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Parametric Studies for Enhancing Performance & Emissions of DI-CI Engine Using Biodiesel Blended Nano fuel

Raveena Gaikwad[1], Sneha Shinde[2], Vinay Mulay[3], Rohan Bansal[4], C. Srinidhi[5]
[1, 2, 3, 4] *UG Students, Department of Mechanical Engineering, Suman Ramesh Tulsiani Technical Campus Faculty of Engineering Pune, Maharashtra, India*
[5]*Assistant Professor, Department of Mechanical Engineering, Suman Ramesh Tulsiani Technical Campus Faculty of Engineering Pune, Maharashtra, India*

Abstract: This paper aims to communicate the diesel engine performance and emission characteristics fueled with biodiesel and to reduce NOx emission. Biodiesel is a possible alternate fuel to reduce
The dependency on fossil fuel and can replace petroleum fuels. The essence of additives in Biodiesel like Al_2O_3, CNT, CeO_3, ZnO_2, TiO_2, CoO2, CuO, FeO_2, and others with respect to properties, performance and emission are depicted. The literature reviews spotlights, addition of Nano-metallic and non-metallic additives in biodiesel radically improve the properties of trans esterified esters and later contribute to secondary atomization thereby enhancing combustion of this esters resulting in better performance with reduced emissions.
Keywords: Biodiesel, Nano- additives, performance, emission, thermo-physical properties.

I. INTRODUCTION

The demand for petroleum based fuel has grown in an extensive way because of the increasing industrialization and the growth in transportation sector. This growth has an adverse effect on the economy and remains a monopoly in the fuel trade. In order to meet growing demand in energy sources the biodiesel are prepared from readily available materials like Straight Vegetable Oils and animal fats, etc. The growing concerns on the environment and the effect of greenhouse gases have received more and more interests in the use of biodiesel. Biodiesel is one of the best substitutes for petroleum diesel fuel. Biodiesel is produced from various available natural sources namely Palm, Jatropha, Pongamia, Grape seed, Mahua, Castor, Cotton seed, Tobacco seed, Rubber seed, Rice bran, Neem, Coconut, Sunflower oil, etc. Neat oil produced from these natural sources is chemically processed by "transesterification", in which the alcohol is added to the neat oil under mild condition in existence of a base catalyst. During esterification process, the triglycerides present in the oil get converted into alkyl esters and glycerol. The transesterification process is carried out in the temperature range of around 50^oC to 80^oC with the addition of methanol or ethanol. The base catalyst commonly used are sodium hydroxide (NaOH) and potassium hydroxide (KOH).Generally, the vegetable oil feedstock for biodiesel are categorized into two, namely edible and non-edible sources. In order to improve the Biodiesel Properties, fuel additives are added, which involves usage of organic based or metal based substances. Often these are simply soluble in fuel and its main purpose is to improve and provide beneficial characteristics to the fuel without disturbing the performance and combustion constraints. The fuel additives are broadly classified as refinery products, distribution system products, and automotive performance enhancement products. They are again subdivided into following categories namely antioxidants, cetane improvers, anti-knocking agents, anti-freezing agents, stability imrovers, additives to prevent corrosion, cold flow improvers, fuel borne catalysts, anti-wear agents, etcany studies concerning Nanoparticle blended fuel have been inked. Usually Metallic based and oxygen containing compound such as aluminum oxide, titanium oxide which acts as a combustion catalyst for oxygenated hydrocarbon fuels. Many other properties of Biodiesel are also similar to diesel. However, higher viscosity and density of the biodiesel lead to higher BSFC and higher smoke emissions.

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A. *Fuel Additives and Its Importance*:

Additives are organic based or metal based substances which are basically soluble in fuel and its main purpose is to improve and provide useful characteristics to the fuel without disturbing the performance and combustion constraints. The fuel additives are broadly classified as refinery products, distribution system products, and automotive performance enhancement products. They are again subdivided into following categories namely antioxidants, cetane improvers, anti-knocking agents, anti-freezing agents, stability improvers, additives to prevent corrosion, cold flow improvers, fuel borne catalysts, anti-wear agents, etc.

