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Economics, Formulation Techniques and Properties of Biodiesel: A Review

[1]Mathur Y. B., [2]Poonia M. P. and [3]Jethoo A. S.

[1]Government Polytechnic College, Bikaner (India)
[2] Department of Mechanical Engineering, Malaviya National Institute of Technology, Jaipur (India)
[3]Department of Civil Engineering, Malaviya National Institute of Technology, Jaipur (India)

Corresponding author: asjethoo@gmail.com

Abstract:
Due to limited resources of fossil fuels and the environmental concern, there has been improved focus on vegetable oils and biodiesel fuel as an alternative source of energy. Governments across the world are injecting huge amount of money into the development of this sector in an attempt to reduce their dependency on fossil fuels. However, the alternative diesel fuels must be technically and environmentally acceptable, and economically competitive. From the viewpoint of these requirements, triglycerides and their derivatives may be considered as viable alternatives for diesel fuels. One of the main problems of vegetable oil use in diesel engine is their higher kinematic viscosity due to which problems occur in pumping and atomization, ring-sticking, carbon deposits on the piston, cylinder head, ring grooves, etc. Hence, straight vegetable oils have to be modified to bring their combustion related properties closer to diesel. This fuel modification is mainly aimed at reducing the viscosity in order to get rid of flow/ atomization related problems. In the present work, efforts have been made to understand and compile the outcome of researches on economics of biodiesel fuel, issues associated with use of vegetable oil in diesel engine by using some well known techniques available to overcome higher viscosity related problems for making them compatible with the hydrocarbon-based diesel and biodiesel fuel properties.

Keywords: Biodiesel, Blending, Micro-Emulsion, Pyrolysis, Transesterification, Vegetable Oil

1.0 Introduction:
The conventional fossil fuel resources are depleting continuously at an alarming rate resulting in increasing dependency on renewable sources of energy. Fossil fuel combustion has also degraded the environment and earth has become a subtle place for survival of mankind. Among the various renewable energy options, biodiesel from seed oil crops have a great potential for meeting the future increasing demands of petroleum and its products. Biodiesel is gaining worldwide acceptance as an environment-friendly solution to the energy and environment degradation crisis. It is an accepted option for achieving energy security, reduction in imports, rural employment, and for improving the agricultural economy (Parikh, 2005). Biodiesel results in substantial reduction of un-burnt hydrocarbons, carbon monoxide, and particulate matter (Srivastava and Prasad, 2000; Banapurmath *et al*., 2008; Baiju *et al*., 2009; Beepanraj and Lawrence, 2011). Hence at this particular juncture, much emphasis has to be given for exploitation of sustainable, long lasting, renewable sources of energy.

1.1 Historical Background of Biodiesel:
Dr. Rudolf Diesel, who invented the first Diesel Engine in 1895, used only biofuel in his engine. His visionary statement was "*The use of vegetable oils for engine fuel may seem insignificant today, but such oils may become in course of time, as important as petroleum and coal tar products of the present time*". The above prediction is becoming true today as more and more biodiesel is being used all over the world (Hossain and Davies, 2010; Dileep *et al*., 2007). Despite the widespread use of fossil petroleum-derived diesel fuels, interest in vegetable oils as fuel for internal combustion engines was reported in several countries during the 1920s and 1930s. The use of biodiesel was recognized much later and became technically relevant only after the energy crisis in the year 1973 and afterwards. More recently, in 1977, Brazilian scientist Expedito Parente invented and submitted first industrial process for the production of biodiesel for patent (Gerhard, 2005).

