Biodiesel: An Alternative Fuel for I.C. Engines

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Abstract— With the advancement in technology and increasing industrialization of world there has been an increase in energy demand. This energy requirement is primarily met by petroleum based fuels, which being non-renewable in nature necessitates finding alternative fuels which are renewable. Biodiesel is one of the alternatives which are renewable. Biodiesel is a biofuel, produced from biomass. These include biodiesels, biogas, bio-alcohols, and etc. This paper reviews the characteristics, production methods, methods of purification, and effects of biodiesels on diesel engines and current statuses of biodiesels. The paper also discusses biodegradability, lubricating properties, stability, economic feasibility, and emissions of biodiesels as engine fuel.

Keywords: Alcohols, Biodiesels, Bio-fuels, Emissions, I.C. Engines, Renewable fuel.

I. INTRODUCTION

Today, the world is confronted with two major problems: energy crisis and degrading environment. The major reason is excessive use of fossil fuels. So, it has become necessity to search for alternative fuels, which promises to solve both these problems and offer sustainable development. Biofuels are one feasible solution to these problems, as automobiles are one of the major contributor towards the consumption of petroleum based fuels and also major source of green house emissions [1-3]. Biofuels offer two major advantages over petroleum based fuels that Biofuels are renewable and relatively clean. Various Biofuels include biogas, biodiesel, vegetable oils, alcohols, etc. This study concentrates on accessing the vitality of using alternative fuels in the existing I.C. engines.

Increasing energy requirement and decreasing energy resource reserves has stimulated research in renewable, emission free and non-petro fuels. It has been estimated that the world energy reserves will last 41 years, 63 years, 218 years for oil, natural gas and coal respectively [1, 4, 5]. The increasing prices of crude oil may also be the reason behind the growing interest in Biofuels.

A. Effect on Environment and Human Health

Use of petroleum based fuels also leads to environmental problems such as increase in level of carbon dioxide in atmosphere, acid rain, air pollution, smog and climatic changes over the globe. The population of the automobiles is increasing rapidly, increasing energy requirements and putting pressure on the use of petroleum based fuels. Due to this there has been a continuous increase in pollutants level spite of the stringent norms on emissions.

The pollutants include CO, HC, NOx, particulate matter, SO2, CO2, methane, aldehydes, xylene, benzene, toluene etc. These pollutants contribute to several adverse effects on human health. CO aggravates heart disorders, impairs oxygen carrying capacity of blood and is very fatal in large dosage. NOx cause respiratory problems. HC causes eye irritation, cough and drowsiness [6-8].

These pollutants also have adverse effect on environment. SO2 and NOx are the main cause of acidification and acid rain. Ozone depletion is caused by methane, CO, CO2, etc. [9, 10]. Biofuels on contrary are relatively clean and their emissions are quite low. So, they have been viewed as a potential alternative to petroleum based fuels.

B. Biofuels for automobile sector

Automobile sector contributes a major share in consumption of fossil fuels and also the major contributor to environment degradation. Replacing petroleum fuels by biofuels in automobile sector can help to reduce pollution and help to tackle the fuel crisis.

A variety of Biofuels are available but biodiesel and bio-ethanol are considered the main Biofuels. Biodiesels can be directly produced from vegetable oils, edible oils, vegetable oil waste, animal fat, and crops like Jatropha [11-14]. Bio-ethanol can be derived from a number of crops including wheat, corn, sugarcane, etc. Ethanol is produced through fermentation of sugar derived from cellulosic biomass [15]. Due to the oil crisis there has been an increase in interest in producing fuels from biomass. Biofuels can be manufactured from different sources and through different processes; [12] Figure 1 shows the overview of different conversion processes to produce Biofuels from different sources.

