meter

4.3.9 Exhaust Gas Analyzer

The amount of a particular gas contained in a sample is ascertained using a device known as a gas analyser. These gadgets are widely utilized in a wide range of sectors, including environmental monitoring, automotive emissions testing, medical diagnostics, and industrial operations. Gas analysers use a range of detection techniques, including as thermal conductivity, electrochemical sensing, and spectroscopy, to precisely quantify the presence of gases.



Fig. 4.7: Exhaust Gas Analyzer

Gas analyzers are crucial for monitoring air quality, detecting pollutants, and figuring out if rules are being adhered to in environmental applications. Through process monitoring of gas composition and safety assurance, they optimization in a business environment. Cleaner and more fuel-efficient cars are a result of the measurement of exhaust emissions using automotive gas analysers.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 RESULTS

The Jatropha oil was used for the preparation of biodiesel. For the transesterification of Jatropha oil, methanol and sodium hydroxide were used. The oil to methanol ratio is 1:6 and 5 grams of sodium hydroxide is used as catalyst per liter. The reaction time was 120 minutes at the temperature of 60°C. The yield was 63.5%.

Table 5.1: Transesterification of Jatropha oil

S. No	Parameters	Results
1	Free fatty acid	1.69 %
2	Catalyst (NaOH) quantity	5 grams
3	Oil to methanol molar ratio	1:3
4	Temperature	60 °C
5	Reaction time	120 minutes
6	Yield	63.5 %

5.2 PROPERTIES OF JATROPHA OIL

5.2.1 Kinematic Viscosity

A fluid's resistance to progressive deformation caused by tensile or shear stress is measured by its viscosity. It is equivalent to the loose definition of thickness for liquids. The ratio of the dynamic viscosity (μ) to the fluid density (ρ) is known as the kinematic viscosity, commonly referred to as "momentum diffusivity". The Greek letter nu is typically used to represent it (ν).

5.2.2 Flash Point

The flash point is the lowest temperature at which vapors of volatile materials will ignite in the presence of an ignition source. The auto ignition temperature—sometimes mistaken for the flash point—is the temperature at which vapor will ignite

on its own without the assistance of an ignition source. The fire point is the lowest temperature at which vapor will burn after it has been ignited and the ignition source has been removed. The vapor's fire point is higher than its flash point because it can be reliably relied upon to extinguish when the ignition source is removed. The temperature of the ignition source will obviously be much higher than the flash point or fire point, even if they are not directly correlated.

5.2.3 Fire Point

A fuel's fire point is the lowest temperature at which, when ignited by an open flame, the fuel's vapour will burn for at least five seconds. Substances will ignite momentarily at the flash point, which is a lower temperature, but they may not release enough vapour to keep the fire going. Most material property tables simply include the material flash points. Though it's generally safe to presume that the fire points are around 10°C higher than the flash points. Testing to see if the fire site is safety essential is still necessary. The fire point is tested using an open cup apparatus.

5.2.4 Calorific Value

When a material completely burns with oxygen under conventional conditions, the total energy produced as heat is known as the calorific value. Usually, when oxygen and a hydrocarbon or other organic molecule combine, carbon dioxide, water, and heat are released. It may be expressed with the quantities:

- energy/mole of fuel (kJ/mol)
- energy/mass of fuel
- energy/volume of the fuel

5.2.5 Acidic Value

The amount of free fatty acids contained in biodiesel is indicated by its acid value, which also indicates the acidity of the sample. It is the amount of potassium hydroxide (KOH) in milligrams needed to neutralize the free acids in one gram of material, as determined by titration. Triglyceride conversion that isn't fully completed during manufacturing or feedstock contamination might cause excessive acid values. Elevated acid concentrations have the potential to cause soap production

during transesterification, which might disrupt the separation process and reduce the quality of biodiesel. To guarantee that biodiesel satisfies quality standards, performance criteria, and regulatory specifications during the manufacturing and use processes, it is imperative to monitor and regulate acid levels.

Table 5.2: Properties of Jatropha Biodiesel

S.No	Parameters	Results
1	Density (g/cc)	0.853
2	Kinematic Viscosity @ 40°C (cSt)	3.18
3	Flash point by PMCC method (°C)	147
4	Fire point by PMCC method (°C)	158
5	Calorific value (Cal/g)	5981.38
6	Acidic Value (gram of oil/mL of NaOH)	3.92

5.3 BLEND PROPORTION OF BIODIESEL

Table: 5.3 Blend Proportions of Biodiesels

S.No	Blends	Diesel (Wt%)	Biodiesel (Wt%)	Amyl Alcohol (%)
1	B15	80	15	5
2	B20	75	20	5
3	B25	70	25	5



Fig.5.1: Biodiesel Blends B15, B20, B25

5.4 PERFORMANCE CHARACTERISTICS

5.4.1 Variation of BSFC vs BP

Brake specific fuel consumption, or BSFC, is a metric used to quantify engine efficiency. It displays the amount of fuel used in relation to each unit of power produced. Typically, BSFC is expressed as mass per unit of power per unit of time, such as grams per kilowatt-hour (g/KWh) or pounds per horsepower-hour (lb/hp-hr). A lower BSFC rating indicates greater fuel efficiency since the engine needs less fuel to produce a given level of power instead of more.

The engine design, the fuel type, and the operating circumstances (such as speed and load) may all affect the BSFC values. 39 BSFC data is used by engine manufacturers and researchers to improve engine performance, increase fuel efficiency, and reduce emissions.

Engineers may identify an engine's most efficient operating points and make modifications to increase overall engine efficiency by looking at BSFC curves. Using a VCR diesel engine, the BSFC of the biodiesel mix is tested. The results are summarized in table 6.1, which is shown below.

