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The Performance, Combustion and Emission Analysis of Ci Engine Fuelled with Waste Cooking Oil Biodiesel in Addition of Graphene Nanoparticles and Isopropanol

V. Bhargava Linga Raju[1], A. Vijin Prabhu[1]

[1] Department of Mechanical Engineering, GMRIT, Rajam 532127, Andhra Pradesh, India

Abstract

Increasing energy demand, higher oil prices, depleting oil reserves, and environmental pollution issues associated with the help of fossil fuels have renewed interest in developing clean alternative fuels. Nowadays, extensive research is in process to find an alternative fuel and improve its quality. Nanoparticles are a relatively new technology that can be used to improve the properties of fuel. In this research the performance, combustion and emission of CI Engine fueled with WCO Biodiesel in addition of graphene nanoparticles and isopropanol has been evaluated. The graphene nanoparticles with proportions varied from 25ppm, 50ppm and 75ppm were mixed into WCO Biodiesel 20% (B20) + Isopropanol 20% (ISO20) + Diesel 60% (D60) fuel blend. The fuel blends are Diesel, WCO Biodiesel 20% (B20), WCO Biodiesel 20% (B20) + Isopropanol 20% (ISO20) + Diesel 60%(D60), WCO Biodiesel 20%(B20) + Isopropanol 20%(ISO20) + Diesel 60%(D60) + Graphene nanoparticles 25ppm (G25), WCO Biodiesel 20%(B20) + Isopropanol 20%(ISO20) + Diesel 60%(D60) + Graphene nanoparticles 60ppm(G60), WCO Biodiesel 20%(B20) + Isopropanol 20%(ISO20) + Diesel 60%(D60) + Graphene nanoparticles 75ppm(G75). The experiment is conducted on four stroke single cylinder CI engine. Addition of Isopropanol into the WCO Biodiesel blend showed slightly higher BTHE compared B20. However, addition of Graphene nanoparticles showed not much improvement in BTHE. Addition of Graphene nanoparticles at 75ppm showed 0.21% reduced BSFC compared to B20 + ISO20 + D60. Addition of Graphene nanoparticles at 25 ppm and 75 ppm showed 6.43% and 8.7% increased HRR respectively when compared to diesel. Addition of Graphene nanoparticles at 75 ppm showed 2% increase in In-cylinder pressure compared to B20 + ISO20 + D60. Addition of Graphene nanoparticles at 75 ppm showed 2.9% and 1.58% reduced NO_X and smoke opacity emission compared to Diesel Biodiesel Isopropanol blend respectively. Addition of Graphene nanoparticles into Diesel Biodiesel Isopropanol blend showed optimized all over characteristics.

Keywords: waste cooking oil biodiesel, isopropanol, graphene nanoparticles, performance, combustion, emission

Nomenclature

ASTM	American society for testing and materials	NaOH	Sodium hydroxide
IC	Internal combustion	Al_2O_3	Aluminium oxide
DI	Direct injection	CeO_2	Cerium oxide
bTDC	Before Top Dead Centre	Tio_2	Titanium dioxide
CR	Compression ratio	GO	Graphene oxide
IT	Injection timing	BTHE	Brake thermal efficiency
IP	Injection pressure	BSFC	Brake specific fuel consumption
WCO	Waste cooking oil	EGT	Exhaust gas temperature
MOME	Mahua oil methyl ester	HRR	Heat release rate
FFA	Free fatty acids	CO	Carbon monoxide
DEE	Di-ethyl ether	HC	Hydrocarbon
H_2SO_4	Sulphuric acid	NO_x	Oxides of nitrogen
KOH	Potassium hydroxide	CO_2	Carbon dioxide
WCO	Waste cooking oil	WCOME	Waste cooking oil methyl ester
PPM	Parts per million	GNP	Graphene nanoparticle platelets
PM	Particular matter	MWCNT	Multi walled carbon nanotubes

HSD	High speed diesel	NPs	Nanoparticles

1.Introduction

In recent days, improved environmental issues, the depletion of petroleum assets, and a variety of socioeconomic factors have fueled research into the development of less expensive and more environmentally friendly alternative fuels derived from renewable resources. Many scientists have attempted to create diesel fuel from vegetable oil derivatives. Fatty acid esters (biodiesel) derived from the transesterification of vegetable oils have properties similar to petroleum-based totally diesel gasoline [1]. Biodiesel is appealing because it is highly biodegradable, has low toxicity, and can replace diesel in a wide range of applications, including boilers and internal combustion engines, without requiring major engine modifications or performance losses. Furthermore, when compared to regular diesel, biodiesel can reduce hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM) emissions while almost completely eliminating CO_2 emissions [2]. Furthermore, as global consumption of vegetable oils has increased over the last five years, the amount of WCO produced per year by any country is enormous. The huge number of vegetable oil is consumed in homes, restaurants, and fast-food establishments. In addition, the estimated WCO collected by various countries is as follows: Canada produces 120000–135000 tonnes per year, while the US and UK produce 0.6 million and 200,000 tonnes per year, respectively. Every year, 140 billion litres of WCO are produced in India. More than 60% of all WCO produced in the world is properly disposed of [3]. Several studies have been conducted in recent years on the production of biodiesel fuel from waste oils and the transesterification of waste cooking oils with methanol and KOH as catalysts. WFO (waste frying oil) with varying catalyst concentrations. They discovered that a catalyst/WFO ratio of 0.6 percent yields the highest methyl ester yield. Another study found that the optimum catalyst amount is about 0.5–0.6 g of catalyst per 100 g of plant oil triglyceride. Researchers created diesel-like fuel from waste engine oil for an internal combustion engine and investigated the fuel's effects on engine performance and exhaust emissions to evaluate waste engine oil. They concluded that the properties of diesel-like fuels were similar to those of petroleum-based diesel fuels and that they could be used as cost-effective fuels in internal combustion engines based on the results of the tests [4]. Despite having all of the benefits, biodiesel has some disadvantages. When used on a long-term basis, the higher viscosity and density of biodiesel cause injection problems. The increased NOx emissions caused by the use of biodiesel fuel is also a critical issue. It has been discovered that after-treatment methods for reducing NOx emissions have very limited commercial application. As a result, there is a need for supplementary fuels that can be mixed with biodiesel to improve the overall engine characteristics. In this regard, alcohol has been tried as a fuel additive or supplementary fuel, which provides more oxygen and increases the heat of evaporation of the fuel, lowering NOx and PM emissions [5].