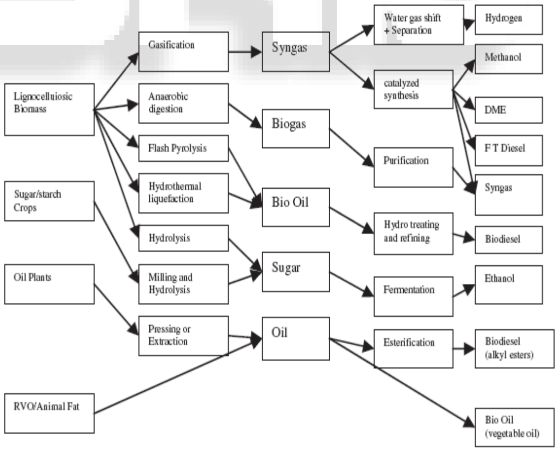

Fig. 1: Overview of conversion processes of Biofuels.

Before any alternative fuel is to be used in existing systems the following factors need to be taken care of:

- The extent of modifications that need to be done in the existing hardware to make it compatible with the alternative fuel, extensive modification involve huge capital which makes it difficult to implement.
- Investment cost: Cost is incurred in the development of infrastructure to process the alternative fuels. If infrastructure cost required is high then it may act as a constraint.
- Environmental compatibility: The alternative fuel should be environment friendly and

compatible to environment as compared to the conventional fuels. If the new fuel causes more pollution then it will be unacceptable as fuel.

– Maintenance and other additional costs such as routine maintenance, equipment wear and lubricating oil life should be low. Excessive additional cost will not be accepted by users and fuel will not be accepted.

Due to various benefits of Biofuels, developed and developing nations are showing interest in Biofuels. European Union has committed to promote the use of Biofuels as a substitute for mineral based fuels in transport or automobile sector [15]. In 2010, Biofuel production reached 105 billion liters, up 17% from 2009, [16] and now the Biofuels provided 2.7% of the world's road transport fuel. In 2010, the world ethanol production reached 86 billion liters. US along with Brazil are the world's largest producers, accounting together for 90% of total world production. The European Union, accounts for 53% of all biodiesel production in 2010.[16] In 2011, 31 countries made mandatory to blend Biofuels with conventional fuels to be used in transport sector.[17] By 2050, The International Energy Agency aims that Biofuels will meet more than 25% of the world demand as fuel in transportation sector.[18]

II. BIODIESEL: A BIOFUEL

An Biodiesel is derived from biomass sources like vegetable oils, animal fats, crops and plants like Jatropha. Biodiesel is produced mainly from vegetable oils like sunflower oil, soybean oil, etc by transesterification of triacylglycerols. Due to economic and social reasons it is necessary to replace edible oils by low cost and reliable feedstock for the production of biodiesels. These include non-edible plant oils, waste fry oils, etc. Currently, edible oils are the main resources for the production of biodiesel (more than 95%) [19].

Chemically, biodiesels are the mixture of fatty acid alkyl esters (FAAEs) and most often the methyl or ethyl esters obtained by the alcoholysis of triacylglycerols, obtained from vegetable oil and animal fats. In the reversible and consecutive alcoholysis reaction, one mole of acylglycerols reacts with one mole of alcohol and one mole of ester is formed at every step in the absence or presence of a catalyst. Alcoholysis of vegetable oil can be catalyzed using chemical (acids, bases) or by enzyme. Non-catalytic alcoholysis reactions occur at higher temperatures and pressures and still do not have any practical application.

A. Types of feedstock for biodiesel production

Feed stocks for biodiesel production can be traditionally categorized into the following main groups [20]: vegetable oils (edible and non-edible), animal fats and waste cooking oils. Additionally, oils derived from algae have been emerging in recent years as the fourth category of growing interest because they have high oil content and rapid production of biomass [21, 22].

Different kinds of feedstock used in different countries for biodiesel production depending upon climatic conditions and soil are rapeseed oil in Canada, sunflower oil in Europe, soybean oil in US, palm oil in Southeast Asia, coconut oil in Philippines, etc. However, the rapidly growing world population and extensive human consumption of edible oils can cause significant problems, for instance, starvation in developing countries. Therefore, non-edible plant oils become very promising alternative feedstock for biodiesel production because of large demand for edible oils as food, the higher prices of edible oils than that of fossil fuels and the lower cost of non-edible oil plant cultivation. However, there will always be a competition between edible and non-edible oily plants for land available.

