

# **OPTIMIZED BIODIESEL PRODUCTION FROM WASTE COOKING OIL USING HETEROGENEOUS MgO-ZnO NANOCOMPOSITE**

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Engineering degree in  
Mechanical Engineering

By

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**INSTITUTE OF SCIENCE AND TECHNOLOGY**

**(DEEMED TO BE UNIVERSITY)**

**Accredited with grade “A++” by NAAC**

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**APRIL 2024**



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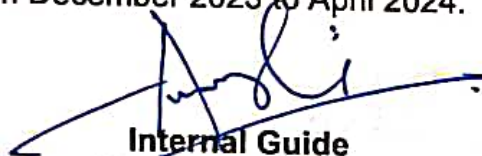
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## DEPARTMENT OF MECHANICAL ENGINEERING

### BONAFIDE CERTIFICATE

This is to certify that this Project Report is the Bonafide work of RAHOON S (Reg. No. 40150718) and JOHANNES RICHY J (Reg. No. 40150706) who carried out the project entitled "OPTIMIZED BIODIESEL PRODUCTION FROM WASTE COOKING OIL USING HETEROGENEOUS MgO-ZnO NANOCOMPOSITE" under our supervision from December 2023 to April 2024.

  
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## DECLARATION

We, RAHOON S (Reg. No. 40150718) and JOHANNES RICHY J (Reg. No. 40150706) hereby declare that the Project Report entitled "**OPTIMIZED BIODIESEL PRODUCTION FROM WASTE COOKING OIL USING HETEROGENEOUS MgO-ZnO NANOCOMPOSITE**" done by us under the guidance of **Dr. M. ANISH, M.E., Ph.D.**, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Mechanical Engineering.

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## ABSTRACT

The objective of this experimental investigation is to examine the operational efficiency, combustion dynamics, and exhaust emissions of a diesel engine that is equipped with variable compression ratio (VCR) technology. The engine will utilise a blend of biofuel (B20) that has been injected with nano additives. Biodiesel produced through transesterification of Waste Cooking Oil utilized nanoparticles of a nanocatalyst synthesized via the precipitation process, alongside characterization techniques including scanning electron microscopy and X-ray diffraction. Following their incorporation into the biofuel blend through the utilisation of a magnetic stirrer, the nano additions were subsequently exposed to ultrasonication. The fuel combinations mentioned above were utilised throughout the duration of the testing protocol. A mixture of 20% biodiesel and 80% diesel (B20) was prepared. Zinc oxide and Magnesium oxide nanoparticles at concentrations of 15ppm, 30ppm, 45ppm, 60ppm, and 75ppm were added to the B20 blend. The blend consisted of diesel, B20, B20+Nanocatalyst15, B20+ Nanocatalyst30, B20+Nanocatalyst45, B20+Nanocatalyst60, and B20+ Nanocatalyst75 in B20 fuel characteristics was observed by adding Zinc oxide and Magnesium oxide nanoparticles. The outcomes engine was operated under various load situations, ranging from 0% to 100%, while maintaining a steady speed and a fixed compression ratio of 20:1. The findings were acquired by the utilisation of diesel fuel in its optimal operational circumstances. The combination of B20 fuel and Nanocatalyst at a concentration of 45 ppm exhibited a significant enhancement in comparison to pure diesel. An increase of 3.62% in brake thermal efficiency and a decrease of 3.3% in specific fuel consumption serve as evidence of this enhancement. The addition of micro catalyst nanoparticles to blended biofuels decreases the release of carbon monoxide and hydrocarbons into the environment, hence reducing emissions. Boosting the concentration of nanocatalyst in the fuel mixer offers the added benefit of minimizing nitrogen oxides (NO<sub>x</sub>) emissions. Nano catalyst particles within the fuel blend act as an oxygen buffer, engaging with oxygen to curb the formation of nitrogen oxides. This forms the basis for the occurrence of this specific scenario.

Keywords: Biodiesel, VCR engine, Waste Cooking Oil, Performance, Combustion, Emission, Nanocatalyst.

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## **LIST OF ABBREVIATIONS**

|                 |                           |
|-----------------|---------------------------|
| BTE             | BRAKE THERMAL EFFICIENCY  |
| SFC             | SPECIFIC FUEL CONSUMPTION |
| RME             | RAPESEED METHYL ESTER     |
| SME             | SOY METHYL ESTER          |
| PME             | PALM METHYL ESTER         |
| WCO             | WASTE COOKING OIL         |
| AFME            | ANIMAL FAT METHYL ESTER   |
| JME             | JATROPHA METHYL ESTER     |
| Nox             | NITROGEN OXIDE            |
| FAME            | FATTY ACID METHYL ESTER   |
| CO <sub>2</sub> | CARBON DIOXIDE            |
| VE              | VOLUMETRIC EFFICIENCY     |
| EGT             | EXHAUST GAS TEMPERATURE   |
| CO              | CARBON MONOXIDE           |
| HC              | HYDRO CARBON              |
| SO              | SMOKE OPACITY             |
| CP              | CYLINDER PRESSURE         |
| CA              | CRANK ANGLE               |
| NHRR            | NET HEAT RELEASE RATE     |
| NC              | NANO CATALYST             |

# **CHAPTER 1**

## **INTRODUCTION**

### **1.1 HISTORY AND BACKGROUND**

The modern internal combustion engine, widely utilized today, traces its roots back to the Industrial Revolution of the 18th and 19th centuries. Etienne Lenoir, a prominent French engineer, is credited with developing the initial compact gas-powered engine in the early 1800s. However, it wasn't until later in the 19th century that Nikolaus Otto, a German engineer, successfully created the first operational internal combustion engine due to earlier models' low efficiency. Otto's groundbreaking finding continues to influence the fundamental structure of contemporary engines. In order to efficiently convert fuel into mechanical energy, these engines employ a four-stroke cycle consisting of intake, compression, combustion, and exhaust phases. At the core of this procedure lies a piston enclosed within a cylinder, thereby enabling streamlined functionality. Karl Benz's 1885 invention, the Benz Patent-Motorwagen, marked the practical debut of automobiles, powered by internal combustion engines. Similarly, the Wright Brothers' pioneering flight in 1903 signaled the beginning of engine-powered aircraft, setting the stage for aviation's evolution. The introduction of jet engines in the 1930s and 1940s revolutionized air travel, significantly boosting speed and efficiency. Subsequent developments, like diesel engines in the mid-20th century, further improved fuel efficiency, finding widespread use in various applications such as power generators, ships, trucks, and buses. In contemporary times, there's been a growing emphasis on developing engines with enhanced efficiency and reduced environmental impact. This has led to the emergence of hybrid and electric variants, integrating various technologies aimed at minimizing fuel consumption and pollution.

### **1.2 INTRODUCTION OF BIODIESEL AND ITS GENERATIONS**

Biofuels are commonly categorized into primary and secondary types based on their composition and production methods. Primary biofuels include landfill gas, firewood, wood chips, and pellets, while secondary biofuels encompass bioethanol,

butanol, biodiesel, and hydrogen. These biofuels are produced from organic matter. Biodiesel, bioethanol, and butanol are among the initial stages of biofuel production. Biodiesel is generated through a chemical process that utilises a diverse range of feedstock, such as rapeseed, soybeans, sunflower, palm, coconut, and animal fat, in varying proportions [1]. The production process involves the fermentation of starch obtained from sources such as wheat, barley, corn, potatoes, sugarcane, and sugar beets [2]. Second-generation biofuels involve synthesizing bioethanol, bio-butanol, and/or diesel from lignocellulosic materials such as straw, wood, and grass. Examples include *Jatropha*, cassava, and *Miscanthus* used in bioethanol and biodiesel production [3]. However, the initial iteration of biofuel production poses economic and environmental challenges, exacerbated by the need for agricultural land, which competes with food production for the growing global population. Second-generation biofuel production faces challenges like the requirement for substantial cultivation areas and the presence of woody plant parts not suitable for food production [4]. To address these challenges, microalgae offer a promising solution due to their ability to produce significant biomass on smaller land areas. Biodiesel, a sustainable biofuel, is derived from vegetable oils, animal fats, or recycled oils used for cooking through transesterification. This chemical process involves combining the feedstock with alcohol, typically methanol, and a catalyst like sodium hydroxide, resulting in methyl ester—the primary constituent of biodiesel. Various classifications of biodiesel and their manufacturing processes exist, providing alternatives for sustainable energy production [5].

#### *First Generation of Biodiesel*

- Rapeseed methyl ester (RME), sourced from rapeseed oil, stands as the primary biodiesel feedstock favored in Europe.
- Soy methyl ester (SME), extracted from soybean oil, holds the key position as the primary feedstock for biodiesel manufacturing in the United States.
- Palm methyl ester (PME), derived from palm oil, serves as the predominant biodiesel feedstock in the Asian region.

### *Second Generation of Biodiesel*

- Waste cooking oil methyl ester (WCOME) is a produced biodiesel derived from recycled cooking oil, a residual by-product generated by various food enterprises, restaurants, and households, offering an alternative to traditional cooking oil.
- Animal fat methyl ester (AFME) is a residual substance derived from animal fats like tallow and lard, commonly produced as a by-product within the meat industry.
- Jatropha methyl ester (JME) is sourced from jatropha oil, an oilseed unfit for human consumption that can be cultivated on unproductive land.

### *Third Generation of Biodiesel*

- Algal methyl ester (AME) is a type of methyl ester derived from oil extracted from algae, which have the ability to flourish in many aquatic environments and produce a significant amount of oil.

The use of biodiesel as a renewable energy source shows potential in reducing the emission of nitrogen dioxide (NO<sub>x</sub>) and decreasing the environmental carbon footprint [6]. The utilisation of plant feedstock has been found to result in a reduction in the carbon content incorporated into the fuel. The carbon originated from the Earth's atmosphere. Furthermore, biodiesel exhibits a reduction in the release of air pollutants, including carbon monoxide, nitrogen oxides, and carbon dioxide, as compared to diesel derived from fossil fuels. A study conducted in 1998 by the United States Department of Energy and the United States Department of Agriculture revealed that the utilisation of pure biodiesel in urban buses leads to a notable reduction in the life cycle emissions of total particulate matter by approximately 32 percent, carbon monoxide by approximately 35.4 percent, and sulphur oxides by approximately 8 percent when compared to the life cycle emissions of conventional diesel fuel. [7].