Many researchers examined the biodiesel and its blends with alcohols as additives to study the engine characteristics. D.H. Q et al [6] studied biodiesel blend B50 with Methanol had two different proportions: 5% and 10%. The BDM5 and BDM10 have a high ability to eliminate smoke emissions. BDM5 and BDM10 have similar peak cylinder pressure and peak pressure rise rate, NOX and HC emissions, and CO emissions are reduced to BD50. Nadir Yilmaz et al [7] studied biodiesel blends with ethanol at four proportions: 3%, 5%, 15%, and 25%. Overall, alcohol blended fuels increased CO emissions, NOX and HC decreases compared to diesel fuel. Gokhan Tuccar et al [8] studied Microalgae biodiesel, diesel with butanol at D70B20But10 and D60B20But20, and MB-diesel blend D80B20 were all investigated. Exhaust emission values can be improved. Kamel Bencheikh et al [9] They studied the effects of biodiesel–diesel–propanol ternary blends. The addition of propanol to the biodiesel-diesel blend further increases its BSFC and BSEC and reduces CO, NOx, smoke and EGT. Yuvarajan Devarajan et al [10] studied mustard oil biodiesel with n-octanol at different blends: M100, M90O10, M80O20, and M70O30. The thermal efficiency of biodiesel and octanol blends is higher than that of biodiesel. Higher energy density and the oxidation effect of n-octanol improve fuel oxidation and reduce CO, HC, and NO_X emissions.

Many researchers examined the biodiesel and its blends with nanoparticles as additives to study the engine characteristics. Sumit Roy et al [11] studied Biodiesel with Al_2O_3 nanoparticles was studied at various proportions blends, diesel alumina blend, and biodiesel diesel blends proportions of 10%, 20%, 30%. When compared to biodiesel without these additives, the in-cylinder pressures increase, HC, CO, the opacity of their emission levels reduces. Addition of nanoparticles reduced NO_X and smoke opacity, reduction. Prabu and Anand [12] studied jatropha biodiesel with cerium and alumina nanoparticle blends at different proportions. For biodiesel and NPs test fuel, a reduction of NO, unburned HC, CO, and smoke opacity when compared to biodiesel. BTHE increases both the biodiesel and NPs test fuels compared to biodiesel. Nivin and Thangaraja [13] studied with fossil diesel, Karanja, and WCO biodiesel. The Nano additives with B20 blend at proportions of 20, 40, and 60 ppm. Overall improvement in performance and emission reduction is observed with 40 ppm and 60 ppm of NPs. The ignition delay and premixed burn fraction were reduced with the introduction NPs. Amith Kishore Pandian et al [14] studied mahua biodiesel with a Tio_2 nanoparticle blend at different proportions. Emissions for biodiesel are lower than for diesel. The emissions are Biodiesel and NPs blend, and biodiesel diesel blend at maximum braking power. NOx emissions, Ignition delay for biodiesel and NPs blends are significantly reduces. Ahmed I. EL-Seesy et al [15] studied non edible oil biodiesel with MWCNT at different proportions. B20 fuel blend were found lower Pmax, and a higher level of emissions. Addition of MWCNT with B20 showed higher peak pressure, shorter ignition delay. The nanoparticles dose level that improves the performance of the engine fuelled by biodiesel-diesel blended fuels.

According to a survey on the production of biodiesel from various resources, the feedstock alone accounts for nearly 75% of the total cost of production of biodiesel. As a result, lower-cost raw materials are required to reduce the cost of biodiesel. Furthermore, waste cooking oil causes many disposal issues all over the world by polluting river water, clogging drainage, and so on. Thus, producing biodiesel from waste cooking oil is one of the better ways to use it efficiently and economically while avoiding disposal issues. Because of their oxygenating properties and environmental factors, alcohols are used as one of the substituents in high-performance blends. According to reports, lower alcohols such as methanol (CH_3OH) and ethanol (C_2H_5OH) are unsatisfactory due to their poor fuel properties. Researchers are now concentrating their efforts on higher alcohols such as propanol, butanol, and pentanol, which have long carbon chains, a high heat of evaporation, and a high cetane number. Many researchers are conducting experiments on biodiesels by adding additives such as metal and metal oxide nanoparticles and liquids (methanol, ethanol). Recent advances in materials science have resulted in exciting potentials for the development of propulsion fuels. Nano particles, nanotubes, graphene, and reactive nanocomposite powders are among them. According to this viewpoint, nanoparticles are added to base fuel because of their remarkable properties such as thermal properties, mechanical properties, specific surface area, magnetic, electric properties, optical properties, reactivity, high surface to volume ratios, and energy densities. Graphene has piqued the interest of researchers due to its intriguing mechanical, electrochemical, and electronic properties. Waste cooking oil biodiesel was considered as an alternative fuel in this experiment. 20% of isopropanol and 20% of waste cooking oil biodiesel were added to diesel to form a fuel blend. The addition of graphene nanoparticle into the WCO biodiesel-isopropanol fuel blend has not been studied. The effect of graphene nanoparticles in WCO biodiesel-isopropanol on the performance combustion and emission characteristics of ci engine has been studied in this research.

2.Materials and Methods

2.1 Materials

2.1.1 Waste Cooking Oil Biodiesel

Cooking oil that has oxidized at high temperatures and is re-used is hazardous to one's health. Essentially, the frying process can be defined as foodstuff in hot oil. This process occurs at temperatures ranging from 170 to 1900 degrees Celsius and involves the transfer of heat and mass. Water is separated from fat and absorbed by fatty food while heat is transferred from oil to food. It is estimated that approximately 35,104- 45,104 tons of waste cooking oil is produced as a result of the oil refining process and consumption of obtained oil. Spilled waste oils cause collector system clogging, groundwater pollution, domestic waste water pollution, and raise the cost of treatment processes. For these reasons, assessing vegetable waste in biodiesel production is critical for environmental pollution prevention, human health, and the national economy. [25]. Biodiesel is produced from vegetable oils, yellow grease, waste cooking oil, or animal fats. The fuel is produced by transesterification a process that converts fats and oils into biodiesel and glycerine. Commercially available waste cooking oil biodiesel was purchased.

