Operational and Environmental Impact of Biodiesel on Engine Performance: A review of Literature

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Abstract- The world presently is facing problem of crisis in fossil fuels and environmental pollution. Urbanisation, industrialisation and increasing population has led to steep rise in consumption of fuel all around the world. This indiscriminate usage of fuel has forced to think beyond conventional sources of fuel especially the replacements of petroleum diesel and gasoline. Biodiesel in this case offers a great prospect. As biodiesel in derived mainly from bio materials like plants either edible or non-edible, it is very much reproducible. But due to high viscosity of these biodiesel they cannot be used directly for engine operation. Their blend with diesel can be used as fuel in engine without any modification in the engine. The aim of present paper is to study the impact of various biodiesel on engine performance and its environmental aspects. The study reveals that B_{20} biodiesel will be substitute to diesel as an alternative fuel. The result show that Brake Specific Fuel Consumption (BSFC) and Brake Thermal Efficiency (BTE) for B_{20} biodiesel is same as for diesel.

Keywords—Biodiesel, BSFC, BTE, Emission, Performance.

1. Introduction

Since the revolution of industry all across the world, energy needs of human beings have increased drastically so as to maintain living standards and keep up the economic growth. In past decades, fossil fuels like coal, petroleum and natural gas have played a major role in fulfilling the needs of energy. The rate at which fossil fuels are being used, these are expected to get exhausted in near future. So need of hour is to look beyond conventional sources of fuel and develop alternate sources of fuel. Biodiesel offers a great choice as an alternative fuel. In recent decades, there has been continuous use of diesel engines due to their lower operating cost, higher thermal efficiency, longer durability. Along with this, diesel engines emit higher amount of NOx and particulate matter (PM) than gasoline engines. So with continuous use of diesel engines in around the globe, there is risk of degradation of environment in longer run. With excessive release of exhaust with NOx, HC or CO emissions, there are various effects like acid rain, photochemical smog, global warming, nose and eye irritation, visibility impairment [1]. Pollution of atmospheric air is required to be reduced. Diesel engines emit lower carbon monoxide (CO) and hydrocarbon (HC) emissions but emit higher NOx and particulate matter [2]. Biodiesel being an oxygenated fuel, it produces a complete combustion, provides excellent emission properties, and create less negative environmental effects. In literature, some experimental results show high CO and NOx emissions, others present low CO, HC, and smoke emission. CO emission decreases by approximately 4‐46.5% in a high load condition. HC emission decreases with a low percentage of biodiesel present in the fuel blend and in a high load condition. Particulate matter, decreases with increased biodiesel content in the fuel blend. NOx emission increases by 4.15‐14.18% with increased biodiesel percentage in the fuel blend. However, it decreases by 4‐39% with the presence of low biodiesel percentage in the fuel blend. Smoke level gets decreased by (20‐43%) with a high engine load and high biodiesel concentration in the fuel blend [3,4].

Emission results of Mahua biodiesel show that it gives low CO, HC, NOx, and smoke emission but in some cases there is high NOx. CO emission decreases by 0.02–0.16% with the increase in biodiesel concentration in the fuel blend. HC emission dramatically decreases by 35-60% with the increase in biodiesel percentage in the fuel blend and in high engine load condition. NOx emission increases (6–16%) with increased engine load and high biodiesel percentage in the blend. However, it decreases (9–27%) when mahua ethyl ester is used. Smoke level decreases (5–46%) in a full load condition and with high biodiesel percentage present in the fuel blend. [5,6].

Due to the swift drop in crude oil reserves, the use of biodiesel and vegetable oils as substitute to conventional liquid fuels is being adopted in many countries. Climatic conditions and soil properties are the main factors on which selection of feedstock depends. For instance, soybean oil is preferred in America whereas in European countries, rapeseed and sunflower oils are popular, palm oil used in Southeast Asian region (especially in Malaysia and Indonesia), and coconut oil in Philippines are being considered as alternatives to diesel [7].