There are many plants that can produce non-edible oils. The advantages of non-edible oils as diesel fuel are liquid nature portability, renewability, lower sulfur and aromatic contents and biodegradability, while their disadvantages are higher viscosity, lower volatility and higher percentage of carbon residue as well as reactivity of unsaturated hydrocarbon chains [24]. Animal fats such as chicken fat, white grease and yellow can be used for conversion into biodiesel. However, there is a limited amount of animal fats available, so they can't meet the world's fuel requirements. Animal fats also create problems during the biodiesel production since they became solid wax at room temperature [25]. Waste cooking oils have a great potential and a good choice as feedstock for biodiesel production because they are either priceless or cheaper than virgin vegetable oils (2–3 times) [25]. The transesterification process of waste cooking oils into alkyl esters reduces the molecular weight to one-third, the viscosity by about one-seventh and the flash point slightly, whereas the pour point is considerably increased [25]. But some issues related to the waste cooking oils are, they may be contaminated by from the cooking process (polymers, FFAs, etc.) and their conversion to biodiesel is complicated. Many review papers are related to the use of waste cooking oils as feedstocks for biodiesel production [26–28].

The amounts of oily crops, both edible and non-edible, animal fats and waste cooking oils are limited, so it is unlikely to provide worldwide biodiesel production demand. The search for other renewable sources is needed to provide the required amount of oily feedstock. In recent years a high interest has arisen towards producing biodiesel from microalgae. The advantages of microalgae using for biodiesel production are: much higher biomass productivities than land plants, some species can accumulate up to 20–50%. And no agricultural land is required to grow the biomass and they required only sunlight and a few simple and cheap nutrients [25]. Various oils extracted from seeds or kernels of non-edible crops are potential feedstock for biodiesel production. The important non-edible oil plants are jatropha, tobacco, mahua , neem , sea mango , castor , cotton , etc. [25]. Table 1 presents a summary on the oily plants and the oil contents of their seeds or kernels based on literature survey [25]. Only several, most important and most frequently used non-edible oils were selected for further discussion.

Table. 1: Oil content in seeds and kernels of some non-edible plants.

Botanical Name	Local Name	Oil content, %	
		Seed, wt.%	Kernel, wt.%
Jatropha Curcas	Jatropha, Ratanjyot	20–60	40–60
Pongamia Pinnata	Karanja, Pungam	25–50	30–50
Azadirachta Indica	Neem	20–30	25–45
Madhuca Indica	Mahua	35–50	50

Schleichera Triguga	Kusum	10.65	
Ricinus Communis	Castor	45–50	
Linum Usitatissimum	Linseed	35–45	
Cerbera Odollam (Cerbera Manghas)	Sea Mango	54	6.4
Gossypium sp.	Cotton	17–25	
Nicotiana Tabaccum	Tobacco	36–41	17
Argemone Mexicana	Mexican Prickly Poppy	22–36	
Hevea Brasiliensis	Rubber Tree	40–60	40–50
Simmondsia Chinensis	Jojoba	45–55	
Thevetia Peruviana	Yellow Oleander	8.41	67
Moringa Oleifera	Moringa	33–41	2.9
Thlaspi Arvense	Field Pennycress	20–36	
Datura Stramonium		10.3–23.2	

Jatropha plant is one of the most promising potential oil sources for biodiesel production in South-East Asia, Central and South America, India and Africa. Today, it is the major feedstock for production of biodiesel in developing countries like India, where the annual production is about 15,000 t [25]. It can grow almost any-where, on waste, sandy and saline soils, under different climatic conditions as well as under low or high rainfall and frost. Jatropha oil is toxic to people and animals, this is the main drawback of jatropha oil [25]. Castor plant is easily grown as a weed and has similar ecological requirements as jatropha. It is grown in India, China, Brazil, and Thailand. India produces about 0.73 Mt yearly, which is 60% of the world castor production [12]. Castor oil is has a viscosity up to 7-times higher than that of other vegetable oils. The high viscosity of crude castor oil is a problem for its direct use as a fuel.

B. Production and refining of Biodiesel

Vegetable oils can be converted into biofuel using four ways: blending, micro-emulsions, pyrolysis and transesterification [24].