2.1.2 Isopropanol

Propanol is a three-carbon alcohol with the molecular formula (C_3H_8O) and a molecular weight of 32.04. It has no color and is flammable. Propanol is classified into two isomers: 1-propanol (also known as n-propanol) and 2-propanol (also known as isopropanol/isopropyl alcohol). The most cost-effective method of producing propanol from petrochemicals is isomeric. The high cost of producing propanol has been identified as the primary reason that propanol cannot be used in internal combustion engines. However, the superior fuel properties of propanol over ethanol and methanol, such as higher density, CN, KV, flash point, as well as lower auto-ignition temperature and latent heat of evaporation, prompted research into propanol in CI engines. [24]. For this work, commercially available Isopropanol were purchased from sree Lakshmi scientific enterprises, Visakhapatnam. The specifications of Isopropanol used in the study are given in Table 1.

Table 1 Specifications of Isopropanol

Specifications	Unit	Standards	Results
Description: clear colorless liquid (< 10 hazen) (characteristic odor) (compare odor against standard)		Should comply	Complies
Solubility: miscible with water forming clear Colorless solution		Should comply	Complies
Acidity (in ml n/1)	%	0.05 max	<0.050
Aldehydes & ketones [$(CH_3)_2CO$] (by g.c.)	%	0.05 max	<0.050
Assay (by g.c.)	%	99	99.9
Non-volatile matter	%	0.01 max	0.0008

Water (by k.f.)	%	0.1 max	0.06
Weight per ml (at 25°c) (in gm/ml)		0.783 - 0.787	0.7850

2.1.3 Graphene nanoparticles

Table 2. Specifications of Graphene Nanoparticles

Graphene, a single atomic layer of SP2-bonded carbon atoms tightly packed in a two-dimensional (2D) honeycomb lattice, has stimulated the scientific community's interest. Graphene, as a novel nanomaterial, has distinct electronic, optical, thermal, and mechanical properties. Graphene is an enthralling substance. It has a large theoretical specific surface area, high intrinsic mobility, high young's modulus, and thermal conductivity, and its optical transmittance and good electrical conductivity merit attention for applications such as transparent conductive electrodes, among many others. [16]. For this work, commercially available graphene nanoparticles were purchased from nano research lab, Jharkhand. The specifications of graphene nanoparticles used in the study are given in Table 2.

Table 2. Specifications of Graphene Nanoparticles

Nanoparticle	Graphene nanoparticles
Cas number	1034343-98-0
Molecular formula	C
Specification’s purity	98-99%
Diameter average X & Y dimension	5-10 um
Thickness average Z dimension	3-6 nm
Average number of layers	3-6 layers
SSA	210-300 m^2/g
State	Amorphous powder
Colour	Black
Bulk density	0.241 g/cc
Molecular weight	12.01 g/mol
Morphology	Flaky

2.2 Sample preparation

In this current study, the materials used to prepare the test samples were diesel/WCO biodiesel blend, diesel/WCO biodiesel/isopropanol blend, and three different proportions of graphene nanoparticles in the diesel/biodiesel/isopropanol fuel blend. The proportions of graphene nanoparticles in the fuel blend were 25, 50, and 75 ppm. Twenty percent by volume of WCO biodiesel was added to diesel to form the B20 fuel blend. Twenty percent by volume isopropanol was added to the diesel/WCO biodiesel blend (B20) to form the B20+ISO20 fuel blend. Three more samples of B20+ISO20+D60 with different concentrations of graphene nanoparticles in it (25, 50, and 75 ppm) were prepared by continuously stirring for twenty minutes on a hot plate with magnetic stirrer [28].

2.3 Experiment setup and procedure

The experimental setup is illustrated schematically in Figure 1. The diesel engine is a single-cylinder, four-stroke, naturally aspirated compression ignition engine with a 200-bar injection pressure, a speed of 1500 RPM, and a compression ratio of 17.5:1. An eddy current dynamometer is used for loading. K-type thermocouple sensors are used to measure the temperatures of the coolant and exhaust gases. Roto meters are used to measure the flow rates of engine cooling water and calorimeter water. Pressure sensors are used to record changes in pressure. The system is linked to a computer, which receives signals and produces pressure-crank angle plots. The engine specifications are shown in the table 3. A fuel line connects to a This burette is where the fuel passes and the fuel flow rate is measured. An AVL Digas 444 gas analyser is used to measure engine exhaust gas emissions, and an AVL 437C smoke meter is used to measure smoke opacity. At first, the engine runs on B20 WCO biodiesel with the rated injection. To obtain the baseline data, the engine is run at a pressure of 200 bar under loading conditions of 25, 50, 75, and 100 percent of full load. Once the engine has reached steady state, the fuel consumption rate, percentage of applied load, and engine speed are recorded. These values are used to calculate performance parameters such as brake power (BP), brake thermal efficiency (BTE), and brake system fluid capacity (BSFC). During the experiments, CO, NOx, CO2, and HC emissions are measured with an AVL Digas 444. The smoke opacity and exhaust gas analysis were measured using an AVL 437C smoke meter. The blend of WCO biodiesel isopropanol and graphene nanoparticles was created. The engine is then started, and once it has reached steady-state conditions, the previously noted performance parameters and emissions are measured. Similarly, all of the experiments are repeated with different fuel samples [5].

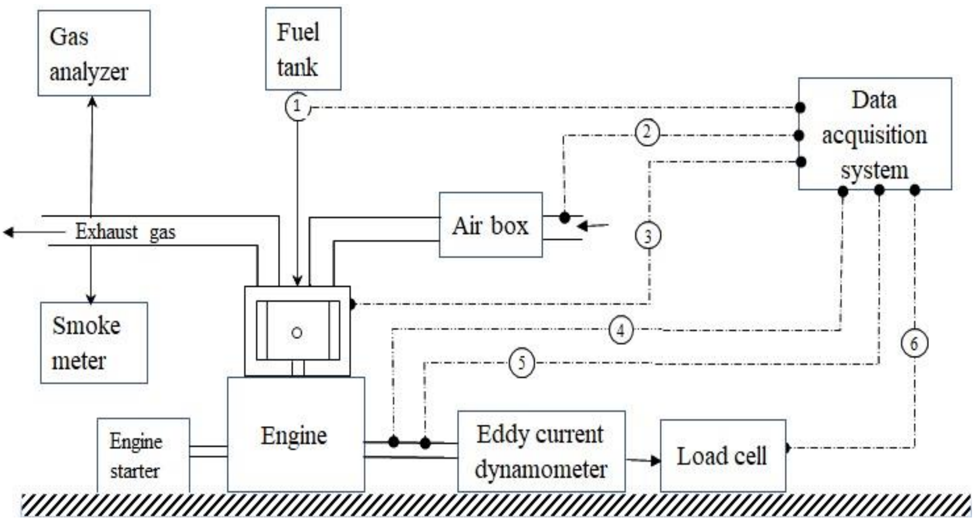

Fig1 Line diagram of CI Engine

The following shown in line diagram of IC Engine

1. Fuel flow sensor
2. Air flow sensor
3. Pressure sensor
4. Speed sensor
5. Crank angle encoder
6. Load sensor

Table 3. Specifications of IC Engine

Parameter	specifications
Manufactured by	Kirloskar
Engine type	4 stroke direct injection diesel engine
No of cylinders	1
Bore	87.5 mm
Orifice diameter	17 mm
Type of cooling	Water cooled
Speed	1500 rpm
Power	5.2 kw
Compression ratio	17.5: 1
Stroke	110 mm