### **1.3 INTRODUCTION OF WASTE COOKING OIL**

The extraction of biodiesel from waste cooking oil entails the conversion of leftover cooking oil, obtained from diverse sources such as residential and commercial establishments, into a renewable and environmentally friendly fuel. Transesterification, a chemical reaction commonly utilized for this purpose, transforms the oil into biodiesel and glycerin. This reaction involves combining the oil, alcohol, and a catalyst to produce the desired products. Following transesterification, the biodiesel undergoes a series of steps including separation, washing, and drying to remove any impurities. This comprehensive procedure ultimately yields a fuel suitable for use in diesel engines. By adopting this method, waste cooking oil can be repurposed in an environmentally friendly manner, thus reducing reliance on fossil fuels.

### **1.4 CATALYST IN TRANSESTERIFICATION PROCESS**

Biodiesel synthesis involves the transesterification process, where triglycerides react with short-chain alcohols in the presence of a catalyst to produce biodiesel. To mitigate the reversible nature of this response, an excessive amount of alcohol is employed to manipulate the equilibrium towards the advancement of biodiesel production [8]. The generation of biodiesel is achieved via a chemical procedure referred to as transesterification, which involves the application of a catalyst. This process entails the interaction between triglycerides and short-chain alcohols. An excessive amount of alcohol is employed as a means to shift the balance towards the synthesis of biodiesel. This approach is used to acknowledge the reversible nature of this reaction [9]. The technique comprises three sequential steps that can be reversed. Initially, the process involves the conversion of triglycerides into diglycerides. Subsequently, diglycerides undergo a transformation into monoglycerides, which is then further converted into glycerol. The production of an ester molecule occurs simultaneously with each glyceride transition [10]. The transesterification process is influenced by various contributing factors. Hence, it is imperative to implement modifications to the production procedures to achieve the intended results, thereby ensuring the manufacture of biodiesel that meets the

established quality standards [11]. The amounts of liberated fatty acids, the percentage of moisture, and water content are critical characteristics that play a crucial role in determining the quality and progression of the process [12]. However, depending on the FFA and commonly known as esterification, preceding the transesterification process may be necessary the presence of a catalyst speeds up the reaction, increasing the yield of the product. Various catalysts are employed in the transesterification process for biodiesel synthesis. As previously noted, catalysts play a crucial role in the transesterification process and are of considerable importance to our research group. Recent academic literature suggests that these catalysts can be grouped into four primary categories: nanocatalysts, biocatalysts, heterogeneous catalysts, and homogeneous catalysts. These categories encompass a variety of catalyst types utilized across different applications [13].

## **1.5 TYPES OF CATALYSTS:**

### ***1.5.1 Homogeneous Catalysts***

The homogeneous base-catalyzed transesterification process has shown impressive catalytic efficiency using various catalysts such as alkaline metal alkoxides hydroxides or sodium/potassium carbonates [14]. This method yields high-quality biodiesel and facilitates methanol recovery, while the resulting glycerin by-product is suitable for pharmaceutical applications. However, the combustion of biodiesel may produce formaldehyde or acetaldehyde, necessitating the complete removal of glycerin. Despite its efficacy, homogeneous base-catalyzed transesterification has challenges in fully converting oil with high levels of free fatty acids into biodiesel. This phenomenon leads to a significant increase in soap manufacture, a widely recognised concern [15]. The use of a basic catalyst aids in soap synthesis, crucial for preventing unwanted separation of biodiesel, glycerin, and wash water, as stated in reference [16]. Successful transesterification of triglycerides requires an excess of methanol and specific air pressure and temperature conditions (60-70 degrees Celsius). However, the alkali catalyst often requires extended reaction times, spanning multiple hours, to ensure successful completion of the transesterification process [17,18].



### **1.5.2 Bio Catalysts**

Enzymes have long been recognised as crucial agents in facilitating a diverse range of chemical processes, let us examine the extensive utilisation of nitrile hydratases across many industrial contexts. The utilisation of these enzymes has greatly facilitated the production of substantial amounts of acrylamide, so exemplifying a commendable application that warrants commendation. One illustrative scenario is to the utilisation of nitrile hydratases within industrial environments. Moreover, enzymes have consistently been a prevalent constituent of detergents for the majority of the three decades that have transpired since the inception of the chemical business [19]. Protein-derived catalysts have found increasing use in synthesizing increasingly complex compounds, particularly in contemporary times. Within the pharmaceutical industry, the utilization of these catalysts has been prioritized. Enzymes present numerous advantages to users by combining the selectivity of a directed group with the efficiency of a single reagent within a single molecule [20]. In the past two decades, there has been a significant increase in the use of enzymes in combination with other enzymatic systems to enable simultaneous activities. The effective completion of numerous comprehensive synthesis projects can be attributed to the successful integration of synthetic and enzymatic methodologies. Enzymes play a crucial role in the various chemical departments engaged in industrial processes [21]. Until recently, access to enzymes for chemical production was limited primarily to lipases and ketoreductases (KREDs). Only this restricted range of enzymes was available [22]. As a result of this expansion, researchers now have access to a diverse range of enzymatic tools. The concept of "bio-retrosynthesis" gained substantial attention in 2014 when it was discovered that the nucleoside didanosine could only be synthesized using enzymatic methods. This discovery sparked significant interest in the concept of "bio-retrosynthesis" [23].

### **1.5.3 Heterogeneous Catalysts**

The utilisation of heterogeneous catalysts constitutes a fundamental component in numerous chemical processes. The catalysts operate within a discrete phase separate from the gas or liquid products and reactants, commonly assuming a solid state. The primary objective of catalysts is to enhance the rates of reactions, rendering them a crucial constituent in a diverse range of industrial procedures. These activities encompass the production of chemicals and fuels, alongside endeavours aimed at environmental remediation [24]. Typically, solid heterogeneous catalysts consist of metal oxides, metals, or metal-based compounds that are supported on porous substrates. It is important to acknowledge that this category extends beyond the aforementioned types of catalysts. Heterogeneous catalysts can occasionally exist in the form of liquids or gases that are immobilised on solid support structures. Nevertheless, in these particular cases, they do not exist in a solid state [25]. The efficacy of a heterogeneous catalyst is influenced by two key factors: its surface area and the abundance of active sites it harbours. The active sites refer to distinct regions present on the catalyst's surface, where reactant molecules can adhere and engage in chemical reactions. These geographical areas are commonly known as "hot spots" [26]. The catalyst's surface serves as a substrate for the adsorption of the reactant molecules, so initiating the commencement of the chemical reaction. The phenomenon of adsorption leads to a decrease in the inherent bond strength exhibited by the reactants, hence facilitating the subsequent reaction and the generation of products [27].

## **CHAPTER 2**

### **LITERATURE SURVEY**

Plant oils and animal fats are examples of renewable sources that can be used to produce biodiesel, which is an alternative fuel. It is considered a more ecologically sound and sustainable option compared to traditional petroleum-based diesel fuel, in part because it produces fewer harmful emissions when burned. Consequently, biodiesel has gained significant interest because to its capacity to tackle many energy and environmental issues.

recent years, there has been a significant growth in research on the production, characterization, and application of biodiesel, with numerous studies published on various aspects of the topic. The objective of this literature study is to conduct a comprehensive examination of the existing body of knowledge pertaining to biodiesel. This will be achieved by providing a concise overview of significant results derived from pertinent scholarly literature pertaining to the topic.

Verma, M. L., Puri et al. (2016) An experimental study was conducted to evaluate diesel engine emissions and performance using combinations. For the growth of any region of the world, energy is a crucial issue. The market issues a warning to shift toward sustainable fuel for the coming generation as a result of the increase in crude oil prices and the accompanying global emissions. The need for energy is growing because of the expanding global population, the necessity for energy in industrial applications, the use of vehicles, and power generating equipment [28].

Moreira, K. D. S., de Oliveira, A. L. et.al (2020) in this investigation, the characteristics of tall oil methyl ester-diesel fuel mixes were examined as potential alternative fuels. The researchers explored the use of blends consisting of tall oil methyl ester and diesel fuel as a promising option for diesel engines. To produce tall oil methyl ester, methyl alcohol and tall oil fatty acids were carefully combined. The inclusion of tall oil methyl ester in the diesel fuel blends led to a notable increase in engine power and torque output, with improvements of up to 6.1% and 5.9%

respectively. However, the revised fuel combinations also resulted in a significant rise in NO<sub>x</sub> emissions, reaching up to 30%, while CO emissions experienced a substantial decrease of 38.9%. Interestingly, the opacity of the smoke did not exhibit any noticeable changes throughout the study [29].

Méndez, J. C., Arellano, U et.al (2022) conducted a study to investigate the effects of engine speed and the concentration of alumina nanoparticles in diesel-biodiesel blended fuels on the performance and emission characteristics of a six-cylinder, four-stroke diesel engine. Alumina nanoparticles were synthesized and added to the diesel-biodiesel blend at concentrations of 40, 80, 120, and 160 parts per million. These fuel blends were used to operate the diesel engine at various speeds ranging from 800 to 1000 rpm [30].

It demonstrates the fluctuation in emission and the impact of nanoparticles. The inclusion of nanoparticles had a favorable impact on the variance of emission across all test fuels, being the best for maintaining stable and constant emission levels [31].

A study conducted by Liu, C. H., Huang, C. C., Wang et al. (2018) investigated the combustion and emissions characteristics of a microalgae oil biodiesel blend (B20) in a single- cylinder diesel engine. The results showed that B20 had similar combustion characteristics to petroleum-based diesel, but with lower emissions of particulate matter, carbon monoxide, and unburned hydrocarbons [32].

The use of biodiesels, which are long-chain monoalkyl (methyl, ethyl, and propyl) esters extracted from vegetable oils or animal fats, can be reduced with minimal negative environmental impact [33].

Since then, researchers have experimented with different biodiesel sources and compositions to improve efficiency and reduce emissions. Researchers have been switching increasingly to biodiesel in place of diesel in recent years, and this is the most effective way to meet emission standards [34].

