Exploring Performance and Emission Traits of CI Engine Fueled by Waste Cooking Oil- derived Biodiesel Enhanced with Nano Particles

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Research Article

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Exploring Performance and Emission Traits of CI Engine Fueled by Waste Cooking Oil-derived Biodiesel Enhanced with Nano Particles

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Abstract

In this groundbreaking experimental study, examines the impact of copper oxide (CuO) and Titanium oxide (TiO_2) nanoparticles on both emissions and performance of a 4.15 kW diesel engine fueled by waste cooking oil biodiesel. B20 test fuel blends fortified with 50 ppm concentrations of CuO and TiO_2 nanoparticles, subjected to rigorous testing across diverse engine loads (20%, 40%, 60%, and 80%) while maintaining a constant speed of 1,500 rpm. Through meticulous evaluation of key performance metrics such as brake thermal efficiency (BTE) and brake-specific fuel consumption (BSFC), coupled with the analysis of emissions including CO, CO_2, HC, and NOx, we observed remarkable enhancements. Notably, the introduction of 50 ppm copper oxide and titanium oxide nanoparticles into biodiesel blends resulted in a notable boost in brake power (BP) and BTE, showcasing a remarkable surge from 12.39% to 22.14% in BP and 4.92% to 15% in BTE, underscoring their profound impact of particular significance, B2050CuO exhibited superior combustion characteristics compared to titanium nanoparticles, leading to elevated flame temperature and reduced ignition delay, thereby translating into improved engine performance, enhanced braking power output, and overall superior brake thermal efficiency. Furthermore, CuO and TiO_2 nanoparticle blends demonstrated a significant reduction in CO emissions at full load with a 50 ppm dosage, achieving reductions of 6.32%, 8.57%, and 6.25%, respectively. Moreover, for B20 and B2050 TiO_2 blends, HC emissions saw a notable drop by 9.14%, 6.57%, and 2.817%, promoting efficient combustion through enhanced fuel molecule interaction. Comparatively, the inclusion of B20, B2050TiO_2, and B2050CuO fuel blends led to substantial reductions in CO2 levels by 14.4%, 4.8%, and 3.75%, along with lowered NOx emissions by 5.2%, 3.125%, and 2%, highlighting their potential in mitigating environmental impact."

Keywords: *Biodiesel, Copper Oxide, Titanium Oxide, Nanoparticle, Performance, Emissions, Additives*

1 INTRODUCTION

1.1 Background of the Study

Diesel engines' versatility has led to their adoption into a variety of industries and applications. Because of the threat posed by global warming, countries have enacted rigorous environmental pollution regulations. This necessitates the use of alternative fuels, research in this field, and efforts to improve combustion quality in order to reduce the environmental impact. Due to the depletion of fossil fuels and the negative effects they have on the environment, the need for renewable energy sources is expanding globally. Strict emission standards and regulations established by governmental organizations have compelled academics and researchers in this sector to seek alternatives to fossil fuels[1]. The primary goal is to reduce pollution caused by internal combustion engines while increasing access to renewable energy. To avoid additional environmental damage, alternative fuels must be made accessible in addition to the more traditional forms that rely on petroleum. For some time now, there have been consistent efforts in this direction to reduce global demand for fossil fuels. CI engines emit pollutants such as carbon dioxide, monoxide, nitric oxide, hydrocarbons, nitrogen dioxide, and smoke or particle matter. As a result of the negative effects of fossil fuel consumption, discovering biofuels to utilize in diesel engines has become critical. The cost of biodiesel is the biggest impediment to its commercial scale deployment[2].

WCO biodiesel is non-toxic, biodegradable, and contains less sulfur. WCO biodiesel can be utilized in CI engines without requiring extensive engine modifications. Transesterification is the process by which fatty acid and short-chain alcohol esters are transformed into biodiesel. This process made use of homogeneous alkaline catalysts such as NaOH, KOH, and CH3ONa. Methanol is widely used in the transesterification process to produce biodiesel. The operational restrictions of the transesterification process determine the biodiesel yield, also known as the amount of biodiesel, produced by the process. The use of biodiesel or biodiesel blends in engines can result in lower CO, HC, and PM emissions. Biodiesel can be applied straight in diesel engines without any modifications because it is readily available, environmentally beneficial, non-toxic, and has a tiny amount of sulfur that may be recycled . Nanoparticles utilization in biodiesel engines has been the subject of a great deal of published work . The normal practice calls for the use of

2.Methods and Materials

2.1 Research Methods

To address the general and specific objectives of this work a well-designed methodology was followed. There were combinations of procedures that were used to accomplish this study collecting waste cooking oil, purchase methanol, Sodium hydroxide (NaOH), cupper and titanium nanoparticles then produce biodiesel from waste cooking oil by transesterification method. And preparing blended fuel by mixing diesel, biodiesel, copper and titanium nanoparticles and 2% by weight of total blending as an additive to biodiesel-diesel blended fuel, and using surfactants to avoid phase separation between nanoparticles blended fuel. And make the experimental setup of the test engine for making experiment and analysis of experimental results. This thesis work was conducted based on the following procedures summarized as shown in Figure 1 below.