Table 1. Production of biodiesel feedstocks in several countries [8]

Country	**Feedstock**	**Production Capacity (billion litres/year)**	**Production Year**
Malaysia	Palm oil	0.147	2011
Indonesia	Palm oil	2.200	2012
Thailand	Palm oil	2.080	2011
Philippines	Coconut oil	0.138	2012
India	Jatropha	0.140–0.300	2011
China	Waste cooking oil	0.568	2012

Emission results of Linseed biodiesel also shows positive results with low emissions of CO, HC, NOx, and smoke. CO decreases when a high content of biodiesel is present in fuel blends and in a high engine load condition. Linseed biodiesel produces higher HC emission when higher biodiesel content is present in the fuel blends and in a higher load condition. HC emission dramatically decreases with the increase in fuel injection pressure. NOx emission generally increases when used high biodiesel percentage in the fuel blend. Smoke level decreases but NOx emission increases with increased fuel injection pressure [5]. Low emissions of CO, HC, NOx, and smoke opacity were observed when jatropha biodiesel was used. CO and HC emissions increase because of high engine load with EGR operation and gradually decrease because of a high percentage of biodiesel concentration present in fuel blends. CO emission decreases by 5.57–35.21% and HC emission decreases by 14.91–32.28% because of high biodiesel content in fuel blends. NOx emission decreases with EGR operation but increases with increased engine load and biodiesel content in fuel blends. NOx emission increases by 3.29–10.75% in some specific conditions. However, it reduces in a full load condition. Smoke opacity increases in a high engine load condition but decreases with the increase in biodiesel concentration in fuel blends [9].

The aim of this paper is to review the available production methods of biodiesel from different feedstocks, comparison of different fuel properties to select best among several vegetable oils and the comparing them on basis of performance and emission characteristics. This gives a better idea about viability of biodiesel for its operation in diesel engine and its impact on environment. It is aimed to remove the gaps associated with use of different feedstock for biodiesel production and their selection as per the results obtained from literature.

2. World Energy Scenario

In recent decades, due to rapid growth all around the world, industrialisation, development of people, increases in population, energy requirements have touched new heights. Over the past 25 years, total energy supply has increased steadily. However, with the current consumption rates, the reserves of crude oil and natural gas will diminish after approximately 41.8 and 60.3 years, respectively. Crude oil reserves are vanishing at a rate of 4 billion tons a year. If this rate continues, oil deposits will be exhausted by 2052 [10].

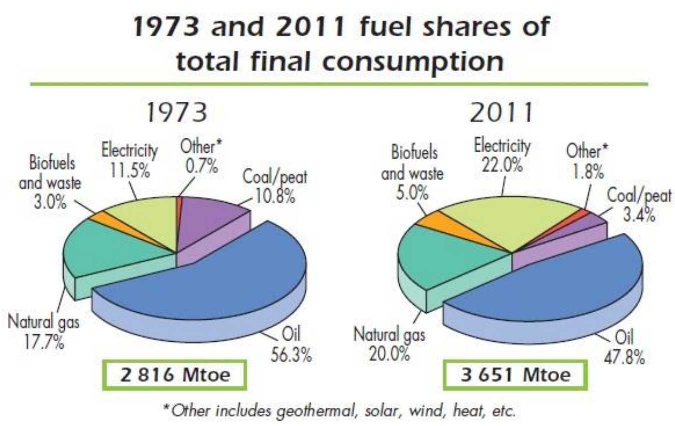

Fig 1. Shares of Total Consumption of Fuel [11]

Figure 1 explains the shares the total consumption of fuel in world. As stated, consumption of fuel has increased from 2816 Million Tonnes of Oil Equivalent (Mtoe) in 1973 to 3651 Mtoe in 2011. The reason behind this is mainly industrialisation, increase in population resulting in inflated energy needs. Due to awareness usage of fossil reserves like Coal and Oil have dipped a bit as Coal usage has depreciated from 10.8% to 3.4% and Oil from 56.3% to 47.8%.

