

Experimental Investigation on Novel Heterogeneous Catalyst Blend in DI-Diesel Engine with Hydrogen Enrichment

Submitted in partial fulfilment of the requirements for the award of

**Bachelor of Engineering Degree in
Mechanical Engineering**

By

ASHOKAN VIKRAM (38150016)

PARANTHAMAN (38150075)



**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 - 600 119

MAY – 2022



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 **PARANTHAMAN (38150075)** who carried out the project entitled "**Experimental Investigation on Novel Heterogenous Catalyst Blend in DI-Diesel Engine with Hydrogen Enrichment**" under my supervision from November 2021 to March 2022.

Internal Guide

Dr. J. HEMANANDH

Head of the Department

Dr. G. ARUN KUMAR

Submitted for Viva voce Examination held on 09/05/2022.

Internal Examiner

External Examiner

DECLARATION

I, **PARANTHAMAN**, hereby declare that the Project Report entitled “**EXPERIMENTAL INVESTIGATION ON NOVEL HETEROGENEOUS CATALYST BLEND IN DI-DIESEL ENGINE WITH HYDROGEN ENRICHMENT**” done by me under the guidance of **Dr. J. HEMANANDH, M.E., Ph.D.** at **Sathyabama Institute of Science and Technology, Chennai** is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Mechanical Engineering.



DATE: 09/05/22

SIGNATURE OF THE CANDIDATE



PLACE: Chennai

SIGNATURE OF THE CANDIDATE

ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to the 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 thanks to **Dr. PRAKASH, M.E., Ph.D., Dean, School of Mechanical Engineering,** and **Dr. G. ARUN KUMAR M.E., Ph.D., Head of the Department, Department of Mechanical Engineering,** for providing me with the 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. J. HEMANANDH, M.E., Ph.D., Associate Professor, Department of Mechanical Engineering** for his valuable guidance, suggestions and constant encouragement paved way for the successful completion of my project work.

I wish to 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

In recent years, humanity has been pressed to rethink how it obtains energy and how it manages and regulates the eventual disposal of trash into the environment. Biofuels are being touted as a viable replacement for fossil fuels. This study investigates the effects of combining Potato Peel & Coconut Husk Ash (PCC) as a novel heterogenous bio-catalyst for the transesterification of Waste Cooking Oil (WCO) with detailed EDAX and SEM results. Different test fuels were created using the bio-catalyst namely (WCOP 10, WCOP 20,) which were then enriched with Hydrogen in a CI Engine Kirloskar, In varying concentrations of 3 LPM, 9 LPM. Tests were conducted to study the engine characteristics and engine emissions.

LIST OF CONTENTS

CHAPTER No.	TITLE	PAGE No.
1	INTRODUCTION	1
	1.1 ALTERNATIVE FUELS	1
	1.2 BIOFUELS	1
	1.3 BIODIESEL	2
	1.4 ADVANTAGES OF BIODIESEL	3
	1.5 DISADVANTAGES OF BIODIESEL	3
	1.6 APPLICATIONS	4
	1.7 WASTE COOKING OIL AS A FEEDSTOCK	4
	1.8 CHARACTERIZATION OF CATALYSTS	5
	1.8.1 HOMOGENEOUS CATALYST	6
	1.8.2 BASE CATALYST	6
	1.8.3 ACID CATALYST	6
	1.8.4 HETEROGENEOUS CATALYST	6
	1.8.5 BASE CATALYST	7
	1.8.6 INSIGHT INTO COCONUT HUSK AS SOLID CATALYST	7
	1.8.7 INSIGHT INTO POTATO PEEL AS A SOLID CATALYST	8
	1.9 TRANSESTERIFICATION	8
	1.10 HYDROGEN	9
2	LITERATURE SURVEY	15
3	AIM AND SCOPE OF THE PROJECT	19
4	MATERIALS AND METHODS	20
	4.1 PROCUREMENT OF MATERIALS FOR TRANSESTERIFICATION	20
	4.2 PREPARATION OF CATALYST	20

4.3 CATALYST ANALYSIS	21
4.5 ELEMENTAL COMPOSITION OF BIO-CATALYSTS	22
4.6 FREE FATTY ACID TEST FOR WASTE COOKING OIL (WCO)	23
4.7 TRANSESTERIFICATION	23
4.8 EXPERIMENTAL SETUP	24
4.9 SPECIFICATION OF ENGINE	25
4.10 TEST PROCEDURE	26
5 RESULTS AND DISCUSSION	28
5.1 EMISSION OF CARBON MONOXIDE	28
5.2 EMISSION OF HYDROCARBON	28
5.3 EMISSION OF NITROUS OXIDE	29
5.4 EMISSION OF CARBON DIOXIDE	30
5.5 BRAKE THERMAL EFFICIENCY	31
5.6 BRAKE SPECIFIC FUEL CONSUMPTION	31
5.7 PRESSURE AND CRANK ANGLE	32
5.8 HEAT RELEASE RATE	33
CONCLUSION	34
REFERENCES	36

LIST OF ABBREVIATIONS

ACRONYM	EXPANSION
PCC	Potato Peel & Coconut Husk Ash
WCO	Waste Cooking Oil
WCOP (10&20)	PPC Bio-Diesel And 10% & 20% Pure Diesel.
WCOB (10 & 20)	BPC Bio-Diesel And 10% & 20% Pure Diesel
3 & 9 LPM	Hydrogen Flow Rate At 3 & 9 L/Min
CI	Compression Ignition
CO	Carbon Monoxide
HC	Hydrocarbon
CO ₂	Carbon Dioxide
NO _x	Nitrous Oxide
O ₂	Oxygen
BTHE	Brake Thermal Efficiency
BP	Brake Power
SFC	Specific Fuel Consumption
DI	Direct Injection
HRR	Heat Release Rate

LIST OF FIGURES

FIGURE No.	TITLE	PAGE No.
1.1	Catalyst Characterization	5
1.2	SEM Images of CH	7
1.3	EDAX of CH	7
1.4	SEM Images of PP	8
1.5	EDAX of PP	8
1.6	Engine Testing Rig Setup	12
1.7	Cross-Sectional View of Engine Cylinder in CAD	13
4.1	(a) Placing the sample in a muffle furnace	20
4.1	(b) Calcinated sample in a crucible	20
4.2	SEM images of (a) Potato Peel	21
4.2	SEM images of (b) Coconut Husk	21
4.3	EDAX graphs of (a) Potato Peel	22
4.3	EDAX graphs of (b) Coconut Husk	22
4.4	Illustrations of Transesterification process	24
4.5	Schematic of the testing rig	26
4.6	Engine Testing Rig Equipment	27
5.1	Emissions Graphs of Carbon Monoxide	28
5.2	Emissions Graphs of Hydrocarbon	29
5.3	Emissions Graphs of Nitrous Oxide	30
5.4	Emissions Graphs of Carbon Dioxide	30
5.5	Performance Report on Brake Thermal Efficiency	31
5.6	Performance Report on BSFC	32
5.7	Performance Report on Pressure and Crank Angle	32
5.8	Performance Report on Heat Release Rate	33

LIST OF TABLES

TABLE No.	TITLE	PAGE No.
1	Elemental Composition of Bio-Catalyst PP & CH in Percent	22
2	FFA Test Parameters	23
3	Fuel Properties In Accordance To ASTM D975 Standards	25

CHAPTER 1 - INTRODUCTION

1.1 ALTERNATIVE FUELS

Alternative fuels are derived from non-fossil fuel sources. The majority are manufactured in the United States, lessening our reliance on foreign oil, while a few are generated from renewable sources. They often produce less pollution than gasoline or diesel.

Ethanol is produced in the United States from corn and other crops. It emits fewer greenhouse gases (GHGs) than gasoline or diesel. Electricity is generated in the United States from a variety of sources, including coal, fossil fuels, atomic power, and renewable energy.

While using electricity to power automobiles produces no piping emissions, creating electricity produces pollutants and greenhouse gases. Biodiesel is a type of diesel made from vegetable and animal lipids. It always emits fewer pollutants into the atmosphere than petroleum-based diesel.

Natural gas is a fuel that is plentiful in the United States. It emits fewer pollutants and greenhouse gases.

Propane, often known as liquefied fossil oil gas (LPG), is a fuel that is widely available in the United States. It emits fewer damaging air pollutants and greenhouse gases than gas. Domestically, hydrogen will be produced using fossil fuels (such as coal), atomic power, or renewable resources such as hydropower. Pure H-powered cell vehicles generate no harmful emissions into the atmosphere.

1.2 BIOFUELS

Energy obtained from biofuels is referred to as bioenergy. Biofuels are fuels created directly or indirectly from organic matter, such as biomass, plant materials, and animal waste.

Bioenergy currently meets about 100 percent of global energy needs. Many of these are accounted for by ancient unprocessed biomass such as fuelwood, charcoal, and animal dung, which provides the greatest energy for a large number of people in underdeveloped nations who utilize it mostly for food preparation and heating.

Biofuels may now be extracted from materials such as wood, crops, and garbage using more advanced and cost-effective conversion technology. Despite the fact that the phrase is widely used in the literature in a very narrow sense to refer primarily to liquid biofuels, biofuels will be solid, gaseous, or liquid for transport.

Agricultural crops, as well as ordinary food plants and specific energy crops, could be used to make biofuels. Biofuels can be made from biological, agricultural or forestry wastes, or municipal wastes, as well as by-products and wastes from the food industry and food service.

There is a differentiation between primary and secondary biofuels. Organic resources are used in an unprocessed form in primary biofuels like fuelwood, wood chips, and pellets, principally for heating, cooking, and electricity production. Secondary biofuels are liquid biofuels such as fermentation alcohol and biodiesel that can be used in automobiles and industrial activities as a result of biomass processing.

Bioenergy is primarily used in residences (80%), with a smaller percentage used in businesses (18%), while liquid biofuels for transportation are still used.

Bioenergy is especially employed in homes (80%), to a lesser extent in business (18%), whereas liquid biofuels for transport still play a restricted role (2%). Even though the assembly of liquid biofuels for transport has big speedily in recent years it presently represents only one of total transport fuel consumption and solely 0.2 to 0.3% of total energy consumption worldwide.

1.3 BIODIESEL

Biodiesel is a clean-burning alternative fuel made from locally available renewable resources. This biofuel could be created from a combination of carboxylic acid alkyl radical esters derived from vegetable oils, animal fats, or recycled greases. Biodiesel is used in compression-ignition (diesel) engines in its purest form wherever it is sold, with very few or no modifications.

Nowadays, diesel engines only have a passing resemblance to the engine that a scientist built. His engine was built from the ground up to run on coal soil. Furthermore, they may run on the theme of something that will burn for the first several decades. Automotive diesel engines were quite tolerant when it came to the fuel they used, even if it was late in the 1970s. Today's diesel engines are far more cost-effective and environmentally friendly than their predecessors, thanks in part to the fact that they

run on a more restricted fuel. It allows engine manufacturers to fine-tune their equipment for increased performance. The physical and chemical properties of biodiesel and fuel are very similar. They're similar enough that biodiesel can be used in modern diesel engines.

Biodiesel and fuel can be mixed in any proportion. We have the ability to discover at truck stops and petrol stations, biodiesel blends like B20, which is two-hundredth biodiesel and eightieth diesel, are available. When biodiesel is mixed with gasoline, the result is a cleaner-burning fuel than diesel alone. Everyone has seen the black clouds, or soot, that erupt from a diesel truck's exhaust after it is loaded. However, when biodiesel is mixed with diesel, the amount of soot produced is reduced, and dirty diesel become clean diesel.

1.4 ADVANTAGES OF BIODIESEL

- Produced using renewable resources.
- Compatible with existing diesel engines.
- Emissions of greenhouse gases are reduced (e.g., B20 reduces CO₂ by 15 percent).
- Locally grown, produced, and distributed.
- Refineries for biofuels that are less polluting.
- Non-Toxic and Biodegradable.
- Improved Fuel Economy.
- Reduced reliance on foreign oil.
- Air quality has improved.
- Biodiesel is unquestionably a safer fuel than fossil fuels.
- Biodiesel has the potential to end the energy crisis and politics.