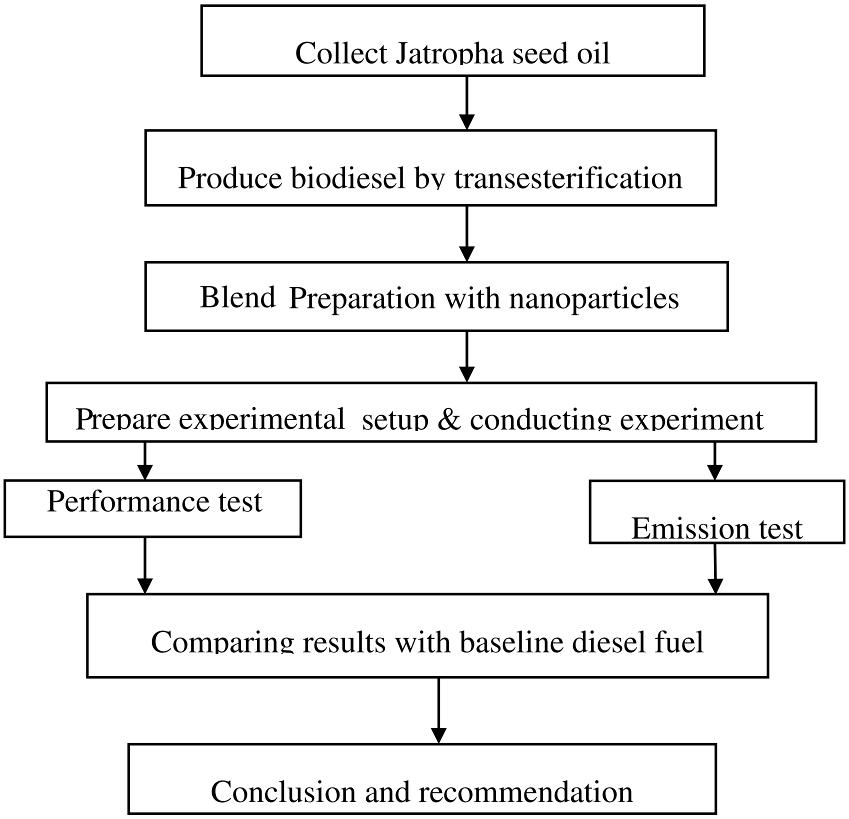

Figure 1 Block diagram of the procedure of this thesis work

2.2 Production of Biodiesel by Transesterification Process

Used cooking oil or used cooking oil is a potential raw material for making biodiesel. Used cooking oil can be converted to biodiesel because the chemical composition contains free fatty acids (FFA) and when reacted with alcohol and using simple technology will become biodiesel. To convert these waste cooking oil to biodiesel transesterification processes are used. The waste cooking oil used in this research was obtained from hotels in Bishoftu city. The chemical and reagent for synthesize include methanol, and NaOH were purchased from Market. Methanol was used as alcohol for the transesterification reaction. NaOH was used as base catalyst[35]. The transesterification process of waste cooking oil was making triglycerides of waste cooking oil react with methyl alcohol (methanol) by using sodium hydroxide (NaOH) as catalyst to produce biodiesel and glycerol. This process was performed at Chemistry department laboratory of defiance engineering University. To produce biodiesel from waste cooking oil by transesterification process follow the bellow steps explained by the flow chart in figure 2.

Figure 2 Conceptual flow chart of overall biodiesel production from waste cooking oil

$$Biodiesel\ yield = \frac{Quantity\ of\ biodiesel\ produced}{Quantity\ of\ feedstock\ oil\ used} x100 \ldots\ldots\ldots\ldots\ldots\ldots \text{(Eqn 3.1)}$$

2.3 Preparation of Nanoparticle's Biodiesel Mixtures

Nanoparticles are created as dry powder in the first step using inert gas condensation, chemical vapor deposition, mechanical alloying, or other suitable procedures, and then distributed in the second step.This method of nanofluid preparation is less expensive than the single step method. This approach is most typically utilized to prepare nanoparticle blends with diesel and biodiesel [36]. Purchased from the market, aluminum oxide and titanium dioxide nanoparticles, each with an average size below 40 nm, possess a distinctive high surface contact area, elevating their surface activation energy. UV spectroscopy images captured the optical nuances influenced by size, shape, concentration, agglomeration, and refractive index near the surfaces of the spherical CuO and TiO_2 nanoparticles, both boasting a smooth surface at an average size of 40 nm. Employing Span 2% as a surfactant ensured stability in the base fluid, facilitating proper bonding with the base fuel. Utilizing ultrasonication at 30 kHz for 60 minutes, a precise quantity of 50 ppm nanoparticles and 2 ml of Span80 surfactant were seamlessly blended with biodiesel, as depicted in Figure 3. Dry powder nanoparticles were transformed into a fluid solution, overcoming Vander Waals forces causing aggregation. Achieving stable Nano fluid involved employing surfactant addition and pH alteration, with D100, B20, B20CuO50, and B20$TiO_2$50 representing different fuel formulations in this study.

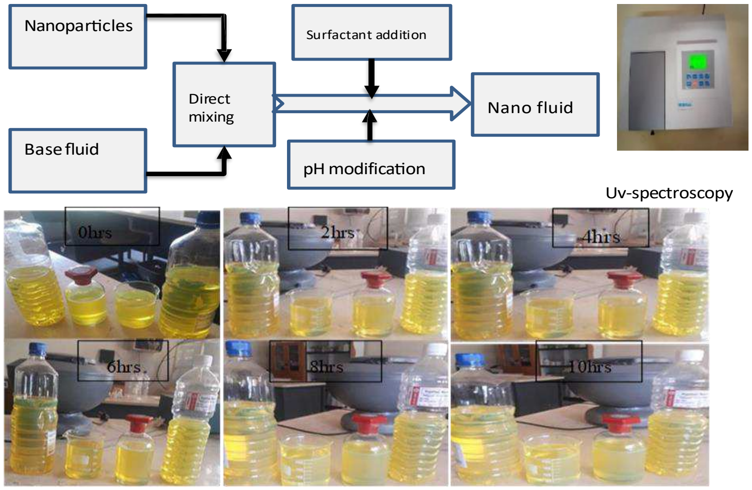

Figure 3 Preparation of Nanoparticles by using two-step methods

2.3 Experimental Analysis

The experiment was carried out at Defence University's College of Engineering by a R180 diesel engine set up at the automotive workshop. With a single-cylinder, four-stroke, water-cooled, naturally aspirated, rated power of 5.15 kW @2600 rpm, and loaded with a hydro dynamometer, the technical specifications of the engine are shown below in Table 3-3. The experiment was conducted at a constant engine speed of 1500 rpm with an injection pressure of 20 MPa. The schematic representation of the experimental setup and photographs are illustrated below in Figures 3.6 and 3.7, respectively. The setup enables the evaluation of performance parameters and emission constituents of the diesel engine. The engine performance parameters include BP, BSFC, and BTE. An FGA 4100-4G exhaust gas emission analyzer is used to measure the levels of engine exhaust emissions. The CO, CO_2, and HC emissions were measured in percentage volume (%Volume), during each run of the engine. The technical specification and the photographic view of the FGA 4100-4G type exhaust gas automotive emission analyzer as illustrated below in Table 1.