Table 5.4: BSFC values of biodiesel blends and diesel

BP (KW)	B15	B20	B25	Diesel
0.2	1.2	1.14	1.12	1.4
1	0.5	0.49	0.45	0.55
1.8	0.41	0.39	0.37	0.49
3	0.36	0.33	0.30	0.39

Table 6.1 provides comprehensive details on the exact fuel consumption for various loads across several samples, enabling us to compare the outcomes with diesel. Upon comparing all the biodiesel blends, it becomes clear that mix B25 outperforms diesel and every other blend, while blends B15 and B20 exhibit comparable consumption rates. When compared to all other biodiesel mixes, diesel is shown to have a higher specific fuel consumption when braking power increases.

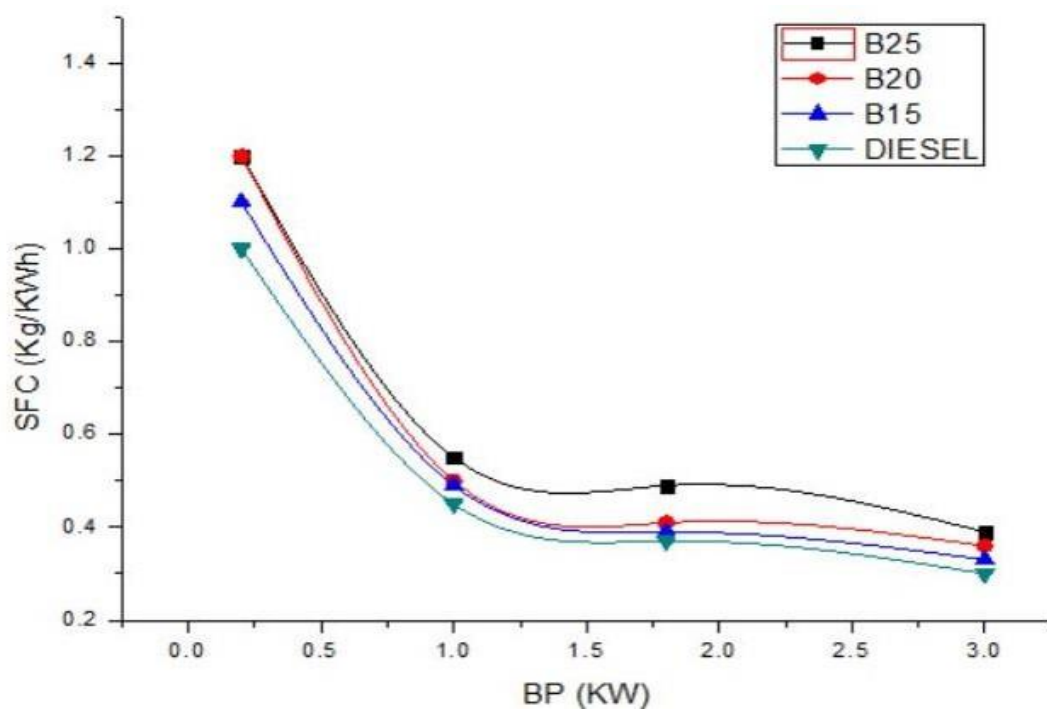


Fig. 5.2: Specific fuel consumption (SFC) of biodiesel blends and diesel

5.4.2 Variation of BTE vs BP

An additional crucial indicator for assessing an engine's efficiency is its brake thermal efficiency (BTE). It gauges how successfully fuel energy is transformed into productive mechanical labor. Stated differently, it denotes the proportion of the fuel's overall energy content that is transformed into productive labor. Greater efficiency is shown by a greater brake thermal efficiency since less fuel is wasted as waste heat and more of the fuel's input energy is transformed into workable work. 41 Enhancing brake thermal efficiency is a primary objective in engine development since it results in increased fuel efficiency and lower emissions. Engineers do this in several ways, including by enhancing heat management systems, decreasing frictional losses, and optimizing combustion processes.

Table 5.5: Brake thermal efficiency (BTE) values of biodiesel blends and diesel

BP (KW)	B15	B20	B25	Diesel
0.2	7	6	16.5	8
1	18	17	22.75	19
1.8	23.4	22.5	29.4	25
3	27.8	25.8	32	28.2

By giving detailed information on the precise brake thermal efficiency over a range of loads for multiple samples, table 5.2 allows us to compare the results with diesel. Samples B15, B20 and B25 have progressive brake thermal efficiency where B25 and B15 are having the highest and lowest BTE amongst the blends respectively. Diesel is having an higher overall BTE than all the three biodiesel blends.