1.2 Feedstock for Biodiesel Production:
Biodiesel, derived from the oils and fats of plants like Soybean, Cotton, Sunflower, Jojoba, Rapeseed, Canola, Jatropha Curcas, Thumba and animal fat by transesterification process can be used as a complete substitute or an additive to diesel up to maximum possible extent (Sahoo and Das, 2009; Xuezheng *et al*., 2009). Owing to their availability, various oils have been in use in different countries as feedstock for biodiesel production. The

vegetable oils used for biodiesel are mainly Rapeseed or Sunflower oil in Europe, the USA and Canada uses Soyabean, Rapeseed, other waste oils and fats; frying oil and animal fat is the chosen option in Ireland; Castor oil and Soyabean oil is used in Brazil; Coconut oil is preferred in Malaysia and Philippines; Palm oil in Thailand, Malaysia, Indonesia and the Philippines; Cotton Seed oil in Greece; Linseed and Olive oil in Spain; Jatropha and Karanja in used in India, Nicaragua and Africa to produce biodiesel (Frank *et al*., 2009; Altin *et al*., 2001, Arjun *et al*., 2008). Several other non-edible plants such as Neem (*Azadirachta Indica*), Meswak (*Salvadora Species*), Mahua (*Madhuca indica*), Rubber (*Hevea Species*), Castor (*Ricinus communis*), Diploknema Butracea, Garcinia Species and Thumba (*Citrullus colocynthis*) can also be used for producing biofuels in India (Barnwal and Sharma, 2005; Mohibbe *et al*., 2005; Augustus *et al*., 2003).

1.3 Biodiesel as Fuel for Diesel Engines:

Biodiesel, the renewable liquid fuel produced from biological raw material is a good substitute for petroleum diesel. Biodiesel contains no petroleum, but it can be blended at any level with petroleum diesel to create a biodiesel blend. It can be used in compression ignition engines with little or no modifications. As an alternative fuel, biodiesel can provide almost same power output as of diesel (Gumus and Kasifoglu, 2010; Zafer and Mevlut, 2008; Christian *et al*., 2009, Pall *et al*., 2009). The conversion process of vegetable oil into biodiesel is quite efficient, in nearly one-to-one ratio. Among the many advantages of biodiesel fuel which includes its safe use in all conventional diesel engines, offers almost the same performance and engine durability as conventional diesel fuel, non-toxic and reduces tailpipe emissions, visible black smoke and noxious fumes and odours and higher cetane number which improve the combustion characteristics. However NO_X emission of biodiesel increases because of rapid combustion and other fuel characteristics. Diesel fuel blends with biodiesel have superior lubricating properties with reduced wear and tear on the diesel engine components. The most common diesel fuel blends are B10 containing 10 percent biodiesel and B20 containing 20 percent biodiesel (Sirisomboon *et al*., 2007; Nag *et al*., 1995).

Lot of research work is being done to analyse the engine combustion and performance using straight vegetable oils as well as biodiesel but fewer researchers have analysed and compiled the economics of biodiesel, its formulation techniques and fuel related properties in recent past. In this paper, a detail survey of literature is therefore undertaken to comprehensively review the different recently published research papers on economical viability, conversion of straight vegetable oil into biodiesel and combustion related properties of biodiesel fuel for their utilization in diesel engines.

2.0 Economics of Biodiesel:

Economical feasibility of biodiesel depends on the price of the crude petroleum and the cost of transporting diesel through long distances. It is certain that the cost of crude petroleum is bound to increase due to increase in its intensive demand, limited supply, strict regulations on the aromatics and sulphur contents in diesel fuels which will result in higher cost of production of diesel fuels as removal of aromatics from the distillate fractions requires capital-intensive processing equipments. The major economic factor to consider for input costs of biodiesel production is the feedstock (price of seed, seed collection and oil extraction, transport of seed and oil), which is about 75–80% of the total operating cost. Other important cost related factors are labour, methanol and catalyst for biodiesel conversion for straight vegetable oil, which must be added to the feedstock. Cost recovery will be through sale of oil cake and of glycerol (Mulugetta, 2009). The volatile oil prices due to increased demand have necessitated for continuous research and development into the biodiesel sector so as to increase the production of biodiesel of suitable quality and at reasonable price so that it can compete with diesel fuel. Between 2001 and 2006 alone, the global annual production of biodiesel grew up by 43% (Victor *et al*., 2010).

