Performance Study of Pongamia Pinnata Biodiesel- Diesel Blend Fueled CI Engine with Aluminum Oxide Nanoparticle As Additives

Chethan G.G[1]
[1]UG Scholar,
Department of Mechanical engineering
Amruta Institute of Engineering And Management Sciences Bidadi, Karnataka, India

Zubair [3]
[3]UG Scholar
Department of Mechanical engineering
Amruta Institute of Engineering And Management Sciences Bidadi, Karnataka, India.

Yashwanth.R[2]
[2]UG Scholar,
Department of Mechanical engineering
Amruta Institute of Engineering And Management Sciences Bidadi, Karnataka, India

Kotresh.U[4]
[4]Assistant Professor,
Department of Mechanical engineering
Amruta Institute Of Engineering And Management Sciences Bidadi, Karnataka, India

***Abstract*— Biodiesel being one of the renewable, biodegradable alternatives to fossil fuels Biodiesel is commonly produced by the transesterification processes of various edible and non-edible oils from plants as well as waste oils and animal fats Without requiring major engine modification biodiesel can compete with conventional diesel fuel. Moreover, biodiesel is preferred due to its favourable lubrication properties, low carbon emission, higher cetane number than diesel fuel, no aromatics, no sulphur environment friendly and non-toxic nature. Regardless of the fact that poor oxidation stability, higher density and lower calorific value of biodiesel as compared to diesel are some of the drawbacks, therefore, most of the shortcomings associated with the use of biodiesel are addressed by adding suitable additives, various literatures shows that oxygenated additives are improving chain reaction, higher thermal efficiency and heat release rate with marginal decrease in exhaust emissions. Pongamia pinnata can be a potential source for production of biodiesel. In the present experimental work planned to investigate the performance, emission and combustion characteristics of Diesel, Pongamia pinnata biodiesel blend with Aluminum oxide nanoparticle as additives in a single cylinder four stroke diesel engine. Pongamia pinnata biodiesel blend B20 shows optimum performance and emission as on various literature for that optimized blend (B20) various proportion of Aluminium oxide nanoparticle (50 ppm , 100 ppm and 150 ppm) are added in present investigation.**

Keywords*— *Diesel engine, Biodiesel, Titanium oxide Nanoparticles, Transesterification ,Combustion, Emission.

I. INTRODUCTION

1.1 Diesel Engine

The compression ignition engines are widely used due to its reliable operation and economy. As the petroleum reserves are depleting at a faster rate due to the growth of population and the subsequent energy utilization, an urgent need for search for a renewable alternative fuel arise. Also the threat of global warming and the stringent government regulation made the engine manufacturers and the consumers to follow the emission norms to save the environment from pollution. Recently, diesel engine has received considerable attention because of its high thermal efficiency and low emission. However, the better fuel economy, low green gas emission, much longer life span, less maintenance and reliability are the properties of a diesel engine results in their wide spreads use in transportation, thermal power generation and many more industrial and agricultural application. As advance technologies becoming available, researchers are looking into new strategies such as common rail fuel injection, multiple injections and low temperature combustions to reduce the harmful emissions and increase the engine efficiency. Studies on the use of ethanol in diesel engines have been continuing since 1970s.Since 19th century, ethanol has been used as a fuel for compression ignition (CI) engines. Among these alternative fuels, biodiesel and nano particle have received much attention in recent years for compression Ignition diesel engines.

Diesel engine plays a vital role in power generation, transportation and industrial activities. The reason for the surge in diesel popularity is simple better fuel economy at minimal expense. Typically, a diesel is 20 to 30 percent more efficient than an equivalent petrol engine. Diesel fuel is priced moderately higher than gasoline but diesel has a higher energy density, i.e. more energy can be extracted from diesel as compared with the same volume of gasoline. Therefore, diesel engines in automobiles provide higher mileage, making it an obvious choice for heavy-duty transportation and equipment. Demand for petroleum products, in particular diesel is set to increase rapidly. Transport sector is one of the fastest growing energy subsectors in the economy for two reasons one, concomitant with growth of the economy would come the increase in demand for both freight and passenger movement and two, India's base as far as mobility is concerned is very low as compared to the rest of the world. The worrisome accepts of India's growth for transport demands are the fact that over 80% of passengers and 60% of freight are moved by road. In the diesel engine, only air