1.5 DISADVANTAGES OF BIODIESEL

- Variation in Biodiesel Quality.
- Low-temperature use is not recommended.
- Some engines' rubber hoses may be harmed by biodiesel
- Biodiesel is Expensive Compared to Petroleum.
- Biodiesel is made from petroleum diesel.
- Monoculture refers to the practice of growing the same crop over and over instead of experimenting with other varieties.

- The engine is clogged.
- Fertilizer usage has increased.
- Suitability in a certain region.

1.6 APPLICATIONS

- In the Automobile industry
- In Aviation
- In cooking
- Energy Generations
- Clean oil Spills and Grease

1.7 WASTE COOKING OIL AS A FEEDSTOCK

WCO biodiesel manufacturing can partially replace fossil fuels while also alleviating the energy crisis and pollution. Furthermore, WCO is less expensive than fresh vegetable oils, lowering the cost of biodiesel production. If the FFA content of WCO is greater than 15%, the WCO can be classified into two categories. Then it's referred to as brown grease; otherwise, it's referred to as 'yellow grease.' Every year, 1 billion tonnes of WCO are produced around the world. WCO was gathered in the EU at a rate of 0.7–1 MT each year, according to estimates.

Around 65[thin space (1/6-em)] tonnes of WCO were found among the 80[thin space (1/6-em)] tonnes of WCO. Thousands of tonnes were gathered in the UK alone, mostly from large restaurants and food processing plants.

As a result, WCO disposal is a big concern, as it would otherwise contaminate water and the environment in general. Although some WCO oil was used in the manufacturing of soap, the vast majority of WCO was discarded into rivers and landfills. In light of this, producing biodiesel from WCO not only decreased the cost of biodiesel, but also handled the WCO disposal problem and reduced pollution.

1.8 CHARACTERIZATION OF CATALYSTS

Both the catalysts and the FAME generated are characterized using a variety of analytical techniques. As needed, each analytical technique will be detailed in the following sections. Fourier transform infrared spectroscopy (FT-IR) is commonly used

to detect the presence of various functional groups in catalysts as a preliminary investigation, while X-ray diffraction (XRD) can be used to evaluate crystallinity and qualitative detection of elements present in catalysts. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) can be used to examine the surface appearance, particle size, and structure of catalysts (TEM). In Figure 1.1 we can note the classification of catalysts.

Energy-dispersive X-ray spectroscopy is used to analyse the chemical compositions (EDX). X-ray fluorescence (XRF) and X-ray photoelectron spectroscopy (XPS) examinations are frequently performed for the quantitative determination of the elements contained in the catalyst, as well as to provide chemical state information. Brunauer–Emmett–Teller (BET) analysis is used to determine the surface area, pore-volume, and pore diameter, whereas thermogravimetric analysis is used to determine the catalysts' thermal stability (TGA). NH₃ and CO₂ temperature-programmed desorption (TPD) studies are commonly used to determine the acidity and basicity of catalysts.

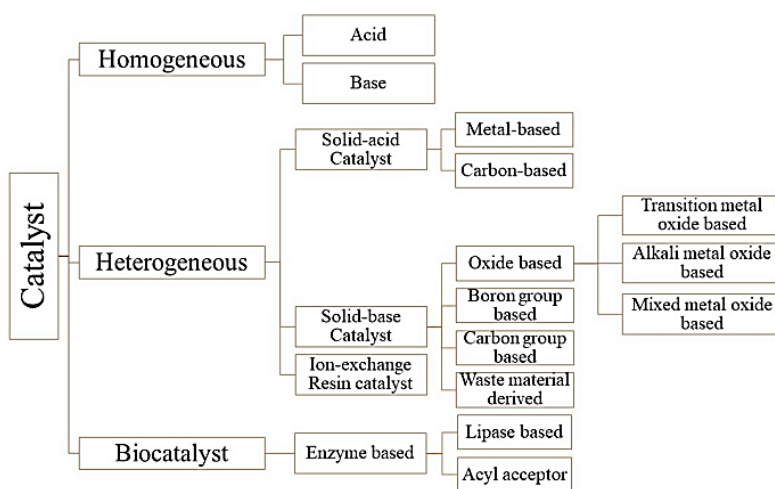


Fig. 1.1 Catalyst Characterization

1.8.1 HOMOGENEOUS CATALYST

The homogeneous catalysts utilized for the transesterification reaction are classified into two groups, such as (i) base catalysts (for example, NaOH and KOH), and (ii) acid catalysts, such as sulphuric, sulphonic, hydrofluoric, and hydrochloric acids.

1.8.2 BASE CATALYST

Homogeneous base catalysts are most widely investigated in the transesterification of vegetable oil to FAME, as they are cheap and easily accessible. To date, several

homogeneous base catalysts have been utilized for the synthesis of FAME, *e.g.*, KOH, NaOH, and NaOCH₃

The use of NaOH and KOH as catalysts resulted in outstanding catalytic activity for biodiesel generation, including a short reaction time and a high biodiesel output, and all of this happened at room temperature and pressure. However, there are certain drawbacks to this method, such as the formation of water as a by-product, which reduces biodiesel production. However, it is fit for refined vegetable oils with low FFA content (ranging from less than 0.5 wt% to less than 2 wt%).

1.8.3 ACID CATALYST

Because they are more reactive and less expensive, base catalysts are frequently favoured over acid catalysts. Base catalysts, on the other hand, may react with the FFA in the feedstock during transesterification, resulting in soap formation via saponification, which consumes the catalyst and reduces its reactivity. Meanwhile, an acidic catalyst is neutral to FFA and hence produces better results when transesterifying or esterifying vegetable oils or fats with a high FFA content (>2%). It has issues with the atmosphere and corrosion. 69 Acid-catalysed biodiesel synthesis is not particularly popular and is investigated less because of these drawbacks.

1.8.4 HETEROGENEOUS CATALYST

Although the homogeneous catalyst has its own benefits, such as high reactivity and low cost, its use in biodiesel production comes with several drawbacks. The low quality of glycerol produced, the fact that the catalyst cannot be regenerated, and the lengthy procedure needed in biodiesel purification are all examples of these flaws. As a result, the entire process is labour-intensive and inefficient. As a result, in recent years, the heterogeneous catalyst has gotten a lot of interest for biodiesel production, because it can be tuned to specific needs and easily recovered and reused for multiple cycles of catalytic.

The following benefits of using a solid catalyst in transesterification make the process more environmentally friendly: The catalyst can be reused, very little wastewater is formed throughout the process, glycerol separation from the final mixture (glycerol, biodiesel, and catalyst) is considerably easier, and high purity glycerol is obtained.

1.8.5 BASE CATALYST

Basic heterogeneous catalysts have received the most attention in recent years because they may overcome the limitations of homogeneous basic catalysts and exhibit outstanding catalytic activity under mild reaction conditions. These catalysts, on the other hand, are only suited for biodiesel feedstocks with low FFA content; otherwise, the catalysts will react with the FFA and form soap via the saponification reaction. This makes separating biodiesel from glycerol time-consuming, lowering biodiesel yield. This section goes over several solid base catalysts that have been reported in the literature, including alkaline metal oxides, transition metal oxides, mixed metal oxide/hydroxides, zeolites, and biomass-based catalysts.

1.8.6 INSIGHT INTO COCONUT HUSK AS SOLID CATALYST

We chose coconut husk as the raw material for catalyst manufacturing since it is abundant and affordable in nature. The catalyst is made using a simple approach that involves just controlled heat treatment (combustion) and no chemical processing, with the ash obtained being used directly for biodiesel production.

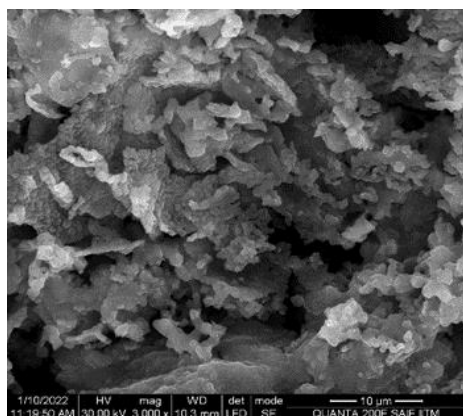


Fig. 1.2 SEM Images of CH

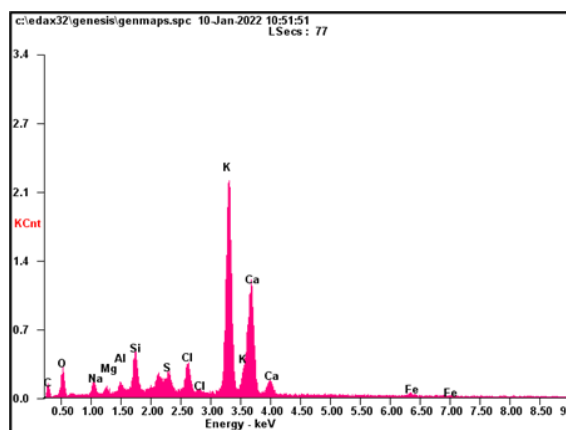


Fig. 1.3 EDAX of CH

As seen in Figure 1.2 and Figure 1.3 indicate the presence of high K content intrinsically present in coconut husk-derived catalyst is adequate for outstanding catalytic activity, creating biodiesel meeting international requirements even by room temperature reaction.

1.8.7 INSIGHT INTO POTATO PEEL AS A SOLID CATALYST

The potato peel has been transformed into a possible source of bio-diesel and green heterogeneous catalysts using a sustainable processing method. The thermochemical conversion waste (biochar) was repurposed as a green, renewable, and long-term

source for heterogeneous catalysts. Calcination was used to recover the alkali and alkaline-rich biochar, which was then converted into bio-based mixed metal oxide and carbonates.

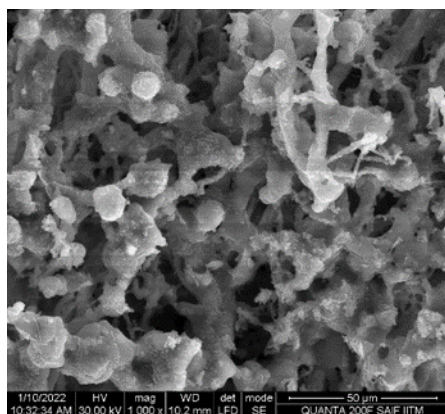


Fig. 1.4 SEM Images of PP

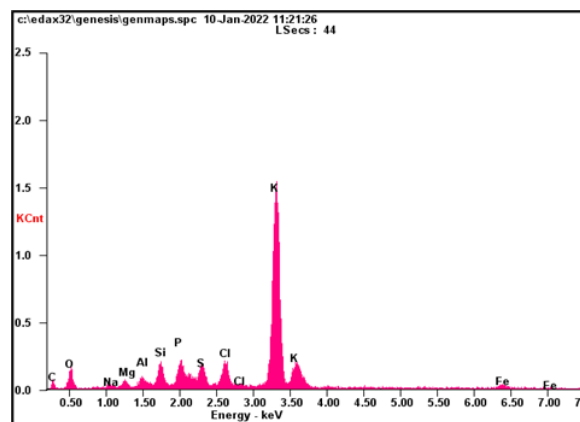


Fig. 1.5 EDAX of PP

Since the scientific world hasn't tapped into the potential of the Potato peel as a versatile heterogeneous catalyst there aren't many details regarding the catalytic activity of the bio-catalyst. But through various tests such as SEM & EDAX we were able to map put the morphological and chemical compounds present in it as shown above in Figure 1.4 and Figure 1.5. We noted the presence of strong base catalyst potassium in the bio-waste which indicate the potential use in the transesterification of biodiesel.

1.9 TRANSESTERIFICATION

The process of allowing non-edible oil to chemically react with alcohol is known as transesterification or alcoholysis. Methanol and ethanol are the most widely used alcohols in this process because of their low cost and availability. This reaction is commonly used to lower the viscosity of non-edible oil and convert triglycerides to ester. Catalytic transesterification and noncatalytic transesterification are the two methods for transesterification.

