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CuO Nanoparticle Integration for Optimized Combustion and Sustainable Utilization of Waste Plastic Methyl Ester

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ABSTRACT

This research analyzes the pyrolysis process which aims to convert waste plastics, primarily polypropylene, polystyrene, and high density polyethylene, to useful biofuels. During the process of controlled pyrolysis, using cokes and a silica catalyst, waste plastic is transformed into plastic oil. To enhance the fuel properties and the combustion efficiency, the research also focuses on the addition of copper oxide CuO nanoparticles to Waste Plastic Methyl Ester (WPME) blends. CuO is dispersed into the WPME blends using the ultrasonication process and the resultant fuel is subjected to a series of analyses. The combustion test has been performed on a Kirloskar vertical diesel engine to analyze engine performance and emissions for which it has been observed that the blends with WPME+CuO nanofillers has registered improvement in the combustion efficiency along with decrease in the emissions of a number of pollutants such as CO, HC, NOx, and smoke. The research confirms that waste plastic can successfully be used to produce biofuels and that CuO nanoparticles offer considerable improvement to the biofuel performance as well as catalytic properties in the biofuel. These findings improve the global status of the renewable energy sources and vicinity waste offer a more sustainable method of energy use.

Keywords: *CuO nanoparticles, Waste Plastic Methyl Ester, Combustion Enhancement, Emission Reduction, Renewable Energy Sustainability*

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1. INTRODUCTION

Diesel fuels are widely used in industries including automotive, agriculture, and power generation due to their high thermal efficiency and fuel economy. Finding alternative fuel sources is often a rewarding experience [1]. Modernization necessitates the use of plastics in everyday life; a majority of the instruments we use, such as water containers, disposable plastic tableware, plastic bottles, are made of plastic [2]. The use of plastics in social undertakings improves convenience and functionality, addressing elementary, secondary, and tertiary needs [3]. Over many years, there has been a constant improvement in both the chemistry of combustion and the product required by burning [4].

Because of its high oxygen content and renewable nature, biodiesel is often regarded as the best alternative fuel source for both fuel extender and fuel component [5]. In comparison to diesel fuel, biodiesel is less hazardous more environmentally friendly, and biodegradable [6]. Pure vegetable oil and agricultural feed stocks are used to make alternative fuel for compression ignition engines, such as biodiesel, which is used in place of regular diesel fuel [7]. Because of this, it is thought that the feed stocks from such renewable resources, such as agricultural waste and edible and non-edible organic oils, might completely replace diesel fuel in CI engines [8].

The need for sustainable energy sources around the world has spurred extensive study into innovative combustion methods and alternative fuels [9]. In this regard, waste plastics have become a viable feedstock for the generation of biofuels, providing a solution to the problems of waste management and energy sustainability [10]. For compression ignition (CI) engines, waste plastic methyl ester (WPME), which is produced by pyrolyzing waste plastics, offers a promising sustainable fuel alternative [11]. Considering its potential, WPME encounters obstacles concerning combustion efficiency, such as partial combustion, elevated emissions, and constraints on engine performance [12]. To overcome these obstacles, creative solutions are needed to increase WPME's combustion properties and compatibility with CI engines [13].

Recent developments in nanoparticles have created new opportunities to improve the characteristics of fuel and the efficiency of combustion [14]. Copper oxide (CuO) nanoparticles are one of these developments; they have been thoroughly researched as fuel additives to enhance combustion performance due to their exceptional catalytic qualities [15]. A comprehensive investigation of the literature indicates that there is an increasing number of research on the use of CuO nanoparticles as fuel additives in different types of alternative fuels such as edible and non-edible oil [16]. These investigations demonstrate how CuO nanoparticles can improve fuel atomization, enable quicker and more thorough burning, and lower the number of pollutants released while using traditional liquid fuels [17].

The study focuses on the production of waste plastic methyl ester (WPME), a biodiesel feedstock that has received limited attention. The aim is to further improve the fuel properties of WPME by blending it with CuO nano particles additives. The use of these additives recovers the pre-mixed combustion, leading to developed temperatures in the combustion chamber. Additionally, the higher surface area of symmetrical CuO nano particles increases thermal conductivity [18]. This article aims to analyze and investigate these effects of their respective names: B0, which is 100% pure diesel fuel, B20, which is 80% diesel and 20% WPME, B20 + 25 ppm CuO, B20 + 50 ppm CuO, B20 + 75 ppm CuO, and B20 with 100 ppm CuO. The concentrations of these additives are subject to change the performance characteristics and the emission of CI engines are enhanced when nano particles are added to advanced diesel fuel and/or biodiesel mixes, according to prior research. Specifically, this research set out to synthesize graphene oxide micro fuels. Afterwards, graphene oxide nano fuels were introduced to the biodiesel-diesel test fuel in increments of 25, 50, 75, and 100 ppm. The engine was run on pure diesel fuel (B0) and a binary mixture of diesel and waste plastic methyl ester (B20) in order to collect reference data. Nanoparticles of CuO added to WPME blends boost combustion efficiency, which in turn increases emissions of (CO), (HC), and smoke when contrasted with conventional diesel.

The remaining section of this work is formed like; Section 2 depicts the materials and methodology. The Experimental method is explained in Section 3 with its experimental results deliberated in Section 4 and finally Section 5 concludes the overall work.

2. MATERIALS AND METHODOLOGY

The waste plastic (PP, PS, and HDPE) that was collected from the local authority's disposal area was divided into tiny pieces during the research procedure, with sizes varying from 0.2 to 0.8 cm, as seen in figure 1.