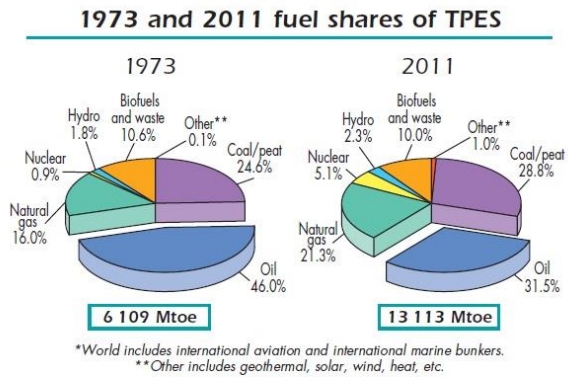

Fig 2. Fuel shares of Total Primary Energy Supply (TPES) [10]

Figure 2 explains share of various fuels in Total Primary Energy Supply (TPES) where fossil fuels hold a great mark as about 60% of total energy supplied is still extracted from Oil and Coal which although has decreased as it was about 70% in 1973.

3. Biodiesel as an Alternative Fuel

Directly using vegetable oil in diesel engine is not recommended due to its high viscosity. To solve this issue, it is converted biodiesel which is engine-friendly to quite extent. There are mainly four ways to convert vegetable oil into biodiesel:

- Direct Use and Blending
- Micro-emulsion
- Pyrolysis
- Transesterification

3.1 Direct Use and Blending

Direct use of vegetable oils means using oil in form of fuel as it is. Oil can be used as blend or pure form. The main advantages of using vegetable oils as fuel are:

- Liquid nature which ensures portability,
- Heat content (found to be about 80% of diesel fuel)
- Availability in abundance
- Renewability

Results so obtained are not satisfactory and researchers do not consider this process much practical. The disadvantages found during usage of vegetable oils as fuels are mainly:

- High viscosity
- Low volatility
- Presence of free fatty acid content
- Formation of gum due to oxidation

But these complications arise only after the engine is run on vegetable oils for longer period of time, especially with direct-injection engines [12].

3.2 Micro-emulsion

Micro-emulsion is a system of water, oil and an amphiphile which is a single optically isotropic and thermodynamically stable liquid solution. To rectify problem of high viscosity of vegetable oil, micro-emulsion of oil with some alcohol such as methanol, ethanol and 1-butanol can be used.

The main disadvatange for this problem was incomplete combustion of fuel which results harmful emission of exhaust gases. It is very difficult to achieve stable fuel with help fo emulsions.

3.3 Pyrolysis

Pyrolysis is the transformation of one substance into another by means of heat or by heat in presence of a catalyst and mainly in absence of air. The paralyzed material can be vegetable oils, animal fats, natural fatty acids or methyl esters of fatty acids [12].

Pyrolysis results in decrease stability of the oil which makes it unsuitable for engine operation.

3.4 Transesterification

Transesterification is a process in triglycerides like vegetable oil are made to react with an alcohol in the presence of catalyst to produce fatty-acid esters and glycerol. Methanol and ethanol are very popular alcohols due to their low cost and physical and chemical advantages. They are easily dissolved in and react quickly with triglycerides. There is need of catalyst also for reaction to complete in short span of time. Figure 3 shows the transesterification reaction where triglyceride is reacted with alcohol in presence of catalyst. It basically substitutes glycerol of the glycerides with three molecules of mono alcohols three molecules of methyl ester of vegetable oil which is termed as biodiesel. During the transesterification reaction about 10 weight percentage of fatty acid, glycerol is produced.

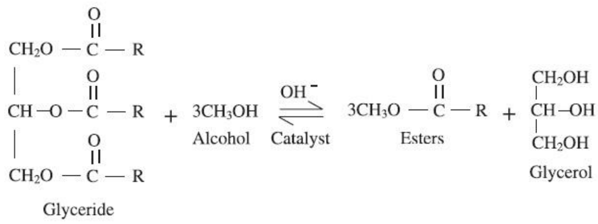

Fig. 3. Schematic of Transesterification reaction

Production of glycerol is expected to increase with increase in production of biodiesel [13,14].

