TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS

THESIS NO: M-172-MSESPM-2020-2023

PERFORMANCE, COMBUSTION AND EMISSION CHARACTERISTICS OF COPPER OXIDE NANOPARTICLES ADDITIVES WITH PINE OIL–DIESEL BLEND ON SINGLE CYLINDER FOUR STROKE DIESEL ENGINE

By

Bhuwesh Pant

(076/MSESP/002)

A THESIS REPORT

SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND

AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

IN ENRGY SYSTEM PLANNING AND MANAGEMENT

OCTOBER, 2023

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Head
Department of Mechanical and Aerospace Engineering
Pulchowk Campus, Institute of Engineering
Lalitpur, Nepal

INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS
DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

The undersigned hereby verify that they had read, and recommended to the Institute of Engineering for approval, thesis entitled **“PERFORMANCE, COMBUSTION AND EMISSION CHARACTERISTICS OF COPPER OXIDE NANOPARTICLES ADDITIVES WITH PINE OIL - DIESEL BLEND ON SINGLE CYLINDER FOUR STROKE DIESEL ENGINE”** submitted by **Bhuwesh Pant** in the partial fulfillment of the requirements for the degree of Master of Science, Energy System Planning and Management.

Supervisor, Surya Prasad Adhikari, PhD.
Associate Professor
Department of Mechanical and Aerospace Engineering,
Pulchowk Campus, Institute of Engineering, TU

External Examiner, Daniel Tuladhar, PhD.
Professor, Head of Department
Department of Mechanical Engineering, Kathmandu University

Committee Chairperson, Sudip Bhattrai, PhD.
Assistant Professor, Head of Department
Department of Mechanical and Aerospace Engineering
Pulchowk Campus, Institute of Engineering, TU

Date: 8th October 2023

ABSTRACT

For heavy duty applications like power generation and transportation, Compression Ignition (CI) engines have proved to be the best option. However, the drain of conventional fuels in speedy trends, growing prices, environmental issues, etc. has led attention in alternative sources of energy. A research study was performed to assess the combustion, performance and emission traits of fixed-speed compression ignition engine by incorporating copper oxide nanoparticles as a fuel additive in blends of pine oil biodiesel. The study examined B20 with copper oxide nanoparticles at concentrations of 25 ppm, 50 ppm, and 75 ppm under different engine loads while maintaining a consistent engine speed of 1500 rpm. Also, fuel properties such as density, flash point, calorific value, viscosity, pour point, cetane number and cloud point of blended samples were experimentally tested. The engine performance result shows that BP of all samples were comparable to Diesel and B20. IMEP of B20 + 50 ppm and SFC of B20 +75 ppm was found to be better than other samples. At higher load 12kg, BTE increment of 0.25%, 1.98%, 2.05% and 2.2% was observed for B20 and higher concentration of CuO additives respectively. Similarly, the combustion parameters Cylinder Pressure and Net Heat Release were also improved on rising concentration of CuO nanoparticle. The smoke opacity dropped by 2.98%, 3.73%, 20% and 25% for B20 and increasing doses of Nano additives samples. Tested data shows that the incorporation of CuO nanoparticles in pine oil biodiesel blends improves combustion, performance characteristics, and reduces smoke opacity significantly.

ACKNOWLEDGEMENT

Research can never be completed without the help of wonderful people. Regarding my research, I intent to express my gratitude to all respectable individuals, friends, and family members who encouraged, supported, guided, and inspired me to finish this research work.

I would like to express my gratitude to my supervisor, Associate Professor Dr. Surya Prasad Adhikari, in a respectful manner, acknowledging his valuable support throughout this research endeavor. This includes his outstanding supervision, insightful suggestions, and dedicated efforts. His direction, continuous encouragement, guidance, and support during the research period led to the effective completion of this task. I am also very much thankful to my coordinator Ass. Prof. Dr. Nawraj Bhattarai for strong guidance and encouragement.

I appreciate the support provided by my friends, co-workers, and colleagues Er. Lochan Devkota, Er. Khem Raj Bhatta, Er. Amir Khanal, and Rupesh Lal Karna throughout this project.

I also extend my gratitude to my spouse, family members, and everyone who has offered support in any way throughout the accomplishment of this thesis.

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List of Abbreviation

CI	: Compression Ignition
CuO	: Copper Oxide
B20	: Pine Oil – Diesel Blend with 20% Pine oil
PPM	: Parts Per Million
BP	: Brake Power
IMEP	: Indicated Mean Effective Pressure
SFC	: Specific Fuel Consumption
BTE	: Brake Thermal Efficiency
ME	: Mechanical Efficiency
UV	: Ultra Violet
XRD	: X- Ray Diffraction
FWHM	: Full Width at Half Maximum
FTIR	: Fourier Transform Infrared Spectroscopy
IEA	: International Energy Agency
NiO	: Nickel Oxide
ZrO_2	: Zirconium Dioxide
TiO_2	: Titanium Dioxide
CO	: Carbon Monoxide
HC	: Hydrocarbon
NO_x	: Nitrogen Oxides
Fe_2O_3	: Ferric Oxide
Al_2O_3	: Aluminum Oxide
ZnO	: Zinc Oxide
MgO	: Magnesium Oxide
AF	: Air Flow
CO_2	: Carbon Dioxide
NPLs	: Nanoparticles
IC	: Internal Combustion
$CuSO_4$	: Copper Sulphate
NaOH	: Sodium Hydroxide
°C	: Degree Celsius

CHAPTER ONE: INTRODUCTION

1.1 Background

The energy consumption is indeed increasing due to the rise in global population and economy. This trend is driven by various factors, including urbanization, industrialization, and the adoption of energy-intensive technologies. The projection of a 6% increase in global oil demand from 2022 to 2028, as mentioned in the IEA Oil Report (2023), underscores the continued reliance on fossil fuels. This can pose challenges in terms of both supply and environmental sustainability. Given the environmental concerns associated with fossil fuels and the finite nature of these resources, there's a growing need to transition to alternative and renewable energy sources. This transition is vital for mitigating climate change and reducing greenhouse gas emissions. The blending biodiesel in diesel fuel improves the calorific value and good solubility due it’s inherent oxygen content as compared to diesel fuel.

1.1.1 Biodiesel in CI Engine

Over time, investigations have shown that biodiesel may be blended with other additives and commercial diesel in various ratios to amplify both the fuel's characteristics and the efficiency of diesel engines however, there have been some difficulties especially with the viscosity of the fuel. CI engines, at the forefront of alternative technology, are viable candidates for biodiesel and its mixes. As a result, the general public is becoming more interested in these eco-friendly fuels. Diesel engines can run on vegetable oils as fuel. When used as fuel, they are often referred to as pure vegetable oils or pure vegetable oils, regardless of whether the engine has been modified. Injection systems in contemporary engines are designed to provide and efficiently atomize diesel fuel. SVO must first be heated before being used in diesel engines. In the majority of contemporary engines, the heating system consists of glow plugs which uses power of battery to heat the oil or a heater installed inside the vegetable oil tank that transfers heat to the cooling engine (Kumar P. S., 2014). Prior to being used to fuel diesel engines, the fuel characteristics of vegetable oils must be improved by being converted to esters (biodiesel). Numerous substances, including edible and non-edible oils, animal fat, and microalgae, have been used in the production of biodiesel. One of these sources is pine oil, a renewable biomass fuel that can be combined with diesel fuel derived from petroleum because of their similar properties. (Raman, 2013).

1.1.2 Nanoparticles in Fuels

The incorporation of nanoparticles into fuels, such as in gasoline, is an emerging field that holds promise for improving fuel properties and combustion efficiency. Nanoparticles can enhance thermal conductivity, increase surface area-to-volume ratios, improve mass diffusivity, and alter auto-ignition temperatures. Nano-modified fuels can lead to more efficient and cleaner combustion processes, potentially reducing emissions of pollutants. Also, nanoparticles additives in fuel improves thermal properties and combustion characteristics which can increase the overall efficiency of engines. For achieving a sustainable energy future will likely require a combination of strategies, including the continued advancement and adoption of renewable energy sources, efficiency improvements, and advancements in energy storage technologies, alongside innovations like nanotechnology in fuel modification.

1.2 Problem Statement

The global increase in the price of crude oil, especially in recent times, has forced many developed and developing countries to develop plans and approaches to make fuel from alternative and renewable sources. At the international and domestic levels, there have been a number of studies related to this issue, after which countries around the world have developed business plans to create and use nanoparticles to supplement fuel/ Biofuel in IC engines.

Since, Nepal is bearing trade deficit in petroleum product and the almost transport services in Nepal are fossil fuel based, there is the need of wise and efficient use of petroleum-based engines. The nanoparticles additive fuel blends can be better option for the IC engines for reducing the emissions and increasing thermal efficiencies. So, this research is about experimental study and analysis of the performance, combustion parameter along with emission testing on CI engine fuel blended with copper oxide nanoparticles additives. Thus, having distinct features of copper oxide and pine oil, blend of these two with diesel would give more overall performance in single fuel blend.

1.3 Objectives

1.3.1 General Objectives

i. To analyze performance, combustion and emissions characteristics of Copper Oxide nanoparticles additives with Pine Oil – diesel blend on 4-stroke CI engine.

1.3.2 Specific Objectives

Specific objectives of this research endeavor will be,

i. To synthesize and characterize copper oxide nanoparticles.
ii. To prepare the biodiesel-diesel blend with 20% pine oil (B20).
iii. To prepare Pine oil-diesel blend with copper oxide nanoparticle additives at various concentration.
iv. To analyze and compare performance, combustion as well as emission parameters of pine oil diesel blend.

1.4 Limitations

The research work consisted of the following challenges and limitations:

i. The equipment's available till now in our country does not provides complete parameters.
ii. After a month of storage of blend of pine, a small white precipitate accumulates at the bottom which needs filter before use in diesel engine.
iii. Synthesis of nanoparticle in laboratory is complex task due to limited infrastructures.
iv. The price of oil from pine at present is higher than of commercial diesel due to its limited extraction in our country.

CHAPTER TWO: LITERATURE REVIEW

Alternative and renewable fuels are needed in view of the increased demand for oil, environment protection issues as well as climate changes (Shirneshan, 2020). In contemporary times, to enhance the performance, combustion, and emission characteristics of internal combustion engines, additives based on nanoparticles like NiO (Campli, 2017), ZrO2 (Venu H. &., 2016), TiO2 (Venu H. S., 2019) are employed for blending in fuel of diesel engines.

The utilization of blended fuels in diesel engines can lead to heterogeneous combustion and enhanced ignition reactions, ultimately resulting in increased energy density (Chen, 2018). To completely form the final product, heterogeneous combustion occurs and heat is transferred convectively to the unburned reactants. Additionally, greater surface area to volume ratio caused the oxidation to occurs faster and hence the enthalpy of combustion becomes higher (Sivakumar, 2018). Nanoparticles offer various advantages, such as a rapid evaporation rate, effective atomization, sufficient flame sustainability, and optimal air-fuel mixing, all contributing significantly to the substantial reduction of ignition delay. A more efficient atomization of the fuel will result in an earlier combustion process. For enhancing the combustion characteristics and effectiveness of traditional fuels using metal nanoparticle additives. However, these additives have their drawbacks which are mainly caused by the possibility for combustion engines using metal nanoparticles to produce exhaust gases containing solid metallic oxides as residual particulate matter that poses a serious risk to human health which emphasizes the need for incorporation of particulate filters into engines exhaust. The potential for agglomeration, supply costs and challenges related to the implementation of consistent dispersion are further disadvantages (Basu, 2016).

An experimental investigation was conducted to assess performance, combustion characteristics, and emissions of an engine of variable compression ratio operating at a fixed speed. The study involved introducing CuO nanoparticles additives in a blend of diesel and biodiesel. Also, research focuses the influence of introducing CuO nanoparticles at different concentrations (25, 50, 75, and 100 ppm) into methyl ester-diesel blended (B20) fuel. Experimental examinations were conducted on a compression-ignition engine, exploring various engine loads while keeping the engine speed constant (Kalaimurugan K. S., 2019). Performance as well as emissions of diesel engine powered with the water-alumina diesel emulsion were investigated in another experimental investigation (Sadhik, 2012). According to the findings, alumina fuel blends improved engine performance while also lowering pollution emissions. (Gumus, 2016), reveled inclusion of 50 ppm CuO or Al_2O_3 nanoparticle to plain diesel increased brake power and the torque while lowering CO, HC, and NOx emissions. The concentration of (50 ppm) nanoparticles was kept constant and impact of hybridization was ignored.

Similarly, (Gad, 2021) concludes that the blending alumina nanoparticles with crude diesel oil at varying weight ratios (20, 30, and 40 mg/L) leads to enhanced thermal efficiency during engine testing. Specifically, the inclusion of 40 ppm Nano-alumina in commercial diesel oil demonstrates an improvement in thermal efficiency of up to 5.5% compared to using pure diesel fuel. Comparative to pure diesel fuel, there were observed average decreases in specific fuel consumption of 3.5%, 4.5%, and 5.5% at dosage levels of 20, 30, and 40 ppm, respectively. Furthermore, when the system was fully charged, the inclusion of 40 ppm Nano-additives in diesel engine operation led to reductions of approximately 17%, 25%, 30%, and 33% in smoke, HC, CO, and NOX emissions, respectively.

Another experimental study investigated the influence of blending biodiesel, titanium dioxide, n-butane, and diesel on the performance and emission limitations of a compression-ignition (CI) engine (Ors, 2018). The incorporation of TiO2 led to magnify combustion pressure and heat release rate (HRR), thereby enhancing brake torque and power by up to 10%. Additionally, the introduction of TiO2 nanoparticles resulted in a decrease of approximately 30% in brake-specific fuel consumption (BSFC). While emissions of hydrocarbons (HC) and carbon monoxide (CO) were reduced, nitrogen oxide (NO) and carbon dioxide (CO2) levels increased. Furthermore, researchers asserted that the combination of waste frying oil biodiesel, TiO2, and standard butane addition could enhance combustion, emissions, and overall engine performance.

