Indian energy scenario, biodiesel oxidation, impact on fuel system and engine performance & emission characteristics – A review

Rahul Krishnaji Bawane[1*], A. Muthuraja[2], Gajanan N. Shelke[3]

[1,2]*Department of Mechanical Engineering, Sandip University, Nashik, Maharasthra, India*

[3]*Department of Mechanical Engineering, Sandip Institute of Engineering and Management, Nashik, Maharashtra, India*

Presented in International Conference on Advancements and Futuristic Trends in Mechanical and Materials Engineering held at Indian Institute of Technology Ropar (IITR), Rupnagar, during December 5-7, 2019.

ABSTRACT

The research in searching of new feedstock and biodiesel has mainly been focused on economical use and increasing blend proportion, and its impact analysis and optimization for the last one and half decades. But recent researches and their findings approaches to favor on understanding and popularization for biodiesel. In the present work, literatures were cited from years 2010 to 2019, and reviewed production and sale of automobile also energy scenario of India, biodiesel performance on an engine, fuel supply system components and oxidation stability. It was found that negative or no change, majority of them reported the reduction in HC, CO, CO_2 and NO_x emission with use of biodiesel, but simultaneously higher fuel consumption, exhaust gas temperature, lower heat release rate and power from available literature. The wear rate and injector clogging and fuel filter plugging problems are also reported in the favor of use of biodiesel.

KEYWORDS

Biodiesel,
Emissions,
Oxidation,
Fouling.

1. Introduction

It is necessary to review recent research findings in the field of road transport fuel supply and demand scenario, various opportunities to reduce the dependency on the conventional petroleum fuel for vehicles, national air pollution history, today's status and the severity of the contribution to bad air quality from the transportation section and to find the various opportunities to change the current scenario to the better direction towards clean atmosphere, good health society and environment. The present work emphases literature review summary and explanation of the current state of knowledge on the said topic based on the previous researchers finding and contribution to the society in terms of adding knowledge to the existing one.

Among all available road transport vehicles energy sources, biodiesel found the feasible alternative to diesel fuel. Biodiesel sources are renewable, eco-friendly and biodegradable in nature and can be produced from edible and non-edible vegetable oils or animal fats.

The use of edible oil for biodiesel production raise the problem to domestic use, demand and supply chain, which is reduced by the use of non-edible vegetable oil for biodiesel as they available in plenty and eliminate the competition for food. Non-edible oils are more efficient and environment friendly also the byproduct from these are useful and cost-wise non-edible oils are cheaper than edible oils.

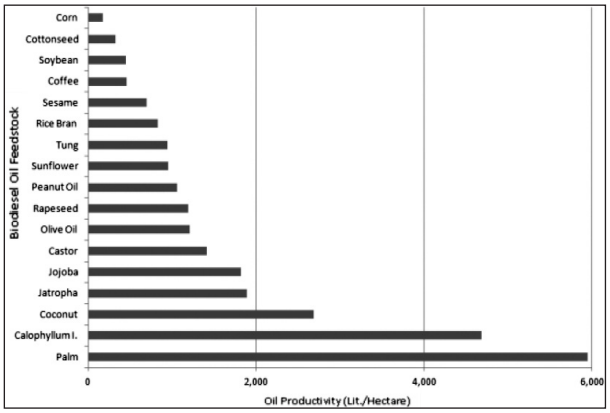


Fig. 1. Biodiesel feedstock oil productivity yield [1, 2].

*Corresponding author,
E-mail: rahul_bawane@rediffmail.com

Comparing to production of petro-diesel product, production of biodiesel is easy and more convenient and can be handle by individuals on a very small to medium scale and it is inexpensive with small investment. Especially for non-edible oil biodiesel, is more profitable and there is no competition with food supply chain and also government promotes such project by training schemes and finance.

This review analyzes critically a segment of a published literature through summary, classification, and comparison of previous research studies. For published literature related to impact of vehicular emission on air quality, search of new alternative fuel sources to minimize the petroleum fuel dependency, various methods of methodology used to optimize the engine performance to catch-up the emission norms and future of the vehicle energy sources and its opportunities.

2. Automobile Sales and Fuel / Energy Scenario

In this section, a review of the past sale and production of the automobiles vehicles on the indian road and the indian energy senario has been discussed.

Automobile sector production of vehicles including passenger vehicles, commercial vehicles, three wheeler, two wheeler etc. in April-March 2018 was 29,075,605 vehicles as compared to the production of 25,330,967 vehicles in April – March 2017 which was showing increase in production by 14.78%.