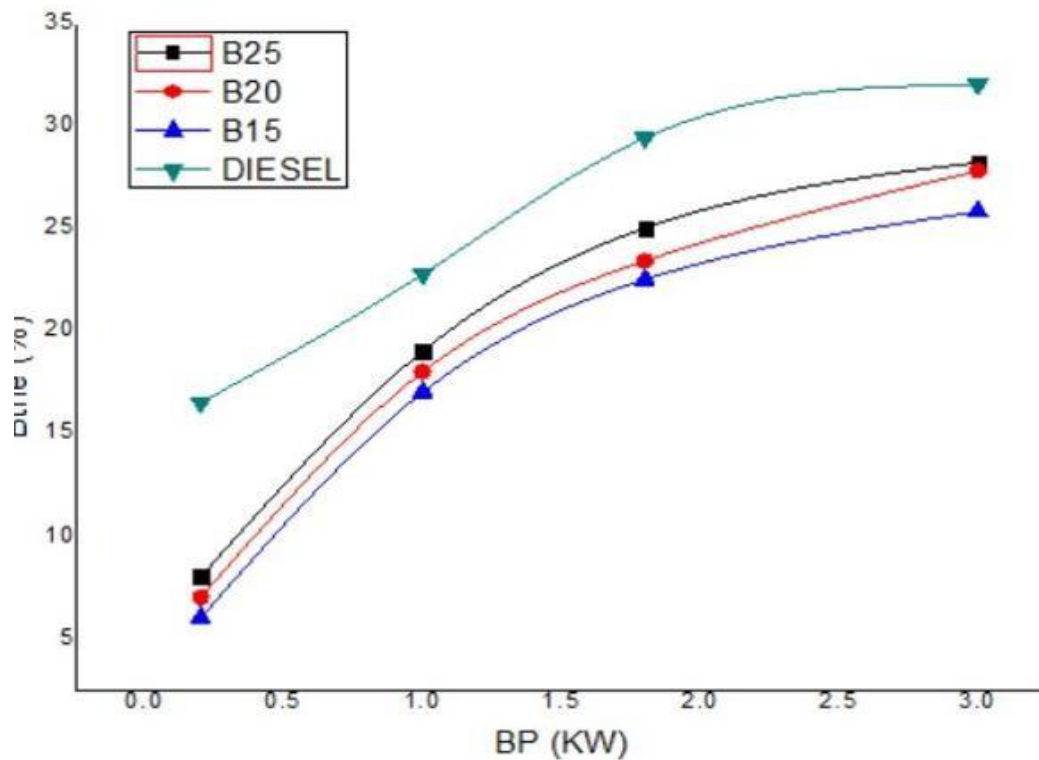


Fig. 5.3: Brake thermal efficiency (BTE) of biodiesel blends and diesel

5.5 EMISSION CHARACTERISTICS

5.5.1 Variation of HC vs BP

Fossil fuels such as coal, natural gas, and petroleum are mostly made up of hydrocarbons, which are atoms of hydrogen and carbon. They are also produced when combustion processes are not completed. Hydrocarbons are essential for the manufacture of gasoline, petrochemicals, and energy, and they play key roles in many other industrial applications. Around the world, they are the main energy source used for heating, power production, and transportation. Hydrocarbons can take the form of alkanes, alkenes, alkynes, or aromatic compounds, each of which has distinct chemical characteristics and applications due to its varied molecular structure.

Because they are pollutants, hydrocarbons are a problem in environmental settings. Unburned hydrocarbons are released into the environment via incomplete combustion, which occurs in industrial or automotive engines and contributes to the

development of smog and air pollution. Furthermore, hydrocarbons released into bodies of water may cause harm to aquatic ecosystems.

Table 5.6: Hydrocarbon emissions of biodiesel blends and diesel

BP (KW)	B15	B20	B25	Diesel
0.2	3	2	1	4
1	4	3	2	6
1.8	5	3	2.5	9
3	8	7	4	12

It is observed that all the three biodiesel blends have a distinct HC output where B25 blend takes the lead by giving the least HC output followed by B20 and B15. Even though a dip is observed in the HC output of B20 blend, it is quite linear with the increase in brake power. Diesel shows a HC output higher than all the given biodiesel blends.

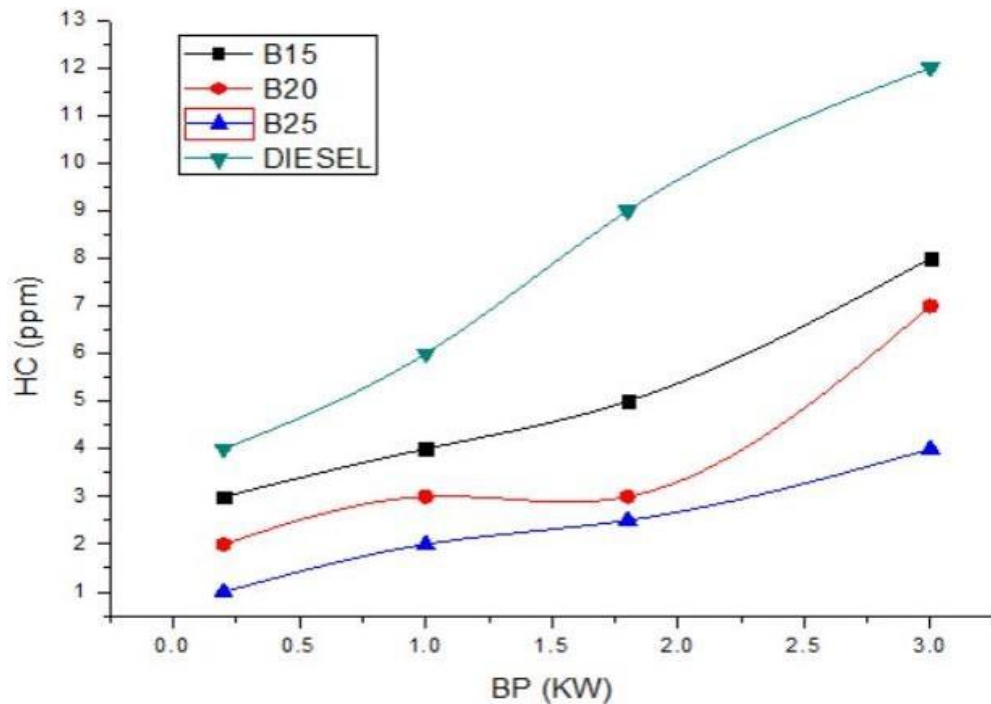


Fig.5.4: Hydrocarbon emissions of biodiesel blends and diesel

5.5.2 Variation of CO vs BP

Carbon monoxide (CO) is a colorless, odorless gas made up of one carbon atom and one oxygen atom. It results from the incomplete burning of carbon-based fuels, which include coal, wood, natural gas, and gasoline. CO is produced when there is insufficient oxygen present during burning, which causes partial oxidation of carbon. When inhaled, this gas poses a major health danger to people and animals, making it a notable air pollution. It prevents the circulation from carrying oxygen, which can lead to symptoms ranging from minor headaches and light headedness to serious consequences including blurred vision, cognitive impairment, and in extreme cases, death from long-term or high-exposure exposure.

The main sources of CO emissions in metropolitan areas are motor cars, although other sources include industrial activities, household heating systems, wildfires, and vehicle exhaust. Many precautions are taken to lessen the risks connected to CO exposure. These include limiting emissions from industrial sources through legislation, putting carbon monoxide detectors in homes to warn residents of excessive CO levels, and equipping cars with catalytic converters to lower emissions.