4. Sources of Biodiesel:

Feedstock preparation of biodiesel can be broadly classified into three categories:

- Edible Oils
- Non edible oils
- Other Sources

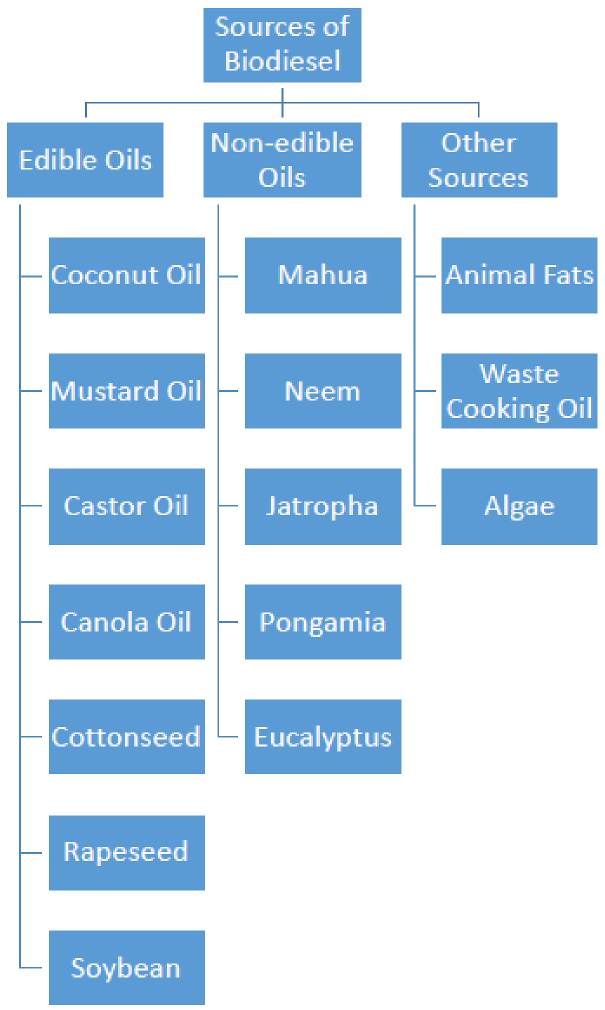

Fig. 4. Different sources of biodiesel

As shown in figure 4, there are various edible oils like coconut, mustard, castor, soybean, cottonseed, rapeseed, canola oil which can be used for production of biodiesel. Similarly under non-edible oils, Mahua, neem, jatropha, pongamia and eucalyptus are main sources of oil. Algae is also emerging as prominent sources of biodiesel nowdays. In earlier times, mostly edible oils were used to prepare biodiesel. Most of the edible oils are produced from the crop land. Demerits of preparing biodiesel from edibles oils has negative impression on agricultural crops because of additional land use which also affects the environmental. Moreover, producing biodiesel on a large scale needs substantial agricultural area. If the same thing is applied to whole world, the influence on world food supply will be critical concern. The best possible alternate to overcome this issue is use of non-edible oils for production of biodiesel. Hence, the non-edible oils such as jatropha, karanja, mahua, castor, eucalyptus oil will be important as a non-edible plant oil source for biodiesel production [15].

4.1 Fuel Properties of Vegetable Oils

Out of various available straight vegetable oils, Castor, Canola, Cottenseed, Rapeseed, Soyabean were selected as edible oils, Mahua, Neem, Jatropha, Pongamia, Eucalyptus as non-edible oils and their properties were compared to petroleum diesel. The main reason behind selection of these oils as source of fuel is their availability in abundance in India. The main problem which arises during usage of vegetable oil in place of diesel is higher viscosity. Researchers have reported that due to high viscosity there are deposits of carbon on injectors and valve seat. It also leads to poor fuel atomization, and incomplete combustion. Carbon deposition on piston rings and cylinder wall results in the dilution and thickening of the lubricating oil that may break or cause the failure of some mechanical parts of the engine [16].