India has rich and abundant forest resources with a wide range of plants and oilseeds. The production of these oilseeds can be stepped up many folds for producing diesel fuels. Economical feasibility of biodiesel depends on the price of the crude petroleum and the cost of transporting diesel to long distances to remote markets in India. Further, the strict regulations on the aromatics and sulphur contents in diesel fuels will result in higher cost of production of conventional diesel fuels. The reason for high biodiesel prices are the limited availability of biodiesel feedstocks. The biodiesel program in any country has a time lag between policy planning and actual implementation and hence the introduction could be gradual, gaining the maturity only after 4-5 years. This is especially applicable to India where biodiesel is proposed to be made from non-edible oils. Presently, the availability of these oils is very limited and the price of such oils is higher than petro-diesel. For successful launch of biodiesel availability of oil on large scale has to been assured at reasonable price and abundance availability of biodiesel feedstocks. Palm oil and refined soybean oil are the main options that are traded internationally. The costs for biodiesel production from palm oil, soybean oil and Jatropha oil are estimated about Rs 45.0 /litre, Rs. 44.0/litre and Rs 39.0 /litre, respectively (Demirbas, 2009). Industry sources in India, estimate current biodiesel finished production costs at anywhere between Rs 32.0 to 45.0 per litre (Joseph, 2006; Singh, 2009).

The Ministry of Petroleum and Natural Gas announced the biodiesel purchase policy in October 2005. The Policy provided for the purchase of biodiesel at 20 specified purchase centres in 12 different states in India at Rs 25.0 /litre (inclusive of taxes/duties) from January 2006. This price was subject to review every six months. The last price revision of biodiesel was done in December 2006, when it was fixed at Rs 26.50/litre (Altenburg *et al*., 2008). The Indian government also announced, on 23rd December 2009, attractive incentives to encourage biofuels plantation in wastelands and to utilise indigenous bio-mass feed stocks for production of biofuels. It addresses the issues across the entire value chain from plantations, and processing to marketing of biofuels. India's new policy on biofuels targets blending at least 20 percent biofuels in diesel and petrol by 2017. This implies that 13.38 million tons of biodiesel will be required. Detail economic analysis of vegetable oil based biofuels in Spain was done by Dorado *et al.* (2006). They identified that the price of the feedstock was one of the most significant factors. Also, glycerol was found to be a valuable by-product that could reduce the final manufacturing costs of the process up to 6.5% depending on the raw feedstock used. Some other researchers (Prueksakorn *et al.,* 2010; Hill *et al.,* 2006; Zhou and Thomson, 2009; Ben, 2009; Govindasamy *et al*., 2009; Wu *et al.,* 2009; Naoko *et al.,* 2009; Comporn and Shabbir, 2009; Huanguang *et al.,* 2010; Foidl *et al.,* 1996; Bona *et al.*, 1999) stated the possibilities of development of energy crops and biodiesel in Europe, Mexico, Japan, Thailand, China, and India.

3. Fuel Formulation Techniques:

One of the main problems of vegetable oil use in diesel engine is their higher kinematic viscosity because of heavier triglycerides and phospholipids, due to which problems occur in pumping and atomization, ring-sticking, carbon deposits on the piston, cylinder head, ring grooves, etc. Straight vegetable oils are not suitable as fuels for diesel engines; since they have to be modified to bring their combustion related properties closer to mineral diesel. This fuel modification is mainly aimed at reducing the viscosity in order to get rid of flow/ atomization related problems. Heating/ pyrolysis, dilution/ blending, micro-emulsification, and transesterification are some well known techniques available to overcome higher viscosity related issues associated with use of vegetable oil in diesel engine and to make them compatible with the hydrocarbon-based diesel fuels (Agarwal, 2007; Bajpai and Tyagi, 2006; Sharma, 2009).