## **CHAPTER 3**

### **AIM AND SCOPE**

#### **3.1 AIM**

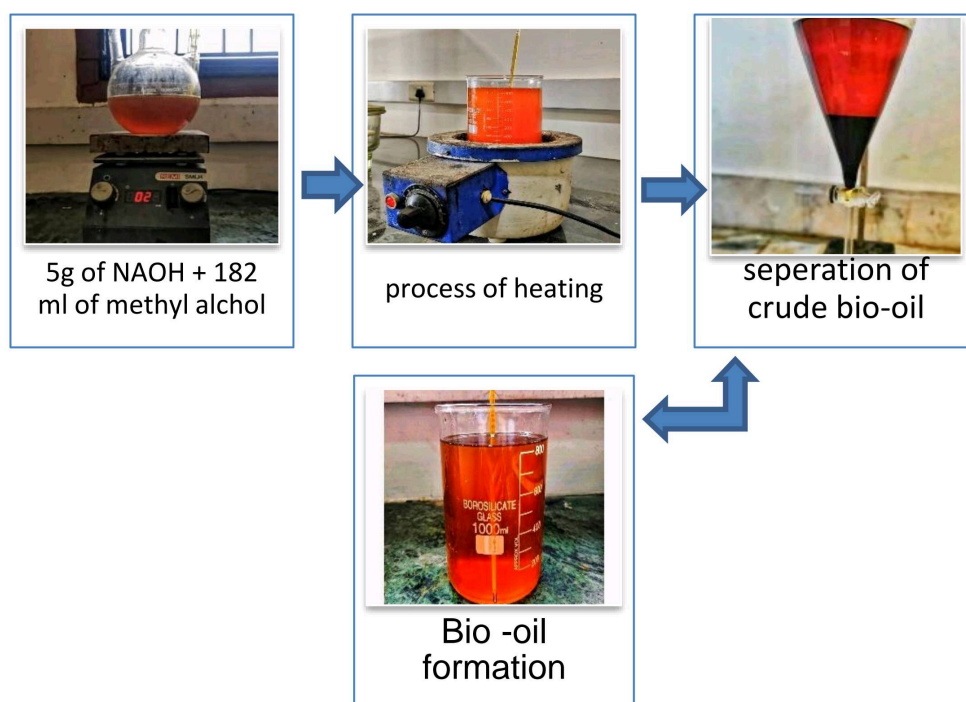
It is expected that the incorporation of a nanocomposite of magnesium oxide and zinc oxide, together with ethanol, in the biodiesel generation process will lead to enhanced efficiency. Because of their extraordinary properties, including as their high surface area and catalytic activity, nanocomposites have garnered a lot of attention in recent years. There is a possibility that these one-of-a-kind qualities could improve the transesterification process, which is an essential part of the manufacture of biodiesel. By using ethanol as the alcohol, the process may be more sustainable and less energy-intensive compared to traditional Ethanol-based biodiesel production. However, it is imperative to highlight that further investigation and testing would be required to assess the effectiveness and feasibility of this methodology.

#### **3.2 SCOPE**

Biodiesel, acknowledged as a high-potential alternative fuel, assumes a crucial function in mitigating the release of detrimental pollutants into the natural surroundings. Furthermore, it presents a viable and enduring resolution to address the escalating need for fossil fuels. The present compilation of scholarly investigations presents a potential solution to the challenge of efficiently harnessing high viscosity blends in conventional diesel-powered automobiles. Furthermore, it is crucial to emphasise the enhancement in the simultaneous administration of rail direct injection. By implementing this methodology, diesel engines can function with increased levels of efficiency.

### 3.3 METHODOLOGY

- STEP 1; Take 1 liter of “Waste cooking oil” or any other oil in Glass Separatory Funnel.
- STEP 2; Preheat the oil at 60 degree and then add catalyst “Methanol + NaOH/KOH” in the ratio of 1:3. (naoh-5g and methanol-182ml).
- STEP 3: The reaction is allowed to conduct for 90 minutes.
- STEP 4; After 90 minutes, Two layers are created in glass funnel. The upper most layer consists of crude glycerin, while the lower layer is formed of biodiesel.”. Separate the biodiesel from glycerin.
- STEP 5; 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-DIESEL”.
- STEP 6; B20 blend formation (80% of diesel +20%bio-oil) + Nano catalyst (MgO-ZnO).
- STEP 7: Testing of engine emission and performance characteristics using blends.
- Figure. 3.1 shows Biodiesel Preparation Flow Chart.



**Fig:3.1: Biodiesel Preparation Flow Chart**

## **CHAPTER 4**

### **MATERIALS AND METHODS**

#### **4. MATERIALS AND METHODS**

The manufacturing of biodiesel involves the utilization of a nano-composite consisting of magnesium oxide (MgO) and zinc oxide (ZnO). These oxides possess exceptional quality, characterized by a purity level of 99% and an average particle size of 10 microns. The process involved five distinct mix weight ratios: 100:0, 75:25, 50:50, 25:75, and 0:100, denoted as NCPs1-5, respectively. After determining the accurate weights and ratios of the raw materials, they were mixed into an ethanol alcohol mixture and homogenized using a Hielscher ultrasonic device. The device operated at a power output of 2 watts, a frequency of 26 kilohertz, and a rotational speed of 1000 revolutions per minute to ensure uniform distribution across the materials. After the process of homogenization, the mixtures were subjected to a four-hour thermal treatment using a friction mill. The drying procedure was subsequently conducted utilising an IMS oven, which was adjusted to a temperature of  $65 \pm 5$  °C, for a period of three hours. Ultimately, the amalgamated powders underwent sintering in MTI Corporation's GSL1600X furnace, maintaining an average temperature of 400 degrees Celsius for a duration of one hour.



## 4.1 MATERIALS USED

The materials used for this project are Magnesium oxide, Zinc oxide and Ethanol are shown in Figure 4.1



**Fig: 4.1: Materials used**

## 4.2 INSTRUMENTS USED

Instruments used for this project are Ultrasonicator, Magnetic stirrer, Hot air oven.

### 4.2.1 Ultrasonicator

The utilisation of ultrasound in the manufacturing process of biodiesel has witnessed a substantial surge in popularity over an extended period of time. This phenomenon is attributed to the ability of ultrasound to achieve uniformity among reagents through acoustic cavitation. Acoustic cavitation is defined by the formation of cavitation bubbles, which cause the rise in temperature within the reaction medium. This approach entails the expeditious formation and subsequent dissipation of cavitation bubbles, resulting in a reduction of reaction time from many hours to a matter of minutes. Consequently, the reaction rates are enhanced while the quantity of catalyst employed is diminished. Reactions are commonly conducted using simple ultrasonic baths or probes that work within the frequency range of 20 to 50 kHz. These devices often have an output power of over 200 W. Figure 4.2 shows Ultrasonicator device. The achievement of this outcome has been facilitated by the accessibility of cost-effective equipment that possesses the potential to attain

favourable conversion values, even when operating at low power levels, such as 50 W or below. Ongoing research is being conducted to explore the potential of ultrasound in accelerating the transesterification process and its utility in monitoring biodiesel reactions. Both of these opportunities are currently under investigation in the field of ultrasound. The incorporation of low-power ultrasonography into an inline methodology for assessing reaction completion not only yields time and energy savings, but also aids in the mitigation of waste formation. Ultrasonography has been extensively utilised across several domains over an extended period of time, proving to be an indispensable tool for the investigation and characterization of materials. The incorporation of ultrasonic analytical techniques in the production of biodiesel is a relatively recent advancement that warrants careful attention. This chapter aims to assess the advancements achieved in the application of ultrasonic techniques for the manufacturing and examination of biodiesel. Furthermore, this chapter will assess the present condition of the technology and offer perspectives on the forthcoming advancements in the field of engineering.



***Fig: 4.2: Ultrasonicator***

#### **4.2.2 Magnetic Stirrer**

The magnetic stirrer is a commonly employed laboratory apparatus. The system can consist of either a stationary electromagnet or a magnet that rotates and produces a magnetic field. The aforementioned apparatus serves multiple functions, encompassing the agitation and mixing of liquids, as well as the facilitation of rapid rotation. Furthermore, it is common for magnetic stirring systems to incorporate an integrated heating system in order to facilitate the heating of the liquid being swirled. However, in the context of dispersing tiny particles, it appears that depending just on magnetic or mechanical churning is inadequate. To attain the dispersion of nanotubes, it is often important to supplement this method with additional dispersion techniques that exhibit enhanced efficacy, such as sonication. The reactor employed the semi-batch approach. Initially, the reactor was filled with MAO, and subsequently, a precise amount of 1-hexene was introduced once it reached its maximum capacity. Figure 4.3 shows magnetic stirrer process. Subsequently, the implementation of the ethylene atmosphere system took place. After the ethylene monomer had reached saturation in the reaction medium, the polymerization process was initiated by introducing a catalyst solution consisting of one millilitre (20 micromoles). To commence the polymerization process for the borane and borate system, the monomer solution was subjected to sequential additions of alkylaluminum, borane or borate, and the complex. Subsequently, the polymerization reaction was let to proceed for a pre specified duration prior to its cessation through the utilisation of acidic methanol. Subsequent to the polymer's precipitation, it underwent filtration, methanol washing, and subsequent hoover drying at a temperature of sixty degrees Celsius for a duration of six hours. The polymer was characterised by determining its molecular weight using GPC and analysing its microstructure using  $^{13}\text{C}$  NMR.



***Fig: 4.3: Magnetic stirrer***

#### **4.2.3 Hot Air Oven**

The hot air oven is a versatile laboratory apparatus that serves multiple functions, such as drying, sterilising, and heating. The experimental setup involves filling the oven chamber with heated air, which is circulated throughout the chamber to ensure uniform distribution of heat to the treated materials. Hot air ovens are frequently employed in diverse environments, encompassing research facilities, industrial establishments, and educational establishments. Figure 4.4 shows hot air oven process Typically, these devices offer a temperature range spanning from the surrounding temperature to 250 degrees Celsius or above, and are equipped with a thermostat component that facilitates temperature regulation. The enhancement of air circulation within the chamber of specific hot air ovens, particularly those equipped with a fan, enables the attainment of consistent heating or drying of materials during the processing stage. Hot air ovens are commonly employed for sterilisation due to their ability to attain elevated temperatures. These baking machines have the capability to effectively eradicate microorganisms from various



objects and apparatus. Furthermore, these devices are employed for the specific objective of desiccating a diverse array of items, including glassware, biological specimens, and chemicals. Moreover, hot air ovens are employed to heat materials for various applications, such as the sterilisation of chemicals and the preservation of materials at specific temperatures for quality control testing. Hot air ovens are known for their reliable performance and adaptability in many laboratory and industrial settings, including tasks such as heating, drying, and sterilisation.