B. *Antioxidants*

Biodiesels are fatty acid methyl esters produced by transesterification process which are ready to react with oxygen by the process called auto-oxidation. To avoid auto-oxidation of biodiesel in the diesel blend, additives like BHT (Butylated hydroxytoluene), TBHQ (Tert-butyl hydroquinone), BHA (Butylated hydroxyanisole), PG (Propyl gallate), and PA (Pyrogallol) are mixed with diesel biodiesel blends.

C. *Additives to Improve Cetane Number*

During cold conditions, the wax content present in the biodiesel begins to freeze and results in crystal like structure which affects the cold filter plug point (CFPP). This situation may be avoided by using additives like ethylene vinyl acetate copolymer, glycerol ketals, glycerol acetates, phthalimide and succinimide copolymers which improves the cloud point property of the fuel.

D. *Metal based Additives*

The burning characteristics of the fuel can also be improved by the addition of metals and metal oxides to the fuel in the range of micro or Nano sizes through ppm or percentage by weight ratios. Metals like iron (Fe), aluminum (Al), magnesium (Mg), manganese (Mn), silver (Ag), gold (Au), copper (Cu), boron (B), graphene, silica (Si), etc. and metal oxides like aluminum oxide (Al2O3), cobalt oxide (Co3O4), cerium oxide (CeO_2), titanium oxide (TiO_2), zinc oxide (ZnO), copper oxide (CuO) etc., are used as additives to improve the fuel physio-chemical properties. After several studies, researchers have found that the modification of fuel with respect to its physio-chemical properties yields better results in enhancing the engine performance and controlling the exhaust emissions rather than carrying out engine modifications. With reduced exhaust emissions, ignition delay, cold flow characteristics etc. along with comparable performance characteristics, using biodiesel as fuel is found to be favorable.

Table No1: Comparison of emission parameters under various test conditions and additives

Sr. No	Engine Type	Test Condition	Base Fuel	Nano Additive PPM/ %	UBHC	CO	NO_x	Ref
1	1- Cylinder TV-I VCR Engine	Constant Speed, Varying Load		NiO / 20ppm; 40ppm	-	-	↓ With NA	[1]
2	Single cylinder, water cooled DI diesel engine.	Zero/half/full loading conditions	Diesel	Aluminium Oxide, Zinc Oxide, Iron Oxide	↓ 21.25%	↓ 25%	↑	[4]
3	single cylinder, four stroke DICI	Constant Speed, Varying Load	Jatropha oil	AlO(OH)	↓ 39%	↓ 50%	↓ 42%	5
4	Single cylinder, 4 stroke DICI	Constant Speed, At full load	Diesel	Al_2O_3,CNT,CeO_3,ZnO_2,TiO_2, CoO_2,CuO,FeO_2	↓ 8%	↓ 25-40%	↑ 3-5%	6
5	4-stroke single cylinder CI diesel engine	Constant Speed, Varying Load	Castor oil	CERIA , CNT	↓ 39.2%	↓ 0.42%	↓ 9.8%	19

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6	Single cylinder, 4 stroke DICI	Constant Speed, Varying Load	Biodiesel	FeCl3	↓ 52.6%	↓ 26.6%	↑	16
7	Single cylinder,4 stroke DICI	Constant Speed, Varying Load	Jatropha Methyl Esters	CNT	↓	↓	↓ 69%	17
8	4- stroke, single cylinder, diesel engine,	Constant Speed, Varying Load	Diesel	Al_2O_3, CuO	↓ 5%	↓ 8%	↓ 2%	11
9	single cylinder, 4 stroke, DI Diesel engine	All load	Jojoba Biodiesel	CNT	↓ 60 %	↓ 50 %,	↓ 45 %,	12
10	single cylinder, 4 stroke, DI LHR engine	1500 rpm, constant ,at peak load	CSOME, NKOME	3.5 g of sodium hydroxide (NaOH) and 200 ml of methyl alcohol (CH3OH)	↑ 3.52% and 2.41%	↑ 26.92% - 39.53%	↑ 21.67% and 11.69%	14
11	single-cylinder CI Diesel Engine	At all loads	aluminum, iron, boron	Diesel	↑ 8% - 4%	↓ 25–40%	↑	15
12	Single Cylinder, DI diesel engine	3600 rpm, at full load condition	T60 diesel fuel	(Co)-based additive	-	↓ 19.52 - 53.37%.	↓	20

