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Review Research Paper

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Biodiesel from Non-Edible Vegetable Oils: A Review on Engine Performance and Emission Characteristics

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ABSTRACT

The demand of mineral diesel is increasing day by day due to more use of diesel engines in different sectors. The exhaust emission of diesel engines is a major source of air pollution. The source of mineral diesel is also limited and will be exhausted within some years if it is used at current rate. At present, one of the alternatives of mineral diesel is biodiesel, which is obtained from renewable sources like vegetable oil, animal fat, etc., by trans-esterification process. Presently non-edible vegetable oils are preferred for biodiesel production to avoid the food crisis. There are several non-edible oil plants available in nature which contain sufficient amount of oil and can be used as feedstock for biodiesel. This paper provides an overview regarding the source of different potential non-edible vegetable oils, methods of reduction of viscosity, engine performance, combustion characteristics and emission characteristics of different types of biodiesel. The performance of blended biodiesel, salient features and challenges of biodiesel are also studied.

INTRODUCTION

The use of diesel engine is rising due to its efficiency, reliability, cost effectiveness and higher energy density. The diesel engines are mostly used in transport vehicles and their exhaust emission is a prime cause of air pollution. Simultaneously, the source of mineral diesel is limited and will be exhausted within some years if consumed at the current rate. Both, the energy security and the vehicular pollution are major concerns of the whole world and there is a need of an alternative eco-friendly liquid fuel which can be a substitute to the mineral diesel. At present, one of the alternatives is biodiesel which is obtained from renewable sources like vegetable oil, animal fat or algae by trans-esterification process. Presently, most of the countries produce biodiesel from edible oils, called as first generation feed stocks, like soyabean, rapeseed, sunflower, palm, peanut and coconut. The use of edible oil for production of biodiesel may create food crisis in the future. So, biodiesel from non-edible vegetable oils is another option for both food and energy security. Most of the non-edible vegetable oil plants grow naturally in forests and some of these grow in waste, less fertile, degraded and barren lands and do not affect the existing crop production. The collection of seeds will also be an alternative source of income for people and can help to improve the rural economy.

NON-EDIBLE VEGETABLE OILS

There are more than 350 number of oil bearing plants available in nature containing sufficient amount of oil (Acharya et al. 2017). Some of these contain toxic components which cannot be used as food but can be used as potential feedstock for biodiesel production. The oil content of the seed is an important parameter when a particular seed is chosen for extraction of oil commercially. Table 1 presents some of the promising non-edible vegetable oils being used as a source of biodiesel and their oil content percentage. The physico-chemical properties of some of these oils are presented in Table 2. Some salient features regarding non-edible vegetable oils can be inferred from Tables 1 and 2.

- Seeds of non-edible vegetable plants contain sufficient amount of oil that can be extracted economically.
- The calorific value of most of the vegetable oils is lower than that of mineral diesel.
- The kinematic viscosity of vegetable oils is very high (more than 10 times that of mineral diesel).

BIODIESEL PRODUCTION PROCESSES

The vegetable oil cannot be used in diesel engine directly as it possesses very high viscosity; and cannot be atomized properly which may create different problems in engine operation. In order to use the vegetable oil as fuel, the same must be pre-treated to reduce its viscosity to a useable range. There are different methods of reduction of viscosity as given below (Atabani et al. 2013, Subramaniam et al. 2013).

Table 1: List of non-edible oil plants and oil content percentage (Atabani et al. 2013).

Sl No.	Plant	Botanical Name	Oil Content (Seed), %	Oil Content (Kernel), %
1	Jatropha	*Jatropha curas*	20-60	40-60
2	Karanja	*Pongamia pinnata*	25-50	30-50
3	Mahua	*Madhuca indica*	35-40	50
4	Polanga	*Calophyilum inophyllum*	65-75	22
5	Neem	*Azadirachta indica*	20-30	40-50
6	Castor	*Ricinus communis*	46-55	-
7	Soapnut	Sapindus mukorossi	23	-
8	Moringa	*Moringa oleifera*	40	-
9	Jojoba	*Simmondsia chinensis*	45-55	-
10	Karabi	*Thevettia peruviana*	-	67
11	Kusum	*Schleichera oleosa*	60-70	-
12	Seamango	*Cerbera odollam*	54	6.4
13	Rubber	*Hevea brasiliensis*	50-60	40-50
14	Tobacco	*Nicotiana tabacum*	36-41	17
15	Putranjiva	*Putranjiva roxburghii*	41-42	-
16	Croton	*Croton megalocarpus*	40-45	-
17	Kapok	*Ceiba pentandra*	24-40	-
18	Poon	*Sterculia feotida*	50-60	-

Table 2: Physico-chemical properties of some raw vegetable oils and mineral diesels.