1.10 HYDROGEN

Hydrogen is classified as an alternate fuel under the 1992 Energy Policy Agreement. The possibility to use hydrogen fuel cells in zero-emission cars, as well as the fuel cell's quick filling time and excellent efficiency, has sparked interest in hydrogen as a transportation fuel. Compared to a gasoline-powered internal combustion engine, a

fuel cell with an electric motor is two to three times more efficient. Hydrogen may be used as a fuel in internal combustion engines.

Reverend W. Cecil described the first effort at creating a hydrogen engine in 1820. In a paper titled "On the Application of Hydrogen Gas to Produce Moving Power in Machinery," Cecil presented his findings to the Cambridge Philosophical Society. The vacuum concept, in which atmospheric pressure forces a piston back against a vacuum to generate power, was used in the engine. The vacuum is formed by burning a hydrogen-air mixture and then letting it expand and cool.

Despite the fact that the engine functioned properly, vacuum engines were never commercially viable. N. A. Otto (the developer of the Otto cycle) reportedly employed ---a synthetic production gas for fuel during his experiments with combustion engines Key Points & Notes in the 1860s and 1870s, which had a hydrogen content of over 50%. Otto tried gasoline as well, but found it too risky to work with, so he went back to using gaseous fuels. The carburettor, on the other hand, ushered in a new era in which gasoline could be utilized both effectively and safely, and interest in alternative fuels waned.

Since hydrogen has the best energy-to-weight ratio of any fuel, it has been employed extensively in the space program. Liquid hydrogen is the preferred rocket fuel, and it has been used in the upper stages of launch vehicles on numerous space missions, including the Apollo moon missions, Skylab, the Viking Mars probes, and the Voyager Saturn mission. Concerns about clean air, stronger air pollution regulations, and a desire to minimize on fossil fuels have reignited interest in hydrogen as a vehicle fuel in recent years.

As an addition to a hydrocarbon fuel, hydrogen can be beneficial in internal combustion engines. Because both gases may be stored in the same tank, hydrogen is most typically blended with high-pressure natural gas for this purpose. When hydrogen is mixed with other fuels, it is normally stored separately and mixed in a gaseous condition right before ignition. In general, using hydrogen in conjunction with other fuels that require substantial storage systems, such as propane, is impracticable.

Liquid fuel and gaseous hydrogen cannot be held in the same container. Because of its low density, hydrogen will float on top of the liquid and not mix. Furthermore, because liquid fuels are held at low pressures, just a little amount of hydrogen may be

introduced to the vessel. Liquid hydrogen cannot be kept alongside other fuels in the same container. The low boiling point of hydrogen causes other fuels to freeze, resulting in fuel "ice"! Hydrogen can be mixed with compact liquid fuels like gasoline, alcohol, or diesel as long as they are kept separate.

The gasoline tanks can be shaped to fit into vacant places on the vehicle in these applications. Existing vehicles of this type often run on one or the other fuel, but not both at the same time. This technique has the advantage of allowing the vehicle to continue to operate even if hydrogen is not available. Because hydrogen's autoignition temperature is too high, it cannot be used directly in a diesel (or "compression ignition") engine (this is also true of natural gas). As a result, diesel engines require spark plugs or the use of a little amount of diesel fuel to ignite the gas (known as pilot ignition). Hythane, for example, is a commercially accessible gas mixture that contains 20% hydrogen and 80% natural gas. A natural gas engine does not need to be modified at this ratio, and tests have shown that emissions are decreased by more than 20%. Further reductions in emissions can be achieved by mixing more than 20% hydrogen with natural gas, although additional engine changes are required.

In terms of nitrogen oxide emissions and fuel economy, the lean operation of any internal combustion engine is hazardous. The disadvantage of lean operation with hydrocarbon fuels, as with hydrogen, is a lower power output. Hydrocarbon engines' lean operation has additional disadvantages. Despite being over the fuel's LFL, lean mixes are difficult to ignite. Misfire occurs as a result, increasing unburned hydrocarbon emissions, lowering performance, and wasting fuel. Another problem is that 3-way catalytic converters have a lower conversion efficiency, resulting in higher hazardous emissions.

All of these disadvantages are mitigated to some extent by mixing hydrogen with other hydrocarbon fuels. Because hydrogen has a low ignition energy limit and a high burning speed, it is easier to ignite hydrogen/hydrocarbon mixtures, minimizing misfire and so improving emissions, performance, and fuel economy. When it comes to power output, hydrogen increases the energy density of a lean mixture by raising the hydrogen-to-carbon ratio, which enhances torque at wide-open throttle.

1.11 COMBUSTIVE PROPERTIES OF HYDROGEN

The properties that contribute to its use as a combustible fuel are its:

- Low ignition energy
- Small quenching distance
- High autoignition temperature
- High flame speed at stoichiometric ratios
- High diffusivity
- Very low density
- Wide spectrum of flammability

1.12 HYDROGEN FUEL DELIVERY SYSTEM IN CI ENGINES

Pre-ignition can be reduced or eliminated by modifying or redesigning the fuel delivery system. The three primary forms of hydrogen fuel delivery systems are central injection (or "carburetted"), port injection, and direct injection. During the intake stroke, central and port fuel delivery systems inject a fuel-air combination. The injection is made at the inlet of the air intake manifold in the case of central injection or a carburettor. It is injected at the inlet port in the event of port injection. Direct cylinder injection is a more advanced technology that involves generating the fuel-air mixture inside the combustion cylinder after the air intake valve has been closed.

1.13 EXPERIMENTAL SETUP

The present work was carried out in a Kirloskar make single-cylinder, water-cooled, four-stroke, direct injection (DI) diesel engine, running at peak rated power of 5.2kW at a speed of 1500 rpm and has a compression ratio of 17.5:1. Provision is also made for interfacing airflow, fuel flow, temperatures, and load measurement. One valve is connected to the silencer and the other valve is connected to the smoke meter from the exhaust valves. NDIR (non-dispersive infrared) approach was used to measure CO (in percent volume), HC (ppm), NO_x (ppm), and CO₂ (ppm) emissions using an AVL 444 di-gas analyser. The smoke density in HSU was measured using an AVL 437 C free accelerator smoke meter (Hartridge smoke unit). The entire engine setup is shown in Figure 1.6 below.



Fig. 1.6 Engine Testing Rig Setup

Engine Test Rig with few significant instruments-

- 1) AVL Gas Analyzer 444N.
- 2) Single Cylinder Diesel Engine Block.
- 3) Loading column with displays for RPM and Fuel Consumption Tube.
- 4) Data Acquisition systems.
- 5) Electric Load Coupler Dynamometer.

1.14 HYDROGEN INJECTION

Direct injection, manifold injection, and continuous manifold injection are the three ways of adding hydrogen to a diesel engine. The manifold injection process involves injecting hydrogen into the air intake manifold and replacing the air with hydrogen. In the case of direct injection, hydrogen is delivered directly to the cylinder head as illustrated in Figure 1.7, but the engine must be modified to ensure durability in the face of high combustion temperatures.

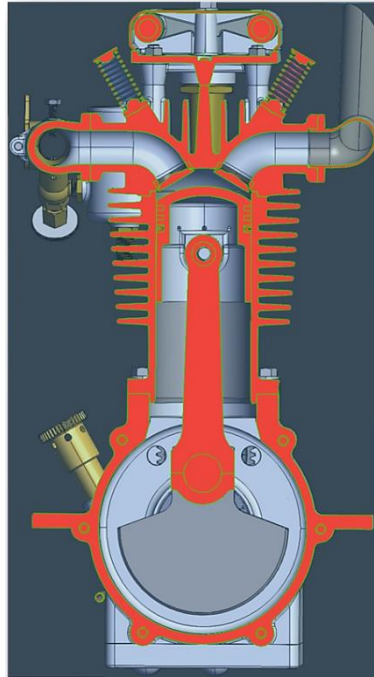


Fig. 1.7 Cross-Sectional View of Engine Cylinder in CAD

In a CI engine, hydrogen can be used in a dual fuel mode. Because hydrogen is the primary fuel in this mode, ignition can be accomplished using diesel pulverization, which is renowned as the most practicable approach when combustion stability is considered. As a result, methods such as timing manifold/port injection, direct hydrogen injection, and continuous manifold injection are used. Because of anomalous combustion, such as knock, pre-ignition, and backfire, the engine's working area is limited while using continuous manifold injection. Because a portion of the intake air is replaced by hydrogen due to a decline in volumetric efficiency, engine output is reduced in both timing manifold/port injection and continuous manifold direct injection techniques.

Direct hydrogen infusion can help solve these problems. In this situation, however, a diesel engine modification and the installation of a high-pressure H_2 injector on the cylinder head are required. Because this high-pressure H_2 injector is hard to come by, it should be built to a specific design that provides longevity at high combustion temperatures. As a result, the timing manifold/port injection approach allows hydrogen to be used in dual-fuel diesel engines with diesel pulverization. Hydrogen has a larger flammability limit, a faster flame speed, and a faster combustion velocity when compared to diesel fuel]. Hydrogen also has a short quenching distance, a high thermal value, and a strong diffusivity. As a result, using hydrogen in diesel engines

via the dual fuel mode with diesel pulverization is beneficial because PM emissions are lowered. CO₂, HC, and CO emissions are all reduced because hydrogen does not contain carbon.

CHAPTER 2 - LITERATURE SURVEY

1. Abbaszadeh (2014) [1] researched the effective parameters on biodiesel purification through wet washing. It was observed that acidified water had the best effect on catalyst and soap removal and in case of water residue, tap water showed best results.
2. Mustafa Atakan Akar (2018) [2] conducted an experiment to investigate the performance and emission characteristics of hydrogen-enriched waste oil biodiesel in a compression ignition engine and found hydrogen addition dropped CO and CO₂ emissions.
3. Mohanad Aldhaidhawi (2017) [3] conducted an experimental study on combustion characteristics and performance of tractor diesel engine fueled with diesel, Biodiesel blends, and hydrogen-enriched fuel. The results were found to have lesser emissions due to hydrogen enrichment.
4. Mustafa Kaan Baltacioglu (2016) [4] conducted a comparative study on the performance and emission characteristics of a pilot injection diesel engine with the addition of alternative fuels like pure hydrogen, HHO, and biodiesel.
5. Sangita Banga, Pradeep K.Varshney (2015) [5] compared the efficiency of bio sorbents with organic adsorbents in the purification of Jatropha curcas-based biodiesel by dry washing and observed better performance in biosorbents.
6. Elli Maria Barampouti (2021) [6] conducted an experiment on the sustainable utilization of potato peel based on biofuel production and concluded that the high content of carbohydrates included in potato peel paste can be used for the production of biofuels.
7. Achanai Buasri (2012) [7] experimented with the transesterification of waste cooking oil with methanol in presence of potassium hydroxide catalyst. The study concluded that the optimum conditions for achieving maximum yield consisted of a residence time of 2 hours, reaction temperature of 60°C, and molar ratio 16.
8. Radu Chiriac (2013) [8] studied the emissions of a diesel engine using B20 and the effects of hydrogen enrichment. The results indicated that the presence of hydrogen does not significantly affect the combustion duration.