Table 5.7: Carbon monoxide (CO) emissions of biodiesel blends and diesel

BP (KW)	B15	B20	B25	Diesel
0.2	0.01	0.01	0.01	0.02
1	0.03	0.025	0.02	0.03
1.8	0.04	0.045	0.035	0.048
3	0.07	0.05	0.042	0.075

It is observed from the results that diesel is having a higher CO output than all the other biodiesel blends. Whereas amongst the blends, B15 shows the least CO output and B20 with the highest. Blend B25 has a lesser overall CO output than B20 and diesel. Even though B25 shows a spike in CO at around 2 KW brake power, at around 3 KW, the emissions are decreasing.

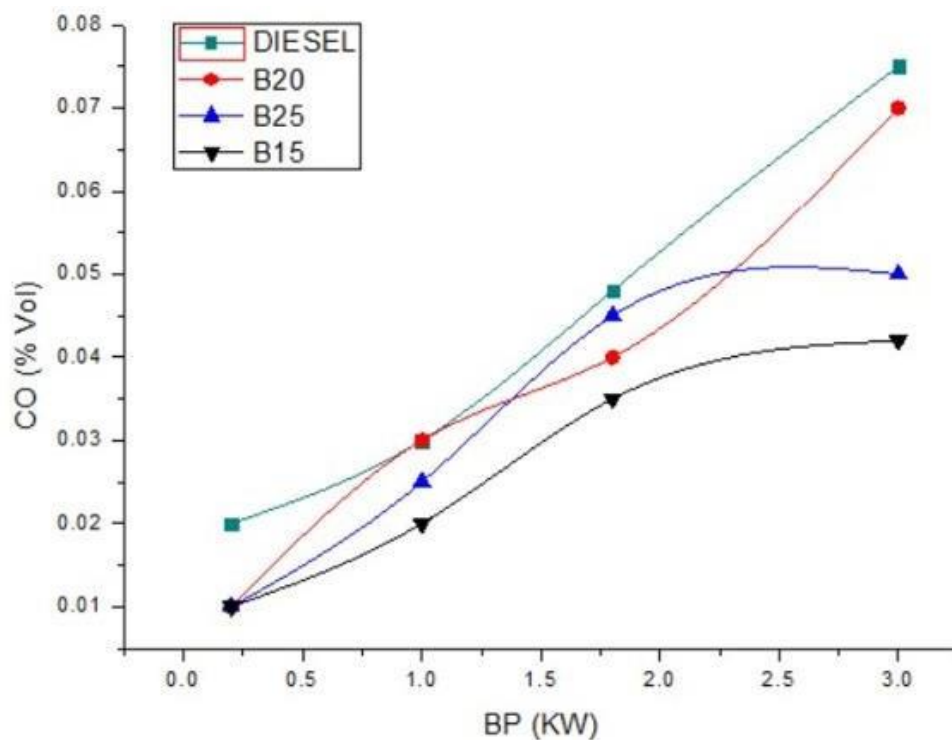


Fig 5.5: Carbon monoxide (CO) emission of biodiesel blends and diesel

5.5.3 Variation of NO_x vs BP

Nitrogen monoxide (NO) and nitrogen dioxide (NO₂) are the most common forms of oxides of nitrogen (NO_x), a highly reactive gas mixture of nitrogen and oxygen atoms. Nitrous oxide (N₂O) is another gas that contributes to NO_x pollution. High-temperature combustion processes, such as those found in automobiles, power plants, industrial boilers, and aviation engines, are the main source of NO_x. Principal origins of NO_x emissions consist of:

Transportation: Diesel engines, in particular, are a major source of NO_x emissions from a variety of combustion-powered vehicles, including automobiles, trucks, ships, and airplanes.

Industrial Processes: NO_x is also produced when fossil fuels burn in power plants, industrial boilers, and manufacturing operations.

Agriculture: The use of fertilizers based on nitrogen has the potential to generate nitrous oxide, which is a strong greenhouse gas and a cause of NO_x pollution.

Fossil fuel combustion for heating in residential buildings has the potential to release nitrogen oxides (NO_x).

NO_x is a key factor in air pollution and environmental deterioration because it helps create ground-level ozone and particulate matter, both of which are harmful to the environment and human health. Exposure to NO_x has been linked to cardiovascular disorders, respiratory problems, and an aggravation of asthma and other respiratory ailments.

In addition to their negative effects on health, NO_x emissions cause smog, acid rain, and eutrophication of aquatic bodies. To reduce NO_x emissions, laws and emission standards for automobiles, factories, and power plants must be put into place. Additionally, cleaner fuels and technologies must be promoted, and emission control technologies such as exhaust gas recirculation (EGR) and selective catalytic reduction (SCR) must be adopted.

Table 5.8: NO_x emissions of biodiesel blends and diesel

BP (KW)	B15	B20	B25	Diesel
0.2	220	200	180	250
1	280	250	230	355
1.8	320	340	280	485
3	580	450	300	750

The results show that when biodiesel blends are used instead of diesel, the NO_x emissions are significantly reduced. Blend B25 continues to have the lowest NO_x emission during the test. On the other hand, blends B15 and B20 exhibit comparable NO_x output, with a 2 KW overlap, and B15 tends to exhibit greater NO_x emissions as brake power increases. Diesel produces more NO_x overall than any of the three biodiesel mixes tested.

