

HYDROGEN EFFECT ON CI ENGINE UNDER DUAL FUEL MODE

Submitted in partial fulfilment of the requirements for the award of
Bachelor of Engineering degree in
Automobile Engineering

By

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the Bonafide work of **SABINESH V** (Reg. No. 40860003) and **SHAYANDHAN K** (Reg. No. 40860004) who carried out the project entitled "**HYDROGEN EFFECT ON CI ENGINE UNDER DUAL FUEL MODE**" under our supervision from December 2023 to April 2024.

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ABSTRACT

Biodiesel have emerged as a potential substitute to conventional fossil fuels due to their lower emissions of greenhouse gases and renewable resources. Waste-cooking oil have gained considerable attention in recent years in the production of biodiesel, owing to their both high output and fat content. Biodiesel is regarded as a clean and renewable fuel that is considered to develop the agricultural economy as well as reducing the dependency on the petroleum-originated fuels. One promising method for extracting bio-diesel from waste cooking oil is transesterification. The resulting bio-diesel properties has been tested like density, calorific value, viscosity, heating value, and some elemental composition with different instruments.

The B20 blend has been tested with diesel,3lpm,6lpm and 9lpm addition of hydrogen in the CI engine. The following parameters were tested and contrasted brake thermal efficiency (BTE), specific fuel consumption (SFC) and emission parameters like CO, CO₂, NO_x, and HC. Further, the brake specific fuel consumption and the exhaust gas temperature of the test samples were drastically improved due to the presence of hydrogen. The addition of hydrogen led to a small improvement in NO_x. B20 fuel produced more NO_x emissions per engine load overall when compared to other test samples.

This study presents an in-depth look into B20 blend with hydrogen as a fuel for compression ignition engines. This review focuses dual-fuel methods and its properties, methods of biodiesel utilization in CI engines, effects of hydrogen usage on the performance, combustion and emission characteristics, and challenges of hydrogen dual-fuel mode operation and solutions to overcome these challenges.

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LIST OF SYMBOLS AND ABBEREVIATIONS

H ₂	Hydrogen
B20	Biodiesel
CO ₂	Carbon Dioxide
CH ₄	Methane
SO ₂	Sulphur Dioxide
NO _x	Nitrogen Oxide
PM	Particulate Matter
CO	Carbon Monoxide
HC	Hydro Carbon
UHC	Unburned Hydrocarbon
SMR	Steam Methane Reforming
CI	Compression Ignition
EGR	Exhaust Gas Recirculation
SCR	Selective Catalytic Convertor
BTE	Brake Thermal Efficiency
SFC	Specific Fuel Consumption
°C	Degree Celsius
cm	Centimetre
%	Percentage
rpm	Rotation per minutes

CHAPTER 1

INTRODUCTION

1.1 GENERAL

At the current rate of consumption, 171,000 kg of coal, 116,000,000 L of petrol and 186,000 L of oil are consumed every second. It is claimed that the widespread use of biofuels in place of fossil fuels will help reduce the amount of greenhouse gases (GHGs) released into the atmosphere. To fulfil the rising energy needs for transportation and reduce GHG emissions, biodiesel, one of the biofuels, is a renewable energy source that is overemphasized[1]. However, using biodiesel in a compression ignition engine has a few minor limitations. For instance, the atomization of liquid fuel is negatively impacted by its high viscosity value. In addition, because most biodiesels have lower calorific values, using them reduces the engine's output of power. The combustion of biodiesel typically results in greater NO_x emissions[2]. Biodiesel can be made from a variety of organic materials, including waste oils, algae, animal fats, and vegetable and animal fats[3]. The higher price of biodiesel compared to diesel fuel made from petroleum creates a barrier to its commercial acceptance. It was informed that the cost of the raw materials (feedstock) accounts for roughly 70 to 85% of the entire cost of producing biodiesel[4]. The benefits of producing biodiesel from waste oil include lowering production costs and eliminating the harmful environmental effects of non-edible waste oil. In order to satisfy the properties needed by the engine, hydrogen is thought to be the ideal additive option to be blended into diesel[5]. One of the most prevalent elements in the universe, hydrogen is seen as a possible future alternative fuel. The fact that hydrogen burns cleanly and sustainably, releasing just water vapor and heat, is one of its main advantages. As a potential method to lower pollutants and increase fuel efficiency, researchers have recently concentrated on the use of hydrogen in compression ignition engines, also referred to as diesel engines. In diesel engines, the combustion chamber receives a direct injection of fuel, which ignites as it meets the hot compressed air. However, substantial levels of nitrogen oxides (NO_x) and particulate matter (PM), which are bad for the environment and people's health, are produced when diesel fuel is burned.

Numerous characteristics of hydrogen make it a desirable fuel for compression ignition engines. The fuel has a high-octane rating, which indicates that it has a low knocking resistance and can be squeezed to a greater ratio before ignition. This makes it possible for greater combustion efficiency, which can enhance fuel efficiency and reduce emissions. In addition, hydrogen has a high flame speed, which means it burns more quickly than diesel fuel and produces fewer emissions as a result. Because hydrogen has a lower energy density than diesel fuel, employing it in compression ignition engines can be difficult. One of the most effective kinds of internal combustion engines, compression ignition engines have been around for more than a century. Research on the utilization of hydrogen to generate a moving power for equipment dates back approximately two centuries[6]. Due to their great efficiency, dependability, and longevity as well as the fact that they generate less carbon monoxide (CO) and hydrocarbon (HC) than other power sources, diesel engines were widely employed to create energy for the industrial, transportation, agricultural, and other sectors. Global warming and environmental damage are often increased by emissions from compression ignition engines[7]. Plenty of studies were done, and the engine's performance was recorded following the use of different vegetable oils. According to research on the engine's performance using biodiesel with Mahua oil as its primary component, there was a significant decrease in the number of hydrocarbons released into the atmosphere as well as an improvement in the engine's Specific Fuel Consumption when compared to the conventional fuel used[8]. In general, it is said that using biodiesel results in increased NO_x emissions and lower engine power. .In order to improve the combustion performance of biodiesel, experiments are being conducted on its use in dual-fuel mode with a second fuel[9]. Chiriac and Apostolescu [10] A fifty kW, 4-cylinder, 4-stroke, injected to CI engine running on B20 fuel was used to test the effects of hydrogen enrichment on the emissions. When hydrogen was added to the intake air of a CI engine running on B20 gasoline, NO_x emissions increased while smoke and CO emission decreased. Jeyaseelan et al.[11].examined the effects of hydrogen addition on engine performance, combustion, and emission characteristics for both biodiesel-diesel (B20) and hydrogenated biodiesel-diesel (HB20). The energy contribution of 10% for the hydrogen addition remained constant.

There are several additives that can be used to improve the quality of biodiesel fuel, including metal-based , oxygen-containing , antioxidant and cetane improver additives .Even though researchers have primarily studied the performance, emission, and combustion characteristics of various fuel and additive combinations, including diesel-biodiesel, diesel-hydrogen, biodiesel-hydrogen, there are only a few studies that look at the effects of hydrogen and nanoparticle addition together into diesel-biodiesel blends to eliminate draw[12]. The goal is to determine the ideal hydrogen addition rate and improve the performance and emissions of CI engines powered by biodiesel.

1.2 BIODIESEL

Bio-diesel is a renewable and sustainable alternative to petroleum-based diesel fuel, derived from biological sources such as vegetable oils or animal fats through a process called transesterification. This eco-friendly fuel has gained prominence as a viable option to reduce dependency on fossil fuels and mitigate environmental impacts associated with conventional diesel combustion. One of the primary feedstocks for biodiesel production is vegetable oil, commonly sourced from crops like soybean, rapeseed, palm, and sunflower. Animal fats, recycled cooking oils, and even algae are also used as alternative feedstocks. The choice of feedstock significantly influences the properties of the biodiesel produced, impacting factors such as viscosity, cetane number, and oxidative stability. The production process involves the reaction of triglycerides present in oils or fats with an alcohol, typically methanol or ethanol, in the presence of a catalyst. This chemical transformation results in the formation of biodiesel (methyl or ethyl esters) and glycerol as a byproduct. The glycerol produced can be utilized for various industrial applications or refined for additional uses. Biodiesel is compatible with existing diesel engines and infrastructure, making it a seamless option for blending with traditional diesel fuel or using as a standalone alternative. It possesses several environmental advantages over conventional diesel, including lower greenhouse gas emissions and reduced particulate matter, contributing to improved air quality.