Government of India, under the ministry of power, Central Electricity Authority (CEA), annually published the Load Generation Balance Report (LGBR). This report included energy requirement and availability in million unit and peak demand and availability in mega watt for the year 2018-19, this report also compared the previous year actual power supply position with the present forecasted power supply position in the LGBR report. LGBR [4].

The forecasting for the country power position in the year 2018-19 considered the existing power availability and included renewable energy sources, availability of fuel and water for power stations. Power capacity of 9626 MW adding during the year 2018-19, in which 8216.15 MW of

Table 1
Impact of biodiesel use [3].

Sr. No.	Impacts of Biodiesel Use	Description
1	Economic Impacts	Sustainability Fuel diversity Increased number of rural manufacturing jobs Increased income taxes Increased investments in plant and equipment Agricultural development International competitiveness Reducing the dependency on imported petroleum
2	Environmental Impacts	Green house gas reductions Reducing of air pollution Biodegradability Higher combustion efficiency Improved land and water use Carbon sequestration
3	Energy Security	Domestic targets Supply reliability Reducing use of fossil fuels Ready availability Domestic distribution renewability

thermal power station, 910 MW of hydro power station and 500 MW of nuclear power station. The total projected power generation in the country will be 1265 Billion Units, considering current working power station and expected commissioned power station during the year 2018-19. LGBR [4].

Indian road transport total vehicles consist of 79% of two wheelers, 4% of three wheelers, 3% of buses and trucks, 12% of economy four wheelers and 2% of premium four wheelers. For electric vehicle on Indian roads, India needs a minimum 10GWh of cell by 2022 and this will increased to 50 GWH by the year 2025. NITI Ayog World Energy Council [5].

Gowri et al., [6], has estimated consumption of energy and impact on environment of vehicles using well-to-wheel and vehicle life cycle techniques. Vehicle emissions in well-to-wheel consist of production of feedstock, its transportation, the conversion into fuel, distribution of fuel and combustion of fuel. The Calculation of emission in well-to-wheel by using Greenhouse Gases Regulated Emissions and Energy Consumption in Transportation (GREET) and Vehicle emission in vehicle life cycle was investigated on the basis of mass, material used for vehicle manufacturing, energy and its types utilized for operation of vehicle and the life span of the vehicle. Researcher reported CO_2 emission from electric vehicle in comparison to IC engine is more in China, where as it is less in Germany, USA and Japan.

3. Biodiesel and Engine Performance & Emission Characteristics

In this section, a review of research work in the field of reduction emission from road vehicles and findings of new alternative energy sources and its potentials has been discussed.

From the available literature, It was witnessed that the current engines are designed for only the diesel fuel, therefore, the engine for biodiesel is comparatively less in performace. This may

Table 2
Vehicle life cycle emission form electric vehicle [6].

Energy Sources	Description	CO2 Emission
Renewable Energy Sources	Wind Turbine Energy	7 gm / MJ
	Nuclear Energy	9 gm/MJ
	Solar Power	30 gm/MJ
	Hydropower	11 gm/MJ
Non-Renewable Energy Sources	Coal	300-350 gm / MJ
	Natural Gas	100-120 gm / MJ

Table 3
Statistics of effects of pure biodiesel [8].

Parameters	No. of Literatures						
	Reviewed	Reported Increase		Reported Similar		Reports Decrease	
	Nos.	Nos.	%	Nos.	%	Nos.	%
Power	27	2	7.4	6	22.2	19	70.4
Economy	62	54	87.1	2	3.2	6	9.7
PM emissions	73	7	9.6	2	2.7	64	87.7
NOx emissions	69	45	65.2	4	5.8	20	29.0
CO emissions	66	7	10.6	2	3.0	57	84.4
HC emissions	57	3	5.3	3	5.3	51	89.5
CO2 emissions	13	6	46.2	2	15.4	5	38.5

also due to the less calorific value of biodiesel. However, some researcher have reported that by increasing power output upto B20 as compared to diesel, as the biodiesel inherently having oxygen content approximately 10% in weight that improve combustion specially at rich zone which result in more complete combustion. Also fuel system working on the volumetric basis and as the density of biodiesel blend is higher than neat diesel fuel, in addition to this, biodiesel blends have more viscosity which reduces internal leakages in the fuel pump which causes more mass of fuel flow rate is pumped to the engine and result in increase in power. Wali et al., [7]. If further increase the biodiesel blend, the power shows decreasing trends and reach to lesser than diesel fuel and reported minimum among all blend for B100.