Vegetable oil	Density at 15°C, kg/m³	Kinematic viscosity (40°C), cSt	Flash point, °C	Cloud point, °C	Pour point, °C	Calorific value (MJ/kg)	Reference
Jatropha	921	52	220	9	4	38.66	(Mofijur et al. 2013)
Karanja	912	27.84	205			34	(Raheman & Phadatare 2004)
Mahua	960	24.58	232	-	15	36.1	(Raheman & Ghadge 2007)
Polanga	896	71.98	221	-	-	39.25	(Atabani & Cesar 2014)
Neem	878	24.14	-	-	-	26.65	(Ali et al. 2013)
Castor	960	226	317	-	-	36.20	(Panwar et al. 2010)
Soapnut	917	39.57	-	-	-	-	(Chen et al. 2013)
Moringa	897.5	43.33	268.5	10	11	38.05	(Mofijur et al. 2014)
Jojoba	865	24.05	275	-	-	49.34	(Al-Hamamre & Al-Salaymeh 2014)
Karabi	899	-	-	-	-	-	(Deka & Basumatary 2011)
Sea Mango	919	29.57	-	-	-	40.86	(Kansedo et al. 2009)
Rubber	910	66.2	198	-	-	37.5	(Ramadhas et al. 2005)
Putranjiva	918	37.62	48	-	-	39.58	(Haldar et al. 2009)
Croton	910	29.84	235	-	-	39.33	(Atabani et al. 2014)
Kappok	905	34.45	170.5	-	-	39.587	(Ong et al. 2013)
Poon	937.4	63.90	198.5	-	-	39.793	(Ong et al. 2013)
Diesel	824	2.30	53	1	-8	42	

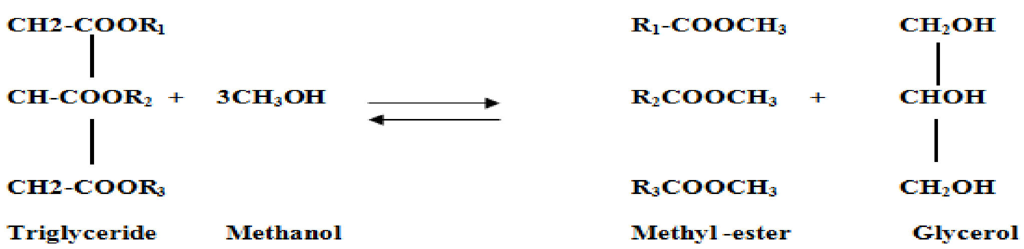

Fig. 1: Trans-esterification reaction of vegetable oil (Atabani et al. 2013, Jain & Sharma 2010).

Table 3: Biodiesel standards of different countries (Jain & Sharma 2010, Chen et al. 2013).

Sl No	Properties	India BIS	USA ASTM -D-6751 -07b	France General official	Germany DIN	Italy UNI	Austria ONC 1191	Europe EN-14214: 2008	Taiwan CNS-15072
1	Density (15°C), g/cm^3	0.87-0.89	-	0.87-0.89	0.875-0.89	0.86-0.89	0.85-0.89	860-890	860-890
2	Kinematic viscosity (40°C), cSt	1.9 - 6	1.9-6	3.5-5	3.5-5	3.5-5	3.5-5	3.5-5	3.5-5
3	Flash point, °C (min)	130	130	100	110	100	100	101	101
4	Cetane number (min)	40	47	49	49		49	51	51
5	Acid number (KOH/g) (max)	0.5	0.8	0.5	0.5	0.5	0.8	0.5	0.5
6	Carbon residue (max)	0.05	0.05	0.05	0.05	0.05	0.05	0.03	0.03
7	Oxidation stability (hrs) min	6	3	-	-	-	-	6	6

