Biodiesel as an alternative fuel for compression ignition engines – A review

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Abstract - *Sustainable development of natural resources in this technological galloping era goes hand in hand with the issues like cleaner environment, plantation of oil providing trees etc. Considering the petroleum crises, rapidly increasing prices, uncertainties concerning petroleum fuels availability and environment and type of land required for the growth of Biodiesel plants available with India, fuel from renewable products like edible/non-edible oil cannot be ignored. The aim of this paper is to provide the information of considerable importance on biodiesel to the researchers, engineers. To achieve the goal, this paper summarizes the information on biofuel development, feedstock around the world, oil extraction technic, biodiesel production processes. Furthermore, this paper will also discuss the advantages of biodiesel compared to fossil fuel. In the subsequent section, the combustion behavior of biodiesel in an internal combustion engine is discussed. To determine the future and goal of automotive technology the study found that, feedstock selection for biodiesel production is very important as it associates 75% production cost. Moreover, the test of fuel properties is very important before using in the engine which depends on the type of feedstock, origin, and production process. Most of the researchers reported that the use of biodiesel in diesel engine reduces engine power slightly but reduces the harmful emission significantly. Finally, the study concludes that biodiesel has the potential to be used as a diesel fuel substitute in diesel engines to solve the energy and environment crisis. Also the efforts have been made to include the biodiesel scenario in India.*

Key Words: **Biodiesel, edible oil, feedstock, emission, diesel engine, biofuel.**

1. INTRODUCTION

Transportation system plays an important role to develop the economy of any country in the world. Nowadays the key issue for worldwide transportation sector is the energy supply, which is being fulfilled by fossil fuels such as gasoline and diesel fuel. Globally, an average consumption of energy in the transport sector is increased by 1.1% per year due to the development of motorization industry. It has been reported that only the transportation sector have 63% share in the step up of total global liquid fuel consumption from the year of 2010– 2040. Also, the significant growth of worldwide motorization industry has resulted in the increase of harmful pollutant emissions to the earth. It is very important to mention that, there are about 22% of global GHG (greenhouse gas) emission comes only from the transportation sector. Not only the International Energy Agency (IEA) predicted the emissions of GHG (carbon dioxide) from transport sector will be increased by 92% between 1990 and 2020 and it is also estimated that 8.6 billion metric tons carbon dioxide (CO2) will be released to the atmosphere from 2020 to 2035 [21]. Vehicular emissions such as particulate matter (PM), hydrocarbon (HC), carbon dioxides (CO2), carbon monoxides (CO) and nitrogen oxides (NOx) are hugely responsible for the air quality deterioration. Thus due to fast depletion of fossil fuels and pollution crisis is demanding an urgent need to carry out research work to find out the viable alternative fuels. As diesel fuel is largely consumed by the transportation sector. Biodiesel fuels have all the characteristics of the conventional fossil fuel and can be used as a substitute to it. Thermodynamic tests based on the engine performance evaluations have established the feasibility of using biodiesel oil (vegetable oils). It has been found that vegetable oils hold special promise in this regard, because they can be produced from the plants grown in rural areas. Vegetable oils from crops such as soyabean, peanut, sunflower, rape, coconut, karanja, neem, cotton, mustard, jatropha, linseed and caster have been evaluated in many parts of the world in comparison with other non-edible oils. Karanja (pungamia) is an oil seed-bearing tree, which is non-edible and does not find any suitable application with only 6% being utilized of 200 million tonnes per annum [17].

Biodiesel have the distinct advantages of being renewable, biodegradable, & eco-friendly fuel. Biodiesel has higher viscosity, density, pour point, flash point and cetane number than diesel fuel. Biodiesel is an oxygenated fuel which contains 10–15% oxygen by weight. Also it can be said a Sulfur free fuel. The energy content or net calorific value of biodiesel is about 12% less than that of diesel fuel on a mass basis. Using optimized blend of biodiesel and diesel can help reduce some significant percentage of the world's dependence on fossil fuels without modification of CI Engine, and it also has important environmental benefits. For example using optimized blend of biodiesel and diesel instead of the conventional diesel fuel significantly reduces the exhaust emissions particulate matter (PM), carbon monoxide (CO), sulfur oxides (Sox), and unburned hydrocarbons (HC).

1.1 Indian scenario

At present, India is producing only 30% of the total petroleum fuels required. The remaining 70% is being imported, which costs about Rs. 80,000 crore every year. It is an astonishing fact that mixing of 5% bio-diesel fuel to the present diesel fuel is made available in our country, which can save about Rs. 4000 crore every year. It is estimated that India will be able to produce 288 metric tonnes of bio-diesel by the end of 2012, which will supplement 41.14% of the total demand of diesel fuel consumption in India. The planning commission of India has launched a bio-fuel project in 200 districts from 18 states in India. It has recommended two plant species, viz. jatropha (Jatropha curcas) and Palm (Elaeis Guineensis) for bio-diesel production [17]. The recent auto fuel policy document states that bio-fuels are efficient, eco-friendly and 100% natural energy alternative to petroleum fuels. As per Ministry of Rural Development, the National Mission on Bio-diesel is proposed to be "implemented in two phases. The first phase will involve a demonstration stage for plantation of jatropha on four lakh hectares, and associated research activities for establishing the commercial viability of the fuel. Phase two will involve self-sustaining expansion of the bio-diesel programme. The overall objective of the national mission is to promote the creation of national infrastructure for production of bio-diesel through cultivation of jatropha plant and processing of its oil.