Reversible transesterification reactions are the most common method of converting oils into biodiesel and the most promising solution of the high viscosity oil problem. The main factors affecting transesterification reaction and produced esters yield are: the molar ratio of alcohol:oil, type of alcohol, type and amount of catalyst, reaction temperature, pressure and time, mixing intensity as well as the contents of water in oils.

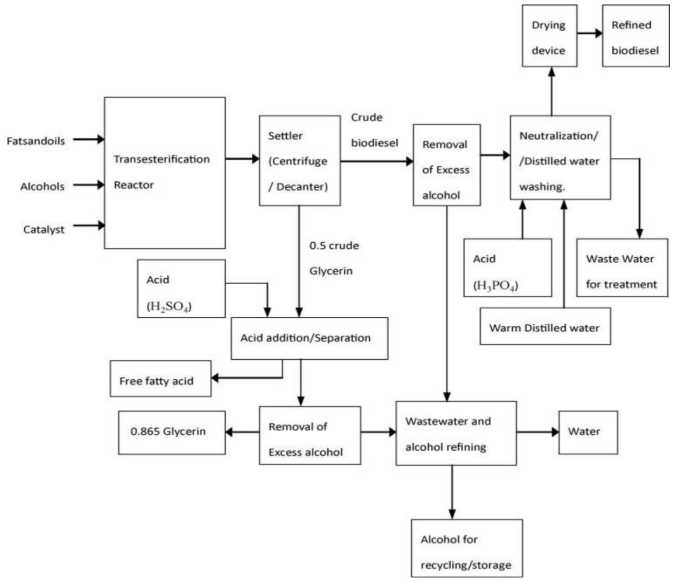

Fig. 2: Conventional biodiesel production and purification.

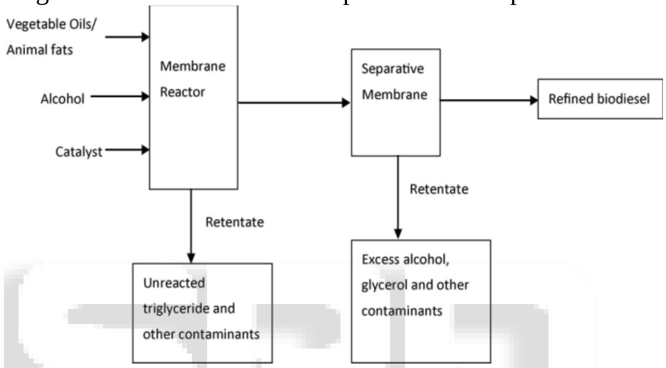

Fig. 3: Biodiesel production and purification using membrane technology.

C. Transesterification methods for modification of non-edible oils into biodiesel

The transesterification reaction can be non-catalyzed or acid catalyzed, base catalyzed or an enzyme catalyzed. Depending on the solubility of the chemical catalyst in the reaction mixture, transesterification reaction can be homogeneously or heterogeneously catalyzed. These reactions can be accomplished as one-step (base or acid) or two-step (acid/base) processes, depending on the content of FFA. According to the literature study, the catalyst loading, the alcohol:oil molar ratio and their interactions have the greatest impact on the yield, while the effects of the reaction temperature and the interaction temperature-catalyst loading were not significant[25].

Of several possible methods for biodiesel production from non-edible oils, their transesterification reaction with an alcohol in the presence of a catalyst is the most suitable method. Both one- and two-step processes of homogeneously and hetero-geneously catalyzed alcoholysis of non-edible oils are used today in the biodiesel synthesis. In the case of one-step processes, the choice between base and acid catalysts mainly depends on the FFA content (or acid value) in the non-edible oil. Base catalysts are preferable in the case of non-edible oils with a lower FFA content, while acid catalysts are suitable to the oils having a high amount of FFAs due to the ability of acid catalyst to simultaneously catalyze esterification and alcoholysis reaction. Two-step (acid/base) processes, employed when non-edible oils have a high FFA content, are an effective method to obtain a high biodiesel yield within a short reaction time. Sometimes, the modified catalysts with dual basic and acidic sites or the mixture of acid and base catalysts are employed with the same goal. The use of solid catalysts instead of homogeneous ones is more desired for many reasons such as reduced environmental pollution and higher qualities of biodiesel and glycerol. However, a completely heterogeneous two-step process has not been developed yet.

