A REVIEW ON THE EFFECT OF DIFFERENT NANOPARTICLES ADDITIVE WITH FUEL USED IN COMPRESSION IGNITION (CI) ENGINE.

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ABSTRACT

The transportation sector needs the energy to run the vehicles, this energy getting from fossil fuels. So, the over-dependency on fossil fuels is ascribed to many issues like overcast and pollution which is a major problem. Thus, many researchers tackle these problems and try to accomplish them somewhat. They used biodiesel in place of fossil fuels. After that the addition of new advancement is nanoparticles in base fuel. Multifold nanoparticles are used in research due to their thermophysical and thermochemical properties. The nanoparticles exhibited a large surface area and immense surface-to-volume ratio, improved the fire point, flash point, pour point, thermal conductivity and combustion process, etc. These all phenomena depend on different sizes of nanoparticles, different concentrations, and base fuel that mixes the nanoparticles. The aims of using this type of fuel are to reduce toxicity and increase the performance of the engine. Researchers have analyzed performances and emissions of the engine with regards to their loads, brake power, brake mean effective pressure, speeds, compression ratios, advancement in fuel injection timing. This is a review on the properties of nanoparticles along with biodiesels and their effect on compression ignition engine performance (brake specific fuel consumption and brake thermal efficiency), combustion parameters (cylinder pressure and exhaust gas temperature) of fuel, and exhaust emissions (NO_X, CO, CO_2, HC, etc.) to the engine. The results were reported at different operating conditions. This paper summarized the inevitable published works of many researchers who resulted in better consequences in this area of research. This review will help to find out the better nano fuel for enhancing the performances and reducing the emissions of engines for further research.

Keywords: Nanoparticles, Biodiesel, CI engine, Performances, combustion, Emissions.

ABBREVIATIONS

NP_S- Nanoparticles
BD- Biodiesel
BSFC- Brake specific fuel consumption
BTE - Brake thermal efficiency
BP- Brake Power
CP- Critical pressure
HRR- Heat releasing rate
NO_X- Oxides of nitrogen
CO- Carbon monoxide
CO_2- Carbon dioxide
UBHC- Unburnt hydrocarbons
η_o- Overall efficiency
GO- Graphene oxide
Al_2O_3- Aluminum oxide
CuO- Copper oxide
ZnO- Zinc oxide
GO- Graphene oxide
GSBD- Grapeseed oil biodiesel

RPM- Revolution per minute
PPM- Parts per million
CST- Centistokes (CGS unit of kinematics viscosity)
ID- Ignition delay
SPM- Specific particulate matter

1. Introduction

This is the review of the rapidly expanding effects of fossil fuel and their alternatives in the transportation sectors. In the last few decades, the consumption of fossil fuel in CI engines is increased. Due to the use of diesel many types of issues rising like the performance of the engine, pollution issues, cost issues, etc. So now shift to alternative and sustainable fuels such as biodiesel with nano additives. Many types of biodiesels like vegetable oil, animal oil, etc. have been used in recent years for the increment into properties of the fuel and reducing the emissions like harmful gases such as NOx, CO_2, HC CO, etc. from the exhaust emissions. It is ascribed to increase in performance of the engine such as the efficiency of the engine. To decrease the ignition delay and increase the fuel consumption rate the researcher mixed nanoparticles as an additive. The additive can be zinc oxide (ZnO), copper oxide (CuO), Titanium Oxide (TiO_2), Alumina (Al_2O_3), cerium oxide (CeO_2) and magnesium oxide (MgO), Cobalt oxide (Co_2O_3), etc. nanoparticles. These nanoparticles are used with biodiesel in different sizes (1nm - 100nm) and different concentrations. The engine runs at different operating conditions and gives results according to their conditions.

The nanomaterials when mixed with biodiesel it ascribed to reduce toxicity, viscosity, give less heating values and increase molecular weight, cetane number and density of biodiesel. In many research, diesel and biodiesel are used as the base fuel. The use of nano additives affects fire point, flashpoint and enhance the specific fuel consumption due to their catalytic properties [1,2]. In studies, it is found that cerium oxide nano additive has better performance, enhances the brake thermal efficiency and makes fuel as better consumption into the engine, and reduces hydrocarbons (HC), NO_X, CO_2 [3]. The experimental setup of a diesel engine is shown in . In a study adding of TiO_2 with diesel and observed enhancement into properties of fuel such as fire point, calorific value, viscosity, and density in comparison to diesel [4]. It is reported that an improvement in brake thermal efficiency and reduction in brake-specific fuel consumption. It also affects exhaust emissions and they observed an increment in NO_X. The results are shown in *4. Results*

Table *5*.

It was also investigated that the use of titanium oxide (TiO_2) with dairy scum biodiesel results in a 1.67% enhancement of efficiency was reported by Sunil et. al. [5]. TiO_2 blended fuel helps in fuel-borne oxygen it causes the proper combustion of fuel results in enhancing the overall efficiency and BTE of the engine, the fuel consumption due to minimization of ignition delay are observed, and also reduces the exhaust emissions due to proper combustion. In an experimental study, it is found that nanoparticles are fuel-efficient and the combustion temperature is also improved by bulk material of nano additives [6]. To enhance the properties of fuel it needs to mix the nanoparticles due to its properties like thermophysical property, thermal conductivity and the ratio between surfaces to the volume [6]. They tested by using zinc oxide with algae oil biodiesel and found the diminishment in BSFC and increases the BTE. The reason behind these all reduction and increment parameters are described in the results and discussion.

Previously the author mentioned that cottonseed oil biodiesel is the best alternative to fossil fuels but due to the presence of triglycerides, it cannot be used directly in CI engines. Firstly, it was tested as per the ASTM standards. They show in their research that the trans-esterification process applies for production of biodiesel and mixes the zinc oxide (ZnO) nanoparticles with biodiesel for used as a fuel in the CI engine. The overall result after experimental testing is depicted that the improvement in the performance and combustion process of the engine and reduces the exhaust emission due to more oxygen availability into nano fuel [7]. Another result investigated after using the neem oil with biodiesel and reported that the calorific value of fuel is increased which is the reason for the increase in the brake specific fuel consumption (BSFC) [8]. They used iron oxide (Fe_3O_4), zinc oxide (ZnO) additives in their research and results show that brake thermal efficiency enhanced however, they found diminishing into brake thermal efficiency after using silicon dioxide (SiO_2) additive. In an experimental study, Al_2O_3 nanoparticles were investigated [9]. These nanoparticles are used with butanol diesel blends (B20) in the absence of surfactants. In this study, the author mentioned that the researchers analyze using different ideas like common rail fuel injection system to reduce the emission and some researchers are analyzed after modification into CI engine such as catalyst and filters used into vehicles. They reported that using surfactant in Al_2O_3 + butanol mixture fuel which is affected the combustion characteristics. Gumus et. al. [10] addressed in their research addition of Al_2O_3 and CuO with diesel resulted in reducing the BSFC and NO_X at maximum load and 1500 to 3600 RPM speed. They compared the results of both Al_2O_3 and CuO nanoparticles. They found an increment in flashpoint temperature and cetane number of fuels after mixing the nanoparticles. They also show the process of improving the stability of fuel after variation of pH value and the use of dispersant in their work. They mentioned also the effect of pH of the suspension if the pH of suspension varies then the variation is shown into surface charge density. They reported also the effect of sodium silicate by adding into fuel for maintaining the settling rate of aluminum oxide (Al_2O_3) but due to the addition of sodium silicate the suspension is destabilized. Thus, they use ammonium polymethacrylate solution (Dravan-C). Due to high molecular weight and little tendency, it has low viscosity and increases the stability of the fuel. To determine the isoelectric pH and dispersant they applied the sedimentation test under various conditions. In a review, Yusof et. al. [11] also stated the methods to improve the stability. They exhibited the method of ultrasonication, transformation into the surface, adding the surfactant, and controlling pH.

In another experimental study cerium oxide (CeO_2) and zinc oxide (ZnO_2) nano additives mixed with grapeseed oil biodiesel in various concentrations (50 PPM and 100 PPM) have been analyzed to enhance the oxidation stability [12]. They analyzed zinc oxide (ZnO) and cerium oxide (CeO_2) nanoemulsion in which nano additive mixed with water and then fuel blend prepared by grapeseed oil biodiesel after mixed with nanoemulsion, 1% span, and 80% surfactant. They found different thermophysical properties than diesel fuel but these fuel blends have some issues like gumming problems, injector fouling issues, and atomization difficulties. The issues problem is solved by the transesterification process, it enhances the properties of fuel blends [13]. It is also found that converting grapeseed oil into biodiesel through different processes by some researchers [12,14]. They have used base catalyst transesterification, thermal cracking, and pyrolysis. Gumus et. al [10] found diminishing the BSFC, increment into brake thermal efficiency and decreasing the pollution content into single-cylinder direct injection CI engine at various loads. Another research depicted soyabean methyl ester and zinc oxide nano additive into VCR diesel engine at different loads. They used the fuel in three concentrations 25, 50, 75 PPM. They added sodium dodecyl sulphate for changes in stability and surface of the fuel and decreases the surface tension into fuel blends. They defined also nanoparticle mixed for increasing flash point, fire point, calorific value, and reducing the viscosity and density of the fuel. Then the results found better combustion of fuel and it improves the performances and reduces the emission of engine. In a review, the comparison between the properties of microparticles and nanoparticles has been expressed. Due to the immense surface-to-volume ratio, better thermophysical properties, and excessive thermal conductivity, the nanoparticles give better results than microparticles [15]. In another research, Nayak et. al. [16] also experimented with zinc oxide (ZnO) with waste cooking oil. They also experimented with aluminum oxide (Al_2O_3) and graphene oxide (GO) in their research. They performed on diesel engine at 1500 RPM, 200 bar pressure and 23^0 fuel injection before top dead center on 0 to 100% load. They used the transesterification process for preparing the biodiesel and ultrasonication for preparing the nano fuel blends. They found the better performance for graphene oxide in comparison to other nano fuel blends but the emission is lowered after being used to zinc oxide fuel blends as compared to other fuel blends at all loads.