Fig 1.1: Biodiesel preparation from waste cooking oil

1.3 HYDROGEN FUELS

The investigation of alternative fuel sources, particularly hydrogen fuel, is being driven by the demand for sustainable energy and the growing concern over climate change. Due to its potential to lower greenhouse gas emissions and contribute to a cleaner environment, hydrogen fuel, sometimes known as "green" or "clean" fuel, is an alternative energy source that has attracted a lot of attention. It is created from water using electrolysis. Steam-methane reforming (SMR), followed closely by coal and oil gasification (CG), is the primary source of industrial H_2 . These processes for manufacturing H_2 also produce greenhouse gases, which are thought to be the main contributors to climate change[13]. In comparison to fossil fuels, hydrogen provides a few benefits, including zero emissions, a high energy density, and domestic availability. Through the electrolysis process, which divides water into hydrogen and oxygen with the help of an electrical current, hydrogen fuel is created. After that, the hydrogen can be transferred and stored for use as fuel. Using natural

gas or other hydrocarbons in a procedure known as steam reforming is another way to make hydrogen fuel. However, because carbon dioxide is a byproduct of this process, it is not as pure as electrolysis. As a fuel, hydrogen (H_2) is viewed as a viable energy source. Compared to fossil fuels based on hydrocarbons, H_2 is a more efficient fuel due to its high energy yield and low heating value. The "fuel of the future" is therefore considered to be hydrogen[13].

1.4 PRODUCTION

Compression ignition (CI) engines can run on the hydrogen generated by the fuel cell. Since hydrogen is a carbon-free material, its burning in an IC engine produces almost no greenhouse gas emissions. Even at lean mixture operation, the combustion of hydrogen has high heat transfer properties, which raises the combustion temperature and improves engine efficiency[15]. Diesel or any other alternative fuel (pilot fuel) with a low auto-ignition temperature is fed straight into the cylinder to ignite hydrogen[15]. Hydrogen is a plentiful and adaptable element that may be employed in a variety of sectors, including manufacturing, transportation, and energy. As a potential means of decreasing greenhouse gas emissions and ensuring a sustainable energy future, hydrogen production has been gaining popularity. There are several methods for producing hydrogen, including steam methane reforming, electrolysis, and coal gasification.

1.4.1 Steam methane reforming

The most used technique for making hydrogen is steam methane reforming (SMR). Natural gas and hot steam are combined in this process to create hydrogen and carbon dioxide. The method is quite effective and generates a lot of hydrogen, but it also releases a lot of greenhouse gases. SMR cannot produce hydrogen in a sustainable manner over the long term.

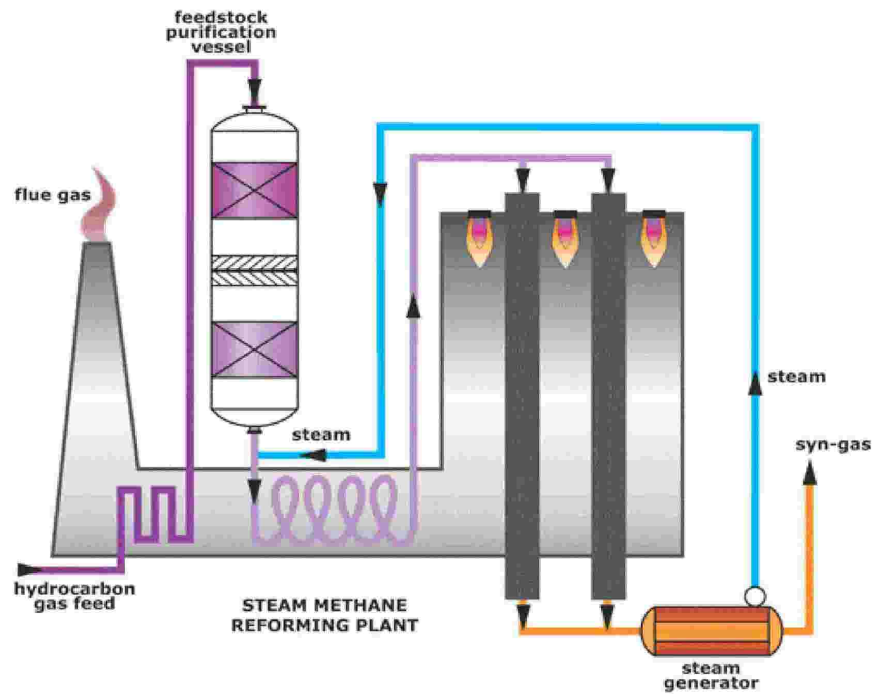


Fig 1.2: Steam Methane Reforming

1.4.2 Electrolysis

Using electricity, water molecules are split into hydrogen and oxygen. The method can be driven by renewable energy sources like solar or wind, making hydrogen production using it a sustainable process. However, electrolysis is currently more expensive than SMR, and the technology needs to be improved to be commercially viable.

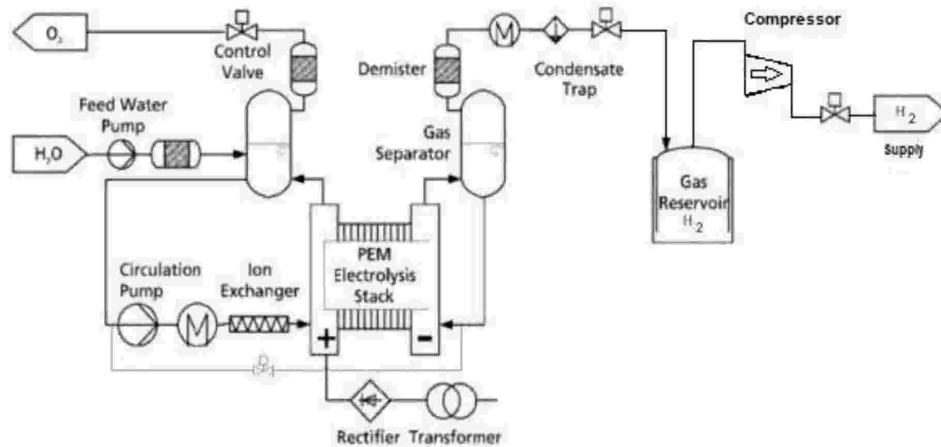


Fig 1.3: Electrolysis

1.4.3 Coal gasification

In this process, biomass—such as wood chips or agricultural waste—is cooked at high temperatures with a finite amount of oxygen. A gas mixture containing hydrogen and carbon monoxide is created as a result, and this gas mixture can be separated and used as fuel.

1.4.4 Biomass gasification

To produce hydrogen and other gases, biomass—such as wood chips or agricultural waste—is heated in the presence of steam. The method can be driven by renewable energy sources like solar or wind, making hydrogen production using it a sustainable process. However, the technology needs to be improved to be competitive on the market.

1.5 PROPERTIES

The process of producing hydrogen gas for use as a fuel is referred to as hydrogen fuel production. A versatile and clean-burning fuel, hydrogen may be used to power fuel cells, power vehicles, and power many industrial processes.

- **High energy content:** In comparison to other fuels like petrol or natural gas, hydrogen has a very high energy content per unit mass. In other words, it can produce a lot of energy from a small amount of fuel.
- **Clean combustion:** Water is the only byproduct of hydrogen's clean combustion. Because of this, it is an extremely desirable fuel for lowering greenhouse gas emissions and enhancing air quality.
- **Abundant:** The most prevalent element in the universe is hydrogen, which can be created from a multitude of sources, including renewable energy sources like wind and solar energy.
- **Lightweight:** Since weight plays a crucial role in energy efficiency in transportation applications, hydrogen is a particularly lightweight gas.
- **Safe:** Despite being incredibly combustible, hydrogen is very safe when used properly. Systems using hydrogen fuel are extremely dependable and risk-free to use thanks to a few safety features.
- **Versatile:** Hydrogen is versatile and can be used in a wide range of operations, including the production of energy in fuel cells, transportation fuel, and industrial feedstock.
- **Efficiency:** When compared to conventional combustion engines, hydrogen fuel cells are more effective, which means they can convert a higher proportion of the fuel's energy into useful power.