***Fig: 4.4: Hot Air Oven***

### **4.3 PREPARATION OF BIODIESEL**

While edible oils are commonly used in cooking, resulting to the generation of significant amounts of cooking oil, it's essential to replace the oil used for cooking after just one or two uses due to its potential adverse effects on human and animal health. Improper disposal of cooking oil poses a significant environmental threat, especially when it enters waterways and landfills. Reusing leftover cooking oil as a source of energy for engines is a potential solution that might be implemented in order to address the issues that have been raised. Converting this oil into biofuel is crucial due to its unsuitability as an engine fuel in its natural state. The biofuel production process involved using residual cooking sunflower oil obtained from our student accommodation, with additional potential sources in Dindigul.

This document describes the transesterification technology used to obtain biofuel from Waste Cooking Oil (WCO). The initial step involves blending diesel fuel and WCO biofuel, followed by incorporating a 20:80 (B20) proportion into the resulting mixture. The energy extraction occurs from the resultant blend, marking an essential step in the process. Table 4.1 shows Properties of the modified fuels and diesel.

**Table 4.1: Properties of the modified fuels and diesel**

| Properties                                       | Diesel | B20    | B20+Nanocatalyst15 | B20+Nanocatalyst30 | B20+Nanocatalyst45 | B20+Nanocatalyst60 | B20+Nanocatalyst75 | AST M Standard | Test methods |
|--------------------------------------------------|--------|--------|--------------------|--------------------|--------------------|--------------------|--------------------|----------------|--------------|
| Gross calorific value (kJ/kg)                    | 42,348 | 40,689 | 41,086             | 41,120             | 41,157             | 41,215             | 41,315             | ----           | AST M D240   |
| Density (kg/m <sup>3</sup> )                     | 835    | 845    | 850                | 852                | 858                | 862                | 863                | 860-900        | AST M D4052  |
| Kinematic viscosity at 44°C (mm <sup>2</sup> /s) | 2.6    | 2.3    | 2.25               | 2.3                | 2.33               | 2.4                | 2.49               | 1.9-6          | AST M D445   |
| Flash point in°C                                 | 49     | 51     | 54                 | 56                 | 57                 | 63                 | 71                 | >130           | AST M D93    |
| Fire point in°C                                  | 68     | 66     | 72                 | 78                 | 80                 | 85                 | 88                 | ----           | AST M D93    |
| Cetane number                                    | 52     | 51.7   | 51.7               | 52.4               | 53.8               | 53.3               | 53.2               | >47            | AST M D613   |
| Boiling point°C                                  | 255    | 325    | NM                 | NM                 | NM                 | NM                 | NM                 | ----           | AST M D1120  |
| Surface tension (mN/m)80°C                       | 22.05  | 24.16  | NM                 | NM                 | NM                 | NM                 | NM                 | ----           | ----         |
| Latent heat of vaporization (kJ/kg)              | 260    | 340    | NM                 | NM                 | NM                 | NM                 | NM                 | ----           | AST M D93    |

#### **4.3.1 BIO-DIESEL EXTRACTION FROM WASTE COOKING OIL**

Utilising recycled cooking oil for the creation of biodiesel not only provides a sustainable energy source but also successfully tackles waste management issues. The method of transesterification involves the conversion of triglycerides present in aged cooking oil into biodiesel and glycerol, thereby offering a viable and environmentally friendly alternative for fuel production. Alcohol, such as methanol or ethanol, plus a catalyst are necessary for this reaction. The utilisation of biodiesel produced from recycled cooking oil exhibits potential as a feasible substitute for traditional diesel, thereby mitigating greenhouse gas emissions and diminishing reliance on non-renewable energy sources. The mitigation of environmental contamination can be achieved through the utilisation of residual cooking oil, underscoring the significance of employing appropriate disposal techniques. This methodology not only presents an environmentally sustainable fuel substitute but also contributes to the establishment of a circular economy by converting waste into a valuable asset. Fig 4.5 shows Extraction of bio-diesel from waste cooking oil.



***Fig: 4.5: Extraction of bio-diesel from waste cooking oil***

#### ***4.3.2 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 transterification method has a low sulfur content, making it a cleaner alternative to traditional fossil fuels [35]. Some of the key properties that can be tested include viscosity, heating value, water content, and elemental composition. 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 [36]. The prepared fuel blend is tested for their physical and chemical properties using various scientific instruments, and the results are obtained.

#### ***4.3.3 Blending of Nano catalyst Nanoparticles with Biofuel:***

A rare metallic oxide known as nano catalyst, naturally occurring in the Earth's crust, exhibits unique properties enabling it to serve as an effective oxidizing agent within catalytic converters, with a slight tendency towards moisture absorption. The present investigation entailed the incorporation of different concentrations of MgO-ZnO nanoparticles into a biodiesel mixture consisting of 20% biodiesel (B20) by the utilization of ultrasonication. The nanoparticles were allowed to blend thoroughly with the fuel mixture for thirty minutes. The magnitudes of the doses varied between 15 parts per million (ppm) and 75 ppm. To ensure thorough homogenization between the fuel samples and nanoparticles, a mechanical agitator was employed [37].



#### **4.3.4 Properties of biodiesel**

Biodiesel is an alternative fuel made from vegetable oils, animal fats, or recycled cooking oil. It has comparable qualities to petroleum-based diesel fuel, however there are notable distinctions due to its differing chemical makeup. Biodiesel has the following key properties:

**Density:** The density of biodiesel is comparatively lower than that of petroleum fuel, which may potentially impact its energy content per unit volume.

**Viscosity:** The flow of biodiesel through fuel injectors and pumps may be influenced due to its increased viscosity compared to petroleum diesel.

**Flash point:** Due to its higher flash point compared to petroleum diesel, biodiesel has enhanced safety characteristics in terms of handling and storage.

**Cetane number:** Biodiesel exhibits a superior cetane number in comparison to petroleum diesel, hence signifying its enhanced ignition and combustion characteristics.

**Sulphur content:** Biodiesel has almost little sulphur, which minimises sulphur oxide (SO<sub>x</sub>) and particulate matter emissions.

**Lubricity:** Because biodiesel is more lubricious than petroleum diesel, it helps minimize engine wear and lengthen engine life.

**Oxygen content:** Because biodiesel contains more oxygen than petroleum diesel, it can enhance combustion efficiency and minimize carbon monoxide (CO) and unburned hydrocarbons (HC) emissions.

**Cold flow qualities:** Biodiesel has poor cold flow properties, which can cause it to thicken and form gels at low temperatures, resulting in fuel filter blockage and engine stalling.

#### 4.4 EXPERIMENTAL SETUP

A decision was reached to utilise biodiesel produced from used heating oil in order to conduct this experiment. Throughout the duration of the investigation, a four-stroke diesel engine featuring a single cylinder was utilised. At commencement of the engine, conventional diesel fuel was employed, considering all pertinent parameters as outlined in Table 4.2. The dynamometer employed eddy current for engine loading. Essential instrumentation for measuring crank angle and combustion pressure was included in the equipment to facilitate prompt utilization. The engine was equipped with a piezoelectric pressure sensor and a crank angle indicator device to monitor the combustion process. In order to ensure precise measurements of cylinder pressure, heat release rate, and ignition delay, it is imperative to calculate the average output signal from a pressure transducer across a span of fifty cycles. This procedure is essential for maintaining adherence to system standards and ensuring the accuracy of measurements. It is imperative to initiate the engine without any external load and increase its rotational speed to 1,500 revolutions per minute (rpm) using a warm-up operation prior to conducting steady-state measurements. Steady-state measurements can only be carried out after this step. The study aims to monitor and analyze brake thermal efficiency and emission parameters during steady conditions, particularly focusing on engine performance and emission levels when the engine reaches 1500 RPM. These parameters include nitrogen oxides, ethane gas temperature and composition, carbon monoxide concentration and composition, smoke opacity, and smoke vapor pressure. The coordinated operation of a smoke meter and a particle size analyzer is depicted in Diesel exhaust smoke meters are utilized to gauge the extent of light obstruction resulting from smoke emissions from diesel engines.

The smoke meter serves a dual purpose: evaluating combustion efficiency and quantifying smoke density. Electrical components facilitate control over multiple measuring heads within smoke meters. These measuring heads feature an optical unit among their inventory of capabilities. In the experimental procedure, a laser beam is transmitted through a non-heated container while the analyzer measures the wavelength of the selected sample. The analyzer is equipped with an optical filter that selectively removes any light that surpasses the detection wavelength of

the gas molecule being studied, so guaranteeing the accuracy of the obtained results. The measurements generated by the detector remain unaffected by the presence of gas molecules other than the specific one under examination due to their inherent inability to absorb light at the particular wavelength. Four distinct load circumstances and three engine speeds (500, 800, and 1100 revolutions per minute) were employed during the course of the investigation. Nevertheless, as a result of limitations in engine power, only two loads were conveyed at a speed of 1100 revolutions per minute. A magnetic dynamometer was employed to apply the load, and data was collected under steady-state conditions at a consistent velocity. The dataset encompasses the emissions of five separate gaseous constituents, namely carbon monoxide (CO), hydrocarbons (HC), carbon dioxide (CO<sub>2</sub>), oxygen (O<sub>2</sub>), and nitrogen oxides (NO<sub>x</sub>). Furthermore, the collected data includes assessments of fuel efficiency and optimization of engine combustion. The Opacity test device, calibrated by an Indian company, was utilized to assess emissions during production.