Table No.2: Comparison of performance parameters under various test conditions for Nano metal additive blended fuel

Sr. No	Engine Type	Test Condition	Base Fuel	Nano Additive	BTE	BSFC	Ref
1	4-stroke single cylinder DI diesel engine	Constant Speed, Varying Load	POME10POME20POME30	NiO / 20ppm; 40ppm	↑ 6.2%	↓ 5.6%	1
2	Single cylinder water cooled DI diesel engine	Zero load, Half load, Full load	Diesel	AL_2O_3 ZnO Fe_2O_3	-	-	4
3	Single cylinder, four stroke, DI, CI	Constant speed, 1500rpm	Jatropa	AlO(OH)	↑ By 6%	↓ lesser than the petroleum diesel, With increase with dosage level of NP	5

4	Single cylinder, four stroke, DI diesel engine	Full Load	Diesel	Al_2O_3, CNT, CeO_3, ZnO_2, TiO_2, CoO_2, CuO, FeO_2	↑ By 9%	↓By 7%	6
5	4-stroke single cylinder CI diesel engine	Constant Speed, Varying Load	Castor oil	CERIA, CNT	↑ 7.5%	↑ 4.6%	19
6	Single cylinder,4 stroke DICI	Constant Speed, Varying Load	Biodiesel	FeCl3	↓ 6.3%	↓8.6%	16
7	Single cylinder,4 stroke DICI	Constant Speed, Varying Load	Jatropha Methyl Esters	CNT	↑24.8%	↑	17
8	Single cylinder, four stroke, DI diesel engine	At all Loads	Diesel	Al ,Bo	↑By Avg 7%	↓ By 7%	15
9	Single cylinder diesel Engine	At all Loads	Tall biodiesel	Co based additive	-	↓ By 5.01%	20

II. DISCUSSION ON PERFORMANCE OF ENGINE WITH USAGE OF NANO ADDITIVES IN BIODIESEL

C.Srinidhi et al [1] has investigated the effect of palm oil methyl ester with addition of Nickel oxide Nano particle on the performance of diesel engine. The result showed that there was a significant change in fuel properties. The investigation revealed that the fuel dosed with Nanoparticle showed better thermal efficiency of 6.2% also there was reduction in BSEC and BSFC by 5.119% and 5.6% in comparison to their Biodiesel blends. Hariram Venkatesan et al [6] has mentioned various Nano-metallic additives and their effect on performance of Single cylinder, four stroke, DI diesel engine. The results showed increase in BTE by 9% and decrease in BSFC by 6%. M. Srinivasa Rao et al [5] have studied the effect of Aluminum oxide hydroxide nanoparticle as a fuel additive on DICI engine. The results of the testfuels were analyzed and compared with those of diesel. The results revealed that the performance parameter like BTE, BSFC was lower for biodiesel than that for neat diesel. V. Arul Mozhi Selvan et al [19] studied the performance of a variable compression ratio engine using Cerium Oxide Nanoparticles and Carbon Nanotubes as nanoparticles additives in Diesterol blends. The combined effect of CERIA and CNT as fuel-borne nanoparticles additives in the Diesterol fuel blend results in increase of BTE, BSFC by 7.5%, and 4.6% respectively. Rakhi N. Mehta et al [15] has investigated performance of single cylinder CI Engine using base diesel blended with Aluminum, Boron, and Iron as nanoparticles. The effect of Nano fuels A1, B1 and F1 on the Engine performance parameter showed a noticeable reduction of 7% in specific fuel consumption with A1 in comparison to diesel also at higher load the brake thermal efficiencies increased by 9%, 4%, and 2% as compared to diesel.