The petro-diesel molecules are saturated and non-branched molecules with carbon atoms ranging between 12 and 19 whereas, Vegetable oils are usually triglycerides generally with a number of branched chains of different lengths and are the mixture of organic compounds ranging from simple straight chain compound to complex structure of proteins and fat-soluble vitamins. The typical molecular structure of vegetable oil molecule is shown in Figure 1, where R^1, R^2 and R^3 represent hydrocarbon chain of fatty acids. The chemical composition of different vegetable oils is presented in Table 1.

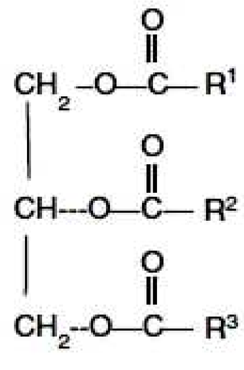


Figure 1: Molecular Structure of a Typical Vegetable Oil Molecule

Table 1: Fatty acid Composition of Some Vegetable Oils

Vegetable Oils	Fatty Acids Composition (%)									
	14:0	**16:0**	**18:0**	**18:1**	**18:2**	**18:3**	**20:0**	**22:0**	**22:1**	**24:0**
Jatropha	-	12-17	6.70	37-63	19-41	-	-	-	-	-
Karanja	-	3.7-7.9	2.4-8.9	44.5-71.3	10.8-18.3	-	-	-	-	1.1-3.5
Rapeseed	-	3	1	64	22	8	-	-	-	-
Neem	0.2-0.26	13.6-16.2	14.4-24.1	49.1-61.9	2.3-15.8	-	0.8-3.4	-	-	-
Sunflower	-	9	2	12	78	-		-	-	-
Soyabean	-	6-10	2-5	20-30	50-60	5-11	-	-	-	-
Corn	1-2	8-12	2-5	19-49	34-62	Traces	Traces	-	-	-
Peanut	-	11	2	48	32	1	1	2	-	1
Mahua		16-28.2	20-25.1	41-51	8.9-13.7	-	0-3.3	-	-	-
Rice Bran	0.4-0.6	11.7-16.7	1.7-2.5	39.2-43.7	26.5-35.1	-	0.4-0.6	-	-	0.4-0.9
Palm	1.5	43	5	40	10	-	0.5	-	-	-
Castor	-	-	2-3	3-5	3-5	80-90	-	-	-	-
Olive	-	9-10	2-3	73-84	10-12	Traces	-	-	-	-
Tallow	3-6	24-32	24-31	37-43	2-3	-	-	-		-

3.1 Heating/ Pyrolysis:

Heating/ Pyrolysis is the process in which high molecular weight compound breaks in to smaller compounds by means of heat with or without catalyst. Pyrolysis refers to a chemical change caused by the application of heat energy in the absence of air or oxygen. The liquid fractions of the thermally decomposed vegetable oils are likely to get converted into liquid oils. Many investigators have studied the Pyrolysis of triglycerides to obtain products suitable for diesel engines (Babu, 2008; Bridgwater, 2003). The Pyrolyzate oils have almost same viscosity, flash point, and pour point compared to diesel fuel with equivalent calorific value. The cetane number of the Pyrolyzate oil has been found to be lower. The Pyrolyzate oils from vegetable oils contain acceptable sulphur content, water and sediment and give acceptable copper corrosion values but unacceptable ash and carbon residue. Mechanisms for the thermal decomposition of triglycerides are likely to be complex because of many structures and multiplicity of possible reactions of mixed triglycerides (Manurung *et al.,* 2009).

3.2 Dilution/ Blending:

High viscosity fuels like vegetable oils can be mixed with low viscosity fuel like diesel to overcome overall viscosity. These blends can then be used as diesel engine fuels. Dilution of vegetable oils can be accomplished with a solvent, methanol or ethanol. Vegetable oil can be directly mixed with diesel and may be used to run diesel engines. Blending of vegetable oil with diesel have been experimented successfully by many researchers.