Table 1.1 Hydrogen properties

PROPERTIES	UNIT	HYDROGEN
Auto ignition temperature	K	858 [16]
Minimum ignition energy	MJ	0.02 [16]
Calorific value	Mj/kg	120 [8]
Low heating values	Mj/kg	120 [17]
Stoichiometric air fuel ratio	-	34.2 [17]
Quenching gap in air	Cm	0.064 [9]
Burning velocity in NTP air	Cm/s	265-325 [9]
Heating value	Mj/kg	119.93 [12]
Specific gravity	-	0.091 [18]
C:H:O	%	- [19]
Flaming temperature in air	K	2318 [9]
Chemical formula	-	H ₂ [20]
Sulphur	Mg/kg	- [20]
CO ₂ formation	gmCO ₂ /kwh	- [21]
Volumetric fraction fuel in air	-	0.290 [21]
Octane number	-	>130 [22]
Cetane number	-	- [22]
Molecular weight	kg/kmol	2,01 [23]
Flame speed	cm/s	270-325 [23]
Purity	%	99.9 [21]
Self-ignition temperature	K	855 [21]
Boiling point	K	20-27 [24]
Combustion energy	mj	3.37 [24]
Net lower heating value	mj/kg	119.93 [24]
Viscosity at 15.5°C	Centipoise	- [24]

1.6 METHODS OF HYDROGEN FUEL ADDITION IN CI ENGINE

Due to its potential advantages, such as lower pollutants, increased engine performance, and higher fuel efficiency, hydrogen fuel addition in a compression ignition (CI) engine has been taken into consideration as an alternative fuel source. There are several methods of hydrogen fuel addition in CI engines, including hydrogen injection, hydrogen blending, and dual fuel combustion. Hydrogen injection involves injecting hydrogen gas directly into the combustion chamber of a CI engine.

1.6.1 Port injection

In this technique, air and hydrogen gas are both fed into the engine's intake port. Before entering the combustion chamber, the hydrogen gas and air combine, creating a homogenous mixture. Depending on the engine operating circumstances, an electronic control unit (ECU) can regulate the injection timing and volume. Port injection has the advantage that it may be applied to existing engines and does not require significant engine modifications. In contrast to direct injection, it delivers hydrogen more inefficiently.

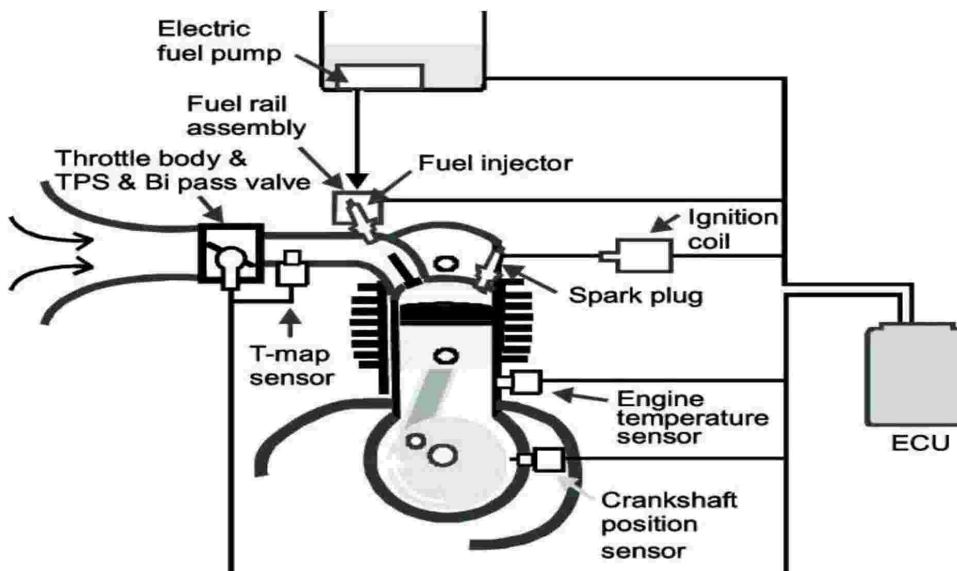


Fig 1.5: Port injection

1.5.2 Direct injection

In this procedure, a fuel injector is used to deliver high pressure hydrogen gas straight into the combustion chamber. The combustion chamber's air and hydrogen gas combine to create a more uniform mixture. An ECU can be used to precisely manage the injection timing and volume. Direct injection has the advantage of having a higher hydrogen delivery efficiency than port injection, which leads to improved engine performance and lower emissions. But it necessitates considerable engine modifications, such as the installation of high-pressure fuel injectors and a separate hydrogen storage system.

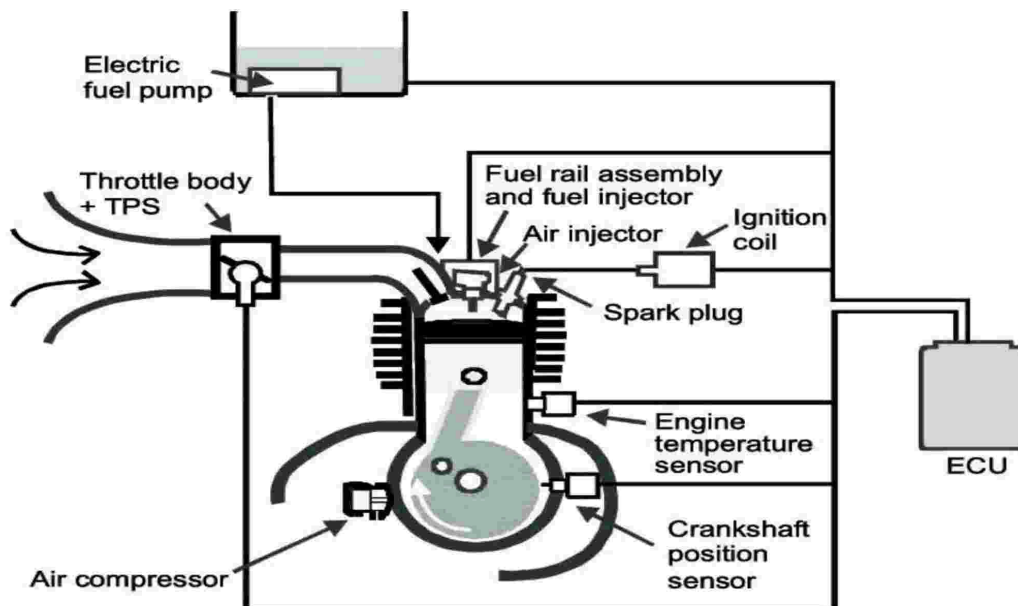


Fig 1.6: Direct injection

1.6.3 Hydrogen blending

Hydrogen blending involves mixing hydrogen gas with the diesel fuel in the fuel tank before entering the engine. In this method, a blending system is used to combine hydrogen petrol and diesel fuel outside the engine. The current fuel system is then used to feed the engine with the blended fuel. The benefit of external mixing is that it does not necessitate significant engine or fuel system changes. In contrast to internal mixing, it delivers hydrogen more inefficiently. Inside the engine,

hydrogen petrol and diesel fuel are blended using a specialized injector or mixer. The conventional diesel injection method is then used to ignite the blended fuel. Internal mixing has the advantage of having a higher hydrogen delivery efficiency than external mixing, which improves engine performance and reduces emissions. However, it necessitates major engine changes, such as the installation of a unique injector or mixer and a separate hydrogen storage system.

1.6.4 Pilot injection

To ignite the hydrogen-air mixture, a small amount of diesel fuel is pumped into the combustion chamber as a pilot injection. After a brief interval, the hydrogen gas is then introduced into the combustion chamber to finish the combustion process. Pilot injection has the benefit of not requiring significant engine modifications and allowing the engine to continue operating solely on diesel fuel. However, compared to premixed combustion, it is less efficient at delivering hydrogen.

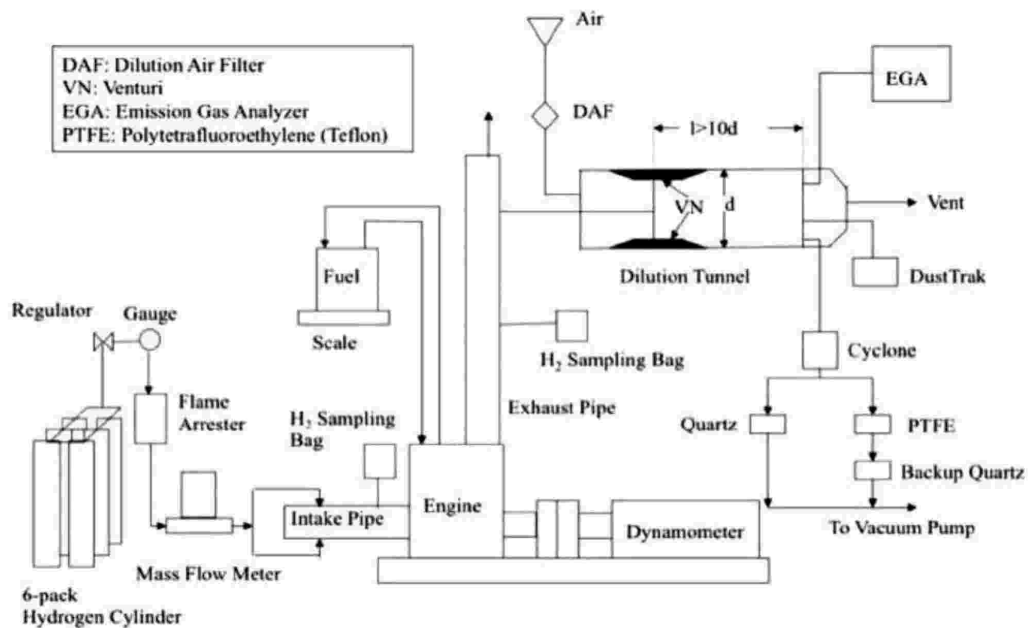


Fig 1.7: Pilot injection

CHAPTER 2

LITERATURE SURVEY

The following shows a survey of bio-diesel extraction from waste cooking oil. Testing of bio-oil with diesel blends, characteristics of the engine performance and emissions parameters.