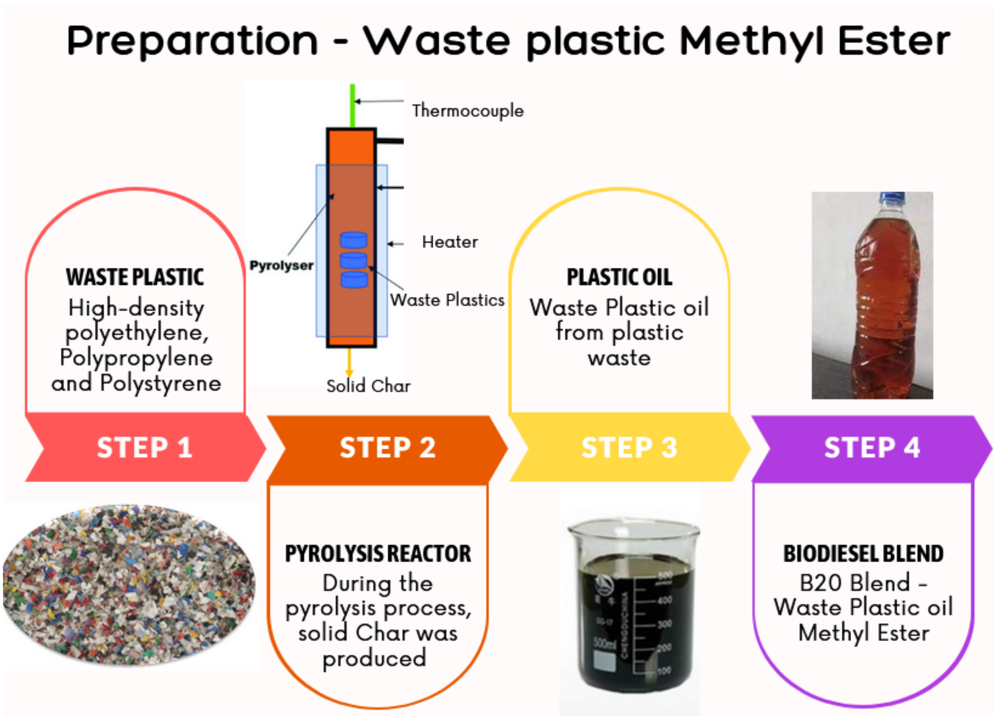


Figure 1. Preparation - Waste Plastic Methyl Ester

These chips of plastic were then thoroughly cleaned to get rid of any foreign materials, and they were left to air dry in the hot oven until all of the moisture had been gone. The procedure was conducted using a 60 cm diameter by 85 cm height reaction chamber. The total input feed consists of a combination of sized plastic chips, 10% weight-composition coke, and 1% weight-composition silica catalyst. The operating temperature throughout the reactor was consistently maintained between 350 and 475 degrees Celsius by using a temperature monitoring system. Five hours were spent conducting the reaction at atmospheric pressure. Gaseous fractionation were formed during the pyrolysis process, solid coke waste was generated at a rate of 10% by weight, and plastic oil was generated at a rate of 75% by weight of input. Propylene, isobutane, ethane, and methane are mixed in trace amounts (5% by weight) with these gaseous fractions [19].

The procedure's gaseous byproducts are processed by passing through the water chambers and being released into the surrounding atmosphere. In addition to processing the non-condensable products, this procedure turns the gaseous products into liquids. Most of the poisons either burn off or are decreased when there is no oxygen present. Another decrease takes place when a catalyst is present. The features that diesel and Waste Plastic Methyl Ester with CuO have are listed in Table 1.

Table 1. Properties - Diesel and Waste Plastic Methyl Ester/ CuO Nanoparticles

Properties	**Diesel**	**WPME**	**B20+25 (CuO) ppm**	**B20+50 (CuO) ppm**	**B20+75 (CuO) ppm**	**B20+100 (CuO) ppm**
Density at 40 °C (kg/m3)	833	890	891	893	895	899
Kine. Viscosity at 40 °C(cSt)	2.7	3.2	3.25	3.34	3.45	3.56
Cetane number	54	47	47.1	47.3	47.8	47.9
Flash Point(°C)	54	71	73	75	78	79
Fire point (°C)	48	44	44.3	44.7	45	45.2

2.1 Copper oxide nanoparticles

The vendor that supplied the copper oxide (CuO) nanoparticle was Aldrich, situated in Bangalore. The provider offered 99.9% pure black nanopowder. A snapshot of a CuO nanoparticle is shown in Figure 2. The size range of the nanoparticles was 30–40 nm. The cuO nano-additive was added, and the WPME20 test fuel's thermo-physical properties gradually improved. Using an accurate digital balance and the circumstances frame in the base fuel, which varied from 25, 50, 75 to 100 ppm, the concentration levels of copper oxide nanoparticles were established. Then, using an ultrasonicator, the (CuO) nanoparticles were dispersed at concentration levels of 25, 50, 75 and 100 ppm in the WPME20 fuel sample. A 200 W ultrasonicator operating at 40 kHz was utilized to produce an even distribution of CuO nanoparticles in WPME20 test fuel. The Ultrasonicator was agitated at 350 rpm and 75°C in temperature. The procedure was run for one and a half hours to guarantee proper dispersion. According to ASTM guidelines, the fuel characteristics of diesel, WPME20, WPME20CuO5. WPME20CuO50, WPME20CuO75 and WPME20CuO100 fuel samples were examined. The test fuels containing CuO nanoparticles had an improvement in density as a result of the nanoparticles' increased attentiveness in the biofuels.