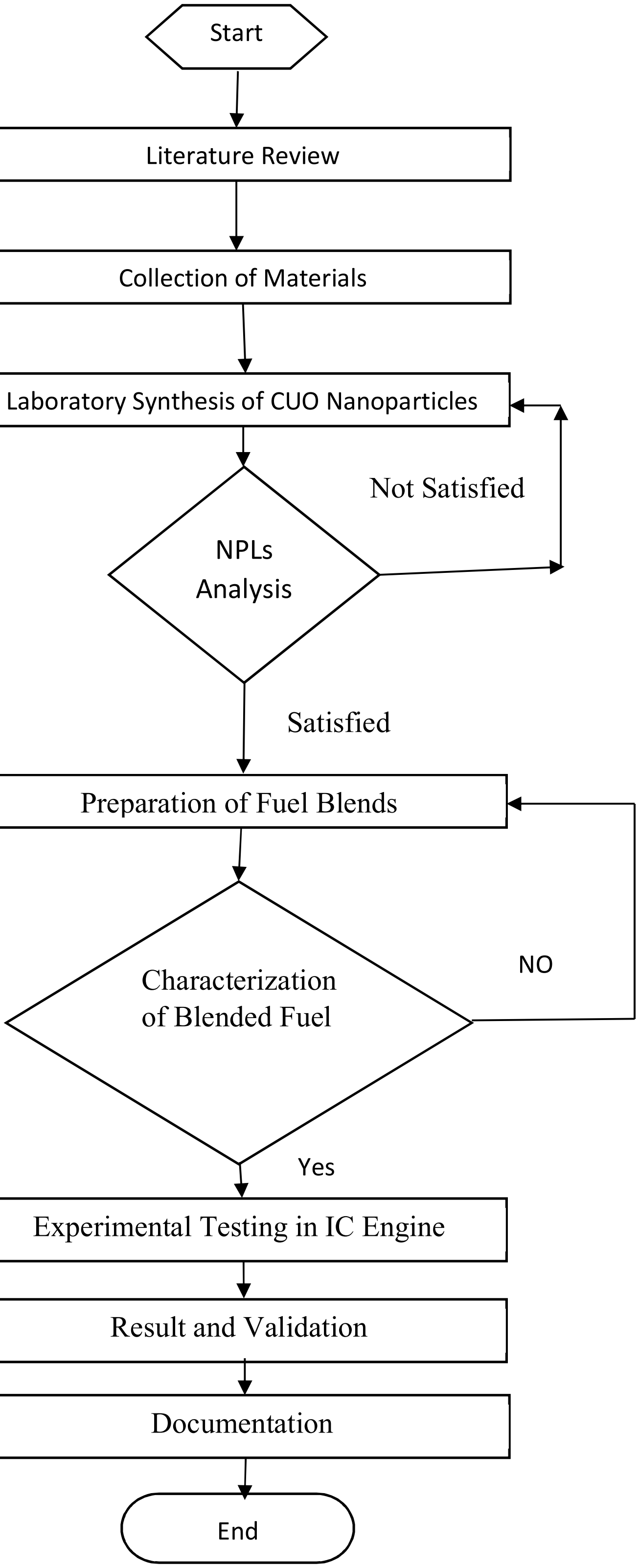
(Ozgur, 2015) illustrated that the introduction of nanoparticle additives, such as MgO, Fe2O3, TiO2, ZnO, Al2O3, and SiO2 into regular diesel fuel resulted in a declination of nitrogen oxides emissions. (Ooi, 2016) examined the combustion parameters of a compression-ignition (CI) engine through the utilization of nanoparticles, specifically graphite oxide, cerium oxide, and aluminum oxide. The incorporation of these nanoparticles in the diesel engine led to a visible improvement in combustion and declination in harmful emissions.

(Devkota, 2021) conducted an experimental testing on the performance of a compression-ignition (CI) engine powered with blends of waste cooking oil biodiesel. The experimental results indicated that the indicated power (IP) and specific fuel consumption (SFC) of the blended biodiesel showed slight improvements. Similarly, it was observed that brake power (BP) and brake mean effective pressure (BMEP) were comparable to those of diesel fuel. In a parallel manner, (Joshi, 2021) conducted a study on the performance characteristics of a single-cylinder, four-stroke diesel engine fueled by a blend of pine oil and diesel (B20). The study concluded that the blended fuel exhibited improved performance, with a notably lower brake specific fuel consumption (BSFC) by 18.75% compared to pure diesel fuel. Additionally, the blend demonstrated an increase in brake thermal efficiency (BTE) of 13.5%, particularly under a 50% loading condition of the engine.

According to the various literature reviews, there have been no studies focusing on the use of a mixture of pine oil and CuO nanoparticles additive in diesel engines, thus, the focus of my thesis is to provide an extensive examination that explores and contrasts the impacts of varied concentrations of CuO nanoparticles with pine oil diesel blends into diesel engines. In conclusion, blends of CuO nanoparticles and pine oil at different concentrations were introduced into diesel fuel, and their influence on combustion (In-cylinder pressure and heat release rate), performance (brake power, indicated mean effective pressure, air-fuel ratio, specific fuel consumption (SFC), brake thermal efficiency (BTE), and mechanical efficiency), and emission (smoke opacity) parameters of a compression-ignition (CI) diesel engine were investigated under different loads.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Flow Chart



3.2 Synthesis of Nanoparticles

A nanoparticle is a particle or structure characterized by having at least one dimension within the nanoscale, which spans from 1 to 100 nanometers. Materials at the nanoscale exhibit distinctive and frequently enhanced physical and chemical properties compared to their larger counterparts. This occurrence is ascribed to the substantial surface area vs. volume ratio and the impact of quantum size effects. Diverse categories of nanoparticles encompass metal nanoparticles, metal oxide nanoparticles, polymers, carbon-based materials, and others.

There are numerous ways to create nanoparticles, each having benefits and drawbacks. The preferred approach is determined by the desired nanoparticle properties, size, shape, and application. Some typical techniques for creating nanoparticles are as follows:

i. **Chemical Precipitation**: This technique produces nanoparticles by combining a solution containing precursor salts with a reducing agent or a precipitating agent. Using sodium borohydride as a reducing agent, silver nitrate is used to synthesize silver nanoparticles.

ii. **Sol-Gel Technique**: This technique involves through a series of condensation and hydrolysis reactions, a precursor solution (often a metal alkoxide) is transformed into a gel, which is then dried and calcined to produce nanoparticles. This technique is commonly applied to metal oxide nanoparticles such as iron oxide, copper oxide nanoparticles.

iii. **Electrochemical Deposition**: This technique involves through the use of an electric current, nanoparticles are deposited onto a substrate using electrochemical techniques. This technique is used for preparing electrode and thin film materials.

iv. **Solvothermal/Hydrothermal Synthesis:** This technique involves high-temperature, high-pressure aqueous solutions or organic solvents are used to create nanoparticles, enabling controlled growth and crystallization. This technique is frequently used to create complex, high-quality nanoparticles, such as nanowires and nanorods.

The Copper Oxide nanoparticles essential for this research were synthesized using the Sol-Gel Method, a commonly employed technique for producing nanoparticles from metal oxides. The copper oxide nanoparticles were synthesized on material science laboratory, IOE, Pulchok Campus, Pulchok, Lalitpur. It was carried out on following steps as shown further.

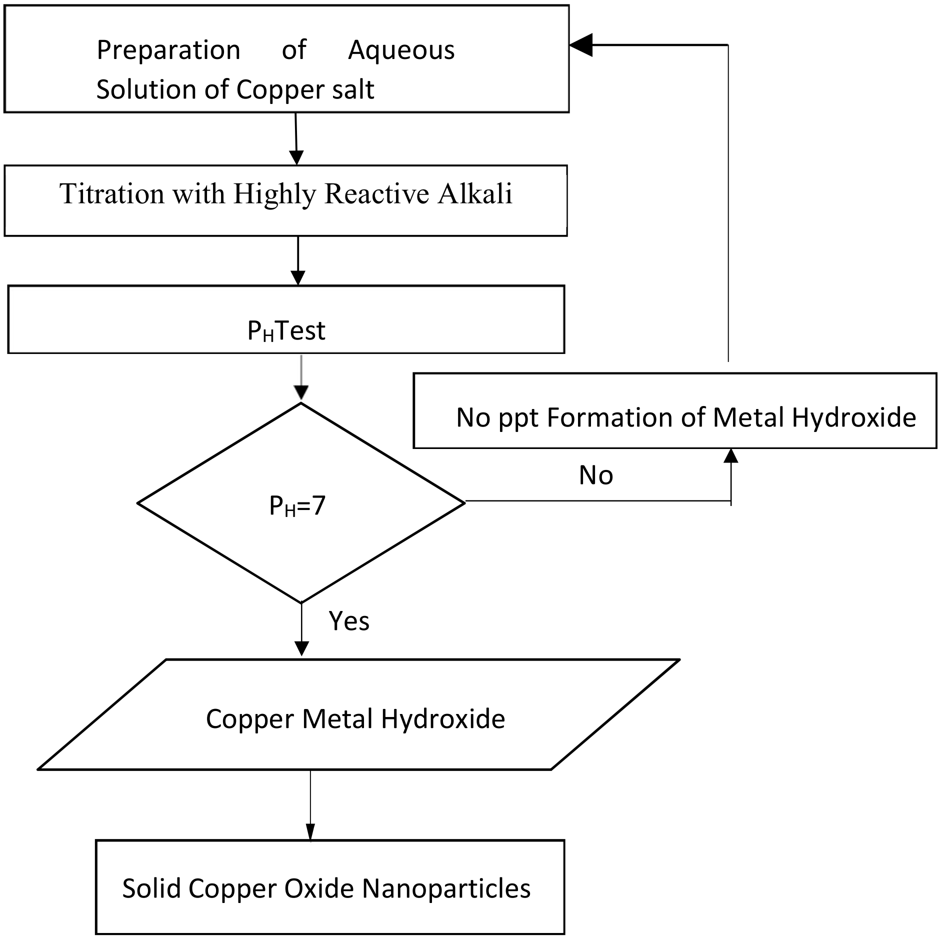


Figure 3.1 Schematic Flow chart of Copper Oxide Nano Particle Synthesis

The following are the steps that are performed during nanoparticle synthesis by sol-gel and a very visible precipitate that has been clearly isolated from the remainder of the solution confirming the formation of copper oxides nanoparticles.

i. Cleaned the round bottom flask and prepared the aqueous $CuSO_4$ solution with 0.5M concentration.
ii. An aqueous solution was created in a sterile round-bottom flask, then transferred to a 200ml beaker. Subsequently, as the solution reached a

temperature of 100°C, 1 ml of glacial acetic acid was introduced, and stirring was maintained throughout.

iii. A NaOH (0.5 mol) solution of volume 200ml is prepared and gradually mixed with heated $CuSO_4$ solution till the pH level observed to be 7. The solution underwent a color transformation from green to black immediately upon the addition of NaOH, accompanied by the formation of a significant quantity of black precipitate.

iv. After the precipitation process, the precipitate underwent centrifugation was washed thoroughly with deionized water, repeating the washing procedure three to four times. Subsequently, the precipitate obtained was left to ambient air for drying upto 24 hours and more. The stoichiometry of chemical reactions occurred in the following areas:

$Molecular\ weight$, W=63.55+ 32.06+ (4∗15.99) =160g,

$Concentration$, C = 0.5M

$Volume, V = 1\ Litre$,

To ascertain the necessary quantity of solid copper sulfate, formula employed is shown below:

$M = C*W*V$

Where,

C denotes the required Molar Concentration,

V denotes the Volume,

M denotes the Molar mass of $CuSO_4$.

W denotes the Molecular Weight

$m = 0.5*160*1=80g$

$CuSO_4\,(0.5M) + 2NaOH \rightarrow Cu(OH)_2 + Na_2SO_4$

Under application of heat, copper hydroxide undergoes decomposition, leading to the formation of copper oxide in accordance with the following reaction.

$Cu(OH)_2 \rightarrow CuO + H_2O$

The preparation of Copper Oxide Nanoparticles was carried out through a precipitation technique, utilizing NaOH and $CuSO_4$ as the precursors.

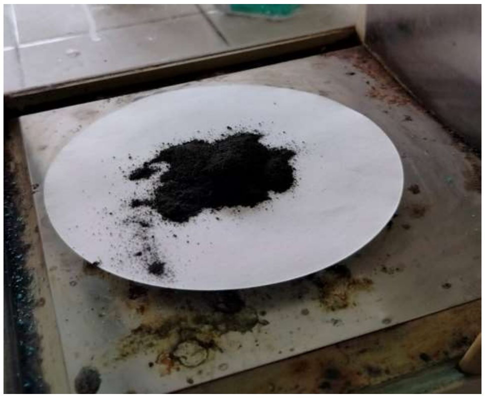


Figure 3.2 Synthesized Copper Oxide Nanoparticle

3.3 Characterization of Nano Particles

Thus, synthesized copper oxide nanoparticles underwent characterization through UV-Absorption Testing and X-ray Diffraction (XRD).

3.3.1 UV Test

UV-visible absorption spectroscopy is a characterization technique that investigates the absorption of substances in relation to wavelength. The visible spectrum ranges from 380 nm (violet) to 740 nm (red), and the near-ultraviolet region encompasses wavelengths of around 200 nm (Kumar P. e., 2020).

3.3.2 X-Ray Diffraction Analysis (XRD)

Powder X-ray diffraction (XRD) is a rapid analytical technique primarily used to identify the phases of crystalline materials and provide information about unit cell dimensions. The copper oxide nanoparticles generated were analyzed through X-ray Diffraction (XRD) over a rotation angle spanning 20 to 40 degrees. The peaks and troughs of the intensity graph were measured in different angles. The highest peaks were employed for size calculation from the formula provided in equation 3.1. The Scherer equation was applied to identify the average crystallite size.