BIO-OIL EXTRACTION FROM WASTE COOKING OIL USING TRANSESTERIFICATION

The output and quality of the produced bio-oil can vary depending on the kind of waste cooking oil utilized in the transesterification process [21]. The extraction of bio-diesel from waste cooking oil through the transesterification process presents an innovative and sustainable approach to repurposing used culinary oils. Transesterification involves the chemical reaction of triglycerides in the waste oil with an alcohol, typically methanol or ethanol, in the presence of a catalyst. This reaction leads to the formation of bio-diesel, known as methyl or ethyl esters, and glycerol as a by-product. This process not only converts discarded cooking oil into a valuable energy resource but also contributes to waste reduction and environmental conservation. The resulting bio-diesel exhibits properties suitable for use as a biodiesel fuel, offering a cleaner and renewable alternative to traditional petroleum-based diesel [17]. Additionally, the utilization of waste cooking oil for bio-diesel extraction aligns with the principles of circular economy, promoting the efficient and sustainable use of resources while addressing environmental challenges associated with improper disposal of cooking oil.

TESTING BIO-DIESEL IN ENGINES WITH HYDROGEN-BIODIESEL BLENDS

Testing bio-diesel in engines is a dynamic investigation at the nexus of alternative fuels, especially when combined with hydrogen-diesel blends. Bio-diesel, which is produced by transesterification from waste cooking oil, is added to hydrogen-diesel mixes to improve combustion and lessen its environmental effect [7]. The combination of hydrogen and bio-diesel offers a two-pronged strategy for greener energy options. While hydrogen enriches the combustion process and may

increase engine performance and efficiency, the bio-diesel component helps to reduce carbon emissions and promote sustainability [9]. In order to determine the feasibility and ideal blend ratios, engine testing entails evaluating factors including ignition characteristics, combustion stability, and emissions profiles.

A REVIEW - ON THE PERFORMANCE AND EMISSIONS OF THE CI ENGINE IN THE ADDITION OF HYDROGEN

To improve the efficiency of diesel engines, a number of researchers have suggested adding hydrogen to regular diesel fuel in internal combustion (IC) compression ignition (CI) engines [2]. This is because hydrogen has a higher flame propagation speed than other fuels, which causes it to raise the fuel's H/C ratio overall and shorten the combustion period. High in-cylinder peak pressures and temperatures, combustion knock, increased emissions (NO_x), and a high self-ignition temperature are the primary drawbacks of using hydrogen as a fuel[10].

PERFORMANCE AND EMISSION CHARACTERISTICS OF A COMMON-RAIL CI ENGINE FUELED WITH DIESEL/WASTE COOKING-OIL BLENDS IN THE HYDROGEN ADDITION

The impact of adding hydrogen on the efficiency and emissions of a commercial CI engine running on fuel blends of diesel-waste cooking oil and biodiesel (B20).The goal is to find the ideal hydrogen addition rate while simultaneously increasing the biodiesel- fueled CI engine's performance and emissions. The tests were run at constant engine speed (1750 rpm) and at varying engine loads (40, 60, and 80 Nm) [15]. Hydrogen was introduced into the intake air at flow rates of 3, 6, and 9 lpm by volume for each diesel and B20 fuel test.

THE COMBUSTION CHARACTERISTICS OF A COMMON CI ENGINE FUELED WITH WASTE COOKING OIL BIODIESEL BLENDS

When compared to fossil fuels, biodiesel, which may be made from vegetable, animal, and waste oils, offers a number of significant advantages. These include being non-explosive, having low sulphur and aromatic content, being harmless to the environment, and it is renewable.[15] Aldhaidhawi et al. examined

the effects of varying B20 fuel energy content (between 0% and 5%) on engine performance, emissions, and combustion characteristics. B20 fuel is made up of 80% diesel and 20% rapeseed methyl ester blends, by volume [21]. The impact of adding hydrogen to the inlet air of a CI engine running on B7 (7% biodiesel+83% diesel) fuel was examined by Rocha et al. in order to determine how it affected engine performance. A single-cylinder, four-stroke, air-cooled, direct-injection diesel generator was employed in this investigation. Up to 10% of the entire fuel mass was supplied as hydrogen to the intake manifold [18]. The impact of running a single cylinder, four stroke, water cooled, direct injection CI engine powered by waste cooking biodiesel in dual-fuel mode with hydrogen, fuel injection timing (IT) and EGR on the engine's performance, emissions, and combustion characteristics [15].

CHAPTER 3

AIM AND OBJECTIVE

3.1 AIM

The aim of this study is to investigate the feasibility of producing bio-oil from waste cooking oil using the transesterification method and injecting hydrogen to test the engine performance, emission parameters, and combustion parameters with the produced bio-oil and blending it with diesel.

3.4 OBJECTIVE

To study the effect of performance and emission characteristics with B20 blend and addition of hydrogen in CI engine

3.3. SCOPE

The bio-diesel obtained from waste cooking oil extracted from various methods such as transesterification or esterification. The extracted bio-diesel will be tested for its quality, including its density, viscosity, and calorific value.

The obtained bio-diesel will next be combined with diesel and hydrogen examined for engine performance and emission characteristics.

3.4. METHODOLOGY

- ❖ STEP 1; Take 1 liter of "Waste cooking oil" or any other oil in Glass Separatory Funnel.
- ❖ STEP2; Preheat the oil at 60 degree and then add catalyst "Methanol + NaOH/KOH" in the ratio of 1:3. (naoh-5g and methanol-182ml)
- ❖ STEP3: The reaction is allowed to conduct for 90 minutes.
- ❖ STEP4; After 90 minutes, two layers are formed in glass funnel. Top layer is "Biodiesel" and the bottom layer is "Crude glycerin".

- ❖ STEP5; Wash it by 1 liter of hot water until the PH is neutralized. After that heat the biodiesel for 110degree so that moisture is gone. Now we got our required product “BIO-OIL”.
- ❖ STEP6; B20 blend formation (80% of diesel +20%bio-oil)
- ❖ STEP7: In the addition of hydrogen with B20 blend formation for the testing of engine emission and performance characteristics

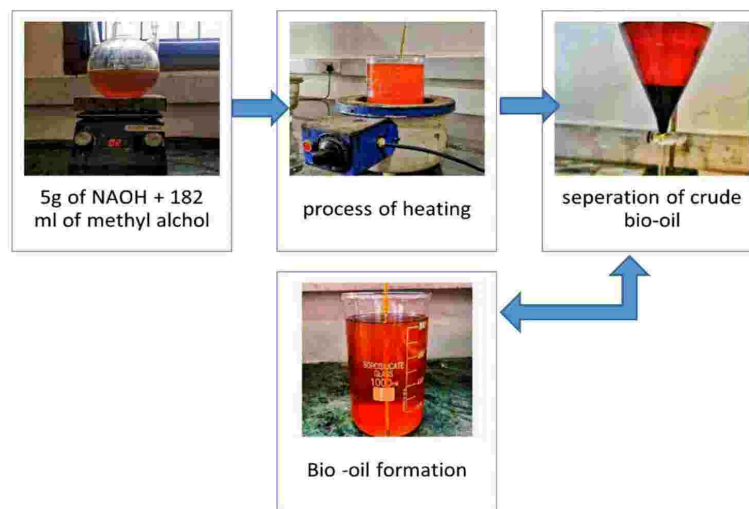


Fig 3.1: Processes of biodiesel extraction from waste cooking oil

CHAPTER 4

MATERIALS AND METHODS

4.1 BIO-DIESEL EXTRACTION FROM WASTE COOKING OIL

Biodiesel extraction from waste cooking oil presents a sustainable solution for both waste management and renewable energy production. Cooking oil waste, which is usually thrown away after use, has a high triglyceride content that can be transformed into biodiesel via a procedure known as transesterification. In this procedure, glycerol and biodiesel are produced as by-products when the triglycerides react with an alcohol—typically methanol or ethanol—while a catalyst is present. The biodiesel produced from waste cooking oil can be used as a substitute for conventional diesel fuel, reducing greenhouse gas emissions and dependence on fossil fuels. Moreover, utilizing waste cooking oil for biodiesel production reduces environmental pollution by diverting the oil from landfills or improper disposal methods. This approach not only offers an environmentally friendly alternative to traditional diesel but also promotes a circular economy by transforming waste into a valuable resource.