9. Shyamal Das, and Surya Kanth (2022) **[9]** evaluated the influence of hydrogen enrichment in a diesel engine fueled with diesel and palm biodiesel blend. They concluded that the hydrogen addition relatively lowers the CO emissions.
10. A.C. Eloka (2017) **[10]** conducted a study to investigate the effects of local metallic salts on thermal and physico-chemical properties of tropical *Thevetia peruviana* and *Jatropha curcas* for biodiesel production through transesterification.
11. Anietie O.Etim, and Eriola Betiku (2018) **[11]** experimented on the potential of ripe plantain fruit peels as an eco-friendly catalyst for biodiesel synthesis and observed that it can be a sustainable source for biodiesel production.
12. Mingming Fan, and Hao Wu (2019) **[12]** experimented on synthesizing an alkaline catalyst using waste banana peel and found that the calcined banana peel catalyst showed better catalytic performance.
13. Shin Han, Ga-Yeong Kim (2019) **[13]** experimented with biodiesel production from oleaginous yeast by using banana peel as a carbon source and observed that banana peel can be a cheap feedstock for biodiesel production.
14. Husin, Abubakar (2018) **[14]** researched the use of coconut husk as a solid catalyst for biodiesel production from *Cerbera manghas* seed oil and found coconut husk ash catalyst displays high potential as a solid catalyst for practical application.
15. Modather F.Hussein (2021) **[15]** conducted an experiment on potato peel waste-derived solid acid catalyst for the esterification of oleic acid to biodiesel and observed high oleic acid conversion efficiency of 97.2% at 5 wt%, molar ratio of 12 at 80°C after 2.5 hours.
16. Monnie John (2021) **[16]** conducted an experiment to investigate biodiesel synthesis via transesterification of sunflower oil employing waste ginger leaves derived catalyst. The experimental result shows that 1.6 wt% catalyst, 6:1 molar ratio, 1.5 hours of reactime gave the best results.
17. Surya Kanth, and Sushmita Debbarma (2021) **[17]** conducted a comparative study on performance analysis of diesel engine fueled with hydrogen-enriched edible and non edible biodiesel and found edible oil provides better performance than non edible biofuel.
18. Surya Kanth, and Sushmita Debbarma (2020) **[18]** conducted an experimental study on the effect of hydrogen enrichment in the intake air of diesel engine fuelled with honge biodiesel blend and diesel. The study observed better results with biodiesel blends.

19. Surya Kanth, Sumita Debbarma (2020) **[19]** conducted an experimental investigation of hydrogen-enriched rice brand biodiesel in a diesel engine, and found hydrogen enrichment with biodiesel blend has better results compared to neat diesel fuel.
20. Yasin Karagoz (2016) **[20]** conducted an experimental study on the effect of hydrogen enrichment on combustion characteristics, emissions, and performance of a diesel engine.
21. Harendra Kumar, A. Annam Renita (2021) **[21]** conducted an experiment on process optimization and characterization of biodiesel production from used cooking oil using a heterogeneous eggshell - coconut pith catalyst and obtained 72% biodiesel yield.
22. Prashant Kumar (2015) **[22]** conducted an experimental study on the utilization of renewable and waste materials for biodiesel production as a catalyst. He obtained more than 97% biodiesel yield by using coconut husk ash as a catalyst.
23. Dae-Won Lee, Young Moo Park (2009) **[23]** classified the solid base catalyst for transesterification into six categories and focused on the heterogeneous base catalyst for transesterification in biodiesel production.
24. Dennis Y.C. Leung (2010) **[24]** studied different approaches of reducing free fatty acids in raw oil and refinement of crude biodiesel. He also described other new processes of biodiesel production.
25. D.Y.C. Leung (2006) **[25]** conducted an experimental study on the characteristics and performance of catalysts used for alkaline catalyzed transesterification and optimization for the production of biodiesel.
26. Hoah Chinh Nguyen (2021) **[26]** discussed the catalytic activity, advantages and disadvantages of bio-based catalysts. He observed better catalytic activity in potassium based bio catalysts.
27. Mustafa Ozcali (2017) **[27]** investigated the performance and emission characteristics of a diesel engine fueled with hydrogen-enriched Castor oil methyl ester diesel blends.
28. Parthasarathy.M (2016) **[28]** conducted an experimental study on the effect of hydrogen enrichment on ethanol-biodiesel blend on performance and emission characteristics of diesel engine.
29. Hendrick Maxil Zarate Rocha(2017) **[29]** conducted an experimental investigation of the effects on the performance of a diesel generator set at a constant electric

power of 2.43 kW operating with 7% biodiesel blend and being enriched by hydrogen. He observed reduced ignition delay in B7 due to an increase in hydrogen content.

30. N. Saravanan, G. Nagarajan (2008) **[30]** conducted an experimental study of hydrogen enriched air induction in the compression ignition engine.
31. Selcuk Sankoc (2019) **[31]** conducted an experimental study to investigate the effects of hydrogen addition on biodiesel blends in terms of performance, combustion, and emission under different engine operating conditions. He concluded that the addition of hydrogen in a diesel engine usually exhibits fewer emissions.
32. Hasan Serin (2018) **[32]** conducted an experimental study on performance and emission characteristics of hydrogen-enriched tea seed oil biodiesel and concluded that the blends of tea seed biodiesel with diesel slightly aggravated the performance characteristics of the test engine.
33. Meeta Sharma (2012) **[33]** conducted an experimental study to investigate the catalytic activity of wood ash for transesterification of jatropha oil. The study revealed that the ester conversion of 97-99% could be achieved with wood ash catalyst.
34. S. Sulain, N.I.F. Ruslan (2017) **[34]** conducted an experimental study on heterogeneous catalysts, synthesized from a mixture of coconut waste and eggshells in the ratio of 5:1 for biodiesel production and observed the highest FAME yield of 81%.
35. Indika Thushari, Sandhya Babel (2019) **[35]** conducted an experiment on biodiesel production from waste palm oil using coconut coir husk derived catalyst and the highest biodiesel yield of 89.9% was obtained.
36. Gokhan Tuccar (2018) **[36]** studied the emission and engine performance analysis of a diesel engine using hydrogen-enriched pomegranate seed oil biodiesel and observed improved performance characteristics of the test engine.
37. Vinu Vadery, Binitha N. Narayanan (2014) **[37]** conducted an experiment on Room temperature production of Jatropha biodiesel over coconut husk ash and observed high catalytic activity in coconut husk catalyst.

CHAPTER-3

AIM AND SCOPE OF THE PROJECT

3.1 AIM

The aim of this experimental work is to convert waste cooking oil (WCO) to Bio Diesel (FAME) utilizing a novel blend of heterogeneous bio-catalysts (Potato Peel & Coconut Husk). Furthermore, the yielded FAME will be blended with diesel at various percentages before being enriched with hydrogen at 3LPM and 9LPM to investigate the blends combustion, emission, and performance Characteristics.

3.2 SCOPE

The scope of this work is to:

- Use solid waste such as (Potato Peel & Coconut Husk) a Bio-catalyst to synthesize biodiesel.
- Improve the performance of the engine with addition of hydrogen in combustion process.
- Reduce emissions such as HC, CO and CO₂ by injection of hydrogen.

CHAPTER 4 - MATERIALS AND METHODS

4.1 PROCUREMENT OF MATERIALS FOR TRANSESTERIFICATION

WCO and bio-catalyst was collected from small-scale restaurants for the Transesterification process. These chemicals were procured from the concerned supplier and biodiesel was processed at the IRC Sathyabama University, Chennai and Engine Testing was conducted at Sri Venkateswara Engineering Consultancy Services, Kanchipuram.

4.2 PREPARATION OF CATALYST

Potato peels (PP) and Coconut Husk (CH) were gathered from nearby restaurants. To remove any pollutants in the by-products, they were washed in neutral water. Later to remove the moisture content, it was dried at 100°C for a total of 5 hours [12]. The dried peels were ground into a powder form (40g), with a maximum particle size of less than 2 mm. The collected samples were then placed in a muffle furnace with the help of a crucible as shown in figure 4.1 (a) and were calcined at 600°C at a rate of 10°C per minute. The temperature was held at 600°C for 2 hours under atmospheric pressure to generate the cultivated PP & CH biochar as shown in Figure 4.1 (b) this process helps to disintegrate any contaminants. Due to the melting point (740°C) of Potassium Oxide, calcination above 700°C has been shown to have a negative influence on the performance of the catalyst in prior studies [11]. Later, the samples were kept at a low temperature to preserve their catalytic properties until the next stage of the experiment [33].



(a)



(b)

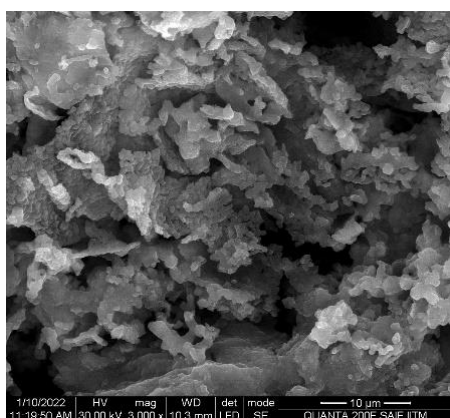
Fig. 4.1: (a) Placing the sample in a muffle furnace (b) Calcinated sample in a crucible

4.3 CATALYST ANALYSIS

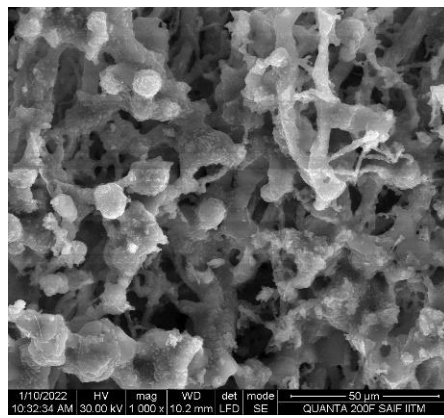
The catalysts were well characterized using Scanning Electron Microscopy (SEM) & EDX analysis techniques to assess their chemical compositions, structure, and morphology. The EDX analysis revealed the presence of several alkali metals and alkaline earth metals in both the samples, which provide the basic sites for the transesterification reactions to produce FAME.

4.4 MORPHOLOGICAL ANALYSIS

A scanning electron microscope (SEM) was utilized to capture images at a magnification of 1000x resolution with working distance (WD) at 30.00kv, high voltage (HV) at 10.5 mm. The micrographs are shown in Figures 4.2 (a)–4.2 (b) represents Potato Peel and Coconut Husk. The surface of Figure 4.2 (a) has a mixture of small flake-like aggregates, and while, Figure 4.2 (b) shows a more distinct spore-like structure with thin strands connecting across the surface [11]. These samples provide a clear indicator of increased surface area which is proportional to the catalytic activity of the catalyst. This goes with the conjunction made by Sharma and his group who noted that heat treatment hinders leaching of Potassium (K) and therefore, increases the shelf life of the catalyst [33].



(a)



(b)

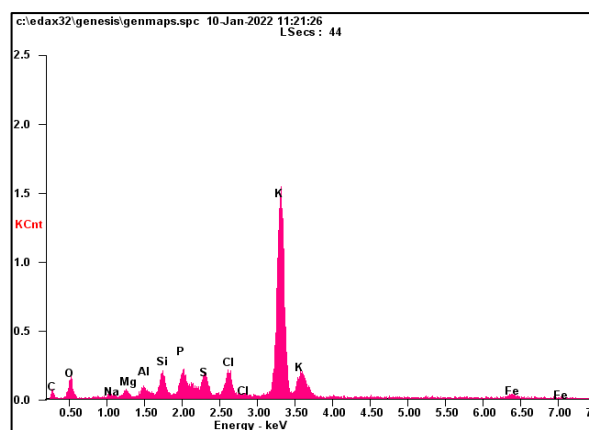
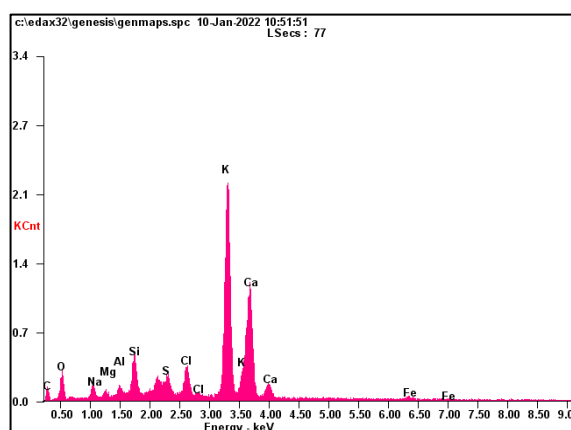
Fig. 4.2: SEM images of (a) Potato Peel (b) Coconut Husk

4.5 ELEMENTAL COMPOSITION OF BIO-CATALYSTS

Table 1 shows the results of the Energy Dispersive X-Ray Analysis (EDAX) carried on the calcinated bio-catalysts. These results reveal the elemental composition present in the bio-chars. The main elements present were K, Na, Ca, Mg, Fe, Al, Si, S, Cl, O, and C. Potassium is the element of interest since it is mainly responsible for the strong basic character of the catalyst in transesterification of triglycerides to biodiesel. From Figure 4.3 (a) & (b) and the Table-1 we can infer that potassium has shown the highest percentage of composition throughout both the samples with PP at 32.47 percent and CH at 22.8 percent but with marginal traces of Cl, Si and S in too. Studies have shown that the carbon and oxygen contents of the coconut husk decrease upon higher temperatures during calcination the same can be inferred for the potato peels [37].