Another experiment on zinc oxide (ZnO) nano additive with diesel fuel was carried out [1]. They mix the zinc oxide (ZnO) in 250, 500 and 1000 PPM concentrations. They analyzed the performance and emissions at different speeds (1500 to 300 RPM), compression ratios (15.5 to 20.5) and fuel injection timing (19.5 to 24.5 degrees) before top dead center. It was found better performance with zinc oxide nano fuel at 1000 PPM concentration on maximum speed (3000 RPM), compression ratio (20.5) and 24.5^0 fuel injection timing. They used the Lamborghini direct injection diesel engine for their experimental study. Some numerical simulations for better emission and performance results were carried out and compared the experimental and numerical results in some studies [1,17,18]. In this study, solved the governing equations using with diesel RK software which is defined by Fiveland and Assains [1,19,20]. Magnesium oxide (MgO) and algae oil biodiesel were analyzed in a four-stroke single-cylinder diesel engine which performed on 1500 RPM, 17.5:1 compression ratio, fuel injection timing of the engine set on 23.5^0 before top dead center and cylinder pressure at 200 bar [21,22]. In this study biodiesel fuel blends (B20) were prepared with 20% biodiesel and 80% diesel fuel after that they mixed 25, 50, 100 PPM magnesium oxide (MgO) into B20 fuel blends and used the transesterification process. They convert methyl ester by FT-IR spectroscopy method in their research and pretending of nanoparticles using SEM and EDS techniques. They observed the better performance on MgO nano fuel blends and reduction in the HC, CO and smoke as compared to B20 biodiesel. However, they observed enhancement into NO_X emission after using MgO nano fuel blend as compared to B20 biodiesel. In an experimental study non-metal oxide nanoparticle graphene oxide (GO) with Oenothera Lamarckian biodiesel (B20) in which nanoparticles were mixed in 30, 60 and 90 PPM concentrations [23]. They mentioned in their work that the preparation of nano fuel blend by ultrasonication process. They used the fuel blend after mixing with Graphene oxide (GO) into biodiesel (B20) and compared its results to pure diesel. They also mentioned in their work the preparation process of nano fuel using with catalyst and it resulted after reacting with alcohol and triglyceride [24,25], Which resulted an improvement in brake power, exhaust gas temperature, and deterioration in CO_2, CO, unburnt hydrocarbon, and NO_X. In a study, Agbulut et.al. [26] also experimented with diesel fuel and copper oxide (CuO) in 1000 PPM and 2000 PPM concentrations. They analyzed the performances and emission results on different speeds (2000 to 3000 RPM) with 250 RPM. They mentioned in their research work after mixing the 2000 PPM copper oxide that no clogging issue in filter and fuel injection was found. They prepared fuel for their research by ultrasonication process. They compare the cylinder pressure, Exhaust gas temperature, brake specific fuel consumption, brake thermal efficiency, HC, CO, CO_2 and NO_X results to the diesel fuel. They get better performances, combustion process and reduction in emissions. They defined in their study about heat release rate begins at the start of combustion [27], the lag between negative heat-releasing rate improves when injection value in starting treated as crank angle and the difference between the start of combustion and start of injection at a speed indicates the injection delay [28,29].

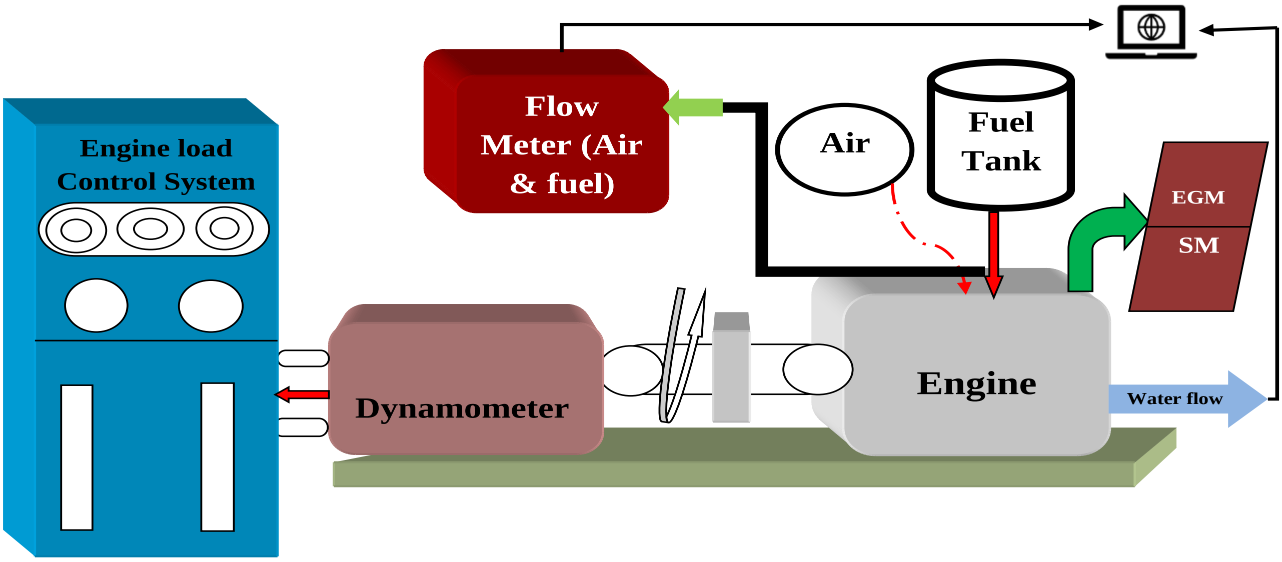


Figure 1 Compression Ignition engine experimental set up.
* EGM – Exhaust gas measuring device, SM- Smoke meter, Flowmeter- for air and fuel both.

Table 1 Some experimental work of available data for metal oxides and non-metal oxide-

Sr. No.	Researcher, year	Nanoparticle with biodiesel	Working on	Summary of work and Results
1.	[30]	ZnO + Neo Chloris oleoabundans algae oil (B20), 50,75,100 PPM	Overall efficiency, BSFC, HRR, CP	In this research, the algae oil biodiesel was used in different concentrations. The fuel is prepared by the ultra-sonication process. The diesel was used for experimental analysis. The results reported that increasing into performance and combustion of the engine.
2.	[7]	ZnO + Cottonseed oil, 80 PPM	BSFC, BTE, CP, NO_X, CO, HC	In this research, biodiesel is prepared by the trans-esterification process. Four-stroke diesel engine used for experimental works. The results reported increasing the performances and reducing the emissions.
3.	[8]	Fe_2O_3 / ZnO / SiO_2 + D75NB25+Neem oil, 200 PPM	BSFC, BTE, NO_X, CO, HC	This research investigated the addition of ZnO, Fe_2O_3, SiO_2 with neem biodiesel and compared the results. The fuel is prepared by ultrasonication. A twin-cylinder water-cooled diesel engine was used. The results observed after mixing ZnO, Fe_2O_3 is better than SiO_2 nano additive in performances and emissions.
4.	[16]	ZnO / Al_2O_3 / GO + waste cooking Oil (BD),	BSFC, BTE, NOx, CO, HC	This experimental test was done on the single-cylinder CI engine at 1500 RPM speed. In this experiment, fuel was prepared by transesterification process after mixing 20% WCO and 80% diesel. The result reported that HC, CO, NO_X is reduced performance is increased.
5.	[1]	ZnO, 250, 500, 1000 PPM	BSFC, BTE, EGT, NO_X, SPM, SO_2, CP_{MAX}, ID	In this experimental research, the work is carried out on diesel engines at different speeds (1500-3000 RPM), compression ratio (15.50 to 20.50) and fuel injection timing (19.5^0 to 24.5^0). The nano fuel blend is prepared by an ultra-sonicator. The results of performance and emission were shown on different speeds, compression ratios and fuel injection timing. They also used simulation for numerical analysis.
6.	[9]	Al_2O_3 + Butanol - Diesel blend (B20), 30, 50, 100 PPM	BSFC, BTE, CP, HRR, NO_X, CO, HC, PM	In this research, the nanoparticles were used in the absence of surfactants. The direct injection four-stroke water-cooled diesel engine runs at 1800 RPM were used for experimental works. The result is that it enhances the performance, maintains good combustion, and reduces emissions.
7.	[10]	Al_2O_3, 25, 50, 75, 100 PPM / CuO, 50 PPM + Diesel	BSFC, NO_X, CO, HC	In this numeric experimental study physicochemical properties of nanoparticles were examined and observed the stability of nano fuel. The experiment was performed on water-cooled four-stroke diesel engines. This resulted in a reduction in performance (BSFC) and emissions of the engine.
8.	[31]	ZnO, 25, 50, 75 PPM + Soyabean oil BD	BSFC, BTE, HRR, NOx, CO_2, CO, HC	In this experimental work, soyabean oil BD with zinc oxide nano additives were used in different concentrations in the VCR diesel engine. The results were tested at various concentrations and different compression ratios 18.5 and 21.5 at different loads. In this research, fuel was prepared by sodium dodecylbenzene sulphonate surfactant in an ultrasonicator. Better results were found on the use of ZnO nano additive with maximum compression ratio. It resulted in that improvement in performances and decreased the CO, CO_2 and HC emission except for NO_X emission of the engine.
9.	[26]	CuO, 1000, 2000 PPM + Diesel	BSFC, BTE, NOx, CO, HC	In this study, the experimental work is based on a high concentration of nanoparticle blends. The fuel is prepared by ultrasonication process. In this study the combustion property was analyzed with regards to crank angle, performances and emissions of engine analyzed at different speeds. The results were found that better combustion, performances and diminishing into emissions according

				to the concentration increase into fuel.
10.	[32]	CuO, 25, 50, 75, 100 PPM + algae oil BD + Diesel	BSFC, BTE, CP, HRR, NOx, CO, HC	This research used algae oil biodiesel (B20) and diesel fuel along with copper oxide nano additives. All experiments were done with Kirloskar four-stroke diesel engine. The fuels were prepared by ultrasonication process. They compare the results of nano fuel with diesel and B20 fuel. They found good performance, combustion and influential reduction in CO, and HC. However, they find more than the emission of NO_X with nano fuel from diesel and B20 fuels. They measured combustion parameters with crank angle and performances with loads.
11.	[23]	GO, 30, 60, 90 PPM + Oenothera lamarckiana BD	BTE, CP, HRR, NOx, CO_2, CO, HC	This experiment is done after using graphene oxide nanoparticles in the concentrations of 30, 60, 90 PPM with Oenothera Lamarckian biodiesel. They used the transesterification process for the preparation of fuel. They compare the results with used three types of fuel in the Lamborghini diesel 3LD 510 engine at 2100 RPM. They analyzed the performance and emissions of the engine.