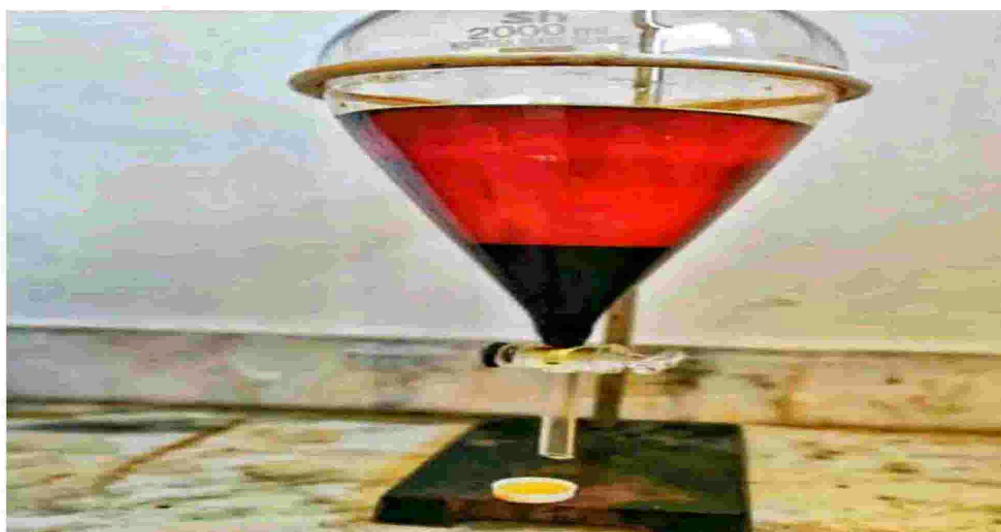


Fig 4.1: Extraction of bio-diesel from waste cooking oil

4.2 BIO-DIESEL PROPERTIES AND ITS TESTING

The bio-diesel produced from this process has several unique properties that make it an attractive fuel source. For instance, it has a high energy density, which means it can produce more energy per unit of volume than many other fuels. Additionally, bio-diesel produced using the transesterification method has a low sulphur content, making it a cleaner alternative to traditional fossil fuels [36]. Some of the key properties that can be tested include viscosity, heating value, water content, and elemental composition. Viscosity is a crucial factor in determining how quickly bio-oil flows. The existence of contaminants in the bio-diesel can be determined with the aid of elemental composition analysis, which can also reveal information about the bio-possible oil's uses [15]. The prepared fuel blend is tested for their physical and chemical properties using various scientific instruments, and the results are obtained.

4.2.1 Density Measurement

A hydrometer is a tool used to determine specific gravity. It is accurate to within 0.01. Using a hydrometer, the density of the biodiesel blend is determined. 25ml of a bio-diesel are poured into the beaker along with a hydrometer with a proper specific gravity. Stabilization occurred once the hydrometer was submerged in the beaker. The hydrometer showed the specific gravity value after immersion. At last, the result of the bio-oil density is 0.8635gm/cc.



Fig 4.2: Density Measurement

4.2.2 Viscosity Measurement

A Canon-Fenske viscometer is used to calculate viscosity. A solution of acetone was used to clean and then dry the viscosity tube. Bio-oil in the amount of 50ml was added to the viscosity tube. The oil was pulled to the viscometer's upper mark using suction force. To get the bio-oil sample up to bath temperature, the viscometer was placed in a bath of constant temperature with the use of a holder, with the bath temperature set at 45°C for a period of 30 minutes [24]. After the biofuel had achieved the upper mark, the suction force is reduced, and the time it takes for it to descend from the upper mark is recorded. The result obtained for the bio-oil viscosity ranges from 1.9-6.



Fig 4.3: Viscosity Measurement

4.2.3 Calorific Value Measurement

An instrument called a bomb calorimeter is used to calculate calorific value. It consists of a bomb, fire unit, offsetting stirrer, gas escape valve, water coat, clock, pressure gauge, crucible, igniting wire, a thermometer, and calorimeter container. Calculating the quantity of heat generated by burning 10ml of bio-diesel in a closed chamber yields the calorific value [38]. Then the calorific value of the bio-diesel is 7213.252 kJ/kg.



Fig 4.4: Calorific Value Measurement

Table 4.1: properties of biodiesel

PROPERTIES	UNIT	VALUE
Calorific value	KJ/Kg	7213.252
Moisture content	%	0.22
Cloud and pour point	°C	-4
Density	gm/cc	0.8635
Kinematic viscosity	Centistoke	3.22

4.3 ENGINE TESTING SET-UP

Every test conducted for this investigation was carried out with an engine load of 15, 20, and 25 Nm and at a constant speed of 1750 rpm. In the tests involving the diesel and B20 fuels, three, six, and nine litres per minute of hydrogen were introduced into the intake air. The percentage of hydrogen energy in all fuel energies introduced into the cylinder is known as the energy shares of hydrogen (HES), and it is computed. To enable operation in dual fuel mode, the engine is changed, and hydrogen is pumped into it in various ways as a secondary fuel. The connector that is fastened to the hydrogen cylinder mount is used to control the flow rate. Additionally, an air flow metre was used to measure the mass flow rate, and an anemometer was used to monitor the inlet air speed in the air box. The k-type thermocouple was utilised in relation to temperature [38]. The K-type was also used to monitor the temperatures of the exhaust gases. The AVL gas analyser was used to measure the emissions of CO, NO_x, and HC.



Fig 4.5: Engine setup

4.4 ENGINE EMISSIONS

Engine emissions refer to the gases and particulate matter released into the atmosphere as a by-product of combustion processes within internal combustion engines. These emissions can come from various sources, including vehicles, power plants, industrial facilities, and even residential heating systems. AVL Di gas 444 N Gas Analyzer equipment is used to determine how much harmful gas and hydrocarbon are emitted when improved bio-diesel is utilized in engines, the smoke emission characteristics were examined. This is probably because the bio-diesel has less sulphur, nitrogen, and aromatics than regular oil. However, due to the bio-diesel's greater oxygen content and potential for slightly higher CO and UHC emissions. To address the emissions challenges associated with bio-oil, several approaches have 35 been proposed [18]. Another approach is to use exhaust gas recirculation (EGR) to reduce the formation of NO_x

4.4.1 Hydrocarbon

The partially burned and unburned hydrocarbons, which finally cannot combine with the oxygen gas, are the main cause of the hydrocarbon emissions. As a result, the combustion process becomes unfinished. According to reports, hydrogen petrol in both conventional diesel and biodiesel mixes emits fewer hydrocarbons, and these emissions appear to further decline as the fuel's overall enrichment increases. Additionally, it causes the temperature to rise during combustion, which causes hydrocarbons to oxidise after they flame out. The THC emissions increased as the amount of hydrogen increased in the investigation done by Talibi et al. [14]. It was mentioned that the decrease in the amount of O₂ taken into the cylinders was most likely the reason for this increase. Oxygen is less available when pilot diesel fuel is burned with a higher proportion of hydrogen. The local air-to-fuel ratios fall as a result. Diluted air is injected with the primary diesel fuel. This could be the cause of the increased THC emissions.

4.4.2 NO_x Emissions

A number of factors, including temperature and duration of combustion, are significant when considering nitrogen emissions. In contrast, a significant amount of nitrogen gas is released by both conventional diesel mixes and biodiesel blends. This can be the result of the gasoline burning, which typically raises the temperature and pressure inside the cylinder. It has been found that during part-load experiments, the cylinder walls typically absorb heat, resulting in a lower temperature. Comparisons can be seen in the NO_x emission figures for each engine load between the B20 and diesel fuel tests, with hydrogen enrichment. In comparison to the diesel fuel testing, the B20 fuel tests often revealed increased NO_x emissions with the hydrogen addition.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 EFFECT OF HYDROGEN ADDITION ON PERFORMANCE

The addition of hydrogen to a compression ignition (CI) engine has garnered a lot of attention and research recently due to its potential to improve engine performance and reduce emissions. Even though hydrogen burns at a faster rate than liquid fuels, adding hydrogen to the mixture boosted premixed combustion in both operating conditions. (Sukjit et al., 2013). Hydrogen can improve combustion stability, which can lead to quieter engine running, improving the experience for both the operator and adjacent people. Because hydrogen has a high calorific value, it raises the temperature of the gases in the cylinder, which encourages a faster combustion process and this causes a rise in mean indicated pressure and a decrease in BSFC [12]. The Caliber of the fuel injection, the act of atomizing a fuel, the compression ratio, the fuel's thermal value when it is pumped into the cylinders, and a variety of other variables influence how efficiently a diesel engine operates. A few of these factors are inextricably linked to fuel injection [40]. To acquire pertinent data about various conditions affecting the combustion process and engine performance, HR analysis is crucial [31]. To fully realize the advantages of this technology, however, issues with fuel distribution, ignition control, and hydrogen storage must be resolved.