Upon activation, the machine requires approximately five minutes to attain its optimal operating temperature. Once all necessary preparations are completed and the system reaches full functionality, the display will show "PASS" to indicate the status. The second step entails applying pressure to the designated PURGE button to initiate the cleaning cycle of the internal components of the machine. Therefore, it is recommended to place the primary non-dispersive infrared (NDIR) sensor in the conditions of the surrounding environment. Activating the ZERO buttons is crucial for establishing the no validation point. Once the primary sensor completes its auto-calibration process, typically lasting around twenty seconds, a "READY" notification will appear on the screen. This observation suggests that the sensor is prepared for insertion into the intake tube of the engine without encountering any further complexities. Subsequently, the gadget undergoes calibration in order to collect data pertaining to the exhaust emissions generated by the engine. Based on the instrument technical specifications, the indicated levels of uncertainty for CO, HCl, nitrogen oxides NO<sub>x</sub>, atmospheric CO<sub>2</sub>, and O<sub>2</sub> are 0.01%, 1 ppm, 0.1%, and 0.01% correspondingly a slanted glass container was utilized to measure the intake of the engine. Simultaneously, the time required for the container to reach its maximum capacity with gasoline was documented. To reduce the risk of

observational errors, each experiment's duration was evaluated at least twice. The engine's output power can be calculated by multiplying the generator's output current with its output voltage, enabling an evaluation of the energy conversion process's effectiveness. With the generator operating at a speed 2.4% higher than the engine's rotational velocity, precise assessment of the load exerted on the engine required the use of multiple masses combined with a lever linked to the generator. Employing this method successfully facilitated achieving a well-balanced load and enabled accurate estimation of its magnitude.

**Table 4.2: The variable compression ratio engine specification**

| <b>General details</b> | <b>4 stroke, water cooled,<br/>variable, compression ratio<br/>engine,compression ignition</b>  |
|------------------------|-------------------------------------------------------------------------------------------------|
| Compression ratio      | 5:1 to 22:1 (variable)                                                                          |
| Number of cylinders    | Single cylinder                                                                                 |
| Rated power            | 3 .8 kW at 1500 rpm                                                                             |
| Ignition               | Compression ignition                                                                            |
| Bore                   | 80mm                                                                                            |
| Loading                | Eddy current dynamometer                                                                        |
| Speed                  | 1500 rpm                                                                                        |
| Stroke                 | 110mm                                                                                           |
| Starting               | Manual crank start                                                                              |
| Air flow transmitter   | Pressure transmitter                                                                            |
| Load sensor            | Strain gauge load cell                                                                          |
| Rotometer              | Pressure transmitter                                                                            |
| Cooling                | Water                                                                                           |
| Temperature sensor     | TypeK—Chromel (nickel-<br>chromium alloy)/ alumel<br>(nickel- aluminium alloy)<br>thermocouples |

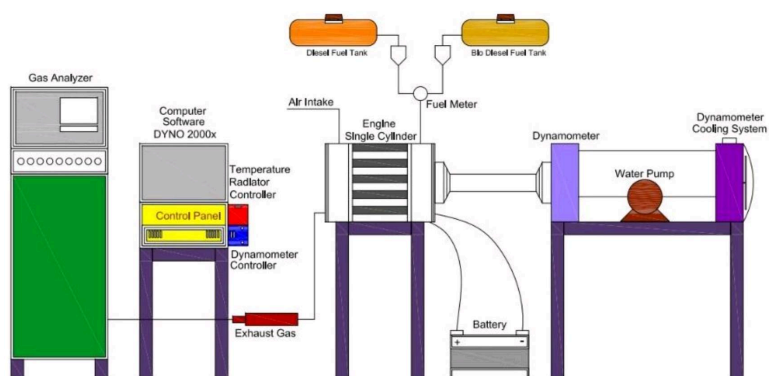
## 4.5 ENGINE SETUP

A comprehensive examination of the performance, combustion, and emission characteristics of the Variable compression ratio engine is presented in this study. The experimental procedure encompassed a systematic manipulation of the load, ranging from 0 to 25 percent, while simultaneously maintaining a set compression ratio of 20:1 and a consistent speed of 1500 revolutions per minute. Moreover, the engine was conducted in a consistent state without any modifications. The experiment was conducted in triplicate, with the average outcome being employed to ascertain the requisite parameters. In order to collect essential engine data, preliminary experiments were carried out utilising conventional diesel fuel under diverse operational circumstances. Fig 4.6 is Experimental setup of engine. Fig 4.7 shows Schematic diagram of engine.

Following the attainment of the ideal engine temperature, a sequence of experiments were carried out utilising various combinations of biofuels infused with nanoparticles, namely B20, B20 with Nano Catalyst15, B20 with Nano Catalyst30, B20 with Nano Catalyst45, B20 with Nano Catalyst60, and B20 with Nano Catalyst75. The tests were conducted under different load circumstances (0%, 25%, 50%, 75%, and 100%), while keeping the injection pressure constant at 160 bar. The aforementioned methodology successfully tackled the issue of cold starts. The collection of experimental data was conducted in order to assess the performance of the engine, as well as the combustion characteristics and emissions. An examination was conducted to compare it with a normal diesel engine working at maximum capacity. Table 4.3 presents the fatty acid content of methyl ester derived from waste cooking oil. The online MN-05 model MARS portable flue gas analyzer was used to evaluate emission parameters. The zero setting feature of the analyzer readjusts the sensor by introducing fresh air. In this study, a computerised data acquisition system was utilised to collect and analyse experimental data, employing sensors. The different Indian standards used for emission analysis are specified in Table 4.4. Table 4.5 shows Accuracy measurements of engine.



**Fig:4.6: Experimental setup**



**Fig:4.7: Schematic diagram of the experimental setup**

**Table 4.3: Fatty acid composition of waste cooking oil**

| Fatty acid      | Structure(xx:y) | Formula  | Composition (wt %) |
|-----------------|-----------------|----------|--------------------|
| Palmitic acid   | C1:0            | C16H32O2 | 8.31               |
| Stearic acid    | C18:0           | C18H36O2 | 6.46               |
| Oleic acid      | C18:1           | C18H34O2 | 14.3               |
| Linoleic acid   | C18:2           | C18H32O2 | 64.9               |
| Linolenic       | C18:3           | C18H30O2 | 1.33               |
| Arachidic acid  | C20:0           | C20H40O2 | 1.89               |
| Lignoceric acid | C24:0           | C24H48O2 | 1.51               |

xx indicates the number of carbons and y the number of double bonds in the fatty acid chain

**Table 4.4: Indian standards used for emission analysis**

| Elements        | Standard                    |
|-----------------|-----------------------------|
| CO <sub>2</sub> | IS 13270: (reaffirmed 1999) |
| CO              | IS 11293:1992               |
| NO <sub>x</sub> | IS 11255 (Part 7)—2005      |
| Hydrocarbon     | --                          |

**Table 4.5: Accuracies of the measurements**

| Measurements              | Accuracy    |
|---------------------------|-------------|
| Speed of engine           | ±4 rpm      |
| Time                      | ±0.20%      |
| Specific fuel consumption | ±1%         |
| Temperature               | ±2 °C       |
| Crank angle encoder       | ±0.5°CA     |
| Piezoelectric sensor      | ±0.50%      |
| Power                     | ±3%         |
| Calculated Results        | Uncertainty |
| Power                     | ± 1 %       |
| Specific fuel consumption | ± 2 %       |
| Crank angle encoder       | ± 0.5° CA   |

## 4.6 ERROR ANALYSIS

Possible sources of inaccuracies in the experimental results encompass a range of factors, such as instrument selection, calibration procedures, observation methods, working conditions, environmental conditions, potential human error, and the



methodology employed during the experiment. Prior to commencing the measurement collection procedure, it is imperative to calibrate both the apparatus and the sensors. Experimental data can be broadly classified into two primary error categories: accidental errors and instrumental errors, with instrumental errors being the more prevalent kind of error. Equation 4.1 is used to measure Uncertainty measurements in engine testing.

$$U_{\text{total}} = \sqrt{\{(U_{\text{bte}})^2 + (U_{\text{sfc}})^2 + (U_{\text{Egt}})^2 + (U_{\text{CA}})^2 + (U_{\text{PR}})^2 + (U_{\text{NOx}})^2 + (U_{\text{HC}})^2 + (U_{\text{CO}})^2\}}$$


---


$$U_{\text{total}} = \sqrt{\{(1.4)^2 + (1.3)^2 + (1.4)^2 + (1.6)^2 + (1.5)^2 + (2)^2 + (1)^2 + (1)^2\}}$$

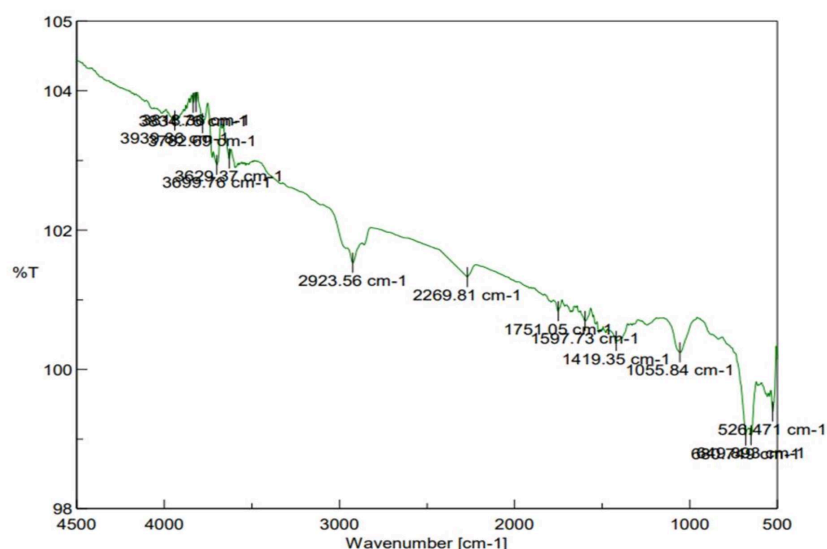
$$= \pm 4.05$$
(4.1)

## 4.7 RESULT

### 4.7.1 Fourier-transform infrared spectroscopy (FTIR)

FTIR is a method employed to acquire the infrared spectrum of absorption or emission from a material, whether it is solid, liquid, or gas. This method quantifies the absorption of infrared light by the sample material across different wavelengths of radiation. Fig 4.8 shows the result of FTIR. This absorption is indicative of the functional groups present in the material, which allows for the identification and characterization of chemical compounds. FTIR spectroscopy, which makes use of the Fourier transform technology, has a wide range of applications in a variety of fields, including pharmaceuticals, materials science, and forensic science, amongst others, for the purpose of conducting qualitative and quantitative analyses of samples.