1. Pre-heating
2. Blending/Dilution
3. Pyrolysis
4. Micro-emulsification
5. Trans-esterification

Out of these processes, trans-esterification is the best method of reduction of viscosity of vegetable oils as regards to quality and economy is concerned. The trans-esterification process is being widely used for production of biodiesel (Singh & Sahni 2017). The chemical equation of the trans-esterification process is shown in Fig. 1. In this process, reduction of viscosity of straight vegetable oils is achieved when the vegetable oil (ester) is mixed with an alcohol in presence of some catalyst which yields another alcohol and another ester. The refined low viscous oil obtained by such process is called biodiesel. For preparation of biodiesel, alcohols like methanol and ethanol are mostly preferred as these are less costly and easily available. The sodium hydroxide (NaOH) and potassium hydroxide (KOH) are used as catalyst (Atabani et al. 2013, Jain & Sharma 2010).

Different factors like temperature of reaction, proportion of alcohol to vegetable oil, catalyst used and mixing intensity influence the trans-esterification process. After trans-esterification, the viscosity of vegetable oil reduces and can be used in a diesel engine in a pure or blended form. The problems associated with raw vegetable oils like improper atomization and low volatility are reduced to a greater extent in trans-esterified oil. This helps in the formation of homogeneous air-fuel mixture and proper combustion. The quality of biodiesel depends on different factors like feedstock quality, fatty acid composition, oil content of feed stock, refining process and post production parameters (Atabani et al. 2013). So to produce biodiesel of uniform characteristics, different countries have developed their own standard which is presented in Table 3. The physico-chemical properties of some of the biodiesels obtained from non-edible vegetable oils are given in Table 4.

ENGINE PERFORMANCE

Many researches are being carried out to study the performance of pure biodiesel and its blend in different types of diesel engines. In this section, different parameters like Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC), peak pressure, heat release rate and exhaust gas analysis have been reviewed and summarized in Table 5. The difference in engine output parameters and exhaust emission using biodiesel and mineral diesel is shown in percentage. The increase in value is shown as $\uparrow$ and decrease in value is shown as $\downarrow$.

Brake Specific Fuel Consumption (BSFC)

The rate of fuel consumption is an important factor to evaluate the suitability of a fuel in an engine, as far as fuel economy is concerned and the same is evaluated by the fuel consumption per unit power output or brake specific fuel consumption (BSFC). It is observed from Table 5 that the BSFC of engines operated with biodiesel is higher than that of mineral diesel. In this study, a maximum increase of 55% in BSFC for jatropha biodiesel (Datta et al. 2014) and minimum increase of 5% in BSFC for neem biodiesel (Dhar et al. 2012) than that of mineral diesel is reported. However, a reduction of 7% in BSFC for jojoba biodiesel than that of mineral diesel (Saleh 2009) is reported which is attributed to its higher calorific value (47.38 KJ) than that of mineral diesel (44.30 KJ). The BSFC of an engine also depends on several other factors like load, speed, injection pressure, injection timing and size of the engine, but when BSFC of a particular engine is compared using different fuels, the calorific value of the fuels plays an important role. The fuel with higher calorific value shows lower BSFC and vice-versa. In this study many researchers have reported that

Table 4: Physico-chemical properties of biodiesels.