Table 1 Technical specifications of the R180 CI-engine

Name	**Details**
Make mode	R180
Engine type	4-stroke, water-cooled, single-cylinder, DI diesel engine
Loading device	Hydro-dynamometer
Rated power	5.67 kW at 2600 rpm
Cylinder bore and stroke	80 mm x 80 mm
Displacement volume	402 cc
Compression ratio	21:1
Injection timing	23^0 BDC
Injection pressure	20MPa

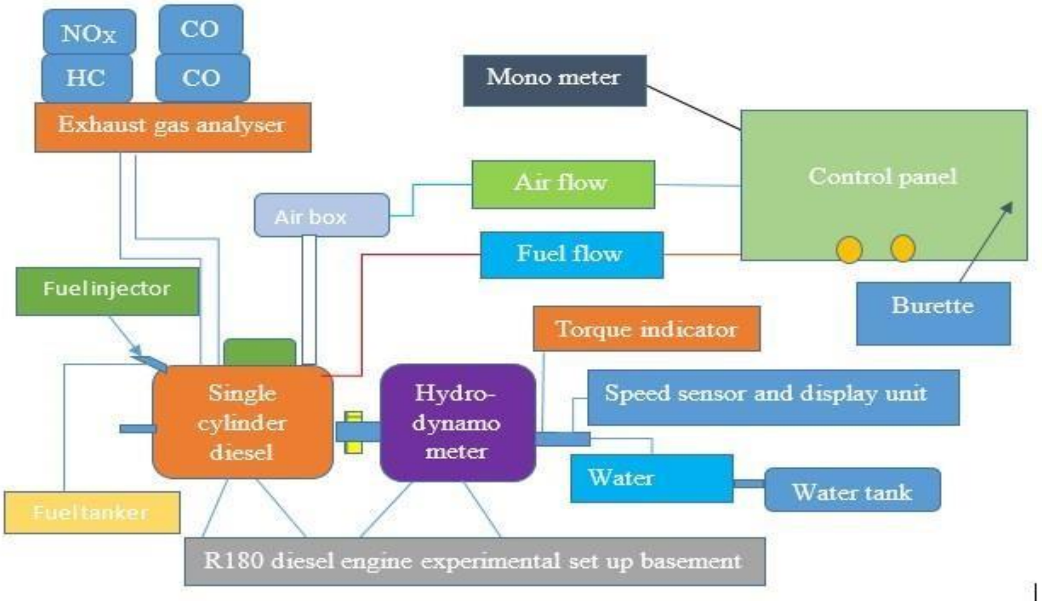

Figure.4 Schematic representation of the experimental setup

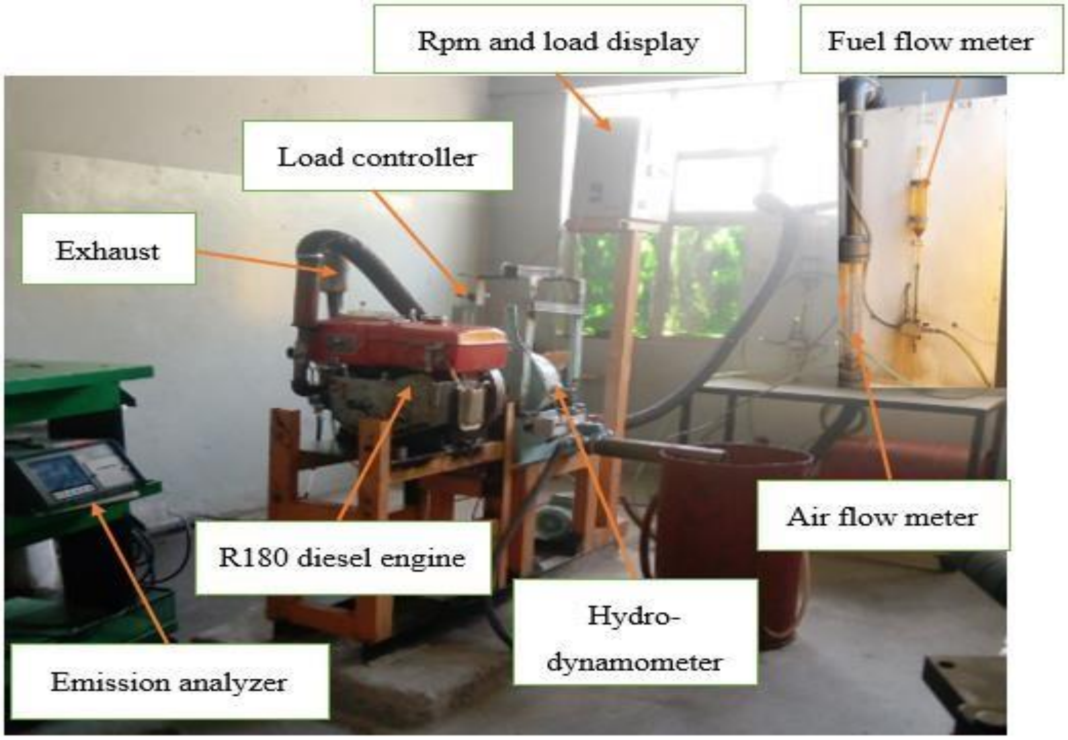

Figure.5 Photograph of the experimental setup

Figure 4-5 above depicts the schematic arrangement and photographic view of the experimental sets used in this work. These include the data acquisition system, diesel engine, hydraulic dynamometer, exhaust gas analyzer, air flow meter, and proximity sensors for speed measurement.

2.4 Performance Parameter Analysis

The performance characteristics such as brake power, brake thermal efficiency, and brake specific fuel consumption of a diesel engine when it operated with diesel fuel and biodiesel blend fuel with nano particles at different engine loads were discussed in the following sections below.