Catalyst %	K	Cl	Si	Na	S	Fe	Al	Mg	Ca	O	C
PP	32.47	3.81	3.84	1.79	3.47	1.36	2.19	1.99	0	25.58	19.3
CH	22.8	3.1	5.1	4.37	2.3	0.72	2	1.75	14.73	26.11	17.2

Table 1: Elemental Composition of Bio-Catalyst PP & CH in Percent



(b)
a) Potato Peel, (b) Coconut Husk

WASTE COOKING OIL (WCO)

Preliminary test FFA test was done for WCO to determine the amount of catalyst required to convert the triglycerides present in the oil to fatty acid methyl ester (FAME)

for successful transesterification. This step plays a crucial role since it helps in avoiding any possible chances for soap formation due to deficiencies in the catalyst quantity moreover, products will be extremely difficult to separate. This test is done in order to determine whether either transesterification or esterification is supposed to be done for the given specimen. 5g of the sample is taken, after which 2.5 ml of iso-propyl alcohol is added, after which 4 drops of 0.1 normality of NaOH is added. The sample is then heated for 60 degrees Celsius and subsequently cooled down to room temperature. 2 drops of an indicator called Phenolphthalein was added to titrate the solution against the normality of NaOH. As a result, the end point appears to be pink in colour. Then note the burette reading. Hence, the FFA of WCO was 0.33, which means $0.33 < 4$. Hence, transesterification was carried out. Reading can be noted in the Table 2 below.

Sample	Oleic acid	NaOH	Burette Reading
5.06	2.82	0.1	2.2

Table 2: FFA Test Parameters

4.7 TRANSESTERIFICATION

In the process of transesterification, the oil is a triglyceride that dissociates into fatty acid methyl ester and glycerol. All the processes are illustrated in a flowchart in Figure 4.4. Methanol is added to this reaction in presence of a catalyst. Firstly, 800 ml of oil was preheated at 60°C, later it was brought down to room temperature. Catalyst Potato Peel & Coconut Husk Ash (PCC) were mixed in 1:1 ratio with a 6 % loading rate. This data was inferred from Vinu Vadery and his group where they reported in their study that indicate 6 % loading rate to provide most efficient catalytic activity since potassium is a strong base present in the catalyst [37]. The oil was transferred to a 3 necked bottom flask which was attached by a reflux condenser at one of its necks. This condenser helps saving losses from evaporation due to heating. The oil was transferred into another flask and it was stirred with the help of a mechanical stirrer to keep the catalyst agitated for 240 mins. After a detailed study of the ratios proposed by various renowned authors has showed that methanol of a feasible ratio of 1:15 projected high yield percentages when compared to other counterpart ratios [37] [35] [24]. After the addition of the catalyst, the mixture was stirred for 3 hours at 400 rpm. 3 hours later, the mixture was transferred to a separating funnel. It was observed that

a partial separation of the 2 layers was distinctly visible. This result was seen after carrying out 3 wet washing processes. The wet washing process eliminates the excess methanol content in the mixture [1]. Successfully, this procedure gave a total yield of 98% of biodiesel.

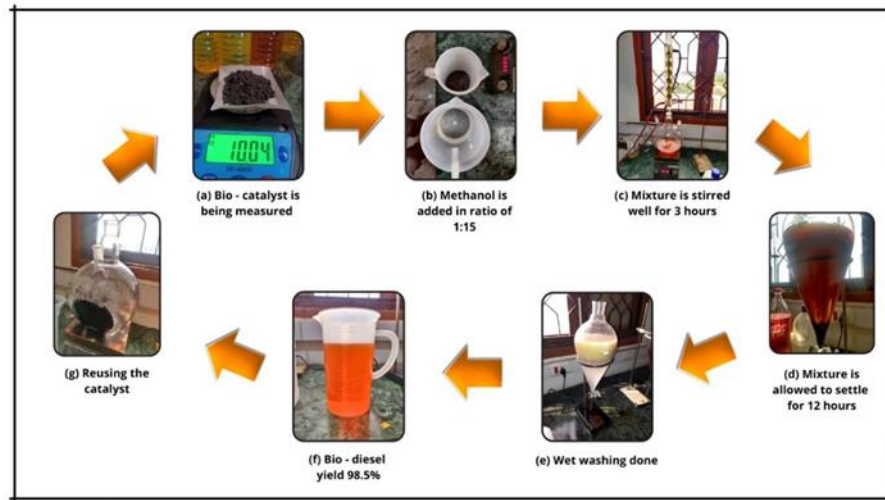


Fig. 4.4 Illustrations of Transesterification process

4.8 EXPERIMENTAL SETUP

The present work was carried out in a Kirloskar make single-cylinder, water-cooled, four-stroke, direct injection (DI) diesel engine, running at peak rated power of 5.2kW at a speed of 1500 rpm and has a compression ratio of 17.5:1. Provision is also made for interfacing airflow, fuel flow, temperatures, and load measurement. One valve is connected to the silencer and the other valve is connected to the smoke meter from the exhaust valves. NDIR (non-dispersive infrared) approach was used to measure CO (in percent volume), HC (ppm), NO_x (ppm), and CO₂ (ppm) emissions using an AVL 444 di-gas analyser. The smoke density in HSU was measured using an AVL 437 C free accelerator smoke meter (Hartridge smoke unit). Cross sectional view of the engine cylinder can be noted in Figure 4.5.

4.9 SPECIFICATION OF ENGINE

Type	Four-stroke, Single Cylinder Vertical Water-Cooled Diesel Engine
Power	5.2 kW
Speed	1500 rpm

Bore Diameter 87.5mm

Stroke Length 110mm

Compression ratio 17.5:1

Table 3: Fuel properties in accordance to ASTM D975 Standards

S.No	Parameters	BioDiesel	Pure Diesel	Hydrogen	ASTM D975
1.	Density	874 Kg/m ³	830 Kg/m ³	0.083 Kg/m ³	820-860 kg/m ³
2.	Kinematic Viscosity @ 40°C	1.32 mm ² /s	2.5 mm ² /s	1.9-4.1 mm ² /s	1.9-4.1 mm ² /s
3.	Flash Point	57°C	52°C	500°C	60-80°C
4.	Fire Point	73°C	60°C	-	-
4.	Calorific Value	34,584 KJ/Kg	42,000 KJ/Kg	1,50,000 KJ/kg	42000 KJ/Kg

Various fuel factors of Biodiesel, Pure Diesel, Hydrogen, and ASTM standards of pure Diesel have been studied, and the Density and Calorific Value of Hydrogen is the lowest when compared to the other fuels. As shown in Table 3, the flash point of Hydrogen is higher than that of Biodiesel, Pure Diesel, and Pure Diesel in ASTM Standards. Biodiesel, on the other hand, has the lowest Kinematic Viscosity and a greater Fire Point than Pure Diesel.

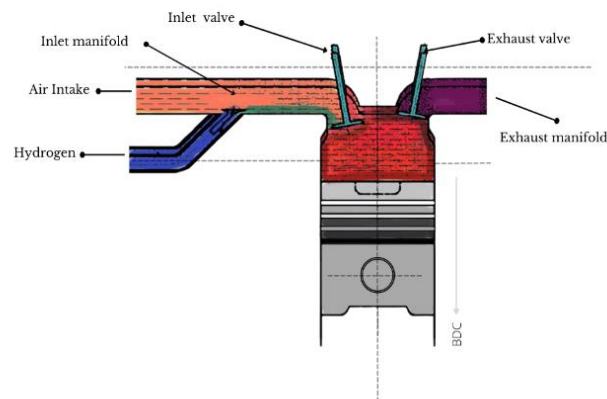


Fig. 4.5 Schematic of the testing rig

4.10 TEST PROCEDURE

For this experimental work, the engine and the auxiliary systems had thorough safety checks to ensure safe & accurate measurements during the runs. At first, bio-diesel blends were made namely WCO P10 3LPM & WCO P20 3LPM and WCO P10 9LPM & WCO P20 9LPM. The engine block was connected with a hydrogen cylinder, flame arrester was used to avoid any backfire from the combustion of H_2 in the supply line. The first test run of WCO P10 was initiated where 3 LPM of H_2 was allowed to enrich the fuel during the combustion in the engine cylinder, for loading the engine an eddy current dynamometer was coupled to the engine which was used to increase the load by 25% at 5 intervals (0%, 25%, 50%, 75%, 100%). In the due period, time (seconds) was noted for 10cc of fuel consumption. The engine in-cylinder pressure was monitored using a piezoelectric pressure transducer of air-cooled type with an inline charge amplifier. The exhaust gas emissions such as carbon dioxide (CO_2), carbon monoxide (CO), unburned hydrocarbon (UBHC), oxides of nitrogen (NO_x), and excess oxygen (O_2) present in the exhaust were measured and recorded by AVL gas analyzer. All the data was interfaced with the systems using RS232. Consequently, all the blends were tested with 3 LPM and 9 LPM at varying loads. Table 3 indicates fuel properties in accordance to ASTM D975 Standards including hydrogen as well.



Fig. 4.6 Engine Testing Rig Equipment

Engine Test Rig with few significant instruments in Figure 4.6:

- 1) AVL Gas Analyzer 444N.
- 2) Single Cylinder Diesel Engine Block.
- 3) Loading column with displays for RPM and Fuel Consumption Tube.
- 4) Data Acquisition systems.
- 5) Electric Load Coupler Dynamometer.

CHAPTER 5 - RESULTS AND DISCUSSION

5.1 EMISSION OF CARBON MONOXIDE

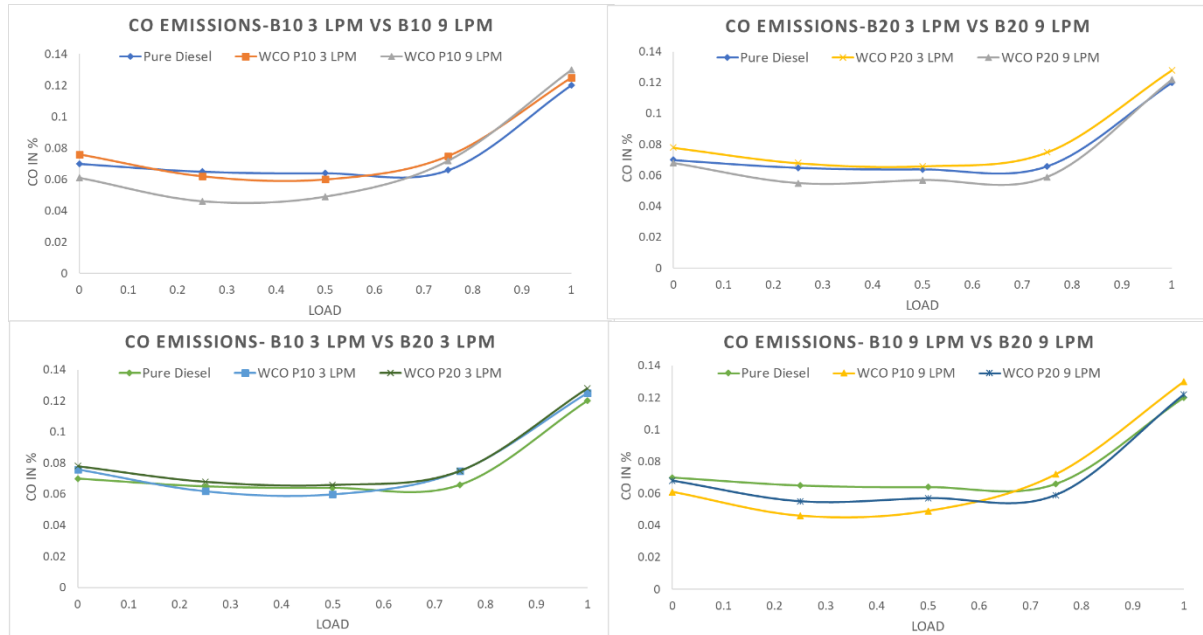


Fig. 5.1 Emission Graphs of Carbon Monoxide with respect to load

The variation of carbon monoxide levels to the hydrogen enrichment at different operation conditions are presented in Figure 5.1. The graphs show a minor increase in CO emissions between B10 3LPM and B20 3LPM. Emission is also examined between B10 3LPM and B20 3LPM. There is a similar marginal rise. On the other hand, emission is compared between 9LPM B10 and 3LPM B10, as well as 9LPM B20 and 3LPM B20. B20 9LPM releases the least CO of the four blends, whereas B20 3LPM emits the most. The increase in CO trends could be due to lack of air supply and time for post-oxidation, carbon monoxide is released during the combustion of fuel which contributes for excess CO at the exhaust manifold [27]. Moreover, CO emissions are strongly influenced by the air-fuel ratio in relation to stoichiometric quantities. This can be noticed under high loads with richer fuel mixture [32].