Oil	Density at 15^0C g/cm^3	Kinematic Viscosity (40^0C) cSt	Flash point ^0C	Cloud point ^0C	Pour point ^0C	Calorific. Value (MJ/kg)	Cetane Number	Acid value	Oxidation Stability (hrs)	References
Jatropha	0.860-0.880	4.23-5.2	148-182.5	2.8-13	2-4.2	34.5-42.67	51-58.2	0.28-0.05	3.02-9.41	Jain & Sharma 2010, Mofijur et al. 2013, Chauhan et al. 2012
Karanja	0.876-0.912	3.99-10.29	160-187	12-14.6	-1 to 5.1	36.12-42.13	57.6	0.43-1.53	1.82-11.6	Nantha Gopal & Thundil Karupparaj 2014, Raheman & Phadatare 2004
Mahua	0.865-0.916	3.98-6.04	127-208	3-13	6	36.8-41.82	51	0.26-0.41	8.2	Puhan et al. 2005a, Raheman & Ghadge 2007, Godiganur et al. 2009, Acharya et al. 2017a
Polanga	0.87	3.45-.4.92	140-170	10-13.2	2-13.2	38.66-41.42	51.5-59.5	0.34	13.08-14.27	Atabani & Cesar 2014, Ong et al. 2013, Sahoo et al. 2007
Neem	0.86	3.7-5.96	76-152	9	2	38.15-38.5	51	-	1.39	Ragit et al. 2010, Dhar et al. 2012, Prabhu et al. 2013
Castor	0.96	10.50	149	-14	-	39.16	48.9	1.008	44	Panwar et al. 2010
Soapnut	0.878	4.48	177	-	-	-	58	0.12	15.1-16.3	Chen et al. 2013
Moringa	0.869-0.883	5.05-5.4	150.5	18-19	17-19	39.82	51-67	-	3.02-26.2	Rashid et al. 2008, Atabani et al. 2014
Jojoba	0.866	19.2	61	-	-	47.38	63.5	-	-	Saleh 2009
Karabi	0.875	4.33	75	12	3	44.98	61.5	0.057	-	Deka and Basumatary 2011, Bora 2009
Rubber	0.874	4-5.81	69-130	4	-8	-	-	0.118	-	Ramadhas et al. 2005, Satyanarayana & Muraleedharan 2011
Putranjiv	0.883	5.81	152	-	2	39.25	40.2	-	-	Haldar et al. 2009
Croton	0.867	4.05	178.5	-4	-3	39.53	-	-	1.1-4.04	Atabani et al. 2014, Aliyu et al. 2011
Kappok	0.857-0.877	4.15-4.17	156.5-169	2.5-3	1.7	40.49	47-57.2	0.36-0.38	4.42	Vedharaj et al. 2013
Poon	0.875	4.92-6.0	160.5-162	12	-3 - 1	40.17-40.21	54-56.5	0.14	3.44	Devan and Mahalakshmi 2009
Sal	0.8765	5.89	127	-	-	32.65	-	-	<6	Pali et al. 2015

BSFC varies inversely with engine load. The possible cause of the inverse variation of BSFC with engine load is the percentage increase in fuel requirement to operate the engine is less than the percentage increase in brake power due to the relatively less portion of heat losses at higher loads (Godiganur et al. 2009). The speed of the engine also affects the BSFC. Some researchers also studied the variation of BSFC with engine speed and reported that BSFC decreases initially up to a certain engine speed and then it increases (Aydin & Bayindir 2010, Ong et al. 2013).

Brake Thermal Efficiency (BTE)

The brake thermal efficiency of an engine depends on several factors, but characteristics of fuel are the dominant factor when comparison is made among different fuels for a particular engine. As reported by most researchers, BTE of an engine run by biodiesel is lower than that of mineral diesel, which is attributed to the lower calorific value and higher kinematic viscosity of biodiesel. But BTE of jojoba biodiesel is higher than that of mineral diesel due to its higher calorific value (Saleh 2009) and higher BTE of neem biodiesel is due to its higher oxygen content that helps for its better combustion (Dhar et al. 2012). The BTE of an engine is affected by factors like load and speed of the engine. Most of the researchers reported that BTE of an engine is directly proportional to engine load, which is attributed to the reduction in heat loss and an increase in power with increase in load (Kivevele et al. 2011). The brake thermal efficiency of a biodiesel fuelled engine initially increases with an increase in engine speed; reaches a maximum level and then decreases. Mofijur et al. (2014) studied the performance and emission characteristics of moringa and palm biodiesel in a four cylinder in-line engine of rated power 78 kW and reported that the brake power increases up to 1500 rpm and then decreases. Saleh (2009), studied the performance of a twin cylinder diesel engine, rated power 26 hp at rated speed of 1500 rpm using jojoba biodiesel and reported that the brake thermal efficiency of pure jojoba biodiesel increases up to 1700 rpm; then it decreases. Ong et al. (2014) studied the performance of a single cylinder, 7.7 kW diesel engine using different blends of jatropha, kapok and polanga biodiesel (10%, 20%, 30% and 50%). They reported that brake thermal efficiency increases up to 1900 rpm; then it decreases.