Nanthagopal et al., [9] used higher alcohols n-pentanol and n-octanol to prepare blend with Calophyllum oil biodiesel, and tested against the pure biodiesel and diesel. It is found that alcohol decreases auto ignition quality and density of fuel blend. The study are blended with biodiesel, blending of higher alcohols with biodiesel reduces the auto ignition quality and density of the blends, The study found that there is increase in brake thermal efficiency (BTE) upto 8.9%, CO emission increased upto 50%, smoke emission upto 35% but at the same time it is reported that there is decrease in HC emission upto 22%, NOx emission 6.8%. Ong et al., [18]. When the same researcher [2019] tested diesel engine for ternary blend of diesel, biodiesel, and decanol, it is reported that there is increase in NOx emission and reduction in CO, HC and Smoke emissions.

Rajet et al., [10] used biodiesel from Calophyllum oil and found there is no much variation in the HC, CO, CO_2, and NOx emissions at all loads conditions but the peak pressure and the rate of pressure rise were higher and increase with increase in load.

Dharmaraja et al., [11] conducted experiment using rice bran oil biodiesel blend, 20% blend reported lower ignition delay and full load which increases the rate of vaporization as shown higher cetane number. authors reported increase in BTE and exhaust gas temperature (EGT) (by 7.8%) and decrease in HC, CO, CO_2 and NOx and smoke (by 21.62%) emissions.

Helin et al., [12] conducted an experiment using blend of biodiesel and Methylfuran (MF) fuel as alternative to diesel engine, finding of the study were, the blend shows shorter burning duration and larger ignition delay at higher load conditions, the emission of HC and CO shows decreases whereas NOx reported to be increased.

Manigandan et al., [13] tested corn oil biodiesel with pentanol and titanium as additives, found that there is improvement in BSFC by 6.3%, BP by 22%, and decrease in emission of CO, HC and smoke with NOx reduction by 16%.

Raman et al., [14] prepared fuel blend of biodiesel from rapeseed oil and diesel which then tested and reported as lesser in BTE, peak pressure, heat release rate, with decrease in CO and HC emission, but reported that there is raise in EGT and brake specific fuel consumption (BSFC) with increase in NOx and smoke emissions.

Adaileh et al., [15] tested waste cooking oil (WCO) biodiesel blends against neat diesel and observed that, there is lower emission of CO, HC and CO_2 with increase in BTE, EGT, BSFC and NOx emission.

Chaurasiya et al., [16] has conducted an experiment using biodiesel from Jatropha, Soybean and Waste Cooking Oil blend and reported results as, there is decrease in NOx emission as compared to diesel fuel but Jatropha shows lowest, and WCO shows highest values among biodiesel blends. At the same time all biodiesel blends shows increase in BSFC and EGT with lower values for CO emissions.

Abed et al., [17] prepared biodiesel from Jatropha, Palm, Algae and Waste Cooking Oils and blend with diesel in proportion of 10% and 20%, experimentally found that, emission of CO, HC, CO_2 and smoke for biodiesel blend of Jatropha, Algae and Palm were lesser than diesel, but CO_2 emission for Waste Cooking Oil biodiesel blend was higher than diesel. Emission of NOx found to be higher for all the blends.

Santos et al., [19] produce biodiesel from peanut oil and evaluated potential as an alternative fuel to 14.2 kW (small) and 60 kW (large) diesel engine, the results shows that, when engine fuel with neat biodiesel, the emission of CO, HC and CO_2 are higher for smaller engine and lower for larger engine. Where BSFC and NOx emission found to be higher than diesel in both the engines.

Nahian et al., [20] have used tranesterified palm oil biodiesel blend, and investigation was reported

for B10 and B20 as, BTE, BSFC for B10 is slightly lower than diesel and higher than B20, but the CO and NOx emissions were slightly lower than diesel fuel for both the biodiesel blends [20].

Shailaja et al., [21], sesame oil is used as biodiesel feedstock and various blend with diesel were tested in diesel engine and found, better CO, HC, CO_2, and NOx emission characteristics as compared to diesel engine and enhanced performance in term of BTE, Mechanical Efficiency.

Shehata et al., [22], conducted experiment for B100 sunflower biodiesel and B20 of jojoba oil biodiesel and compare with neat diesel engine performance, finding of the study were, both test fuel shows lower BTE, BP and higher BSFC because of lower heating value of biodiesel which in tern shows lower EGT and NOx emissions. At the same time both test fuel shows, higher CO and CO_2 emission which is due to higher Carbon-Hydrogen ratio.

4. Biodiesel and Impact on Fuel Supply System & Components

Use of biodiesel as a fuel blend with diesel or higher alcohols and ternary blend, for a short run investigation of engine performance and emission characteristics are reported positive, which shows improvement in performance parameters like BTE, BSFC etc. and reduction in emission parameters like NOx, CO, HC etc. But for the long run, there are adverse effect on the engine performance and emission characteristics due to excessive accumulation of carbon and lacquer deposits on the injector, combustion chamber, valves and piston, also it is observed that the fuel spray pattern is changed due to clogging of injector holes and spray penetration and cone angle is disturbed which result in degradation of engine parts and performance.