The Scherer formula is represented as

$$D = K\lambda / \beta cos\theta$$

Where D denotes the average crystallite size,

λ denotes the wavelength radiation, β denotes the FWHM of the reflection peak, which exhibits the highest intensity in the diffraction pattern. And

θ represents the angle at which the peak is located.

The Scherer constant (K) is included in the formula to account for the shape of the particle, with a value of 0.9 commonly used for spherical crystals.

3.4 Preparation Of different Fuel Blends

Following are the characteristics of the commercial diesel taken from petrol pump.

Table 3.1 : Thermophysical properties of Diesel

Diesel Property	Value
Kinematic Viscosity	1.9 – 4.1 Cst
Dynamic Viscosity at 20°C	6.5 mPas
Calorific Value	43200 KJ/Kg
Density at 15°C	830 kg/m3
Cetane Number	30-65
Flash Point (Minimum)	52°C
Flash Point (Maximum)	78°C
Pour Point °C	-2 to -15
Surface Tension at 20°C	29.4 mN/m
Initial Boiling Point	174.5°C
Final Boiling Point	380.3°C

Pine Oil was collected from Shantinagar which was made by the process of steam distillation at 150°C of resins (which is collected from the roxburghii plant). After the continuous distillation of resin, it is converted into the solid form called (rosin), liquid form called (turpentine oil). This turpentine oil consists of the following physical properties.

Table 3.2 Thermophysical properties of Pine oil

Pine Oil Properties	Value
Kinematic Viscosity	1.8(mm^2/sec) at 40°C
Calorific Value	43,012 kJ/kg
Density	846.3 kg/m^3
Flash Point	46°C
Cetane Number	19

Various mixtures of pine oil and diesel, incorporating nanoparticle fuel samples, were designated as B20, B20 + 25 ppm, B20 + 50 ppm, and B20 + 75 ppm. Test fuels incorporating nanoparticle blends were produced utilizing ultrasonication, a method that uniformly disperses nanoparticles in a base fluid by exposing the base medium to high-frequency sound waves.

The nanoparticles were quantified at 25 ppm and evenly distributed in pine oil diesel blends using an ultrasonicator operating at a power of 110 W and a frequency of 35 kHz for a duration of 30 minutes. This procedure was replicated for mass proportions of 50 and 75 ppm for CuO nanoparticles added to biodiesel fuels, which were then placed under steady conditions to assess stable properties (Karthikeyan et al. 2017).

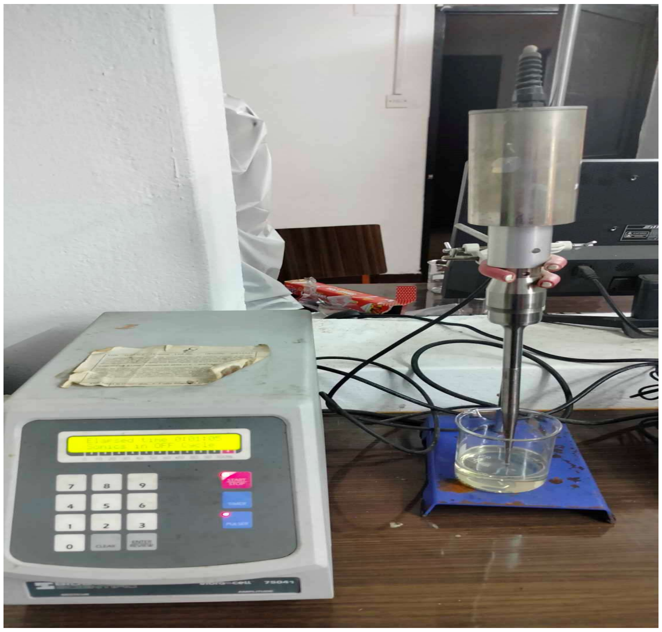


Figure 3.3 Blending of CuO Nanoparticles on ultrasonication machine with ultrasonication of fuel

Fuel Bends (B20) with nanoparticle additives blended by 20% pine oil & 80% diesel with composition of CuO nanoparticle at 25 ppm, 50 ppm and 75 ppm by ultrasonication process and blend with 50 ppm nanoparticles was sent to Nepal Oil Corporation for thermophysical properties and following results are obtained.

Table 3.3 Thermophysical properties of B20 & B20+50ppm

S. N	Parameters	Diesel	Pine	B20	B20+50 ppm
1	Pour Point, ^{0}C	-25	-33	-10	-15
2	Flash Point, ^{0}C	57	45	42	44
3	Kinematic Viscosity @40°C, cSt	5	2.33	2.268	2.15
4	Density@15°C, kg/m^3	853	842	840	841
5	Calorific Value, Kcal/kg	10038	11602	11214	11320
6.	Calculated Cetane No.	51	19	51	52

3.5 Fourier Transform Infrared Spectroscopy (FTIR) Test

FTIR Spectroscopy, is an analytical method utilized for the identification of organic, polymeric as well as in some cases, inorganic materials. In FTIR analysis, IR light is employed to scrutinize test samples, discern their chemical features. The FTIR device directs infrared (IR) radiation, ranging from approximately 10,000 cm^{-1} to 100 cm^{-1}, across a sample, among which some radiation gets absorbed and some get transmitted. The molecules in the sample convert the absorbed radiation into rotational and/or vibrational energy. The signal detected at the detector is then presented as a spectrum, typically spanning from 4000 cm-1 to 400 cm-1, acting as a unique molecular fingerprint for the sample. Each molecule or chemical structure generates a distinct spectral fingerprint, making FTIR analysis a valuable method for identification of chemical. The test sample B20+50 ppm was tested in Department of Plant Resource, Thapathali.

3.6 Test Engine Specification

The testing Engine for our research work of testing fuel Diesel+ Pine Oil+ Copper oxide nanoparticle were carried out at Institute of Engineering, Thapathali Campus, Thapathali Kathmandu. The specifications of the test engine were provided in the table below:

Table 3.4 Test Engine Specification

S.N.	Descriptions	Specification
1	Make	Kirloskar CI Engine
2	Type	Water cooled CI Engine
3	Strokes Number	4
4	Cylinders Number	1
5	Starting Method	Electrical Motor / Manual
6	Combustion Principle	C I
7	Loading	Dynamometer loading

8	Compression Ratio Range	15 – 18
9	Crank Radius	55 mm
10	Length of connecting Rod	300 mm
11	Maximum Speed (RPM)	1500

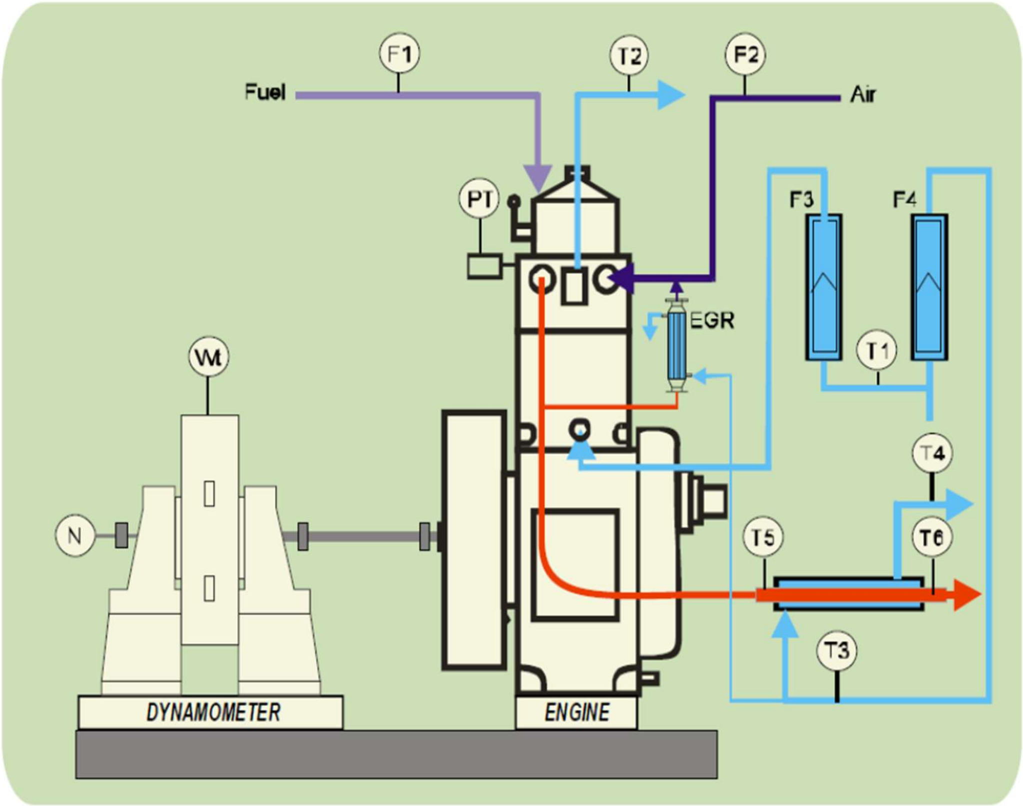


Figure 3.4 Schematic Arrangement of Test Engine

Source: (VCR ENGINE TEST SET UP 1CYLINDER, 4STROKE, DIESEL WITH EGR)

3.7 Engine Performance Parameters

Indicated Power (IP): Indicated Power is characterized as the power generated from the combustion of fuel within the cylinder of an Internal Combustion (IC) Engine. It essentially encompasses the sum of Friction and Brake Powers.

Indicated thermal efficiency, ITE (η_t): It is the ratio of energy in the indicated power output to the energy input from the fuel. n_t

$$\eta t = \frac{\text{Indicated power}}{\text{Fuel Energy}}$$

$$\eta t\ (\%) = \frac{\text{Indicated Power(KW)}\times 3600}{\text{Fuel Flow(Kg/Hr)}\times\text{Calorific Value(Kj/Kg)}} \times 100$$

Brake thermal efficiency (η_{bth}): It provides a measure of the overall efficiency of the engine. It is defined as the ratio of energy in the brake power output to the energy input from the fuel.

$$\eta\text{bth} = \frac{\text{Brake Power}}{\text{Fuel Energy}}$$

$$\eta\text{bth}\ (\%) = \frac{Brake\ Power(KW)\ \text{x}\ 3600}{Fuel\ Flow(Kg/Hr)\ \text{x}\ Calorific\ Value(KJ/Kg)} \times 100$$

Mechanical efficiency (η_m): It is defined as the ratio of power delivered by crankshaft to power output generated at engine's piston.

$$\eta\text{m} = \frac{\text{Brake Power (Mechanical Work output)}}{\text{Indicated Power (Indicated Work Output)}}$$

and

Frictional Power (FP) = Indicated Power (IP) – Brake Power (BP)

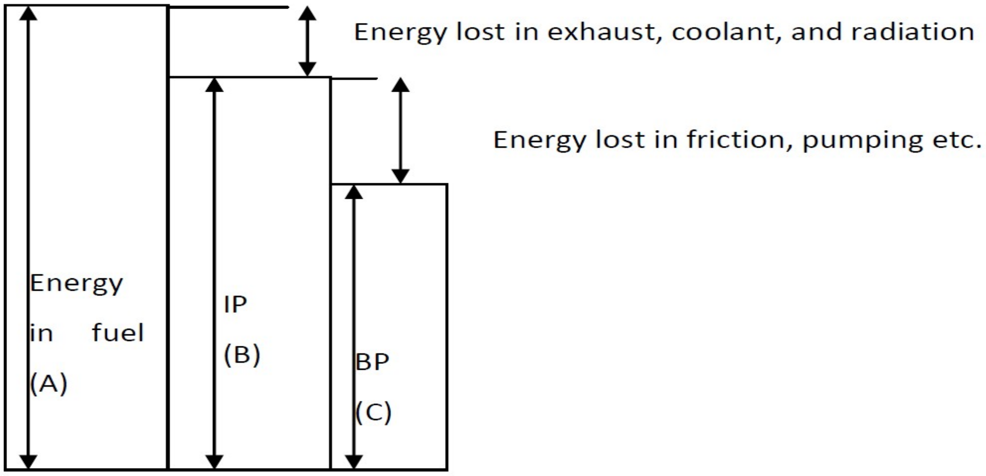


Figure 3.5 Schematic Representation of Different Efficiencies

Indicated Thermal Efficiency (ITE) = B/A

Brake Thermal Efficiency (BTE) = C/A

Mechanical Efficiency (ME) = C/B

Volumetric Efficiency (η_v): Volumetric efficiency is a parameter used to measure how well an internal combustion (IC) engine fills its cylinders with air or fuel-air mixture. It is expressed as a ratio of the actual amount of air (or air-fuel mixture) drawn into the cylinder during the intake stroke to the amount the cylinder could theoretically hold at atmospheric pressure. Volumetric efficiency is crucial in assessing the breathing capability of an engine and is a key factor in determining its overall performance. Volumetric efficiency can be calculated as:

$$\eta v = \frac{\text{Volume of air} - \text{fuel mixture taken into cylinder}}{\text{Maximun possible volume in the cylinder}}$$

$$\eta v = \frac{V_{air}}{V_c}$$

Where

η_v= volumetric efficiency

V_{air} = volume of air taken into cylinder [cc, L, or m^3]

V_c = cylinder swept volume [cc, L, or m^3]

Specific fuel consumption (SFC): Specific fuel consumption (SFC) in an internal combustion (IC) engine is a measure of the fuel efficiency of the engine, typically expressed in terms of the amount of fuel consumed per unit of power produced. Specific fuel consumption is often used in the context of aircraft engines, where it is a critical parameter for assessing the fuel efficiency of propulsion systems. If indicated power (IP) is employed in calculating SFC, it is referred to as indicated specific fuel consumption (ISFC), and if brake power (BP) is utilized, it is termed brake specific fuel consumption (BSFC). Thus,

$$\text{ISFC} = \frac{60w_f}{\text{i.p.}} = \frac{3600}{\text{H.V.}\eta_i}, \text{Kg/i.kWh}$$

$$\text{BSFC} = \frac{60w_f}{\text{b.p}} = \frac{3600}{\text{H.V.}\eta_b}, \text{Kg/b.kWh}$$

Power: It is defined as the rate of doing work. It is also referred as the product of force and linear velocity or the product of torque and angular velocity. Therefore, measuring power involves determining both force (or torque) and speed. Thus, power generated at the output shaft of engine is called brake power and is expressed as:

Power (P) = NT / 60,000 (Kw)

Where

Torque (T) = WR (Nm)

N is speed (RPM)

W = 9.81 * Net Mass Applied (Kg)

R= Radius (m)

Mechanical efficiency is defined as the ratio of brake power to indicated power. Thus,

$$\eta_m = \frac{b.p.}{i.p.}\left(or \frac{b.p.}{b.p.+f.p.}\right) = \frac{b.m.e.p}{i.m.e.p} = \frac{\eta_b}{\eta_i}$$

Mean effective pressure (MEP) and torque: It is described as a theoretical pressure assumed to exert force on the piston during the entire power stroke.