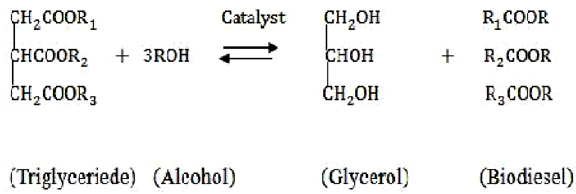
The dilution of Sunflower oil with diesel fuels in the ratio of 1:3 by volume has been studied and engine tests were carried out by Ziejewski *et al.* (1983). They concluded that the blend could not be recommended for long term use in the direct injection diesel engines due to density difference.

Pryor *et al.* (1983) had conducted the short term and long term performance tests with blends of vegetable oil with diesel. In short term performance test, crude-degummed Soybean oil and Soybean ethyl ester were found suitable substitutes for diesel fuel. A longer term evaluation of the engine when using 100% crude soybean oil was prematurely terminated severe injector chock led to decreases in power output and thermal efficiency. Parmanik (2003) studied the properties and use of Jatropha oil and diesel fuel blends in compression ignition engine. The heating value of the vegetable oil was comparable with ordinary diesel fuel and cetane number was slightly lower than diesel oil. He also studied the effect of blending Jatropha oil with diesel fuel in compression ignition engines. Significant improvement in engine performance was observed as compared to pure vegetable oil. The exhaust gas temperature was reduced due to reduced viscosity of the vegetable oil diesel blends. It was found that the fuel consumption was increase with a higher proportion of the Jatropha oil in the blends. Acceptable thermal efficiencies of the engine were obtained with blends containing up to 50% (by volume) of Jatropha oil.

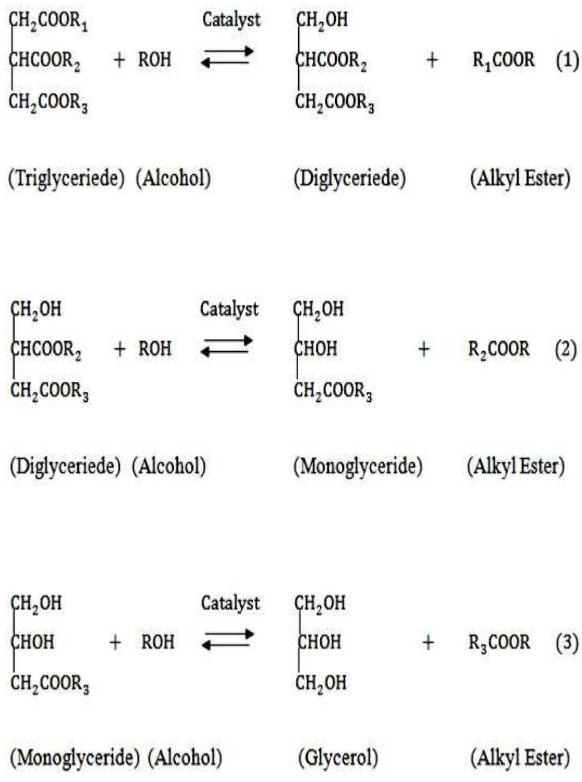
The tests were conducted by Forson *et al.*(2004) on a single-cylinder direct-injection engine operated on diesel fuel, Jatropha oil and blendes of diesel and Jatropha oil in proportions of 97.4%/ 2.6%; 80%/ 20%; and 50%/ 50% by volume. The test results showed that Jatropha oil can be conveniently used as a diesel substitute in a diesel engine. The test results further showed increases in brake thermal efficiency, brake power and reduction of specific fuel consumption for Jatropha oil and it blends with diesel.

3.3 Micro-Emulsification:
A micro-emulsion is a system consists of a liquid dispersed, with or without an emulsifier, in an immiscible liquid, usually in droplets smaller then colloidal size. Micro-emulsions are isotropic, clear, or translucent thermodynamically stable dispersions of oil, water, surfactant, and often a small amphiphilic molecule, called co-surfactant. The droplet diameters in micro-emulsions range from 100 to 1000 Å. A micro-emulsion can be made of vegetable oils with an ester and dispersant (co-solvent), or of vegetable oils with an alcohol and a surfactant and a cetane improver, with or without diesel fuels. Micro-emulsions, because of their alcohol content have lower volumetric heating values than diesel fuels, but the alcohols have high latent heat of vaporization and tend to cool the combustion chamber, which would reduce nozzle choking. A micro-emulsion of methanol with vegetable oils can perform nearly as well as diesel fuels. Ziejewski *et al.* (1984) showed that the engine performance were same for a micro-emulsion of 100 % sunflower oil and the 25 % blend of sunflower oil in diesel.