5.1.1 Brake thermal efficiency

The fig 5.1 tells us about the BTE of the blends of B20 with Diesel, 3LPM, 6LPM and 9LPM In the addition of hydrogen at various loads pf percentage like 25%, 50%, 75%, and 100%. The 9LPMH₂ OF B20 blends has high BTE and the blend 3LPMH₂ OF B20 has low BTE. At the load of 100% the BTE reaches at its peak level. The BTE decreases as the bio-diesel percentage in diesel is increased. This may be due to low calorific value of blends [43]. BTE is a key metric that can be used to evaluate the efficiency of the engine. A higher BTE indicates that the engine is able to convert a greater amount of the energy in the

fuel into useful work [24]. The engine can be operated under different conditions, such as varying the engine speed, load, and injection timing, to determine the optimal operating conditions for the fuel. The BTE can be calculated based on the measurements of the fuel consumption and the output power of the engine. The BTE can provide insights into the efficiency of the engine and can help to optimize the operating conditions for the fuel. This can be achieved by optimizing the combustion process, improving the fuel injection system, reducing heat losses, and minimizing frictional losses. An increase in BTE is desirable as it can lead to higher fuel efficiency and lower emissions. On the other hand, when the BTE of an engine decrease, it suggests that the engine is wasting more fuel energy and not converting it into useful work. This can occur due to inefficient combustion, poor fuel quality, engine wear and tear, and other factors [20].

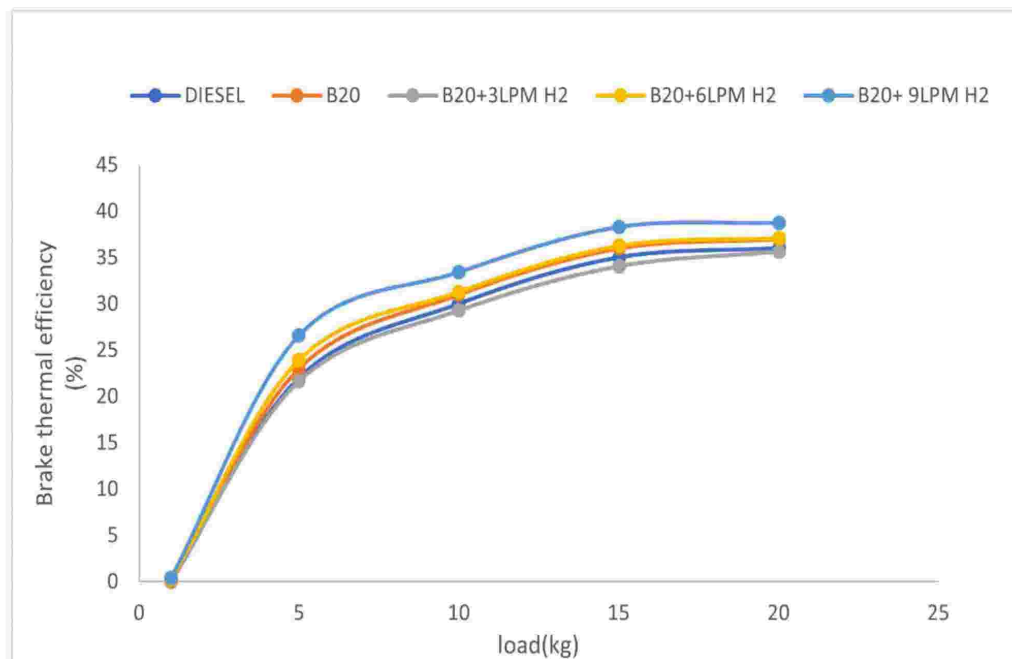


Fig 5.1: Brake thermal efficiency with respect to load

5.1.2 Specific fuel consumption

The mass fuel flow rate divided by engine power is known as the SFC. The engine's efficiency in using gasoline is gauged by the SFC, which is dependent on the fuel's properties [19]. Fig. 5.1 tells us that the brake-specific fuel consumption of the blends of B20 with diesel, 3 lpm, 6 lpm, and 9 lpm in the addition of hydrogen at different load conditions ranges from 25% to 100%. The figure shows that the B20 blend is high at 25% load and low at 100% load. The BSFC gradually decreases from 25% to 100% in load conditions. The sample of 9 lpmh₂ has low BSFC at higher and lower loads compared to the B20 blend. The BSFC may rise or fall as a result of employing bio-diesel and diesel blends, according to the blend ratio and engine conditions of operation. For instance, the BSFC may increase if the mixture ratio is elevated in bio-diesel and low in diesel due to the greater viscosity and lower thermal conductivity of bio-diesel when compared to diesel. Reduced engine efficiency and higher emissions of greenhouse gases and particles could result from this. The BSFC values of 3 lpm, 6 lpm, 9 lpm, and B20 in the addition of hydrogen compared with conventional diesel fuel showed 14%, 7%, 24%, and 28% reductions in BSFC values at the initial load condition. Hydrogen had less of an impact on SFCs from B20 fuel tests than it did from diesel fuel tests. The reason could be attributed to the lower heating values of B20 fuel and hydrogen combined. The hydrogen and air mixture was too lean for B20 pilot fuel to ignite at low loads. At high loads, when the hydrogen mass share was reduced, this was quite significant. Weak combustion and ignition are the results.

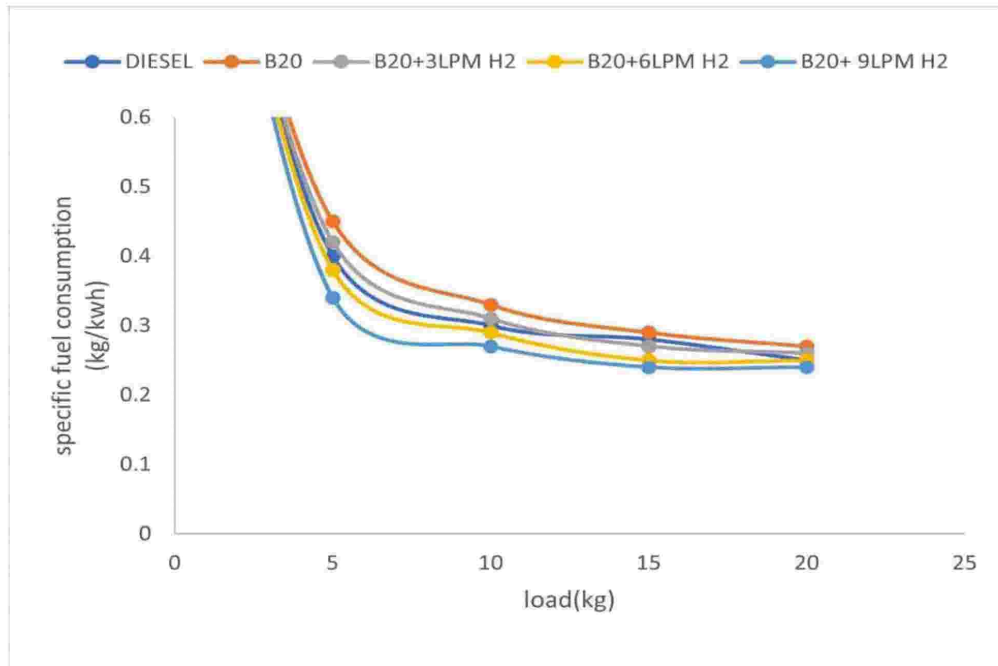


Fig 5.2: Specific fuel consumption with respect to load

5.2 EFFECT OF HYDROGEN ON EMISSION

Considering its distinct characteristics and potential to lower emissions, hydrogen is receiving more and more interest as a potential replacement fuel for compression ignition (CI) engines. In terms of lowering conventional pollutants and addressing greenhouse gas emissions, using hydrogen in CI engines can have a considerable impact on emissions. In CI engines, hydrogen has the potential to significantly lower emissions of dangerous pollutants like nitrogen oxides (NO_x) and particulate matter (PM). Due to its role in air pollution and harmful impacts on human health, NO_x emissions from diesel engines are a significant problem. The fast flame speed and broad flammability range of hydrogen enable more thorough combustion. This results in lower combustion temperatures, which lower NO_x generation. Furthermore, combustion of hydrogen creates almost little particulate matter, making it a desirable choice for reducing PM emissions, a well-known problem in diesel engines. In consequence of its high hydrogen-to-carbon ratio, hydrogen burns cleanly and emits little carbon dioxide (CO_2). In reality, when produced from

renewable sources, such as electrolysis utilizing green power, hydrogen is frequently regarded as a zero-emission fuel. This can have a major effect on lowering the known climate change-causing greenhouse gas emissions from CI engines. In CI engines, hydrogen has the potential to dramatically cut emissions. It offers a viable approach for reducing air pollution because it can reduce NO_x and PM emissions. Additionally, hydrogen can function as a zero-emission fuel, aiding in the fight against climate change, when it is produce from sustainable sources.