2. Properties of Nanoparticles-

The properties of nanoparticles are summarized in this review. In recent years, a hike in the cost of fossil fuel and pollution is a major concern. This problem was tackled by researchers by using biodiesel along with nanoparticles that are viable like fossil fuel [1,9,33,34]. Moreover, many researchers are using nanoparticles with biodiesel due to its potential benefits, this led to the ultimate solutions without the modification in the CI engine [1,35]. Due to thermochemical and thermophysical properties, it results in enhancing the performance and control of the exhaust emission. The major challenge is maintaining the stability of blended nanoparticles [14,36,37] and the production of heat due to the presence of oxidizing elements in engines which is reviewed by Bidir et. al. [38].

The different varieties of nanoparticles blended with fuel in different concentrations. There are two types of nanoparticles used in research nowadays are metal oxides and non-metal oxides. The metal oxides are used according to their properties such as excessive surface volume to size ratio, immense surface area and thermal conductivities. When the nanoparticles are added with the biodiesel, it increases the fire point, flash point, density, viscosity and lowers the calorific value which enhances engine performance, reduces the toxicities and helps in the proper combustion process [38–42].

In another review, Saxena et. al. [43] mentioned that for enhancing the properties of the fuel metal nanoparticles are used by the researchers. These are useful for enhancing the performance and combustion process and reducing the harmful emissions from the exhaust. They observed also that metal oxides of magnesium (Mg), iron (Fe), beryllium (Be), copper (Cu), platinum (Pt), aluminum (Al), boron (B), cerium (Ce), etc. are mainly used. These nano additives in fuel helps to enhancing the performance, combustion process, and reduce the ignition delay, and toxic element from the exhaust. It observed that due to thermal conductivity, the immense surface to size ratio and large surface area of ZnO, Fe_2O_3, CeO_2, TiO_2, Co_2O_3, CuO metal oxides used as a fuel additive and photocatalyst [9,44,45]. Fayad et. al. [9] reported also Al_2O_3 nanoparticles mixed with biodiesel without the surfactant because after the addition of surfactants the combustion property will be influenced. Gumus et. al. [10] addressed in their research that metal oxide such as aluminum oxide (Al_2O_3), titanium oxide (TiO_2) and copper oxide (CuO) have the combustion catalyst property due to carrying oxygen content [46–49] which is ascribed to improve the efficiency during the combustion process and decrease the toxicity. They also reported that due to the mixing of very small size nanoparticles, it increased the surface area to volume ratio therefore, it does not clog into filter and fuel injector and more amount of fuel properly reacts with the oxidizer. Gavhane et. al. [31] mentioned the comparison of nanoparticles to microparticles. They defined improvement into the performance but reduced the particle formation after using microparticles but this problem was accomplished by nanoparticles.

3. Properties of Fuel-

The engine required fuel energy for the running of vehicles which are mainly driven from gasoline and diesel. The use of this type of fuel is ascribed for more exhaust emission, lower performance of the engine, combustion and reduced life of the engine. To accomplish these problems the researcher tested biodiesel instead of diesel fuel. The biodiesel is used in the engine without any modification into the CI engine. The preparation of nano fuel is shown in *Figure 2* which is commonly made by mixing the nanoparticles into base fuel (diesel) or biodiesel. Biodiesel is more lubricating than diesel fuel. Biodiesel is a biodegradable renewable source that is produced from the vegetable oils and animal oil such as soyabean, mustard, canola, tallow, pork-lard, etc. and it is also produced by recycling the waste cooking oil. Biodiesel (B20) is produced by using 20% biodiesel and 80% conventional diesel. According to the biodiesel program by the department of agriculture US [50], biodiesel has excessive oxygen content, flashpoints and more cetane numbers as compared to diesel fuels. It is attributed to the proper ignition of fuel. But this idea shows some issues related to the biodiesel being used first time in a diesel engine, it may need to change the fuel filter because the biodiesel is solvent. Many researchers reported cold flow issues while using biodiesel first time. Saxena et.al [43] has been reviewed also in their work that biodiesel has some issues like inflexible environmental norms, less calorific value and cold flow properties. They also described the reason for mixing the nanoparticles to resolve these issues. After mixing the nanoparticles into biofuels, the nano fuel properties are better than diesel and it is viable like diesel fuel. Moreover, they described improvement in the stability of nano fuel [1,51,52]. Gavhane et. al. [31] expressed in their research article to enhance the performance of the engines and reduce the toxicity by using alcohol-based additives in biodiesel such as butanol, ethanol, diethyl ester, etc. [53]. Its consequence in decreasing the emission due to higher reaction with oxygen, less calorific value, lubrication properties and low creation of lean mixture of fuel results in a decrease in the performances of engine. However, the enhancement in engine performance has been analyzed first by Eastman n.d. [54].

In the research article [16] and [55] mentioned the production of biodiesel vegetable oil, alkyl ester of fatty acids such as soyabean oil, rapeseed oil, sunflower, castor oil, palm oil and animal oil such as pork lard, chicken, etc. but the cost of vegetable oil is high in comparison to animal oil biodiesel. In a study the drawback of using biodiesel is the enhancing emission of nitrogen oxides were mentioned [23,56,57].

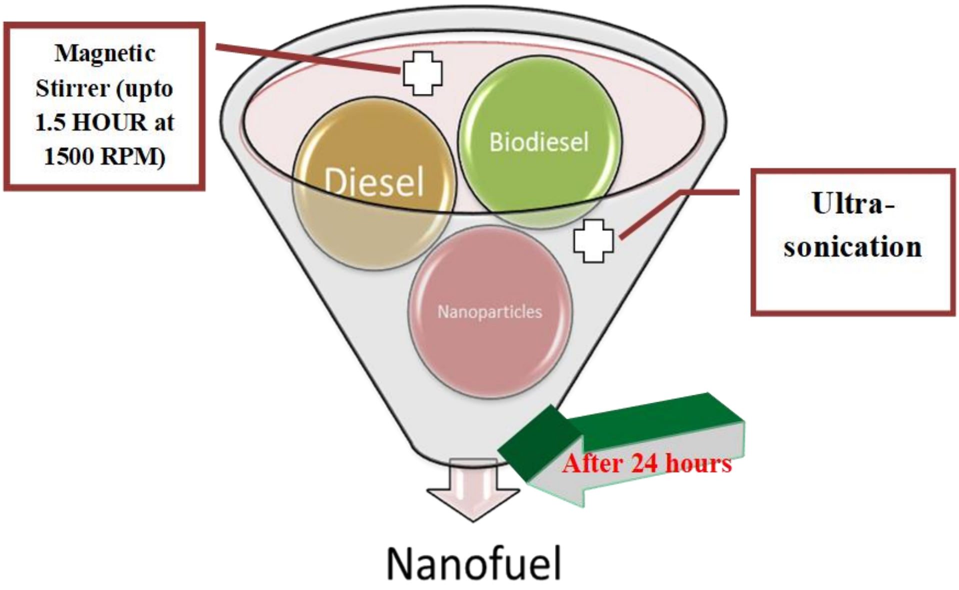


Figure 2 Nano fuel preparation common Process.

The cost of biodiesel is less than diesel. The alternative fuel price report by the US Department of Energy, it depicted the national average retail fuel price on October 15, 2021. The department had also shown a comparison between the prices of fuels and compared the price of biodiesel (B20) and diesel fuel in

Table 2 along with region-wise variations shown in Comparison between average prices by region of B20 fuel and diesel fuel:*Table 3*.

Table 2 List of different fuels National average retail fuel price (include public and private stations)-[50]

Conventional And Alternative Fuel, October 2021			
SR. No.	**Fuel Type**	**Price on October 15, 2021 (in INR)**	**Units of Measurement**
1.	Petrol or Gasoline	248.43	Per gallon
2.	Diesel	236.93	Per gallon
3.	Ethanol (E85)	205.94	Per Gasoline gallon equivalent
4.	Liquified Natural Gas (LNG)	174.49	Per Diesel gallon equivalent
5.	Compressed Natural Gas (CNG)	204.34	Per gallon
6.	Propane	237.40	Per gallon
7.	Biodiesel (B20)	246.38	Per gallon
8.	Biodiesel (B99/B100)	284.58	Per gallon

Table 3 Comparison between average prices by region of B20 fuel and diesel fuel:[50]

Average Retail Prices by Region			
SR. No.	**Region**	**Biodiesel (B20) Prices (INR/gal)**	**Diesel Prices (INR/gal)**
1.	Lower Atlantic	199.95	250.13
2.	Central Atlantic	221.67	244.89
3.	New England	210.44	255.37
4.	Midwest	244.14	253.12
5.	Rocky Mountain	274.09	265.11
6.	Gulf Coast	236.65	231.41
7.	West Coast	309.29	328.01
	NATIONAL AVERAGE PRICE	**246.38**	**260.61**

These are region-wise prices difference between biodiesel and diesel. Thus, biodiesel is used in CI engines according to their properties mentioned in Table *4*. The fuel properties measure according to ASTM standards after mixing the nano additives at different concentrations. In this study compare the properties between biodiesel and Diesel after the addition of nanoparticles into fuel.

