

BIODIESEL: AN ECO-FRIENDLY ALTERNATE FUEL FOR THE FUTURE – A REVIEW

by

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In today's society, researchers around the world are searching for ways to develop alternate forms of fuel. With the ever-rising fuel costs, developing alternate energy is a top priority. Biodiesel was developed to combat the high gas and oil prices. It is especially made for use in diesel cars and trucks. Biodiesel can be made from all natural foods that can produce oil. Oils such as vegetable, canola, peanut, rapeseed, palm, and olive oil can be used as bio diesel fuel. Virtually all oils that are used in the kitchens everyday can fuel automobiles. Biodiesel fuel is better for the environment because it burns cleaner and does not pollute the atmosphere. It is non-toxic and biodegradable, making it the perfect fuel. Many car manufacturers are realizing that the bio diesel automobile is becoming more popular, and are jumping on the bandwagon, by developing their own version of a biodiesel vehicle. They realize that the need for these vehicles will increase, and predict that they will be ready for the onslaught.

Diesel engines have superior fuel efficiencies, and hence they are predominantly used in commercial transportation and agricultural machinery. Due to the shortage of diesel fuel and its increasing costs, a need for an alternate source of fuel for diesel engines is imminent. This paper investigates the suitability of biodiesels as such an alternative with particular reference to automobiles. It reviews techniques used to produce biodiesel and provides a comprehensive analysis of the benefits of using biodiesel over other fuels.

Key words: *biodiesel, B20, B100, transesterification, flash point, performance, cetane number, economics*

Introduction

The fossil fuel resources are fast depleting, thus forcing an increase in oil prices globally and posing a threat to many oil importing countries. This situation needs immediate attention as oil consumption is ever increasing, thanks to industrialisation and motorisation of the whole world. Diesel fuel is largely consumed by the transportation sector. The diesel engine was originally developed with the intention of running on a wide-variety of fuels. Due to their superior fuel efficiency, diesel engines have found their way into most transportation systems and agricultural machines. Historically, the availability of large quantities of cheap petrodiesel led to its usage as the primary fuel for diesel engines. These conditions however, have changed over time and there is currently a shortage of cheap diesel fuels. Political instabilities in major oil-producing countries have worsened this situation, forcing an immediate search for an alternative source of fuel for diesel engines. This paper looks at biodiesels as a viable solution to this impending problem. Use of biodiesel in a conventional diesel engine results in substantial reduction in unburned hydrocarbons (UBHC), carbon monoxide (CO), particulate matters (PM), and oxides of nitrogen (NO_x).

The primary advantage of using biodiesel is that, it does not require any modification to the standard diesel engine. Other alternatives that require such modifications are not practical, since they are costly, and involve a huge effort to redesign the existing engines. The history of biodiesel began in the 1880s, when Rudolph Diesel designed a compression engine using peanut oil. R. Diesel desired to show that this was a far better method than the use of fossil fuels. This technique was present in diesel engines until around the 1920s. The manufacturers started to use petroleum fuels as an alternative measure, after this time. In 1912, R. Diesel said, "The use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in course of time as important as petroleum and the coal tar products of the present time" [1]. Rudolf Diesel's prediction is becoming true today with more and more biodiesel being used all over the world.

Biodiesel can be obtained from a variety of renewable sources such as vegetable oils and animal fats. Vegetable oils from crops such as soyabean, peanut, sunflower, rape, coconut, karanja, palm, cotton, mustard, jatropha, linseed, and coستر have been evaluated in many parts of the world in comparison with other non-edible oils. These sources can be obtained directly from agricultural feed stocks, or by recycling used oil such as cooking grease. The pure form of biodiesel is called as "neat biodiesel" (B100). It can also be blended with petrodiesel in various proportions (common form B20 *i. e.* 20% biodiesel and 80% petrodiesel). It can also be used as a sulfur-free lubricating fuel additive in smaller percentages (typically 2%).