III. DISCUSSION ON EMISSION PARAMETER WITH USAGE OF NANO ADDITIVES IN BIODIESEL

A. KESKIN et al [20] mentioned that the addition of tall oil with cobalt based additive resulted in increased CO emissions, and smoke emissions also higher NOx emissions were measured at low engine speed. AHMED I. EL-SEESYA et al [12] have studied the Influence of Multi-Walled Carbon Nanotubes Additives into Non-Edible Biodiesel-Diesel Fuel Blend on Diesel Engine. The use of MWCNTs resulted in improved engine performance parameters no matter the studied dose level. It is observed that there was reduction in NOx by 45 %, CO by 50 %, and UHC by 60 % respectively. SONER GUMUS et al [11] showed that the addition of nanoparticles like aluminum oxide and copper oxide resulted in improved emission than neat biodiesel. The results showed that the Emissions of CO, HC and NOx with the addition of Al2O3 to neat diesel are significantly lower with up to 11%, 13% and 6%, respectively while Emissions of CO, HC and NOx with the addition of CuO to neat diesel are lower with up to 5%, 8% and 2%. BASAVARAJ M. SHRIGIRI et al [14] have investigated the emission and combustion characteristics using two methyl esters: One is obtained from cotton seed oil and other from neem kernel oil. The use of these methyl ester with diesel fuel resulted in increase in

NOx emission in LHR engine along with slight increase in CO, smoke and HC emissions. M.R. KAMLESH et al [4] have studies the effect of nanoparticle on the emission of CI engine.in this Neat Diesel is blended with Aluminium Oxide nanoparticles, Zinc Oxide nanoparticles and Iron Oxide nanoparticles. Performance tests were carried out on a single cylinder engine which showed a decrease in the concentration of the pollutants with the use of nanoparticles, which may be attributed to the oxidizing nature of the nanoparticles.

IV. LITERATURE REVIEW

C.SRINIDHI et al [1] have found that the Performance investigations on a Single Cylinder Tangential Vertical-I VCR Engine which was fueled with blends of palm oil methyl ester and conventional diesel in volumetric proportions of 10%, 20 % and 30% naming B10, B20 and B30.The experimental analysis revealed that the fuel dosed with Nanoparticle showed better thermal efficiency of 6.2% and reduction in BSEC and BSFC by 5.119% and 5.6% in comparison to their regular Biodiesel blends.

SHIYASHARAN PATEL et al [2]have found the comparison of different fuels with respect to the diesel which is taken as reference fuel. It was concluded that BTE decreases slightly whereas BSFC increases as the engine fueled with PJBD80E20 as compare to neat diesel fuel at different load conditions. In the same testing condition, a slight decrease in CO and HC emission and significant reduction in NO_x emission were observed, however, there is a slight increase in smoke emission was observed as compare to diesel fuel.

K. JOHN SAMUEL et al [3] have found an experimental data obtained for performance and emission parameters for biodiesel fuels are checked in par with mineral diesel. For all the biodiesel blends, the trend for BTE is found increasing whereas BSFC followed a decreasing trend at all operated loads. Particulate emissions except HC and NOx are lesser in biodiesel blends than diesel due to the presence of dissolved oxygen. Also the addition of diethyl ether to crude pongamia has significant impact on performance improvement and reduced emissions when compared to other blends. From this experimental study it is concluded that pongamia oil because of its rich availability in India can be the best fuel for blending with diesel and using for small and medium scale energy producing vehicles.

M.R. KAMLESH et al [4] have found that the diesel engines are a major source of contributors of emissions such as carbon monoxide, hydrocarbons, nitrogen oxides and particulate matter. Performance tests were carried out on Kirloskar AV1 single cylinder engine. Results show a decrease in the concentration of the pollutants with the use of nanoparticles, which may be attributed to the oxidizing nature of the nanoparticles.

M.SRINIVASA RAO et al [5] have found that a sequence of experimental investigations conducted on a biodiesel fueled Direct Injection Compression Ignition (DICI) engine with an objective of improving its working characteristics using Aluminium Oxide Hydroxide(AlO(OH)) nanoparticle as a fuel.

B. ASHOK et al [6] have found that Calophyllum inophyllum oil is non-edible in nature could be used as a source for biodiesel esterification in India and it is also available in abundant quantities in places such as Southern east and East Asia and Australia. The research work examines the suitability of Calophyllum inophyllum as promising feedstock for biodiesel production and its employability in diesel engine operation. Itcan be seen that the CIME biodiesel resulted in slight decrease in brake thermal efficiency. The hydrocarbon and carbon monoxide emissions are reduced with the use of biodiesel with significant penalty in oxides of nitrogen emissions.