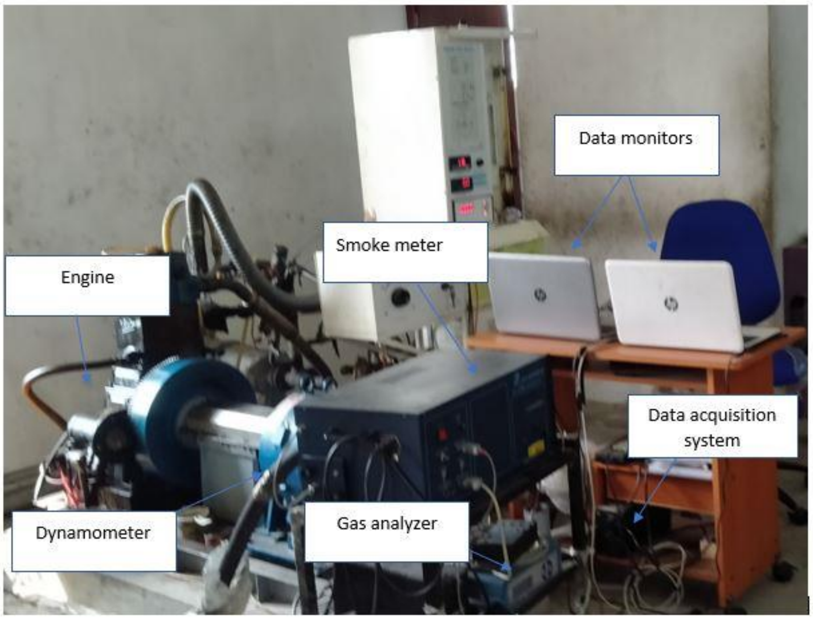

Fig 2. Photograph of CI Engine

2.4 Analytical method of sample fuels

Standard methods were used to determine the physical and chemical properties of biodiesel, which are shown in Table. The following test methods were used to analyse the properties of biodiesel and blends. Biodiesel's density is an important property. The density of any liquid at a given temperature is defined as its mass per unit volume. A hydrometer was used to measure density at a temperature of 312 K. The flash point temperature of biodiesel fuel is the lowest temperature at which the fuel will ignite when an ignition source is applied. The flash point varies with the volatility of the fuel. The fire point is the lowest temperature at which a sample will burn for 5 seconds. The flash points of the samples were determined using an automated Pensky–Martens closed-cup apparatus at temperatures ranging from 50 to 1900 degrees Celsius. The calorific value of a fuel is the amount of thermal energy released per unit amount of fuel when the fuel is completely burned and the combustion products are cooled back to the initial temperature of the combustible mixture. It determines the amount of energy in a fuel. The calorific value of biodiesel and its blends was determined using an ASTM D240 bomb calorimeter. The viscosity of oil is a measurement of its internal fluid friction to flow, which tends to resist any dynamic change in fluid motion. The Redwood Viscometer is used to measure viscosity. The Redwood viscosity value is the time it takes for 50 mL of oil to flow out of a standard Viscometer at a specific temperature. [21].

Table 4. Characteristics of Sample fuels

Characteristics	DIESEL	B20	B20 ISO20 D60	B20 ISO20 D60 (Graphene 25ppm)	B20 ISO20 D60 (Graphene 50ppm)	B20 ISO20 D60 (Graphene 75ppm)
Kinematic Viscosity @40°C in cst	2.54	2.36	2.26	2.16	2.14	2.15
Flash point °C	42	47	30	31	30	30
Fire point °C	48	56	32	33	33	34
Gross calorific value kj/kg	42500	41424.3	39004.52	39116.61	39173.34	39227.26
Density in kg/m^3	840	850	833	834	835	836

3.Result and discussion

3.1 Performance Analysis

3.1.1 Brake thermal efficiency:

The fluctuation of BTHE with various loads of diesel, waste cooking oil B20 and graphene nanoparticles fuel blends depicts in Fig 3. BTHE improved as load increased for all fuels. The results reveal that the BTHE of all fuel samples was inferior to the diesel at every load condition. The addition of isopropanol increases brake thermal efficiency compared to B20. The increase in the composition of graphene nanoparticles in the fuel blend showed decreasing brake thermal efficiency. The brake thermal efficiency of all the fuel samples indicated lower brake thermal efficiency compared to diesel. At full load, the brake thermal efficiency values for D100, B20, B20+ISO20+D60, B20+ISO20+D60+G25, B20+ISO20+D60+G50, and B20+ISO20+D60+G75 are 33.61, 31.35, 32.67, 32.58, 32.43, and 32.28%, respectively. BTHE was 4.2% higher in B20+ISO20+D60 than in B20 and 2.7% lower in diesel. The BTHE for WCO biodiesel is lower compared to diesel. Because of its lower volatility, increased viscosity, and lower calorific value When compared to the WCO biodiesel operation, the BTHE of the WCO biodiesel-GRAPHENE blended fuels is improved. This is primarily due to WCO biodiesel-graphene nanoparticles' improved combustion properties [2]. The 75PPM (B20+ISO20+D60+G75) dosage levels and reduced BTHE could be attributed to an increase in fuel viscosity caused by the increased dosage level of graphene nanoparticles, resulting in poor atomization of fuel droplets and increased fuel consumption and a lower BTHE [16].