This paper gives a review of biodiesel production, experimental investigation on different vegetable oils, characterization, results obtained use of by bio-diesel are briefed.

1.2 Sources of Biodiesel feedstock.

The main characteristics of typical oil crops that have been found useful for biodiesel production are summarized in the following paragraphs. Fig1. Shows the various non-edible vegetable oil feedstock's for biodiesel.

Cottonseed

Among non-foodstuffs, cotton is the most widely traded commodity. It is produced in more than 80 countries and distributed worldwide. After the harvest, it may be traded as raw cotton, fiber or seeds. In cotton mills, fiber and seeds are separated from raw cotton. Cotton fiber is processed to produce fabric and thread, for use in the textile industry. In addition, cotton oil and flour are obtained from the seed; the latter is rich in protein and is used in livestock feed.

Soybean

It is a legume originating in East Asia. Depending on environmental conditions and genetic varieties, the plants show wide variations in height. Leading soybean producing countries are the United States, Brazil, Argentina, China, and India. Biodiesel production form soybean yields other valuable sub-products in addition to glycerin: soybean meal and pellets (used as food for livestock). Grain yield varies between 2,000 and 4,000 kg/hectare. Since the seeds are very rich in protein, oil content is around 18%.

Rapeseed and Canola

Rapeseed adapts well to low fertility soils, but with high sulfur content. With a high oil yield (40–50%), it may be grown as a winter-cover crop, allows double cultivation and crop rotation. It is the most important raw material for biodiesel production in the European Community. However, there were technological limitations for sowing and harvesting in some Central and South American countries, mainly due to the lack of adequate information about fertilization, seed handling, and storage (the seeds are very small and require specialized agricultural machinery). Moreover, low prices in comparison to wheat (its main competitor for crop rotation) and low production per unit area have limited its use.

Rapeseed flour has high nutritional value, in comparison to soybean; it is used as a protein supplement in cattle rations. Sometimes canola and rapeseed are considered to be synonymous; canola (Canadian oil low acid) is the result of the genetic modification of rapeseed in the past 40 years, in Canada, to reduce the content of erucic acid and glucosinolates in rapeseed oil, which causes inconvenience when used in animal and human consumption. Canola oil is highly appreciated due to its high quality, and with olive oil, it is considered as one of the best for cooking as it helps to reduce blood cholesterol levels.

Oil Palm

Oil palm is a tropical plant that reaches a height of 20–25 m with a life cycle of about 25 years. Full production is reached 8 years after planting. Two kinds of oil are obtained from the fruit: palm oil proper, from the pulp, and palm kernel oil, from the nut of the fruit (after oil extraction, palm kernel cake is used as livestock food). Several high oil-yield varieties have been developed. Indonesia and Malaysia are the leading producers. International demand for palm oil has increased steadily during the past years, the oil being used for cooking, and as a raw material for margarine production and as an additive for butter and bakery products. It is important to remark that pure palm oil is semisolid at room temperature (20–22 C), and in many applications is mixed with other vegetable oils, sometimes partially hydrogenated.

Fig.1 Various non-edible vegetable oil feedstock for biodiesel

Safflower

Safflower adapts well to dry environments. Although the grain yield per hectare is low, the oil content of the seed is high, from 30 to 40%. Therefore, it has economic potential for arid regions. Currently, safflower is used in oil and flour production and as bird feed. There are two varieties, one rich in mono-unsaturated fatty acids (oleic acid) and the other with a high percentage of polyunsaturated fatty acids (linoleic acid). Both varieties have a low content of saturated fatty acids. The oil from safflower is of high quality and low in cholesterol content. Other than being used for human consumption, it is used in the manufacture of paints and other coating compounds, lacquers and soaps. It is important to note that safflower oil is extracted by means of hydraulic presses, without the use of solvents, and refined by conventional methods, without anti-oxidant additives. The flour from safflower is rich in fiber and contains about 24% proteins. It is used as a protein supplement for livestock feed.

Castor Seed

The castor oil plant grows in tropical climates, with temperatures in the range 20–30 C; it cannot endure frost. It is important to note that once the seeds start germinating, the temperature must not fall below 12 C. The plant needs a warm and humid period in its vegetative phase and a dry season for ripening and harvesting. It requires plenty of sunlight and adapts well to several varieties of soils. The total rainfall during the growth cycle must be in the range 700–1,400 mm; although it is resistant to drought, the castor oil plant needs at least 5 months of rain during the year. Castor oil is a triglyceride, ricinolenic acid being the main constituent (about 90%). The oil is non-edible and toxic owing to the presence of 1–5% of ricin, a toxic protein that can be removed by cold pressing and filtering. The presence of hydroxyl groups in its molecules makes it unusually polar as compared to other vegetable oils.

Jatropha

Jatropha is a shrub that adapts well to arid environments. Jatropha curcas is the most known variety; it requires little water or additional care; therefore, it is adequate for warm regions with little fertility. Productivity may be reduced by irregular rainfall or strong winds during the flowering season. Yield depends on climate, soil, rainfall and treatment during sowing and harvesting. Jatropha plants become productive after 3 or 4 years, and their lifespan is about 50 years. Oil yield depends on the method of extraction; it is 28–32% using presses and up to 52% by solvent extraction. Since the seeds are toxic, jatropha oil is non-edible. The toxicity is due to the presence of curcasin (a globulin) and jatrophic acid (as toxic as ricin).