Table 1. Fuel Properties of various vegetable oils [16, 17]

Type of Oil	Vegetable oils	Specific gravity at 150 °C	Kinematic viscosity (cSt)(38 °C)	Flash point (°C)	Cetane number	Heating values (MJ/kg)	Cloud point (°C)	Pour point (°C)
Edible Oils	Castor	0.970	29.7	229	51.2	39.7	-11.6	-31.7
	Canola	0.916	20.6	232	40	25	-3.9	-31.6
	Cottenseed	0.914	33.5	234	41.8	39.5	1.7	-15.0
	Rapeseed	0.911	37.0	246	37.6	39.7	-3.9	-31.7

	Soyabean	0.913	32.6	254	37.9	39.6	-3.9	-12.2
Non-edible Oils	Mahua	0.880	30.4	226	52.4	41.82	13	15
	Neem	0.961	22.6	175	32	40	22	11
	Jatropha	0.912	55	240	40-45	39-40	16	-
	Pongamia	0.882	55	110	51	46	23	-
	Eucalyptus	0.913	2	53	-	43.27	-	-
Petroleum	Diesel	0.82-0.86	1.3-4.1	60-80	40-55	42	-15 to -5	-33 to -15

Fuel properties of edible and non-edible oils are given in Table 1 which describes the kinematic viscosity of most of oils except eucalyptus oil ranges from 22 (at 30 °C) to 55 at (at 38 °C) whereas same of diesel is 4 at maximum. So the overcome the high viscosity, certain processes have to be adopted like preheating of oil etc. Table also reports viscosity of Canola oil in edible oils and Eucalyptus in non-edible are lowest so these can be prospective as a source of fuel. Heating Values for most of oils are found to be comparable with diesel fuel.

5. Discussion of Findings

Biodiesel prepared from vegetable oil is tested on diesel engine. While testing biodiesel is usually tested in form of blends for example B_{XX} refers to biodiesel blend with XX percentage of biodiesel in neat diesel. Main performance parameters such as Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTE), brake power, brake torque, brake thermal energy consumption are generally studied. Factors such as air‑fuel mixture, fuel injection pressure, fuel spray pattern, and fuel properties affect performance. Some of the engine performance characteristics from literature are given in Table 2 and discussed below.

Roy et al. [18] concluded that Canola oil biodiesel had similar efficiency to that with diesel at various speeds. There is no noteworthy variation in fuel conversion efficiency with up to 5% blends in contrast to diesel at all engine speeds. However, on further increasing the biodiesel content up to 20%, efficiency increased by factor of 1% to 1.5% than diesel operation. A little higher efficiency with biodiesel blends resulted in less BSFC with increase of these blends than they should have been in accordance with their higher heating values. Moving further, the higher efficiency with biodiesel than diesel delineates that combustion of blended fuels is better in comparison to diesel [18]. Castor biodiesel was experimented by Panwar et al. [19] on 4-stroke water cooled direct injection diesel engine and from results it has been seen that, BSFC decreased with increasing load for all the blends. Using low proportion of biodiesel B_{10}, the BSFC of the engine is lower than that of diesel for all loads. In a hindsight for B_{20} blend, BSFC was found to be more than that of diesel. Dhar et al. [20] experimented with Karanja biodiesel and found that BSFC was lower than mineral diesel. Although for some higher proportion of biodiesel, BSFC was seen following an increasing trend. At lower engine loads, higher biodiesel blends have lower BTE in comparison to diesel, which almost plateaued to diesel fuel at higher engine loads. At higher engine speeds and loads, biodiesel blends resulted in lower CO emissions than diesel. Though at lower engine loads, BSCO emissions of higher biodiesel blends were more than mineral diesel. For soybean biodiesel, BSFC increased with an increase in the biodiesel blend ratio. The average BSFC values over the entire rpm band for the B_{10}, B_{50}, B_{20} and B_{10} blends were 2%, 4%, 7%, 9% greater than the BSFC of diesel [21]. The impact of the biodiesel on the engine performance is dependent on the relation of fuel injection and the fuel properties like oxygenation nature, the higher viscosity and the lower calorific value of biodiesel, and these factors have a substantial impact on the spray formation and combustion [22].