D'Amico et al., [23] found that now a days many researcher focused on evaluation of injector deposition using Gas Chromatography (GC) or Mass Spectrometry (MS) analysis and for characterized the microstructures of depositions Field Emission Scanning Electron Microscopy (FESEM) and Energy Dispersive X-ray Spectroscopy (EDXS) are used. In the authors study, the use of biodiesel/liquid fuel result in accumulation of carbon deposition at injector nozzle, which affect the engine performance and emission characteristics. To characterized these carbon accumulation on nozzle, imaging analysis method is adopted by the researcher, for which he use low cost digital camera, a closed box for accommodating injector and camera and 100W lights to built a diffused illumination. Researcher develop a method to compare the injector nozzle fouling effects by photography and processing the images obtained a pixel count which then use to analyzes fouling index. The researchers took a picture and processed in a matrix of pixels and a injector fouling index was identifies with reference to the clean injector nozzle.

Liaquat et al., [24] and Liaquat et al., [25], researcher conducted an endurance test for 250 hr engine run and compared the variation of parameters of 20% palm oil biodiesel (PB20) and 20% jatropha oil biodiesel (JB20) fuel blend against neat diesel fuel. During the experiment, investigation is carried out for fuel injector depositions, lubricating oil viscosity and contamination, fuel economy and engine emissions. On the basis of visual inspection, Scanning Electron Microscopy (SEM) and Energy Dispersive S-ray Spectosocpy (EDS) are used to analyze and concluded that, there is higher level carbon accumulation on the fuel injector tip for the use of Biodiesel blend, lubricating oil shows higher wear metal

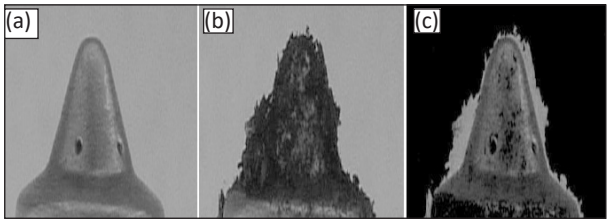


Fig. 2. Injector Nozzle at (a) Clean, (b) Dirty and (c) Difference Analysed [23].

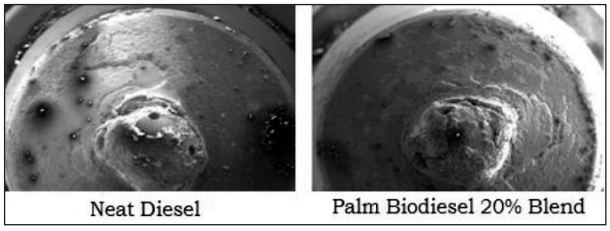


Fig. 3. Injector nozzle deposition under SEM micrographs [24].

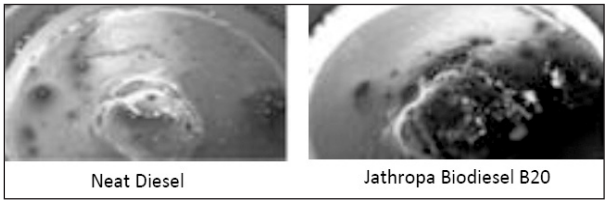


Fig. 4. Injector nozzle deposition under SEM micrographs [25].

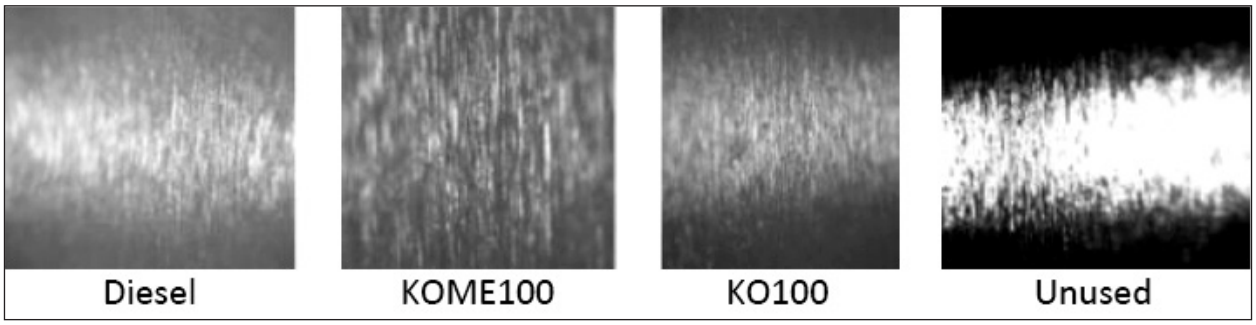


Fig. 5. Optical microscopy images of nozzle needle [26].