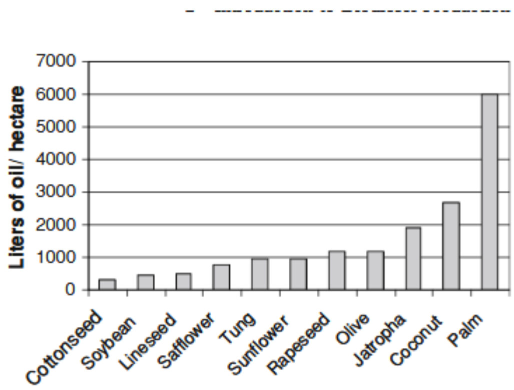

Fig.2 Approximate oil yields for different crops

Fig.2 presents approximate oil-yield values (in liters per hectare) for some of the crops discussed in this chapter. It is important to note that the data in Fig.2 only show the oil yields of different crops. However, for the comparison of economical suitability it must be borne in mind that in addition to oil, some crops are grown for fiber or protein production. For instance, soybean has an oil content of 18% (maximum), whereas the remainder is mostly protein (usually used as livestock feed).

1.3 Biodiesel Production Processes.

The vegetable oil based fatty acid methyl esters (FAME), popularly known as biodiesel, is gaining importance as an environment-friendly diesel fuel substitute or extender. Biodiesel is an alternative diesel, made from renewable biological sources such as vegetable oils and animal fats by chemically reacting oil or fat with an alcohol, in the presence of a homogeneous and heterogeneous catalyst. The product of the reaction is a mixture of methyl esters, which are known as biodiesel, and glycerol, which is a high value co-product (bio-esters), ethanol, and biogas of which worldwide large quantities have been produced so far and for which the production process is considered 'established technology'.

Bioethanol is a substitute of gasoline and it is a full substitute for gasoline in so called flexi-fuel vehicles. It is derived from sugar or starch through fermentation. Bioethanol can also serve as feedstock for ethyl tertiary butyl ether (ETBE) [30] which blends more easily with gasoline. Biogas, or bio methane, is a fuel that can be used in gasoline vehicles with slight adaptations. It can be produced through anaerobic digestion of liquid manure and other digestible feedstock. At present, biodiesel, bioethanol and biogas are produced from commodities that are also used for food.

Biodiesel is a substitute of diesel and is produced through transesterification reaction of vegetable oils, and residual oils and fats, with minor engine modifications. It can serve as a full substitute as well. This chemical reaction converts an ester (vegetable oil or animal fat) into a mixture of esters of the fatty acids that makes up the oil (or fat). Biodiesel is obtained from the purification of the mixture of fatty acid methyl esters (FAME).

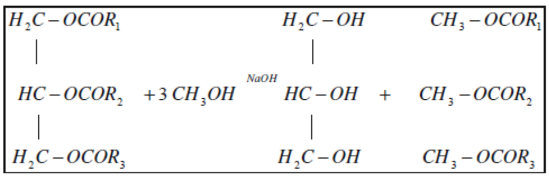

Fig.4 – Basic transesterification reaction with methanol

A catalyst is used to accelerate the reaction Fig.4 According to the catalyst used, transesterification can be basic, acidic or enzymatic, the former being the most frequently used. A generic transesterification reaction is presented in Eq (1.3.1); RCOOR' indicates an ester, R''OH an alcohol, R'OH another alcohol (glycerol), RCOOR'' an ester mixture and cat a catalyst [44].

RCOOR' + R''OH ↔ (cat)↔ R'OH + RCOOR''
-------**Eq (1.3.1)**

When methanol is the alcohol used in the transesterification process, the product of the reaction is a mixture of methyl esters; similarly, if ethanol were used, the reaction product would be a mixture of ethyl esters. In both cases, glycerin will be the co-product of the reaction. This is shown schematically in Figs. 3 and 4.

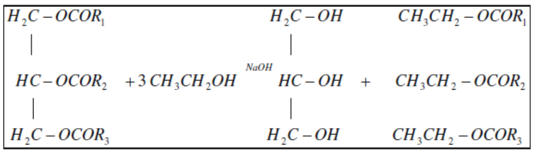

Fig.3 Basic transesterification reaction with ethanol

2. Biodiesel as a Diesel Engine Fuel

2.1 fuel properties of various biodiesel

Table 1 summarizes several of the most important physical/ chemical properties of biodiesel (FAME)[17,20]. Important properties that are directly related to biodiesel (FAME) itself, and are reported frequently in the literature, include kinematic viscosity (mm2/S), density (kg/I), cloud point (0C), pour point (0C), heating value (MJ/kg), and flash point (0C). All these properties are included in Table 1, along with cetane index (CI), which was reported by many authors. Many researchers have reported that fuel properties of non-edible biodiesels vary depending on their fatty acid and chemical composition. Therefore, before using non-edible-based biodiesels in diesel engines, measuring the fuel properties of selected biodiesels is necessary. The fuel properties of biodiesels are specified by different standardization organizations; the ASTM D6751 and EN14214 [20], ASTM D976 and D4737 [31] are the most popular standards for biodiesel. The following section discusses the fuel properties of the reviewed biodiesels.