5.2 EMISSION OF HYDROCARBON

The released hydrocarbon emissions were compared against Pure Diesel. The minor rise in hydrocarbon emissions is significant in the majority of instances. Figure 5.2 compares the emission of unburned hydrocarbons from B10 against B20 (9LPM), B10 vs B20 (3LPM), 3LPM VS 9LPM (B10), and 3LPM vs 9LPM (B10) (B20). From the results we can infer that incomplete combustion, low chamber temperature, weak sealing in the cylinder and piston, and even a thin lubricating oil coating in the

combustion stage can all contribute to unburned hydrocarbon emissions as a byproduct in the emissions [36]. Additionally higher HC emissions come from a lack of effective fuel and air mixing. It can be shown that if hydrogen is added to diesel, UHC emissions will increase marginally.

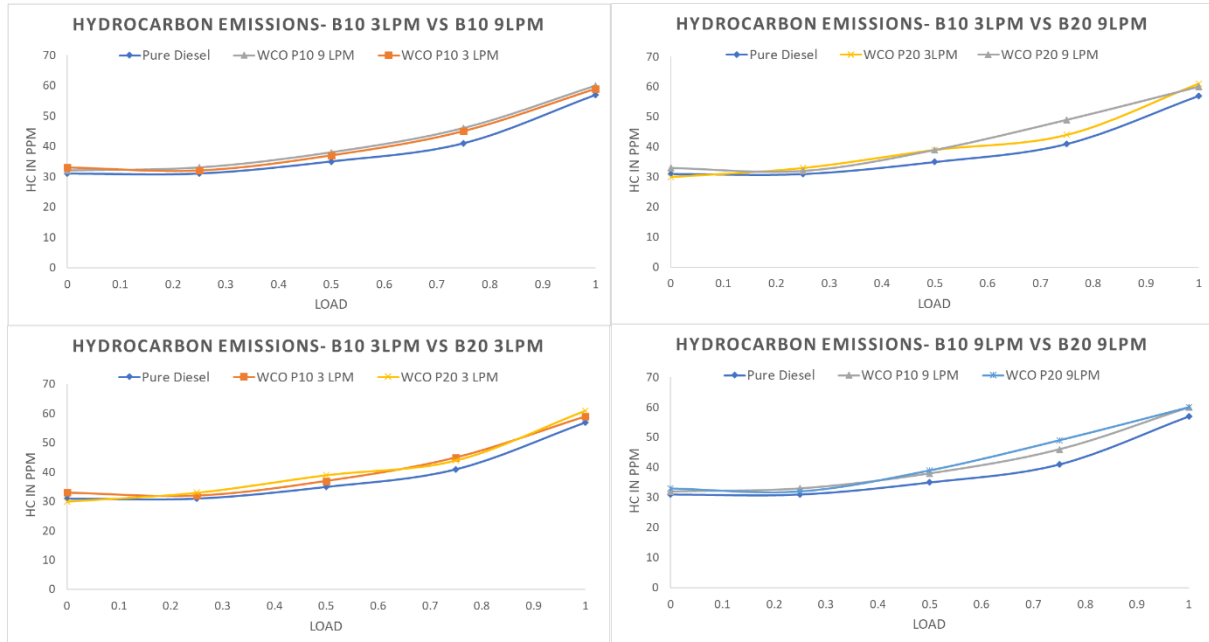


Fig. 5.2 Emission Graphs of Hydrocarbon with respect to load

5.3 EMISSION OF NITROUS OXIDE

Figures 5.3 depicts nitrous oxide comparisons for several blends, including B10 against B20 (9LPM), B10 vs B20 (3LPM), 3LPM vs 9LPM (B10), and 3LPM vs 9LPM (B20). High temperatures are the primary source for the creation of Nitrogen Oxide in the exhaust emissions. When the load is minimal, there is no substantial increase in NO_x . When the load exceeds 30%, however, NO_x emissions gradually deviate and end up higher than pure diesel in comparison. NO_x generation is influenced by the combustion local temperature, oxygen concentration, and nitrogen residence duration at the chamber's high temperature [4]. Hence, when hydrogen is added to the chamber, the temperature rises, resulting in an increase in NO_x emissions which can be seen in the above graphs when fuel is enriched with hydrogen.

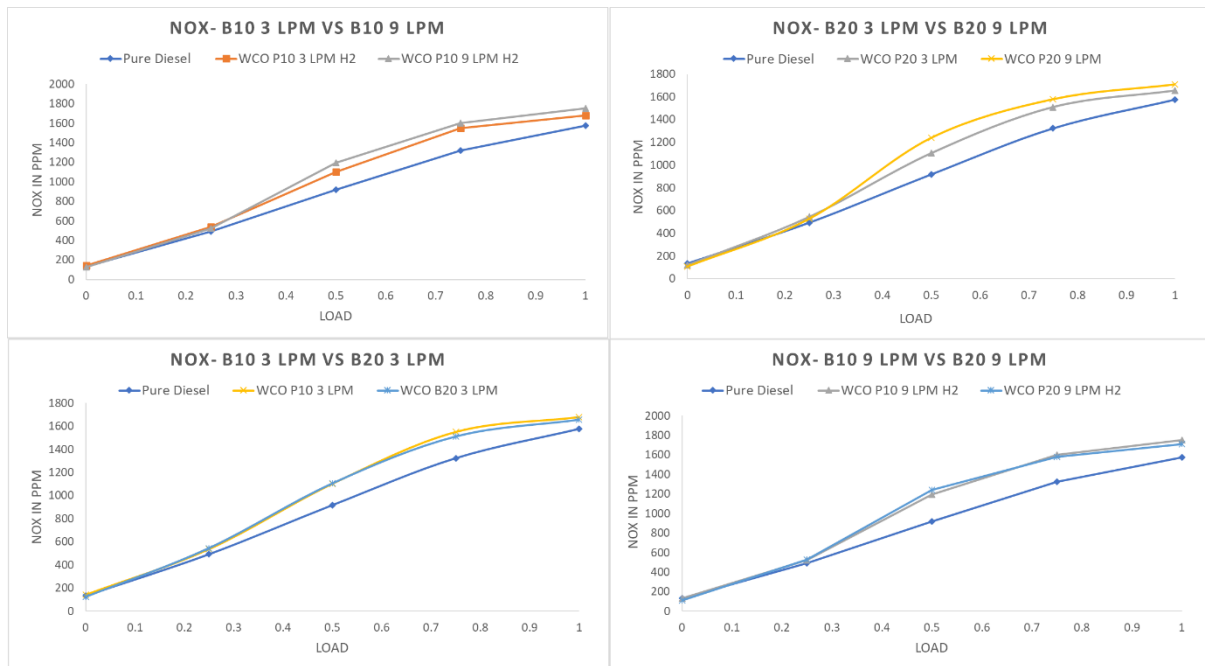


Fig. 5.3 Emission Graphs of Nitrous Oxide with respect to load

5.4 EMISSION OF CARBON DIOXIDE

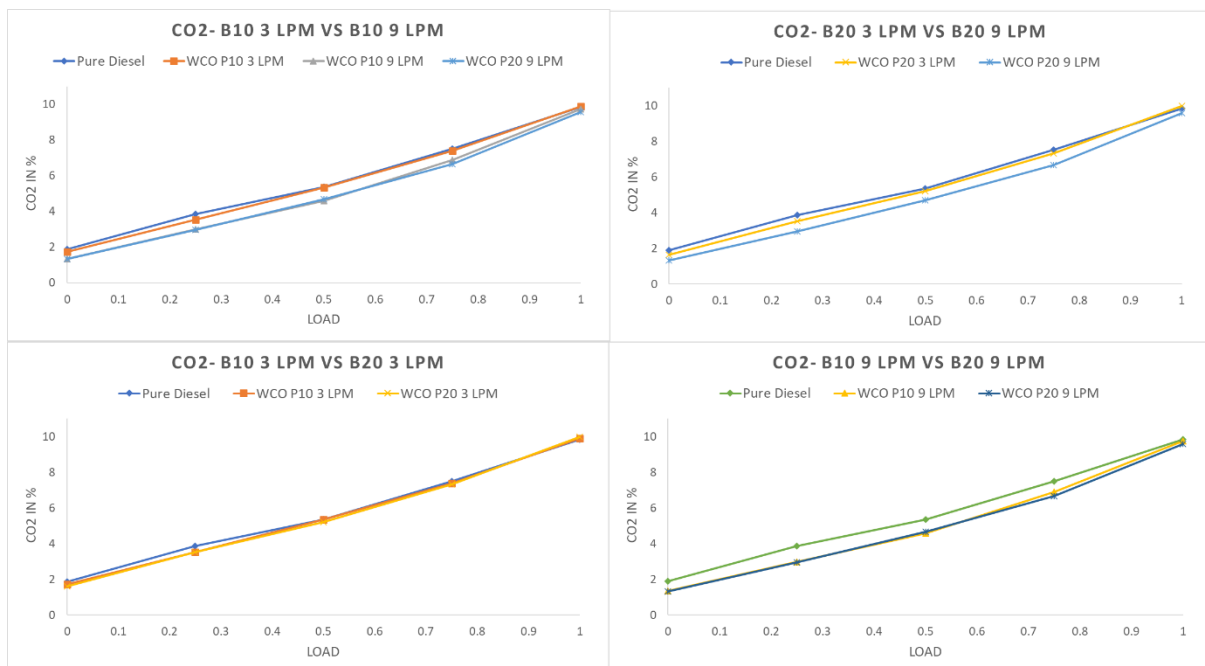


Fig. 5.4 Emissions Graphs of Carbon Dioxide with respect to load

Figure 5.4 shows Carbon Dioxide emissions comparison for a variety of mixes, including B10 vs B20 (9LPM), B10 vs B20 (3LPM), 3LPM against 9LPM (B10), and 3LPM vs 9LPM (B20) (B20). Overall, it is obvious that carbon dioxide emissions are decreasing. To begin, the emissions of B10 3LPM and B20 3LPM are compared, and

it is obvious that the carbon emitted by both blends is comparable to diesel, with a little difference in beginning load situation when compared to diesel. Second, the CO₂ emissions of B10 9LPM and B20 9LPM are compared, revealing that both blends emit less CO₂. One of the most common causes of reduction is the absence of carbon, which is absent in pure hydrogen and hydroxy gas. The findings are also consistent with previous research [8].