is initially introduced into the combustion chamber. The air is then compressed with a compression ratio typically between 15:1 and 22:1 resulting in 40-bar pressure compared to 8 to 14 bars in the petrol engine.
The fuel injector ensures that the fuel is broken down into small droplets, and that the fuel is distributed evenly. The heat of the compressed air vaporizes fuel from the surface of the droplets. The vapor is then ignited by the heat from the compressed air in the combustion chamber, the droplets continue to vaporize from their surfaces and burn, getting smaller, until all the fuel in the droplets has been burnt. The start of vaporization causes a delay period during ignition, and the characteristic diesel knocking sound as the vapor reaches ignition temperature and causes an abrupt increase in pressure above the piston. The rapid expansion of combustion gases then drives the piston downward, supplying power to the crankshaft. Model airplane engines use a variant of the Diesel principle but premix fuel and air via a carburetion system external to the combustion chambers.

1.2 Biodiesel

Biodiesel and diesel are not chemically similar biodiesel composed of long chain fatty acids, where as diesel is mixture of aliphatic and aromatic hydrocarbons that contains approximately 10-15 carbons. The fuel prices are increasing as a consequence of spiraling demand and diminishing supply, we need to choose a cost effective fuel to meet our needs. Diesel powered vehicles and equipment's account for nearly half of all nitrogen oxides and more than two thirds of all particulate matter emissions. Emissions of diesel-fueled vehicle have high concentration of NOx and particulate matter. The mixture contain carbon particle that are exceptionally small in size, less than one micron. These particle may be deeply inhaled into the lung and carry with them a collection of attached hazardous compound. Moreover the rapid depletion of fossil fuels due to widespread use has forced to search for some low emission and renewable sources. Current transportation technologies that are based on fossil fuel combustion have created a fragile and environmentally harmful system. Fossil fuel combustion is harmful to the environment because of the emissions that they contain, among other toxic and carcinogenic pollutants, greenhouse gases such as Carbon Dioxide.

EXPERIMENTATION

1.3 Pongamia biodiesel

The biodiesel used in this study is obtained from pongamia oil by transesterification process. It is the process by which fatty acid is converted into its corresponding ester. The mixture of pongamia oil, methanol and sodium hydroxide (NaOH) as catalyst is taken in the reaction chamber fitted with condenser and thermometer. The entire mixture is heated at a temperature of 65ºC for 2 hours and then cooled down to room temperature. After cooling, two layers are observed with top layer identified as methyl ester and bottom layer as since it has more density. Then the top layer is washed with distilled water and drained out. Finally Pongamia oil methyl ester (PME) is obtained as product and is used in the present study. Tests are conducted to analyze the composition and physical chemical properties of biodiesel are presented Table 1. It is comprehended that the physicochemical properties of biodiesel differ from that of conventional diesel, which could affect the diesel engine performance and emission characteristics.

Purity	99%
Average particle size	10-25nm
Color	White
Crystallographic structure	Spherical
Atomic weight	79.8658 gm/mol
Melting range	1830 ^{0}C – 1850 ^{0}C
Boiling range	2500 ^{0}C – 3500 ^{0}C
Density at 20^{0}C	3940 kg/m^3

Table-1: Properties of Pongamia biodiesel

1.4 Nanoparticle

Synthesis of Alumina nanoparticles
Alumina nanoparticles were synthesized by using a sol-gel method. About 18.76 g of aluminum nitrate was dissolved with citric acid in the deionized water. The molar ratio of the citrate/nitrate (C/N) was 0.5. The solution was stirred continuously for several hours at 60°C until it turned into a yellowish sol. Then, the solution was heated up to 80°C under constant stirring until the transparent gel was formed. The gel was dried at 90°C in the oven for 12 hours. The dried gel was ground and sintered at 600°C, labeled as Sample A. The synthesis of alumina nanoparticles was repeated by using the same process as described above and were sintered at temperature of 700°C, 800°C, 900°C, 1000°C, 1100°C, and 1200°C, labelled as Sample B, Sample C, Sample D, Sample E, Sample F, and Sample G, respectively.