Power in kW = (P LAN/n 100)/60 in bar

Where

P = mean effective pressure

L = length of the stroke in m

A = area of the piston in m^2

N = Rotational speed of engine RPM

n= number of revolutions required to complete one engine cycle

n= 1 (for two stroke engine)

n= 2 (for f our stroke engine)

Hence, it is clear that the power produced by a specific engine can be measured using mean effective pressure units. When mean effective pressure is calculated based on brake power, it is called brake mean effective pressure (BMEP), and if determined using indicated power, it is known as indicated mean effective pressure (IMEP).

$$\text{BMEP (bar)} = \frac{\text{Brake Power(Kw)} \times 60}{L \times A \times \left(\frac{N}{n}\right) \text{ x No. Of Cyl} \times 100}$$

$$\text{IMEP (bar)} = \frac{\text{Indicated Power(KW)} \times 60}{L \times A \times \left(\frac{N}{n}\right) \times \text{No Of Cyl} \times 100}$$

Friction Mean Effective Pressure (FMEP) can be expressed as FMEP = IMEP – BMEP.

Thermal efficiency signifies the degree to which the energy added by heat is transformed into network output. It reflects the extent to which the energy added by work is converted into net heat output. The thermal efficiency is occasionally referred to as fuel conversion efficiency, which is defined as the ratio of the work generated per cycle to the amount of fuel energy supplied per cycle that can be released in the combustion process.

Indicated thermal efficiency is a measure of the efficiency of an internal combustion engine in converting the energy released during combustion into useful work.

$$\text{Indicated thermal efficiency}= \frac{\text{indicated work in heat units}}{\text{energy supplied}} = \frac{60\text{IP}}{\text{wf}*\text{H.V}}$$

Where,

wf is fuel supplied, kg/min
H.V. is heating value of fuel, kJ/kg.
Brake Thermal Efficiency, r\b.

Brake thermal efficiency is a measure of the efficiency of an internal combustion engine in converting the chemical energy of fuel into useful mechanical work. It accounts for various losses and inefficiencies within the engine, providing a more comprehensive assessment compared to indicated thermal efficiency

$$\text{Brake thermal efficiency}= \frac{\text{Brake work done in heat units}}{\text{energy supplied}} = \frac{60\text{B.P}}{\text{wf}*\text{H.V}}$$

SFC, or specific fuel consumption, reflects the efficiency with which a power plant converts chemical energy into mechanical energy. The introduction of afterburning typically leads to an elevation in specific fuel consumption and is, consequently, typically restricted to short-duration periods. To achieve the necessary temperature ratio, additional fuel must be introduced into the gas stream. As the temperature rise does not occur at the compression peak, the fuel is not burned as effectively as in the engine combustion chamber, resulting in a higher specific fuel consumption.

3.8 Engine Combustion Parameters

Cylinder pressure: Examining in-cylinder pressure during experimental investigations is crucial for evaluating the performance attributes of biodiesel-blended fuels. Variables such as the specific heat of biodiesel fuel, its chemical energy content, droplet size, ignition delay time, and the quality of the production process impact this pressure parameter. Numerous research studies indicate that in-cylinder pressure tends to be slightly higher for biodiesel blends, primarily due to increased combustion temperatures. Consequently, the use of higher biodiesel blends results in higher in-cylinder pressure when compared to conventional diesel fuel.

Heat Release Rate (HRR): In evaluating diesel engines fueled by biodiesel (BD) blends, analyzing Heat Release Rate (HRR) patterns from in-cylinder pressure data is crucial. Experimental BD blends consistently show higher HRR throughout all combustion stages compared to regular diesel fuel. The second peak in HRR during diffusion burning in BD blends is attributed to a greater volume of BD combustion. Under lower engine loads, maximum HRR values for experimental BD and diesel fuel are similar, but at higher loads, diesel fuel exhibits slightly higher HRR peak points than vegetable oil-based BD blends. Despite lower chemical energy, turpentine oil BD blends display an HRR profile similar to regular diesel fuel.

3.9 Engine Emission Parameters

In the context of emissions, "opacity" typically refers to the extent to which emissions (such as smoke, particles, or gases) reduce light transmission, making it difficult to see through the emitting substance. The term is commonly used in environmental monitoring and regulation, especially for industries and facilities that release pollutants into the air. When evaluating emissions from sources such as industrial plants or vehicles, opacity is measured using instruments such as opacimeters or smoke detectors. These instruments gauge the quantity of light obstructed or absorbed by the exhaust, providing an indication of the extent of opacity or visual obstruction in the exhaust. Various researches have shown that nanoparticles additives in fuel decreases the opacity which is described in next chapter.

CHAPTER FOUR: RESULT AND DISCUSSION

4.1 Characterization of Nanoparticles

The necessary specifications for the nanoparticle have been established, including its clarity and distinct physical properties, through the sol-gel technique of synthesis. The details of the laboratory preparation are provided in the appendix below.

4.1.1 UV Test

The UV-visible spectrum of CuO nanoparticle that are synthesized displays a robust absorbance of UV rays ranging from 200-300 nm, signifying the presence of CuO nanoparticles in the sample. While performing UV test at material science laboratory, IOE, Pulchwok Campus, Pulchwok, Lalitpur, the peak value observed at 266 nm which is in the range of 200 to 300 nm and it confirms the sample is CuO nanoparticles.

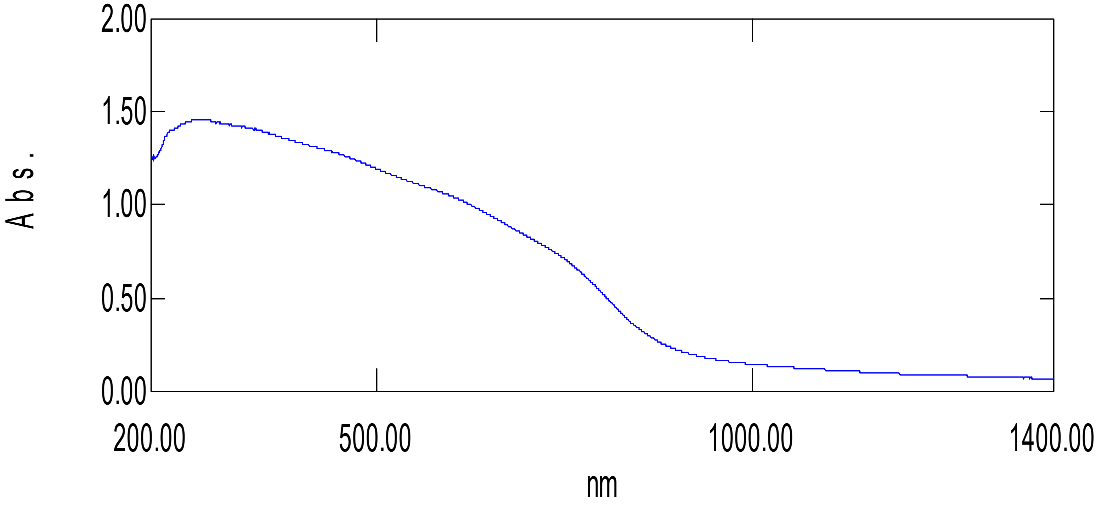


Figure 4.1 UV test of copper oxide (Absorbance vs Wavelength)

4.1.2 X-Ray Diffraction Analysis

Using the Scherer formula, the size determined reflects the mean crystallite size of the Nano-materials. Through X-Ray Diffraction Method, the nanoparticle size was measured to be 80nm. It was ensured that the XRD graph of the synthesized nanomaterial did not contain any extraneous peaks that would arise due to the presence of impurities because the main goal was to find a single crystal structure that would account for the observed entire diffraction spectrum, in both peak intensity and angular position.

The result from XRD analysis is shown below:

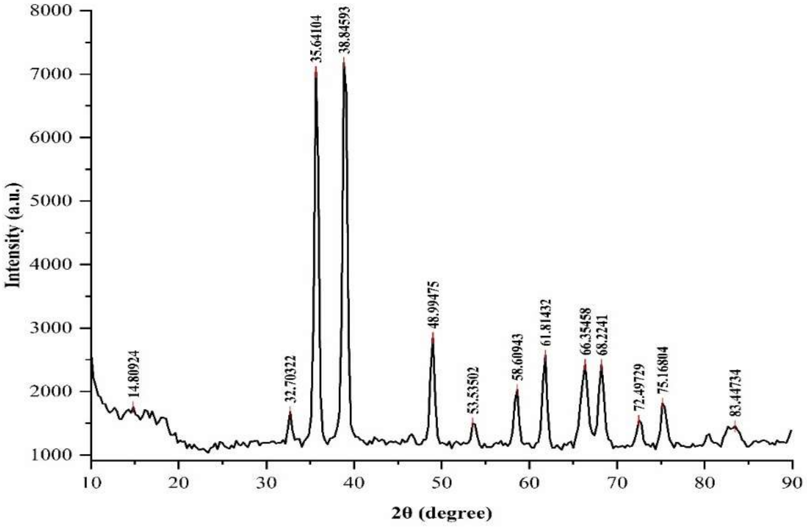


Figure 4.2 X-Ray Diffraction Copper Oxide Nanoparticles

4.2 FTIR test of Blended with Nanoparticle Additives

FT-IR spectroscopy serves to measure the absorption of IR radiation by a sample, presenting outcomes in wavelengths. Analyzing the IR spectrum involves aligning absorption bands (vibrational bands) with the chemical compounds present in the sample. The distinct peak of biodiesel at 1748 cm^{-1} signifies the stretching vibration of the C=O bond which is specifically associated with ester groups (Lamichhane, 2019).

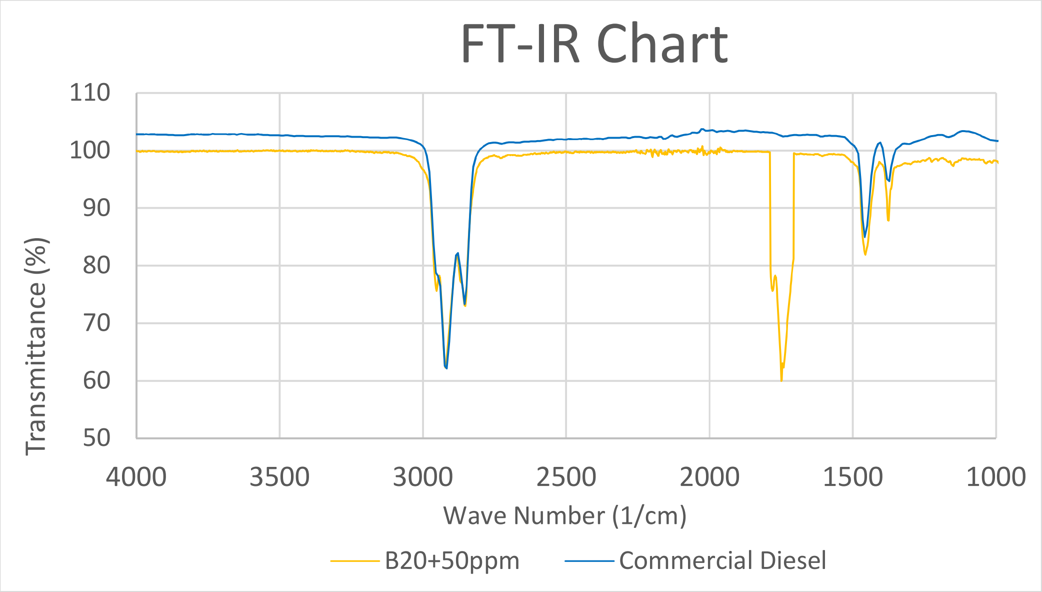


Figure 4.3 FTIR Results

4.3 Performance Testing of the CI Engine

The engine performance parameter, combustion characteristics and emission parameters were tested first by using commercial diesel fuel, Pine oil –Diesel (B20) and Pine oil –Diesel blends with nanoparticles additives, the parameters were taken and all the results were compared which are discussed below:

4.3.1 Brake Power

Figure 4.4 depicts the change in BP (Brake Power) with load for diesel, a pine-diesel blend (B20) and B20 blend with CuO additives of 25ppm, 50ppm & 75ppm concentration. In each scenario, the BP value rises as the load increases. The test revealed that fuel with Nano additives, across all concentrations, exhibited slightly higher BP values compared to both regular commercial diesel fuel and B20 under various load conditions (Joshi, 2021).