The choice of fats and oils for producing biodiesel depends on local availability and affordability. Governmental decisions can also affect the choice of feedstock. Rapeseed oil is preferred in Western Europe, while the United States favors refined soybean oil as a feedstock. Although Brazil is the world's second-largest producer of soybeans, its government is fostering a castor oil-based biodiesel industry. The big palm oil producing countries in Southeast Asia, Malaysia and Indonesia, focus on palm kernel and palm seed oil. Both India and China have huge jatropha (physic nut) plantations under development. Recycled cooking oil is another important feedstock for China. The most important feedstocks by 2010 are expected to be soybean, rapeseed, and palm oils, in descending order. Jatropha and cottonseed oils will show higher growth rates.

Use of biodiesel is catching up all over the world especially in developed countries. In Malaysia, the tropical climate encourages production of biodiesel from palm oil [2]. The US is contributing 25% of the world's green house gas emissions from coal and oil, and about 70% of its oil consumption is from transportation. At present, USA uses 50 million gallons and European countries use 350 million gallons of biodiesel annually. Normally 20% of biodiesel is mixed with fossil diesel. France however uses 50% of biodiesel mixed with diesel fuel. In Zimbabwe, 4 million jatropha have been planted in 2000 hectares by the end of 1997. In Nicaragua, one million *Jatropha curcas L.* have been planted in 1000 hectares. The harvest pod reached 33.000 tonnes in the 5th year with a seed of 5000 tonnes and the oil extracted was approximately 1600 tonnes per year. In Nepal, 22.5 hectares of land have been planted with 40.000 rooted cuttings of jatropha. Rural women's co-operative societies have been trained to extract oil, produce soap and use 30:70 mix (oil/kerosene) of oil and kerosene in stove without smoke [3-5].

Biodiesel production and usage

Biodiesel is a fuel composed of mono-alkyl esters of long chain fatty acids, derived from a variety of vegetable oils or animal fats. Pure biodiesel is designated as B100, and it can conform to different quality standards *e. g.* ASTM D 6751, EN14214, or IS 15607.

Biodiesel production

Various methods are available to use/process vegetable oils as fuel. The important ones are described below.

Blending

Vegetable oil can be directly mixed with diesel fuel and may be used for running an engine. The blending of vegetable oil with diesel fuel has been successfully carried out by various researchers. A diesel fleet was powered with a blend of 95% filtered used cooking oil and 5% diesel in 1982. In 1980, Caterpillar Brazil Company used pre-combustion chamber engines with a mixture of 10% vegetable oil to maintain total power without any modification to the engine. A blend of 20% oil and 80% diesel has been found to be successful [6]. The suitability of a given fuel will depend on the exact ingredients, the design of the engine and the ambient temperatures encountered. Simply mixing vegetable oil with diesel fuel has been shown to be quite effective, and 50:50 to 80:20 blends have been proven to be reliable in most engines. Studies have found that a model 170F diesel engine could be reliably fueled with a 30:70 cotton seed oil and diesel blend [7]. Mc Donnell found that a blend of 25% degummed and filtered rapeseed oil was suitable for use in a direct injection (DI) engine [8].

Long term problems due to high viscosity, injector choking and carbon deposits beside lubrication oil dilution and contamination were faced in direct blending. Micro-emulsification, pyrolysis, and transesterification are potential solutions to problems encountered due to high fuel viscosity [9].

Micro-emulsification

To solve the problem of high viscosity of vegetable oil, micro-emulsions with solvents such as methanol, ethanol, and butanol have been used. A micro-emulsion is the colloidal equilibrium dispersion of optically isotropic fluid micro structures, with dimensions generally in the range of 1-150 nm, formed spontaneously from two normally immiscible liquids and one or more ionic or non-ionic amphiphiles. Micro-emulsions can be prepared from vegetable oils, esters and co-solvents (dispersing agent), or from vegetable oils, alcohol, and surfactants, blended or not with fossil diesel. Micro-emulsions improve spray characteristics by explosive vaporization of the low boiling constituents in the micelles. Micro-emulsions from vegetable oils and methanol have a performance similar to diesel. A micro-emulsion consisting of 53.3% soybean oil, 13.3% of 95% aqueous ethanol and 33.4 vol.% 1-butanol was found to perform comparably to diesel fuel [10]. Two studies of palm oil, diesel fuel and 5-10% water micro-emulsions revealed performance comparable to diesel fuel with less engine wear [11, 12].