2.4.1 Brake Power (BP)

The actual engine power output in kW at the engine's output shaft is referred to as brake power. The torque applied to the crankshaft determines this power. The engine torque and the engine load are also shown on the computer throughout engine operation, and their values fluctuate as the engine load varies.

$$BP = \frac{2\pi NT}{60,000} \text{ (Kw)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(Eqn 3.7)}$$

Where:

N=revolution per minute (rpm)

T=Torque of the engine

2.4.2 Brake Specific Fuel Consumption (BSFC)

Brake Specific Fuel Consumption (BSFC) is a measure of fuel efficiency in internal combustion engines. It is defined as the amount of fuel consumed per unit of power produced by the engine. BSFC is typically expressed in units such as grams of fuel per kilowatt-hour (g/kWhr) or Kilogram per kilowatt-hour (Kg/Kw-hr). In general, as engine load increases, the brake specific fuel consumption tends to decrease. This means that the engine becomes more fuel-efficient at higher loads. It is an engine performance metric that primarily defines the quantity of fuel consumed by the engine in kilograms per hour (Kg/hr) to produce a unit break power of (Kw) when running at a constant engine speed ("N" in rpm). The ratio of the mass flow rate of fuel consumed by the engine to the engine's braking power is known as brake-specific fuel consumption.

$$BSFC = \frac{\dot{m}_{bd}}{BP} \text{ (Kg/Kwhr)} \ldots\ldots\text{(Eqn 3.8)}$$

Where:

BSFC = brake specific fuel consumption in kg/kwhr

$\dot{m}_{bd}$=mass flow rate of biodiesel fuel in kg/hr

2.4.3 Brake Thermal Efficiency

It is the measure of the engine's performance in terms of the conversion of heat energy into mechanical energyy. The ratio of output braking power to the energy provided by the fuel to the engine is known as brake thermal efficiency.

$$BTE = \frac{3600xBP}{\dot{m}_{bd}xLHV_{bd}}x100\,,(\%) \ldots\ldots\text{(Eqn 3.9)}$$

Where:

BTE = brake thermal efficiency (%)

LHV_{bd}= lower Heating value of biodiesel fuel (MJ/kg)

2.5 Emission Analysis

2.5.1 Carbon monoxide (CO)

CO is a result of incomplete combustion. It mostly forms in regions of the cylinder that are too fuel-rich to support complete combustion; although, it may also originate at the lean limit of combustible fuel-air mixtures [56]. If temperatures are high enough, the CO can further react with oxygen to form CO_2. When there is not enough oxygen to convert all carbon to CO_2, some fuel does not get burned and some carbon ends up as CO [39][40].

2.5.2 Carbon dioxide (CO_2)

Carbon dioxide (CO_2) is formed during the combustion process in a diesel engine as a result of the incomplete combustion of oxidation of hydrocarbons in the fuel. During the combustion of diesel fuel, hydrocarbons (which contain carbon and hydrogen) react with oxygen (from the air) to produce carbon dioxide (CO_2) and water (H_2O) as byproducts[37].

2.5.3 Unburned Hydrocarbon (HC)

HC emissions can be either unburned or partially burned fuel molecules and can come from several sources. At ignition, some of the vaporized fuel will already be in a region that is too lean for it to burn and, unless it burns later in the cycle, this fuel will be emitted [55]. If a rich fuel mixture is used there is not enough oxygen to react with all the carbon, resulting in high levels of HC in the exhaust products. Often as an engine ages clearance between the pistons and cylinder walls increases due to wear. This increases oil consumption and contributes to an increase in HC Emissions [33][40].

2.5.4 NO_X Emissions

Nitrogen oxides (NOx) are formed during the combustion process in a diesel engine as a result of high-temperature combustion reactions involving nitrogen and oxygen from the air. The primary contributors to NOx formation are nitrogen (N_2) and oxygen (O_2) from the intake air. Reducing NO_x emissions in diesel engines is a major focus of emission control technologies and regulatory efforts. Techniques such as EGR, which recirculates a portion of exhaust gas into the intake air to reduce combustion temperatures, and SCR, which involves using a catalyst to selectively reduce NO_x to nitrogen and water, are employed to address NOx emissions from diesel engine. The production rate of NO_x is mainly related to the combustion temperature and oxygen concentration [41][42].

3.Result and Discussions

3.1 Characterization Results

The characterization was performed to determine the properties of the produced biodiesel and whether it meets the ASTM standards for biodiesel in order to test its performance in existing diesel engines without modification. test methods have been employed for the determination of various properties of fuel such as Kinematic viscosity, Density, Calorific value, flash and fire points. The nano fuel properties characterized density at @15^0C and 20^0C in kg/m^3, kinematic vicosity@40^0C, and calorific value with American standard testing materials (ASTM/IP/ISO) are characterized at **ETHIOPIAN PETROLEUM SUPPLY ENTERPRISE**. Other properties of the fuel are not checked because of the limitation of testing Machine problem. The results are listed in Table 2.

Table 2 Physiochemical properties of biodiesel blend and nano particles

No n	Property	Test method ASTM	limits	Test result of the biodiesel and nano particles		
				B20	CuO nano particles	TiO_2 nano particles
1	Density @ 15^{o}c,g/ml	D4052	report	0.8433	0.8410	0.8421
2	Density @ 20 ^{O}C, g/ml	D4052	report	0.8398	0.8370	0.83960
3	kinematic viscosity @40^{o}c, (cSt)	D445	_	3.8858	2.878	2.861
4	Calorific value BTU/LB	Calculated	_	19580.30	19601.0	19600

3.2 Engine Performance Characteristics

The performance parameters of a diesel engine while operating on diesel fuel and biodiesel with copper oxide (CuO) and titanium oxide (TiO_2) nano particles at different engine loads, such as brake power, brake thermal efficiency, and brake specific fuel consumption, were discussed in the sections below.

3.2.1 Brake Power (BP)

The addition of nanoparticles to the fuel blend enhances combustion conditions, resulting in increased brake power. These nanoparticles have a lower ignition delay, improve combustion efficiency, and offer higher thermal conductivity. The introduction of copper and titanium nanoparticles in biodiesel fuel improves the surface-to-volume ratio, leading to better combustion quality and increased brake power. Copper nanoparticles outperform titanium nanoparticles, providing higher flame temperature and shorter ignition delay, resulting in improved engine performance. When compared to pure diesel fuel, the addition of 50 ppm copper oxide nanoparticles yields the highest brake power increase of 22.14% at 80% engine load for B2050CuO nanoparticles as shown below Figure 6 [40].