Combustion Characteristics

The combustion of fuel in an engine has a crucial role in the development of power output. An effective combustion of fuel in an engine yields more power and there is a reduction in fuel consumption and exhaust emission. The ignition quality of a fuel is one of the important factors for its combustion and depends upon the chemical composition of the fuel. The chemical composition of the biodiesel is different from mineral diesel. Its higher oxygen content (10-12% more) and higher cetane number helps for its better combustion. Sahoo & Das (2009) exclusively studied the combustion performance of a single cylinder 6 kW diesel engine using jatropha, karanja and polanga based biodiesel and found that all the three fuels show lower ignition delay and lower heat release rate than that of mineral diesel. They also reported that the peak pressure of all the biodiesel is higher than that of mineral diesel. A lower heat release rate of the biodiesels is attributed to its shorter ignition delay as premix combustion phase is less intense for biodiesel than that of mineral diesel (Chauhan et al. 2012, Nantha & Thundil Karupparaj 2014, Vedharaj et al. 2013, Devan & Mahalakshmi 2009). Chauhan et al. (2012) reported that the jatropha biodiesel has a shorter ignition delay, lower peak pressure and lower heat release rate than that of mineral diesel. Nantha et al. (2014) experimented with karanja biodiesel and reported the similar results for combustion i.e., shorter delay period, lower heat release rate and lower peak pressure. The lower heat release rate and shorter ignition delay are attributed to lower accumulation of fuel in premixed combustion phase. Vedharaj et al. (2013) experimented with kapok biodiesel in a single cylinder diesel engine with rated power 5.2 kW and reported that the peak heat release rate of biodiesel is 33% lower than that of mineral diesel which is attributed to the lower calorific value and higher viscosity of biodiesel than that of mineral diesel. The same trend has been reported by Devan & Mahalakshmi (2009) for poon biodiesel.

Emission Characteristics

The vehicular emission is a major source of air pollution and the diesel engines contribute a lot. So, in this section, emission characteristics of different biodiesels like emission of carbon monoxide (CO), hydrocarbon (HC), oxides of nitrogen (NOx) and smoke opacity have been studied

Emission of carbon monoxide (CO): The emission of CO is the result of improper combustion due to insufficient amount of air in the air fuel mixture. As biodiesel contains 10-12 % more amount of oxygen than that of mineral diesel, many researchers reported for lower emission of CO. Raheman & Phadatare (2004) reported for a maximum percentage of reduction (94%) of CO by using the karanja biodiesel and Saleh (2009) reported only 4% reduction of CO by using jojoba biodiesel. The higher amount of oxygen present in biodiesel helps in re-burning of CO in the cylinder and results in reduction in emission (Raheman & Ghadge 2007, Sahoo et al. 2009, Dhar et al. 2012). However, some of the researchers also reported an increase in the emission

Table 5: Engine and emission performance of different non- edible oil biodiesel (↑ increase, ↓ decrease).