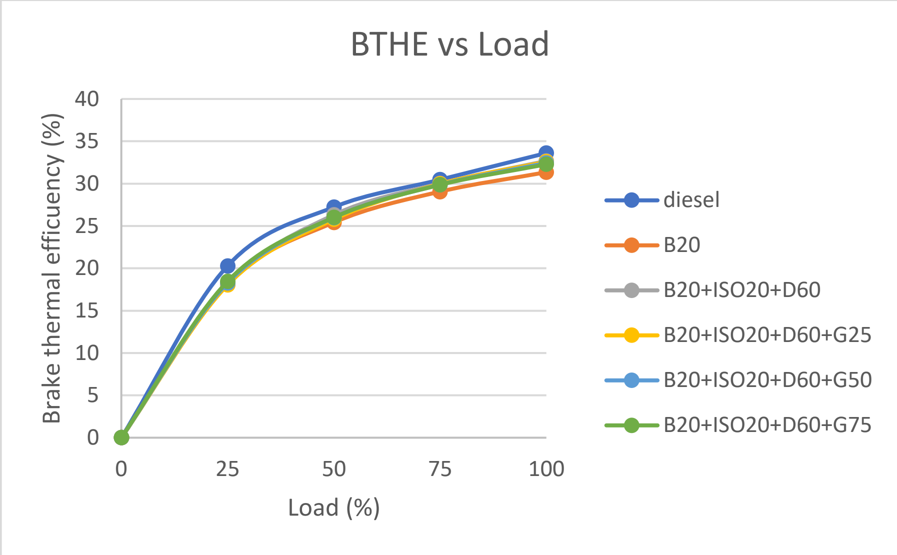

Fig 3. BTHE vs load

3.1.2 Brake specific fuel consumption

The load increases showed BSFC decreases. The addition of graphene nanoparticles reduces BSFC compared to B20+ISO20+D60. All the fuel blends have higher BSFC compared to diesel.

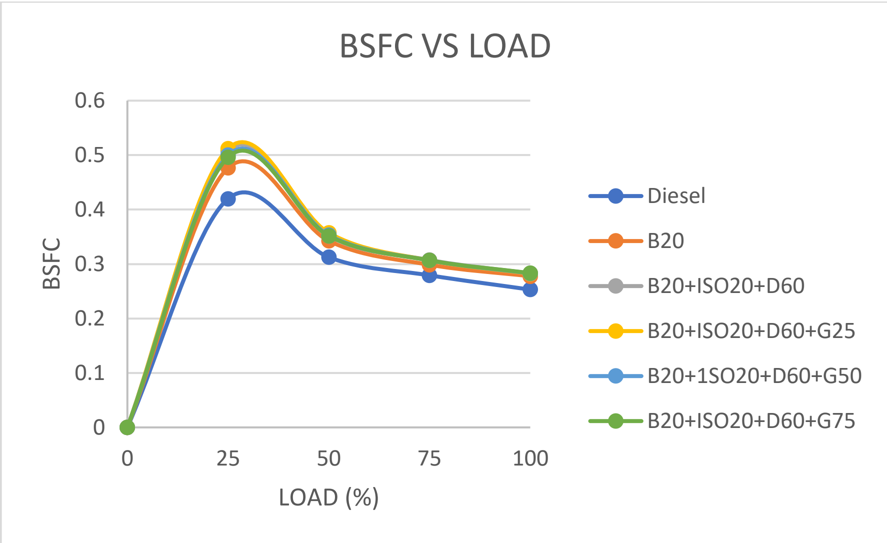

Fig 4. BSFC vs load

The BSFC of the B20+ISO20+D60 is higher than that of the B20.The B20+ISO20+D60+G25 had a lower BSFC than the B20+ISO20+D60. This could be due to the inclusion of GRAPHENE nanoparticles in the blends. It increases the calorific value and density. Furthermore, blends have a higher surface-to-volume ratio for improved catalytic effect, and less fuel is consumed per unit volume of fuel during the combustion process [2]. B20+ISO20+D60 has a higher BSFC than diesel fuel. This could be due to the high oxygen content of waste cooking oil, biodiesel, and isopropanol. The presence of oxygen in the fuel improves combustion but decreases calorific value [3].

3.2 Combustion Analysis

3.2.1 In-Cylinder pressure

Cylinder pressure monitoring is the most effective tool for analyzing the combustion process. Fig. 5 indicates the effect of cylinder pressure with crank angle at full load for diesel, B20, B20+ISO20+D60, and B20+ISO20+D60 with nanoparticles at different dose rates of 25 to 75 ppm. The load increases In-cylinder pressure of the tested fuel sample also increased. The addition of graphene nanoparticles into the biodiesel fuel blend indicated less in-cylinder pressure compared to B20. The addition of graphene nanoparticles at 75ppm into the biodiesel-isopropanol fuel blend showed a 2% higher in-cylinder pressure. However, diesel had a higher in-cylinder pressure compared to other fuel samples.

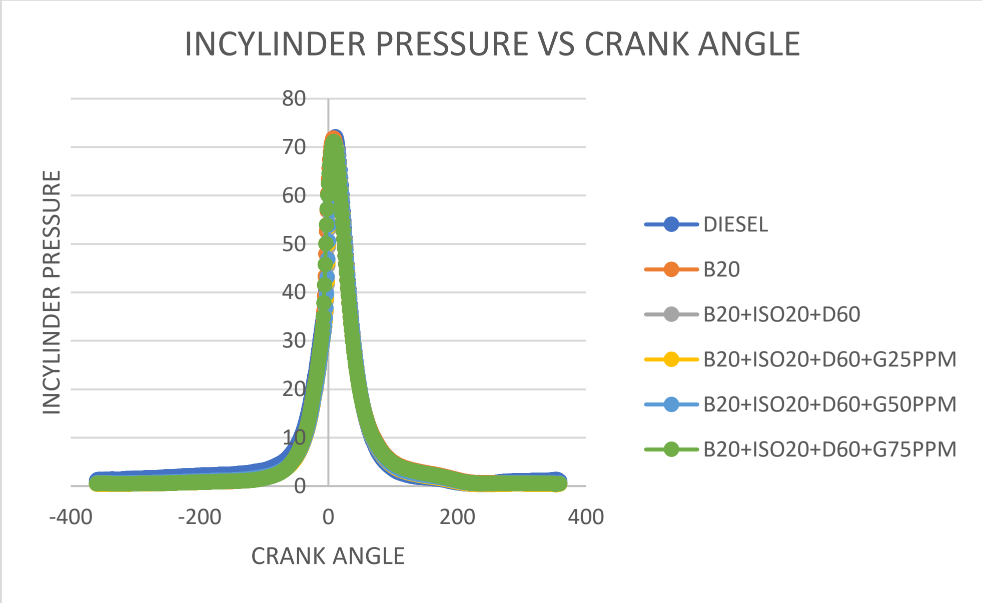

Fig 5. In-Cylinder pressure vs crank angle at full load

The load increases the in-cylinder pressure and the crank angle also increases. The B20 is higher than the diesel, which showed 0.57% at 75% load. Addition of graphene nanoparticles at 25ppm, 50ppm, and 75ppm showed 69.94%, 69.71%, and 71.14%. The addition of the isopropanol biodiesel blend showed a 69.75. The highest peak pressure was at 75ppm compared to B20+ISO20+D60. This could be due to the high rate of convective heat transfer coefficient [16]. Higher concentrations of graphene nanoparticles in fuel aid in the mixing of air and fuel, and their higher thermal conductivity allows for faster heat transfer through fuel molecules. During combustion, the fuel drops became superheated, igniting the graphene nanoparticles found in the fuel form layers, resulting in micro-explosions. Furthermore, the presence of graphene nanoparticles in isopropanol biodiesel fuel blends improves the premixed combustion phase and shortens the diffusion combustion phase [22].