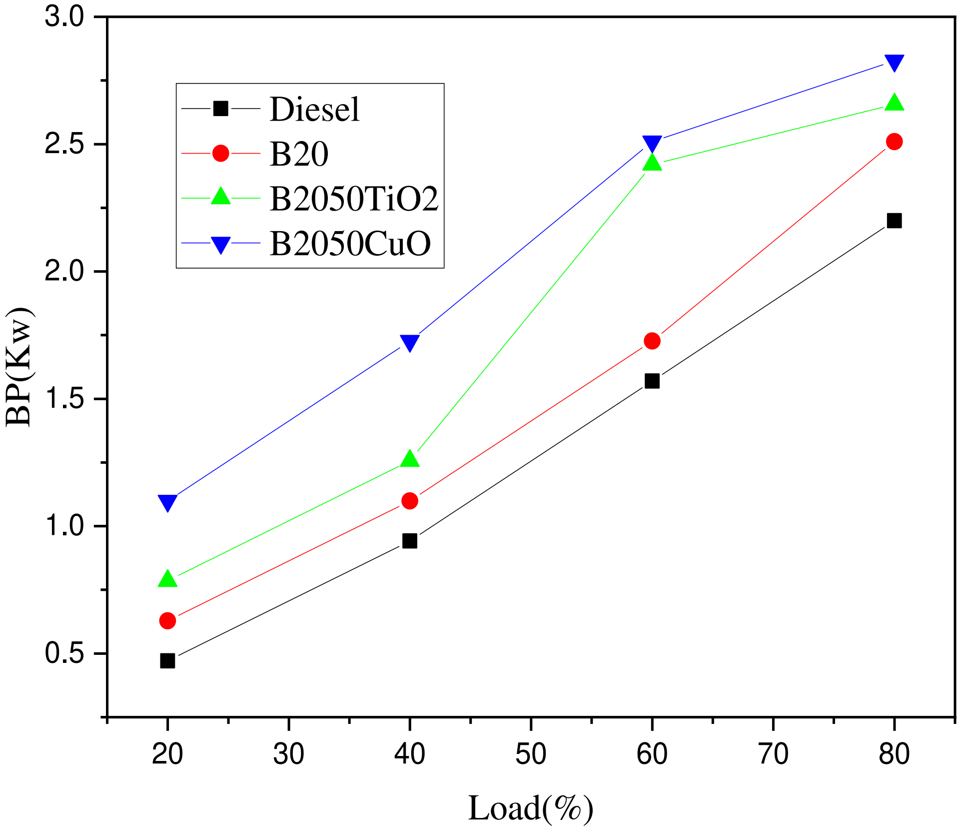

Figure 6 Variation of brake power versus engine load

3.2.2 Brake Thermal Efficiency (BTE)

Brake thermal efficiency (BTE) measures an engine's ability to utilize fuel effectively by comparing mechanical energy output to chemical energy input. Adding titanium oxide and copper oxide nanoparticles to biodiesel fuel blends significantly enhances BTE. The nanoparticles contribute to a shorter evaporation period and reduced physical delay, while their high thermal conductivity promotes early combustion and improved heat transfer. Consequently, the chemical energy of the fuel is efficiently utilized with nanoparticle-enhanced biodiesel blends, leading to increased BTE compared to pure diesel or biodiesel blends. Nano particle fuels exhibit remarkable improvements in BTE, with the highest value achieved for B2050CuO due to its superior surface reactivity. The interaction between fuel molecules and copper oxide nanoparticles promotes more efficient combustion, resulting in a significant increase in BTE. As hown below Figure 7 At 80% engine load, the addition of 50 ppm copper oxide nanoparticles yields an incremental BTE increase of 15% for B2050CuO, while B2050TiO2 shows a 7.8% increase and B20 exhibits a 4.92% increase.[40].

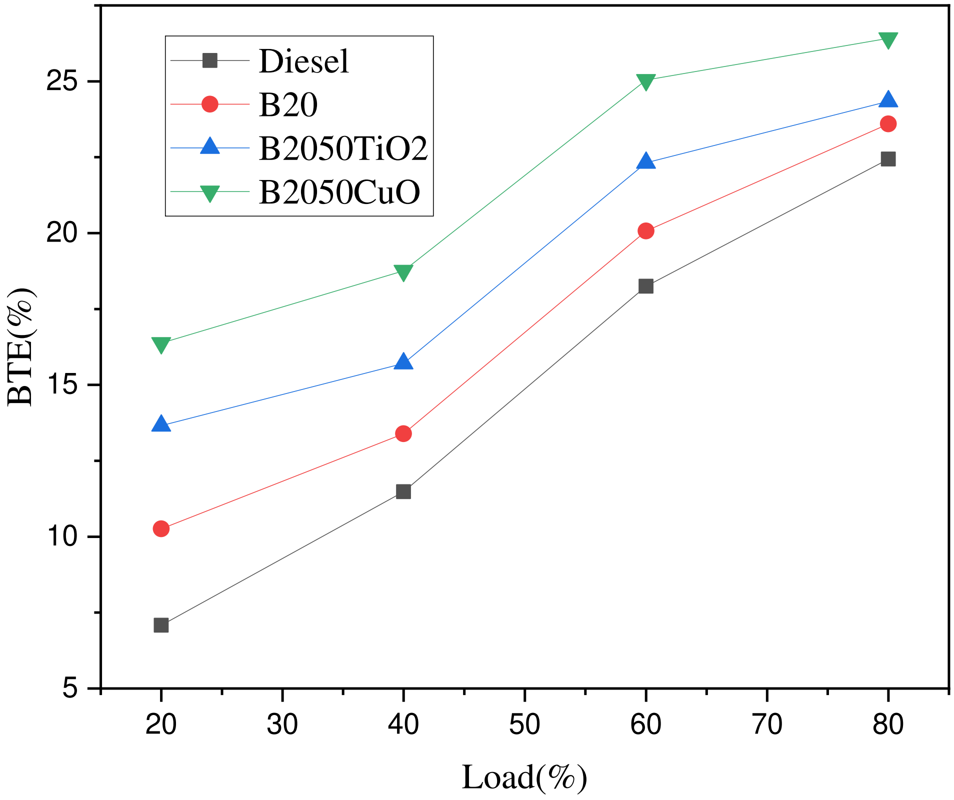

Figure 7 Variation of Brake thermal efficiency versus engine load

3.2.3 Brake Specific Fuel Consumption (BSFC)

The engine's performance is measured by brake specific fuel consumption (BSFC), indicating the fuel mass consumed per unit power output. By incorporating aluminum oxide nanoparticles, a significant reduction in BSFC is achieved. Among the tested blends, B20 exhibits the highest energy consumption at all engine loads, primarily due to its lower heating value and higher kinematic viscosity, which hampers fuel atomization and vaporization. However, the presence of oxygen in the B20 biodiesel-diesel blend promotes combustion and leads to a downward trend in BSFC. The addition of copper oxide (CuO) and titanium oxide (TiO_2) nanoparticles further improves the BSEC (brake specific energy consumption) by reducing BSFC. CuO nanoparticles exhibit a slightly greater reduction compared to TiO_2 nanoparticles, attributed to their higher surface area-to-volume ratio, catalytic activity, improved combustion, decreased physical delay, and increased cetane number. Notably, the B2050CuO blend demonstrates the lowest BSFC profile across all engine load conditions. As shown below figure 8 the introduction of nano additives influences evaporation rate, ignition delay, and spray characteristics, enhancing catalytic activity, combustion efficiency, and subsequently lowering the BSFC profile.[39].