Table 2. Performance Characteristics of biodiesel obtained from various sources

S. No.	Fuel	BSFC	BTE	Emission Characteristics	Main Finding	References
1.	Eucalyptus biodiesel	BSFC for lower blends is more than diesel and as percentage of blend	BTE is 29.92% for diesel, 25.95% for Eu10, 22.66% for Eu30, 24.22% for	Smoke opacity decreased by 64.5% with use of B100 as compared to diesel	Blends like B10, B20 would have	[17]

S. No.	Fuel	BSFC	BTE	Emission Characteristics	Main Finding	References
		is increased BSFC decreases.	Eu50, 30.87% for Eu100.	at full load.	results comparable to neat diesel.	
2.	Canola oil and Diesel Blends	No effect up to 10% of blends. 1.1% to 2.3% increase in BSFC on use of 20% blends	No Change up to 5% of blends. 1% to 1.5% increase in BTE with 10% and 20% blends	CO and HC reduction with biodiesel-diesel blends is significant compared to diesel. NO2 production at high idling is more than 50% of total NOx.	Biodiesel-diesel and canola Oil-diesel blends show higher fuel conversion efficiency than diesel.	[18]
3.	Castor and diesel blends	For B10, BSFC is lower than that of neat diesel. From blends like B20 or higher, BSFC increases.	26.66% BTE for B20 whereas 25.31% for neat diesel which comprises 5.33% increase in BTE	For B10, NO_x is lower than diesel but for rest of blends it is higher than diesel.	Blends up to B20 are found suitable for better engine performance	[19]
4.	Karanja Biodiesel	BSFC of all these fuels first decreased and became lowest at 1800 rpm and then it increased with increasing engine speed.	BTE generally increased with increasing engine load for all fuels.	At higher engine speed and load, lower CO emission and for lower load, higher emissions were found.	At higher loads BTE of all KOME blends was almost same as mineral diesel.	[20]
5.	Soybean	BSFC for B100, B50, B20 and B10 blends were 9%, 7%, 4%, 2% greater than diesel	Conversely to BSFC, BTE is also expected to be lower for higher blends of biodiesel.	Decrease of 28%, 31%, 38% and 46% in CO emissions with use of B10, B20, B50 and B100 respectively.	B20 is the best blend for that.	[21]

S. No.	Fuel	BSFC	BTE	Emission Characteristics	Main Finding	References
6.	Cotton Seed Oil biodiesel and its blends	BSFC for B20, B40 was found to be lower than diesel whereas higher for B60 and B100	BTE for B20, B40 and B60 was 3.74%, 10.46%, 3.27% more than diesel.	Smoke opacity was 50.44% lesser for B100 as compared to diesel at full load.	Blends up to B40 were found to be suitable for use in diesel engine.	[22]
7.	Canola biodiesel - diesel and kerosene biodiesel blends	5% and 10.5% increase in BSFC with use of biodiesel and kerosene respectively.	BTE increases with biodiesel blends. 2.5% more efficiency for biodiesel blends.	CO and HC emissions reduce with use of biodiesel and NO_x emissions increase. NO_2 is significant at low load but reduces at high loads.	BSFC increases with the increase in biodiesel in the blends of biodiesel-diesel	[23]
8.	Coconut Biodiesel	Average increase of 0.53% and 2.11% for B5 and B15 respectively	BTE decreases for biodiesel due to lower heating value	CO_2 and NO_x emissions increased for biodiesel. HC emissions reduced for biodiesel.	Blends like B_5, B_{15}, B_{20} are found more suitable than others.	[24]
9.	Coconut, Palm biodiesel and blends	BSFC for PB30, CB30 and PB15CB15 was 8.58%, 9.03%, and 8.55% higher than diesel	BTE for PB30, CB30, PB15CB15 were 5.03%, 3.84% and 3.97% lower than diesel respectively.	NO_x emission increase with use of biodiesel but significant decrease in CO emissions	Combined blend of palm and coconut biodiesel shows superior Performance.	[25]
10.	Jatropha biodiesel	BSFC for B20 is 5.02% higher than that for diesel	BTE obtained for diesel was 28% and for B20 27.4%.	Increase of 5.52% for B20 of Jatropha biodiesel but this reduced to 3.9% with use of BHT additive whereas CO emissions reduced for every	20% blend of biodiesel holds good results than other blends	[26]