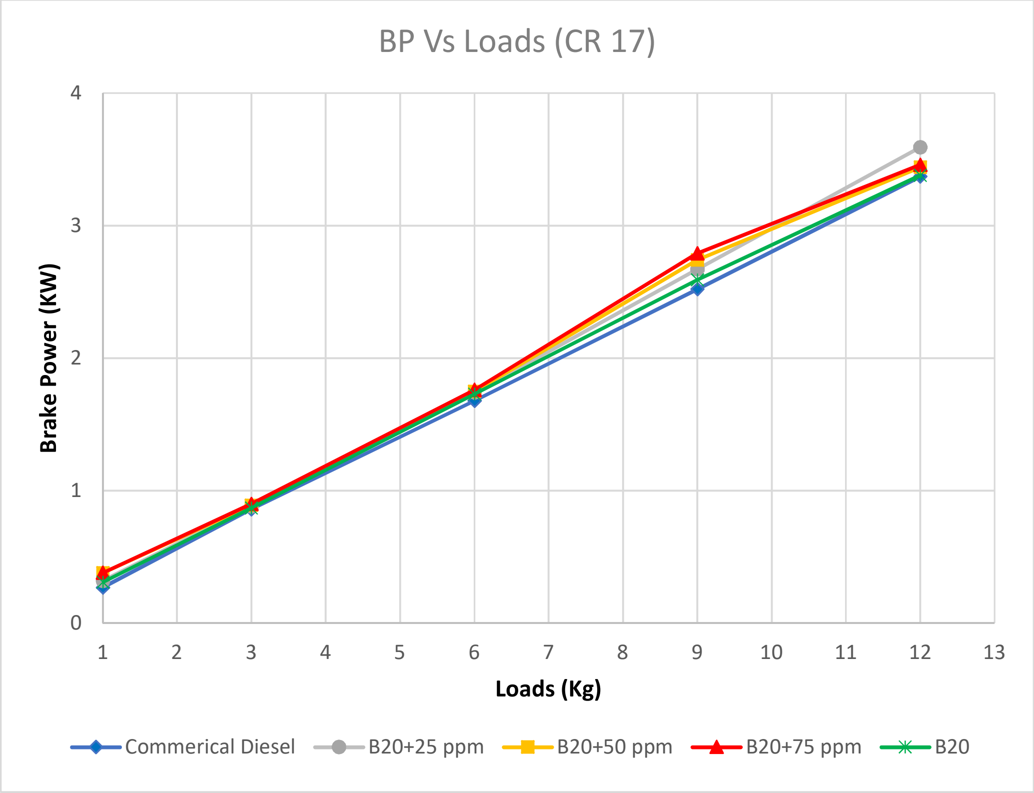


Figure 4.4 Brake Power Vs Load

4.3.2 Indicated Mean Effective Pressure

Figure 4.5 illustrates the comparison of IMEP for diesel and B20 with all test fuels (B20 with CuO nanoparticle additives) which shows that B20 with CuO nanoparticle at all concentration, the value of IMEP increases with an increase in load. However, B20+50ppm nanoparticle shows higher values of IMEP than other cases. The B20+50ppm increased by 60.51%, 67.21%, 41.90%, 28.38% and 29.35% at load 1kg, 3kg, 6kg, 9kg and 12kg respectively as compared to B20 fuel.

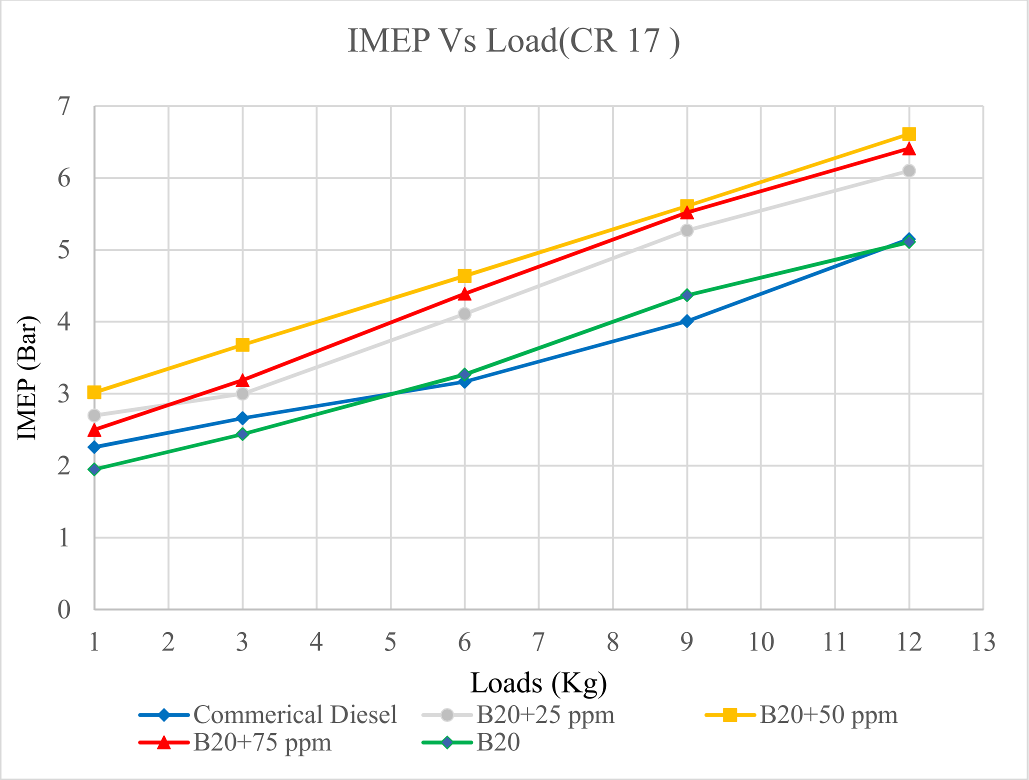


Figure 4.5 IMEP Vs Loads

4.3.3 Air Flow in Engine

Figure 4.6 depicts the changes in air flow for diesel and different combinations of B20 with CuO nanoparticles. A comparison of B20 blends containing CuO nanoparticles at all concentrations was made with diesel fuel, revealing that, in all instances, air flow decreases as the load increases.

At the initial load of 1 kg, the air flow values for diesel and B20 with (25 ppm, 50 ppm and 75 ppm) were determined to be 82.02, 74.33, 76.34, and 77.73 mmWC, respectively. Following an increase in load from 1 kg to 12 kg, the air flow values decreased to 69.28, 66.4, 70.55 and 70.74 respectively.

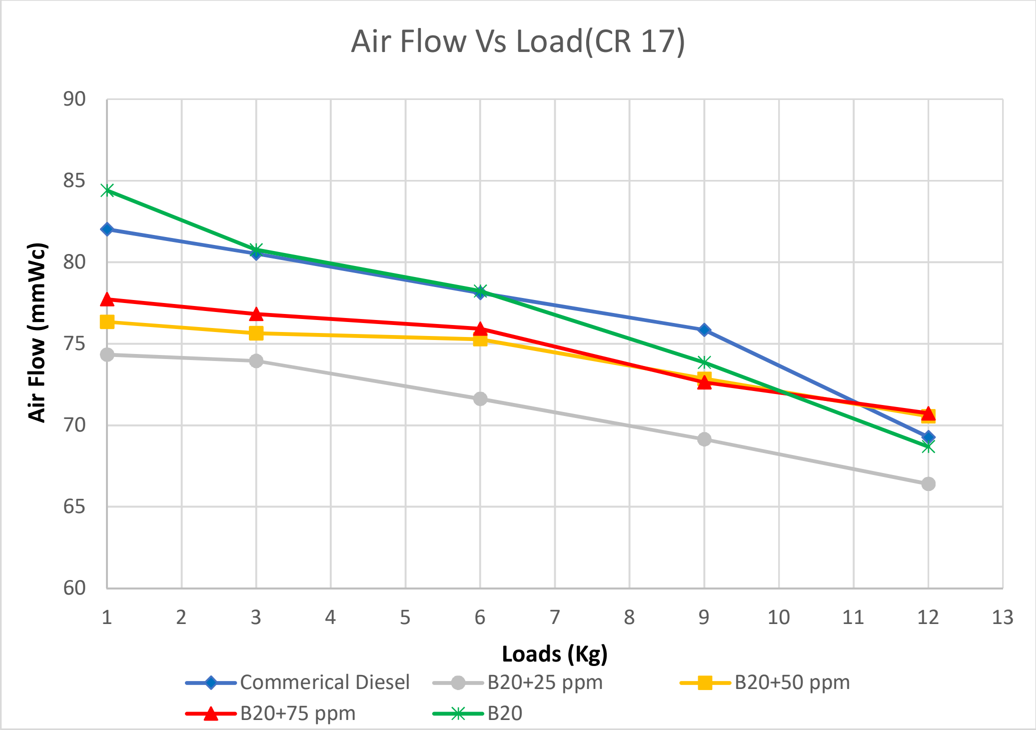


Figure 4.6 Air flow Vs Loads

4.3.4 Brake Thermal Efficiency

Figure 4.7 illustrates how BTE changes with increasing load for various fuel blends. With escalating load in the engine, there is a corresponding increase in BTE, as BTE is linked to Brake Power. The incorporation of CuO nanoparticles in B20 leads to an enhanced BTE compared to both the B20 blend and traditional diesel. Experiment shows the value of BTE for Diesel, B20, B20+25ppm, B20+50ppm and B20+75ppm to be 19.26%, 17.52%, 19.19%, 20.17 and 21.7% at load 6kg which indicates that nanoparticle additive fuels have better BTE. At higher load 9kg, value of BTE for Diesel and B20 increases to 21.7% & 17.81% subsequently then decreases to 16.55% and 14.92% after increasing load to 12 kg, however for all nanoparticle additive fuels, BTE continues to increase to 12kg loads with value of 26.90%, 26.92% and 27.07% for B20+25ppm, B20+50ppm and B20+75ppm respectively.

The findings suggest that incorporating CuO nanoparticles could markedly impact the engine's brake thermal efficiency, and this impact can be ascribed to the improved combustion characteristics of the fuels containing CuO nanoparticles. (Kalaimurugan K. K., 2019).

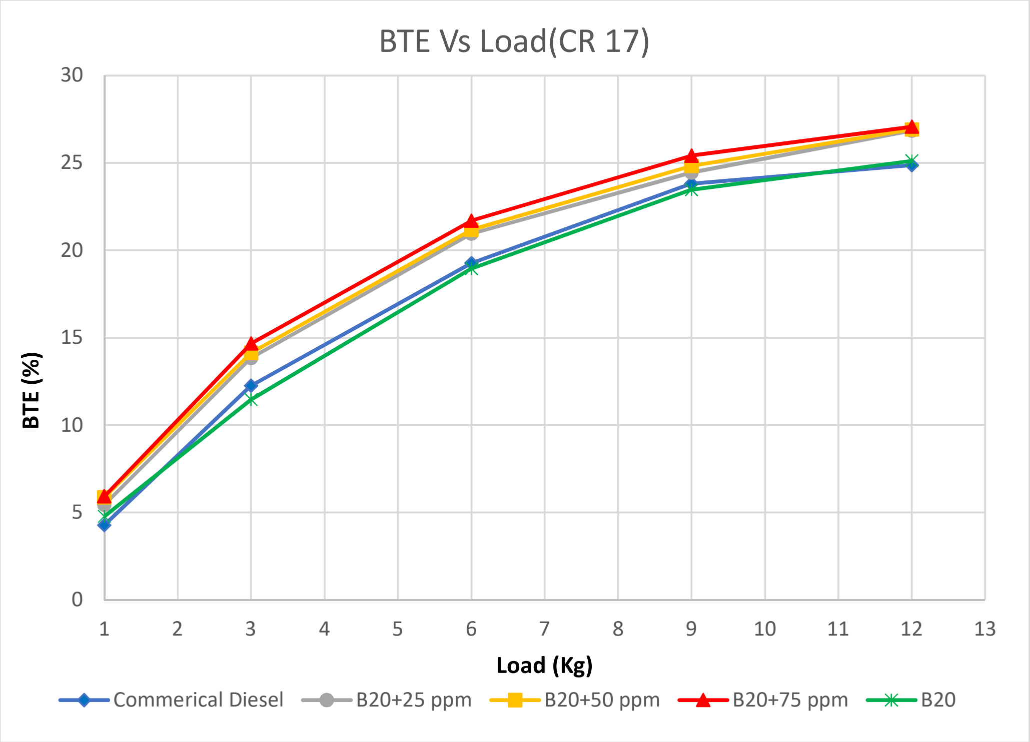


Figure 4.7 BTE Vs Loads

4.3.5 Specific Fuel Consumption

Figure 4.8 indicates the change in SFC with different load across all tested fuel samples. Notably, the SFC of B20 with added CuO nanoparticles decreased as the quantity of CuO nanoparticles increased. These outcomes suggest that CuO nanoparticles enhanced atomization and combustion, consequently reducing fuel consumption while growing power output. Typically, the SFC of fuel blends incorporated with CuO nanoparticles was lower compared to B20, potentially because of lower CV, calorific value of B20 (Karthikeyan, 2018).

The reduced SFC observed with CuO nanoparticles could be linked to the comparatively lower calorific value present in the B20 fuel. This suggests that even though the B20 fuel had a lower energy content compared to the modified blends, the incorporation of CuO nanoparticles led to a more efficient use of the available energy. The results suggest that the incorporation of CuO nanoparticles into B20 fuel blends improved combustion efficiency, reduced specific fuel consumption, and lowered SFC, making it a potentially more efficient and environmentally friendly fuel option despite the lower calorific value of B20.