3.4 Transesterification Process:
The major problems associated with the straight vegetable oil operation in diesel engines are due to their high fuel viscosity and poor volatility. Transesterification of vegetable oils provides a significant reduction in viscosity, thereby enhancing the physical and chemical properties of vegetable oil to improve the engine performance (Tapanes *et al*., 2008). Methyl and ethyl esters of vegetable oils (called as biodiesel) revealed fuel properties similar to diesel. The transesterification process involves reacting triglycerides, present in vegetable oils with alcohols such as methanol or ethanol in the presence of a catalyst (usually sodium hydroxide) at about 70°C to give the ester and the by product, glycerine and water. It has been reported that the methyl and ethyl esters of vegetable oil can result in superior performance than neat vegetable oils. Biodiesel fuels naturally contain oxygen, which must be stabilized to avoid storage problems (Jon, 2005; Patil and Deng, 2009; Vivek and Gupta, 2004; Jha *et al*., 2007). The transesterification reaction is represented by the general equation



The base catalysed production of biodiesel, generally occur using the following steps:



The first step is the conversion of triglycerides to diglycerides, followed by the conversion of diglycerides to monoglycerides and of diglycerides to glycerol, yielding one methyl ester molecule from each glyceride at each step.

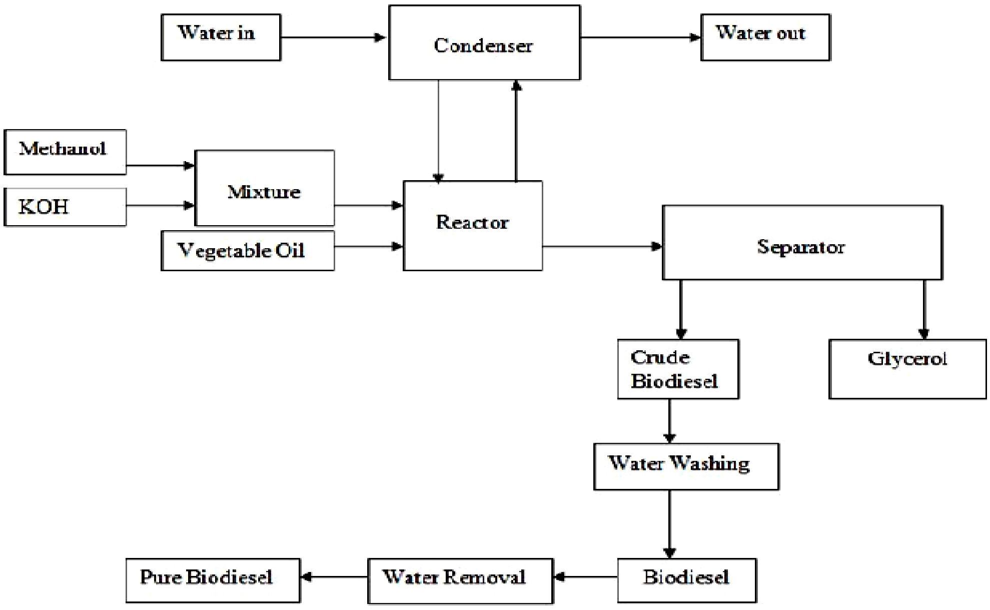


Figure 2: Transesterification Process for Biodiesel Production

Meher *et al.* (2006) studied the effects of catalyst concentration, alcohol/oil molar ratio, temperature, and rate of mixing on transesterification of Karanja oil with methanol. They found that the optimum reaction conditions for methanolysis of Karanja oil was 1% KOH as catalyst, MeOH/oil molar ratio 6:1, reaction temperature 65°C and rate of mixing was 360 rpm for a period of three hrs. The yield of methyl esters was found to be higher than 85% in fifteen minutes and reaction was almost complete in two hours with a yield of 97 %. With 12:1 molar ratio of NaOH/oil or higher, the reaction was completed within one hr. The reaction was incomplete with a low rate of stirring (180 rpm). Further in an optimization study, Meher *et al*. (2006) found that the yield of methyl ester from Karanja oil under the optimal condition was 97-98%.

Rathore and Madran (2008) studied the kinetics of transesterification of Karanja oil into its alkyl esters in supercritical methanol and ethanol without using any catalyst. The effect of molar ratio and reaction temperature on alkyl esters formation was investigated. A micro-emulsion of methanol with vegetable oils can perform nearly as well as diesel fuels. Darnoko and Cheryan (2000) reported experimental data on Palm oil kinetics. It was observed that the rate of alkali-catalyzed (KOH) transesterification in a batch reactor increased with temperature up to 60°C. Further increase in temperatures did not reduce the time to reach the maximum conversion.