Table- 2: Aluminum Oxide Nanoparticles properties

Purity	99%
Average particle size	10-25 nm
Color	white
Crystallographic structure	Spherical
Molecular Weight	**101.96**
Melting point	2040°C
Boiling point	2977°C
Density at 20^{0}C	3.9 g/cm^3
Molar mass	101.96 g/mol

1.5 Experimental Setup

Experiments were conducted on a four-stroke single cylinder direct-injection water-cooled Diesel engine, specifications of engine test rig are listed in Table 3. Diesel engine is coupled with Eddy Current dynamometer for loading and five-gas analyzer was used to measure the emission characteristics such as unburned hydrocarbon(UHC),carbon monoxide(CO), oxides of nitrogen(NO_X),carbon dioxide(CO_2) and oxygen(O_2) values from the exhaust gas. Test was carried out with constant Injection pressure of 200bar at a rated speed of 1500rpm

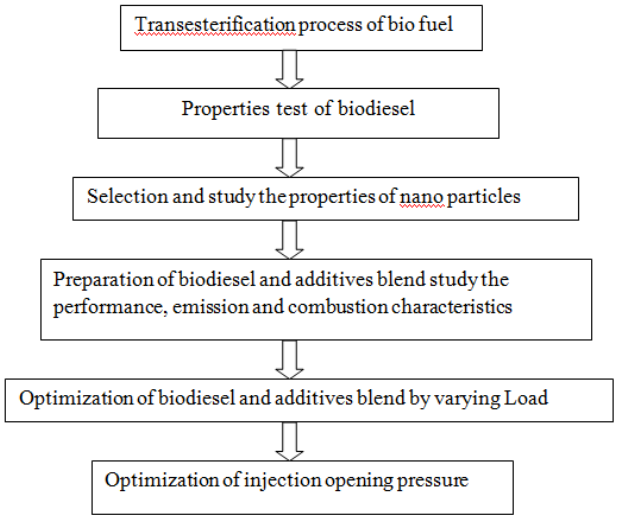
with constant compression ratio 17.5, for the mixture of Diesel, biodiesel and 50ppm, 100ppm and 150ppm Aluminium oxide nanoparticle as additives. From various literatures it was observed that 20% (B20) of biodiesel gives better performance. So, in this experimental study, the same proportion of biodiesel blends with the nanoparticles had been used and experimental tests are carried out as per ASTM standard test procedures.

Table- 3: Engine specification

Engine Parameters	Specification
Engine	Four stroke single cylinder
Make	Kirloskar
Number of cylinders	Single Cylinder
Horse power	3.75 kw
Speed	1500rpm
Bore	80mm
Stroke length	110mm
Compression ratio	17.5 : 1
Starting	Manual
Working cycle	Four stroke
Injection pressure	200 bar
Method of cooling	Water cooled
Method of ignition	Compression ignition
Dynamometer	Eddy Current dynamometer

Figure 1 Four stroke single cylinder diesel engine

1.6 METHODOLOGY



RESULTS AND DISCUSSION

1.7 Preparation of blends

Magnetic stirrer technique was followed for dispersion of Aluminium oxide nanoparticles with the base fuel. A known quantity of nanoparticles were weighed (50ppm, 100ppm and 150ppm) then poured in to B20 blend of Pongamia biodiesel and properties of Diesel, D+B20, D+B20+N50ppm,D+B20+N100ppm and D+B20+N150ppm are measured based on ASTM standard and formulated in table 4.it shows that by addition of nanoparticles calorific value of blends increased and flash point, fire point of fuel are decreased.