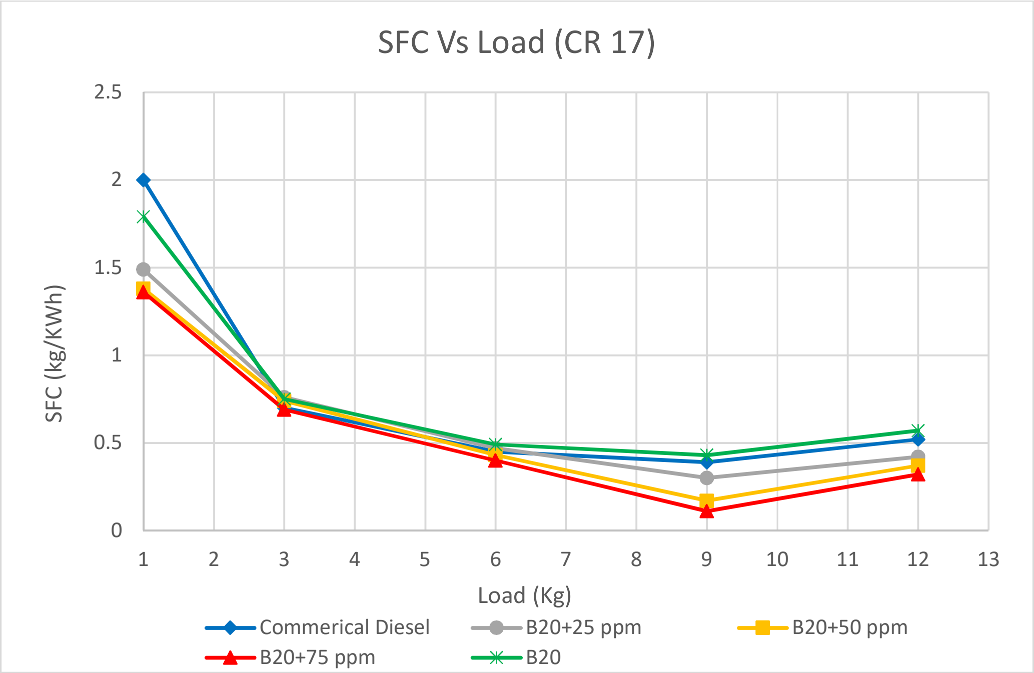


Figure 4.8 SFC Vs Loads

4.3.6 Mechanical Efficiency

Figure 4.9 displays the variation in ME concerning load across different fuel blends. As the engine load increases, so did the ME, given that ME correlates with indicated power. However, the result shows that as increasing the load, mechanical efficiency of commercial diesel is observed slightly higher than nanoparticle additives fuel blends.

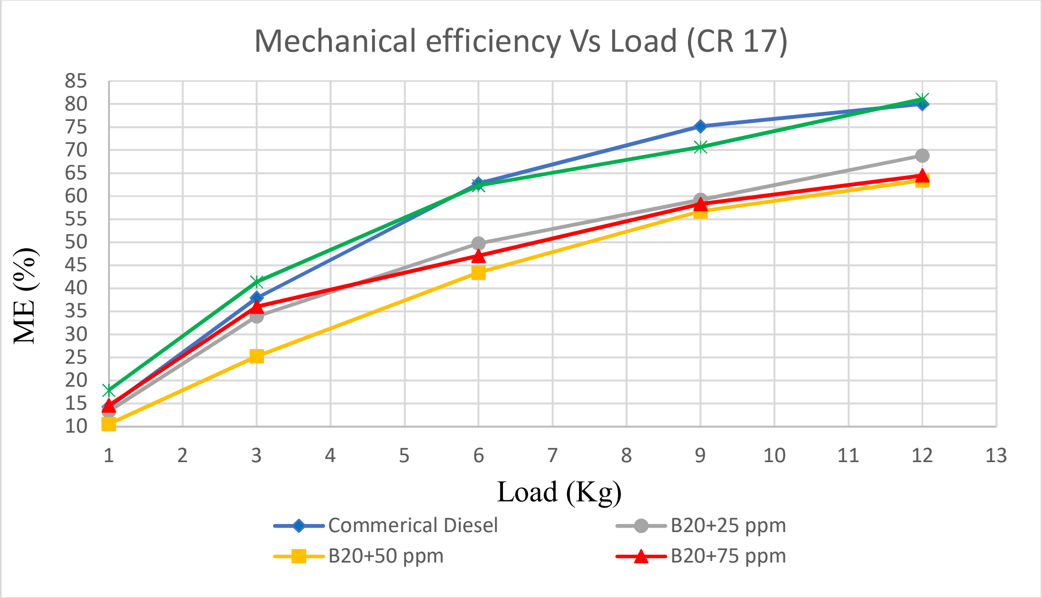


Figure 4.9 ME Vs Loads

4.4 Combustion Testing of CI Engine

4.4.1 Cylinder Pressure

In Figure 4.10, the graph illustrates the fluctuation of cylinder pressure across various crank angles for various biodiesel fuel samples. The cylinder pressure of all fuel samples is comparable to diesel.

Introducing nanoparticles into biodiesel blends led to notable enhancements in cylinder pressure and ignition delay. The highest combustion pressure exhibited an inverse correlation with compression pressure and thermal conductivity. Surprisingly, B20 exhibited reduced cylinder pressure in comparison to all other examined fuels, primarily because of its elevated density and viscosity. This led to a notably slow evaporation rate and insufficient combustion. Conversely, B20+75 ppm resulted in elevated cylinder pressure due to the presence of the fuel's oxygen content, leading to reduced cetane numbers and a prolonged ignition delay duration.

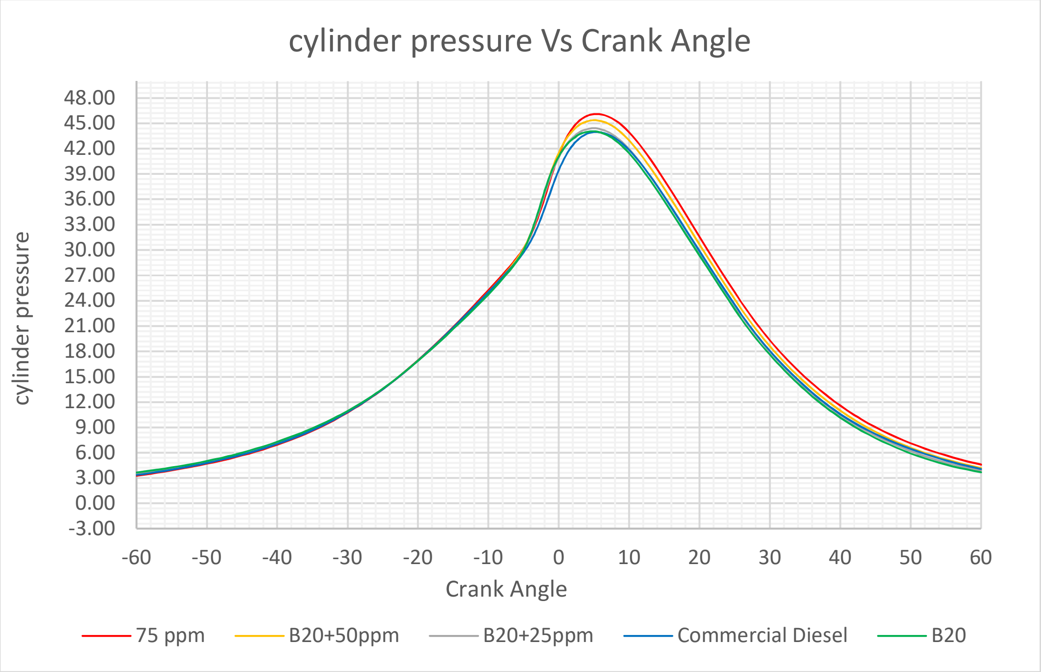


Figure 4.10 Cylinder Pressure Vs Crank Angle

4.4.2 Net Heat Release

Figure 4.11 illustrates the variations in heat release at various crankshaft angles for different combinations of test fuel. Throughout the ignition delay, the heat release remained consistently low for all the tested fuels, indicating fuel evaporation and the transfer of heat from the fuel to the hot air during compression. Following the combustion of fuel, there is a distinct and immediate increase in released heat, peaking during the premixed phase of fuel and air. The extended ignition delay time improves the blending of fuel and air, facilitating a swift combustion rate in the premix combustion stage and leading to a greater net heat release during this phase.

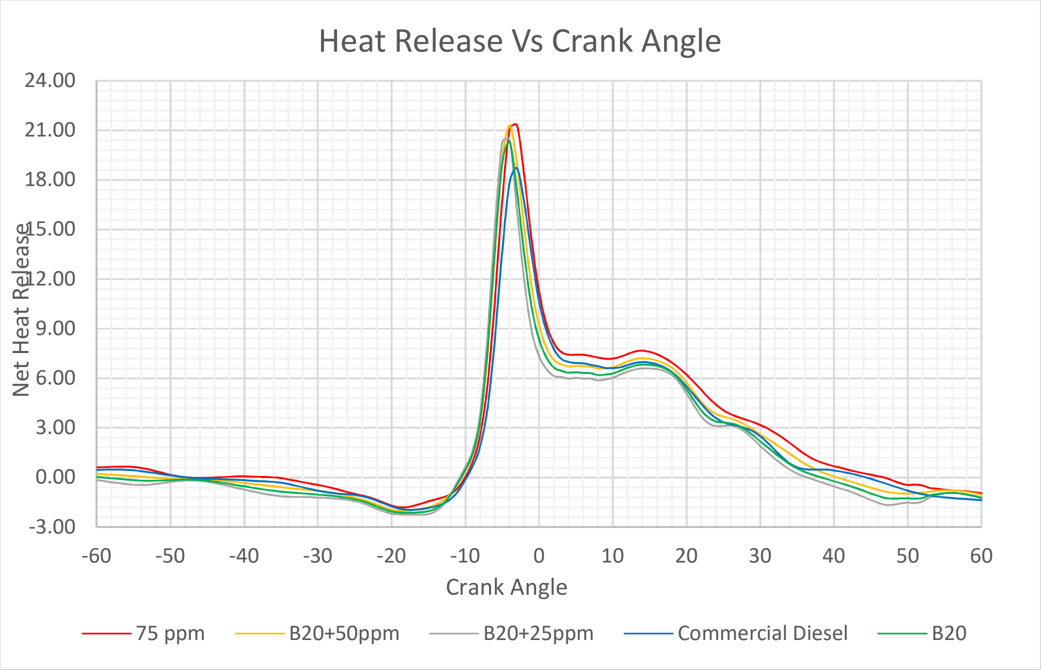


Figure 4.11 Net Heat Release Vs. Crank Angle

4.5 Emission Testing of CI Engine

Smoke Opacity

Figure 4.12 illustrates the changes in smoke opacity with varying loads. The smoke opacity in fuel blends containing CuO nanoparticles was lower than that in the B20 fuel blend and standard diesel. The reduction in smoke emissions can be attributed to the shortened ignition delay and improved ignition properties present in the fuel blends enhanced with CuO nanoparticles. The decline in smoke emissions was predominantly affected by the sulfur and oxygen elements in the mixture, coupled with a decrease in aromatic content. The introduction of CuO nanoparticles in the fuel blends led to a reduced ignition delay, facilitating effective fuel delivery to the combustion chamber, supporting complete combustion, and consequently decreasing smoke emissions.

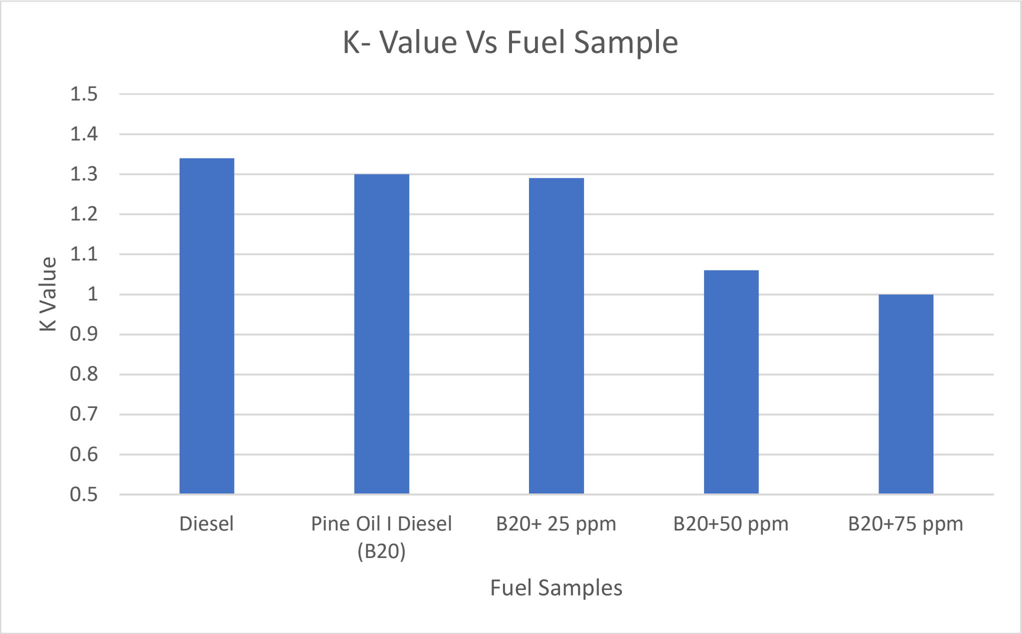


Figure 4.12 Smoke Opacity (K-Value Vs Fuel Sample)

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

A comparative investigation was undertaken to assess the effects of different nanoparticle dosages on the performance, combustion, and emissions of compression ignition (CI) engines utilizing a mixture of pine oil biodiesel (20%). The primary aim of the tests was to elucidate the impact of introducing copper oxide (CuO) nanoparticles into a blend of pine oil and diesel fuel (B20). The experiments were conducted in standard laboratory conditions, incorporating concentrations of 25, 50, and 75 ppm of copper oxide nanoparticles. The study meticulously analyzed how the integration of nanoparticles into commercially available diesel influenced the engine's performance, combustion, and emission characteristics. The conclusions drawn from the current experimental investigation are as follows:

i. CuO nanoparticles was synthesized using aqueous solution of Copper Sulphate and Sodium Hydroxide solution upon calcination at 500°C.
ii. The crystallite size and conformity of synthesized copper oxide nanoparticles was examined by XRD and UV test respectively.
iii. The addition of CuO nanoparticles enhances the thermophysical properties, including viscosity, density, cetane number, flash point, pour point, etc., of the B20 base fuel.
iv. IMEP, BP and BTE were found to be increasing with the advancement in load for all test fuels, SFC of B20+75ppm was superior than other blends at higher loads.
v. Cylinder Pressure along with Net Heat Release of B20+50ppm was viewed better than other test fuel blends and commercial diesel.
vi. Smoke opacity was found to be decreasing for increasing concentration of nanoparticle additives.

5.2 Recommendation

Further study can be performed under following heading in order to fulfill the research gap of this study:

i. Assessment of emission characteristics of pine oil diesel blend with CuO nanoparticles with more concentration than 75ppm.

ii. Examination of performance, combustion characteristics and emission parameters of CI engine for other biodiesel blend with CuO nanoparticles additives.

iii. Study of same research under engine’s varying compression ratio / varying injection pressure.

iv. Analyzing performance parameters, combustion characteristics, and emissions in a compression ignition (CI) engine utilizing an alternative biodiesel blend with diverse hybrid nanoparticle additives.