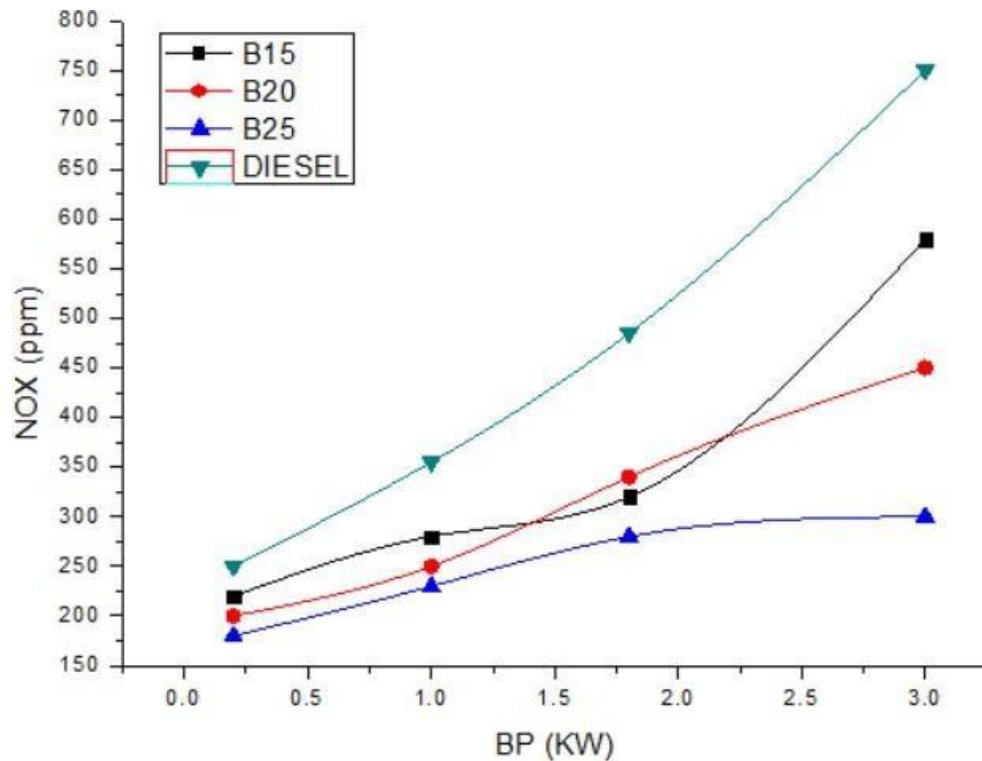


Fig.5.6: NO_x emission of biodiesel blends and diesel in ppm

5.5.4 Variation of CO₂ vs BP

It is produced naturally in the Earth's atmosphere by a number of activities, including the respiration of living things, volcanic eruptions, and the decomposition of organic waste. But human activity has significantly increased atmospheric CO₂ levels, especially when it comes to burning fossil fuels (such as coal, oil, and natural gas) for transportation, electricity, industrial operations, and deforestation. Because CO₂ is a greenhouse gas, this increase in atmospheric CO₂ is one of the main causes of global warming and climate change.

The greenhouse effect is caused by CO₂, which absorbs infrared light and then emits it. Temperatures rise as a result of this process' retention of heat in the Earth's atmosphere. Rising sea levels, changed weather patterns, melting ice caps and glaciers, and other environmental changes are some of the effects that follow.

Many actions are being made to reduce CO₂ emissions and fight climate change. The adoption of renewable energy sources, improved energy efficiency, the use of carbon capture and storage (CCS) technologies, afforestation and reforestation projects, and involvement in global accords such as the Paris Agreement, which attempts to lower greenhouse gas emissions, are a few examples.

Table 5.9: Carbon dioxide (CO₂) emissions of biodiesel blends and diesel

BP (KW)	B15	B20	B25	Diesel
0.2	0.7	0.5	0.4	1.2
1	0.75	0.6	0.5	1.6
1.8	1.1	0.8	0.6	1.8
3	1.4	1	0.7	2.2

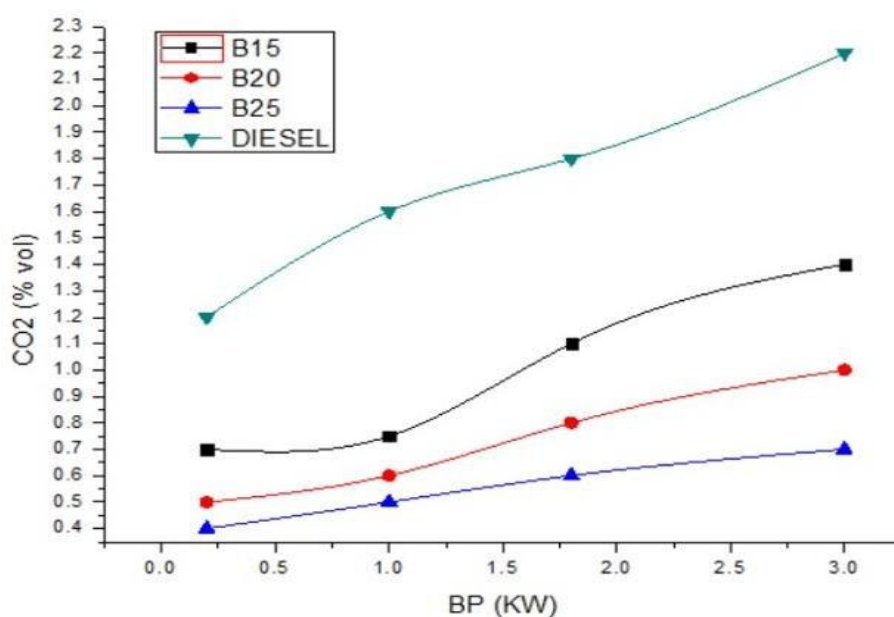


Fig 5.7: CO₂ emissions of biodiesel blends and diesel

From the results, we can understand that all the biodiesel blends give lower CO₂ emissions than diesel while B25 giving the least CO₂ output and diesel having the

highest. Amongst the blends, B15 has the highest CO₂ output followed by B20 and B25, which are all lower than the CO₂ output of diesel.

5.5.5 Variation of O₂ vs BP

The amount of oxygen (O₂) in a fuel component is referred to as its oxygen content (O₂). The oxygen content of hydrocarbon fuels such as coal, natural gas, diesel, and gasoline is usually low or nonexistent. Carbon (C) and hydrogen (H) atoms make up the majority of these fuels, with trace quantities of sulfur, nitrogen, and oxygen (typically less than 1% by weight) present. Oxygen levels can affect the properties of combustion. There is total combustion when enough oxygen is present for hydrocarbon fuels to burn, the main byproducts are carbon dioxide (CO₂) and water (H₂O). On the other hand, incomplete combustion results from inadequate oxygen, which causes the production of pollutants such as unburned hydrocarbons (HC) and carbon monoxide (CO).