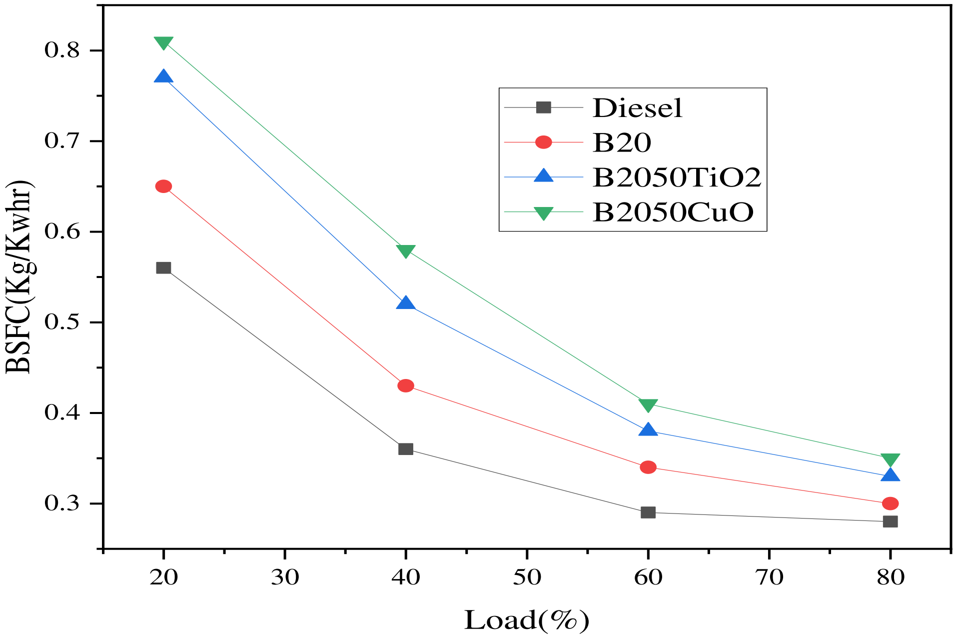

Figure 8 Variation of brake specific fuel consumption versus engine load

3.3 Engine Emission Characteristics

Engine emissions have a substantial impact on both environmental pollution and global warming. The experts have carried out a significant number of trials to enhance the engine's emissions. Alternative fuels with fewer carbon atoms have a significant role in reducing hazardous emissions to a large extent. Emission also identifies the engine's combustion and performance characteristics. This section addresses the emissions of pure diesel and biodiesel with nano particles additives on diesel engines. Now emissions of CO, CO_2, HC and NOx were measured by using Automobile Exhaust Gas Analyzer AVL-444. when the engine run in dual fuel mode at each load with different biogas flow rate was briefly discussed in this section with comparison to pure diesel engine fuel emissions.

3.3.1 Carbon Mono Oxide Emission (CO)

CuO and TiO2 nanoparticles have a significant impact on CO emissions in diesel engines, as demonstrated in Figure 9. As engine load increases, there is a noticeable rise in CO emissions due to variations in the air-fuel ratio. However, the B20N75 blend consistently exhibits the lowest levels of CO emissions across all engine load conditions, thanks to its high oxygen content and cetane number. The addition of TiO_2 and CuO nanoparticles to B20 leads to a substantial reduction in CO emissions, primarily because CuO nanoparticles facilitate the oxidation of CO to CO_2. Compared to the B20 blend, the CuO nanoparticle-doped B20 blend shows lower CO emission levels, with reductions of approximately 6.32%, 8.57%, and 6.25% for B20, B2050TiO_2, and B2050CuO blends, respectively. This reduction is attributed to the catalytic activity of CuO and TiO2 nanoparticles, enhancing atomization, evaporation rate, and combustion within the cylinder. The higher surface area-to-volume ratio of nanoparticles may also influence the rate of heat transfer. Moreover, the decreased ignition delay results in an increased combustion rate, contributing to lower CO emissions. Previous studies have reported the successful reduction of CO emissions by incorporating B2050CuO nanoparticles [39][40].