Table 4 Variation in fuel properties of different metal oxide and non-metal oxide nanoparticles additive when mixed with different concentrations into various types of base fuel-

Sr. No.	**Nanoparticles, concentration**	**Base fuel/ Biodiesel**	**Properties of Fuel**					**Author/ Reference**
			Viscosity (CST)	**Flash Point (^{0}C)**	**Calorific Value (MJ/kg)**	**Fire Point (^{0}C)**	**Cetane number**	
1.	Al_2O_3, 30 PPM	B20	3.126	82	45.32	87	54.6	[9]
	Al_2O_3, 50 PPM	B20	3.064	83	46.47	88	55.7	[9]
	Al_2O_3, 100 PPM	B20	2.846	85	46.57	91	58.3	[9]
2.	CuO, 50 PPM	Diesel	3.5	66	-	-	54.5	[10]
	Al_2O_3, 25 PPM	Diesel	3.5	66	-	-	54.3	[10]

	Al_2O_3, 50 PPM	Diesel	3.5	68	-	-	54.4	[10]
	Al_2O_3, 75 PPM	Diesel	3.5	68	-	-	54.4	[10]
	Al_2O_3, 100 PPM	Diesel	3.6	69	-	-	54.6	[10]
3.	Al_2O_3, 3g	Waste cooking Oil	6.91	100	52.53	140	-	[16]
	ZnO, 3g	Waste cooking Oil	6.45	84	54.2	88	-	[16]
	GO*, 3g	Waste cooking Oil	4.75	100	55.57	140	-	[16]
4.	ZnO, 40 PPM	Cottonseed Oil (B20)	5.83	150	37.2	-	51.48	[7]
	ZnO, 80 PPM	Cottonseed Oil (B20)	4.01	98	39.2	-	51.48	[7]
	ZnO, 120 PPM	Cottonseed Oil (B20)	2.58	68.56	42.02	-	54.96	[7]
5.	ZnO, 200 PPM	B25(Neem Oil)	4.7	106	42.07	-	-	[8]
	Fe_2O_3, 200 PPM	B25 (Neem Oil)	4.8	101	43.81	-	-	[8]
	SiO_2, 200 PPM	B25 (Neem Oil)	4.6	103	42.67	-	-	[8]
6.	Al_2O_3, 30 PPM	B20 (butanol-diesel)	3.126	82	45.32	87	54.6	[9]
	Al_2O_3, 50 PPM	B20 (butanol-diesel)	3.064	83	46.47	88	55.7	[9]
	Al_2O_3, 100 PPM	B20 (butanol-diesel)	2.846	85	47.47	91	58.3	[9]
7.	ZnO, 50 PPM	GSBD	4.40	-	38.78	-	58	[12]
	ZnO, 100 PPM	GSBD	4.42	-	38.9	-	59	[12]
	CeO_2, 50 PPM	GSBD	4.45	-	38.55	-	56	[12]
	CeO_2, 100 PPM	GSBD	4.47	-	38.76	-	57	[12]
8.	ZnO, 25 PPM	Soyabean methyl ester	3.52	48.66	43.4	-	52.55	[31]
	ZnO, 50 PPM	Soyabean methyl ester	3.525	52.55	44.8	-	53.74	[31]
	ZnO, 100 PPM	Soyabean methyl ester	3.531	53.74	43.85	-	53.15	[31]
9.	ZnO, 250 PPM	Diesel	3.1	46.3	-	-	55.1	[1]
	ZnO, 500 PPM	Diesel	3.22	46.8	-	-	55.6	[1]
	ZnO, 1000 PPM	Diesel	3.31	47.6	-	-	56.1	[1]
10.	CuO, 25 PPM	Algae oil BD + Diesel	5.17	175.5	44.6	-	54.5	[32]
	CuO, 50 PPM	Algae oil BD + Diesel	564	176	45.62	-	54.75	[32]
	CuO, 75 PPM	Algae oil BD + Diesel	5.66	176.5	45.92	-	55	[32]
	CuO, 100 PPM	Algae oil BD + Diesel	5.68	177	46.9	-	55.5	[32]
11.	GO, 30 PPM	Oenothera lamarckina BD	5.61	-	44.01	-	-	[23]
	GO, 60 PPM	Oenothera lamarckina	5.54	-	44.37	-	-	[23]

		BD						
	GO, 90 PPM	Oenothera lamarckina BD	5.55	-	44.29	-	-	[23]
12.	CuO, 1000 PPM	Diesel	3.22	-	47.14	-	-	[26]
	CuO, 2000 PPM	Diesel	3.31	-	48.34	-	-	[26]

*** non-metal oxides**

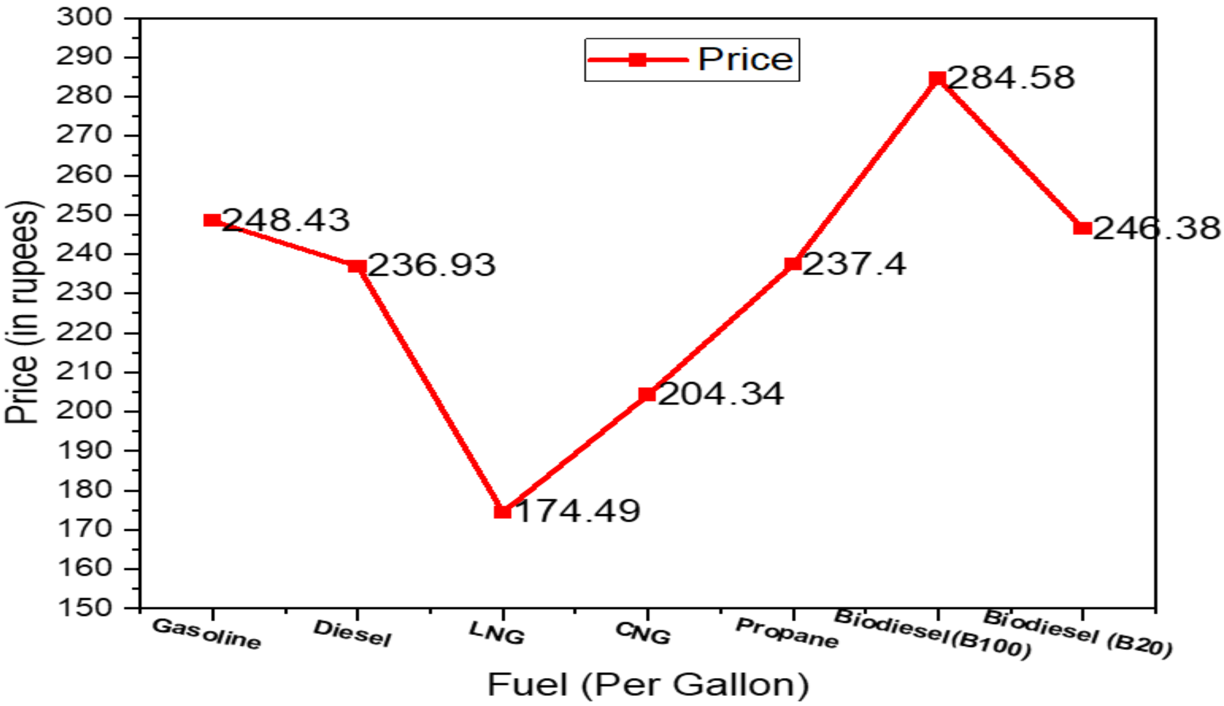


Figure 3 Average retail price of fuels on October 15,2021.

4. Results

Table 5 Comparison of the effect of adding different nanoparticles additive into base fuel-

Sr. No.	Researcher, Year	Nano Additive, Size	Fuel, Concentration	Fuel preparation process	Performance (Maximum %, for the increase ↑ and or decrease ↓ on full load)				Combust-ion		Emissions				Density
		(In nm)	(In PPM)		BP	η_o	BSFC	BTE	CP	HRR	NO_X	CO_2	CO	HC	Kg/m^3
1.	[3]	CeO_2, 10-20nm	Jatropha BD, 40 PPM & 80 PPM	Ultrasonic shaker	-	26%↑	↓	1.5%↑	-	-	30%↓	-	-	40%↓	7.13 g/ml
2.	[4]	TiO_2, 10-20nm	Diesel + ether, 80, 250, 500 PPM	Probe-sonicator	-	-	21.28% ↓	0.9% ↑	-	-	32.2% ↑	16% ↑	25% ↓	18.36 % ↓	4.26 g/ml
3.	[5]	TiO_2, 20-25nm	Dairy scum BD, 125-375 PPM	Sol-gel techniques	-	1.97% ↑	1.47% ↓	31.21% ↑	-	-	1.85% ↓	6.17%↓	37.5 % ↓	36% ↓	-
4.	[30]	ZnO, 50-100nm	Neo Chloris oleoabundans algae oil (B20), 50,75,100 PPM	Ultra-sonication	-	↑	↓	-	4.5 % ↑	35^0c ↑	-	-	-	-	860
5.	[7]	ZnO, <100nm	Cottonseed oil, 40, 80, 120 PPM	Transesterification process	-	-	36.30% ↓	36.22 % ↑	1.006% ↑	-	24.61 % ↓	-	22.91% ↓	78.70 % ↓	826
6.	[8]	ZnO, <50nm	D75NB25(Neem oil), 200 PPM	Ultra-sonication	-	-	12.54% ↓	35.1% ↑	-	-	1.22% ↑	-	0.05 % ↓	0.869 % ↑	857
7.	[8]	Fe_3O_4, 50-100nm	D75NB25(Neem oil), 200 PPM	Ultra sonicator	-	-	0.971% ↓	34.6% ↑	-	-	1.16% ↑	-	0.05 %↓	0.758 % ↑	862
8.	[8]	SiO_2, 10-20nm	D75NB25(Neem oil), 200 PPM	Ultra-sonicator	-	-	1.06% ↑	32.38% ↓	-	-	1.03% ↑	-	0.06 % ↓	0.882 % ↑	858
9.	[9]	Al_2O_3, 50nm	Butanol – Diesel blend (B20), 30,50,100 PPM	Ultrasonic mixer	-	-	7.3% ↓	4.7% ↑	6% ↑	13% ↑	12.37 % ↓	-	42.71% ↓↓	37.46 % ↓	887.8
10.	[10]	Al_2O_3, 27-43nm	Diesel, 50 PPM	Sonic VCX 750 model ultrasonic processor	-	-	1.2% ↓	-	-	-	6% ↓	-	11% ↓	13% ↓	834.3