5.5 BRAKE THERMAL EFFICIENCY

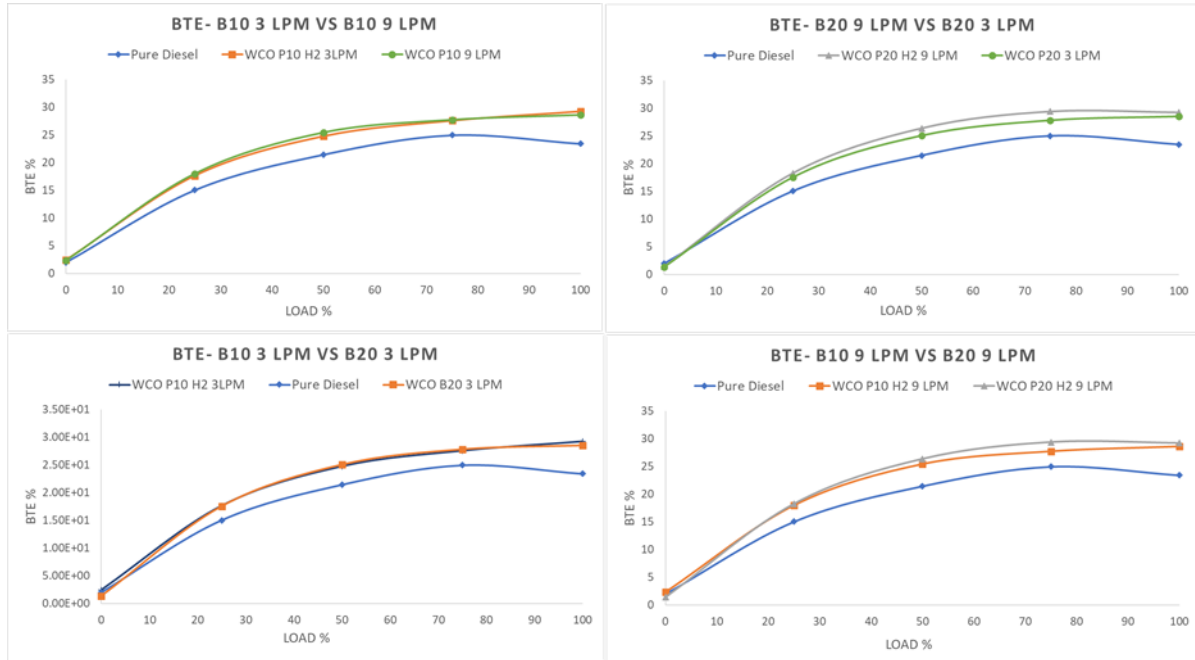


Fig. 5.5 Brake Thermal Efficiency with respect to load

The thermal efficiency of different blends is illustrated in the Figure 5.5. B10 vs B20 (9LPM), B10 vs B20 (3LPM), 3LPM vs 9LPM (B10), and 3LPM vs 9LPM (B20). Overall, it is obvious that as compared to diesel, there is a significant gain in brake thermal efficiency. The high calorific value of hydrogen in the gas mixture, as well as its rapid flame velocity and the presence of atomic hydrogen and oxygen as high energy level equivalents, all contribute to improved brake thermal efficiency.[3]

5.6 BRAKE SPECIFIC FUEL CONSUMPTION

Brake-specific fuel consumption is depicted in graphs in Figure 5.6. All four blends show a reduction in BSFC, with B10 9LPM proving to be the best of the bunch. The lower BSFC could be attributed to the Catalyst, which is PP & CH, or the fuel's higher density and viscosity. Furthermore, the high calorific content of hydrogen has resulted in improved combustion [2].

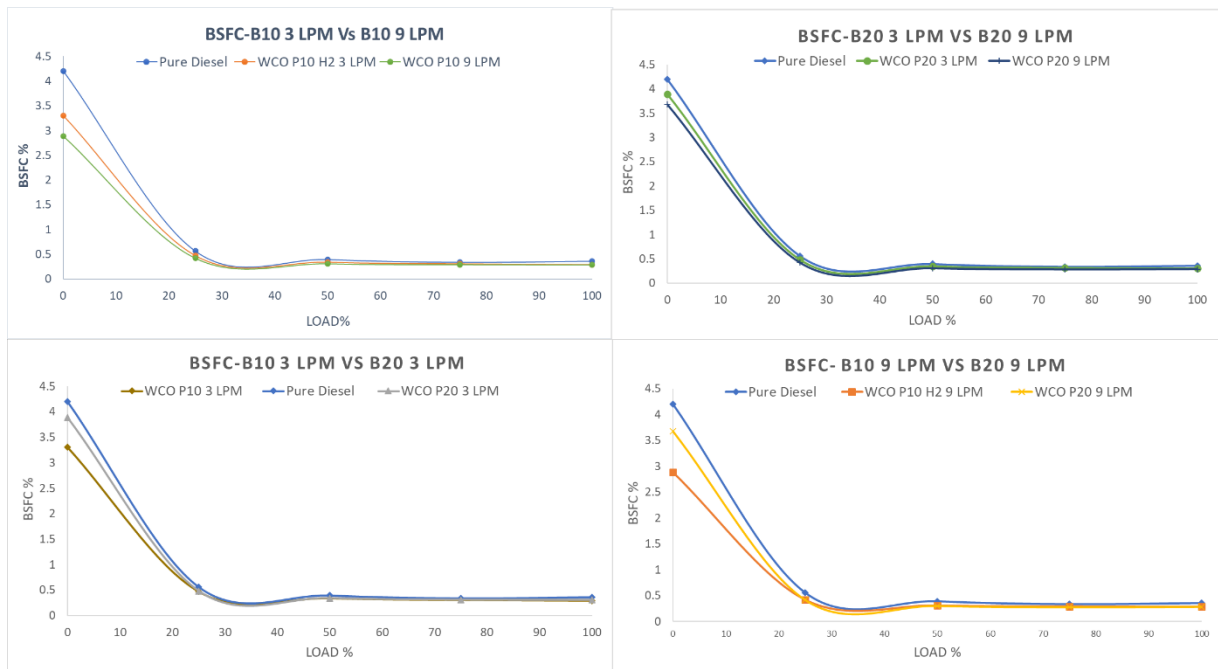


Fig. 5.6 Brake Specific Fuel Consumption with respect to load

5.7 PRESSURE AND CRANK ANGLE

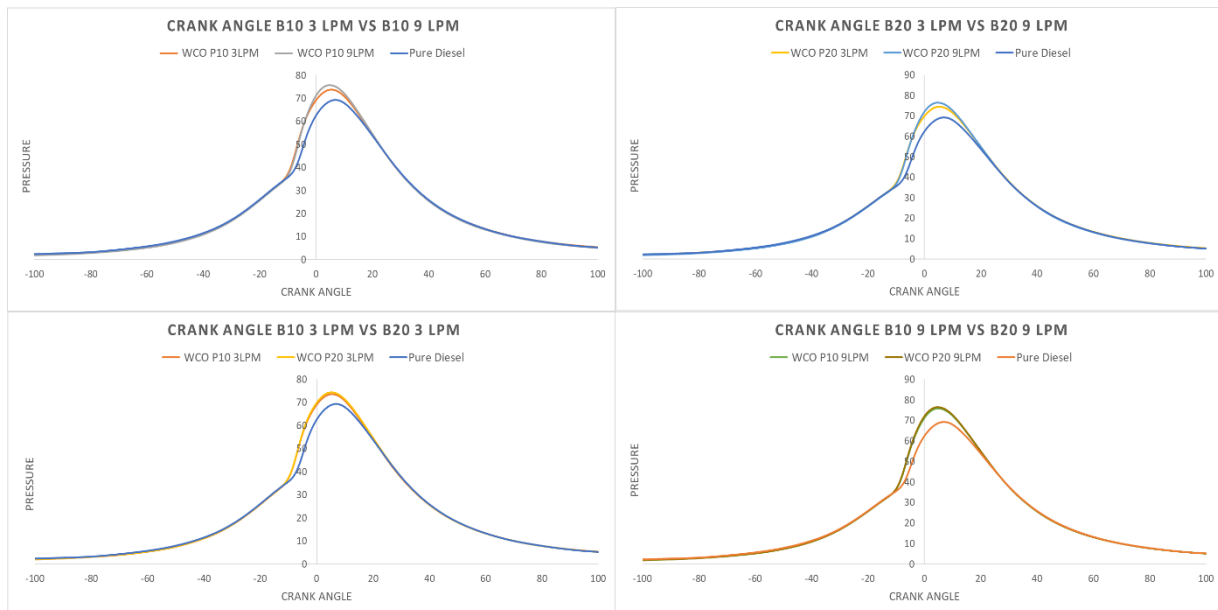


Fig. 5.7 Pressure and Crank Angle with respect to load

The graph above in Figure 5.7 illustrates several blends, including B10 vs B20 (9LPM), B10 vs B20 (3LPM), 3LPM vs 9LPM (B10), and 3LPM vs 9LPM (B20), where pressure and crank angle are measured at 100% load. All four blends show an improvement in pressure rate, with B10 9LPM proving to be the best of the bunch. The pressure angle

has increased significantly, indicating that the fuels have combusted properly and with high flame velocity.

5.8 HEAT RELEASE RATE

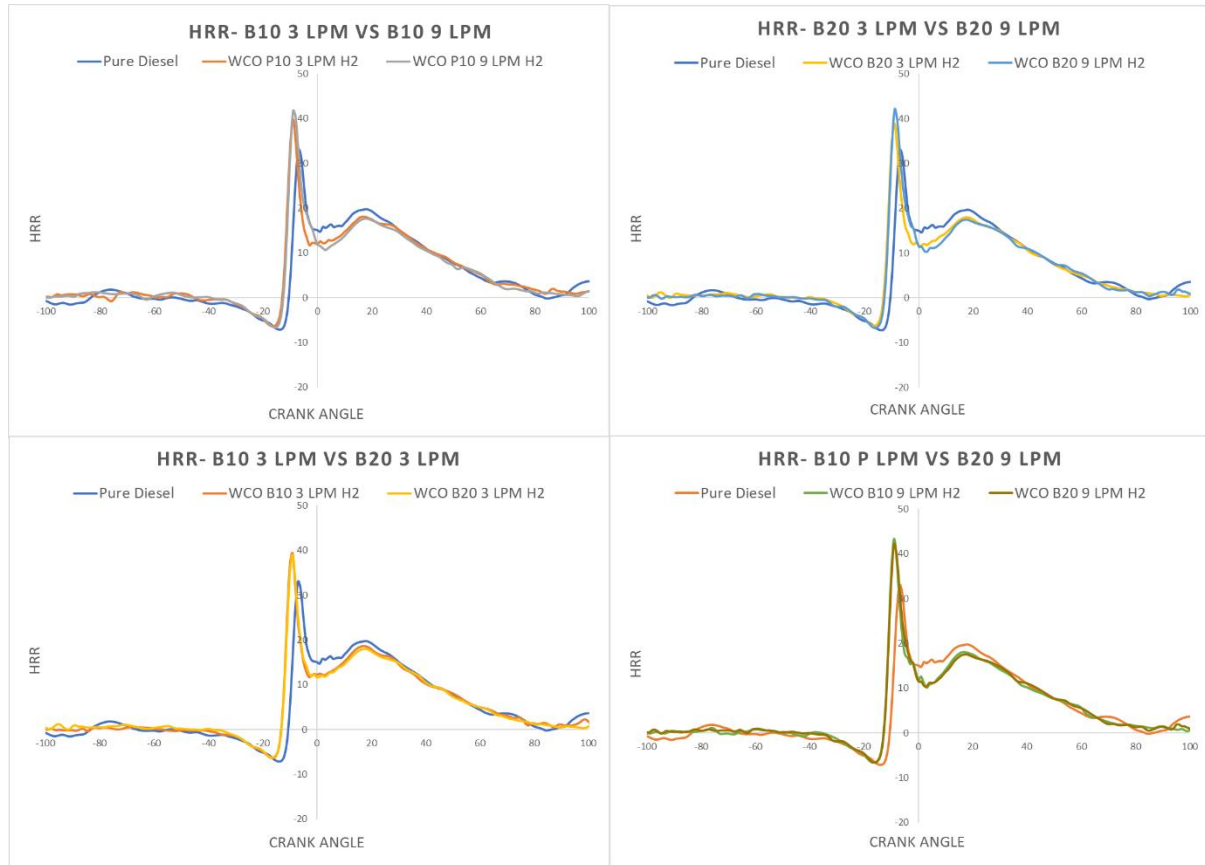


Fig. 5.8 Performance Report on Heat Release Rate

The heat release rate in 100 percent load is represented by the B10 vs B20 (9LPM), B10 vs B20 (3LPM), 3LPM against 9LPM (B10), and 3LPM vs 9LPM (B20) graphs above in Figure 5.8. When compared to pure diesel, it is obvious that there is a significant rise in HRR. The apparent rate of heat release increases with Biodiesel Blends; this behavior could be explained by the fact that Biodiesel B20 has a larger bulk modulus and viscosity, which causes a tiny delay in the start of injection with a small adjustment of the premixed stage of the combustion process [4]. The main reasons for changing combustion properties of Biodiesel fuel are its lower heating value, lower volatility, and higher viscosity as compared to Diesel fuel.