If O₂ levels are low in the fuel means it creates incomplete combustion due to incomplete combustion fuel it emits high level of emission, particle hydrocarbons are produced due to incomplete combustion of fuel.

Table 5.10: Variation of O₂ vs BP values

BP (KW)	B15	B20	B25	Diesel
0.2	20.48	20.25	20	22
1	20.39	19	18.37	20.95
1.8	19.82	19.24	17.96	20.15
3	19.01	18.30	17.46	19.75

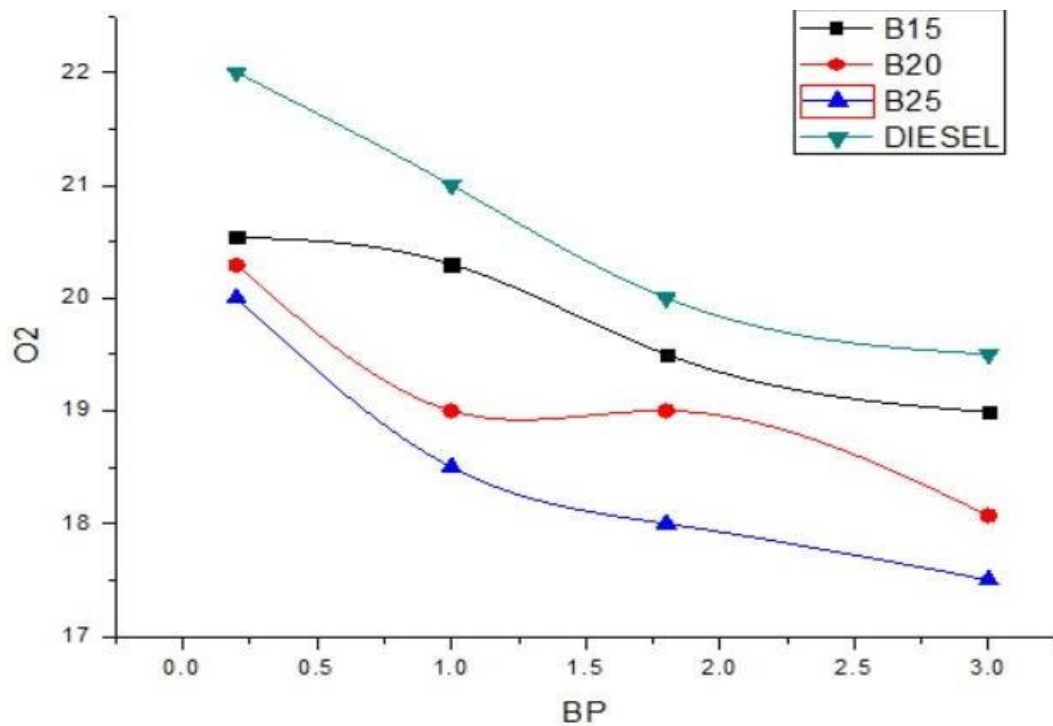


Fig.5.8: Variation of O₂ vs BP values of biodiesel blends and diesel

From the results as mentioned in table 5.7, we can understand that all the biodiesel blends and diesel have a decrease in O₂ output with the increase in brake power. Amongst the blends, B25 has the lowest O₂ output which indicates clean combustion. It is followed by B20 and B15. Diesel has the highest amount of O₂ output amongst all the tested fuels.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 SUMMARY

Amyl alcohol introduces a complicated interplay of elements that affect engine performance and emissions in a compression ignition (CI) engine that uses Jatropha oil. Because of its high cetane number and oxygen concentration, amyl alcohol—a renewable alcohol made from biomass—has been investigated as a possible addition. These properties can improve the characteristics of combustion. Blending Jatropha oil—a non-food vegetable oil that is frequently used as a feedstock for biodiesel—with it is intended to enhance fuel quality and engine efficiency while reducing emissions.

Research has demonstrated that adding amyl alcohol can have a favourable impact on how CI engines use fuel. Because of its high oxygen concentration, it burns more completely, producing less particulate matter and improving thermal efficiency. Furthermore, amyl alcohol's high cetane number contributes to improved ignition characteristics, which result in less engine knock and smoother engine running.

However, adding amyl alcohol may present problems including increased viscosity and poor cold-flow qualities, requiring careful blend ratio optimization to keep fuel flow characteristics within allowable bounds. To guarantee long-term dependability, the effect on engine longevity and compatibility with engine components should also be carefully assessed.

Finally adding amyl alcohol to a CI engine that runs on Jatropha oil appears to have potential benefits for both lowering emissions and increasing combustion efficiency. To overcome obstacles and reach the full potential of this blend for efficient and sustainable engine running, however, more study and optimization are needed.

6.2 CONCLUSION

The research on biodiesel made from Jatropha oil with amyl alcohol has yielded the following conclusions.

- Sample B15 has the lowest Brake Specific Fuel Consumption (BSFC) followed by B20 and B25. Both B15 and B20 are having similar brake specific fuel consumption. Here, the BSFC of B25 blends is on the higher side. Diesel has the least BSFC.
- Sample B25 has the highest brake thermal efficiency and the sample B15 has the lowest brake thermal efficiency. Samples B15, B20 and B25 have progressive brake thermal efficiency where B25 and B15 are having the highest and lowest BTE amongst the blends respectively. Diesel is having a higher overall BTE than all the three biodiesel blends.
- The B15 sample emits more hydrocarbon at maximum load than other blends, while sample B25 emits least hydrocarbons at maximum load due to the blending of Jatropha oil. On comparing all blends with diesel, diesel emits more hydrocarbons than all the three given blends. B20's HC emissions lie between the samples B15 and B25.
- Diesel is having a higher CO output than all the other biodiesel blends. Whereas amongst the blends, B15 shows the least CO output and B20 with the highest. Blend B25 has a lesser overall CO output than B20 and diesel. Even though B25 shows a spike in CO at around 2 KW brake power, at around 3 KW, the emissions are decreasing.
- There is a significant reduce in the NO_x emissions from biodiesel blends as compared to that of diesel. The NO_x emission of blend B25 remains lowest throughout the test. Whereas, blends B15 and B20 give similar NO_x output while overlapping around 2 KW and B15 tends to give higher NO_x emissions.

with the increase in Brake power. Diesel has a higher overall NO_x output than all the three given biodiesel blends.