3.2.2 Heat release rate

The pace at which the chemical energy of the fuel is liberated by the combustion is referred to as the heat release rate. The combustion process of a DI diesel engine is divided into two phases: premixed and diffusion. The rate of heat emission is estimated by using the first rule of thermodynamics. Fig. 6 depicts the variation in heat release rate of diesel, B20, B20+ISO20+D60, and B20+ISO20+D60 with nanoparticles at full load. When compared to diesel, the B20 performed better. The addition of graphene nanoparticles showed a higher heat release rate compared to diesel. Because of the longer ignition delay, diesel isopropanol blends have higher premixed combustion phase (PCP) levels. The premixed combustion phase (PCP) is determined by the cylinder temperature, the time of fuel-air mixing, and the fuel properties. There is a noticeable shift in HRR away from the Top Dead Center at the final phases of combustion (TDC).

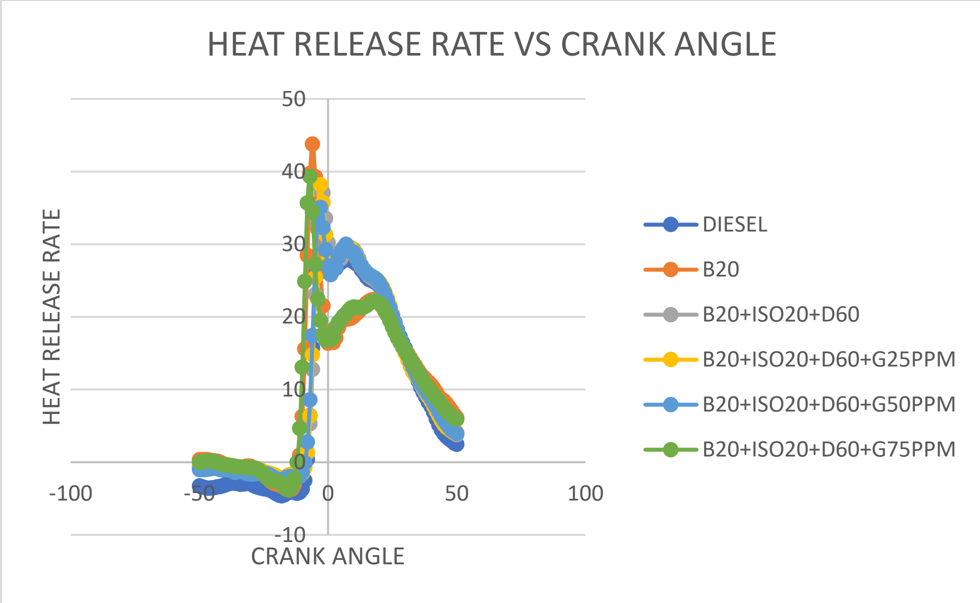

Fig 6. Heat release rate vs crank angle at full load

The increased premixed combustion phase (PCP) values of isopropanol-diesel blends are due to a longer delay period, which promotes better fuel-air mixing rates [3]. In the case of propanol-biodiesel-diesel blends, it is dependent on the biodiesel's ability to form a better air–fuel mixture in order to produce a higher HRR than pure biodiesel [9].

3.3 Emission Analysis

3.3.1 Carbon monoxide (CO)

CO is a hazardous derivative of incomplete hydrocarbon combustion. Fig. 7 depicts the fluctuation of CO with load. The addition of graphene nanoparticles showed higher co showed 36.72% compared to diesel. The B20+ISO20+D60 showed higher CO when compared to diesel. It has been observed that as the load increases, so does the CO emissions. This is due to the fact that the fuel becomes richer as the air–fuel ratio decreases with increasing load [16].

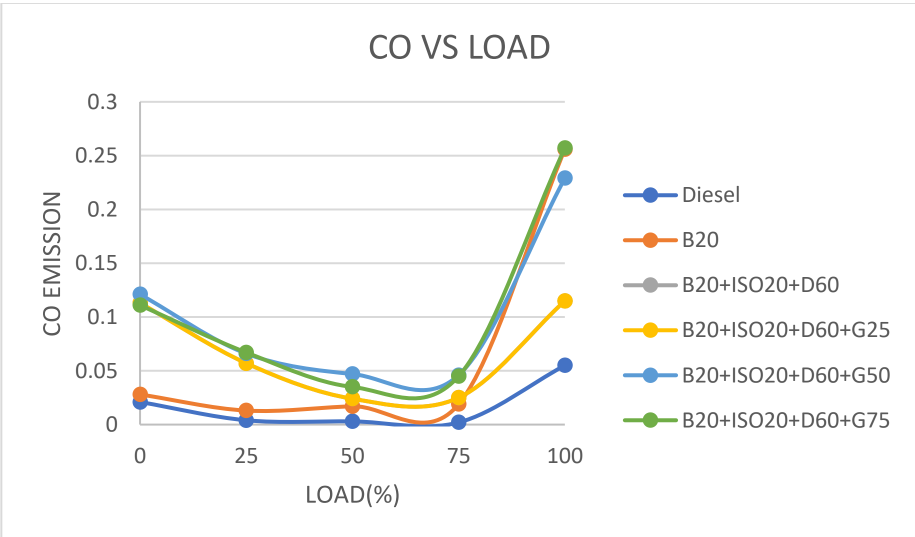

Fig 7. CO vs load

The addition of 50 ppm graphene nanoparticles reduced the B20 and B20+ISO20+D60. Some carbon is converted to CO as a result of improper combustion. The oxygen content of biodiesel, on the other hand, assists in better oxidation during combustion. The addition of graphene nanoparticles reduces

CO emissions even more. This could be attributed to better atomization as a result of the extra surface energy of graphene nanoparticles [22].