Table-4: Properties of Diesel and Biodiesel blends

Fuel	Diesel	D+B20	D+B20+ N150ppm	D+B20+ N2100ppm	D+B20 +N150ppm
Kinematic Viscosity(Cst)	4	5.2	5.21	5.23	5.26
Calorific Value (MJ/kg)	42.3	39.15	41.69	41.86	42.10
Flash Point (°C)	54	72	65	62	58
Fire Point (°C)	65	115	95	78	72

Performance and Emission Characteristics

The engine tests were conducted on a single cylinder diesel engine using different fuel blends in order to enhance engine performance and emission characteristics and results were compared with neat diesel.

2.1 Brake Thermal Efficiency (BTE)

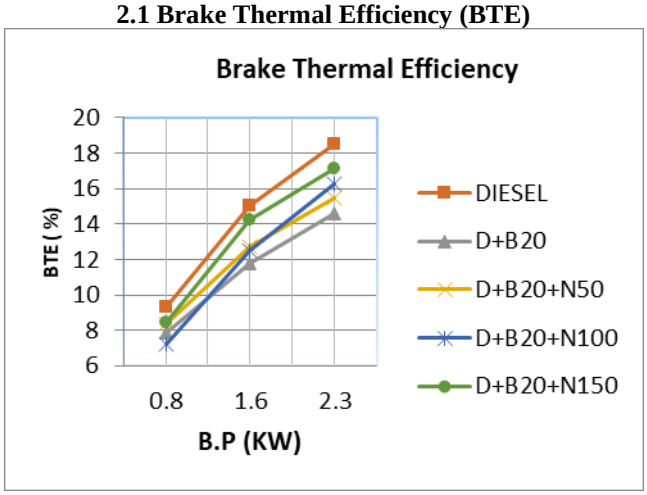


Chart-1: Variation of Brake thermal efficiency with brake power

The brake thermal efficiency of engine was enhanced with increase in Aluminum oxide Nanoparticles quantity in the blends of all loads, D+B20+N150ppm shows better performance compare to other blends, Aluminum oxide nanoparticles promote complete combustion this leads to high flame temperature and efficiency, D+B20+150ppm blend gives maximum efficiency compare to Biodiesel and its blends, D+B20+150ppm blend shows 16.6% high efficiency than Pongamia Biodiesel and D+B20+150ppm blend shows 7.5 % less efficiency than Diesel at maximum load condition.

2.2 Brake Specific Fuel Consumption

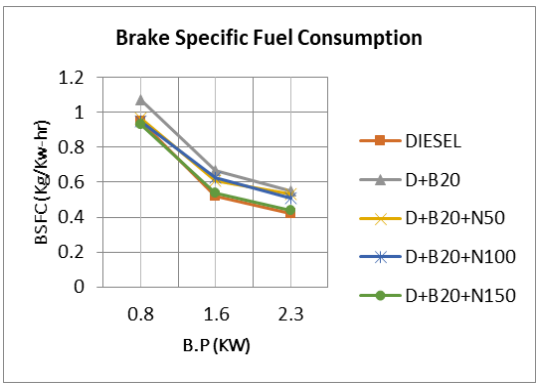


Chart -2: Variation of Brake specific fuel consumption with brake power

Brake specific fuel consumption decreases with increase in engine load, from the comparison it is evident that D+B20 blend consumes 23.6% more fuel then Diesel due to their lower calorific value. Among these blends B20 N150ppm consumes lesser fuel compare to other blends and 8.6 % more fuel consumed compare to diesel at maximum load.