Kinematic viscosity

Viscosity is the most important property of fuel that must be considered to maintain engine performance that is close to diesel operation. High viscosity causes poor flow of fuel in the engine combustion chamber during intake stroke and takes a long time to mix with air. Therefore, it results in delayed combustion. Viscosity of fuel has been proved to decrease with the increase in temperature. Kinematic viscosity is determined using the ASTM D6751 and EN14214 [20], ASTM D976 and D4737 [31] test methods. Table 1 shows that some non-edible biodiesels, such as crambe, peanut, rapseed oil, have high viscosity that ranges from 53.6 mm2/s , 39.6mm2/s, 37.0 mm2/s, respectively, which are higher than that of diesel fuel. However, the viscosity of jatropha, tobacco, and mohua biodiesels ranges from 3.7 mm2/s to 5.8 mm2/s, 3.5 mm2/s to 4.23 mm2/s, and 3.98 mm2/ s to 5.8 mm2/s, respectively, which are close to that of diesel at 2.5–5.7 mm2/s. Therefore, these biodiesels can give better atomization and provide improved combustion than others.

Biodiesel	Kinematic Viscosity at $38^0C(mm^2/S)$	CN	heating value (MJ/kg)	cloud point (^0C)	pour point (^0C)	flash point (^0C)	desity (kg/m^3)
Corn	34.9	37.6	39.5	-1.1	-40.0	277	909.5
Cottonseed	33.5	41.8	39.5	1.7	-15	234	914.8
Crambe	53.6	44.6	40.5	10.0	-12.2	274	904.8
Linseed oil	27.2	28-35	39.3	1.7	-15	241	923.6
Peanut	39.6	41.8	39.8	12.8	-6.7	271	902.6
Rapseed oil	37.0	37.6	39.7	-3.9	-31.7	246	911.5
Safflower	31.3	41.3	39.5	18.3	-6.4	260	914.4
Sesame	35.5	40.2	39.3	-3.9	-9.4	260	913.3
Soyabean	32.6	37.9	39.6	-3.9	-12.2	254	913.8
Sunflower	33.9	37.1	39.6	7.2	-15	274	916.1
Palm oil	**39.6**	**42.0**	**40.13**	**31**	**-**	**267**	**918.0**
Babassu	30.3	38.0	-	20	-	150	946.0
Diesel oil	**2.5-5.7**	**45-55**	**43.8**	**-10**	**-20**	**50-98**	**855**
Karanja	4.37-9.60	53	-	13-15	-3	163	876
Polanga	4-5.4	57	-	13.2-14	4.3	151	888.6
Mahua	3.98-5.8	52	-	3-5	1-6	127	904
Rubber seed	5.81-5.96	37-49	-	4-5	-8	130	860
Jojoba oil	19.2-25.4	63	-	1.7	-6	61	863
Tobacco oil	3.5-4.23	49	-	6-16	-12	152	860
Neem	20.5-48.5	51	-	-	-	34	912
Jetropha oil	**3.7-5.8**	**46-55**	**-**	-	**5**	**163-238**	**864**

Table 1 Properties of various non-edible biodiesels.

Cetane number (CN)

CN is the most important property of fuel that directly affects its combustion quality. Ignition quality of fuel in a power diesel engine is measured by CN. Higher CN implies shorter ignition delay. The CN of pure diesel fuel is lower than that of biodiesel. The CN of biodiesel is higher because of its longer fatty acid carbon chains and the presence of saturation in molecules. CN is based on two compounds, namely, hexadecane and heptamethyl nonane. The CN of biodiesel is measured by the ASTM D613 and EN ISO 5165 test methods [20]. Table 1 show that most biodiesel fuels have higher CN than diesel fuel (45–55), except for rubber seed and linseed biodiesels, which have low CN that is equal to 37–49 and 28–35, respectively. Jatropha, mohua, neem, and tobacco have CN close to that of diesel fuel. Jojoba, karanja, and polanga usually have higher CN than other biodiesels; thus, they are more superior.

Heating value

Heating value is one of the important parameters of fuel that affects both the thermal efficiency and combustion characteristics of an engine. It also measures the energy content of the fuel. The heating value, the heat of combustion of fuel is the thermal energy released per unit quantity of fuel when the fuel is burned completely. Then the products of combustion become cool back again to its primary temperature of the flammable combinations. One of the most important elements of heating value is the moisture content of the fuel. Authors reported that due to the significant oxygen content, it is accepted that biodiesel has about 10% lower mass energy content (MJ/kg) than petroleum diesel. The heating value is not determined by the biodiesel guidelines ASTM D6751 and EN 14214. However in EN 14213 it is recommended for biodiesel the heating value at least 35 MJ/kg [21].

Cloud point and pour point

Biodiesel has higher cloud and pour points than conventional diesel fuel. Cloud and pour points are measured using the ASTM D2500 and D97 test methods, respectively [20]. Table 1 illustrates that rapseed and sesame biodiesels have the lowest cloud point of -3.9 0C, whereas palm oil has the highest cloud point of 31.0 0C. On the contrary, rapseed and Corn biodiesel have the lowest pour point of -31.7 0C and -40 0C, respectively, whereas mohua and Polanga have the highest pour point range of 1–6 0C and 40C respectively.