11.	[10]	CuO, 30-50nm	Diesel, 50 PPM	Sonic VCX 750 model ultrasonic processor	-	-	0.5% ↓	-	-	-	2% ↓	-	8%↓	5%↓	834.1
12.	[12]	ZnO, 36nm	Grapeseed Oil BD, 50,100 PPM	Transesterification process	-	-	↓	29.34% ↑	↑	4.14 % ↓	13% ↓	-	4.6 % ↓	31.07 % ↓	850
13.	[12]	CeO_2, 32nm	Grapeseed Oil BD, 50,100 PPM	Transesterification process	-	-	↓	29.23% ↑	↓	0.02 % ↓	5% ↓	-	4.3 % ↓	13.79 % ↓	853
14.	[31]	ZnO, 350-380nm	Soyabean BD, 25,50,75 PPM	Ultrasonication process	-	-	20.37% ↓	23.2% ↑	-	26.71% ↓	58.52 % ↑	21.66% ↓	41.08% ↓	30.83 % ↓	846.86
15.	[16]	ZnO, <100nm	Waste cooking Oil BD, 3g	Transesterification process	-	-	↓	29.9% ↑	-	-	↓	-	↓	↓	827
16.	[16]	Al_2O_3, <100nm	Waste cooking Oil BD, 3g	Transesterification process	-	-	↓	31.81% ↑	-	-	↓	-	↓	↓	833.5
17.	[16]	GO, <100nm	Waste cooking Oil BD, 3g	Transesterification process	-	-	↓	31.52% ↑	-	-	↓	-	↓	↓	833.8
18.	[1]	ZnO, 30-50nm	Diesel, 250, 500, 1000 PPM	Ultra-sonication process	-	-	1.37% ↓	6.59% ↑	-	-	10.83 % ↓	-	-	-	831.4
19.	[23]	GO, 150nm	Oenothera lamarckiana BD, 30, 60, 90 PPM	Ultrasonic process	-	-	-	↑	↑	↑	↑	↓	↓	↓	838
20.	[58]	GO, 23-27nm	Dairy scum oil BD, 20, 40, 60 PPM	Transesterification process	-	-	8.34% ↓	11.56% ↑	-	-	5.62% ↓	-	38.66% ↓	21.66 % ↓	836.5
21.	[22]	MgO, 50-100nm	Naviculla Sp. algae oil B20, 25, 50, 100 PPM	Transesterification	-	-	↓	↑	-	-	↑	-	↓	↓	731
22.	[26]	CuO, <77nm	Diesel, 1000, 2000 PPM	Ultra-sonicator	-	-	8% ↓	14.6% ↑	-	-	4.7% ↓	-	20.8 % ↓	13.4% ↓	831
23.	[34]	CuO, <50nm	Algae oil BD, Diesel, 25, 50, 75, 100 PPM	Ultra-sonicator	-	-	↓	↑	↑	↑	↑	-	↓	↓	831.9

*All data is taken from maximum results in their respective research papers.

5. Effect of different types of nanoparticle diesel/biodiesel blend on engine parameters (Discussions)- There are many effects on the performance and combustion of the CI engine which is different for various nanoparticle blends. In this review maximum of these researches on Kirloskar diesel engine with an average speed of 1500 RPM and at varying load from 0% to 100%. Many of these researchers reported the consequences of engine efficiency cylinder pressure, brake thermal efficiency, brake specific fuel consumption, heat-releasing rate, etc and exhaust emissions.

5.1 Effect of Nanoparticle Additives on Combustion-

5.1.1 Effect on Cylinder Pressure-

In the analysis of the combustion process, the researchers reported the variation in-cylinder pressure according to changes in the size of nanoparticles and the changes in crank angles. According to Kalaimurugan et.al. [30]**,** when the zinc oxide (ZnO) additive is used with algae oil (BD) as fuel into the engine, cylinder pressure rapidly increased due to the pre-combustion of fuel in the combustion chamber. It means that fuel blends which are burned have a high surface-to-volume ratio, high cetane number and evaporation quality resulting in the minimization of the ignition delay of the engine. And on the other hand, when zinc oxide (ZnO) (40ppm, 80ppm and 120ppm) mixed with B20 biodiesel [7] and reported into their work the cylinder pressure rises due to the viscosity of the fuel. They also observed the minimization of ignition delay by the reason of sautan diameter is smaller, breakup length is shorter, dispersion is high and atomization is better after applying 0% to 100% load. Finally, they found ZnO as the better additive for ignition. Fayad et. al. [9] reported that 6% enhancement into cylinder pressure when mixed the Al_2O_3 nano additive with butanol. The Mixing of fuel shows the reduction in ignition delay because the alcohol-borne oxygen content and more heat vaporization enhance the combustion ability in the cylinder. A catalytic effect on the combustion process is shown in the same investigation performed after the addition of Al_2O_3 additive with B20 in 30, 50 and 100 PPM concentrations [9]. Improvement in maximum pressure from 100 PPM ZnO concentration with GSBD due to the immense surface area by which increase the air-fuel mixture and evaporation rate of fuel is resulted increase in the pressure into the cylinder. The cylinder pressure is low after being used to grapeseed oil biodiesel in comparison to neat diesel were observed in an experimental study [12]. This is because the cetane number of GSBD is lower than the diesel. But after mixing zinc oxide and cerium oxide nanoemulsion at 50 PPM and 100 PPM at different loads. It increases the cetane index of fuel due to the presence of water content in nanoemulsion fuel spaying properly and ignited into the combustion chamber which increases the temperature of the cylinder. Due to the catalytic effects, it boosted the reaction rate of oxygen and due to water content, it can control the rising temperature. So, water content and increased cetane index of fuel resulted in the delay in combustion. Hence, the maximum pressure is increased. Agbulut et. al. [26] experimented with diesel fuel and copper oxide in concentration (1000 PPM and 2000 PPM). They found improvement into maximum cylinder pressure till 2000 RPM.

5.1.2 Effect on Exhaust Gas Temperature (EGT)/Rate of Heat Releases (HRR)-

According to Fayad et.al. [9], the rate of heat-releasing is increased due to the excessive chemical reactivity and immense surface area. They mentioned in their study that nanoparticles have the catalytic effect, results that affected the combustion process and increase the rate of heat release after using the Al_2O_3 with 30, 50 and 100 PPM B20 concentration with butanol-diesel blend but the maximum EGT obtained from 100 PPM concentration of nanoparticles. Grapeseed oil biodiesel with zinc oxide and cerium oxide nanoparticles were used in a research work and found that the exhaust gas temperature increases with GSBD in comparison to neat diesel oil [12]. They mentioned also that when the load increases it burn more amount of fuel and it increases the temperature of engines. But when they used the zinc oxide and cerium oxide nanoemulsion in their experiment, they found that the rate of exhaust gas temperature is decreased due to abbreviate ignition delay and excessive calorific value. It enhances the BTE by enhancing the concentration of nanoparticles at various loads and then they found increment into exhaust gas temperature due to its catalytic effect. A study after experimenting with zinc oxide nano additives and soyabean methyl ester fuel blend at different loads and two compression ratios i.e. 18.5 and 21.5 of the engine were reported [31]. They experimented with a VCR diesel engine at a running speed of 1500 RPM. They found improvement in the rate of heat releases due to shortened ignition delay, this causes improvement in combustion rate. Hoseini et al. [23] observed the results of EGT using with GO nanoparticles in 30, 60 and 90 PPM and B20. They observed that Exhaust gas temperature increases with biodiesel and nano additive fuel blend as compared to B20 fuel and neat diesel. The enhancement in heat releases rate after using the GO fuel blends due to more oxygen supplies during combustion, it improved the combustion process of the engine. The results were reported after using copper oxide in higher concentrations (1000 and 2000 PPM) with diesel up to 3000 RPM [26]. They found the improvement in heat-releasing rate till 2000 RPM engine speed due to less duration between premixed combustion. They found 5.8% increment into EGT for 1000 PPM and 11.53% for 2000 PPM for copper oxide nano fuel.

5.2 Effect of Nanoparticle Additives on Performance of Engine-

5.2.1 Effect on Brake Specific Fuel Consumption (BSFC)-

Sajith el. al. [3] investigated in a study adding TiO_2 with diesel and found reduction into BSFC due to proper burning of air and fuel mixture in comparison to diesel. The minimization of brake-specific fuel consumption with the addition of ZnO nanoparticles and cottonseed oil BD was reported [7]. Zinc oxide leads to decreases in the ignition delay due to its oxidation property, it will improve the air-fuel ratio so the overall combustions process is increased. In a study by Khond et. al [8]**,** brake specific fuel consumption was observed after mixing the iron oxide (Fe_3O_4), zinc oxide (ZnO) with neem oil biodiesel (D75NB25) and reported the reduction into brake specific fuel consumption and found increment into BSFC due to addition of silicon dioxide (SiO_2). The lower calorific value, ignition delay and higher combustion rate is ascribed for reducing brake-specific fuel combustion. Fayad et. al. [9] investigated reduction into BSFC when used Al_2O_3 nano additive with butanol biodiesel (B20) because of lower calorific value. Many of the researchers show this trending reason in their research. In another research, the result reported by Gumus et. al. [10] after experimented on single-cylinder diesel engine at various speed with the Al_2O_3 and CuO nano additive, due to reaction of more oxygen and better effect of nanoparticles on the physical properties of nano fuel. It increases the efficiency of combustion. Thus, the BSFC is reduced by 1.2% and 0.5% respectively when compared to neat diesel.

Praveena et. al. [12] expressed in their research that nano fuels are detonated at the microscopic level and the amount of oxygen into Zinc oxide and cerium oxide increases the reaction. Due to the small size of particles, it improves the evaporation rate of fuel and consumes minimum fuel. They also defined that when the concentration of zinc oxide nano additives is rising, it decreases the brake specific fuel consumption at any load which is always lower than neat diesel fuel. In another study, Zinc oxide nano additives were examined with soyabean oil biodiesel at maximum load and different compression ratios [31]. They reported minimum brake specific fuel consumption of 20.37% on maximum load and 21.5 compression ratio with 50 PPM zinc oxide nanoparticles. In this experimental study zinc oxide (ZnO) was mixed with soyabean oil biodiesel in 25, 50 and 75 PPM concentrations. They examined brake-specific fuel consumption at different loads and two compression ratios 18.5 and 21.5. and observed a low amount of fuel consumed which was 20.37% less than soyabean methyl ester biodiesel fuel with 50 PPM concentrations of nano additives at 100% load and 21.5 compression ratio. Another result for zinc oxide with diesel fuel at different compression ratios (15.5 to 20.5), speeds (1500 to 3000 RPM) and fuel injection timing in a gap of 1.5, 250 RPM and 1^0 respectively was investigated [1]. The specific fuel consumption is decreased with all concentrations of ZnO nano additive fuel blend (250, 500, 1000 PPM) at all speeds, compression ratio, and fuel injection timing before the top dead center as compared to diesel fuel. This causes due to mixing of zinc oxide into fuel, the calorific value of the fuel blend is increased which is lower than the diesel fuel [1,20,59]. So, the specific fuel consumption is decreased due to proper fuel consumption at all concentrations of fuel blends. Arunprasad el. al. [22] analyzed with MgO (25, 50, 100 PPM) and algae oil (B20) biodiesel on full load at 1500 RPM speed and found a reduction in BSFC with MgO nanoparticles as compared to B20 fuel due to higher calorific value and high density and lower viscosity of MgO nano additives fuel than B20 [60]. The lower property of B20 causes inferior mixing of air-fuel mixing which creates an offensive stoichiometric ratio of air-fuel mixture and it also makes the rich mixture of fuel. This rich mixture causes imperfect combustion of fuel [61]. Agbulut et. al. [26] analyzed with higher concentrations of copper oxide nanoparticles (1000 and 2000 PPM) with diesel. They found higher BSFC for diesel fuel as compared to CuO nano additive blends. They mentioned as the concentration of CuO is improved, the BSFC deteriorates between 2000 to 2500 RPM. And after 2500 RPM speed the BSFC is increased. This is because the calorific value or heating value is enhanced after adding the nanoparticles into diesel fuel. The heating value improves the combustion rate in the chamber. They mentioned in their study that more amount of fuel was injected for combustion due to lower heating value. So, as the concentration increases the heating value of fuel is increased. It means that diesel fuel has a lower heating value than CuO nano additive fuel blends [62–66]. They mentioned the reason for maximum reduction in BSFC up to 2500 RPM due to the maximum torque of the engine gained up to 2400 RPM speeds [45,67].