2.3 Carbon Monoxide emissions

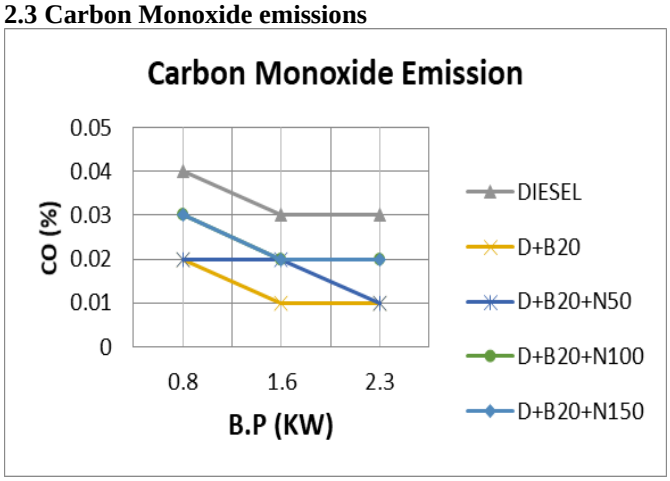


Chart -3: Variation of Carbon monoxide emission with brake power

The carbon monoxide emission decreases with addition of biodiesel and Aluminum oxide nanoparticles compared with neat diesel. Biodiesel blend shows lowest carbon monoxide emission about 0.02 and marginal decrease in carbon monoxide emission compare to diesel in all the blends compare to neat diesel due to higher oxygen content in biodiesel and catalytic impact of nanoparticles.

2.4 Hydrocarbon emissions

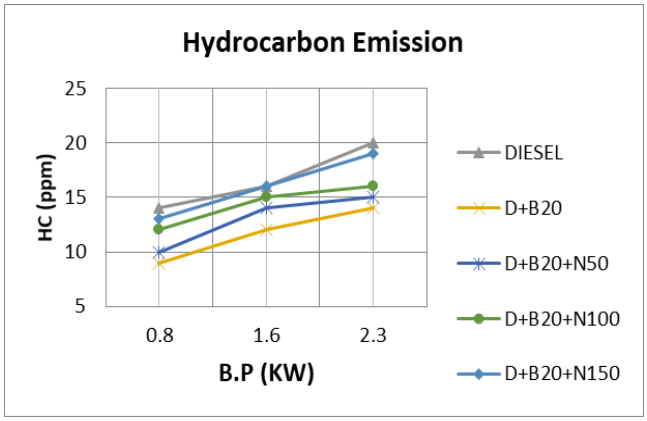


Chart -4: Variation of Hydrocarbon emission with brake power

The addition of biodiesel and Aluminum oxide decreases the hydrocarbon emission when comparing with neat diesel and lowest hydrocarbon emission is in biodiesel blend and marginal decrease in biodiesel with Aluminum oxide nanoparticles blend. Due to high oxygen content in biodiesel and nanoparticles additives promotes complete combustion. B20 N150ppm produces 5.2% less hydrocarbon emission in full load compare to neat Diesel, and 25% less emission in B20 Blend compare to Diesel.

2.5 Oxides of Nitrogen emissions

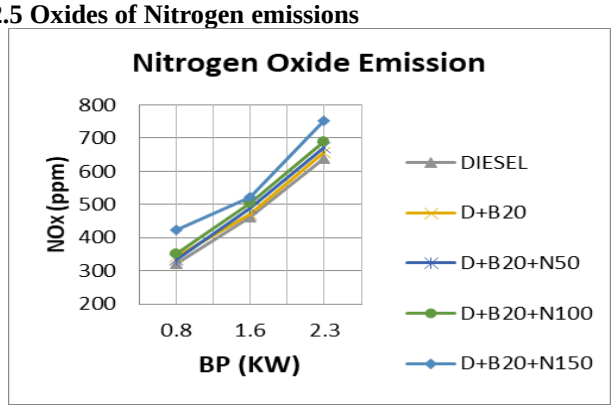


Chart -5: Variation of Nitrogen oxide emission with brake power

Biodiesel and Aluminum oxide nanoparticles blend D+B20+N150 produce14.8% higher emission compare to neat diesel because of rich oxygen content in biodiesel and catalytic properties of nanoparticles generate high combustion temperature which oxidizes more nitrogen in to oxides.