3.3.2 Hydrocarbon (HC)

Hydrocarbon (HC) measurement directly reveals incomplete combustion of fuel molecules. Fig 8. indicates the effect of HC with load. The B20+ISO20+D60 combination reduces HC emission compared to the addition of graphene nanoparticles. The B20 showed reduced HC emissions compared to the B20+ISO20+D60. Because of the catalytic activity and improved combustion characteristics of graphene nanoparticles, HC emissions gradually decrease with the addition of graphene nanoparticles to waste cooking oil biodiesel.

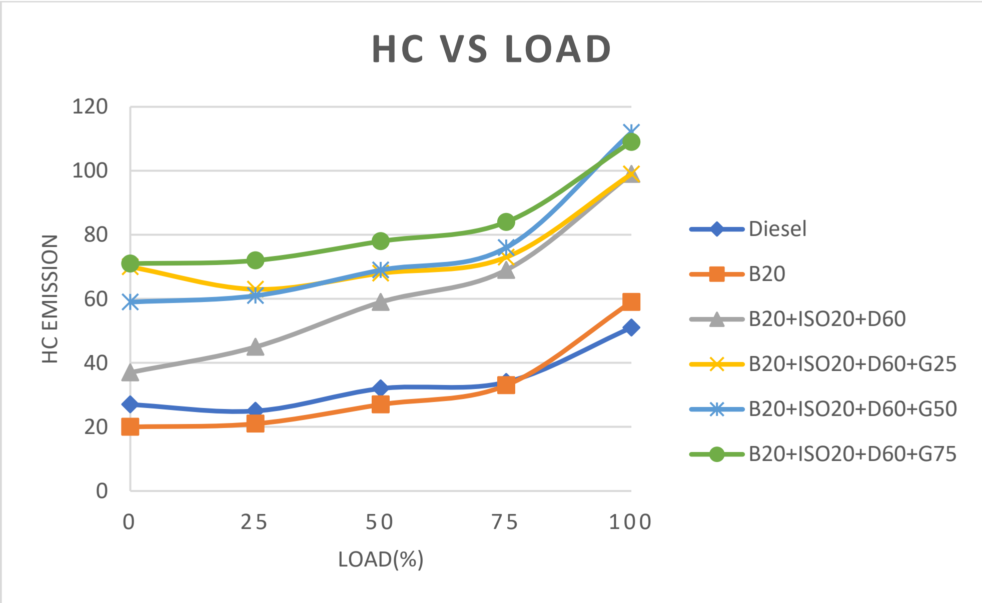

Fig 8. HC vs load

A graphene nanoparticle boosts catalytic and chemical activity, resulting in complete fuel combustion [2]. The amount of HC emitted increases continuously with load, which could be due to the supply of more fuel to meet the load, which raises the fuel–air ratio. Previous studies have revealed a similar pattern. The lower HC emissions for the B20 blend may be attributed to biodiesel providing additional oxygen, which improves combustion and tends to reduce HC emissions [22].

3.3.3 Oxides of nitrogen (NO_x)

The addition of graphene nanoparticles increased NO_x by 28.23% compared to diesel. The B20+ISO20+D60 combination showed higher NO_x than diesel. The addition of graphene nanoparticles to fluid blend B20+ISO20+D60 showed decreasing nitrogen oxides with increasing graphene nanoparticle composition. When compared to diesel, B20+ISO20+D60, and B20, the B20+ISO20+D60+G75 had 10.58%, 2.9%, and 7.6% lower nitrogen oxides. When compared to all fuel blend samples, the B20+ISO20+D60+G75 showed lower nitrogen oxide emissions. Diesel had higher NO_x emissions when compared to B20 test fuel and its metal-oxide nanoparticle blends. NO_x formation is highly dependent on residence time, test fuel oxygen atoms, and in-cylinder temperature [18]. Adding higher alcohols to a diesel–biodiesel blend reduced NO_x emissions by 2.89 percent for all higher alcohols. In general, lower cetane numbers cause ignition delay, which affects the amount of fuel used in premixed combustion and raises the post-combustion temperature, resulting in higher NO_x emissions. However, the amount of oxygen and latent heat of evaporation have a positive effect on the combustion in terms of NO_x reduction. According to the findings of this study, those two factors were more important than the effect of a lower cetane number on NO_x emissions [19].

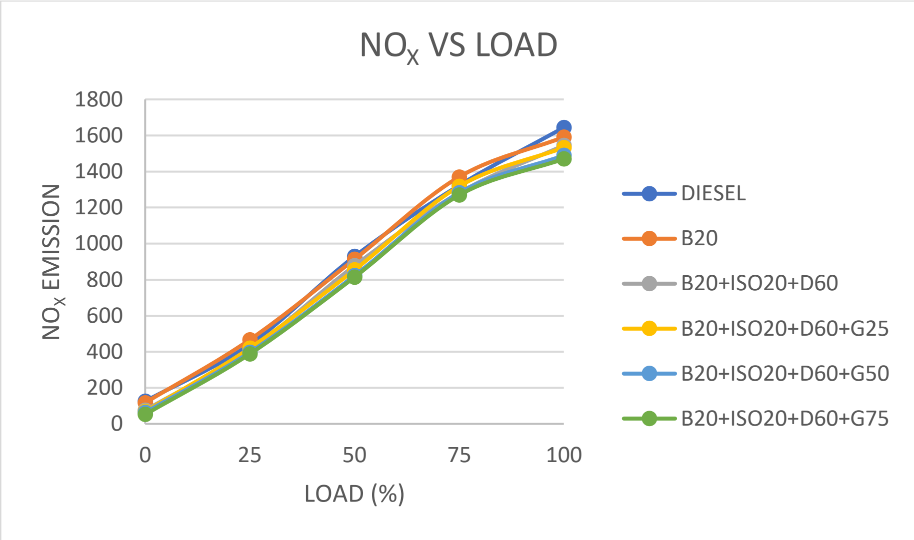

Fig 9. NO_x vs load

3.3.4 Carbon dioxide (CO_2)

The B20+ISO20+D60+G50 showed 2.5%, 1.3%, and 16.3% increases in CO_2 emissions. The load increases as carbon dioxide also increases. The addition of graphene nanoparticles raises carbon dioxide compared to diesel. The B20+ISO20+D60 has higher carbon dioxide compared to diesel. The addition of graphene nanoparticles increases CO_2 emissions compared to diesel and B20.