5.2.2 Effect on Brake Thermal Efficiency (BTE)-

D'silva et. al. [4]**,** observed the result of BTE by addition of titanium oxide (TiO2) with diesel + ether. They expressed due to better mixing of air and fuel in cylinder causes for proper combustion of fuel. Thus, it improves the BTE. Deepak Kumar et.al. [7] reported an improvement into BTE by the addition of ZnO with cottonseed oil biodiesel due to a lower surface area to volume ratio. Thus, it supplied an excess amount of fuel supplied for mixing with air and fuel It ascribed for proper combustion of fuel which helps to improve in BTE. Khond et.al. [8] compared the results of iron oxide, zinc oxide and silicon oxide blends. After using iron oxide (Fe_3O_4) and zinc oxide (ZnO), they reported an increment in the brake thermal efficiency because increasing in evaporation rate [47]. Due to the increased evaporation rate the complete combustion of fuel had been done into the engine cylinder, hence the brake thermal efficiency is increased. However, decreasing in brake thermal efficiency after using silicon dioxide. Fayad et. al. [9] reported also that increment into BTE after using Al_2O_3 with butanol blends because immense alcohol fuel-borne oxygenates emphasize the combustion efficiency so BTE is improved [66]. Praveena et. al. [12] mentioned that when the load increases then it consumed excess fuel and then it resulted in improvement in BTE. They observed in their experimental study after using the grapeseed oil biodiesel with zinc oxide and cerium oxide nanoparticles nanoemulsion. They observed BTE is 3.25% enhanced with GSBD which is less than diesel. But after mixing the zinc oxide and cerium oxide nanoemulsion into fuel blends it enhanced BTE 29.3% and 29.2% respectively. The reason defined that when the nano additives are mixed with the biodiesel it reduces the calorific value slightly and due to the high catalytic effect of fuel and surface to volume ratio of nanoparticles, this stimulates the hydrogen to split it causes to improve the oxidation of fuel. Due to improvement in the oxidation process, the BTE is increased. In another research soyabean fuel with zinc oxide was tested on 100% loads and different compression ratios i.e., 18.5 and 21.5 [31]. They got 23.2% increment into BTE at 21.5 compression ratio and maximum load with the mixing of 50 PPM zinc oxide nano additives into soyabean oil biodiesel. They also mentioned in their research that if the compression ratio of fuel blends increases then the brake thermal efficiency increase. The enhancement of brake thermal efficiency ascribed to less ignition delay, improvement of temperature and pressure into the cylinder and excessive amount of heat releases after mixing the zinc oxide nanoparticles. Rajak et. al. [1] also experimented with zinc oxide nano additives in 250, 500, 1000 PPM concentrations on six different compression ratios (15.5 to 20.5) in the gap of 1.5, speeds (1500 to 3000 RPM) in the gap of 250 RPM and fuel injection timing in the gap of 1 degree. They observed higher brake thermal efficiency on all fuel blends in comparison to diesel fuel. After addition zinc oxide nano additive into diesel fuel, it enhances the combustion behaviors of nano fuel [1,47]. They mentioned that the reason is excessive calorific value also. The calorific value is rapidly increased after mixed zinc oxide nanoparticles into diesel and the effect of this proper combustion may occur so the engine consumed low fuel and brake thermal efficiency is enhanced [1,68,69]. Arunprasad et. al. [22] experimented with magnesium oxide (25, 50, 100 PPM) and algae oil biodiesel at 1500 RPM speed. They found an improvement in brake thermal efficiency in comparison to B20 biodiesel. The reason is mentioned for improved efficiency due to higher heat release rate during combustion of fuel compared to the B20 blend. Agbulut et. al. [26] carried out their research on higher concentrations of copper oxide nanoparticles (1000 and 2000 PPM) with diesel fuel. They found an increment in brake thermal efficiency as compared to diesel fuel due to better catalytic system larger surface to volume ratio and better thermal conductivity improves the heating value and increment into cetane number, it also enhances the combustion rate because more oxygen supplies into the chamber for propagation [44]. They found 5.5% enhancement for 1000 PPM copper oxide fuel and 14.6% enhancement for 2000 PPM copper oxide nano fuel.

5.3 Effect of Nanoparticles Additives on Engine Emissions-

Now a day's the world is fully dependent on fossil fuel, it is the main factor for enhancing pollution. So, for reducing the exhaust pollutant in the atmosphere, many researchers think about alternatives to this fuel. So according to the properties of biodiesel and nanoparticles they used it in their research. These exhaust pollutants are harmful to the environment, ozone and human health so the use of many types of nanoparticles with biodiesel for reducing the carbon mono-oxide (CO), carbon dioxide (CO_2), hydrocarbon (HC), oxides of nitrogen (NO_X), and particulate matter (PMM) from the environment.

5.3.1 Effect on Oxides of Nitrogen (NO_X) Emission-

The oxides of nitrogen measured after using many nanoparticles blends on various load into the combustion-ignition engine. D'silva et. al. [4] observed an increment in NO_X emissions after adding TiO_2 with diesel at maximum load. Sunil Kumar et. al. [5] investigated after using the TiO_2 nanoparticles (125 PPM, 250 PPM & 375 PPM) blends with biodiesel. They found NO_X emission is 1.85% reduced than B20 in 375 PPM TiO_2 blends and at full load. Deepak Kumar et.al. [7] observed a reduction in NO_X with ZnO fuel blends due to lower ignition delay. They also analyzed ZnO is a good absorber of oxygen content and gives a good air-fuel mixture for proper combustion. According to Khond et. al. [8], the emission of nitrogen oxide is high when they used iron oxide and zinc oxide this is because when iron oxide and zinc oxide are mixed with the fuel then due to huge density and immense oxidation, the magnitude of nitrogen oxide is high and when they investigated after mixing silicon oxide in fuel, they found small change into emission. Due to diminutive oxidation, the emission is reduced in comparison to iron oxide and zinc oxide additives. According to Fayad et. al.'s [9] observation, it can say that the Al_2O_3 with butanol mixer of fuel is the alternative of cerium oxide and Jatropha oil biodiesel mixer for reducing the NO_X emissions which is 12.3%. The NO_X is increased on maximum load because the burning of fuel in the chamber increases the temperature but after mixing the Al_2O_3 nano additive with butanol, blended fuel has higher thermal conductivity [70]. So, it reduces the temperature into the chamber due to the suck-up temperature by alcohol fuel-borne oxygenates. Gumus et. al. [10] expressed after using the Al_2O_3 and CuO nanoparticles in single-cylinder diesel engine. The NOx emissions and brake mean effective pressure

(BMEP) is increased for all types of fuels because due to proper combustion the temperature will increase into the cylinder. But after the addition of oxygenates, it reduces the NOx in comparison to neat diesel.

In another research, the NOx emission was depicted by Praveena et. al. [12] after using grapeseed oil biodiesel with zinc oxide and cerium oxide nanoemulsion. They observed NOx is increased as well as increment of load on using GSBD in comparison to neat diesel because biodiesel has the higher oxygen content then the temperature is high during combustion. Thus, they used zinc oxide and cerium oxide nanoparticles in their research. After use, it controls the rising temperature during combustion due to its good catalytic effect. By the mixing of nanoemulsion, the water content into the fuel blend evaporates rapidly. Therefore, it diminishes NOx emissions. They also mentioned, for reducing the huge amount of NOx used through EGR techniques and also attaching some devices like SCR, PDF and DOC can be further used. The result of Zinc oxide on 25, 50 and 75 PPM with soyabean methyl ester biodiesel was observed in another research [31]. But they found a 58.52% improvement in NO_X emission due to rising pressure and temperature into the cylinder. Another experiment on zinc oxide + diesel nano fuel in the concentration of 250, 500 and 1000 PPM at different speeds, compression ratios and fuel injection timing was carried out by Rajak et. al. [1] for measuring NO_X emission. They reported minimum NO_X at the 2500 RPM speed. The maximum NO_X emission was observed with a 1000 PPM concentration of ZnO nano additives at a maximum speed of 3000 RPM. The reason for the increment in the NOx emission rapidly after using the 1000 PPM nano fuel blend is because the 1000 PPM ZnO fuel blend has excessive heating value then the pressure inside the cylinder is enhanced. Thus, the NO_X is improved [1]. In a Study the result of NO_X at the different compression ratios (15.5 to 20.5) was observed. They mentioned that improvement in emission depends upon the different compression ratios [1,71,72]. They found the highest emission of NO_X at a high compression ratio (20.5) and minimum emission at minimum compression ratio (15.5), this is caused due to the temperature into the combustion chamber being reduced with decreasing the compression ratio. Hence, the NO_X emission is reduced. Arunprasad et. al. [22] analyzed a study with magnesium oxide (25, 50 and 100 PPM) and algae oil biodiesel (B20). They found more oxygen content after mixing the nano additive than B20 fuel. Thus, it causes for reducing the temperature of exhaust gas than B20 [73].