- All the biodiesel blends give lower CO₂ emissions than diesel while B25 giving the least CO₂ output and diesel having the highest. Amongst the blends, B15 has the highest CO₂ output followed by B20 and B25, which are all lower than the CO₂ output of diesel.
- All the biodiesel blends and diesel have a decrease in O₂ output with the increase in brake power. Amongst the blends, B25 has the lowest O₂ output which indicates clean combustion. It is followed by B20 and B15. Diesel has the highest amount of O₂ output amongst all the tested fuels.

REFERENCES

1. Abbaszaadeh A., Ghobadian B., Omidkhah M. R., Najafi G., "Current biodiesel production technologies: A comparative review", *Energy Conversion and Management*, nov. 2012, pp. 138–148.
2. Altıparmak, D., Keskin, A., Koca, A. and Gürü, M., 2007. Alternative fuel properties of tall oil fatty acid methyl ester–diesel fuel blends. *Bioresource technology*, 98(2), pp.241-246.
3. Appavu P., Venkata Ramanan M., "Study of emission characteristics of a diesel engine using cerium oxide nanoparticle blended pongamia methyl ester", *International Journal of Ambient Energy*, vol. 41, no 5, pp. 524–527, abr. 2020
4. Armendáriz J., Lapuerta M., Zavala F., García-Zambrano E., Del Carmen Ojeda M., "Evaluation of eleven genotypes of castor oil plant (*Ricinus communis* L.) for the production of biodiesel", *Ind Crops Prod*, vol. 77, pp. 484– 490, dez. 2015.
5. Atmanli, A., 2016. Effects of a cetane improver on fuel properties and engine characteristics of a diesel engine fueled with the blends of diesel, hazelnut oil and higher carbon alcohol. *Fuel*, 172, pp.209-217.
6. Awad, O.I., Mamat, R., Ali, O.M., Yusri, I.M., Abdullah, A.A., Yusop, A.F. and Noor, M.M., 2017. The effect of adding fusel oil to diesel on the performance and the emissions characteristics in a single cylinder CI engine. *Journal of the energy Institute*, 90(3), pp.382-396.
7. Babu, D. and Anand, R., 2017. Effect of biodiesel-diesel-n-pentanol and biodiesel-diesel-n-hexanol blends on diesel engine emission and combustion characteristics. *Energy*, 133, pp.761-776.

8. Burda C., Chen X., Narayanan R., El-Sayed M. A., "Chemistry and properties of nanocrystals of different shapes", *Chemical Reviews*, vol. 105, no 4. pp. 1025–1102, abril de 2005.
9. Chandra Sekhar S. *et al.*, "Biodiesel production process optimization from Pithecellobium dulce seed oil: Performance, combustion, and emission analysis on compression ignition engine fuelled with diesel/biodiesel blends", *Energy Convers Manag*, vol. 161, pp. 141–154, abr. 2018.
10. Channapattana, S.V., Kantharaj, C., Shinde, V.S., Pawar, A.A. and Kamble, P.G., 2015. Emissions and performance evaluation of DI CI-VCR engine fuelled with honne oil methyl ester/diesel blends. *Energy Procedia*, 74, pp.281-288.
11. D'Alessandro B., Bidini G., Zampilli M., Laranci P., Bartocci P., Fantozzi F., "Straight and waste vegetable oil in engines: Review and experimental measurement of emissions, fuel consumption and injector fouling on a turbocharged commercial engine", *Fuel*, vol. 182, pp. 198–209, out. 2016
12. Datla, R., Puli, R.K., Chandramohan, V.P. and Edwin Geo, V., 2019. Biodiesel production process, optimization and characterization of Azadirachta indica biodiesel in a VCR diesel engine. *Arabian Journal for Science and Engineering*, 44(12), pp.10141-10154.
13. Demirbaş, A., 2003. Biodiesel fuels from vegetable oils via catalytic and non-catalytic supercritical alcohol transesterifications and other methods: a survey. *Energy conversion and Management*, 44(13), pp.2093-2109.
14. Ganesan S. *et al.*, "WITHDRAWN: Experimental analysis on DI diesel engine characteristics using watermelon seed oil with Magnesium oxide", *Mater Today Proc*, 2021.
15. Ganesan S., Mohanraj M., Hemanandh J., Sankar S. L, "Experimental studies on VCR diesel engine characteristics using camelina and lemongrass

oil biodiesel with butylated hydroxytoluene as a nano additive”, *Mater Today Proc*, 2022

16. Ghanbari M., Mozafari-Vanani L., Dehghani-Soufi M., Jahanbakhshi A., “Effect of alumina nanoparticles as additive with diesel–biodiesel blends on performance and emission characteristic of a six-cylinder diesel engine using response surface methodology (RSM)”, *Energy Conversion and Management: X*, vol. 11, set. 2021
17. Hosseini S. H., Taghizadeh-Alisaraei A., Ghobadian B., Abbaszadeh-Mayvan A., “Effect of added alumina as nano-catalyst to diesel-biodiesel blends on performance and emission characteristics of CI engine”, *Energy*, vol. 124, pp. 543–552, 2017.
18. Jayaraman J., Laskar I. U. I., Dey K., Arunkumar T., Appavu P., Joy N., “Investigation on titanium oxide nano particles as additives for biodiesel fuelled engine”, *Materials Today: Proceedings*, Elsevier Ltd, Jan. 2021, pp. 3525–3529.
19. Jeyakumar, N. and Narayanasamy, B., 2021. Effect of pentanol-biodiesel blends on performance and emission characteristics of the diesel engine. *International Journal of Ambient Energy*, 42(8), pp.900-906.
20. Juan, J.C., Kartika, D.A., Wu, T.Y. and Hin, T.Y.Y., 2011. Biodiesel production from jatropha oil by catalytic and non-catalytic approaches: an overview. *Bioresource technology*, 102(2), pp.452-460.
21. Karthikeyan S., Elango A., Prathima A., “The effect of cerium oxide additive on the performance and emission characteristics of a CI engine operated with rice bran biodiesel and its blends”, *Int J Green Energy*, vol. 13, no 3, pp. 267–273, Feb. 2016.
22. Kumar, S., Chaube, A. and Jain, S.K., 2012. Experimental evaluation of CI engine performance using diesel blended with Jatropha biodiesel. *international journal of energy and environment*, 3(3), pp.471-484.