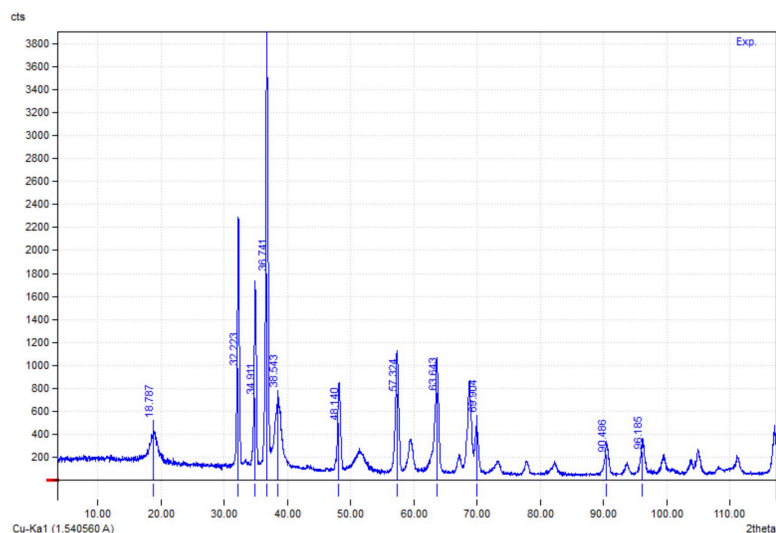




**Fig. 4.8: FTIR Results of Nano catalyst 45**

#### **4.7.2 X-ray Diffraction (XRD):**

The analysis of the crystal structure of various materials can be conducted through the utilisation of X-ray diffraction (XRD), a method that involves the measurement of X-ray scattering. When it comes to nano composites, XRD can be particularly useful in determining Factors such as crystallite dimensions, phase composition, crystallite structure, and preferred arrangement of constituent phases within the composite material are all taken into account. Figure 4.9 shows the result of XRD. Nano composites are materials composed of two or more phases with at least one phase having nanoscale dimensions. These materials often exhibit unique properties due to their nanostructure, and understanding their crystallographic properties is crucial for optimizing their performance in various applications.

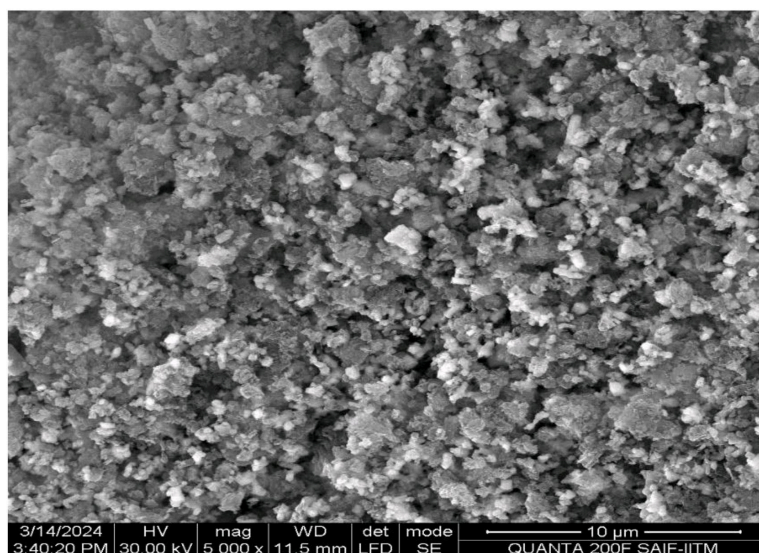


**X-ray diffraction (XRD)**

***Fig :4.9: XRD Results of Nano catalyst 45***

#### **4.7.3 SEM Analysis:**

Scanning Electron Microscopy (SEM) is a potent imaging method utilized for high-magnification examination of material surface morphology and composition. SEM analysis entails directing a focused electron beam onto a sample and detecting the signals produced from the interactions between the electrons and the sample's surface. SEM analysis is widely used across numerous fields including materials science, geology, biology, nanotechnology, and forensic science, among others, due to its versatility in providing detailed surface information and elemental analysis at micro- to nanometer scales. Figure 4.10 shows the result of SEM image.



***Fig: 4.10: SEM Result Nano catalyst 45***

## CHAPTER 5

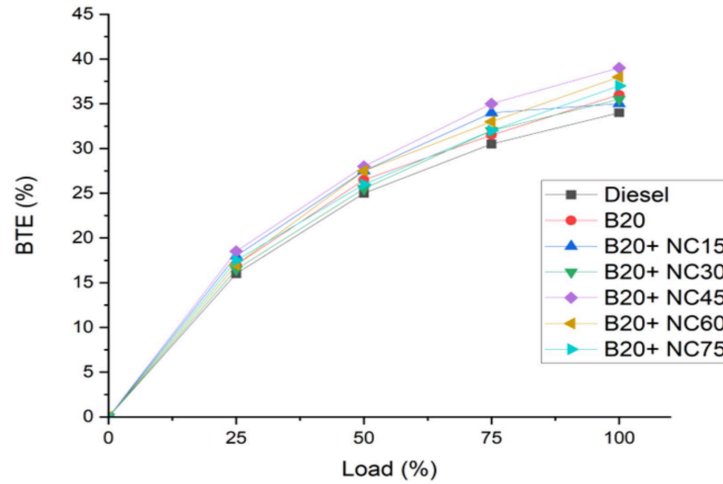
### RESULTS AND DISCUSSIONS

The results were presented after conducting five test batches using various mixtures. In each instance, the specimen is transferred to the gasoline tank during the operation of the engine. This phenomenon takes place during the period in which the engine is in operation. Modifying the loads enables the measurement of efficiency, as well as various indicators of the effectiveness of emission control.

#### 5.1 PERFORMANCE ANALYSIS

##### *5.1.1 Brake Thermal Efficiency*

The assessment of engine energy consumption in relation to the heat generated by fuels is significantly influenced by the thermal efficiency of brakes. Figure 5.1 illustrates the variations in Brake Thermal Efficiency (BTE) observed across different fuel blends and load conditions. Significantly, there is a steady enhancement in thermal efficiency even when the system is subjected to higher loads. Effective air-fuel ratio optimization leads to enhanced BTE through improved combustion. The presence of oxygen in biofuel enhances the efficiency of the B20 fuel mixture. This is attributed to oxygen's presence in biofuel. Furthermore, the dispersion of B20 nanoparticles has a significant role in enhancing BTE, hence offering an additional benefit. This phenomenon can be explained by the presence of B20 nanoparticles, which enhance ignition, prolong the delay period, and promote uniformity in air-fuel mixing within the cylinder [38,39]. The engine efficiency is further enhanced by complete combustion and the release of high heat energy, facilitated by the larger surface area-to-volume ratio of B20 particles. [40,41]. The B20+Nano Catalyst45 blend exhibits a BTE that is 10.5% higher than that of pure diesel.

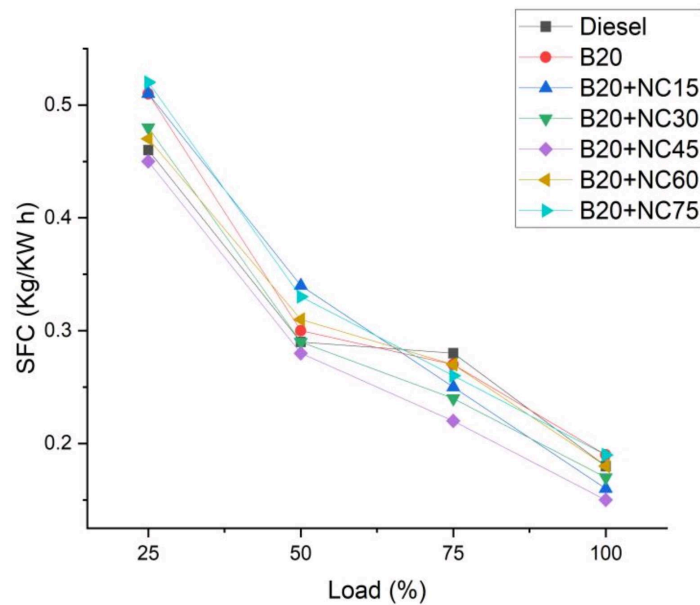


**Fig: 5.1: BTE vs Load**

### 5.1.2 Specific Fuel Consumption

Figure 5.2 illustrates the variations in Specific Fuel Consumption (SFC) across different load conditions for various fuel types including diesel, B20, and blends with different concentrations of Nano Catalysts (15, 30, 45, 60, and 75) [42]. The slope of the SFC diminishes as the engine load increases from 0 to 100 percent. The inclusion of nanoparticles in the B20 mix is a significant component that leads to a reduction in SFC, as emphasised in references [43,44]. The specific fuel consumption coefficients (SFC) for each blend under peak load conditions are 0.23, 0.22, 0.223, 0.213, 0.204, 0.23, and 0.238 kg/kW-hr, respectively. Significantly, when operating at maximum capacity, the B20+Nano Catalyst45 blend exhibits a reduction of 14.03% in comparison to regular diesel. Nanoparticles are incorporated into B20 biofuel to effectively decrease fuel use by impeding the accumulation of carbon on the walls of the cylinder, thus enhancing combustion. The thermal conductivity of MgO-ZnO nanoparticles is enhanced, resulting in improved air-fuel mixing, combustion, and a decrease in selective fuel combustion [45,46]. The aforementioned characteristics possess the capacity to diminish friction within the various components of an engine, hence resulting in enhance the performance

reduce the consumption.