The free fatty acid and moisture content in the starting material are the key parameters for determining the viability of the vegetable oil transesterification process. According to Freedman *et al.* (1984) the free fatty acid quantity should be lower than 1% to carry out the alkali catalysed reaction. In their study, they have observed that if the acid value was greater than 1, more NaOH was required to neutralize the free fatty acids. Water also caused soap formation, which consumed the catalyst and reduced catalyst efficiency. The resulting soaps caused an increase in viscosity, formation of gels and resulted into the separation of glycerol quite difficult. Ma *et al.* (1999) studied the effects of free fatty acids and water content in transesterification of beef tallow. The presence of water had more negative effect on transesterification than free fatty acids. They concluded that for best results, the water content and free fatty acids content in beef tallow should be kept below 0.06 % w/w and 0.5 % w/w respectively.

Zullaikah *et al.* (2005) had successfully made biodiesel from Rice Bran oil with high free fatty acids content. A two-step acid-catalyzed methanolysis process was employed for the efficient conversion of Rice Bran oil into fatty acid methyl esters. Hawash *et al.* (2009) studied the transesterification of Jatropha oil using supercritical methanol in the absence of catalyst under different temperature conditions. Ramadhas *et al.* (2004) reported the use of acid catalyst followed by alkali catalyst in a single process using Rubber seed oil with high free fatty acids content. The objective of this study was to develop a process for producing biodiesel from a low-cost feedstock like crude Rubber seed oil. Iso *et al.* (2001) have studied the transesterification by immobilized lipase in non- aqueous conditions. Noureddini *et al.* (2005) have investigated the biodiesel production by lipase catalyst. The time taken to get the 67 % yield of biodiesel was 72 hours at room temperature. However, the energy input was zero. The reaction time and the cost of lipase were hurdles to commercialize lipase processes.

Table 2: Fuel Related Properties of Biodiesel Produced From Different Vegetable Oils

Biodiesel	Kinematic viscosity (cSt, 40°C)	Density (kg/m^3)	Heating Value (MJ/kg)	Cloud point (°C)	Pour point (°C)	Flash point (°C)	Cetane Number	Carbon Residue (w/w)
Jatropha	5.65	879	38.5	13	-	175	50	-
Karanja	6.87	897	37.9	-	-1	187	49	0.05
Rapeseed	7.2	883	37.37	-	-12	-	51	-
Neem	15	882	38.5	-	-	180	47	-
Sunflower	4.6	868	40.58	1	-	183	45-52	-
Soyabean	4.5	872	39.76	1	-7	178	37-45	1.7
Coconut	3.36	866	36.1	-	-4	122	56	0.03
Peanut	4.9	883	-	5	-	176	54	-
Palm	5.7	880	-	13	-	164	62	-
Babassu	3.6	879	-	4	-	127	63	-
Thumba	3.83-5.86	883	39.37	.5	-	142	53	-
Tallow	-	-	-	12	9	96	--	-