Table 4
Effectiveness rank of antioxidants [27, 29, 30, 31].

Biodiesel	Antioxidant	
	Concentration	Effective Rank
Soybean Oil	8000 ppm	TBHQ > BHT > BHA
	3000 ppm	TBHQ > PY > PG > BHA > BHT
	1000 ppm	TBHQ > PG > BHA > BHT
Cottonseed Oil	1000 ppm	TBHQ > PY > PG
Palm Oil	---	TBHQ > BHA > BHT
Animal Fat	3000 ppm	TBHQ > PG > PY > BHA
Calophyllum Oil	1000 ppm	TBHQ > PG > PY > BHT > BHA

concentrations which decreases viscosity and increases the density of it. The fuel economy and engine emissions reported higher BSFC and NOx emission, but at the same time there is reduction in HC and CO emissions for Biodiesel 20% blend fuel against the neat diesel fuel engine run for long period.

Reddy et al., [26], researcher investigate the wear physiognomies of fuel injection equipment components when diesel engine is run on the biodiesel from Karanja oil. Experiment is carried out for the 250hrs and using three fuels viz. neat diesel and neat Karanja oil biodiesel (KOME100) and Straight Vegetable (Karanja) Oil (KO100). During this study, researchers analyze wear rate, dimensional deviations, weight reduction and surface quality of different components like, fuel injector nozzle needle, plunger, valve etc. from the outcome of the study, researcher concluded that, SVO (KO100) reported minimum wear rate followed by KOME100 and Diesel, this is mainly due to mechanical and thermal stresses induced and secondarily due to fuel causing chemical itching of the material. And the surface quality analyze under Optical Microscopy at zoom of 100x, 200x and 500x, from which it is concluded that KO100 gives best lubricity and minimum surface quality distortion. Weight loss analysis reported that the components like nozzle needle, plunger, valve etc. shows minimum reduction in weight as improved lubricity with biodiesel as compared to neat diesel fuel.

Few researchers only reported the durability of engine and fuel supply system components, as it required more time and costly than other experimental investigation like engine power, economy, performance and emission characteristics etc.

For durability test when engine is fuel with biodiesel and its blends, mainly focused on the carbon deposition on piston, combustion chamber, valves and fuel injectors, engine wear of piston rings, cylinder liner injector valves and valve seat and clogging of fuel injector nozzle and plugging of fuel filters etc.

Many researchers agree to use of biodiesel reduces wear as biodiesel itself act as lubricants and its blend improve the lubricity of the test fuel but some found the negative trend of wear for selected biodiesel, carbon deposits found to be lower by many researchers when engine run with biodiesel and its blends. Jinlin et al., [8].

5. Biodiesel and Oxidation Stability

Vegetable oil and biodiesel use most commonly depends on the various properties, but for the prolong use the most important property is its stability, which shows the ability of the biodiesel

to degradation. In oil stability mainly there are three kind, Storage stability, Thermal stability and most significant Oxidation stability. The vegetable oil biodiesels are more prone to degradation due to thermal-oxidative decomposition, contamination due to outside particles and impurities, oxidation and hydrolysis all these contamination, which change biodiesel properties and hamper the engine performance characteristics. The byproduct formed during oxidation of biodiesel decomposition pay deposition formation in storage container, fuel supply system, fuel filters. Oxidation products of biodiesel are the outcome from the initial accumulation of Hydroperoxides which finally polymerize and form the unsolvable residues that prone to plugging filters, fouling injectors, and degrading engine performance. The polymerization reaction also increase the viscosity of the biodiesel and oxidation to very high levels results in separation of two phases which causes problem of fuel pump and fuel injector operation. Oxidation of biodiesel is unavoidable but using antioxidants one can minimize the rate of oxidation. Mohamed et al., [27], Harrison [28] and Rizwanul et al., [29].

Mohamed et al., [27] and Rizwanul et al., [29], has investigate the effect of antioxidants, pyrogallo (PY), propyl gallate (Pg), tert-butyl-hydroxy-quinone (tbhq), butylated hydroxyl-toluene (BHT), butylated hydroxyl-anisole (BHA) for the biodiesel produced from calophyllum inophyllum. Researcher found that for biodiesel blend B20, oxidation stability using antioxidants tert-butyl-hydroxy-quinone increase from 48.74 hrs to 65.53 hrs.