Pros:

- Renewable
- Incredibly Safe
- Ready to use
- Extends engine Lifespan

Cons:

- May damage fuel filters and pipes
- Can Effect Food Supply
- Little bit Expensive
- Lower fuel Efficiency than Diesel

CONCLUSION

The performance and emission characteristics of a CI engine with Diesel Biodiesel blends and Aluminum oxide nanoparticles as additive were investigated. The following conclusions were made from the experimental results.

The Brake thermal efficiency of engine increases with increase in the nanoparticle quantity in blends, D+B20+150ppm blend shows 16.6% high efficiency than Pongamia Biodiesel and D+B20+150ppm blend shows 7.5 % less efficiency than Diesel at maximum load condition.

Break Specific Fuel consumption decreases with increase in nanoparticle quantity in blends. from the comparison it is evident that D+B20 blend consumes 23.6% more fuel then Diesel due to their lower calorific value.

Carbon monoxide emission compare to diesel in all the blends compare to neat diesel due to higher oxygen content in biodiesel and catalytic impact of nanoparticles.

Nano particles additives promotes complete combustion. B20 N150ppm produces 5.2% less hydrocarbon emission in full load compare to neat Diesel, and 25% less emission in B20 Blend compare to Diesel.

NO_x emission increased by 7% in biodiesel blends due to higher oxygen content and increase combustion temperature.

Based on experimental result it has been concluded that Aluminum oxide nanoparticles enhances the engine performance and considerable reduction in exhaust emissions of diesel engine.

REFERENCES

[1] Ganesh G. Gowrishankar "Effect of Nano-fuel additive on emission reduction in a Biodiesel fuelled CI engine" 978-1-4244-8165-1/11/$26.00 ©2011 IEEE.

[2] Dr. S Karthikeyan "Environmental effects of nano additive Co3O4 in grape seed oil biofuel fuelled in CI engine" https://www.researchgate.net/publication/286135163 may2014.

[3] S.Manibharathi, B.Annadurai, R.Chandraprakash "Experimental Investigation of CI Engine Performance by Nano Additive in Biofuel" International Journal of Science, Engineering and Technology Research (IJSETR), Volume 3, Issue 12, December 2014

[4] J. SadhikBasha , R.B. Anand "Performance, emission and combustion characteristics of a diesel engine using Carbon Nanotubes blended Jatropha Methyl Ester Emulsions" Alexandria Engineering Journal 53, 259–273, 2014.

[5] T. Shaafi, R. Velraj "Influence of alumina nanoparticles, ethanol and isopropanol blend as additive with dieselsoybean biodiesel blend fuel Combustion, engine performance and emissions" http://dx.doi.org/10.1016/j.renene.2015.

[6] C. Syed Aalam , C.G. Saravanan, M. Kannan"Experimental investigations on a CRDI system assisted diesel engine fuelled with aluminium oxide nanoparticles blended biodiesel" Alexandria Engineering Journal 54, 351–358, 2015.

[7] MehrdadMirzajanzadeh , MeisamTabatabaei , Mehdi Ardjmand , AlimoradRashidi, Barat Ghobadian , Mohammad Barkhi , Mohammad Pazouki "A novel soluble nano-catalysts in diesel–biodiesel fuel blends to improve diesel engines performance and reduce exhaust emissions" Fuel 139, 374–382, 2015.

[8] S.Ch. Rao, M.SrinivasaRao "Performance Analysis of DI Diesel Engine Fuelled withDiesel along with Nano Additives" ISSN: 2231-5381, Page 107International Journal of Engineering Trends and Technology (IJETT) – Volume 24 Number 2- June 2015.

[9] G.Balaji and M.Cheralathan "Effect of CNT as additive with biodiesel on the performance and emission characteristics of a DI diesel engine"IJCRGG ISSN: 0974-4290 Vol.7, No.3, pp 1230-1236, 2014-2015.

[10] L.Jeryrajkumar, G.Anbarasu, T.Elangovan "Effects on Nano Additives on Performance and Emission Characteristics of Calophylliminophyllum Biodiesel" IJCRGG ISSN: 0974-4290 Vol.9, No.04 pp 210-219, 2016.