The kinematic viscosity of the WPME20 incorrect fuel slightly improved when CuO Nanoparticles were added. The fire and flash point of the CuO nano concentration biodiesel blends were found to be lower with WPME20 fuel due to the enhanced O2 concentration of the CuO nanoparticles. The attributes of every test fuel sample are listed in Table 1. Characterization of CuO nanoparticles

The CuO nanoparticles were characterized using X-Ray diffraction (XRD) and scanning electron microscopy (SEM). CuO nanoparticles' typical particle size and shape as determined by SEM. A SEM image of CuO nanoparticles at 10,000 magnification is seen in Figure 3. CuO nanoparticles' phases and crystalline structure can be determined using XRD. CuO Nanoparticle phases and crystallite sizes can also be determined with XRD. Using an X-ray using a radiation source (=1.55 Ao) in the 200–1000 range, the XRD pattern of CuO nanoparticles was measured. The XRD spectra of CuO nanoparticles are shown in Figure 4 [20]. CuO Nanoparticles B0, which is 100% pure diesel fuel, B20, which is 80% diesel and 20% WPME, B20 + 25 ppm CuO, B20 + 50 ppm CuO, B20 + 75 ppm CuO, and B20 with 100 ppm CuO shown in figure 5.

Figure 2. Copper oxide nanoparticle reparation

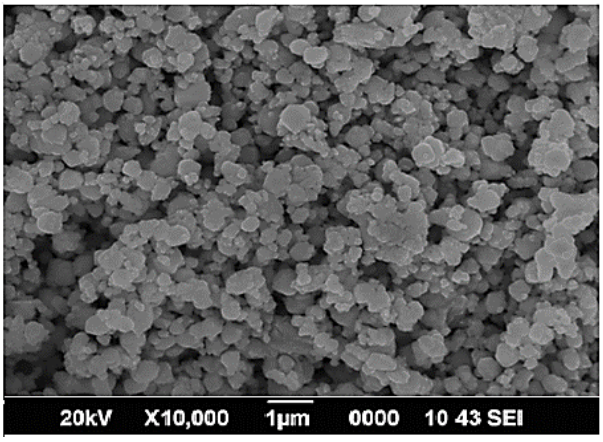


Figure 3.SEM image of copper oxide nanoparticles

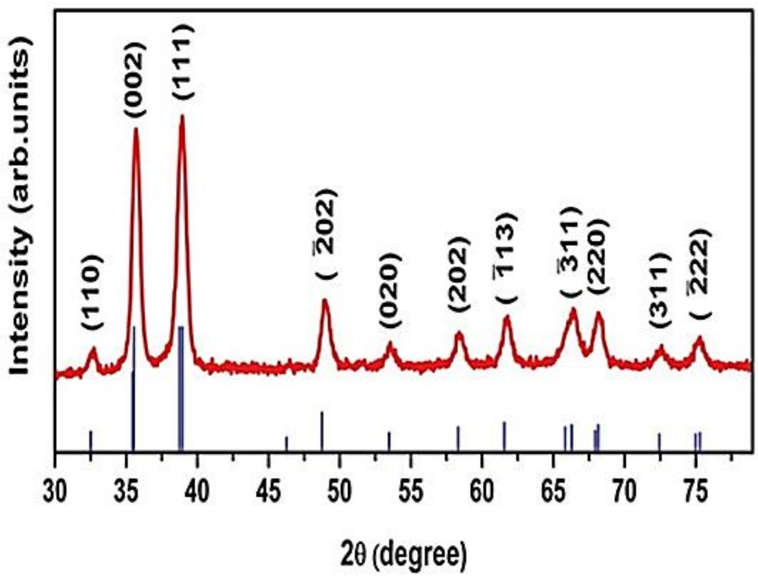


Figure 4.XRD image of copper oxide nanoparticles

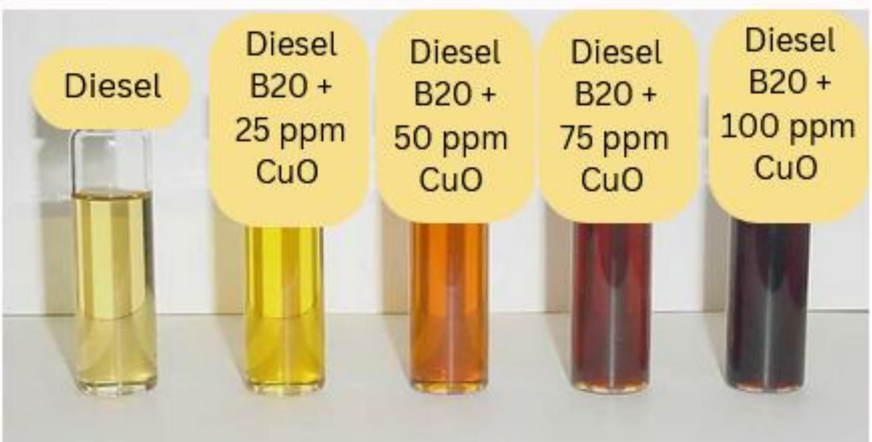


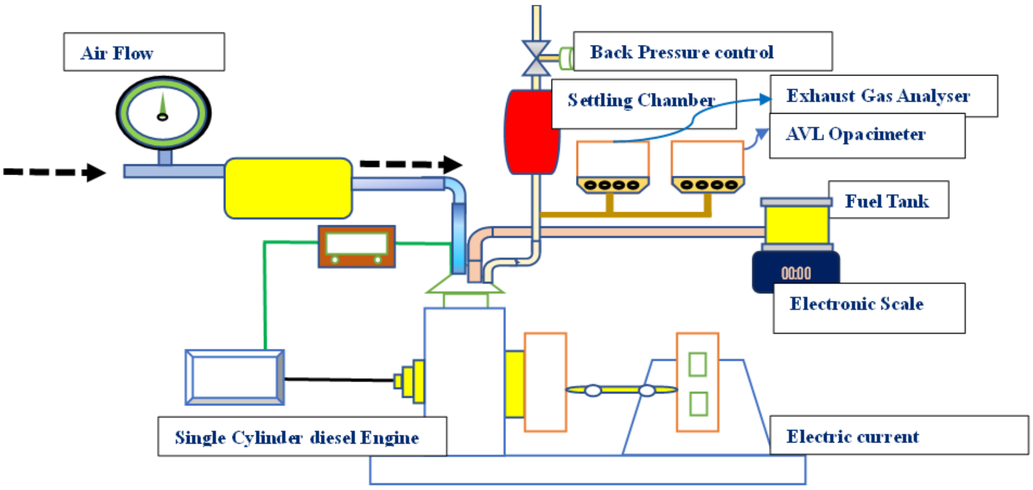
Figure 5. WPME blends containing different levels of CuO nano particles concentration

3. EXPERIMENTAL METHOD

The investigation used a Kirloskar vertical diesel engine. This engine was connected to an electromagnetic dynamo, allowing loads to be delivered at a variety of ranges. Figure 6 shows a schematic design that describes the arrangement of the testing engine. Two tanks of fuel will be required to accommodate both diesel and any additional test fuels. A pressure sensor was mounted to the top of the cylinder's head while data was being collected on the combustion process. To calculate the initial angle, a TDC decoder was used for measurement.