Biodiesel have inherent properties of oxidizes with time when exposed to air. There are many factors which play role in the oxidation process of biodiesel like structure of fatty acid, presence of certain metals which accelerate degradation of biodiesel, higher temperature, extraneous materials, peroxides, light or pressure and antioxidants as well as the surface area of biodiesel exposed to air. Mohamed et al., [27] and Kumar et al., [30]. The change in properties of biodiesel due to oxidation result in formation of gums that clog the filters and injection systems and the presence of hydro-peroxides along with carboxylic acids may corrodes the fuel system. Also oxidation reduces the lubricity of the biodiesel which then causes high wear rate of respective sliding parts. Kumar et al., [30] and Pullen [32]. The changes in composition of biodiesel which includes alteration of acid value, density, viscosity, peroxide value, flash point etc. due to oxidation of biodiesel are responsible for change the chemical properties which then influence in degrading engine performance and emissions, oxidized biodiesel reported 1.2% higher BSFC as compared to un-oxidized biodiesel also shows higher NOx emission and lower heating value of fuel. Mohamed et al., [27], Harrison [28] and Kumar et al., [30].

Ramalingam et al., [31], conducted as study of oxidation stability and engine emissions for the B20 fuel blend of Calophyllum oil biodiesel with the various proportions of leaf extract additives. Researcher conducted experiment with the Neat B20 blend and B20 blends with 0.5%, 1% and 1.5% of additive extracted from calophyllum leaf. Findings of the study were, the NOx and smoke emission level are reduced for the additive B20 blends as compared to neat B20 blend and with more additive % there is more reduction observed. CO and HC emissions found to be increased with increase in additive %, but reported lower than that of diesel fuel. Researcher suggested to leaf extract of calophyllum as additive was may use as renewable replacement for synthetic fuel additives.

6. Conclusion

From the critical review of the avilable litearatures on performance of biodiesel, oxidation stability, fouling, and emmision characteristics. The following conclusions were arrived;

1. The average 250 lacks vehicles have been delivered in last five years in india. Therefore, switching to e-vehicles is not feasible option in existing senario as it demands additional 50 GWH energy by the year 2025.
2. Most commonly NOx emission was increased with the use of biodiesel, result due to changes in spray pattern.
3. CO emissions reduced with biodiesel and its blends mainly due to lower carbon to hydrogen ratio of biodiesel.
4. Emission level of HC is reduced with increased in biodiesel blend, as the feedstock of biodiesel having different chain length or saturation level.
5. CO_2 emission reduces for biodiesel as a result of low carbon to hydrogen ratio, also overall the CO_2 emission of biodiesel shows reduces greatly from the view of life cycle circulation.
6. The engine durability in general main focus on

carbon deposits, engine wear and problems in the fuel supply system, was observed and enhanced with biodiesel in comparison to conventional fuel system.

7. The inherent properties of biodiesel is to get oxidize with time in the presence of air, using Tert - Butyl - Hydroxy - Quinone anitoxidants shows improvement in oxidation stability.

Acknowledgement

This paper is a revised and expanded version of an article entitled, 'Impact and Performance of Biodiesel on Emissions and Oxidation Stability – A Critical Review' presented in '7th International Conference on Advancements and Futuristic Trends in Mechanical and Materials Engineering' held at Indian Institute of Technology Ropar, Rupnagar, India during December 5-7, 2019.