The use of immobilized lipases and supercritical conditions for transesterification of non-edible oils are currently among the most promising methods for biodiesel production. Lipases are especially suitable because they can catalyze simultaneously both TAG alco-holysis and FFA esterification. The carrying out in non-aqueous environments, easy recovery of glycerol and the use of feedstock with high FFA content are also the advantages of applying enzymes for biodiesel synthesis from non-edible oils over the other meth-ods. However, the relatively high price of lipases at present is their main drawback for their use on the commercial scale. Compared to conventional methods, the transesterification reaction rate under supercritical conditions is higher, the reaction time is shorter, sep-aration and purification of biodiesel are simply, there is no soap formation and no waste generation from catalyst separation and absence of catalyst makes the glycerol recovery easier.

The use of statistical methods, providing the interactions between variables optimizing the process conditions and allowing better knowledge of the process, contributes to the development of economically efficient processes of biodiesel production based on non-edible plant oils. Mathematical models describing the reaction rate are necessary for understanding the fundamental transester-ification kinetics for the reactor design and process scale-up. Not requiring complex computation, simple kinetic models are favor-able when fitted well the experimental data. Several different novel methods have been used in the last decade to improve the biodiesel production from non-edible oils. These methods such as the appli-cation of in situ transesterification processes, ultrasonic irradiation, microwave heating and co-solvent reduce processing time and energy consumption and enhance the ester yield.

III. BIODIESEL AS FUEL IN I.C. ENGINES

The continuous increasing demand for energy and the diminishing petroleum resources has led us to find alternative fuels that are renewable and sustainable. Biodiesel is one of the best alternative fuels. It is the best substitute for petro-diesel and also most advantageous over petro-diesel for its environmental friendliness.

Biodiesel as an alternative to diesel fuel could only be successfully used in compression-ignition diesel engines, if its physical and chemical properties conform to the international standard specifications of biodiesel. Biodiesel fuels are characterized by their cetane number, density, viscosity, cloud and pour points, flash point, copper corrosion, ash content, distillation range, sulfur content, carbon residue, acid value, free glycerine content, total glycerine content and higher heating value, etc. The relatively higher flash point of biodiesel to petro-diesel makes it a safer fuel to use, handle and store. [29]

A. Physicochemical properties of biodiesel fuels

The physicochemical properties of biodiesel are very similar to petroleum based diesel. The viscosity is a very important property of biodiesel fuels since it effects the operation of fuel injection equipment. Also the higher viscosity leads to improper atomization of fuel which affects engine performance and combustion. However the lower the viscosity of the biodiesel, the easier it is to pump, atomizes and achieves finer droplets. Also viscosity is a measure of fuel stickiness, better viscosity values inhibit atomization of fuel in the ignition chamber, and poor values hamper the engine lubrication effects. So, the viscosity values of the biodiesel must be kept within the stipulation range of international standard specification. Transesterification reaction converts triglycerides into methyl or ethyl esters and reduces the molecular weight to one third that of the triglyceride and decreases the viscosity of vegetable oils by a factor of about eight [29]. The viscosities of biodiesel fuel from animal fats such as lard and tallow show the same trends as temperatures, higher than the soybean and rapeseed biodiesel fuels. Virgin and waste vegetable oils have viscosity much higher than that of common diesel fuels and this requires major diesel engines modifications. It has been reported that the burning of vegetable oils in diesel engines results in the formation of unwanted materials such as acrolein and organic acid [29]. These materials have significant negative effects on the performance and longitudinal engine durability. However vegetable oils can be converted into their fatty acid methyl esters by transesterification reaction and can be convertibly used as fuels for diesel engine applications without major modifications [26]. Table 2 summarizes the physicochemical properties of different biodiesel fuels [29].

Table. 2: Physicochemical properties of biodiesel fuels.