CONCLUSION

To summarize, Potato Peels and Coconut Husk were prepared and calcined at 600°C, followed by a SEM EDAX test to determine the specimen's elemental and morphological composition. Then, utilizing blended 1:1 ratio of the heterogeneous catalyst, bio diesel was created. The ratio of oil to methanol used for transesterification was 1:15. A yield of 98 percent was obtained after wet processing was used to eliminate the excess methanol in the combination. Hydrogen enrichment was carried out, with 3LPM and 9LPM hydrogen injections through a manifold, respectively. The fuel was evaluated, and its combustion, emission, and performance were compared to that of pure diesel.

On the experimental investigation we can conclude that

- Potato Peel and Coconut Husk contains high levels of Potassium Hydroxide which acts as a strong base for transesterification. To improve its catalytic activity, it was further calcinated.
- Amount of catalyst used for transesterification was 6% wt. of the oil and a ratio of 1:15 of oil to methanol, thus obtaining a biodiesel yield of 98%
- Through manifold injection emission parameters like Carbon monoxide, Hydrocarbon has experienced a marginal increase. And in both emission 9LPM blends has emitted lower amount of CO and HC when compared to 3LPM.
- As compared to the other three blends, there is a noticeable reduction in carbon dioxide emissions when compared to pure diesel. B20 9LPM emits the least amount of carbon dioxide.
- Nitrous oxide has increased in all four blends; higher temperature causes formation of oxide of nitrogen. This due to hydrogen enrichment which has increased the temperature.
- When compared to pure diesel, there is a steady progression in Brake Thermal Efficiency, and 9LPM B20 has a high BTE when compared to all other blend.
- Brake Specific fuel consumption has lowered substantially with 9LPM B10 blend having the lowest specific fuel consumption.

- Overall, there is an increase in Pressure and crank angle with B10 9LPM blend having the highest-pressure crank angle.
- The HRR rate has grown dramatically, with B10 9LPM having the highest and B20 3LPM having the lowest. When compared to pure diesel, all four blends have greater HRR.

REFERENCES

[1] Abbaszadeh, A., Ghobadian, B., Najafi, G. and Yusaf, T., (2014). An experimental investigation of the effective parameters on wet washing of biodiesel

purification. *International Journal of Automotive and Mechanical Engineering*, 9(1), pp.1525-1537.

[2] Akar, M.A., Kekilli, E., Bas, O., Yildizhan, S., Serin, H. and Ozcanli, M., (2018). Hydrogen enriched waste oil biodiesel usage in compression ignition engine. *international journal of hydrogen energy*, 43(38), pp.18046-18052.

[3] Aldhaidhawi, M., Chiriac, R., Bădescu, V., Descombes, G. and Podevin, P.,(2017). Investigation on the mixture formation, combustion characteristics and performance of a Diesel engine fuelled with Diesel, Biodiesel B20 and hydrogen addition. *International Journal of Hydrogen Energy*, 42(26), pp.16793-16807.

[4] Baltacioglu, M.K., Arat, H.T., Özcanli, M. and Aydin, K.,(2016). Experimental comparison of pure hydrogen and HHO (hydroxy) enriched biodiesel (B10) fuel in a commercial diesel engine. *International Journal of Hydrogen Energy*, 41(19), pp.8347-8353.

[5] Banga, S., Varshney, P.K. and Kumar, N., (2015). Purification of Jatropha curcas based biodiesel by dry washing, using banana peel and mushroom powder as natural adsorbents. *Biofuels*, 6(5-6), pp.261-267.

[6] Barampouti, E.M., Christofi, A., Malamis, D. and Mai, S.,(2021). A sustainable approach to valorize potato peel waste towards biofuel production. *Biomass Conversion and Biorefinery*, pp.1-12.

[7] Buasri, A., Chaiyut, N., Loryuenyong, V., Rodklum, C., Chaikwan, T. and Kumphan, N., (2012). Continuous process for biodiesel production in packed bed reactor from waste frying oil using potassium hydroxide supported on Jatropha curcas fruit shell as solid catalyst. *Applied Sciences*, 2(3), pp.641-653.

[8] Chiriac, R. and Apostolescu, N., (2013). Emissions of a diesel engine using B20 and effects of hydrogen addition. *international journal of hydrogen energy*, 38(30), pp.13453-13462.

[9] Das, S., Kanth, S., Das, B. and Debbarma, S.,(2022). Experimental evaluation of hydrogen enrichment in a dual-fuelled CRDI diesel engine. *International Journal of Hydrogen Energy*, 47(20), pp.11039-11051

- [10] Eloka-Eboka, A.C. and Inambao, F.L., (2017). Production properties studies of tropical *Thevetia peruviana* and *Jatropha curcas* biodiesel using bimetallic-salts as catalysts. In *Proceedings of the world congress on engineering and computer science* (Vol. 2).
- [11] Etim, A.O., Betiku, E., Ajala, S.O., Olaniyi, P.J. and Ojumu, T.V., (2018). Potential of ripe plantain fruit peels as an eco-friendly catalyst for biodiesel synthesis: optimization by artificial neural network integrated with genetic algorithm. *Sustainability*, 10(3), p.707.
- [12] Fan, M., Wu, H., Shi, M., Zhang, P. and Jiang, P., (2019). Well-dispersive K₂O/KCl alkaline catalyst derived from waste banana peel for biodiesel synthesis. *Green Energy & Environment*, 4(3), pp.322-327.
- [13] Han, S., Kim, G. and Han, J., (2019). Biodiesel production from oleaginous yeast, *Cryptococcus* sp. by using banana peel as carbon source. *Energy Rep* 5: 1077–1081.
- [14] Husin, H., Abubakar, A., Ramadhani, S., Sijabat, C.F.B. and Hasfita, F., (2018). Coconut husk ash as heterogenous catalyst for biodiesel production from cerbera manghas seed oil. In *MATEC Web of Conferences* (Vol. 197, p. 09008). EDP Sciences.
- [15] Hussein, M.F., El Naga, A.O.A., El Saied, M., AbuBaker, M.M., Shaban, S.A. and El Kady, F.Y., (2021). Potato peel waste-derived carbon-based solid acid for the esterification of oleic acid to biodiesel. *Environmental Technology & Innovation*, 21, p.101355.
- [16] John, M., Abdullah, M.O., Hua, T.Y. and Nolasco-Hipólito, C., (2021). Techno-economical and energy analysis of sunflower oil biodiesel synthesis assisted with waste ginger leaves derived catalysts. *Renewable Energy*, 168, pp.815-828.
- [17] Kanth, S. and Debbarma, S., (2021). Comparative performance analysis of diesel engine fuelled with hydrogen enriched edible and non-edible biodiesel. *International Journal of Hydrogen Energy*, 46(17), pp.10478-10493.
- [18] Kanth, S., Debbarma, S. and Das, B., (2020). Effect of hydrogen enrichment in the intake air of diesel engine fuelled with honge biodiesel blend and diesel. *International Journal of Hydrogen Energy*, 45(56), pp.32521-32533.

- [19] Kanth, S., Debbarma, S. and Das, B., (2020). Experimental investigation of rice bran biodiesel with hydrogen enrichment in diesel engine. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, pp.1-18.
- [20] Karagöz, Y., Güler, İ., Sandalcı, T., Yüksek, L. and Dalkılıç, A.S., (2016). Effect of hydrogen enrichment on combustion characteristics, emissions and performance of a diesel engine. *International journal of hydrogen energy*, 41(1), pp.656-665.
- [21] Kumar, H., Renita, A.A. and Jabasingh, S.A.,(2021). Biodiesel production from pre-utilized cooking oil using a renewable heterogeneous eggshell-coconut pith catalyst: Process optimization and characterization. *Environmental Progress & Sustainable Energy*, 40(5), p.e13632.
- [22] Kumar, P., Sarma, A.K., Jha, M.K., Bansal, A. and Srivastava, B., (2015). Utilization of renewable and waste materials for biodiesel production as catalyst. *Bulletin of Chemical Reaction Engineering & Catalysis*, 10(3), p.221.
- [23] Lee, D.W., Park, Y.M. and Lee, K.Y., (2009). Heterogeneous base catalysts for transesterification in biodiesel synthesis. *Catalysis surveys from Asia*, 13(2), pp.63-77.
- [24] Leung, D.Y., Wu, X. and Leung, M.K.H., (2010). A review on biodiesel production using catalysed transesterification. *Applied energy*, 87(4), pp.1083-1095.
- [25] Leung, D.Y.C. and Guo, Y., (2006). Transesterification of neat and used frying oil: optimization for biodiesel production. *Fuel processing technology*, 87(10), pp.883-890.
- [26] Nguyen, H.C., Nguyen, M.L., Su, C.H., Ong, H.C., Juan, H.Y. and Wu, S.J.,(2021). Bio-derived catalysts: a current trend of catalysts used in biodiesel production. *Catalysts*, 11(7), p.812.
- [27] Ozcanli, M., Akar, M.A., Calik, A. and Serin, H., (2017). Using HHO (Hydroxy) and hydrogen enriched castor oil biodiesel in compression ignition engine. *International Journal of Hydrogen Energy*, 42(36), pp.23366-23372.
- [28] Parthasarathy, M., Lalvani, J.I.J., Dhinesh, B. and Annamalai, K., (2016). Effect of hydrogen on ethanol–biodiesel blend on performance and emission characteristics of a direct injection diesel engine. *Ecotoxicology and environmental safety*, 134, pp.433-439.

- [29] Rocha, H.M.Z., da Silva Pereira, R., Nogueira, M.F.M., Belchior, C.R.P. and de Lima Tostes, M.E., (2017). Experimental investigation of hydrogen addition in the intake air of compressed ignition engines running on biodiesel blend. *International Journal of Hydrogen Energy*, 42(7), pp.4530-4539.
- [30] Saravanan, N. and Nagarajan, G., (2008). An experimental investigation of hydrogen-enriched air induction in a diesel engine system. *International journal of hydrogen energy*, 33(6), pp.1769-1775.
- [31] Sarıkoç, S., Ünalın, S. and Örs, İ.,(2019). Experimental study of hydrogen addition on waste cooking oil biodiesel-diesel-butanol fuel blends in a DI diesel engine. *Bioenergy Research*, 12(2), pp.443-456.
- [32] Serin, H. and Yıldızhan, Ş., (2018). Hydrogen addition to tea seed oil biodiesel: Performance and emission characteristics. *International Journal of Hydrogen Energy*, 43(38), pp.18020-18027.
- [33] Sharma, M., Khan, A.A., Puri, S.K. and Tuli, D.K., (2012). Wood ash as a potential heterogeneous catalyst for biodiesel synthesis. *Biomass and bioenergy*, 41, pp.94-106.
- [34] Sulaiman, S. and Ruslan, N.I.F.,(2017). A heterogeneous catalyst from a mixture of coconut waste and eggshells for biodiesel production. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 39(2), pp.154-159.
- [35] Thushari, I., Babel, S. and Samart, C., (2019). Biodiesel production in an autoclave reactor using waste palm oil and coconut coir husk derived catalyst. *Renewable energy*, 134, pp.125-134.
- [36] Tüccar, G. and Uludamar, E., (2018). Emission and engine performance analysis of a diesel engine using hydrogen enriched pomegranate seed oil biodiesel. *International Journal of Hydrogen Energy*, 43(38), pp.18014-18019.
- [37] Vadery, V., Narayanan, B.N., Ramakrishnan, R.M., Cherikkallinmel, S.K., Sugunan, S., Narayanan, D.P. and Sasidharan, S., (2014). Room temperature production of jatropha biodiesel over coconut husk ash. *Energy*, 70, pp.588-594.