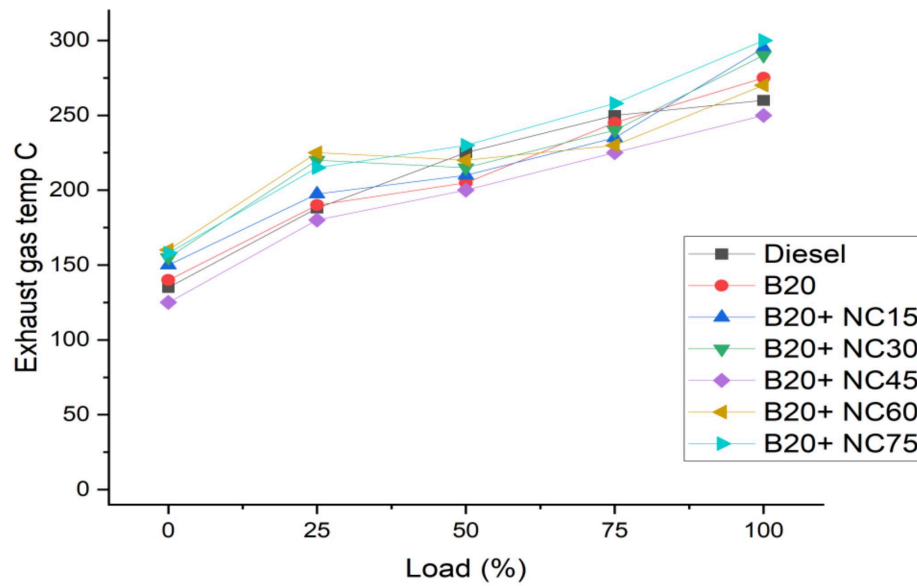


**Fig:5.2: SFC vs load**

### **5.1.3 Exhaust Gas Temperature**

The relationship between the Exhaust Gas Temperature (EGT) and the quantity of petrol supplied to the engine is not directly correlated, a crucial factor to take into account. EGT can be influenced by several parameters, including the duration of ignition delay and the degree of fuel combustion [47]. The comparative analysis of exhaust emission temperatures from various tested fuels is presented in Figure 5.3. The findings of the study suggest that the utilisation of blended fuel results in reduced exhaust gas temperatures in comparison to pure diesel. Adding magnesium oxide and zinc oxide nanoparticles to biodiesel enhances the pace at which fuel droplets evaporate and the mixing of air and fuel. The observed phenomenon can be ascribed to the elevated thermal conductivity and surface-to-volume ratio of magnesium oxide (MgO) [48]. The use of biofuel in conjunction with additives Nano Catalyst45 amplifies the cetane number and heat transfer rates, hence diminishing the duration of ignition delay.] may be responsible for the lower exhaust gas temperatures seen with blended fuels in comparison to diesel [49,50].





**Fig:5.3: EGT vs load**

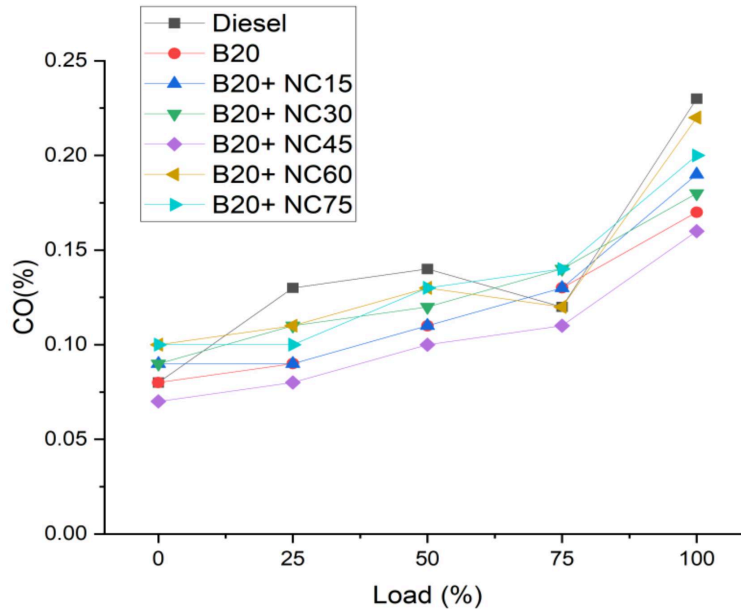
## 5.2 EXHAUST EMISSION CHARACTERISTICS

### 5.2.1 Carbon monoxide (CO) emission

The main factors contributing to carbon monoxide emissions in a crankshaft ignition engine are inadequate combustion of the air-fuel mixture and insufficient oxygen supply within the ignition chamber [51]. Insufficient conversion of carbon monoxide into carbon dioxide is responsible for the heightened levels of carbon monoxide emissions observed in the exhaust [52]. The graphical representation in Figure 5.4 illustrates the carbon monoxide emissions resulting from various test fuels, namely B20, B20+Nano Catalyst15, B20+Nano Catalyst30, B20+Nano Catalyst45, B20+Nano Catalyst60, and B20+Nano Catalyst75. The fuel samples analysed show emissions levels that are 19.9%, 10.4%, 17.19%, 9.42%, 26.24%, and 15.40% higher than regular fuel, respectively. Significantly, the emissions of carbon monoxide (CO) from all fuel mixes exhibit a substantial decrease in comparison to diesel, irrespective of the particular load conditions. Specifically, the blend B20+Nano Catalyst45 exhibits a significant reduction in carbon monoxide (CO) levels when operating at maximum capacity, with a recorded value of 26.24. The observed occurrence can be ascribed to the incorporation of nanoparticles into the



combustion chamber, resulting in heightened oxygen accessibility and improved chemical interaction with the ambient air. As a result, the phenomenon of ignition is enhanced, leading to an expedited transformation of carbon monoxide into carbon dioxide [53-55].

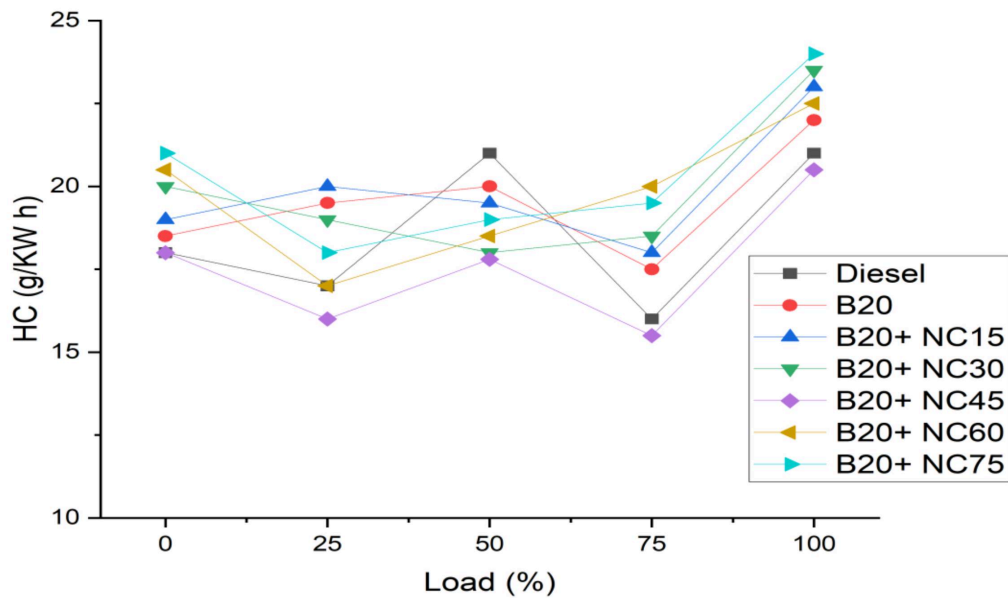


**Fig: 5.4: CO vs load**

### 5.2.2 Hydrocarbon emission

The presence of unburned fuel particles within the combustion chamber is ascribed to the generation of hydrocarbon (HC) emissions in the engine [56]. The variation in hydrocarbon emissions across different fuel types, such as diesel and biodiesel coupled with nanoparticles, under different load circumstances is illustrated in Figure 5.5. Under a 100% load condition, the fuels under investigation demonstrated hydrocarbon emissions of 21, 24, 22, 20, 23, and 25 g/kWhr, whilst diesel revealed a value of 26 g/kWhr. The incorporation of Nano Catalyst nanoparticles into the B20+Nano Catalyst45 blend leads to a marginal reduction in hydrocarbon emissions overall, as compared to alternative fuel sources. This decrease is more pronounced at larger concentrations of nanoparticles. The utilisation of nanoparticles in cylinder walls serves to augment the surface area and function as energy enhancers for the

burning of carbon particles, hence resulting in a reduction of hydrocarbon emissions. The inclusion of a greater quantity of nanoparticles is of utmost importance in the reduction of hydrocarbon emissions, as they serve to augment the surface area and promote the combustion of carbon particles within the walls of cylinders, so ultimately improving the overall combustion process. The inclusion of nanoparticles in fuel samples has been found to decrease the amount of hydrocarbon (HC) emissions released. This is attributed to the fact that nanoparticles enhance the oxygen content, which in turn leads to the oxidation of unburned particles and the production of carbon dioxide and water [57].

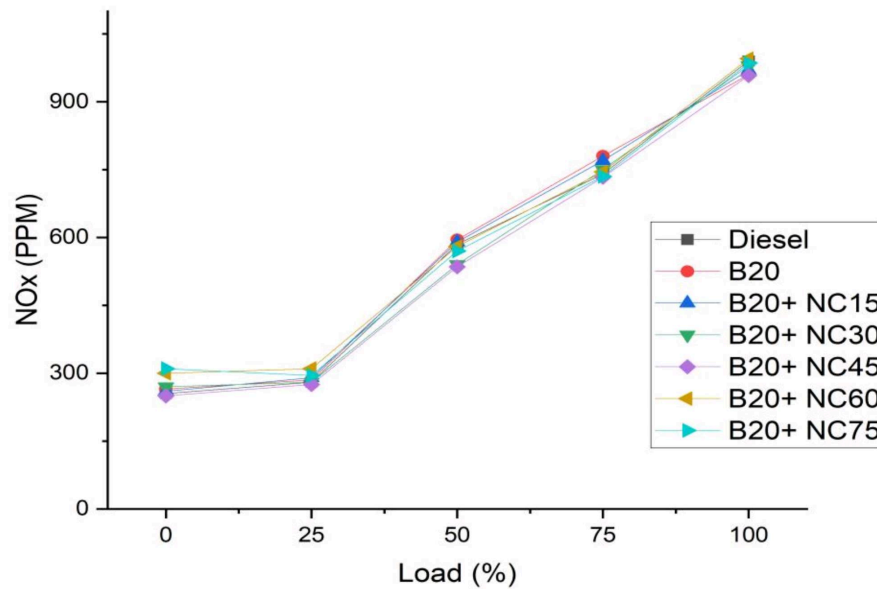


**Fig: 5.5: HC vs load**

### 5.2.3 Nitrogen oxides (NO<sub>x</sub>)

The occurrence of nitrogen oxides (NO<sub>x</sub>), which are detrimental pollutants, is a consequence of increased temperatures within the combustion chamber with higher engine loads. Vegetable-derived biofuels generally include more oxygen and less nitrogen, whereas particulate matter containing a significant amount of oxygen improves combustion rates. Higher engine load leads to increased pressure and temperature, which in turn causes greater emissions of nitrogen oxides [58]. Nevertheless, extant scholarly works indicate that biodiesel-powered engines