Flash point

Flash point is the most important property that must be considered in assessing the overall flammability hazard of a material. At this temperature, vapor stops burning if the source of ignition is removed. Each biodiesel has its own flash point. Many factors affect the change in biodiesel flash point, with residual alcohol content being one of them. Moreover, flash point is influenced by the chemical compositions of the biodiesel; including the number of double bonds, number of carbon atoms, and so on. The flash point of biodiesel is measured using the ASTM D93 and EN ISO 3697 test methods [20]. Table 1 shows that biodiesel has a higher flash point than diesel fuel. The ASTM D6751 standard recommends a minimum flash point of 130 0C for biodiesel, as clearly illustrated in Table 1. With the exception of neem, linseed, and jojoba, all biodiesels meet the ASTM specification.

Density

Density is the property of any fuel which is directly affects the engine performance and is related to the other important characteristics such as viscosity and cetane number. Normally the density of biodiesel is measured by using ASTM standard D1298 and EN ISO 1676 methods [21]. Density also has an influence on combustion quality by changing the mass of the fuel injected through injector. The higher density will increase the size of the fuel droplets and the big droplets in the combustion chamber will be higher as well. Moreover, a fuel with lower density will expand the efficiency of atomization and air–fuel ratio formation, so the changes of density will affect the engine output power due to the different mass of injected fuel. The density of the fuel is related to the engine emissions. Thus the fuel of high density causes the high emissions especially particulate matter (PM) and NOx emission of diesel engine. From the Table 1, it can be seen that the density of different biodiesel is different i.e. Rubber seed biodiesel have a lower density (860 kg/m3), and Babassu biodiesel has higher density (946 kg/m3)[21,20,31].

The oxidative stability of biodiesel (FAME) is a critical in-use property of biodiesel, but was not considered in this summary of fuel properties because it is influenced greatly by the biodiesel (FAME) clean-up and storage practices employed. In addition, some of the biodiesel contained anti-oxidant additives, which modified the inherent stability of the FAME material. There are several other biodiesel (FAME) properties for which specifications have been established, but that also depend largely upon manufacturing and handling practices, rather than being inherent properties of biodiesel (FAME) itself. These include water and sediment, methanol content, ash, metals, acid number, glycerine content, and cold soak filterability. Thus, these properties are not included in the summary Table 1.

2.2 Engine performance of a diesel engine using biodiesel

Researchers have tried different types of biodiesel blends on the volume basis with the diesel and those different blends prepared are subjected to combustion in the diesel engine at different loading conditions, speed, injection pressure, injection timings and other similar parameters and compared engine performance with the conventional diesel under similar conditions. The literature shows significant performance variation obtained among different types of biodiesel blends and discussed step by step.

Elsanusi et al. [1] investigated diesel engine performance using diesel and biodiesel-diesel blends, with their emulsions under various operating conditions. Researcher tested five fuels and their emulsions B0, B10, B20, B30 and B40, with 5%, 10%, and 15% water concentration. Under given operating condition results showed that at 2100 rpm. And at low load, BSFC's of B0, B20 and B40 fuels were 230.9, 232.7 and 234.5 g/kW h, respectively. All emulsion fuels consisting of 15% water content showed higher BSFC than those with 5% and 10% water content, with their base fuels at constant operating conditions.

Brake thermal efficiency of different fuel and their emulsion shows rise with increased engine load. The BTE of EB40W15 increased by 5.85% and 6.75% compared to B40 and B0 respectively, at high load condition.

Khachane et al. [35]deals with the comprehensive review of castor biodiesel blends with the diesel using Diesel engine and the performance of the diesel engine in terms of performance characteristics in terms of Brake Power, Brake Thermal Efficiency, Break specific fuel consumption etc. Research findings showed that neat castor biodiesel when used in engine has higher BSFC than the diesel. Castor biodiesel blends with higher diesel content B5, B10, B20 in the blend has more or less similar performance and emission characteristics as diesel. Biodiesel blend B20 at retarded injection timing and at higher injection pressure showed higher BTE's, lower BSFC, lower NOX emission and lower HC, CO emissions.

Jibhakate et al. [34] has conducted an investigation using different blends of castor biodiesel as 25%, 75% , pure diesel at 100% Exhaust Gas Recirculation(EGR) in order to find out the performance of diesel engine in terms of Brake Power, Brake Specific Fuel Consumption, Brake Mean Effective Pressure and Brake Thermal Efficiency and results are obtained showed the controlled emission and method proved very reliable in terms of fuel economy. Total fuel Consumption when tested against the Brake Power showed the Diesel has lower BSFC as compared to both blends B25 &B75, while B25 has lower BSFC than B75 blend Brake Specific fuel Consumption when tested against Brake Mean Effective Pressure at 100% showed BSFC is higher forB75 blend as compared to B25 & Diesel Brake Thermal Efficiency checked against the Brake Power showed that BTE for B25 was higher than diesel and B75.

Murugesan et al. [17] reviewed the prospects and opportunities of introducing vegetable oil and their derivatives as a fuel in diesel engine. Various blends of vegetable oil with diesel B0, B25, B50, B75 and B100 were used to conduct the test. Results shows that methyl ester of bio-diesel (B100) can be directly used in diesel engines without any modifications for short term with slightly interior performance than that of diesel. Brake thermal efficiency for bio-diesel is slightly increased in B20. Brake-specific energy consumption for B20 is reduced slightly. A blend of 20% by volume of bio-diesel fuel in diesel does not affect any of the measured performance or emission characteristics. Addition of small quantities of bio-diesel to mineral diesel is a suitable strategy for increasing alternative fuel consumption, at least in agricultural engines.