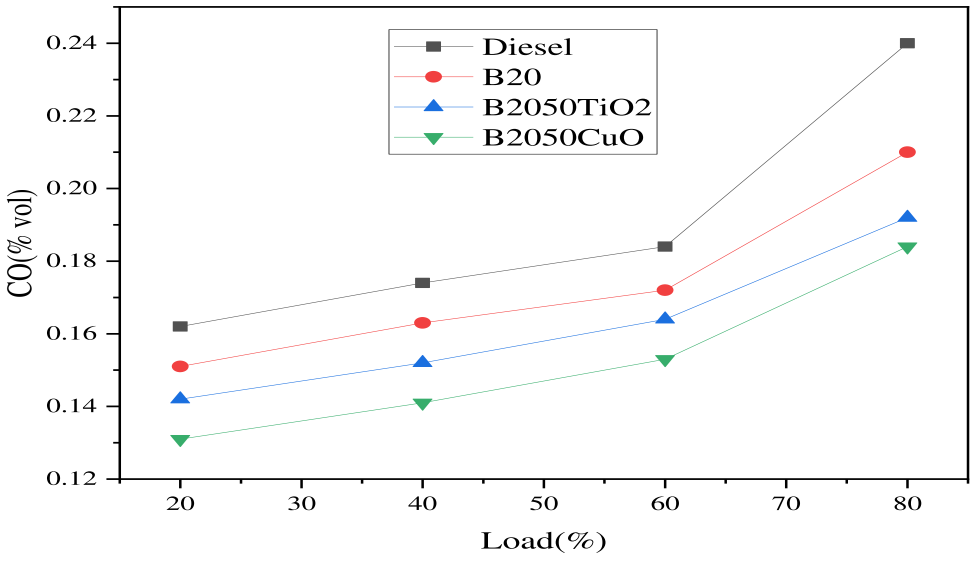

Figure 9 Variation of CO emission versus engine load

3.3.2 Carbon di oxide Emissions (CO_2)

Figure 10 illustrates the changes in carbon dioxide (CO_2) levels across different loads for diesel, B20 biodiesel blends, and their CuO and TiO_2 additives. Generally, biodiesel blends exhibit higher CO_2 emissions compared to diesel fuel. Increasing the volume fraction of biodiesel in diesel leads to higher CO_2 emissions due to a longer and stable diffusion combustion phase and the availability of oxygen in biodiesel, promoting complete combustion. However, the addition of CuO and TiO_2 nanoparticles results in a significant reduction in CO_2 emissions. The CO_2 emissions decrease by approximately 14.4%, 4.8%, and 3.75% for B20, B2050TiO$_2$, and B2050CuO fuel blends, respectively. The presence of metal additives slightly reduces CO_2 emissions at different load conditions. the addition of nanoparticles enhances combustion through catalytic action, thereby increasing CO_2 emissions compared to diesel. Copper nanoparticles in the nano-additive blends facilitate oxidation reactions. Notably, the variations in CO_2 emissions are more pronounced at high loads due to rapid oxidation reactions, while they are less significant at low loads.[28].

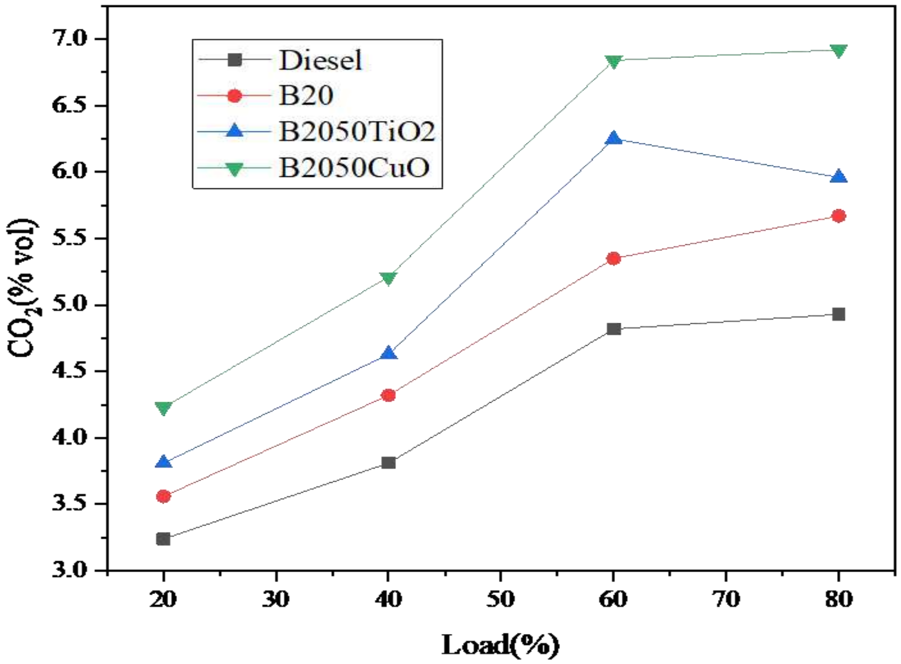

Figure 10 Variation of CO_2 emissions versus engine load

3.3.3 Hydrocarbon Carbon Emissions (HC)

The incorporation of biodiesel blends results in reduced hydrocarbon emissions (HC) due to their higher cetane number and oxygen content. The abundance of oxygen in biodiesel promotes complete combustion, while the higher cetane number reduces ignition delay, decreasing unburned hydrocarbon emissions. HC emissions increase with higher engine loads due to residual fuel in the combustion chamber and quench areas. Notably, pure diesel fuel exhibits higher HC emissions compared to any B20 blend. Moreover, the addition of 50 ppm CuO and TiO_2 nanoparticles to biodiesel blends leads to lower HC emissions. This is attributed to improved air-fuel mixture during fuel injection and enhanced combustion facilitated by the nanoparticles. HC emissions are reduced by 9.14%, 6.57%, and 2.817% for B20, B2050TiO_2, and B2050CuO, respectively, compared to pure diesel fuel. The graph indicates that CuO nanoparticles yield lower HC emissions in biodiesel compared to TiO_2 nanoparticles, likely due to their higher surface reactivity. This increased reactivity enables better interaction with fuel molecules, resulting in more efficient combustion as shown below figure 11[21].

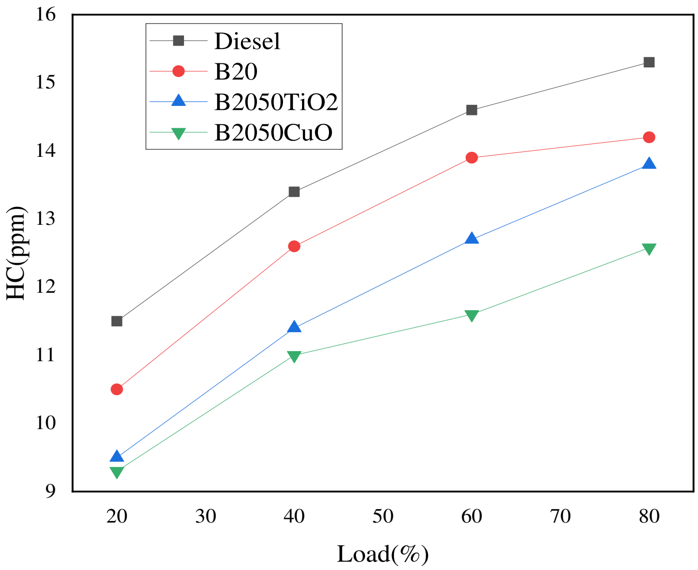

Figure 11 Variation of HC emissions versus engine load

3.3.4 NO_x emissions

CuO and TiO_2 nanoparticles have a notable impact on NOx emissions in diesel engines, as depicted in Figure 12. Higher loads generally result in increased NOx emissions for all fuel variants. Pure diesel exhibits slightly higher NOx emissions compared to B20 due to a higher combustion temperature resulting from increased oxygen content. The addition of CuO and TiO_2 nanoparticles to B20 leads to a decrease in NOx emissions. This reduction is attributed to improved convective heat transfer in the cylinder, resulting in lower average cylinder temperature. Enhanced catalytic activity and effective nitric oxide reduction contribute to the minimized NOx emissions, particularly with CuO nanoparticles. The decrement in NOx emission levels is approximately 5.2%, 3.125%, and 2% for B20, B2050TiO_2, and B2050CuO, respectively, compared to pure diesel fuel. Notably, the inclusion of copper oxide nanoparticles in the biodiesel blend demonstrates a greater reduction in NOx emissions at all loads compared to TiO_2 and B20. This reduction can be attributed to lower gas temperatures in the combustion chamber.[40] [15].