S. No.	Fuel	BSFC	BTE	Emission Characteristics	Main Finding	References
				blend.		
10.	Pongamia biodiesel and it's blends	BSFC for B10 is almost equal to the diesel, for B20, B30, B40, B50 was 3.2%, 10.3%, 13.5% and 14.9% respectively.	BTE for B10 (22.08%), B20 (22%) and B30 (21.03%) was found about nearly equal to diesel (23.39%)	CO and HC emissions reduce with use of biodiesel and improve with increase in blend percentage whereas NO_x emissions increase.	Fuel properties and engine performance for B10, B20 are very similar to diesel so diesel may be well replaced by biodiesel.	[27]
11.	Jatropha Curcas biodiesel	BSFC for B10 is 4% less than diesel, for B20 equal to diesel, for B30, B40, B50 is 3.4%, 5.7%, 7.5% higher than diesel.	BTE for B10 (25.8%), B20 (25.2%) and B30 (24.6%) was found about 1.3%, 0.7% and 0.1% higher than diesel.	-	BSFC and BTE results for B20 blends were best among other blends.	[28]

6. Conclusion

A lot of research has been done in field of biodiesel and it's feasibility in diesel engine because of its economic and environmental benefits as well as its renewable origin. Biodiesel produced from non-edible oil resources can defy the use of edible oil for biodiesel production. Therefore, its demand is growing steadily, and researchers are looking for possible newer sources of non-edible oil. This paper includes review of biodiesel obtained from both edible and non-edible oils following conclusions have been obtained.

1. Biodiesel prepared from non-edible oils have been found more suitable as it won't affect food requirements. Moreover some of plants like
2. Jatropha, Pongamia are barren land plants which have no other significant use.
3. Results from Brake Specific Fuel Consumption report that as the volume of biodiesel is increased BSFC increases as compared to neat diesel. Similar trend is followed by brake thermal efficiency that is lesser efficiency for pure biodiesel.
4. With use of biodiesel, CO and HC emissions get reduced and improve with increase in biodiesel percentage in blend whereas NO_x emissions increase on using biodiesel.
5. B_{20} blend was found to be most suitable among all other blends.

References

[1] Talebizadeh P., Babaie M., Brown R., Rahimzadeh H., Ristovski Z., Arai M. The role of non-thermal plasma technique in NOx treatment: A review. Renewable and Sustainable Energy Reviews, 40, (2014) 886–901.

[2] Verma P., Sharma M.P., Performance and Emission Characteristics of Biodiesel Fuelled Diesel Engines, International Journal of Renewable Energy Research, 5(1) (2015) 245-250.

[3] Sahoo P, Das L, Babu M, Arora P, Singh V, Kumar N. Comparative evaluation of performance and emission characteristics of jatropha, karanja and polanga based biodiesel as fuel in a tractor engine. Fuel, 88 (2009) 1698–707.

[4] Ashraful A.M., Masjuki H.H., Kalam M.A., Fattah I.M.R., Imtenan S., Shahir S.A., Mobarak H.M. Production and comparison of fuel properties, engine performance, and emission characteristics of biodiesel from various non-edible vegetable oils: A review. Energy Conversion and Management. 80, (2014) 202-228.

[5] Puhan S, Nagarajan G, Vedaraman N, Ramabramhmam B. Mahua oil (Madhuca indica oil) derivatives as a renewable fuel for diesel engine systems in India: a performance and emissions comparative study. Int J Green Energy. 4, (2007) 89–104.

[6] Agarwal D, Kumar L, Agarwal AK. Performance evaluation of a vegetable oil fuelled compression ignition engine. Renew Energy. 33, (2008) 1147–56.

[7] Puhan S, Jegan R, Balasubbramanian K, Nagarajan G. Effect of injection pressure on performance, emission and combustion characteristics of high linolenic linseed oil methyl ester in a DI diesel engine. Renew Energy. 34, (2009) 1227–33.

[8] Daud N.M., Abdullah S.R.S., Hasan H.A., Yaako Z., Production of biodiesel and its waste water treatment technologies: A review, Process Safety and Environmental Protection. 94, (2014) 487-508.