4. Properties of Biodiesel:

Biodiesel is a better fuel than diesel fuel in terms of sulphur content, flash point, and aromatic content. The fuel characteristics of biodiesel are close to diesel fuels, and therefore biodiesel becomes a strong alternative to replace the diesel fuels (Demirbas, 2009). The conversion of triglycerides into methyl or ethyl esters through the transesterifcation process reduces the molecular weight to one-third that of the triglyceride reduces the viscosity by a factor of about eight and increases the volatility marginally. Biodiesel has viscosity close to diesel fuels. These esters contain 10 to 11% oxygen by weight, which may improve combustion as compared to hydrocarbon based diesel fuels in an engine (Ejaz and Younis, 2008). The cetane number of biodiesel is around 50 which are higher than diesel. The use of tertiary fatty amines and amides can be effective in enhancing the ignition quality of the diesel fuel without having any negative effect on its cold flow properties. Since the volatility increases marginally, the starting problem persists in cold conditions. Biodiesel has lower volumetric heating values (about 12%) than diesel fuels but has a high cetane number and flash point (Sylvain *et al.*, 2009; Achten *et al.*, 2008; Houfang *et al.*, 2009) Some of the desirable fuel properties of biodiesel derived from different vegetable oils are presented in Table 2.5.

5.0 Conclusions:

Many energy fuels are being recently investigated as potential substitutes for the current high-pollutant diesel fuel derived from diminishing commercial sources. In the past 15 years, biodiesel has progressed from the research stage to a full-production scale in many developed countries. Vegetable oil either from seasonal plant crops or from perennial forest trees origin, after being formulated, have been found suitable for utilization in diesel engines. Many traditional seed oils like Pongamia Glabra, Jatropha (Jatropha Curcas), Mallous Philippines, Garcinia Indica, Thumba, Karanja and Madhuca Indica etc. are available in the country, which can be exploited for biodiesel production purposes. Although biodiesel offers several advantages, including technical, environmental, and socio-economic, it has some disadvantages. Major disadvantages of biodiesel are higher viscosity, lower energy content, higher cloud point and pour point, marginal increase in nitrogen oxides (NO_X) emissions, lower engine speed and power, engine oil degradation, injector coking, engine compatibility, high price of biodiesel and higher engine wear. Important operating disadvantages of biodiesel in comparison with petro-diesel are cold start problems, the lower energy content, higher copper strip corrosion and fuel pumping difficulty. Some of the salient conclusions are drawn on the basis of available literature for economics of bio-diesel, its formulation techniques and combustion related properties:

1. The costs for biodiesel production from palm oil, soybean oil and Jatropha oil are estimated about Rs 45.0 /litre, Rs. 44.0/litre and Rs 39.0 /litre, respectively.
2. The major economic factor to consider for input costs of biodiesel production is the feedstock (price of seed, seed collection and oil extraction, transport of seed and oil), which is about 75-80% of the total operating cost.
3. Other important cost related factors are labor, methanol and catalyst for biodiesel conversion for straight vegetable oil, which must be added to the feedstock. Cost recovery will be through sale of oil, cake and of glycerol.
4. Mechanisms for the thermal decomposition (Pyrolysis) of for biodiesel production are likely to be complex because of many structures and multiplicity of possible reactions of mixed triglycerides.
5. Direct blending of vegetable oil with diesel could not be recommended for long term use in the direct injection diesel engines due to density difference.
6. A micro-emulsion of methanol with vegetable oils can perform nearly as well as diesel fuels.
7. Transesterification of vegetable oils provides a significant reduction in viscosity, thereby enhancing the physical and chemical properties of vegetable oil to improve the engine performance.
8. The fuel properties of biodiesel are close to diesel fuels, and therefore biodiesel becomes a strong alternative to replace the diesel fuel.

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