The density of smoke was determined using an AVL-437C smoke meter, and CO, HC, and NoX emissions were measured using an AVL-444 Di gas spectrometer [21]. After reaching a level of smooth functioning, the engine switched from diesel fuel to plastic oil. Prior to using LDPE plastic oil-diesel blends, the fuel tank was analyzed, followed by the engine. A calculation is performed using the approach to estimate the instruments' range, precision, and margins of uncertainty.

Figure 6.Experimental - Engine Setup



4. RESULTS AND DISCUSSIONS

4.1 Combustion Analysis

4.1.1 Cylinder Pressure Vs CA

In the initial phase of combustion, known as the pre-mixed stage, the maximum pressure exclusive of the cylinder of a diesel engine is precisely determined based on the proportion of gasoline that has been burned. The CuO, or gas opening, is governed by the crankshaft's angular position as it transitions from the compression stroke to the power stroke. The angle achieved is determined on the moment at which the CuO is calculated. Fuel consumption during uncontrolled combustion is directly related to the pressure generated by the engine's cylinders. Figure 7 illustrates the difference in crank angle for cylinder pressure when the load is at its highest. Integrating CuO into WPME increases the generation of oxygen and the concentration of cetane. Furthermore, the large ratio between volume and irregular outer zone causes an increase in cylinder pressure.

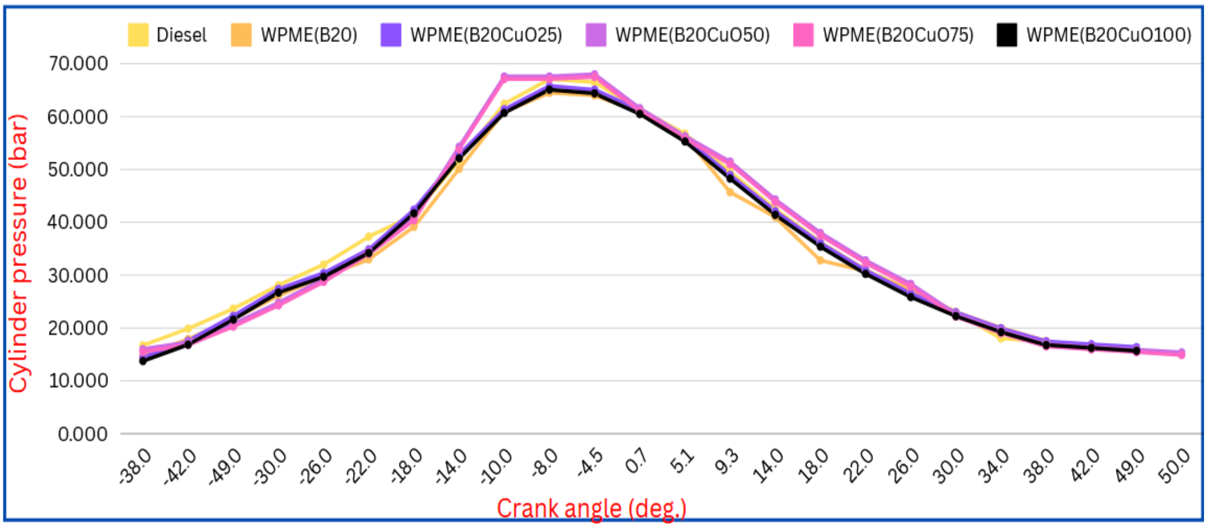


Figure 7. CP vs CA

4.1.2 Heat Release Rate vs CA

The WPME20 blend has a lower HRR than the other fuel blends due to its slower burning velocity and higher molecular weight. All nano fuel mixes have a greater high (HRR) due to their superior surface-to-volume ratio, increased ignition qualities, improved fuel characteristics, and improved heat transmission. Raising the maximum pressure causes an increase in the HRR. Figure 8 illustrates the difference in (HRR) at the maximum loading condition with regard to crank angle. The WPME (B20) had a lower HRR than diesel. Nonetheless, the addition of CuO caused a substantial increase in the HRR. The greater concentration level of WPME(B20CuO75) produced a comparable (HRR) to diesel due to improvements in the fuel's coefficient of variation (CV), a shorter ignition delay period, and a more effective catalytic action [22].