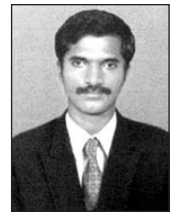
References

1. Bawane, R. K., Muthuraja, A., Shelke, G. N., Gangele, A. (2020). Impact analysis of CalophyllumInophyllum oil biodiesel on performance and emission characteristic of diesel engine under variation in compression ratio, engine load, and blend proportion. *International Journal Of Ambient Energy,* doi.org/10.1080/01430750.2020.1730955.
2. Aninidita, K., Karmakar, Subrata., Mukherjee, S. (2010). Properties of various plants and animals feedstocks for biodiesel production. *Bioresource Technology,* 101(9), 7201–7210.
3. Nada, E.M., ElSolh. (2011). *The Manufacture of Biodiesel from the used vegetable oil* [Unpublished M. S. Research thesis]. Cairo University.
4. India. Central Electricity Authority. (2018). *Load Generation Balance Report – LGBR.*
5. India. NITI Ayog & World Energy Council. (2018). *Zero Emission Vehicles (ZEVs): Towards A Policy Framework*
6. Asaithambi G., Treiber M., Kanagaraj V. (2019). Life Cycle Assessment of Conventional and Electric Vehicles. In: Palocz-Andresen M., Szalay D., Gosztom A., Sípos L., Taligás T. (eds) *International Climate Protection.* Springer, Cham. https://doi.org/10.1007/978-3-030-03816-8_21.
7. Adaileh, W.M., & AlQdah, K.S. (2012). Performance of Diesel Engine Fuelled by a Biodiesel Extracted from a Waste Cocking Oil. *Energy Procedia* 18, 1317- 1334. doi : 10.1016/j.egypro.2012.05.149.
8. Xue, Jinlin., Grifit , Tony E., Hansen, Alan. (2011). Effect of biodiesel on engine performances and emissions. *Renewable & Sustainable Energy Reviews,* 15(2), 1098- 1116. doi:10.1016/j.rser.2010.11.016.
9. Nanthagopal, N.K., Ashok, B., Balusamy, S., Pathy, M., Sahil, G., Atluri, R., Nabi, Md., Rasul, M. (2019). Study on decanol and Calophyllum Inophyllum biodiesel as ternary blends in CI engine. *Fuel,* 239, 862-873. 10.1016/j.fuel.2018.11.037
10. Mohan, T.R., Murugumohan, K., (2012). Tamanu oil - an alternative fuel for variable compression ratio engine. *International Journal of Energy & Environmental Engineering,* 3(1).
11. Dharmaraja, J., Nguyen, D., Shobana, S., Saratale, G., Arvindnarayan, S., Atabani, A.E., Chang, S.W, & Kumar, G. (2018). Engine performance, emission and bio characteristics of rice bran oil derived biodiesel blends. *Fuel,* 239, 153-161. 10.1016/j.fuel.2018.10.123.
12. Xiao, H., Yang, X., Hou, B., Wang, R., Xue, R., & Ju, H. (2019). Combustion performance and pollutant emissions analysis of a diesel engine fuelled with biodiesel and its blend with 2-methylfuran. *Fuel*, 237, 1050-1056.
13. Manigandan, S., Gunasekar, P., Devipriya, J., & Nithya, S. (2019). Emission and injection characteristics of corn biodiesel blends in diesel engine. Fuel, 235 , 723–735.
14. Raman, L.A., Deepanraj, B., Rajakumar, S., Sivasubramanian, V. (2019). Experimental investigation on performance, combustion and emission analysis of a direct injection diesel engine fuelled with rapeseed oil biodiesel. *Fuel,* 246 , 69–74.
15. Adaileh, W.M., & AlQdah, K. S. (2012). Performance of Diesel Engine Fuelled by a Biodiesel Extracted from a Waste Cocking Oil. *Energy Procedia*, 18, 1317- 1334. doi : 10.1016/j.egypro.2012.05.149.
16. Chaurasiya, P. K., Singh, S. K., Dwivedi, R., Choudri, R. V. (2019)Combustion and emission characteristics of diesel fuel blended with raw jatropha, soybean and waste cooking oils. Heliyon. 5(5), doi.org/10.1016/j.heliyon.2019.e01564.
17. Abed, K.A., Gad, M.S., El Morsi, A.K., Sayed, M.M., & Elyazeed, S.A. (2019). Effect of biodiesel fuels on diesel engine emissions. *Egyptian Journal of Petroleum,* 28(2), 183–188. https://doi.org/10.1016/j.ejpe.2019.03.001
18. Ong, H.C., Mahlia, T.M.I., Masjuki, H.H., & Norhasyima, R.S. (2011). Comparison of palm oil, Jatropha curcas and Calophyllum inophyllum for biodiesel: A review. *Renewable and Sustainable Energy Reviews,* https://doi.org/10.1016/j.rser.2011.05.005
19. Santos, B., Capareda, S., & Capunitan, J. (2013). Engine Performance and Exhaust Emissions of Peanut Oil Biodiesel. *Journal of Sustainable Bioenergy Systems*, 03, 272-286. 10.4236/jsbs.2013.34037.
20. Nahian, Md. Rafsan & Islam, Md. Nurul & Khan, Shaheen. (2016, December). *Production of Biodiesel from Palm Oil and Performance Test with Diesel in CI Engine.* In International

Conference on Mechanical, Industrial and Energy Engineering (Bangladesh).