Cracking/pyrolysis

Cracking is the process of conversion of one substance into another by means of heat, or with the aid of catalysts. It involves heating in the absence of air or oxygen, and the cleavage of chemical bonds to yield smaller molecules. The pyrolyzed material can be vegetable oils, animal fats, natural fatty acids and methyl esters of fatty acids. The pyrolysis of fats has been investigated for more than 100 years, especially in the areas of the world that lack deposits of petroleum [13]. Since World War I, many investigators have studied the pyrolysis of vegetable oil to obtain products suitable for engine fuels. Tung oil was saponified with lime and then thermally

cracked to yield crude-oil, which was refined to produce diesel fuel and small amounts of gasoline and kerosene.

Transesterification

Biodiesel is commonly synthesized through a process known as transesterification. This involves a reaction between a short-chain alcohol and a glyceride containing oil (can be plant oil, vegetable oil, fat, or grease) in the presence of a catalyst. The reaction is shown in fig. 1.

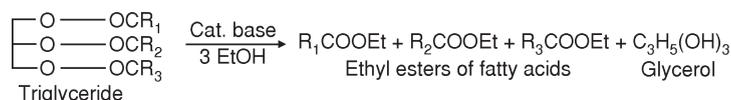


Figure 1. Transesterification process used in biodiesel production

On mass estimation

100 g vegetable oil + 21.7 g methanol 100.4 g biodiesel + 10.4 g glycerol + 10.9 g

The catalyst is usually sodium or potassium hydroxide that has already been mixed with methanol. R_1 , R_2 , R_3 indicate the fatty acid chains associated with the oil or fat, which are largely palmitic, stearic, oleic, or linoleic in nature.

Methanolysis vs. ethanolysis

In methanolysis, emulsions are formed, and separated into lower glycerol portion and upper ester portion. The reaction time is small in methanolysis. In ethanolysis, emulsions are stable and require more complicated separation and purification process. The reaction time is large [14].

The presence of a catalyst facilitates reactions that would be kinetically impossible or very slow without a catalyst.

Acid vs. base catalyzed transesterification

In base catalyzed transesterification, triglycerides and alcohol react in the presence of a basic catalyst, such as NaOH, KOH, and NaOCH₃. This is a well characterized reaction. Optimum conditions are known to result in fast conversions. More than 95% conversion can be achieved in 2 hours. This is the most effective process for pure vegetable oil [15].

Acid-catalyzed transesterification is applicable to processing feedstock with higher free fatty acid (FFA) content, waste vegetable oil, yellow grease, and brown grease with up to 5 wt.% FFA. The reaction of oil/fat with alcohol takes place in presence of acidic catalysts, such as H₂SO₄ and HCl. The reaction is very slow and takes more than 48 hours to achieve more than 95% conversion.

Heterogeneous catalysis vs. homogeneous catalysis

In homogeneous catalysis, the catalyst, reactants, and products are all in one phase, normally the liquid phase. The reactions proceed over an intermediate complex and are often highly selective, but separation of the products and the catalyst is difficult. The process is sensitive to FFA and the water content of the feedstocks. During the process, soap formation with high FFA feedstock and large quantity of effluent water formation as a result of removal of cata-

lyst are observed. The oil needs to be pre-treated for high FFA. Also there is no scope for regeneration or re-utilization.

In heterogeneous catalysis, the catalyst is in one phase, normally solid, while the reactants and products are in another phase. Separation of catalyst and products is easy, but the reaction is often less selective, because the catalyst material is not homogeneous. As the catalyst is regenerated during the process, catalyst cost decreases.