V.K. VENKANNA et al [7] have found that use of raw honge oil blend with diesel fuel in diesel engines with enhanced injection opening pressure appears to be scarce. This research work presents some findings of the use of honge oil and diesel fuel blend in direct injection diesel engine with increased injection opening pressure (IOP). Improved premixed heat release rate was noticed with H30 when the IOP is enhanced.

K. NANTHAGOPAL et al [8] have introduced a new biofuel called as Lemon Essential Oil (LEO) which can be obtained through steam distillation process of lemon rinds. A 20% LEO is blended with diesel (LEO20+ Diesel80) and it is fed as fuel to the engine. The experimental investigation revealed that brake thermal efficiency of LEO20 is marginally higher than diesel at higher loads. Also significant reduction is observed for carbon monoxide, unburned hydrocarbon and smoke emissions. The research work showed that the 20% of Lemon Essential Oil could be partial substitute for conventional diesel engine in near future.

K. VIJAYA KUMAR REDDY et al [9] have found the performance of castor non-edible vegetable oil and its blend with diesel on a single cylinder, 4 stroke, naturally aspirated, direct injection, water cooled, eddy current dynamometer Kirloskar Diesel Engine at 1500 rpm for variable loads.It was observed that the performance characteristics are reduced and emission characteristics are increased at the rated load compared to those of diesel. It is concluded that castor non-edible oil can be used as an alternate to diesel, which is of low cost. This usage of neat bio-diesel has a great impact in reducing the dependency of India on oil imports.

SONER GUMUS et al [10] have found that Nano diesel fuels were prepared by adding aluminum oxide and copper oxide nanoparticles, these nanoparticles were blended with diesel fuel in varying mass fractions by the means of a mechanical homogenizer and an ultrasonicator. The results showed that the stability of Nano diesel can be increased by regulating pH and using dispersant. The storage and combustion characteristics were also improved by adding nanoparticles. The engine test results indicated that the Nano diesel in terms of engine performance efficiency and environmentally friendly emissions could be recognized as the potential candidates in diesel engines.

Ahmed I. EL-Seesy et al [11] have found that Nano-particles of size from 10 to 15 nm with tube length 1-10 microns, the dose level is varied from 10 to 50 mg/l by step of 10 mg/l was mixed into the biodiesel-diesel fuel blend with the help of ultrasonicator. The results of the present study showed that the biodiesel-diesel fuel blend slightly decreases the mechanical engine performance and increases its emission characteristics at all tested engine operating conditions. However, the best emission characteristics are obtained at a dose level of 30 mg/l. While the best of engine combustion characteristics are achieved at a dose level of 50 mg/l.

M.M. Rashed et al [12] have found that the performance and emission characteristics of palm biodiesel, jatropha biodiesel, and diesel fuel. Among the biodiesel-blended fuel, Palm biodiesel showed better performance and minimal emission than jatropha and moringa biodiesel fuel. Although PB20 showed better performance, but performance of MB20 biodiesel blend is comparable with other fuels.

HariramVenkatesan et al [13] have found that Biodiesel is one of the promising substitute source of energy fuel in the transportation sector due to rapid depletion of petroleum reserves on one side and increased energy demand as well as environmental pollution hazards on the other side. Based on this review, it is very clear that non-edible oil based biodiesel is one of the best sources of energy.

Basavaraj M. Shrigiri et al [14] have found that the performance, emission and combustion characteristics of a diesel engine are investigated using two methyl esters: One obtained from cotton seed oil and other from neem kernel oil. e. It is found that, at peak load the brake thermal efficiency is lower by 5.91% and 7.07% and BSFC is higher by 28.57% and 10.71% for CSOME and NKOME in LHR engine, respectively when compared with conventional diesel fuel used in normal engine. It is also seen that there is an increase in NOx emission in LHR engine along with slight increase in CO, smoke and HC emissions.

Rakhi N. Mehta et al [15] have found that Experimental investigation to study the burning characteristics, engine performance and emission parameters of a single-cylinder Compression Ignition (CI) engine using Nano fuels which were formulated by sonicating nanoparticles of aluminum (A1), iron (F1) and boron (B1) in base diesel. Volumetric reduction of 25–40% in CO emission, 8% and 4% in hydrocarbon emission was measured when the engine was fueled with A1 and F1 respectively as compared to emissions from diesel.