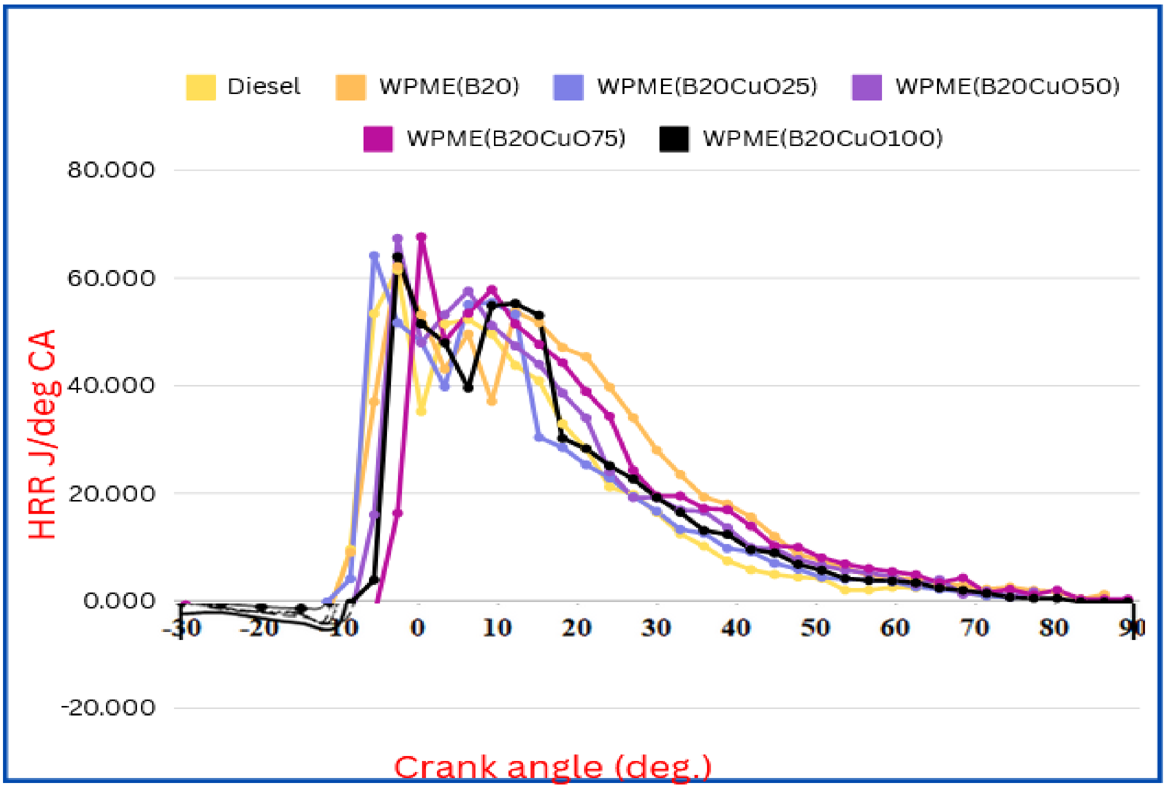


Figure 8. HRR vs CA

4.2 Performance Analysis

4.2.1 BTE vs BP

Figure 9 shows the fuel consumption statistics for diesel, WPME (B20), WPME (B20 CuO25), WPME (B20 CuO50), WPME (B20 CuO75), and WPME (B20 CuO100) blends at various BP values, as well as the change in BTE with percentage load. In compared to the previously discussed biodiesel fuel mixes, the oxides of carbon nanofuels make it easier to burn the fuel charge fully. The BTE increases as a result of graphene oxide's role as an oxygen buffer.

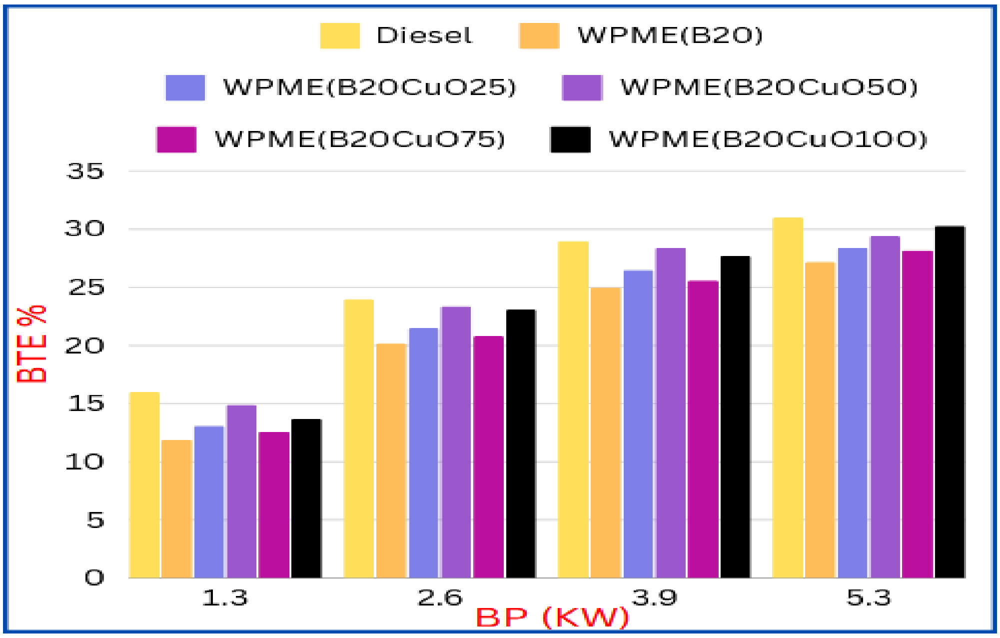


Figure 9. BTE vs BP

As a result, at maximum load, the BTE for WPME (B20) reduced by 7.5% as compared to diesel (i.e., the value for diesel at full load is 15.8%, but the value for WPME (B20) blending at full load is 11.9%. CuO concentrations increased with all circumstances at full load for WPME (B20 CuO25), WPME (B20 CuO50), WPME (B20 CuO75), and WPME (B20 CuO100), with values of 13.1%, 14.9%, 12.6%, and 13.7%, respectively. CuO increases fuel's BTE performance by lowering the (ID), accelerating the heat conversation process, and encouraging faster, better, and more complete combustion of fuel blends [23].