21. Shailaja, M., ArunaKumari, A., Raju, Sita Rama A. V.(2013, September). Performance Evaluation of a Diesel Engine with Sesame Oil Biodiesel and its Blends with Diesel. *International Journal of Current Engineering and Technology.*
22. Shehata, M.S., & Razek, S.M.A. (2011). Experimental investigation of diesel engine performance and emission characteristics using jojoba/diesel blend and sunflower oil. *Fuel,* 90(2), 886–897. https://doi.org/10.1016/j.fuel.2010.09.011
23. D'Amico, M., Zampilli, M., Laranci, P., D'Alessandro, B., Bidini, G., & Fantozzi, F. (2015). Measuring injectors fouling in internal combustion engines through imaging. *In Energy Procedia,* 82, 9–16. Elsevier Ltd. https://doi.org/10.1016/j.egypro.2015.11.873.
24. Liaquat, A.M., Masjuki, H.H., Kalam, M.A., Fazal, M.A., Khan, A.F., Fayaz, H., & Varman, M. (2013). Impact of palm biodiesel blend on injector deposit formation. *Applied Energy,* 111, 882–893. https://doi.org/10.1016/j.apenergy.2013.06.036
25. Liaquat, A.M., Masjuki, H.H., Kalam, M.A., & Rizwanul Fattah, I.M. (2014). Impact of biodiesel blend on injector deposit formation. *Energy,* 72, 813–823. https://doi.org/10.1016/j.energy.2014.06.006
26. Reddy, S.M., Sharma, N., Gupta, N., & Agarwal, A. K. (2018). Effect of non-edible oil and its biodiesel on wear of fuel injection equipment components of a genset engine. *Fuel,* 222, 841–851. https://doi.org/10.1016/j.fuel.2018.02.132
27. Shameer, M.P., Ramesh, K. (2017). Influence of antioxidants on fuel stability of Calophylluminophyllum biodiesel and RSM-based optimization of engine characteristics at varying injection timing and compression ratio. *The Brazilian Society of Mechanical Sciences and Engineering,* 39, 4251-4273. DOI 10.1007/s40430-017-0884-8.
28. Harrison, *B:Oxidative Stability And Ignition Quality Of Algae Derived Methyl Esters Containing Varying Levels Of Methyl Eicosapentaenoate And Methyl Docosahexaenoate,* 'Colorado State University', 2011, (MS Thesis).
29. I.M. Rizwanul Fattah, H.H. Masjuki, M.A. Kalam & B.M. Masum (2014). Effect of synthetic antioxidants on storage stability of Calophyllum inophyllum biodiesel. *Materials Research Innovations*, 18, Sup6, S6-90-S6-94. DOI: 10.1179/1432891714Z.000000000936
30. Kumar, N. (2017, February 15). *Oxidative stability of biodiesel: Causes, effects and prevention.* Fuel. Elsevier Ltd. https://doi.org/10.1016/j.fuel.2016.11.001
31. Ramalingam, S., Govindasamy, M., Ezhumalai, M., & Kaliyaperumal, A. (2016). Effect of leaf extract from Pongamia pinnata on the oxidation stability, performance and emission characteristics of calophyllum biodiesel. *Fuel,* 180, 263–269. https://doi.org/10.1016/j.fuel.2016.04.046
32. Pullen, J., & Saeed, K. (2012, October). An overview of biodiesel oxidation stability. R*enewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2012.06.024

Mr. Rahul Krishnaji Bawane, Assistant Professor, Department of Mechanical Engineering, Pimpri Chinchwad College of Engineering and Research, Ravet, Pune. He has 11 years of experience in teaching field and 4 year of industrial experience. He is Pursuing PhD from Sandip University, Nashik. He had filed 29 Indian Patents and registered 45 copyrights on technical literature, published 2 academic books, and delivered more than 15 lectures on IPR at National and State Level workshops and STTP.



Dr. Ayyankalai Muthuraja, Associate Professor, Department of Mechanical Engineering, Sandip University, Nashik, Maharashtra. He has 10 years of experience in teaching and research experience. He has completed PhD from Indian Institute of Technology, Guwahati. He has published 11 International Journals including 9 SCI/Scopus indexed journals and he has also published 04 Indian Patents and 3 book chapters. He has been doing collaboration research work with different research teams in and around the world. His research interests are Sustainable energy, Nano-Materials, and Tribology and so on. (E-mail: a.muthuraja2010@gmail.com)

Dr. Gajanan N. Shelke, Professor, in Mechanical Engineering Department at Sandip Institute of Engineering and Management, Nasik, Maharashtra, India. He received his Ph.D. from IIT Guwahati. He is into academics from past 23 years. He is working in the area of Fluid and Thermal, Renewable Energy, Exergy analysis, Fixed and Fluidized Bed Gasification, Combustion, Alternative fuels. He is carrying collaborative research with Sandip University. He has published more than 20 research papers in international journals and Conferences. He has contributed as resource person for various faculty development programs and Session Chair in various conferences. He was awarded as Best NSS Program officer by Government of Maharashtra for his dedication to students and society. He is a life member of various societies and worked as a subject expert in Mechanical Engineering.
(E-mail: gnshelke@gmail.com)