Sl. No.	Oil	Engine Type	Load	BSFC	BTE	CO	HC	NOx	Smoke	Reference
1	Mahua	Single cylinder,9kW, 1500rpm, CR-18:1	100%	28%↑	12.5%↓	81%↓	-	14%↑	-	Raheman & Ghadge 2007
2	Mahua	Single cylinder,3.7kW, 1500rpm, CR-16.5:1	100%	20%↑	13%↓	30%↓	35%↓	4%↓	11%↓	Puhan et al. 2005b
3	Mahua	Six cylinder,158bhp, 1500rpm, CR-17.6:1	100%	20%↑	9%↓	44%↓	25%↓	7.5%↑	-	Godiganur et al. 2009
4	Mahua	Single cylinder,4.4kW, 1500rpm, CR-17.5:1	100%	20%↑	13%↓	26%↓	20%↓	4%↓	-	Saravanan et al. 2010
5	Mahua	Single cylinder,5.2kW, 1500rpm, CR-17.5:1	100%	20%↑	13%↓	10%↑	28%↓	14%↓	-	Solaimuthu et al. 2015
6	Jatropha	2kVA D.G Set	100%	15%↑	2.8%↓	-	-	-	-	Jain and Sharma 2010
7	Jatropha	Twin cylinder,7.35kW, 1500rpm	100%	55%↑	28%↓	23.5%↓	25%↑	24%↑	-	Datta et al. 2014
8	Jatropha	Three cylinder,44.1kW, 2200rpm, CR-18:1	100%	13%↑	-	5.5%↑	21%↓	18%↑	64%↓	Sahoo et al. 2009
9	Jatropha	Three cylinder,44.1kW, 2200rpm, CR-18:1	100%	15%↑	10%↓	5.5%↑	35%↓	60%↑	83%↓	Chauhan et al. 2012
10	Jatropha	Four cylinder,T.C,79kW, 3200rpm, CR-18:1	75%	-	-	-	37%↓	13%↑	75%↓	Tan et al. 2012
11	Polanga	Single cylinder	100%	10%↑	3%↓	↓	80%↓	4%↓	40%↑	Sahoo et al. 2007
12	Polanga	Three cylinder,44.1kW, 2200rpm, CR-18:1	100%	11%↑	-	13%↓	7%↓	22.5%↑	69%↓	Sahoo et al. 2009
13	Poon	Single cylinder,4.4kW, 1500rpm, CR-17.5:1	100%	-	10%↓	-	31%↓	11%↑		Devan & Mahalakshmi 2009
14	Rubber	Single cylinder,5.5kW, 1500rpm	100%	12%↑	4%↓	21%↓	-	-	22%↓	Ramadhas et al. 2005
15	Rubber	Single cylinder,5.5kW,1500rpm, CR-16.5:1	100%	-	6%↓	67%↓	17%↓	1%↑	-	Satyanarayana & Muraleedharan 2011
16	Karanja	Single cylinder,7.5kW,3000rpm, CR-16:1	100%	48%↑	7 %↓	94%↓		38%↓	50%↓	Raheman & Phadatare 2004
17	Karanja	Single cylinder,4.4kW, 1500rpm, CR-17.5:1	100%	53%↑	15.5%↓	19%↓	45%↓	26%↑	23%↓	Nantha Gopal & Thundil 2014
18	Karanja	Three cylinder,44.1kW, 2200rpm, CR-18:1	100%	14%↑		5%↓	21%↓	14%↑	69%↓	Sahoo et al. 2009
19	Neem	Single cylinder,7.4kW, 1500rpm, CR-17.5:1	100%	5%↑	12.5%↑	16%↓	28%↓	15%↓	15%↓	Dhar et al. 2012
20	Neem	Single cylinder,4.44kW, 1500rpm, CR-17.5:1	100%	31%↑	10%↓	40%↓	54%↑	20%↑	33%↓	Prabhu et al. 2013
21	Neem	Single cylinder,3.5kW, 1500rpm, CR-18:1	100%	-	4%↓	25%↑	6.5%↑	6.5%↑	15%↑	Balaji & Cheralathan 2015
22	Neem	Single cylinder,5.2kW, 1500rpm, CR-17.5:1	100%	27.75%↑	15%↓	28%↓	2.6%↓	7.5%↑	18%↓	Ragit et al. 2010
23	Croton	Three cylinder,33.56kW, 2500rpm, CR-18.5:1	100%	20%↑	12%↓	90%↑	10%↑	-	15%↓	Aliyu et al. 2011
24	Croton	Four cylinder,T.C,66kW,4000rpm, CR-19.5:1	100%	18%↑	2%↓	15%↑	5.5%↓	11%↑	15%↓	Kivevele et al. 2011
25	Jojoba	Two cylinder,19.38kW, 2500rpm, CR-18.5:1	100%	7%↓	3%↑	4%↓	1%↑	13%↑	70%↓	Saleh 2009
26	Karabi	Single cylinder,3.7kW, 1500rpm, CR-16.5:1	100%	10.3%↑	6.8%↓	-	-	-	-	Balusamy & Marappan 2007
27	Karabi	Single cylinder,5.9kW, 1500rpm, CR-17.5:1	100%	10.3%↑	8.4%↓	37.5%↓	25%↓	25%↑	50%↓	Bora 2009
28	Kapok	Single cylinder,5.2kW, 1500rpm, CR-17.5:1	100%	15%↑	8.3%↓	45%↓	-	10%↓	31%↑	Vedharaj et al. 2013

of CO, which is attributed to higher viscosity and poor spray characteristics of biodiesel (Chauhan et al. 2012, Solaimuthu et al. 2015, Kivevele et al. 2011). The emission of CO increases with increase in load on the engine and decreases with increase in engine speed. The main reason for increasing in CO with increase in load on the engine is attributed to the decrease in air-fuel ratio with increase in load, but decreases in emission with increase in engine speed, is due to the better air-fuel mixing process.