5.2.1 Hydrocarbon (HC)

The source of HC is the cylinder wall, which maintains a thin layer of oil left over as the piston descends and builds up in crevices and any cold parts of the combustion wall. HC and carbon monoxide (CO) emission levels, as the gaseous form of hydrogen will lessen the cylinder line's tendency to wet its walls. Fig. 5.2 tells us that the hydrocarbon emissions of the blends of B20 with diesel at 3 lpm, 6 lpm, and 9 lpm in the addition of hydrogen at different load conditions range from 25% to 100%. The sample of B20, diesel, 3 lpm, 6 lpm, and 9 lpm in the addition of hydrogen has gradually increased at higher load conditions of 70, 70, 70, 80, and 80 ppm. It is noted that the hydrogen gas in both conventional diesel and biodiesel blends exhibits lower emissions of hydrocarbons and that these emissions appear to further decline as the total enrichment of the same increases. Additionally, it causes the temperature to rise during combustion, which causes hydrocarbons to oxidise after they flame out. Due to hydrogen's gaseous condition, its presence in the combustion chamber reduces the wetting wall phenomenon and reduces the emission of HC. A combination of its high calorific value and broad flammability limit, the trend of HC decreased at all injection operating pressures with increasing percentages of H₂ substitution as compared to pure diesel.

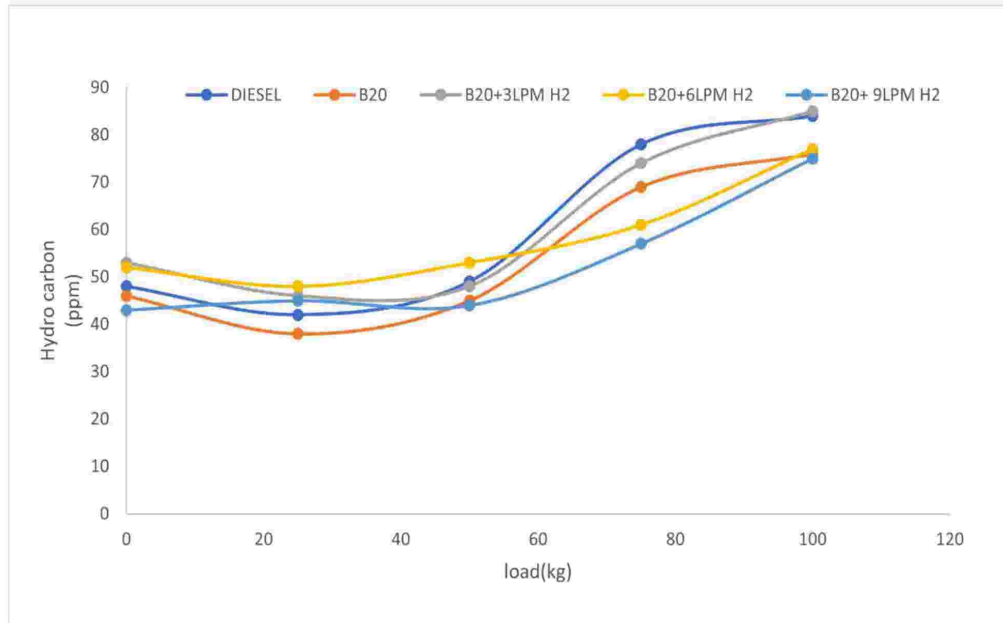


Fig 5.3: Hydrocarbon emission with respect to load

5.2.2 Carbon-monoxide (CO)

The chemical energy wasted as a result of incomplete combustion is represented by CO exhaust emissions. The creation of CO emissions can be influenced by a number of factors, including fuel characteristics, combustion chamber design, equivalency ratio, mass flow rate, start of injection timing, engine load, and others. Only engine exhaust contains carbon monoxide. Figure 5.2 represents the carbon monoxide emission rate for blends of B20 with samples of diesel, 3 lpm, 6 lpm, and 9 lpm in the addition of hydrogen at various load conditions. In higher load conditions, the co-emission rate for diesel is low compared to other samples, and in the same load, the co-emission rate for 9 lpmh₂ is high compared to other samples. In the lower load condition, the co-emission rate for diesel, B20, 3 lpmh₂, 6 lpmh₂, 9 lpmh₂ is 0.038%, 0.037%, 0.05%, 0.037%, and 0.02%. The biodiesel blends release less carbon monoxide than usual diesel when the high loading conditions are taken into account. In a similar vein, using hydrogen gasoline can reduce CO emissions even more. The action of hydrogen may be responsible

for the rise in diffusivity and flame speed. It is a consequence of incomplete combustion, which can be brought on by either insufficient air in the fuel-air mixture or insufficient cycle time for combustion to complete. Due to the late start of combustion in the case of hydrogen replacement, the chamber temperature will drop and incomplete combustion will take place.

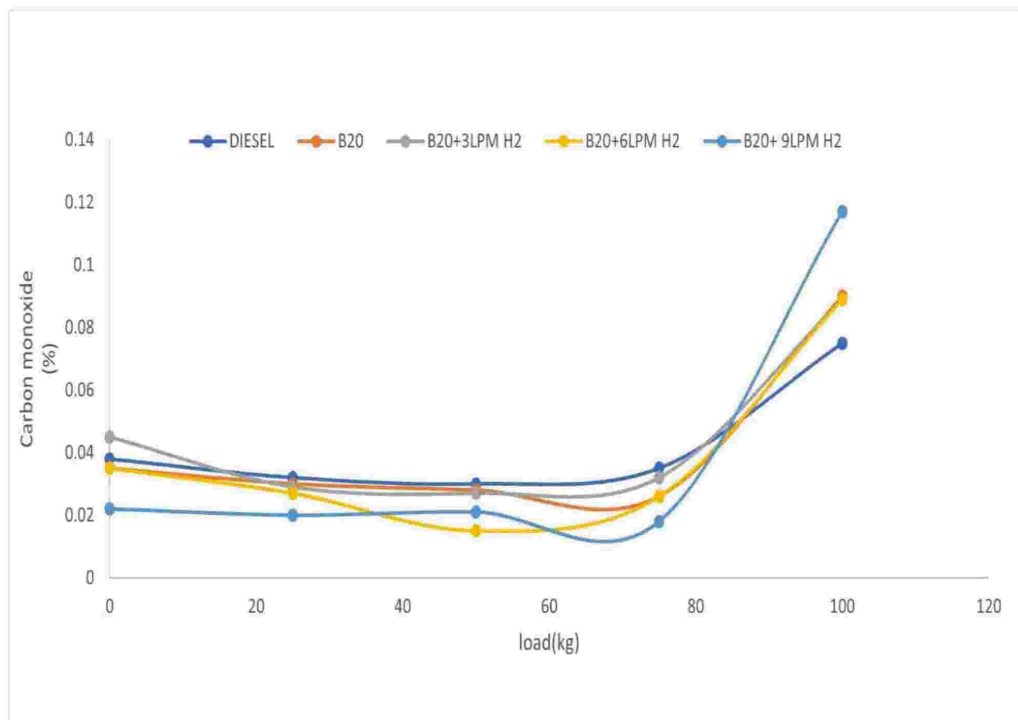


Fig 5.4: Carbon monoxide emission with respect to load

5.2.3 Carbon-dioxide (CO₂)

In a compression-ignition (CI) engine, hydrogen has a sizable effect on CO₂ emissions and shows potential for lowering greenhouse gas emissions. A CI engine that uses hydrogen as a co-fuel or supplemental fuel can significantly reduce its CO₂ emissions. Compared to conventional fossil fuels, hydrogen burns more efficiently and cleanly, with the major waste being water vapours. This means that the combustion process produces fewer carbon dioxide (CO₂) emissions when hydrogen is utilized in CI engines as a standalone fuel or in combination with diesel. As demonstrated in Fig. 5.2, the CO₂ emissions for each test displayed trends that

were similar with the addition of hydrogen. With the addition of hydrogen and the greatest decrease, there was a significant drop in CO₂ emissions for pure diesel and pure B20 fuels. Consequently, 1.5%, 1.77%, and 1.93% of the CO₂ emissions were reduced in the mix of B20 with diesel in the 3 lpmh₂, 6 lpmh₂, and 9 lpmh₂ tests compared to pure diesel. at 40, 60, and 80 Nm of engine load. Because of the higher oxygen concentration in B20, it was seen that the addition of hydrogen had a considerably greater influence on the B25 fuel testing. When compared to other loading regimes, the carbon dioxide emission levels of all test fuel samples demonstrated the greatest values under greater load situations. Hydrogen addition improves the corresponding raw diesel and biodiesel by approximately [39]. It has two properties: one accelerates the combustion process, which increases carbon dioxide emissions; the other improves hydrogen replacement with air, which lowers carbon dioxide emissions. When hydrogen dual fueling employs induction methods that allow for higher enthalpy fractions of hydrogen, CO₂ emissions will be further reduced. When compared to diesel fuel, hydrogen produced through steam-methane reforming emits less CO₂ across its entire life cycle, continuing the downward trend for overall CO₂ emissions (Alrasen 2016).