Vegetable oil methyl ester	Kinematic viscosity (mm^2/s)	Cetane number	Lower heating value (MJ/l)	Cloud point (8C)	Flash point (8C)	Density (g/l)	Sulfur (wt.%)
Peanut	4.9	(37.8 8C)	54	33.6	5	176	0.883
Soybean	4.5	(37.8 8C)	45	33.5	1	178	0.885
Soybean	4.0	(40 8C)	45.7–56	32.7	–	–	0.880 (15 8C)
Babassu	3.6	(37.8 8C)	63	31.8	4	127	0.879
Palm	5.7	(37.8 8C)	62	33.5	13	164	0.880
Palm	4.3–4.5(40 8C)	64.3–70	32.4	–	–	0.872–0.877 (15 8C)	–
Sunflower	4.6	(37.8 8C)	49	33.5	1	183	0.860

Tallow	–		–	–	12	96	–
Rapessed	4.2	(40 8C)	51–59.7	32.8	–	–	0.882 (15 8C)
Used Rapeseed	9.48 (30 8C)	53	36.7	–	192	0.895	0.002
Used Corn Oil	6.23 (30 8C)	63.9	42.3	–	166	0.884	0.0013
Diesel Oil	12–3.5	(40 8C)	51	35.5	–	–	0.830–0.840 (15 8C)

B. Biodegradability of biodiesel

Biodegradable nature of biodiesel is seen to be a solution for waste accumulation leading to environmental pollution. It can be concluded from literature study that biodiesel is non-toxic and degrades about four times faster than petro-diesel [29]. Also its oxygen content improves the biodegradation process. From the literature study it can be stated that under either aerobic or anaerobic prevailing conditions the most important part of biodiesel is degraded within 21–28 days [29].

C. Higher lubricity

Biodiesels have improved lubrication characteristics. Lubricity results of biodiesel and petro-diesel using industry test methods indicate that there is a marked improvement in lubricity when biodiesel is added to conventional diesel fuel [24, 29]. This lubrication property help in improving the fuel injectors and fuel pumps lubrication capacity. It has been observed that the biodiesels reduced the long term engine wear in test diesel engines to less than half of what was observed in engines running on current low sulfur diesel fuel [29].

D. Stability of biodiesel

Biodiesels have low oxidation stability, this leads to the oxidation and polymerization of biodiesel fuel during combustion and storage. These problems lead biodiesel fuel to become acidic, form un-dissolvable gum and sediments that can clog fuel filters. The main reason for oxidation and polymerization is the presence of unsaturated fatty acid chains and the double bond in the parent molecule, which immediately react with the oxygen. This oxidation process of biodiesel is effected by several factors including; temperature, light, extraneous materials, peroxides, contact area between biodiesel and air. One of the methods of improving biodiesel stability against oxidation is the addition of antioxidants deliberately or modification of the fatty esters [29].

E. Lower emissions of biodiesel

Vehicular emission contributes a major part in the total emissions. The use of millions of vehicles across the world generates a lot of gaseous emissions, hence polluting the environment. These emissions include green house gases like CO_2, CO, NO_x, which are attributed to the cause global warming, climatic changes and environmental. Biodiesels are relatively cleaner fuel and helps in controlling emissions. [29] The commercial biodiesel fuel has significantly reduced exhaust emissions 75–83% compared to petro-diesels. It has been reported that combustion of neat biodiesel decreases carbon monoxide (CO) emissions by 46.7%, particulate matter emissions by 66.7% and unburned hydrocarbons by 45.2%. In addition, biodiesels are non-toxic, making it safer to be used in sensitive regions like marine bases, etc where leakage can be lethal.

IV. Advantages of Biodiesel

The application of biodiesel to our diesel engines for daily activities is advantageous for its environmental friendliness over petro-diesel. The main advantages of using biodiesel is that it is biodegradable, can be used without modifying existing engines, and produces less harmful gas emissions such as sulfur oxide. Biodiesel reduces net carbon-dioxide emissions by 78% on a life-cycle basis when compared to conventional diesel fuel. Puppan have discussed the advantages of biofuels over fossil fuels to be: (a) availability of renewable sources; (b) representing CO2 cycle in combustion; (c) environmentally friendly; and (d) biodegrad-able and sustainable. Other advantages of biodiesel are as follows: portability, ready availability, lower sulfur and aromatic content, and high combustion characteristics.