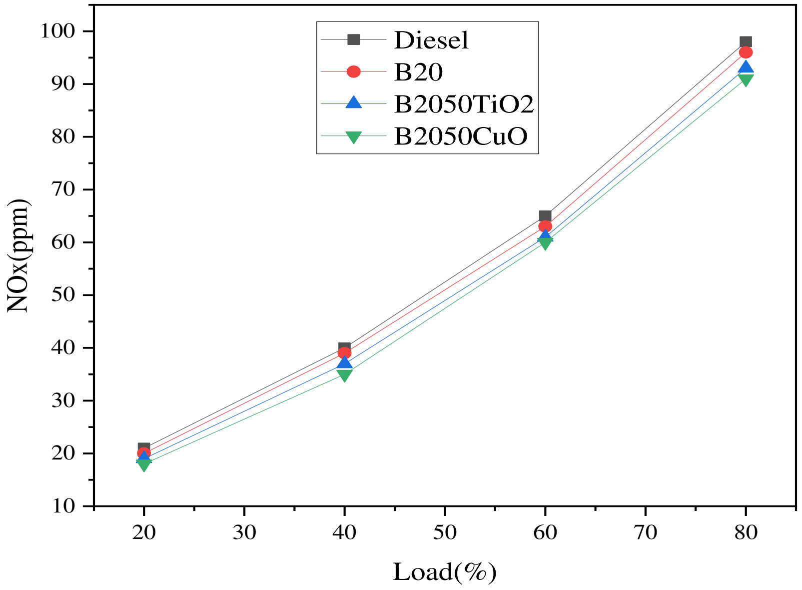

Figure 12 Variation of NO_x emissions versus engine load

3.4 Experimental Uncertainty Analysis

The data acquisition system (DAS) was connected to the diesel engine coupled with hydraulic dynamometer obtain performance and emission values at different loads. proximity sensor was fitted near to the flywheel to ensure a constant speed of the diesel engine (maximum of 1,500 rpm). Meanwhile, tailpipe emissions were analyzed by using a five-gas analyzer AVL444 in the conditions of steady state engine operation. The uncertainty of individual variables is depicted in

Table 3 and the overall uncertainty analysis of measuring variables including performance and emission variables are calculated using Equation 3.10 below:

Table 3 Uncertainty of Measuring Variables

Measuring Parametres	Accuracy (%)	Uncertainity (%)
Load measurment	± 0.04	± 0.4
Speed measurment	±0.037rpm	± 1.7
B. P	±0.91	± 1.46
BTE	0.88	± 1.5
BSFC	± 0.014	± 1.4
CO	± 0.3	± 0.8
NOx	± 0.26	± 0.9
HC	± 0.063	± 0.7
CO_2	± 0.86	± 0.75

Overall uncertainty = $\sqrt{(BTE)^2 + (BSFC)^2 + (BP)^2 + (CO)^2 + (NOx)^2 + (HC)^2 + (CO2)^2}$

Overall uncertainty = $\sqrt{(1.5)^2 + 1.4)^2 + (1.46)^2 + (0.8)^2 + (0.9)^2 + (0.7)^2 + (0.75)^2}$

Overall uncertainty= ± 2.974%

4.CONCLUSION AND RECOMMENDATIONS

4.1CONCLUSIONS

In this study, a 5.15 kW@2600 rpm CI engine underwent testing with various biodiesel blends, sans significant alterations. Evaluating the impact of CuO and TiO_2 nanoparticle additives at 50 ppm dosage, tests explored performance (BP, BTE, BSFC) and emissions (CO, NOx, CO_2, HC) characteristics. Experiments, conducted at constant 1500 rpm, examined Diesel, B20, B20CuO, and B2050TiO_2 blends across different loads (20%, 40%, 60%, 80%) Key findings outlined below.

- Addition of surfactants to base biodiesel fuels ensures stable dispersion of CuO and TiO_2 nanoparticles, enhancing their surface tension and facilitating homogeneous distribution in blended fuels
- Incorporating 50 ppm of copper oxide and titanium oxide nanoparticles into biodiesel blends significantly increases brake power (BP) and brake thermal efficiency (BTE), with B2050CuO exhibiting superior performance due to enhanced combustion features.
- Nano-enhanced fuels demonstrate lower brake specific fuel consumption (BSFC) compared to neat diesel, with CuO nanoparticles yielding slightly lower BSFC than TiO_2 nanoparticles, attributed to their higher surface area-to-volume ratio promoting catalytic activity and improved combustion. Additionally, CO emissions are reduced with the inclusion of CuO and TiO_2 nanoparticles, leading to improved combustion efficiency and reduced HC emissions.

4.2 RECCOMENDATIONS

- Further research should explore nanoparticles of varying sizes to understand their impact on engine performance and emissions, while also addressing safety and stability concerns for commercial vehicle applications.
- Experimentation with nanoparticles in CI engines across different compression ratios should be conducted to assess their efficacy, alongside efforts to establish safety standards and analyze combustion and flame characteristics using visualization techniques.

5. Declaration

1. **Availability of data and materials**

   No, all of the material is owned by the authors, and/or no permissions are required.

2. **Conflict of interest financial interests:**

   Author declares there is no financial interests.

3. **Funding:**

   This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

4. **Auther's Contribution**

   Corresponding Author conceived and designed the study, performed the expermental work, and wrote the manuscript.in additon analyzed, organized data.

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