Sahid et al. [22] conducted the experiments at constant speed of 1500 rpm. By varying the load from 3 to 33 kW using cotton seed oil B0, B20, B40, B60, B80and B100 fuel. The engine performance characteristics and exhaust emissions were observed. Observation shows that Cotton Seed Oil Methyl Ester (CSOME) can be used in blended form as an alternative fuel in any compression ignition engine without any modification. The FC and BSFC increases and BTE decreases with the increase of ratio of biodiesel in blends of diesel and biodiesel. Since the biodiesel fuel is almost free from sulfur so the exhaust emissions are almost free from SOx, when the engine is fed with CSOME and its blends.

Khan et al. [25] uses waste cooking oil methyl ester (WCME) biodiesel (B15, B20 and B25). The experiment was performed on single cylinder, four stroke VCR diesel engines at different loads and a speed of 1500 rpm. The compression ratio was kept 18:1. Exhaust gas emissions were measured by gas analyzer. The parameters used to measure engine performance were SFC, BTE and emission characteristics were CO, CO2, HC and NOx. Conclusion shows BP increases with the load for diesel and its blends with biodiesel also SFC is higher for biodiesel blends than diesel with BTE of diesel is higher than biodiesel blends.

Sanjid et al. [43] conducted the experiment to to evaluate the BSFC, engine power, exhaust and noise emission characteristics of a combined palm and jatropha blend in a single-cylinder diesel engine at different engine speeds ranging from 1400 to 2200 rpm. The test fuels chosen were 100% neat diesel fuel (B0), 10% palm biodiesel with 90% diesel fuel (PB10), 10% jatropha biodiesel with 90% diesel fuel (JB10), 20% palm biodiesel with 80% diesel fuel (PB20), 20% jatropha biodiesel with 80% diesel fuel (JB20), 5% palm and 5% jatropha biodiesel with 90% diesel fuel (PBJB5), 10% palm and 10% jatropha biodiesel with 80% diesel fuel (PBJB10). Results show that the maximum brake power output of PBJB5 was found to be slightly lower than PB10 and slightly higher than JB10. By contrast, the maximum brake power output of PBJB10 was found to be slightly lower than PB20 and slightly higher than JB20 Average BSFC for PBJB5 and PBJB10 were found to be 7.55% and 19.82% higher than B0 respectively average BSFC for PBJB5 and PBJB10 were found to be 4.29% and 4.24% lower than JB10 and JB20 respectively due to their lower density and viscosity than the jatropha biodiesel blends.

Bowen li et al. [4] uses Polyoxymethylene Dimethyl Ethers (PODE), with excellent volatility and oxygen content of up to 49%, have great potential to improve engine performance and emission characteristics, especially for soot reduction. Experiments were carried out in a single-cylinder engine fueled with diesel (D100), biodiesel (B100) and BP15 (15% PODE and 85% biodiesel by volume). Blending PODE in biodiesel improves the combustion, and thus increases combustion efficiency at high EGR conditions. At 40% EGR, combustion efficiency of BP15 is 5% higher than that of D100 and 3% higher than that of B100. Engine efficiency is also improved by blending PODE. The highest ITE of BP15 is higher than 45%, which is 1.2% and 0.7% higher than that of D100 and B100 respectively

Bhupendra singh chauhan et al. [39] and S.Jaichandar et al. [37] evaluated the performance parameters like brake thermal efficiency, brake specific fuel consumption, power output by comparative study of various Jetropha Oil Methyl Esters (JOME) blends with diesel. Bhupendra singh chauhan et al. [39] conducted the tests using D100, B5, B10, B20, B30 and B100. From the test results it is clear that initially with increasing brake power, the brake thermal efficiency of Jatropha biodiesel and its blends also increases together with diesel. The brake thermal efficiencies of the Jatropha biodiesel oil and its blends were found to be lower than diesel fuel throughout the entire range. The brake specific fuel consumptions (BSFC) in case of Jatropha biodiesel and its blends were also found to be higher than diesel fuel. S.Jaichandar et al. [37] checked the same parameters with D100, B20, B50 and B100. Author also concluded that The brake thermal efficiency (BTE) of JOME and its blends was lower compared to that of diesel. At the rated load, the BTE of JOME was lower than that of PBDF by 8.5%. The decrease in BTE at full load was 2.8% for B20and 5.25% for B50. The BSFC for JOME and its blends was slightly higher than that of D100. The BSFC, in general, was found to increase with the increasing proportion of JOME in the D100. The BSFC for B100, B50 and B20, was higher than that of diesel by about 19.6%, 14%, and 5.4% respectively at full load operation.

2.3 Engine emission performance when biodiesel is used in a diesel engine

Elsanusi et al. [1] observed during their tests that smoke intensity in the exhaust gas increased at higher contents of biodiesel in biodiesel blends, perhaps due to higher viscosity. When CO and HC emissions are under considerations results showed biodiesel blend up to 40% lead to reduced Co emission compared to pure diesel at all engine operating conditions.