[9] Huang J, Wang Y, Qin J-B, Roskilly AP. Comparative study of performance and emissions of a diesel engine using Chinese pistache and jatropha biodiesel. Fuel Processing Technology. 91, (2010) 1761–7.

[10] Singh B., Korstad J., Sharma Y.C. A critical review on corrosion of compression ignition (CI) engine parts by biodiesel and biodiesel blends and its inhibition. Renewable and Sustainable Energy Reviews. 16, (2012) 3401– 3408.

[11] Key World Energy Statistics, 2013. International Energy Agency.

[12] Maa F., Hanna M.A. Biodiesel production: a review. Bioresource Technology. 70, (1999) 1-15.

[13] Haas MJ. Improving Economics of Biodiesel Production Through the Use of Low Value Lipids as Feedstocks: Vegetable Oil Soapstack. Fuel Processing Technology. 86, (2005) 1087-1096.

[14] Agarwal A.K. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. Progress in Energy and Combustion Science. 33, (2007) 233–271.

[15] Dwivedi G., Sharma M.P. Prospects of biodiesel from Pongamia in India. Renewable and Sustainable Energy Reviews. 32, (2014) 114–122

[16] Dwivedi G., Sharma M.P. Potential and limitation of straight vegetable oils as engine fuel – An Indian perspective. Renewable and Sustainable Energy Reviews. 33, (2014) 316–322.

[17] Verma P., Experimental Investigation of Diesel Engine Using Biodiesel from Eucalyptus Oil. International Conference on Emerging Materials and Applications at IIT Roorkee Saharanpur Campus. 2014.

[18] Roy M.M., Wang W., Bujold J. Biodiesel production and comparison of emissions of a DI diesel engine fueled by biodiesel–diesel and canola oil–diesel blends at high idling operations. Applied Energy. 106, (2013) 198–208.

[19] Panwar N.L., Shrirame H.Y., Rathore N.S., Jindal S., Kurchania A.K. Performance evaluation of a diesel engine fueled with methyl ester of castor seed oil. Applied Thermal Engineering. 30, (2010) 245–249.

[20] Dhar A., Agarwal A.K. Performance, emissions and combustion characteristics of Karanja biodiesel in a transportation engine. Fuel. 119, (2014) 70–80.

[21] Ozener O., Yuksek L, Ergenc AT, Ozkan M, Effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics. Fuel. 115, (2014) 875–883.

[22] Verma P., Singh V.M. Assessment of Diesel Engine performance using Cotton Seed Biodiesel, Integr. Res. Adv. 1(1), (2014) 1-4.

[23] Roy M.M., Wang W., Alawi M. Performance and emissions of a diesel engine fueled by biodiesel–diesel, biodiesel–diesel-additive and kerosene–biodiesel blends. Energy Conversion and Management. 84, (2014) 164–173.

[24] Liaquat A.M., Masjuki H.H., Kalam M.A., Fattah I.M.R., Hazrat M.A., Varman M., Mofijur M., Shahabuddin M. Effect of coconut biodiesel blended fuels on engine performance and emission characteristics. Procedia Engineering. 56, (2013) 583 – 590.

[25] Habibullah M., Masjuki H.H., Kalam M.A., Fattah I.M.R., Ashraful A.M., Mobarak H.M. Biodiesel production and performance evaluation of coconut, palm and their combined blend with diesel in a single-cylinder diesel engine. Energy Conversion and Management. 87, (2014) 250–257.

[26] Fattah I.M.R., Masjuki H.H., Kalam M.A., Wakil M.A., Rashedul H.K., Abedin M.J. Performance and emission characteristics of a CI engine fueled with Cocos nucifera and Jatropha curcas B20 blends accompanying antioxidants. Industrial Crops and Products. 57, (2014) 132–140.

[27] Dwivedi G., Sharma M.P. Performance Evaluation of Diesel Engine Using Biodiesel from Pongamia Oil. International Journal of Renewable Energy Research. 3(2) 2013.

[28] Dwivedi G., Jain S., Sharma M.P., Impact of Biodiesel and its Blends with Diesel and Methanol on Engine Performance, IJES. 1(2), (2011) 105-109.