[11] Harish Venu and VenkataramananMadhavan "Effect of nano additives (titanium and zirconium oxides) and diethyl ether on biodiesel-ethanol fuelled CI engine "Journal of Mechanical Science and Technology 30 (5) 2361~2368, 2016.

[12] B. Prabakaran , AnuragUdhoji, "Experimental investigation into effects of addition of zinc oxide on performance, combustion and emission characteristics of diesel-biodiesel-ethanol blends in CI engine" Alexandria Engineering Journal 55, 3355–3362, 2016.

[13] Harish Kumar Patel ⇑, Saurabh Kumar, "Experimental analysis on performance of diesel engine using mixture of diesel and bio-diesel as a working fuel with aluminum oxide nanoparticle additive" Thermal Science and Engineering Progress 4, 252–258, 2017.

[14] Amith Kishore Pandian, Dinesh BabuMunuswamy, SanthanakrishnanRadhakrishana, Ramesh BapuBatheyRamakrishnan, BeemkumarNagappan, YuvarajanDevarajan, "Influence of an oxygenated additive on emission of an engine fueled with neat biodiesel" Pet. Sci. 14:791–797, 2017.

[15] HosseinSoukhtSaraee ,HadiTaghavifar, SamadJafarmadr " Experimental and numerical consideration of the effect of CeO2

nanoparticles on diesel engine performance and exhaust emission with the aid of artificial neural network" Applied Thermal Engineering 113, 663–672, 2017.

[16] K. Nanthagopal, B. Ashok ⇑, A. Tamilarasu, AjithJohny, Aravind Mohan "Influence on the effect of zinc oxide and titanium dioxide nanoparticles as an additive with Calophylluminophyllum methyl ester in a CI engine" Energy Conversion and Management 146, 8–19, 2017.

[17] S. Karthikeyan , A. Prathima ,"Environmental effect of CI engine using microalgae methyl ester with doped nano additives" Transportation Research Part D 50, 385–396, 2017.

[18] Seyyed Hassan Hosseini , Ahmad Taghizadeh-Alisaraei , Barat Ghobadian "Performance and emission characteristics of a CI engine fuelled with carbon nanotubes and diesel-biodiesel blends" Renewable Energy 111, 201e213, 2017.

[19] S. Mahalingam& S. Ganesan "Effect of nano-fuel additive on performance andemission characteristics of the diesel engine usingbiodiesel blends with diesel fuel" ISSN: 0143-0750 (Print) 2162-8246, 26 Apr 2018.

[20] MuthusamySivakumar , NallathambiShanmugaSundaram ,Ramasamy Ramesh kumar , Mohamed Hussain Syed Thasthagir "Effect of aluminium oxide nanoparticles blended pongamia methyl ester on performance, combustion and emission characteristics of diesel engine" Renewable Energy 116,518e526, 2018.

[21] A. Prabu "Nanoparticles as additive in biodiesel on the working characteristics of a DI diesel engine" Ain Shams Engineering Journal 9, 2343–2349, 2018.

[22] Anand Kumar Pandey, MilankumarNandgaonkar S Suresh Anil Varghese "The Effect of Cerium Oxide Nano ParticlesFuel Additive on Performance, Combustion,NOx Reduction and Nano Particle EmissionofKaranja and Jatropha Biodiesel in a Military585 kW CIDI Engine" SAE International. 2019-01-0262 Published 02 Apr 2019.

[23] YuvarajanDevarajan&Beemkumar Nagappan2 &GanesanSubbiah "A comprehensive study on emission and performance characteristics of a diesel engine fueled with nanoparticle-blended biodiesel" Accepted: 30 January 2019# Springer-Verlag GmbH Germany, part of Springer Nature 2019.

[24] J B Sajin, GokulOmanakuttanPillai, K Madhav&Saji Varghese "Effect of Nanoparticle on Emission andPerformance Characteristics of Biodiesel" International Journal of Ambient Energy 10.1080/01430750.2019.