KESKIN at al [16] has found that the effects of tall oil biodiesel with cobalt (Co)-based additive on engine performance and exhaust emissions have been experimentally investigated. Co-based additive at the rate of 4, 8, and 12mol/l was added to mixtures of 60% tall oil methyl ester and 40% diesel fuel (T60).

Biodiesel fuels had no noteworthy influence on engine torque and the power output values. Catalyst effects of Cobased additive improved specific fuel consumption values, CO emissions, and smoke emissions. Also higher NOx emissions were measured at low engine speed.

G.R. KANNAN et al [17] have initiated the use of ferric chloride (FeCl3) as a fuel borne catalyst (FBC) for waste cookingpalm oil based biodiesel. The results revealed that the FBC added biodiesel resulted in a decreased brake specific fuel consumption (BSFC) of 8.6% while the brake thermal efficiency increased by 6.3%. FBC added biodiesel showed lower nitric oxide (NO) emission and slightly higher carbondioxide (CO_2) emission as compared to diesel. Carbon monoxide (CO), total hydrocarbon (THC) and smoke emission of FBC added biodiesel decreased by 52.6%, 26.6% and 6.9% respectively compared to biodiesel without FBC at an optimum oerating condition of 280 bar injection pressure and 25.5^o bTDC injection timing.

J. SADHIK BASHA et al [18] have conducted experiment on a single cylinder constant speed diesel engine to establish the effects of Carbon Nanotubes (CNT) with the Jatropha Methyl Esters (JME) emulsion fuel.

The experimental results revealed an appreciable enhancement in the brake thermal efficiency for the CNT blended JME emulsion fuels compared to that of neat JME and neat JME emulsion fuel. At the full load, the brake thermal efficiency for the JME fuel observed was 24.80%, whereas it was 26.34% and28.45% for the JME2S5W and JME2S5W100CNT fuels respectively.

HARISH VENU et al [19] have found the influence of Alumina (Al2O3) nanoparticle on various injections

Strategies. Experiments were conducted with three different injection timings (IT) namely, original timing (ORG IT) of23 deg bTDC, advanced timing (ADV IT) of 27 deg bTDC and retarded timing (RET IT) of19 deg bTDC.Overall, the influence of 25 ppm Al2O3 in RET IT of 19 deg bTDC resulted in better engine performance, combustion and emission characteristics.

V. ARUL MOZHI SELVAN et al [20] have found the performance, combustion and emission characteristics of a variable compression ratio engine using Cerium Oxide Nanoparticles and Carbon Nanotubes as fuel-borne nanoparticles additives in Diesterol (diesel–biodiesel–ethanol) blends. The addition of CERIA and CNT in Diesterol blend increases the cylinder gas pressure when comparing with the neat Diesterol blends. The combined effect of CERIA and CNT as fuel-borne nanoparticles additives in the Diesterol fuel blend contributes for the cleaner combustion and significantly reduces the harmful exhaust gas emissions.

Abbreviations

CNT	Carbon nano-tube
Al2O3	Aluminum oxide
CeO2	Cerium oxide
ZnO	Zinc oxide
CuO	Copper oxide
FeO2	Ferrous oxide
UBHC	Unburned hydrocarbon
CO	Carbon monoxide
NOx	Oxides of nitrogen
NaOH	Sodium hydroxide
KOH	Potassium hydroxide
B20	Blend of Diesel (80%) and biodiesel (20%)
HOME	Honge oil methyl ester
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
JBD	Jatropha biodiesel