4.2.2 BSFC vs BP

Figure 10 illustrates the BSFC difference with percentage load and fuel consumption for diesel, WPME (B20), WPME (B20 CuO25), WPME (B20 CuO50), WPME (B20 CuO75), and WPME (B20 CuO100) blends at various BPs. As the load increases, the BSFC rises. As a result, at maximum load conditions, the BSFC for WPME (B20) increased by 9.1% compared to diesel. Specifically, while diesel has a value of 0.52 Kg/Kw-h at full load, the BSFC for WPME (B20) blended with diesel is 0.57 Kg/Kw-hour. With increasing doses of graphene oxide at full load, the values for WPME (B20 CuO25), WPME (B20 CuO50), WPME (B20 CuO75), and WPME (B20 CuO100) are 0.55 Kg/Kw-h, 0.53 Kg/Kw-h, 0.56 Kg/Kw-h, and 0.58 Kg/Kw-h, respectively.

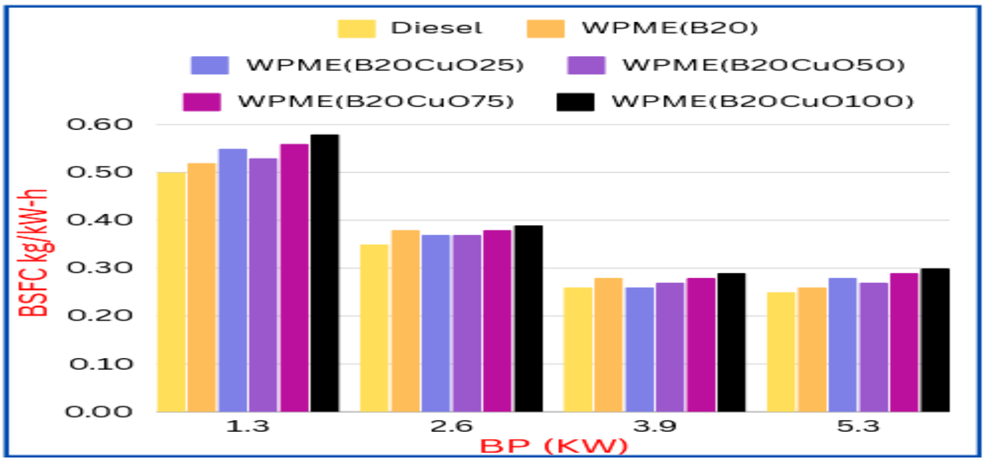


Figure 10.BSFC vs BP

The reason for this is the increased density and lower energy level of WPME blends when compared to pure diesel value. Furthermore, the high viscosity of WPME mixes prevents sufficient atomization of fuel dewdrops [24]. This, in turn, leads to higher fuel consumption during the diffusion stage, reducing combustion efficiency.

4.3 Emission Analysis

4.3.1 CO vs BP

The primary cause of CO emissions is a lack of oxygen in the combustion chamber, which inhibits the fuel from fully combusting. The severity of this problem is regulated by temperature and injection timings.

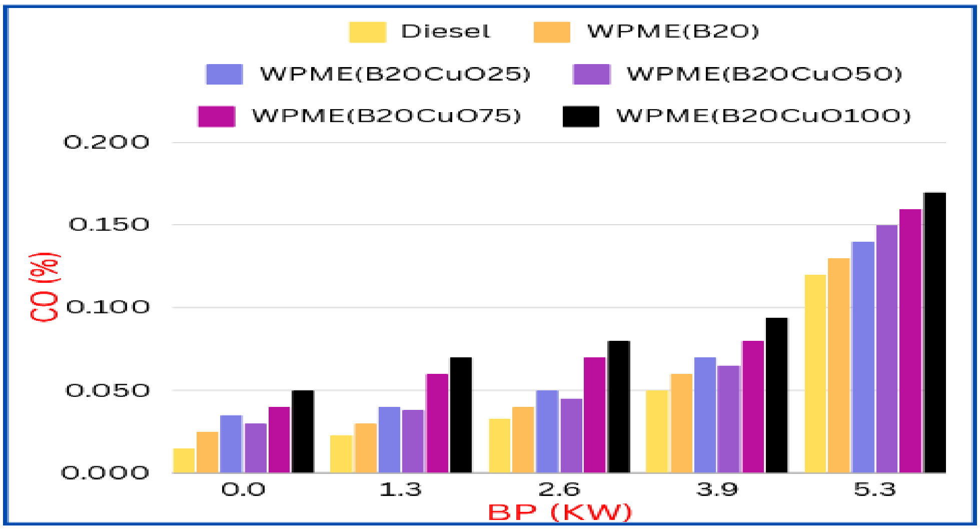


Figure 11. CO vs BP

Figure 11 illustrates the fuel usage for diesel, WPME (B20), WPME (B20 CuO25), WPME (B20 CuO50), WPME (B20 CuO75), and WPME (B20 CuO100) mixtures at different BPs, as well as the difference in CO emission with full load. CuO, an oxygenated additive, adds more oxygen atoms to the ignition chamber [25]. CuO nano fuels increase the fuel's calorific value, causing it to burn more quickly. As a result, at maximum load conditions, CO emissions from WPME (B20) were 9.2% higher than those from diesel. The values for WPME (B20 CuO25), WPME (B20 CuO50), WPME (B20 CuO275), and WPME (B20 CuO100) are 0.14%, 0.15%, 0.16%, and 0.17%, respectively, as the concentration of CuO increases under full load.