Table. 3: Advantages of biodiesel fuels produced from different non-edible oils.

Oil plant	Fuel advantages
Jatropha	Lower PM emission, higher compression ratio associated with higher injection pressure, higher diffusion Combustion.
Karanja	Lower NOx emission
Mahua	Lower CO, HC, NOx emissions, reduced smoke number
Rubber	Lower smoke emission
Neem	Lower CO, NOx and smoke emissions

PM – particulate matter, NOx – nitrogen oxides,
CO – carbon monoxide, HC – hydro carbon

V. APPLICATION OF BIODIESELS IN DIESEL ENGINES

Being a clean fuel derived from natural, renewable and sustainable sources such as vegetable oils, waste cooking oils and animal fats, global focus is on biodiesels to substitute petro-diesel. Biodiesel have physical and chemical properties similar to petro-diesel fuels and thus can easily be used in diesel engines without modification in hardware. Use of biodiesels increase the engine performance and lowers green house gas emissions. The lowering of gas emissions is the biggest advantage of using biodiesel fuel on diesel engines.

Currently biodiesel is compatible in blended form with petro-diesel in the ratio 20 (biodiesel): 80 (mineral diesel) to be used in engines without any modification in engine.

A. Performance of biodiesel

Biodiesels contains approximately 10% oxygen by weight, this oxygen improves the efficiency of combustion, but it slightly increases the apparent fuel consumption rate. Based on the literature study, it can be stated that the compression engine power output of the biodiesel is similar to that of diesel fuel, but can cause long-term durability problems due to effects of carbonization. It can also be stated that use of biodiesel in diesel engine results in a slight reduction in brake power and a slight increase in fuel consumption. However, biodiesels have better lubricating properties petro- diesel, which may result in increased engine life. The exhaust emission of the biodiesel is also lower than the neat diesel. Biodiesel fuel is environmentally friendly, because biodiesel does not produce SOx and also there is no increase in CO2 emission at global level [25, 29].

Usta conducted experiments using biodiesel from tobacco seed oil He conducted experiment on several experimental blends with diesel fuel in an indirect injection diesel engine operating at 1500 and 3000 rpm. Maximum values of torque and power were recorded with a 17.5% blend, inspite of reduced heating value of biodiesel. It was found that there was an increase in torque and power.

B. Biodiesel higher combustion efficiency

The oxygen content of biodiesel improves and facilitates the combustion process and decreases its oxidation potential. Because of this, the combustion efficiency of biodiesel is higher than that of petro-diesel.

VI. Economical Feasibity of Biodiesel

Currently, the cost of producing biodiesel from edible oils is expensive than petroleum-based diesel fuel. This is due to the relatively high costs of vegetable oils (about 1.5 to two times the cost of diesel). Thus, methyl esters produced from vegetable oils cannot compete economically with petro-diesel unless grants are provided by government. The cost of biodiesel can be reduced if we consider non-edible oils and used-frying oils for biodiesel production. The non-edible oils such as babassu, Jatropha, neem etc. are cheaper compared to edible oils and are easily available in many parts of the world. Several nations including Germany, Belgium, Austria, USA, Japan and India discard used frying oils. But, if this oil can be used for making biodiesel, it will help to reduce the cost of biodiesels and help avoid sewerage system problems and induce the recycling of resources.

Currently, pure biodiesel (100%) sells for about $2–$2.50 per gallon. A B-20 mix of 20% biodiesel and 80% diesel will cost about 15–20B more per gallon over the cost of mineral diesel [25].

VII. Conclusion

With the depleting reserves of crude oil and increased demand of energy, it has become necessary to shift our focus toward alternative fuels which are renewable, clean and that can be enforced into use in existing systems with least changes in hardware. And, biofuels are one good alternative, being clean fuel and having their extraction sources renewables. Biodiesel is biofuel which can prove to be a good alternative for diesel. Biodiesels are compatible with existing engines and give a satisfactory performance. Though the production of biodiesel today is costly but in the future they stand a high potential as major fuel in transportation sector. Hence, biodiesel may be considered as diesel fuel substitutes.

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