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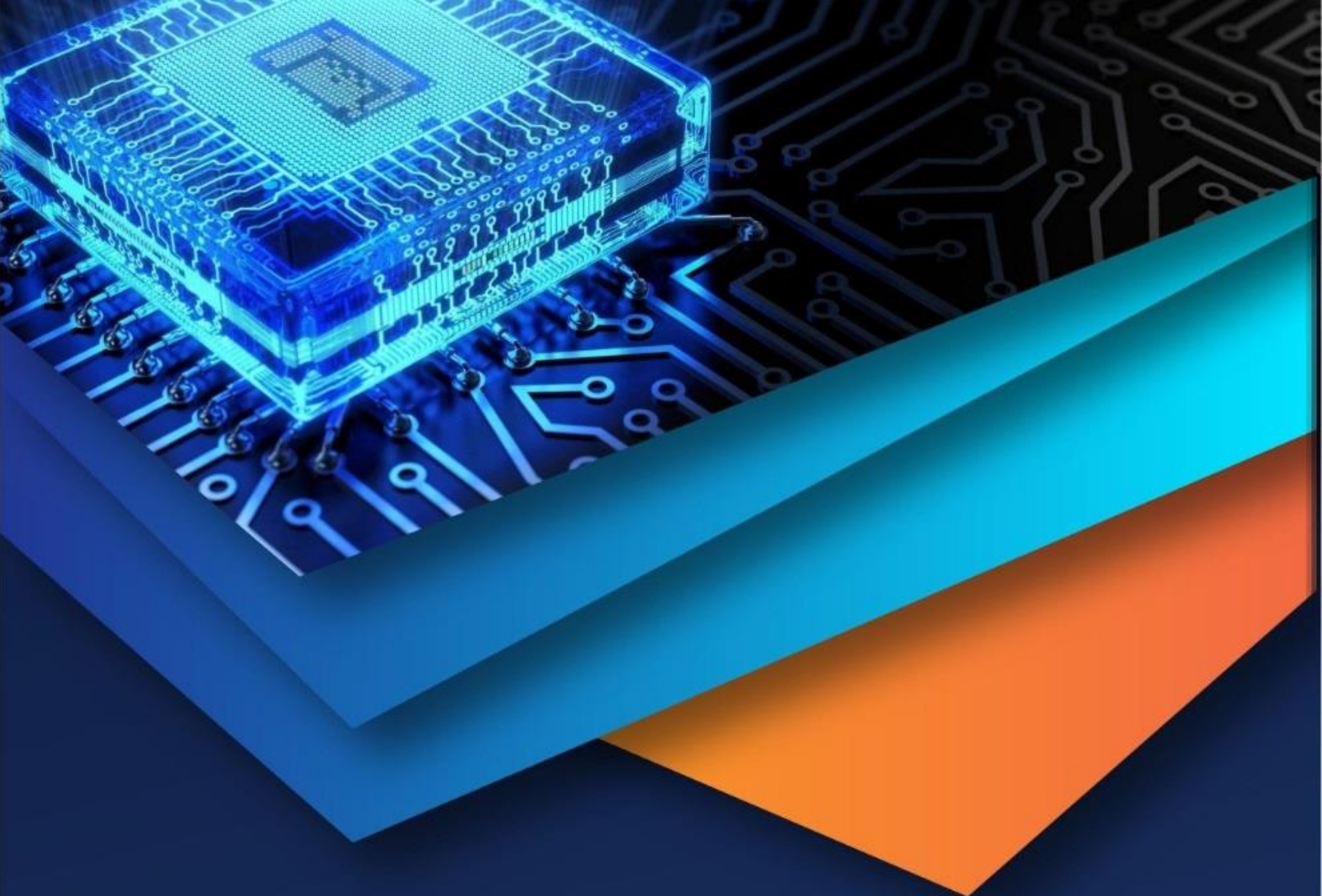
Conclusion

Based on the review, it is understood that the addition of nanoparticles helps in improving the fuel properties as well as reducing the exhaust emissions. Addition of nanoparticles increases BTE which depends upon the base fuel used, amount of nanoparticle added, how well they are mixed with the base fuel, and operating condition of the CI engine. Good mixture formation and lower smoke emission are the vitalfeatures for good CI engine performance. These factors are highly influenced by viscosity and density of the fuel

The performance improvement cannot be achieved with every amount of nanoparticle addition. Therefore, selecting best range of nanoparticle addition is key to get good results on enhanced performance and reduced emission in a CI engine. Some nanoparticles give good result but in some cases it fails to improve neither performance nor emissions. Size of the Nano particle is also a conditions to be considered in using Nano metal additives for improving the fuel properties.

Therefore, selecting the nanoparticles based on the properties of the fuel to be improved will help us to attain better results and lot of researches should be done on this area to select the suitable Nano metal additive based for the fuel. It is also recommended that the nanoparticles dose level is such that it improves the performance of the engine fueled by biodiesel-diesel blended fuels. This enhancement helps to reduces the energy and environmental problems resulting from using the fossil fuels.



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