4.3.2 HC vs BP

When carbon particles ignite inside the combustion zone at the temperature of operation of the cylinder's inner wall, the energy that initiates combustion contained in CuO nano fuels in fuel blends raises the amount of hydrocarbon emissions for all nanofuel mixes. Figure 12 illustrates the fuel consumption for diesel, WPME (B20), WPME (B20 CuO25), WPME (B20 CuO50), WPME (B20 CuO75), and WPME (B20 CuO100) blends at various BPs, as well as the difference in HC emissions with full load.

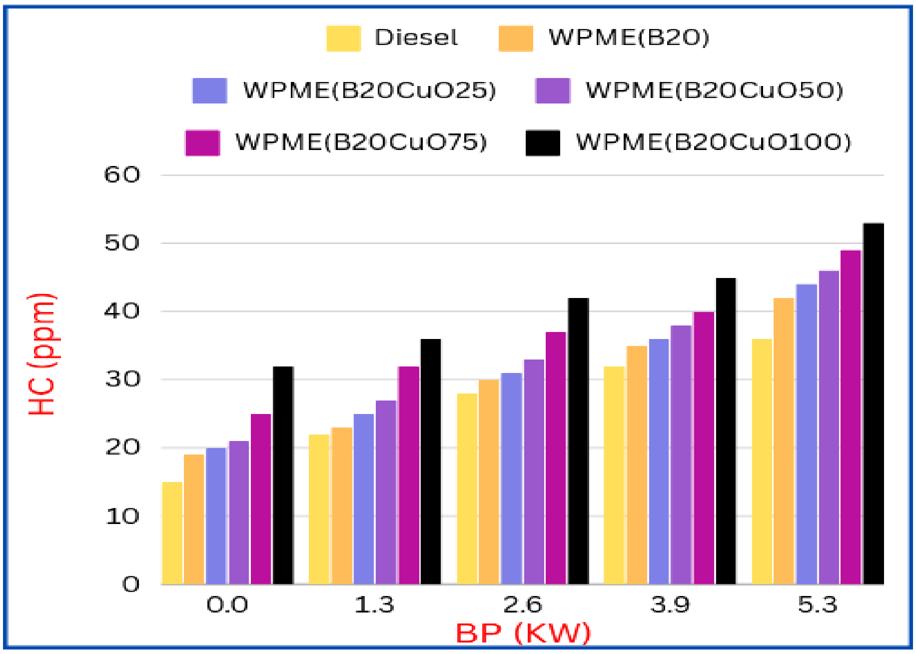


Figure 12.HC vs BP

Increasing the amount of CuO in WPME fuel blends resulted in a considerable reduction in hydrocarbon emissions; nevertheless, it increased HC emissions under all other conditions. As a result, at full load, the HC emission for WPME (B20) increased by 8.5% compared to diesel. The CuO dose was increased with all circumstances at full load for WPME (B20 CuO25), WPME (B20 CuO50), WPME (B20 CuO75), and WPME (B20 CuO100), resulting in 44ppm, 46ppm, 49ppm, and 53ppm, respectively.

4.3.3 NoX vs BP

According to prior research on the inclusion of nano fuel mixtures, a lack of oxygen determines the amount of nitrogen oxide emitted. There are essentially two strategies to reduce NoX emissions: lower the temperature of the DEE additive and the DME additive. Figure 13 illustrates the fuel consumption for diesel, WPME (B20), WPME (B20 CuO25), WPME (B20 CuO50), WPME (B20 CuO75), and WPME (B20 CuO100) blends at varying BPs, as well as the difference in NoX emissions with full load.

As a result, at full load, the NoX emission for WPME (B20) fell by 11.1% compared to diesel. The Concentration of graphene oxide was reduced with all conditions at full load for WPME (B20 CuO25) and WPME (B20 CuO50), with values of 160ppm and 140ppm, respectively, but the NoX emission increased as the GO increased at CuO75 and CuO100 (i.e., WPME (B20 CuO75) and WPME (B20 CuO100), with values of 252ppm and 294ppm. Another option is that the peak cylinder pressure rose, causing a considerable increase in NoX emissions. Because of the presence of butanol and a significant amount of oxygen-donating CuO, the nanofuel blend combination of CuO75 and CuO100 emits the most NoX.