Another experiment on NO_X emission is done [23] after using graphene oxide with B20, B20 and neat diesel. They found increment into NO_X after using GO nano additive fuel blends. This result shown fewer increment than the neat diesel fuel. The reason which is mentioned by the author in their research is due to more oxygen supplies by the nano fuel blend. More oxygen into the chamber improves the temperature inside the cylinder as compared to B20 and neat diesel fuel [74]. However, due to this effect Combustion process is increased but NO_X is also increased for GO nano fuel blends. Agbulut et. al. [26] explained NO_X emission using copper oxide nanoparticles blends in higher concentrations with diesel fuel. They reported after adding the nanoparticle in diesel fuel improves the cetane number of fuels. A higher cetane number of fuels ignited faster than diesel fuel thus, it resulted in higher heat-releasing rate [49]. So, the NO_X emission decreased 4% for 1000 PPM and 6.6% for 2000 PPM for nano fuel.

5.3.2 Effect on Carbon Mono-Oxide (CO) Emissions-

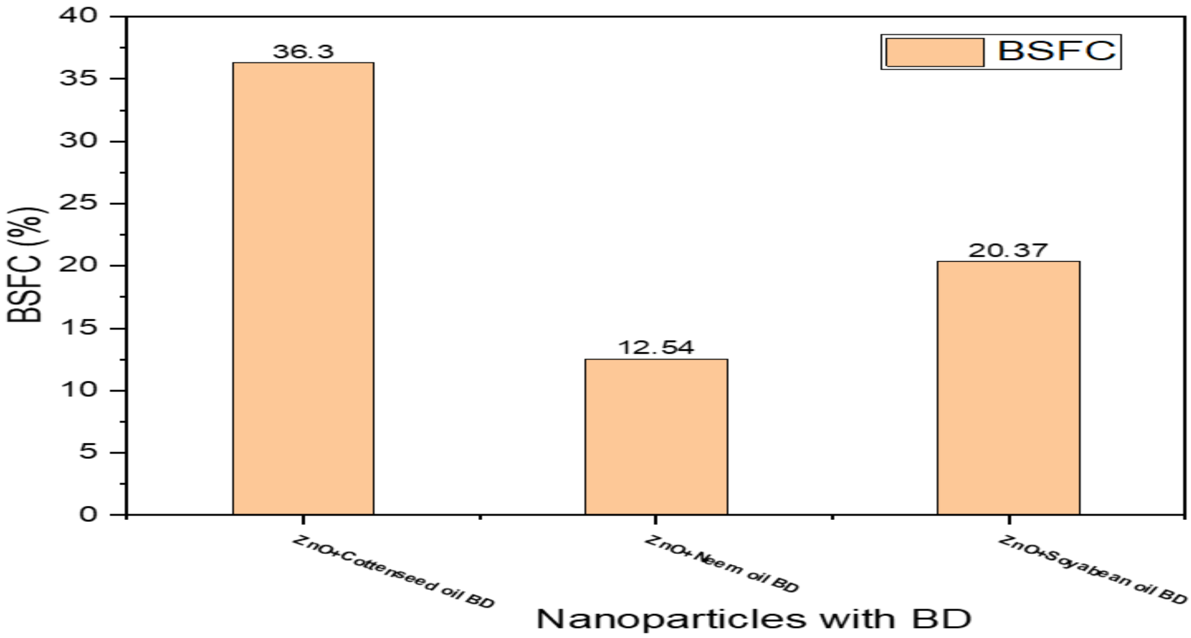
Carbon monoxide is one of the harmful gases of exhaust emissions. The carbon monoxide changes into carbon dioxide in the availability of extensive oxygen into the combustion chamber. D'silva et. al. [4] addressed reduction in CO using TiO_2 with diesel at maximum load. Sunil et. al. [5] found 37.5% lower CO in used 125 PPM TiO_2 blends as compared to B20 fuel. Khond et. al. [8] reported diminishing carbon monoxide (CO) emissions on maximum load in their research after analyzing iron oxide, zinc oxide and silicon oxide nanomaterials blends. They gave the reason that due to the low amount of oxygen content; it affected the conversion of CO into CO_2 [75] and due to the catalytic effect, the oxidation of CO is improved. Fayad et. al. [9] investigated deterioration into CO content is 42.71%. It depends on the material surface area which is added with fuel. They observed the improvement in the surface area which increases the process of combustion and then reduces the content of CO from the exhaust. In the other experimental study Gumus et. al. [10], reported CO emission is decreased after mixing the Al_2O_3 and CuO nanoparticles into fuel because of proper spreading of the fuel in the combustion chamber and due to shorter ignition delay with Al_2O_3 nanoparticles. It causes the proper burning of fuel in the combustion chamber. Thus, it diminished the CO (11%) content more than CuO (8%). Another result of carbon mono-oxide emission was observed by Praveena et. al. [12]. They depicted that CO content is 10.4% decreased as compared to neat diesel fuel on used to neat grapeseed oil biodiesel. it causes more amount of oxygen content in biodiesel thus; fuel was properly combusted. They observed with zinc oxide nanoemulsify fuel blends with concentrations of 50 PPM and 100 PPM at various loads. The CO content is decreased up to 2.3% and 4.7% respectively and when observed with cerium oxide nanoemulsion with concentrations of 50 PPM and 100 PPM at different loads, they found decrement in CO up to 1.8% and 2.5% respectively because cerium oxide nanoemulsion gives better atomization process and due to this effect fuel is spreading properly into the combustion chamber.

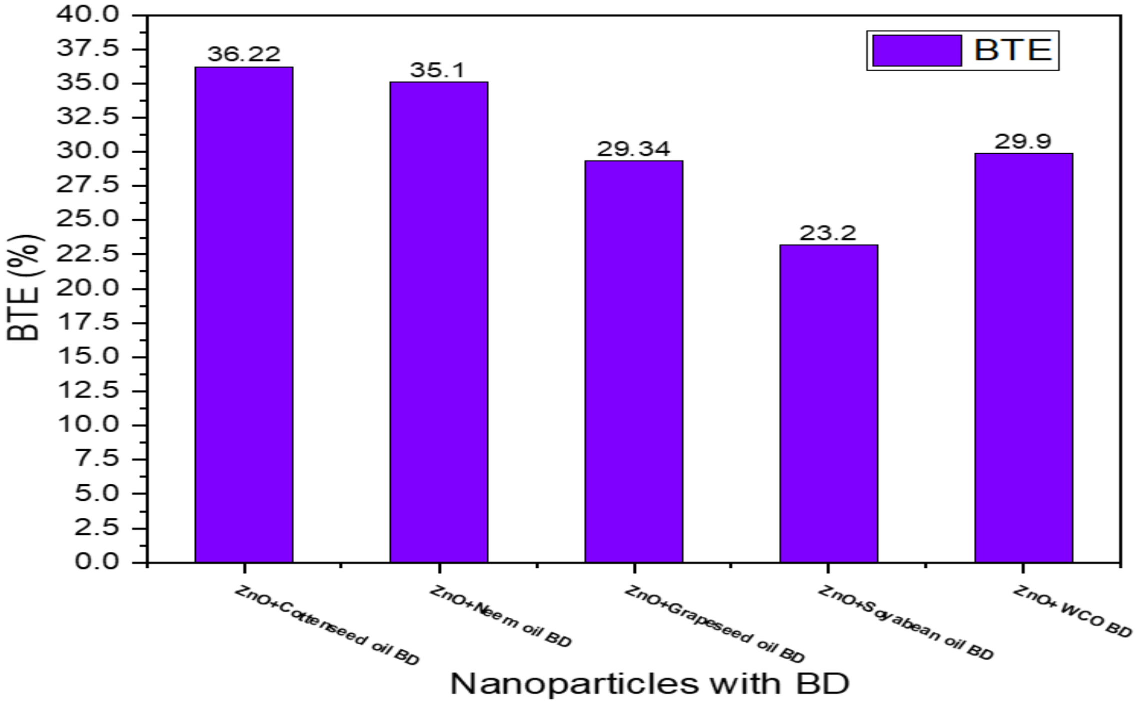
In an experiment also zinc oxide (ZnO) nanoparticles on 25, 50 and 75 PPM with soyabean methyl ester biodiesel by [31]. They examined different loads of the engine and two compression ratios such as 18.5 and 21.5. They found a maximum reduction in CO emission on 50 PPM concentration of zinc oxide nanoparticles at 21.5 compression ratio due to excessive amount of oxygen content the CO is converted into CO_2 [76]. They mentioned that due to excessive oxygen content and reaction of surface area, the pressure and temperature increased into the cylinder and this causes combustion process is completed and CO emission is reduced in comparison to soyabean methyl ester biodiesel. In an experimental work, Arunprasad et. al. [22] used magnesium oxide nanoparticles (25, 50 and 100 PPM) with algae oil biodiesel (B20). They found lower carbon monoxide emissions on MgO nano fuel blends compared to B20. They mentioned the reason that due to better combustion and lesser ignition delay the temperature is increases into the chamber, which was affected by the oxygen content and dwell timing for oxidation for B20 fuel. Thus, the CO emission of magnesium oxide is lower than B20 fuel. Hoseini et. al. [23] analyzed after using the GO in 30, 60 and 90, PPM concentration with B20 and only B20, neat diesel. They compare the results and found that CO emission is increased with GO blended fuel as compared to B20 and diesel fuel. But the very low emission recorded with nano fuel in comparison to B20 with 90 PPM GO nanoparticles but it is more than B20. They mentioned Diesel fuel emission also more than B20 fuel blends. The reason defined by the author is that biodiesel has an excess amount of oxygen content and a higher cetane number [77]. So, improvement of GO nano additives improves CO oxidation and it converts into CO_2.