Lower quality feed stocks can also be used for biodiesel production. The simplification of separation process decreases production cost. Also the waste water is less thus making the process environment friendly.

Supercritical process

This process involves the reaction of alcohol and vegetable oil at high pressure and temperature (pressure 20 MPa and temperature 300 °C). This process is characterised by highly tolerance of FFA and water content, needing no catalyst. The conversion is fast, nearly 100% conversion in 15 minutes. The reaction of transesterification of triglycerides is carried out under supercritical conditions, *i. e.* at temperatures higher than the critical temperature of methanol. The whole system is essentially “dry” and only small water amounts are produced by esterification of the free fatty acids in the feed. Glycerol purification is simplified by the absence of catalyst and low water content. Transesterification reaction will proceed at ambient (30 °C) temperatures but needs 4-8 hours to reach completion. Reaction time can be shortened to 2-4 hours at 40 °C and 1-2 hours at 60 °C. Higher temperatures will decrease reaction times but require pressure vessels because methanol boils at 65 °C. Better agitation should be adopted to accelerate reaction.

The base catalyzed reaction is the most economical way to produce biodiesel since it requires only low temperatures and pressures. It is also highly efficient, since it can produce more than 98% conversion yield. This process is carried out in a biodiesel processor.

Some of the common catalysts used in biodiesel production are: NaOH, KOH, NaMeO (base catalysts) and H₂SO₄, PTSA, MSA, H₃PO₄, CaCO₃ (acid catalysts).

A typical base catalyzed batch process for biodiesel production is shown in fig. 2.

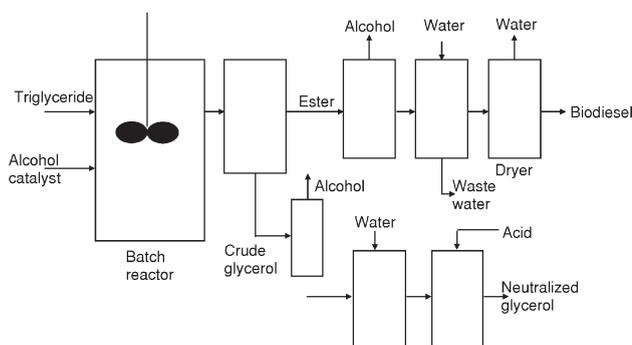


Figure 2. Batch, base catalyzed process

Biodiesel characteristics

The interesting characteristics of biodiesel, which make it a suitable alternative source of fuel for diesel engines, can be summarized as follows.

Ignition quality

Diesel combustion demands self-ignition of the fuel, because it is sprayed near top dead centre (TDC) into a hot, swirling cylinder. Long ignition may also lead to knocking. It is

therefore desirable, that the cetane number be between 40 and 60. Biodiesels have a cetane number in this range and are therefore suitable alternatives in this aspect.

Viscosity

The ease of combustion and thermal efficiency depend on fuel viscosity. Too low viscosity leads to internal pump leakage. Viscosities of biodiesels are comparable to that of diesel.

Heating value

Although the diesel combustion process can accommodate a wide variation in heating value, it is desirable that the calorific value (CV) of the fuels is nearer to that of diesel. Practical systems demand high CV since it reduces the quantity of fuel to be handled. Biodiesels are closer to diesel in this respect too.

Pour-cold-flash points

Pour point and cold point are important for cold weather operation. These values should be below the freezing point of the oil used. The flash point is important from a safety point of view. These values for commercial vegetable oils range from 50 to 300 °C.

A quantitative analysis of these properties is shown in tab. 1.