15% water concentration in emulsion fuels of diesel and biodiesel-diesel blends could realistically be used in diesel engines, which could increase BTE by approximately 6%, with a 30% reduction in NOx and smoke. In addition, HC reduction could be as high as 70% with 15% water concentration in emulsion fuels.
Kwanchareon et al. [2] studied phase behavior and fuel properties of the diesel-biodiesel-ethanol three component fuel system. For this diesel, biodiesel and ethanol were mixed into a homogeneous mixture and each component was varied from 0% and 100% by volume in 10% increment. it was found that CO and HC were reduced significantly at high engine load, whereas NOx increased, when compared to that of diesel.

Taking these facts into consideration, a blend ratio of 80% diesel, 15% biodiesel and 5% ethanol was the most suitable for diesohol production because of the acceptable fuel properties and the reduction of emissions. It is observed that the blend of 90% diesel, 5% biodiesel and 5% ethanol had a heating value very close to that of diesel fuel. And the blend of 80% diesel, 15% biodiesel and 5% ethanol had the highest cetane index.

Khachane et al. [35] reviewed castor biodiesel blends with the diesel with emphasis to emission combustion characteristics & Exhaust gas emission characteristics in

terms of CO, HC, NOX, Smoke Capacity, Particulate matter emission etc. at different loading conditions and speeds and the results of the castor blends are compared with that of the diesel. Biodiesel blend B20 at retarded injection timing and at higher injection pressure showed higher BTE's, lower BSFC, lower NOX emission and lower HC, CO emissions.
Chakrabarti et al. [32] shows when the trial conducted on the diesel engine with castor biodiesel blend with the blending percentage B10 in the High Speed Diesel engine and compared with pure diesel for Exhaust gas emission, it was found that CO2 Emission for B10 was comparatively more than HSD. This may be due to higher carbon atom and higher oxygen content of biodiesel. However CO emission for B10 was slightly lower than diesel. NOX emission for blend B10 is higher than HSD also the emission of Sulphur is more for diesel .for B10 blend higher exhaust gas temperature is recorded ,fuel Oxygen content is less for the B10 while it is higher for the HSD. Particulate matter in exhaust is high for HSD than that of B10.

Sahid et al. [22] concluded that CO, CO2 and HC emissions are reduced by increasing ratio of cotton seed oil methyl ester (CSOME) biodiesel in the fuel. These pollutant gasses are harmful for environment causing global warming and greenhouse effect and hazardous for respiratory system, nervous system, cardiac system and cause various types of skin diseases. Thus the biodiesel is an environmental friendly fuel. The level of NOx rises in the emissions by increasing the proportion of CSOME in the blend, which can be controlled with catalytic conversion, after treatment, and by some modification in the design of fuel injection system of the engine.

Shameer et al. [19] enlightens the momentous of injection parameters like injection timing and injection pressure on the engine emission characteristics. Author focuses upon the advancement and retardation methods of fuel injection timing and injection pressure to inspect the engine emission indicators such as CO, HC, NOx, smoke, particulate matter and CO2 contents. Conclusion shows that the advancement in injection timing resulted in the reduction of CO, HC, particulate matter, smoke and CO2. In the meantime the NOx show augmentation for most of the biodiesel at advanced fuel injection timing. Contradictory results were reported for injection timing retardation. Author concluded that the increase in fuel injection pressure of biodiesel resulted in reduction of CO, HC, particulate matter, smoke and NOx. Meanwhile CO_2 emission increased for higher injection pressure conditions.

Khan et al. [25] observed that the waste cooking oil methyl ester (WCME) biodiesel (B15, B20 and B25) has almost similar behavior like any other biodiesel when used in CI engine. A CO and HC emission decreases with increasing percentage of biodiesel in blends with diesel. Diesel has lowest CO2 emission and among all fuel blends CO2 emission decreases with increasing percentage of biodiesel. NOx emission increases with increasing percentage of biodiesel in blends.

Sanjid et al. [43] tested engine performance, emissions and noise of PBJB5 and PBJB10 palm and jatropha combined biodiesel, diesel blends were investigated and compared with B0, palm and jatropha biodiesel blends. At the expense of a slight increase in BSFC and NO emissions, the PBJB5 and PBJB10 biodiesels showed better emission characteristics than B0. Author concluded that the considerable amount of CO reduction compared with B0 was found for PBJB5 (9.53%) and PBJB10 (20.49%). By contrast, the average HC reductions for PBJB5 and PBJB10 were 3.69% and 7.81% lower than B0. NO emission was increased for all the tested biodiesels compared with B0. However, NO emissions of PBJB5 and PBJB10 were found to be slightly lower than the PB10 and PB20 blends respectively, and almost the same for the JB10 and JB20 blends

Bowen li et al. [4] blended PODE with biodiesel and the combustion and emission characteristics were investigated in a single-cylinder diesel engine. PODE was used to improve the mixture and oxygen content, which does benefit to combustion rate and soot reduction. Result shows that NOx emissions of all three fuels are greatly impacted by EGR. BP15 has the lowest NOx emissions at relatively high EGR conditions due to the lowest heating value. Soot emissions of D100 are considerably higher than those of BP15 and B100. Notably, trade-off relationship between NOx and soot emissions is broken when using BP15 and B100. At the same time, NOx and soot emissions can be controlled below 0.4 g/kW h and 0.01 g/kW h respectively.