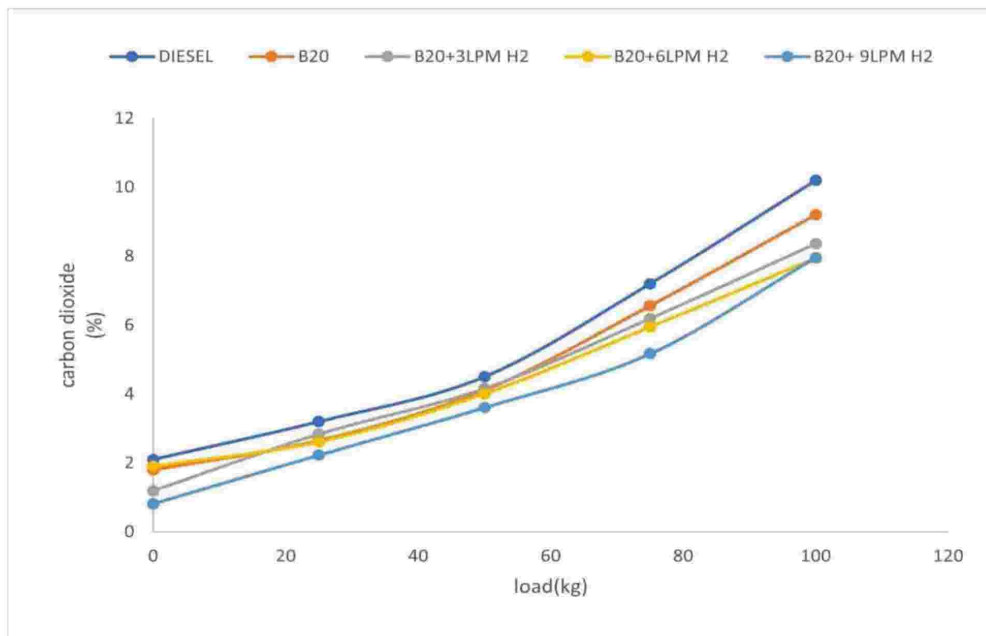


Fig 5.5: Carbon dioxide emission with respect to load

5.2.5 Nitrogen oxide (NO_x)

One of the most dangerous emissions produced by CI engines is NO_x, which is typically composed of 90–95% NO and 5–10% NO₂ [18]. The greater combustion temperature, the combustion chamber's oxygen concentration, and the nitrogen's exposure to high temperatures are the main causes of the NO_x emissions. When the Fig 5.2 was studied, it became clear that for each test, the NO_x emissions rose as the engine load increased. As engine load increases, more gasoline is consumed, raising gasoline temperatures and NO_x emissions. It was found that pure B20 fuel tests yielded somewhat higher NO_x emission levels than pure diesel fuel tests. Similarities can be seen in the NO_x emission figures for each engine load between the B20 and diesel fuel tests, with hydrogen enrichment. In comparison to the other sample fuel tests, the B20 fuel tests often revealed increased NO_x emissions with the hydrogen addition. Natural B20 fuel testing was shown to produce somewhat higher NO_x emission levels than pure diesel fuel tests. The NO_x emission values for each engine load in the B20 and diesel fuel tests, with hydrogen enrichment, show similarities. When hydrogen was added, the B20 fuel tests frequently showed higher NO_x emissions than the other sample fuel tests. The biodiesel blends are seen to create somewhat greater amounts of nitrogen emissions in comparison. Nitrogen gas emissions are correlated with increased oxygen concentrations in biodiesel mixes. The use of biodiesel results in even higher emissions during part-load operation when load concentration is taken into account. This is mostly because of a shorter retention period, which causes the increased temperature in the cylinder to dissipate more quickly.

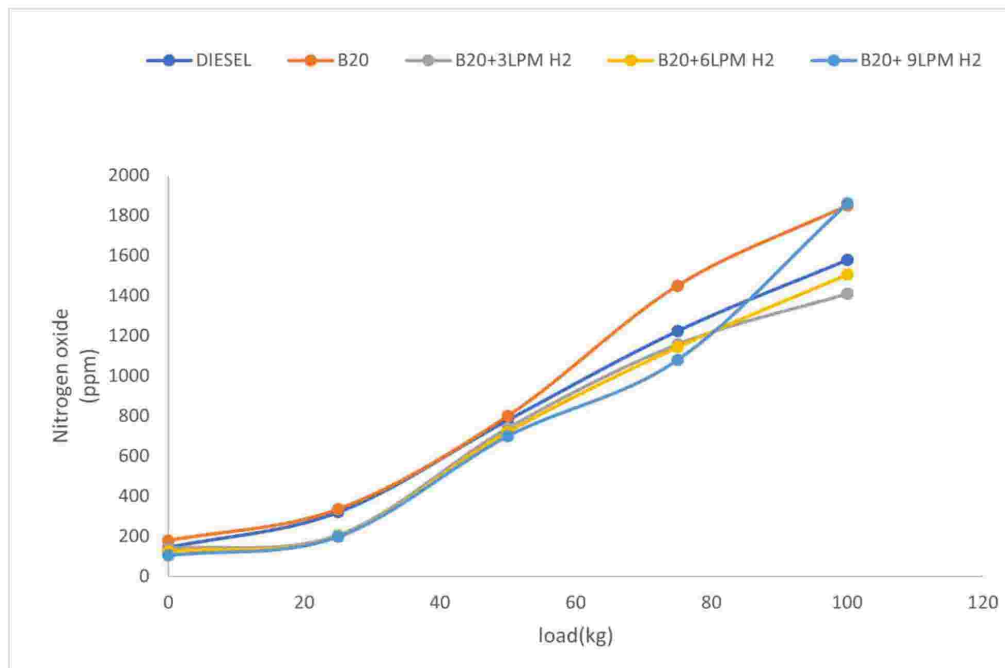


Fig 5.6: Nitrogen oxide emission with respect to load

CHAPTER 6

CONCLUSION

The bio-diesel was extracted from waste cooking oil at various concentrations by using the transesterification process. The bio-diesel properties have been tested and found that the density is 892 kg/m^3 , the viscosity is $6.13 \text{ mm}^2/\text{s}$, and the calorific value is 40850 kJ/kg . B20 biodiesel blend (20% bio-diesel/80% diesel) is 3 lpm, 6 lpm, and 9 lpm addition of hydrogen in CI engine. The performance characteristics and emission parameters have been tested for all the samples. In terms of performance characteristics, BTE and SFC have been tested for the various samples under different load conditions. At last, the emissions parameters of CO, HC, NO_x, and CO₂ have been examined and values generated, leading to the conclusion that bio-diesel can be used as an alternative fuel source in the coming generation. The engine's braking thermal efficiency did not significantly increase with the addition of B20 and hydrogen. Regardless of engine load, the higher viscosity of the biodiesel blends is the cause of the aforesaid lower BTE. At 75% and 100% of engine load, 9LPM indicated 2% greater BTE than plain diesel. Because of the higher heating value, higher calorific value, and poorer braking thermal efficiency of the BSFC, all mixes reported consuming less gasoline than B20. The evaluation of the B20 fuel sample in the presence of hydrogen revealed an increase in CO₂ and CO emissions. At greater load conditions, the highest rise in CO₂ emissions was seen. The addition of hydrogen led to a small improvement in NO_x. B20 fuel produced more NO_x emissions per engine load overall when compared to other test samples. Hydrogen injection into CI engines running on diesel-waste oil biodiesel mixes has the potential to increase combustion efficiency and cut emissions. However, a number of variables, such as the mix ratios, engine layout, and pollution control systems, affect how practical this strategy is. It's critical to carry out additional research and development to optimise this technology for real-world uses, taking into account both environmental and financial factors.

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