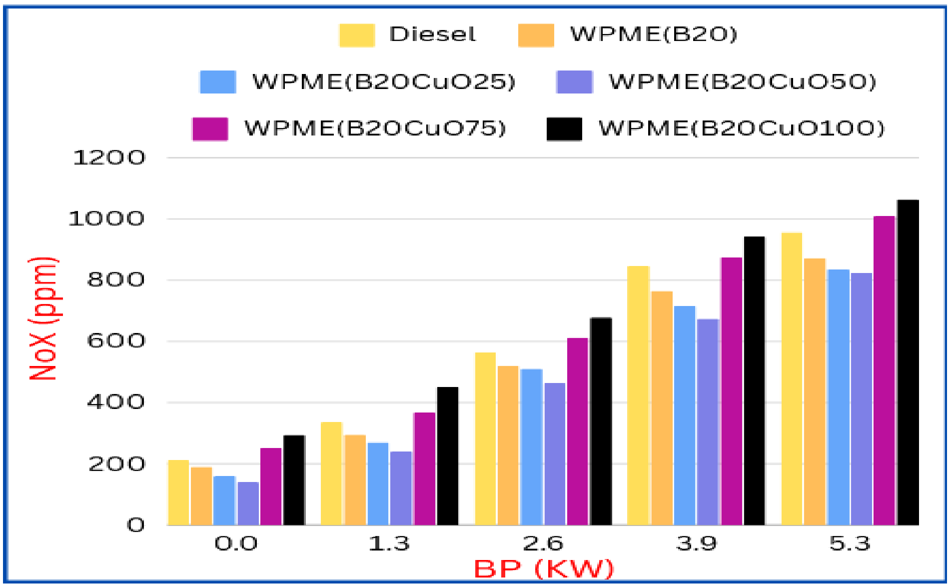


Figure 13.NoX vs BP

4.3.4 Smoke vs BP

Smoke usually originates in the fuel-rich zone; hence it is more likely to occur under full load. An increase in oxygen content in the WPME blend results in a decrease in smoke emissions. The CuO nano fuels act as oxygen donors, affecting the fuel's properties. Figure 14 depicts the fuel consumption for diesel, WPME (B20), WPME (B20 CuO25), WPME (B20 CuO50), WPME (B20 CuO75), and WPME (B20 CuO100) blends at various BPs, as well as the difference in smoke emissions with full load. As a result, at maximum load, the smoke emission for WPME (B20) rose by 8.8% compared to diesel (i.e., for diesel at full load, the value is 23%, but for WPME (B20) blending at full load, the value is 26% ppm. As the Concentration of CuO was increased with all conditions at full load for WPME (B20 CuO25), WPME (B20 CuO50), the value is 27% and 32%, but for WPME (B20 CuO75), and WPME (B20 CuO100), the emission is reduced to 30% and 28%, respectively, because the results show that the fuel is not completely burned under any loading conditions. Furthermore, the higher viscosity and density of CuO75 and CuO100 biodiesel nano fuels are responsible for the increase in smoke emissions that were detected in the use of nano fuels.

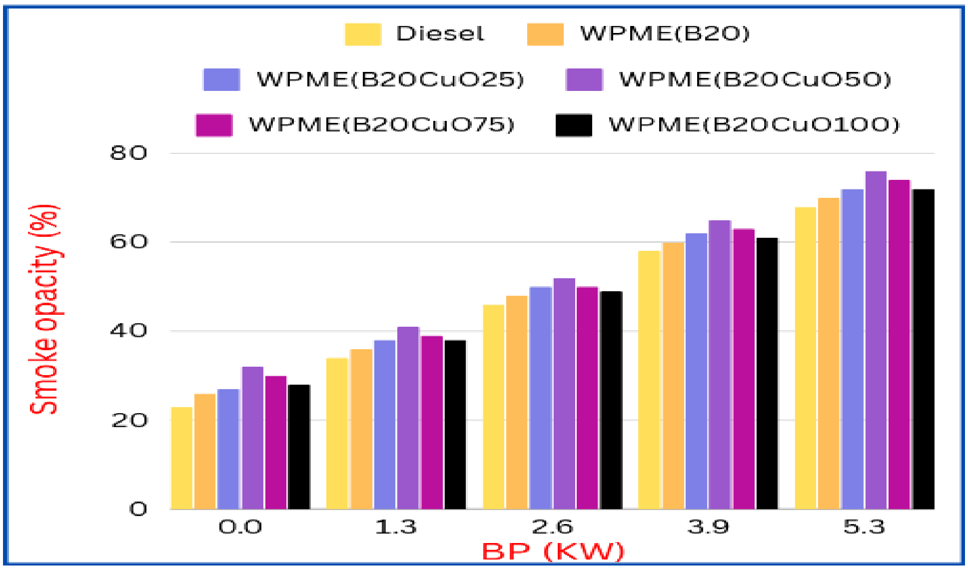


Figure 14. Smoke vs BP

5. CONCLUSION

The combination of CuO nano fuels into WMME biodiesel fuel blends has various effects on engine combustion, performance and emissions were concluded Addition CuO nanoparticles increases high-pressure combustion stage, leading to higher maximum pressure and heat release rate (HRR). WPME (B20 CuO75) and WPME (B20 CuO100) show comparable HRR to diesel due to improved fuel characteristics and quicker ignition delay duration. While WPME (B20) exhibits a slight decrease in (BTE) compared to diesel (11.9% vs. 15.8% at full load), CuO addition improves BTE. WPME (B20 CuO50) shows the highest BTE at full load (14.9%), indicating enhanced combustion efficiency. Addition of CuO reduces carbon monoxide (CO) and hydrocarbon (HC) emissions. At full load, WPME (B20) exhibits CO emissions of 0.13%, while WPME (B20 CuO100) shows 0.17%. HC emissions increase for WPME (B20), but decrease with CuO addition, with WPME (B20 CuO100) showing 53 ppm at full load.

NOx emissions decrease with WPME (B20) compared to diesel (190 ppm and 212 ppm at full load). However, NOx emissions increase with higher CuO concentration, with WPME (B20 CuO100) showing 294 ppm at full load. Smoke emissions increase with WPME (B20) compared to diesel (26% and 23% at full load). However, smoke emissions decrease with higher CuO concentration, with WPME (B20 CuO100) showing 28% at full load. Overall, the addition of CuO nano particles to WPME biodiesel blends improves combustion efficiency, enhances fuel economy, and reduces emissions. However, careful consideration of CuO dosage is necessary to balance emissions reduction with potential increases in NOx emissions...

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