Emission of hydrocarbon (HC): The emission of hydrocarbon is also the result of incomplete combustion which depends upon design and operating parameters. The important operating parameters of engine which affect the HC emission are load and speed. In this study, many researchers reported about reduction of HC emission by using biodiesel instead of mineral diesel. Sahoo et al. (2007) reported for maximum reduction (80%) of HC emission for polanga biodiesel and Ragit et al. (2010) reported minimum reduction (2.6%) for neem biodiesel. The reason for the reduction of HC has been attributed to the presence of more oxygen in biodiesel, which helps for better combustion and results in reduction in HC. But some researchers (Datta et al. 2014, Prabhu et al. 2013, Saleh 2009, Balaji & Cheralathan 2015) reported about an increase in HC and the same is attributed to the higher viscosity and poor spray characteristics of biodiesel which results in increased HC emissions.

Emission of oxides of nitrogen (NOx): The NOx is a generalized term for NO and NO_2. The emission of NOx is an important factor of air pollution as it helps to create photochemical smog and causes acid rain. There are different mechanisms for NOx formation like thermal, prompt, fuel bound nitrogen, N_2O path way and NNH mechanism (Palash et al. 2013). Among these, thermal mechanism is predominant in biodiesel fuelled engines. As per this mechanism, the formation of NOx occurs above temperature of 1700 K. In this study many researchers reported that there is an increase in NOx emission by using pure biodiesel and following factors are responsible for higher NOx emission (Tan et al. 2012, Chauhan et al. 2012, Datta et al. 2014, Raheman & Ghadge 2007, Ragit et al. 2010, Balaji & Cheralathan 2015):

1. Higher oxygen content in biodiesel.
2. Shorter ignition delay period and more quantity of biodiesel undergoing pre-mixed combustion results in higher cylinder pressure and temperature.
3. The combustion duration of biodiesel is lower than that of mineral diesel, the shorter combustion duration results in higher in-cylinder temperature.
4. The NOx emission also increases with engine load due to the high combustion temperature at higher load.

But some researchers also reported that there is a reduction in NOx emission by using pure biodiesel. Puhan et al. (2005a) reported that a lower calorific value and high cetane number of mahua biodiesel helps to reduce the peak pressure rise and results in lower flame temperature and results in reduction in NOx emission. Sahoo et al. (2007) reported that the reduction of NOx emission is due to lower temperature of combustion chamber using biodiesel due to geometry of engine, compression ratio and less reaction time. Vedharaj et al. (2013) reported that the pure biodiesel has higher viscosity which affects the combustion process. Due to lower calorific value, it releases less energy and this helps in the reduction of NOx emission.

ENGINE PERFORMANCE AND EMISSION CHARACTERISTICS OF BIODIESEL-DIESEL BLENDS

Though the use of pure biodiesel as fuel in engine can reduce the emission of CO, HC and smoke significantly, but it increases the emission of NOx. The thermal efficiency of pure biodiesel fuelled engines is also lower than that of mineral diesel fuelled engines. The biodiesel also possesses several drawbacks like lower calorific value, poor cold flow characteristics, poor oxidation stability (Acharya et al. 2017a, Solaimuthu et al. 2015, Atabani & Cesar 2014). In order to address these issues the attention of researchers has been shifted towards blending of biodiesel with mineral diesel. This section presents the performance and emission characteristics of diesel engine using different biodiesel-diesel blends reported by some researchers.

Mofijur et al. (2013) studied the engine performance and emission characteristics of jatropha biodiesel and its blends (10% and 20%) in a single cylinder, variable speed diesel engine and reported that both 10% and 20% blended biodiesel can be used in a diesel engine without any major modifications as lower percentage blended fuels have nearly similar properties as that of mineral diesel.

Chauhan et al. (2012) studied the performance and emission characteristics of a diesel engine fuelled with jatropha biodiesel and its blends (5%, 10%, 20%, 30%) and reported that the engine performance of the jatropha biodiesel and its blend is comparable with that of mineral diesel. They also reported that there is a reduction in emission of CO, HC and smoke density, but increase in NOx emission.