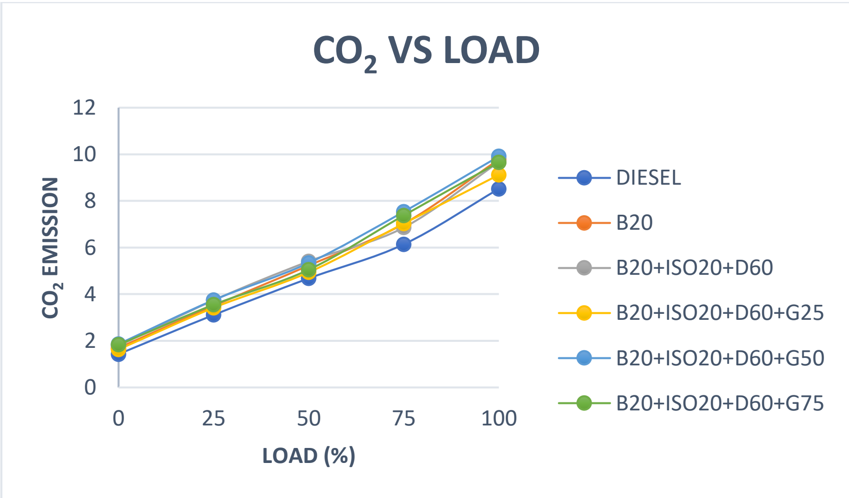

Fig 10. CO_2 vs load

Due to the fact that adding nanoparticles to the nanofluid increased CO_2 and decreased CO emission compared with the absence of nanoparticles in the nanofluid. It should be noted that diesel fuel produces more CO_2 emissions than B20, biodiesel, and nanoparticle blends. This is due to the non-homogeneous air–fuel mixture, which causes the combustion process to degrade [23]. CO_2 emissions rise, while CO emissions fall as engine speed rises. Because of the suitable combustion conditions at this point, the reason for high CO_2 and low CO emissions at high engine speeds can be based on complete combustion. This means that a significant amount of carbon in the fuels is converted into CO_2 as a result of carbon combustion with oxygen present in the combustion air. The most important parameter is the absence of air or oxygen, which causes CO from the exhaust to be rejected without being converted into CO_2 [25].

3.3.5 Smoke opacity

The load increases the smoke opacity too. The waste cooking oil biodiesel results in higher smoke opacity compared to diesel due to its heavier molecular structure and lower volatility. The increase in the composition of nanoparticles in the fuel blend reduces smoke opacity. The B20 has a higher smoke opacity than diesel. The B20+ISO20+D60 has a higher smoke opacity compared to diesel. The addition of nanoparticles reduces smoke density significantly when compared to waste cooking oil biodiesel for all loads. This is because B20+ISO20+D60+graphene nanoparticles blend fuels include shorter ignition delay characteristics [2]. With increase in load, the opacity of smoke rises. This is due to the fact that the fuel becomes richer as the air fuel ratio decreases with increasing load [16]. In the case of biodiesel graphene blended fuels, increasing nanoparticle dosing reduced smoke opacity. This could be attributed to the biodiesel graphene blended fuels' shorter ignition delay characteristics. [4].

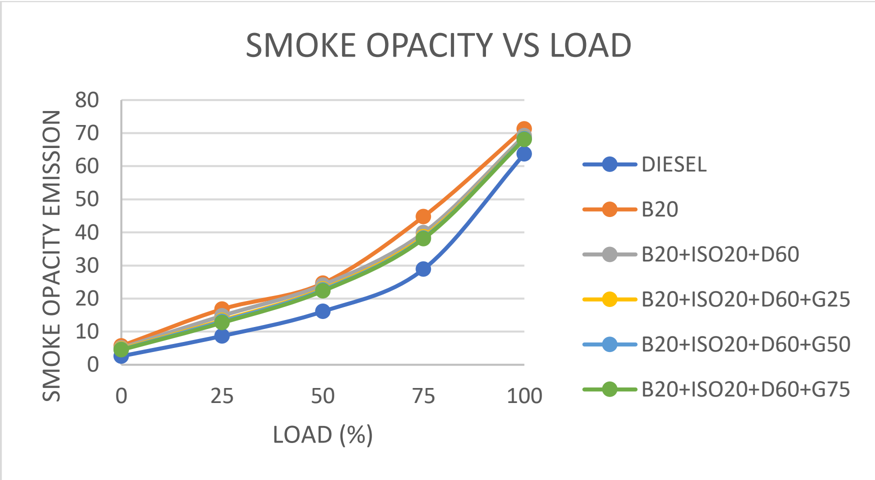

Fig 11. Smoke Opacity vs load

4. Conclusion

The experiments were conducted to show the effect of graphene nanoparticles as an additive to WCO biodiesel and isopropanol blend with diesel. Graphene NPs at proportions of 25, 50, and 75 ppm were added to a biodiesel isopropanol blend. The performance, combustion, and emission parameters of a single-cylinder diesel engine using graphene nanoparticles in various proportions with biodiesel isopropanol blend test fuels were experimentally studied; key conclusions are discussed below.

B20+ISO20+D60 had a BTHE that was 4.2% higher than B20 and 2.7% lower than diesel. The BSFC of B20+ISO20+D60+G75 was 0.21% lower than that of B20+ISO20+D60.The B20+ISO20+D60+G75 fuel blend had 2% higher in-cylinder pressure than the B20+ISO20+D60 fuel blend. When compared to diesel, the B20+ISO20+D60, the B20+ISO20+D60+G25, and the B20+ISO20+D60+G75 had 5.45%, 6.43%, and 8.7% higher HRR. The B20+ISO20+D60 showed 11.60% and 9.17% reductions in HC emissions compared to the B20+ISO20+D60+G50 and the B20+ISO20+D60+G75. The B20+ISO20+D60+G75 reduced NOX emissions by 10.58%, 2.9%, and 7.6%, respectively, when compared to diesel, B20+ISO20+D60, and B20. When compared to diesel, B20+ISO20+D60 and B20+ISO20+D60+G50 had 16.3%, 2.5%, and 1.3% higher CO_2 emissions, respectively. When compared to B20 and B20+ISO20+D60, B20+ISO20+D60+G75 reduced smoke opacity by 4.48% and 1.58%, respectively. However, diesel showed reduced smoke opacity emissions compared to all fuel blends. Smoke opacity gradually decreases with the increasing nano concentrations.

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