Bhupendra singh chauhan et al [39] and S.Jaichandar et al [37], conducted the experiments with jetropha biodiesel blends concluded that Within the whole experimental range, the CO emission from the Jatropha methyl ester and its blends is lower than neat diesel fuel. With increase in biodiesel percentage in biodiesel-diesel blends, CO decreases, as biodiesel is oxygenated fuel and contains oxygen which helps for complete combustion. The values of unburned hydrocarbon emission from the diesel engine in case of Jatropha methyl ester and its blends are less than diesel fuel. The NOx emissions increased with the increasing engine load, due to a higher combustion temperature.

2.3 Advantages of biodiesel as an I.C. Engine fuel.

Some of the advantages of using biodiesel as a replacement for diesel fuel are

- Renewable fuel, obtained from vegetable oils or animal fats.
- Low toxicity, in comparison with diesel fuel.

- Degrades more rapidly than diesel fuel, minimizing the environmental consequences of biofuel spills.
- Lower emissions of contaminants: carbon monoxide, particulate matter, poly-
- Cyclic aromatic hydrocarbons, aldehydes.
- Lower health risk, due to reduced emissions of carcinogenic substances.
- No sulfur dioxide (SO2) emissions.
- Higher flash point (100C minimum).
- May be blended with diesel fuel at any proportion; both fuels may be mixed
- During the fuel supply to vehicles.
- Excellent properties as a lubricant.
- It is the only alternative fuel that can be used in a conventional diesel engine, without modifications.
- Used cooking oils and fat residues from meat processing may be used as raw materials.

2.4 Disadvantages of biodiesel as an I.C. Engine fuel.

There are certain disadvantages of using biodiesel as a replacement for diesel fuel that must be taken into consideration

- Slightly higher fuel consumption due to the lower calorific value of biodiesel.
- Slightly higher nitrous oxide (NOx) emissions than diesel fuel.
- Higher freezing point than diesel fuel. This may be inconvenient in cold climates.
- It is less stable than diesel fuel, and therefore long-term storage (more than six months) of biodiesel is not recommended.
- May degrade plastic and natural rubber gaskets and hoses when used in pure form, in which case replacement with Teflon components is recommended.
- It dissolves the deposits of sediments and other contaminants from diesel fuel in storage tanks and fuel lines, which then are flushed away by the biofuel into the engine, where they can cause problems in the valves and injection systems. In consequence, the cleaning of tanks prior to filling with biodiesel is recommended.

It must be noted that these disadvantages are significantly reduced when biodiesel is used in blends with diesel fuel.

3. CONCLUSION

Biodiesel has attracted much research because of its economic and environmental benefits as well as its renewable nature. 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 review concludes that non-edible oil is a promising source that can sustain biodiesel growth. It is observed that fuel properties vary depending on feedstock, the biodiesel conversion process as well as type of engine used. Most reviewed biodiesel fuels have excellent kinematic viscosity as a internal combustion engine fuels. However, the viscosity ranges of jatropha, palm, and mohua biodiesels are close to that of diesel fuel. Castor seed, Palm oil, Rice bran oil, and jatropha biodiesels are better than others in terms of density. Castor seed, Palm oil, Rice bran oil, jojoba, and jatropha oil biodiesels are excellent in terms of Cetane number. Palm and jatropha biodiesel have better calorific value than other biodiesels. It is observed that several studies were carried out to determine power output, BSFC, and BTE of an I.C. engine operating with non-edible oil-based biodiesel. In most cases, palm oil and jatropha biodiesels gave higher BSFC but had better thermal efficiency than other biodiesels. Their brake power and torque were closer to those of diesel fuel because of their calorific value. Moreover, the low percentage of biodiesel blends (<20%) caused high brake power and reduced fuel consumption because of complete combustion. Therefore, biodiesels with high calorific value and low viscosity are more suitable for the improvement of engine performance. Biodiesel is an oxygenated fuel that leads to complete combustion. Based on several experimental results, the use of Castor seed, Palm oil, Rice bran oil, and jatropha biodiesel in CI engine can reduce CO, HC, and smoke emission with an increase in NOx emission. The low HC emission in most cases is usually caused by advanced injection timing and proper combustion in the combustion chamber. More-over, higher oxygen contains and higher CN, which is favored to lower emission. However, some authors found a significant reduction of NOx emission. Based on the review of the emission characteristics, Castor seed, Palm oil, Rice bran oil, and jatropha biodiesels are concluded to give better emission characteristics than other biodiesels. Therefore, non-edible biodiesel blended with conventional diesel have good potential to replace conventional fuel in the near future.

4. FUTURE SCOPE

As most of the researchers have found out that biodiesel has attracted much research because of its economic and environmental benefits as well as its renewable origin. There is still scope to enhance the purity and quality of different biodiesel blend using various methodologies for thermodynamic model analysis of biodiesel engine in combination with appropriate optimization approach to determine the optimum engine design, blend properties and operating parameters.

Abbreviations

CO – Carbon Monoxide
HC- Hydro Carbon

NOx – Oxides of Nitrogen
BTE - Brake Thermal Efficiency
BSFC- Brake Specific Fuel Consumption
ITE – Indicated Thermal Efficiency
CN –Cetane Number
EGR – Exhaust Gas Recirculation
PODE – Poly Oxymethylene Dimethyl Ethers
WCME – Waste Cooking Methyl Ester
CSOME – Cotton Seed Oil Methyl Ester
JOME – Jetropha Oil Methyl Ester
HSD- High Speed Diesel

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