23. Leung D. Y. C., Wu X., Leung M. K. H., "A review on biodiesel production using catalyzed transesterification", *Applied Energy*, vol. 87, no 4. Elsevier Ltd, pp. 1083–1095, 2010.
24. Mahmudul H. M., Hagos F. Y., Mamat R., Adam A. A., Ishak W. F. W., Alenezi R., "Production, characterization and performance of biodiesel as an alternative fuel in diesel engines – A review", *Renewable and Sustainable Energy Reviews*, vol. 72. Elsevier Ltd, pp. 497–509, 2017.
25. Megala J. Geetha A., "Acute and sub-acute toxicity study of hydroalcoholic fruit extract of *Pithecellobium dulce*", *Nat Prod Res*, vol. 26, no 12, pp. 1167–1171, jun. 2012.
26. Mohsin, R., Majid, Z.A., Shihnan, A.H., Nasri, N.S. and Sharer, Z., 2014. Effect of biodiesel blends on engine performance and exhaust emission for diesel dual fuel engine. *Energy conversion and management*, 88, pp.821-828.
27. Nalgundwar A., Paul B., Sharma S. K., "Comparison of performance and emissions characteristics of di CI engine fueled with dual biodiesel blends of palm and jatropha", *Fuel*, vol. 173, pp. 172–179, jun. 2016
28. Palash S. M., Kalam M. A., Masjuki H. H., Arbab M. I., Masum B. M., Sanjid A., "Impacts of NOx reducing antioxidant additive on performance and emissions of a multi-cylinder diesel engine fueled with *Jatropha* biodiesel blends", *Energy Convers Manag*, vol. 77, pp. 577–585, 2014
29. Prabu A., Anand R. B., "Emission control strategy by adding alumina and cerium oxide nano particle in biodiesel", *Journal of the Energy Institute*, vol. 89, no 3, pp. 366–372, 2016.
30. Qi D. H., Chen H., Geng L. M., Bian Y. Z., "Experimental studies on the combustion characteristics and performance of a direct injection engine

- fueled with biodiesel/diesel blends”, *Energy Convers Manag*, vol. 51, no 12, pp. 2985– 2992, dez. 2010.
31. Rahman S. M. A., Masjuki H. H., Kalam M. A., Abedin M. J., Sanjid A., Sajjad H., “Production of palm and Calophyllum inophyllum based biodiesel and investigation of blend performance and exhaust emission in an unmodified diesel engine at high idling conditions”, *Energy Convers Manag*, vol. 76, pp. 362–367, 2013.
 32. Ramakrishnan, P., Kasimani, R., Peer, M.S. and Rajamohan, S., 2018. Assessment of n-pentanol/Calophyllum inophyllum/diesel blends on the performance, emission, and combustion characteristics of a constant-speed variable compression ratio direct injection diesel engine. *Environmental Science and Pollution Research*, 25, pp.13731-13744.
 33. Reddy, J.N. and Ramesh, A., 2006. Parametric studies for improving the performance of a Jatropha oil-fuelled compression ignition engine. *Renewable Energy*, 31(12), pp.1994-2016.
 34. Roy S. *et al.*, “Effective utilisation of waste cooking oil in a single-cylinder diesel engine using alumina nanoparticles”, *Sustain Energy Fuels*, vol. 4, no 2, pp. 571–581, 2020.
 35. Sekhar S. C. *et al.*, “Emission analysis on compression ignition engine fueled with lower concentrations of Pithecellobium dulce biodiesel-diesel blends”, *Heat Transfer - Asian Research*, vol. 48, no 1, pp. 254–269, jan. 2019.
 36. Shaafi T., Sairam K., Gopinath A., Kumaresan G., Velraj R., “Effect of dispersion of various nano additives on the performance and emission characteristics of a CI engine fuelled with diesel, biodiesel and blends—A review”, *Renewable and Sustainable Energy Reviews*, vol. 49. Elsevier Ltd, pp. 563–573, 1o de setembro de 2015.
 37. Sivaraja C. M., Sakthivel G., “Compression ignition engine performance modelling using hybrid MCDM techniques for the selection of optimum fish

- oil biodiesel blend at different injection timings”, *Energy*, vol. 139, pp. 118–141, 2017
38. Smokers, R. and Smit, R., 2004. Compatibility of pure and blended biofuels with respect to engine performance, durability and emissions. A literature review.
39. Uslu, S. and Celik, M.B., 2020. Performance and exhaust emission prediction of a SI engine fueled with I-amyl alcohol-gasoline blends: an ANN coupled RSM based optimization. *Fuel*, 265, p.116922.
40. Vallinayagam, R., Vedharaj, S., Yang, W.M., Saravanan, C.G., Lee, P.S., Chua, K.J.E. and Chou, S.K., 2014. Impact of ignition promoting additives on the characteristics of a diesel engine powered by pine oil–diesel blend. *Fuel*, 117, pp.278-285.
41. Van Gerpen J., “Biodiesel processing and production”, *Fuel Processing Technology*, vol. 86, no10, pp. 1097–1107, jun. 2005.
42. Yadav A. K., Khan M. E., Dubey A. M., Pal A., “Performance and emission characteristics of a transportation diesel engine operated with non- edible vegetable oils biodiesel”, *Case Studies in Thermal Engineering*, vol. 8, pp. 236–244, set. 2016.