exhibit elevated amounts of nitrogen oxides (NO<sub>x</sub>) in comparison to diesel engines. The inclusion of a substantial amount of nanoparticles in biofuel has potential in mitigating NO<sub>x</sub> emissions by the augmentation of heat transfer characteristics, resulting in a decrease in charge temperature [59]. The emissions of NO<sub>x</sub> are generally observed to increase when load conditions are reduced for all samples. However, an increase in the dose of MgO-ZnO nanoparticles leads to a reduction in NO<sub>x</sub> emissions. Figure 5.6 illustrates the variations in hydrocarbon (HC) emissions across various loads. At maximum vehicle capacity, the B20+Nano Catalyst45 blend reduce the NO<sub>x</sub> emissions by 4.46% in comparison to diesel. Magnesium oxide and zinc oxide exhibit catalytic activity in the reduction of nitrogen oxides (NO<sub>x</sub>) by either providing oxygen for the oxidation of carbon monoxide (CO) or absorbing oxygen, which is essential for the reduction of nitrogen oxides (NO<sub>x</sub>) [60-63].

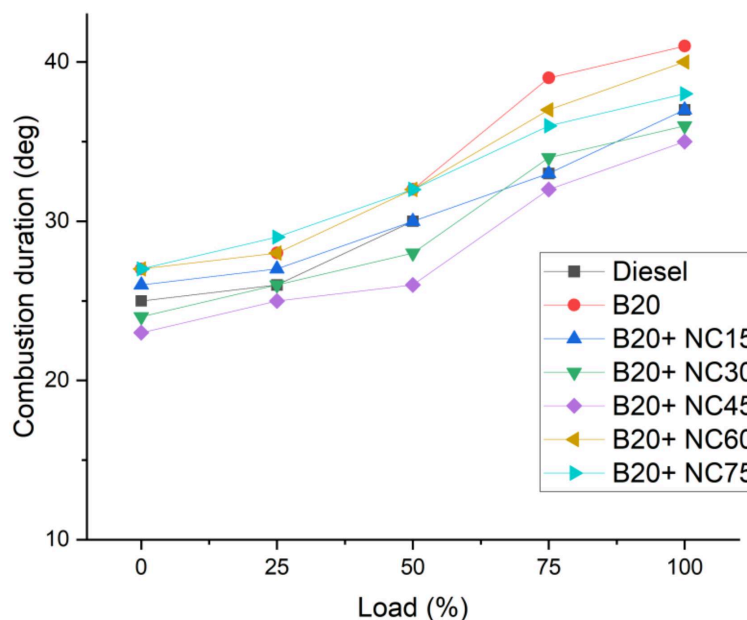


**Fig: 5.6: NO<sub>x</sub> vs load**

#### 5.4.3 Combustion duration

The combustion period, also known as the duration necessary for complete fuel combustion, can be ascertained by examining the quantity of gasoline introduced into the cylinder during each cycle. In general, there is a clear relationship between the length of time that fuel is burned and the amount of force given to the engine. In order to maintain uninterrupted engine performance irrespective of the load, it is

imperative to optimise the fuel supply. The diversity in combustion duration across different fuel blends is depicted in Figure 5.7, so emphasising the underlying volatility of this phenomenon. There are noticeable variations in the composition of blends. The data presented in the figure indicates that the fuel mix B20+Nano Catalyst45, which incorporates nanoparticles, has reduced combustion durations at maximum load in comparison to standard diesel [64-66]. The incorporation of Nano Catalyst45 yields several outcomes, such as enhanced atomization, enhanced heat transfer, and an elevated surface area-to-volume ratio. The collective attributes of these traits augment the efficacy of the burning process, leading to thorough fuel combustion across the chamber and thereby reducing the duration of combustion.

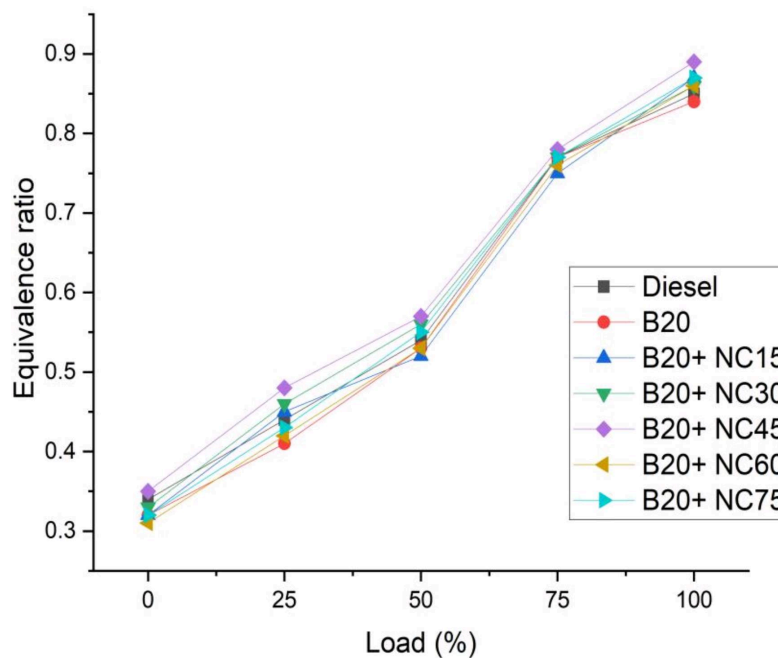


**Fig:5.7: CD Vs Load**

#### 5.4.4 Equivalence ratio

Due to the fact that the equivalency ratio has a substantial influence on both the cylinder pressure and the performance of the engine, it is an extremely important component that should be evaluated. The equivalency ratio between diesel and nanoparticles when integrated into Waste Cooking Oil is depicted in Figure 5.8. The composition of the biofuel mix can be influenced by a range of load circumstances. In the aforementioned scenarios, the amount of air given to the engine remains

constant; nevertheless, the fuel injection is adjusted to maintain consistent engine performance. Such a modification results in variations in the equivalency ratio. When there is a shift in demand from low to high, there is a concomitant rise in fuel availability as a result of load migrating from lower to higher places. The data suggests that there is a change in the equivalence ratio from 0.2 to 0.8 during times of zero load to peak load, irrespective of the magnitude of the load [67,68]. The delay time is minimised due to the positive correlation observed between the equivalency ratio and the temperature of the combustion chamber. The promotion of complete combustion is facilitated by the capacity of Nano Catalyst45 to increase the transmission of heat and augment the ratio of surface area to volume.



**Fig: 5.8: ER Vs Load**



## CHAPTER 6

### SUMMARY CONCLUSION

This study aimed to examine the impact of different dosage levels (15 to 75 ppm intervals of 15 ppm) of MgO-ZnO Nano Catalyst on the performance, combustion, and emission parameters of VCR engines. The investigation was conducted under fixed compression ratios and various loading conditions. The results were then compared to those obtained from a standard diesel engine. The findings of this study were examined and contrasted with the conventional diesel fuel. This investigation yielded the subsequent findings, which are outlined below:

When operating at maximum capacity, the biodiesel mix B20+ NC45, when paired with WCO sourced from North Carolina, exhibits a significant increase of 10.5% in fuel efficiency when compared to conventional diesel fuel. The presence of additives in biofuel is accountable for this phenomenon, as they play a role in augmenting the combustion process by virtue of their catalytic activity resulting from the increased surface-to-volume ratio. In comparison to diesel fuels, which constitute 14.03% of the overall fuel consumption, the specific fuel consumption (SFC) of the B20+NC45 sample exhibits a notable decrease. The findings indicate that the incorporation of nanoparticles into biofuel enhances the thermal conductivity of the air-fuel mixture, hence enhancing combustion efficiency and reducing fuel consumption. Adding MgO-ZnO Nano Catalyst to the biofuel mixture B20+NC45 leads to significant improvements in both the maximum pressure and the heat release rate (HRR). This phenomenon may be attributed to their elevated surface area-to-volume ratio, leading to their remarkable catalytic efficacy. The blend B20+NC45 exhibited a relatively low level of carbon monoxide emission, specifically 26.24%, in comparison to the standard gasoline during full load operation. There exists a potential for the MgO-ZnO nanoparticles to serve as an oxygen buffer, thereby augmenting the effects on air interactions, promoting ignition, and facilitating the conversion of carbon monoxide to carbon dioxide. Nanoparticles facilitate the delivery of oxygen to the carbon particles within the cylinder, so improving the combustion process and reducing the emission of hydrocarbons into the atmosphere. It has been observed that the identical mixture under identical conditions exhibits a load of 20 g/kWhr,

while diesel fuel demonstrates a load of 26 g/kWh under the same load conditions. When operating at maximum capacity, the emissions of nitrogen oxides (NO<sub>x</sub>) are comparatively reduced in comparison to diesel fuel when employing the identical blend. The B20+NC45 blend exhibited a reduction in NO<sub>x</sub> emission of 4.46 percent during peak load operation. The observed phenomenon can be attributed to the integration of nano catalyst particles into biofuel. These particles possess the capability to function as an observer, so reducing the levels of oxygen and NO<sub>x</sub> emissions. The use of nanoparticles at greater dose levels yielded enhanced outcomes, with reported reductions in carbon monoxide, nitrogen oxides, and hydrocarbon levels compared to the original diesel fuel. This occurrence may be influenced by the introduction of particles, which improve the air-fuel mixture and deliver oxygen to promote the combustion process.

This experimental study is directed to increase the efficiency of the VCR stationary engine and reduce the exhaust emissions by adding the metal-based NC nano particle with WCO biofuel as fuel. It is suggested that 20 % of biodiesel mixed with 45 ppm MgO-ZnO nanoparticle mixed blend can be used to run the VCR engine which is environment friendly for agricultural sectors in the southern region of India.



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