[25] Harish Venu&PrabhuAppavu"Experimental studies on the influence of zirconium nanoparticle on biodiesel-diesel fuelblend in CI engine" International Journal of Ambient Energy, 2019.

[26] N Tamil Selvam& A Devaraj "Emission Study ON MGO2 Nano-Additive Doped Biodiesel on Immobile Diesel Engine" International Journal of Ambient Energy, DOI:10.1080/01430750.2019.

[27] V.S. Shaisundaram, M. Chandrasekaran, MohanrajShanmugam, S.Padmanabhan, R. Muraliraja& L. Karikalan "Investigation of Momordicacharantia seed biodiesel with cerium oxide nanoparticle on CI engine" International Journal of Ambient Energy, DOI: 10.1080/01430750.2019.

[28] M. Vinayagam, S. Suresh Kumar, M.M. Ravikumar, S. Mahendiran& T. Raja "Feasibility and emission study on employing MgO nanoparticle as oxygenated additive in neat biodiesel" DOI: 10.1080/01430750.2019.

[29] K.N. Balan, U. Yashvath& N. Prakash "nano- additive for reducing emission in honge biodiesel-fuelled diesel engine" International Journal of Ambient Energy, DOI: 10.1080/01430750.2019.

[30] P. T. Saravankumar, V. Suresh, V. Vijayan& A. Godwin Antony"Ecological effect of corn oil biofuel with SiO2 nanoadditives"To cite this article: P. T. Saravankumar, V. Suresh, V. Vijayan& A. Godwin Antony 2019.

[31] S. Manigandan, P. Gunasekar, S. Nithya& J. Devipriya "Effects of nanoadditives on emission characteristics of engine fuelled with biodiesel" To cite this article: S. Manigandan, P. Gunasekar, S. Nithya& J. Devipriya, Energy Sources, Part A: Recovery, Utilization, andEnvironmental Effects 2019.

[32] S. Ganesan, S. Padmanabhan, S. Mahalingam& C. Shanjeevi "Environmental impact of VCR diesel engine characteristics using blends of cottonseed oil with nano additives" Energy Sources, Part A: Recovery, Utilization, andEnvironmental Effects DOI:10.1080/15567036.2019.

[33] SivasubramanianRathinam, Sajin J B, GanesanSubbiah, Anwar Rajeev,Prakash s &Christopherselvam d "Assessment of the emission characteristics of the diesel engine with nano-particle in neem biodiesel" Energy Sources, Part A: Recovery, Utilization, and Environmental Effects ISSN: 1556-7036 (Print) 1556-7230, 2019.

[34] AbulKalamHossainand Abdul Hussain "Impact of Nanoadditives on the Performance and Combustion Characteristics of Neat Jatropha Biodiesel" 12, 921; doi:10.3390/en12050921 www.mdpi.com/journal/energies, Energies 2019.

[35] S.N.Shreenivasan, C.Chinnasamy"Experimental studies on Diesel Engine using Aluminium NanoParticles as Additives"international research journal of multidisciplinary technovation (IRJMT) 2019.

[36] RashmiRekhaSahoo, Animesh Jain "Experimental analysis of nanofuel additives with magnetic fuel conditioning for diesel engine performance and emissions" www.elsevier.com/locate/fuel, Fuel 236 2019.

[37] SanthanakrishnanRadhakrishnan1 & Dinesh Babu Munuswamy2 &Yuvarajan Devarajan3 &ArulprakasajothiMahalingam "Performance, emission and combustion study on neat biodieseland water blends fuelled research diesel engine" Heat and Mass Transfer, 55:1229–1237, 2019.

[38] Harish Venu&PrabhuAppavu "Combustion and emission characteristics of tamarind seed biodiesel-diesel blends in a compression ignition engine" International Journal of Ambient Energy,2019.

[39] Nivin Joy, DevarajanYuvarajan&NagappanBeemkumar "Performance evaluation and emission characteristics of biodiesel-ignition enhancer blends propelled in a research diesel engine" International Journal of Green Energy ISSN: 1543-5075, 2019.