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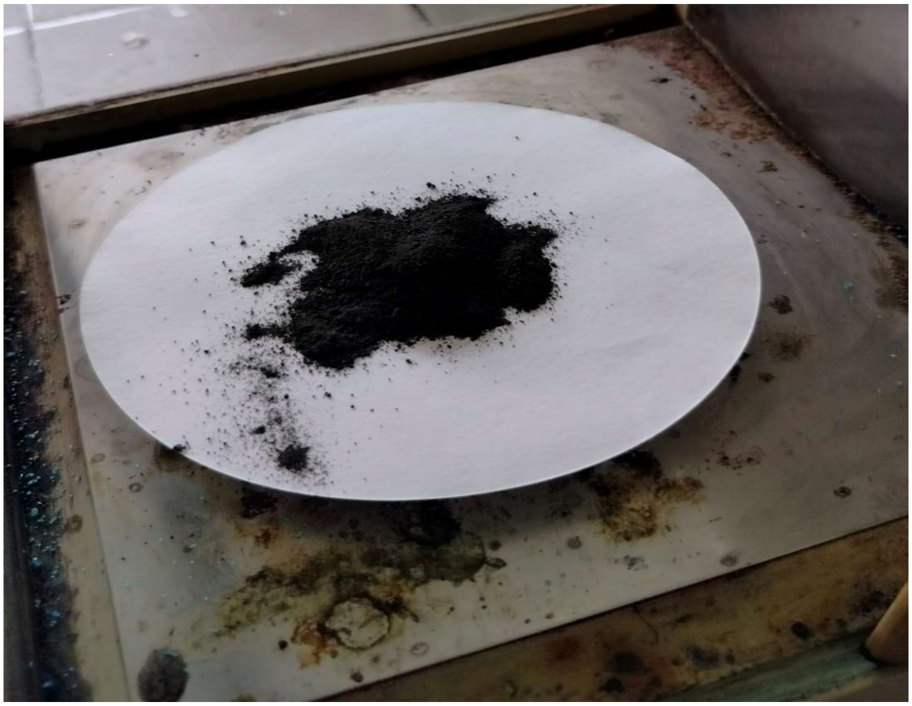
APPENDICES

A. Color Transformation of Solution from Dark Green to Black

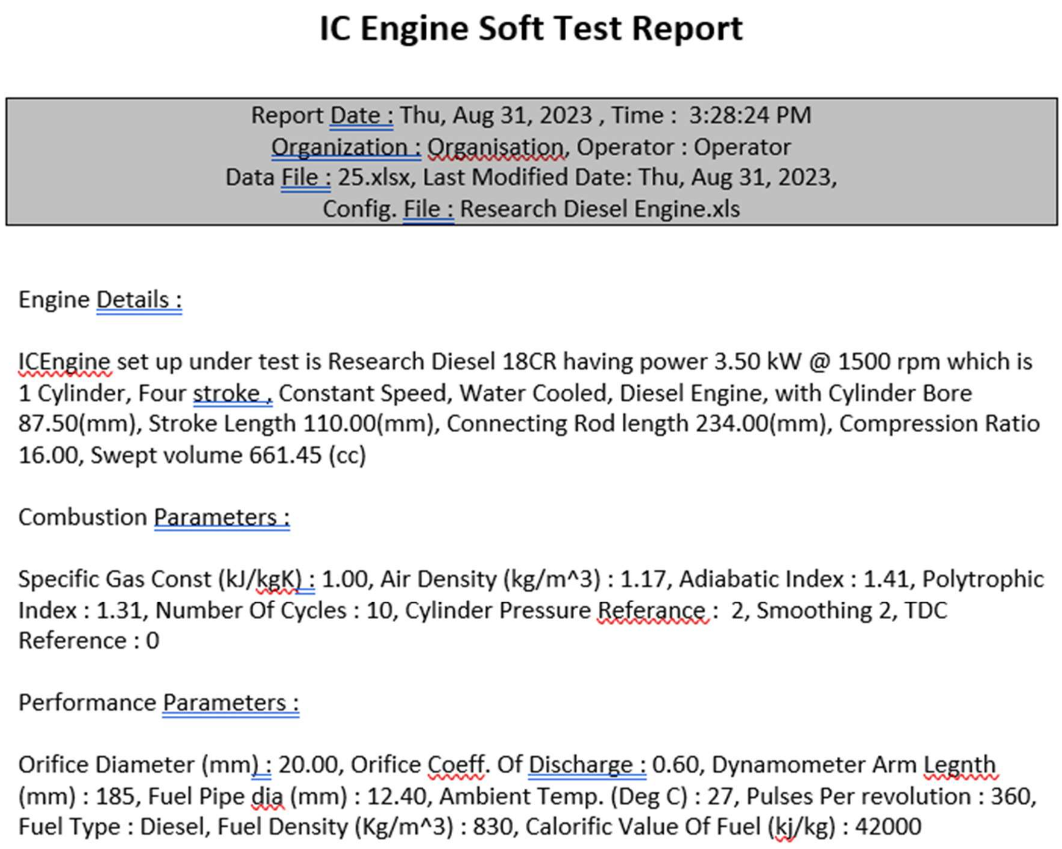
B. Synthesized CuO Nanoparticles



C. Research Engine for performance & combustion testing at Thapathali campus

D. Emission Testing Device at Thapathali Campus

E. Research Engine Detail



IC Engine Soft Test Report

Report Date : Thu, Aug 31, 2023 , Time : 3:28:24 PM
Organization : Organisation, Operator : Operator
Data File : 25.xlsx, Last Modified Date: Thu, Aug 31, 2023,
Config. File : Research Diesel Engine.xls

Engine Details :

ICEngine set up under test is Research Diesel 18CR having power 3.50 kW @ 1500 rpm which is 1 Cylinder, Four stroke , Constant Speed, Water Cooled, Diesel Engine, with Cylinder Bore 87.50(mm), Stroke Length 110.00(mm), Connecting Rod length 234.00(mm), Compression Ratio 16.00, Swept volume 661.45 (cc)

Combustion Parameters :

Specific Gas Const (kJ/kgK) : 1.00, Air Density (kg/m^3) : 1.17, Adiabatic Index : 1.41, Polytrophic Index : 1.31, Number Of Cycles : 10, Cylinder Pressure Referance : 2, Smoothing 2, TDC Reference : 0

Performance Parameters :

Orifice Diameter (mm) : 20.00, Orifice Coeff. Of Discharge : 0.60, Dynamometer Arm Legnth (mm) : 185, Fuel Pipe dia (mm) : 12.40, Ambient Temp. (Deg C) : 27, Pulses Per revolution : 360, Fuel Type : Diesel, Fuel Density (Kg/m^3) : 830, Calorific Value Of Fuel (kj/kg) : 42000

F. Brake Power (Kw) Data of all fuel samples.

load(Kgs)	BP(CD)	B20	BP(25 ppm)	BP(50 ppm)	BP(75 ppm)
1	0.27	0.31	0.32	0.38	0.38
3	0.86	0.87	0.88	0.89	0.9
6	1.68	1.73	1.74	1.75	1.76
9	2.52	2.59	2.67	2.74	2.79
12	3.37	3.38	3.59	3.44	3.46

G. Indicated Mean Effective Pressure (Bar) Data of all fuel samples.

Load(Kgs)	(CD)	B20	(25 ppm)	(50 ppm)	(75 ppm)
1	2.26	1.95	2.7	3.02	2.5
3	2.66	2.44	3	3.68	3.19
6	3.17	3.27	4.11	4.64	4.39
9	4.01	4.37	5.27	5.61	5.52
12	5.15	5.11	6.1	6.61	6.41

H. Air Flow (mmWc) Data of all fuel samples.

Load(Kgs)	(CD)	B20	(25 ppm)	(50 ppm)	(75 ppm)
1	82.02	84.4	74.33	76.34	77.73
3	80.52	80.76	73.95	75.64	76.83
6	78.12	78.24	71.61	75.27	75.93
9	75.85	73.86	69.14	72.86	72.63
12	69.28	68.69	66.4	70.55	70.74

I. Brake Thermal Efficiencies (%) of all fuel Samples.

Load(Kgs)	(CD)	B20	(25 ppm)	(50 ppm)	(75 ppm)
1	4.29	4.78	5.45	5.87	5.93
3	12.26	11.46	13.85	14.13	14.67
6	19.26	18.95	20.95	21.17	21.7
9	23.81	23.47	24.45	24.83	25.42
12	24.87	25.12	26.85	26.92	27.07

J. Specific Fuel Consumption (Kg/Kwh) of all fuel samples.

Load(Kgs)	(CD)	B20	(25 ppm)	(50 ppm)	(75 ppm)
1	2	1.79	1.49	1.38	1.36
3	0.7	0.75	0.76	0.74	0.69
6	0.45	0.49	0.47	0.43	0.4
9	0.39	0.43	0.3	0.17	0.11
12	0.52	0.57	0.42	0.37	0.32

K. Mechanical Fuel Efficiencies (%) of all fuel Samples.

Load(Kgs)	(CD)	B20	(25 ppm)	(50 ppm)	(75 ppm)
1	14.22	17.86	13.35	10.53	14.59
3	37.94	41.36	33.94	25.26	36.05
6	62.76	62.32	49.75	43.41	47.07
9	75.19	70.64	59.2	56.75	58.33
12	80.04	81.08	68.84	63.43	64.5

L. Cylinder Pressure (Bar) Vs Crank Angle Data of all fuel Samples.

75ppm	50 ppm	25 ppm	angle	Diesel	B20
3.29	3.47	3.56	-60	3.37	3.65
3.40	3.58	3.67	-59	3.48	3.76
3.52	3.70	3.79	-58	3.60	3.88
3.64	3.82	3.91	-57	3.72	4.00
3.77	3.95	4.04	-56	3.85	4.13
3.91	4.09	4.18	-55	3.99	4.27

4.06	4.23	4.31	-54	4.14	4.40
4.21	4.37	4.45	-53	4.29	4.53
4.37	4.53	4.61	-52	4.44	4.69
4.53	4.69	4.77	-51	4.61	4.85
4.70	4.86	4.94	-50	4.78	5.02
4.88	5.04	5.12	-49	4.96	5.20
5.07	5.22	5.30	-48	5.15	5.37
5.26	5.42	5.50	-47	5.35	5.58
5.47	5.62	5.70	-46	5.55	5.77
5.68	5.84	5.92	-45	5.77	6.00
5.90	6.07	6.16	-44	6.00	6.25
6.14	6.31	6.40	-43	6.24	6.49
6.39	6.56	6.65	-42	6.49	6.74
6.66	6.83	6.92	-41	6.76	7.01
6.94	7.11	7.20	-40	7.04	7.29
7.23	7.41	7.50	-39	7.33	7.59
7.55	7.72	7.81	-38	7.64	7.89
7.88	8.04	8.12	-37	7.97	8.20
8.23	8.39	8.47	-36	8.32	8.55
8.60	8.75	8.83	-35	8.68	8.90
8.99	9.13	9.20	-34	9.07	9.27
9.40	9.53	9.60	-33	9.48	9.67
9.83	9.95	10.01	-32	9.90	10.07
10.29	10.39	10.44	-31	10.35	10.49
10.77	10.86	10.91	-30	10.82	10.95
11.27	11.35	11.39	-29	11.31	11.43
11.79	11.86	11.90	-28	11.83	11.93
12.35	12.40	12.42	-27	12.37	12.45
12.92	12.97	12.99	-26	12.93	13.02
13.53	13.56	13.57	-25	13.52	13.58
14.16	14.18	14.18	-24	14.14	14.19
14.81	14.83	14.83	-23	14.79	14.84
15.49	15.50	15.50	-22	15.47	15.50
16.20	16.19	16.18	-21	16.18	16.18
16.93	16.91	16.89	-20	16.90	16.88
17.68	17.64	17.62	-19	17.65	17.60
18.45	18.39	18.36	-18	18.41	18.33
19.23	19.16	19.12	-17	19.19	19.09
20.04	19.94	19.89	-16	19.99	19.84
20.86	20.75	20.69	-15	20.80	20.64
21.71	21.57	21.49	-14	21.62	21.42
22.58	22.41	22.31	-13	22.46	22.23

23.46	23.26	23.14	-12	23.30	23.04
24.35	24.12	23.98	-11	24.15	23.86
25.24	25.00	24.84	-10	25.01	24.72
26.14	25.90	25.73	-9	25.88	25.61
27.06	26.84	26.67	-8	26.77	26.56
28.01	27.82	27.65	-7	27.69	27.56
29.02	28.88	28.71	-6	28.65	28.64
30.19	30.17	30.01	-5	29.72	30.00
31.70	31.91	31.76	-4	31.03	31.86
33.72	34.21	34.05	-3	32.76	34.30
36.22	36.88	36.67	-2	34.92	37.00
38.89	39.43	39.08	-1	37.29	39.35
41.28	41.51	40.97	0	39.44	41.09
43.15	43.07	42.38	1	41.17	42.34
44.48	44.13	43.33	2	42.43	43.16
45.36	44.85	43.98	3	43.26	43.73
45.87	45.22	44.30	4	43.76	43.98
46.08	45.37	44.42	5	43.95	44.07
46.05	45.26	44.29	6	43.92	43.89
45.81	44.97	43.98	7	43.67	43.56
45.37	44.47	43.46	8	43.24	43.01
44.75	43.81	42.79	9	42.62	42.32
43.95	42.98	41.96	10	41.85	41.47
43.00	42.01	40.99	11	40.92	40.49
41.93	40.92	39.90	12	39.88	39.40
40.76	39.75	38.74	13	38.75	38.24
39.53	38.52	37.52	14	37.55	37.02
38.25	37.25	36.27	15	36.31	35.77
36.94	35.95	34.99	16	35.04	34.49
35.61	34.63	33.68	17	33.75	33.19
34.26	33.30	32.38	18	32.45	31.90
32.90	31.97	31.08	19	31.15	30.61
31.54	30.64	29.78	20	29.85	29.33
30.19	29.32	28.48	21	28.55	28.05
28.86	28.01	27.20	22	27.27	26.77
27.54	26.70	25.90	23	25.99	25.48
26.24	25.41	24.63	24	24.74	24.22
24.98	24.15	23.38	25	23.51	22.97
23.75	22.93	22.18	26	22.31	21.77
22.56	21.76	21.03	27	21.17	20.63
21.42	20.65	19.94	28	20.07	19.56
20.34	19.60	18.92	29	19.04	18.55