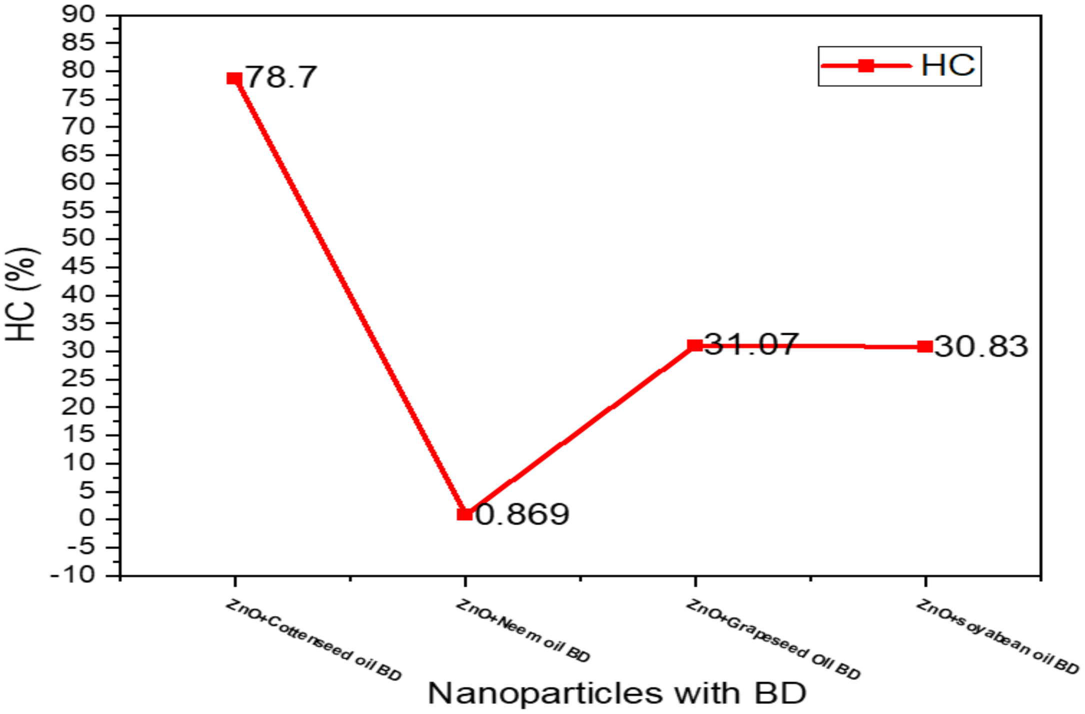
5.3.3 Effect on Unburnt Hydrocarbons (UBHC) Emissions-

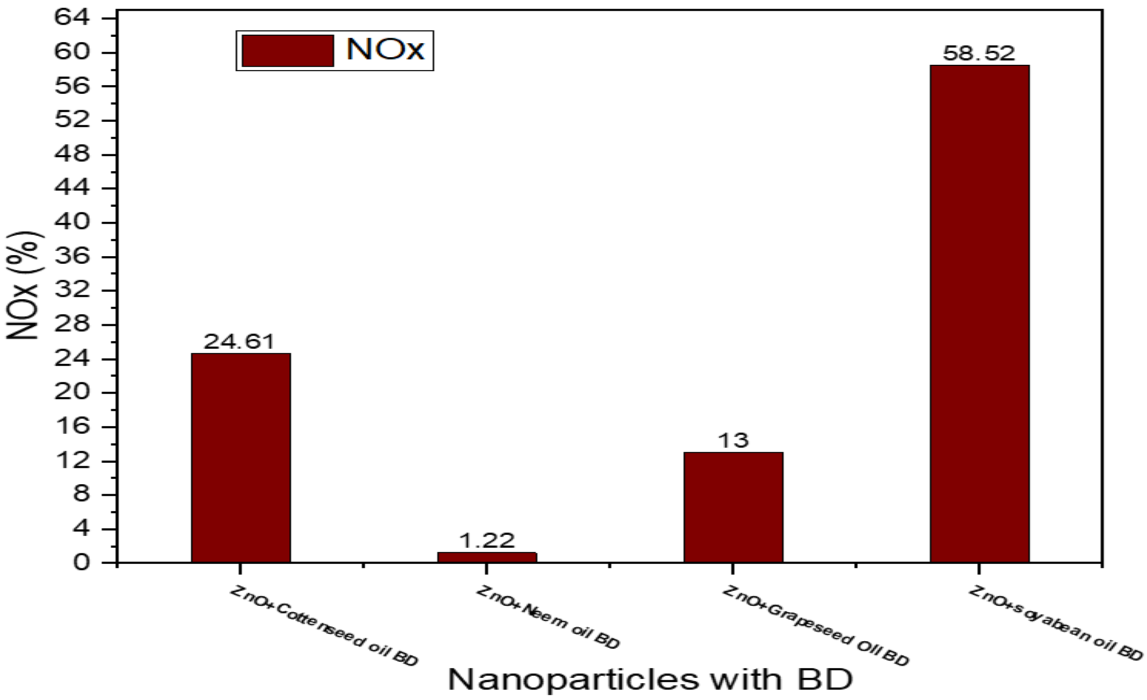
D'silva et. al. [4] analyzed after adding TiO_2 with diesel and found it reduced 18.36% at maximum load due to better oxidation. Sunil et. al. [5] observed the maximum 46% reduction in HC with 125 PPM TiO_2 than other concentrations and base fuel (B20). Khond et. al. [8] analyzed that decreased the hydrocarbon (HC) into CI engine after using iron oxide and zinc oxide nano additives. They found that minimum hydrocarbon emission after mixing the iron oxide into fuel. They defined the reason for decreasing the HC is that when increasing the cylinder pressure and temperature then oxidation is increased and it reduces the hydrocarbon. Fayad et. al. [9] observed that reduction in hydrocarbon (HC) emission is 37.4% because of the addition of Al_2O_3 nanoparticle additive with butanol blends (B20), it has a big surface area and more oxygen content, it causes Proper combustion takes place and it raises the temperature [66,70]. This mixer has a catalyst for the oxidation of hydrocarbons. So, the HC emission is decreased. About the hydrocarbon emission author mentioned in their research the use of Al_2O_3 and CuO nanoparticles in a single-cylinder diesel engine [10]. They observed that the nanoparticles are thermally stable. Due to this property, the oxidation of fuel is done properly. So, mixing of Al_2O_3 nano additive reduces the hydrocarbons by 13% and 5% reduced after using CuO nanoparticles. Praveena et. al. [12] analyzed grapeseed oil biodiesel with zinc oxide and cerium oxide in 50 PPM and 100 PPM concentration. They described that after using biodiesel in the CI engine the HC is decreased because oxygen content increases the combustion of fuel. The cerium oxide nanoemulsion increased the combustion property and it converted into cerous oxide. And when using the zinc oxide nanoemulsion they found the mixing of fuel with air rapidly and due to its higher oxidation, a mixture of stoichiometric created. Hence, the CO content into exhaust is decreased 31.07% and 13.79% respectively as compared to neat diesel fuel.

Gavhane et. al. [31] depicted with added zinc oxide nano additive in 25, 50 and 75 PPM concentration into soyabean methyl ester biodiesel at different loads. They analyze the result on two different ratios that are 18.5 and 21.5. They observed diminishing the hydrocarbon after mixing all concentrations of nanoparticle blended fuel. But they found maximum decrement of 30.83% in hydrocarbon with 50 PPM zinc oxide with soyabean methyl ester at a 21.5 compression ratio. An experimental analysis was done by Arunprasad et. al. [22] with magnesium nanoparticles (25, 50 and 100 PPM) and algae oil biodiesel (B20). They found the reduction into hydrocarbon on used to nano fuel blend as compared to B20 fuel this is caused by better combustion and more cetane number than B20 fuel. They mentioned that due to the presence of more oxygen, the better air-fuel mixture and more cetane number, it helps in better propagation. It reduces the ignition delay and reduced the hydrocarbons. Hoseini et. al. [23] expressed the results of Hydrocarbon emission with analyzed the graphene oxide nanoparticles with Oenothera Lamarckian biodiesel. the hydrocarbon emission decreases as compared to diesel due to more amount of oxygen content and high cetane number. It enhanced combustion property after reducing the ignition delay [78,79]. After adding the graphene oxide nanoparticles, it enhanced the surface area and excessive amount of oxygen. So, due to the effect of catalyst the unburnt hydrocarbon oxidized into water vapors and CO_2. Thus, hydrocarbon is reduced [80].


BSFC
BSFC (%)
36.3
12.54
20.37
ZnO+Cottenseed oil BD
ZnO+Neem oil BD
ZnO+Soyabean oil BD
Nanoparticles with BD


BTE
BTE (%)
36.22
35.1
29.34
23.2
29.9
ZnO+Cottenseed oil BD
ZnO+Neem oil BD
ZnO+Grapeseed oil BD
ZnO+Soyabean oil BD
ZnO+ WCO BD
Nanoparticles with BD





Figures (a),(b),(c),(d) Variation in parameters after addition of ZnO nano additives with different biodiesels.

6. Conclusion- In this paper various researches which is based on different nanoparticles used along with biodiesel into CI engine has been summarized. Researchers found new advancements in fuel technology that is the adding nanomaterials with biodiesel. Nano fuels ascribed the improvement into performances and combustion process and reduction into emissions which are summarized in following points-

- The maximum stability of nanofluid in liquid fuels is only about 6 to 18 days which is a matter of concern and it restricts the use of nano additives with diesel and biodiesel fuel. The two-stage method of surfactant helps stabilization method was found to have better stability and control than all other solution synthesis methods. The pH values ranged from 3.5 to 10.5 for the maximum stable nanofluid solution. A pH value below 3.5 provides good stability to the fuel.
- Most of the experimental investigation studies found that nanofluid has a higher surface area to volume ratio and large reactive surface causes particles of micron and nano length to mix with diesel and biodiesel to enhance the combustion process. This enhances the oxidation of nano fuel resulting in higher combustion enthalpy and density

of energy. The nanoparticle mixes with the biodiesel to enhance the thermophysical properties and show improved combustion characteristics than the micron particles. It reduces the ignition delay due to a higher evaporation rate, improves automization of air-fuel mixing and flame sustainability.

- Engine performance increases due to the high surface area of the nanoparticle which accelerates the combustion process and increases the heat transfer rate. In addition, it was found that the linear relationship between the value of brake power and the doping number of nanoparticles in liquid is only up to RPM values.
- The blending of nano ingredients with liquid fuel reduces hydrocarbon, smoke, CO except for NO_X emission. However, it depicted that TiO_2+diesel+ether nano fuel increases the CO_2 emission. The injection time and higher inlet pressure of nano fuel are enhanced and result in lower toxicities.

Some experimental work used the surfactant and dispersant for enhancing the suspension of fuel, but it increases only for experimental timing. Making the stability for a long time can be further used for research. Other researches for further experimental work can be on the selection of surfactants and dispersants, the effect of fuel injection timing on engine components, working using with nano fuel, cost analysis of nanoparticles and lack of organic carbon-based nanoparticles.

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The idea for this review article- Dr. Ajay Kumar Sharma (Corresponding Author)

Literature Search, data analysis and drafted- Mr. Divyanshu Shukla (First Author)

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