Raheman & Phadatare (2004) studied the engine performance of karanja biodiesel and its blend (20%, 40%, 60%, 80%) in a single cylinder diesel engine and concluded that the biodiesel can be blended up to 40% by volume without compromising with the power output.

Raheman & Ghadge (2007) studied mahua biodiesel and its blends (20%, 40%, 60%, 80%) and reported that mahua biodiesel can be safely blended up to 20% without affecting the engine performance significantly.

Ong et al. (2013) studied the performance of jatropha, kapok and polanga oil biodiesel by blending with mineral diesel (10%, 20%, 30%, 50%) and reported that engine performance and emission characteristics of 10% blend have best results among all fuel blends.

Prabhu et al. (2013) studied the neem biodiesel and its blends (20% and 40%) for its different engine performances and reported that 20% blend is better than higher blends in all respects.

Dhar et al. (2012) studied the performance, combustion and emission characteristics of different blends of neem oil biodiesel and mineral diesel (5%, 20%, 50%, 75%) and reported that lower blends of biodiesel up to 20% can be used in diesel engines without any compromise in the engine performance and emission characteristics.

Aydin & Bayindir (2010) studied the different blends of cotton seed biodiesel (5%, 10%, 20%, 50%) with mineral diesel and reported that lower and medium percentage of blended biodiesel can be used in diesel engines without any modification.

Vedharaj et al. (2013) studied kapok biodiesel and its blends (25%, 50%, 75%) and reported that 25% blend claim for an increase in thermal efficiency and its emission characteristics are also comparable with that of mineral diesel.

Pali et al. (2015) studied the engine performance and emission performance of sal oil biodiesel and its blends (10%, 20%, 30%, 40%) and reported that there is an increase in brake specific energy consumption (BSEC) and decrease in BTE when the blending percentage increases. At peak load condition, there is a reduction of emission of CO, but there is an increase in NOx emission for all the biodiesel blends.

SALIENT FEATURES AND CHALLENGES OF BIODIESEL

This section presents some salient features and challenges of biodiesel as reported by different researchers (Pasqualino et al. 2006, Atabani et al. 2012, Mofijur et al. 2013, Subramaniam et al. 2013, Acharya et al. 2017b).

- It is eco-friendly non toxic and renewable. It contains around 10-12% more oxygen than mineral diesel.
- It is biodegradable. Its inherent higher amount of oxygen content boosts the biodegradation process. Pure biodiesel degrades 85-88% in water.
- It is termed as “carbon neutral” as the photosynthesis of biodiesel yielding plants absorb more carbon dioxide from the atmosphere than they add when used as fuel in engines.
- It is safer to handle as compared to mineral diesel because of its higher flash point.
- It can be easily blended with mineral diesel.
- It can help to reduce the dependency on fossil fuels and helps to improve the energy security of the nation.
- Its use in pure or blended form reduces the exhaust emission significantly.
- It has very good lubricating properties, significantly better than mineral diesel, which can prolong engine’s life.
- It shows shorter ignition delay period as compared to that of mineral diesel.
- It has no sulphur content and does not contribute to acid rain formation.

CHALLENGES OF BIODIESEL

- It has higher viscosity, higher density and higher copper strip corrosion than that of mineral diesel.
- It has unfavourable cold flow properties.
- Most of the biodiesels have low oxidation stability.
- Presently it is more expensive than mineral diesel.

CONCLUSIONS

In this paper, the different aspects of biodiesel obtained from different various non-edible oil has been studied and following conclusions are drawn:

1. The biodiesel from non-edible oils is a better option than edible oil sources, as it does not challenge the food security.
2. It represents a more sustainable source of energy and will play a significant role as a substitute of mineral diesel in future and simultaneously can mitigate the air pollution.
3. These are potentially viable and can be used in a diesel engine without any modification in the existing fuel system.
4. The air pollution can be controlled to a greater extent by using biodiesel as there is a substantial reduction in emission of CO, HC and smoke.
5. The lower percentage blended biodiesel fuels have near equal physico-chemical properties as that of mineral diesel and can be used as substitute of mineral diesel without modification of engine system.
6. More use of biodiesel will improve the economic conditions of rural or tribal people, because feed stocks are mostly available in rural or forest areas.
7. The economy of the nation will also improve due to a reduction in the import of crude oil.

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