19.31	18.61	17.96	30	18.06	17.61
18.34	17.66	17.03	31	17.14	16.69
17.42	16.76	16.15	32	16.26	15.82
16.56	15.90	15.30	33	15.43	14.97
15.73	15.08	14.50	34	14.63	14.17
14.95	14.31	13.73	35	13.86	13.41
14.21	13.57	12.99	36	13.12	12.67
13.50	12.88	12.32	37	12.43	12.01
12.83	12.21	11.65	38	11.77	11.34
12.18	11.58	11.04	39	11.16	10.74
11.58	10.99	10.46	40	10.58	10.17
11.00	10.42	9.91	41	10.05	9.62
10.46	9.89	9.39	42	9.54	9.11
9.96	9.39	8.90	43	9.07	8.62
9.48	8.92	8.45	44	8.63	8.17
9.03	8.47	8.01	45	8.22	7.73
8.60	8.05	7.61	46	7.82	7.33
8.20	7.66	7.23	47	7.45	6.96
7.82	7.28	6.86	48	7.10	6.59
7.47	6.93	6.52	49	6.77	6.25
7.13	6.59	6.19	50	6.46	5.92
6.81	6.28	5.89	51	6.16	5.62
6.50	5.98	5.60	52	5.87	5.34
6.21	5.70	5.33	53	5.60	5.07
5.94	5.44	5.07	54	5.34	4.82
5.69	5.20	4.84	55	5.10	4.60
5.44	4.97	4.62	56	4.87	4.39
5.21	4.76	4.42	57	4.65	4.20
4.99	4.56	4.24	58	4.45	4.02
4.79	4.37	4.05	59	4.25	3.84
4.59	4.19	3.88	60	4.07	3.68

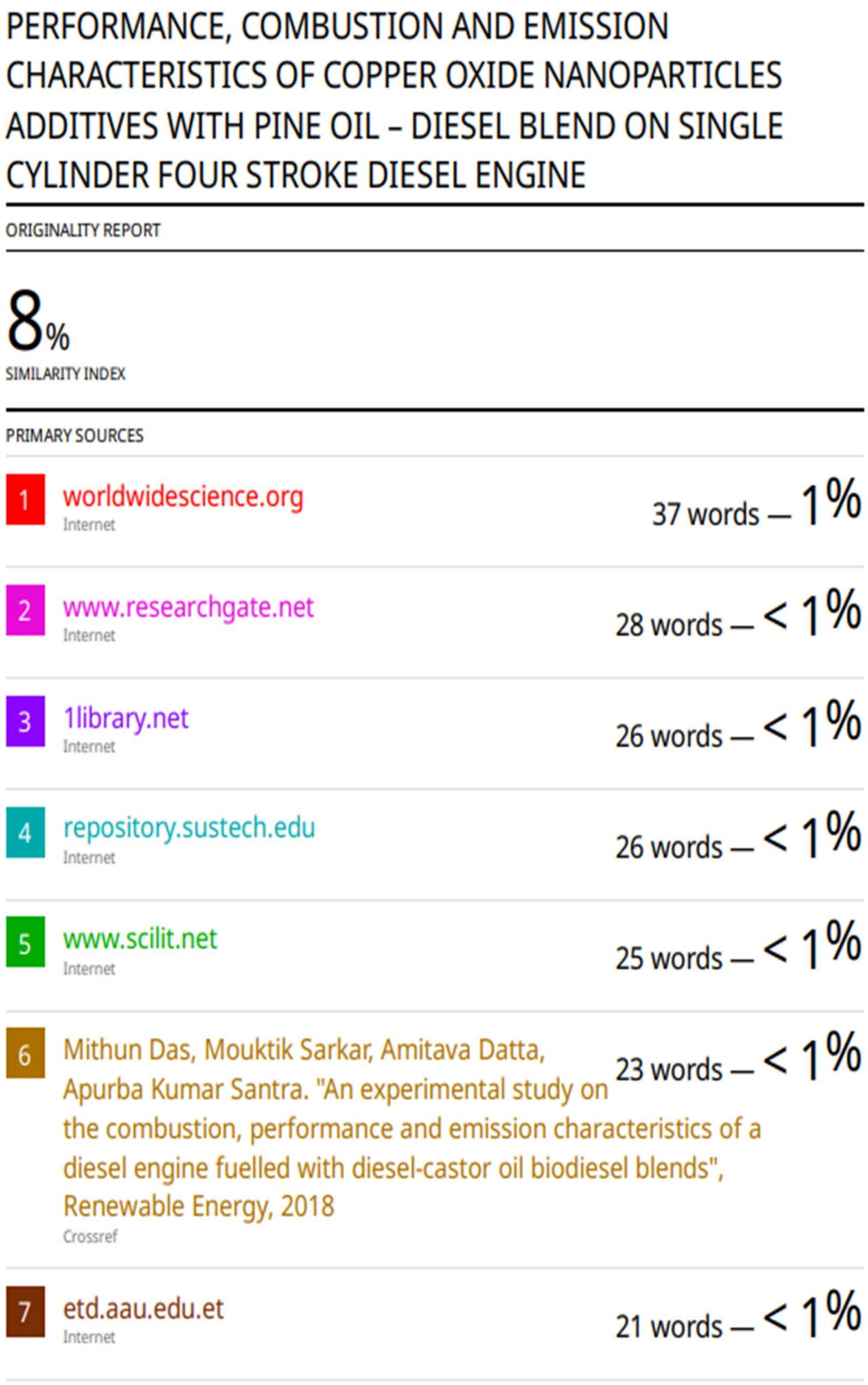
M. Heat Release Vs Crank Angle Data for all fuel Samples.

75 ppm	50 ppm	25 ppm	angle	Diesel	B20
0.61	0.22	-0.16	-60	0.45	0.04
0.62	0.19	-0.22	-59	0.47	0.00
0.64	0.16	-0.30	-58	0.47	-0.06
0.65	0.14	-0.35	-57	0.47	-0.09
0.65	0.11	-0.40	-56	0.46	-0.13
0.63	0.08	-0.45	-55	0.43	-0.17
0.58	0.05	-0.46	-54	0.38	-0.19

0.49	0.01	-0.45	-53	0.32	-0.21
0.38	-0.02	-0.39	-52	0.26	-0.19
0.26	-0.05	-0.33	-51	0.19	-0.18
0.15	-0.08	-0.28	-50	0.13	-0.16
0.07	-0.09	-0.22	-49	0.07	-0.14
0.01	-0.10	-0.19	-48	0.02	-0.13
-0.02	-0.11	-0.19	-47	-0.02	-0.14
-0.03	-0.12	-0.20	-46	-0.05	-0.16
-0.03	-0.15	-0.27	-45	-0.08	-0.21
-0.01	-0.18	-0.35	-44	-0.09	-0.26
0.02	-0.21	-0.44	-43	-0.10	-0.33
0.04	-0.24	-0.53	-42	-0.12	-0.39
0.06	-0.29	-0.65	-41	-0.15	-0.48
0.06	-0.33	-0.73	-40	-0.17	-0.54
0.05	-0.39	-0.84	-39	-0.20	-0.62
0.04	-0.44	-0.93	-38	-0.22	-0.69
0.03	-0.49	-1.01	-37	-0.24	-0.75
0.00	-0.54	-1.08	-36	-0.27	-0.81
-0.04	-0.59	-1.14	-35	-0.32	-0.87
-0.12	-0.64	-1.17	-34	-0.40	-0.91
-0.20	-0.68	-1.18	-33	-0.50	-0.94
-0.29	-0.72	-1.18	-32	-0.60	-0.97
-0.37	-0.76	-1.20	-31	-0.71	-1.00
-0.45	-0.81	-1.23	-30	-0.80	-1.05
-0.54	-0.86	-1.24	-29	-0.88	-1.08
-0.65	-0.93	-1.26	-28	-0.94	-1.12
-0.77	-1.02	-1.30	-27	-0.99	-1.18
-0.89	-1.12	-1.36	-26	-1.02	-1.24
-1.00	-1.23	-1.44	-25	-1.06	-1.33
-1.10	-1.34	-1.55	-24	-1.13	-1.43
-1.21	-1.48	-1.72	-23	-1.25	-1.58
-1.36	-1.65	-1.91	-22	-1.41	-1.76
-1.54	-1.82	-2.07	-21	-1.59	-1.93
-1.70	-1.96	-2.20	-20	-1.76	-2.07
-1.80	-2.02	-2.23	-19	-1.89	-2.12
-1.80	-2.02	-2.25	-18	-1.95	-2.14
-1.72	-1.97	-2.26	-17	-1.96	-2.13
-1.59	-1.89	-2.25	-16	-1.93	-2.10
-1.44	-1.79	-2.22	-15	-1.85	-2.04
-1.32	-1.63	-2.03	-14	-1.74	-1.87
-1.20	-1.39	-1.68	-13	-1.58	-1.58
-1.01	-0.97	-1.04	-12	-1.31	-1.06

-0.62	-0.35	-0.20	-11	-0.84	-0.33
0.04	0.40	0.64	-10	-0.14	0.46
0.98	1.40	1.65	-9	0.69	1.44
2.56	3.38	3.84	-8	1.88	3.43
5.62	7.51	8.61	-7	4.18	7.66
10.74	13.59	15.18	-6	8.39	13.76
16.80	19.26	20.28	-5	13.71	19.05
21.06	21.29	20.42	-4	17.88	20.31
21.31	18.96	16.14	-3	18.72	17.31
18.19	15.03	11.85	-2	16.55	13.43
14.32	11.50	8.85	-1	13.42	10.26
11.24	9.22	7.33	0	10.61	8.34
9.25	7.85	6.55	1	8.86	7.25
8.13	7.11	6.14	2	7.77	6.65
7.59	6.84	6.08	3	7.18	6.45
7.43	6.72	5.98	4	6.99	6.34
7.42	6.75	6.03	5	6.93	6.36
7.42	6.73	5.98	6	6.90	6.33
7.35	6.70	5.98	7	6.81	6.30
7.25	6.59	5.87	8	6.73	6.20
7.18	6.60	5.93	9	6.62	6.22
7.19	6.66	6.03	10	6.62	6.29
7.30	6.83	6.23	11	6.66	6.46
7.47	7.01	6.40	12	6.80	6.63
7.62	7.15	6.53	13	6.92	6.76
7.67	7.21	6.60	14	6.98	6.83
7.60	7.17	6.60	15	6.95	6.81
7.45	7.07	6.55	16	6.84	6.74
7.23	6.90	6.44	17	6.66	6.60
6.95	6.64	6.19	18	6.38	6.35
6.61	6.25	5.74	19	5.99	5.92
6.22	5.73	5.09	20	5.51	5.33
5.77	5.14	4.35	21	4.98	4.67
5.29	4.57	3.69	22	4.45	4.05
4.82	4.13	3.27	23	3.96	3.61
4.40	3.84	3.10	24	3.59	3.38
4.06	3.68	3.12	25	3.34	3.31
3.82	3.56	3.14	26	3.21	3.27
3.65	3.40	3.02	27	3.12	3.14
3.50	3.17	2.72	28	2.98	2.89
3.35	2.90	2.34	29	2.79	2.56
3.17	2.60	1.90	30	2.49	2.18

2.96	2.32	1.50	31	2.09	1.82
2.70	2.03	1.12	32	1.64	1.45
2.41	1.74	0.78	33	1.20	1.11
2.08	1.43	0.48	34	0.84	0.80
1.74	1.12	0.23	35	0.61	0.54
1.42	0.84	0.05	36	0.50	0.34
1.15	0.59	-0.10	37	0.48	0.18
0.95	0.38	-0.25	38	0.48	0.03
0.80	0.21	-0.39	39	0.47	-0.10
0.68	0.06	-0.54	40	0.42	-0.23
0.57	-0.08	-0.70	41	0.35	-0.37
0.45	-0.21	-0.82	42	0.26	-0.49
0.35	-0.35	-1.00	43	0.16	-0.65
0.25	-0.49	-1.18	44	0.04	-0.81
0.16	-0.63	-1.37	45	-0.09	-0.98
0.07	-0.75	-1.53	46	-0.23	-1.12
-0.03	-0.86	-1.67	47	-0.37	-1.25
-0.19	-0.93	-1.66	48	-0.52	-1.29
-0.36	-0.97	-1.58	49	-0.66	-1.27
-0.46	-0.98	-1.53	50	-0.80	-1.27
-0.44	-0.96	-1.55	51	-0.92	-1.29
-0.49	-0.92	-1.46	52	-1.02	-1.24
-0.64	-0.86	-1.20	53	-1.10	-1.09
-0.69	-0.81	-1.07	54	-1.16	-1.01
-0.74	-0.78	-0.97	55	-1.21	-0.95
-0.78	-0.78	-0.93	56	-1.24	-0.93
-0.81	-0.81	-0.97	57	-1.28	-0.97
-0.85	-0.87	-1.04	58	-1.31	-1.03
-0.90	-0.95	-1.14	59	-1.35	-1.12
-0.96	-1.05	-1.27	60	-1.39	-1.22



PERFORMANCE, COMBUSTION AND EMISSION CHARACTERISTICS OF COPPER OXIDE NANOPARTICLES ADDITIVES WITH PINE OIL – DIESEL BLEND ON SINGLE CYLINDER FOUR STROKE DIESEL ENGINE

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