Table 1. Properties of vegetable oils and diesel

No.	Fuel	Dynamic viscosity [20 °C]	Density [mgcm ⁻³]	CV [kJkg ⁻¹]	Cetane number
1.	Diesel oil	4.8	0.845	44870	49.6
2.	Peanut oil	81.8	0.9173	39638	36.4
3.	Sunflower oil	65.6	0.923	39320	33.4
4.	Methyl ester soybean	4.5	0.883	37700	51.3
5.	Soybean	66.4	0.9239	38000	34.8

Other properties

The sulphur content, carbon residue, and ash are responsible for corrosion and forming a residue on the engine parts which will affect the engine life. These values should be as small as possible. Practical values are 0.5% sulphur, 0.27% carbon residue, and 0.01% ash.

Biodiesel blends

It is recommended to use a biodiesel blend because it is going to give better performance. If regular diesel has been used before in the vehicle then the engine may not be able to adapt to pure biodiesel immediately. The fuel filter may get clogged and the fuel may flow too slowly. So the best choice is to start off with blended fuel. In addition, finding pure biodiesel is

very difficult. Most pure forms are not approved through standards, and hence are not available on the market. Commonly used blends and their average properties are shown in tab. 2 [16].

Table 2. Average density and heating value of biodiesel blends

Property	2D	B20	B100	Property	2D	B20	B100
Cetane number	43.3	46.0	47.5	CV gross, [MJkg ⁻¹]	45.3	44.0	39.8
Specific gravity	0.856	0.862	0.886	CV net, [MJkg ⁻¹]	44.0	41.4	37.2
Flashpoint, [°C]	62	90	146	Sulfated ash	0.001	<0.001	0.001
Viscosity, [cST]	2.80	2.92	4.12	Carbon residue	0.00	0.00	0.00
Sulfur, [wt.%]	0.0476	0.0370	0.0000	Cloud point, [°C]	-17	-14	-1
Carbon, [wt.%]	86.9	85.1	77.3	Pour point, [°C]	-21	-15	-3
Hydrogen, [wt.%]	13.1	12.6	11.8	Acid number	<0.005	0.05	0.21
Oxygen, [wt.%]	n. a.	2.1	11.0	Water and sediment	<0.05	<0.02	<0.02
Aromatics, [wt.%]	39.1	n. a.	n. a.	Copper strip corrosion	1A	1A	1A
Olefins, [wt.%]	1.7	n. a.	n. a.	Total glycerine, [wt.%]	n. a.	0.04	0.19
Saturates, [wt.%]	59.2	n. a.	n. a.	Free glycerine, [wt.%]	n. a.	<0.01	0.01

Biodiesel applications and limitations

Applications

Biodiesel is a cleaner-burning diesel fuel, made from 100% natural, 100% renewable vegetable oil, and hence it is widely used in many areas:

- (a) *Home heating fuel* – More people are taking a look at biodiesel as an alternative for heating their home. Most oil-fired or boiler furnaces can use biodiesel (B20), which is a fuel made of 80% traditional heating oil and 20% biodiesel. Some people are getting their furnaces adapted to be able to burn B100, a fuel made entirely of vegetable oils, which burns much cleaner than traditional heating oil.
- (b) *Electricity generation* – Diesel generators that produce electricity are now running on biodiesel fuel. A superior alternative to the typical coal burning electricity generating plants, these are currently being used in the United States. Running on biodiesel is an inexpensive, clean, and renewable way of creating electricity.
- (c) *Trucking industry* – More and more truckers are switching from diesel fuel to biodiesel fuel. The benefits are numerous not to mention the advantage of helping the environment and reducing our dependency on foreign oil, while saving money.
- (d) *Agriculture* – Not only a producer of biodiesel, but also a consumer. Tractors, reapers, tillers, pickers, conveyors, generators, pumps, and irrigation systems which normally uses diesel

fuel, now use biodiesel to fuel their work, bringing agriculture to a full circle from producer to consumer.

- (e) *Marine vehicles* – Commercial fleets such as ferries, recreational yachts, sailboats, and motor boats are all candidates for biodiesel. For example the Pacific Whale Foundation, located in Hawaii, uses biodiesel in their boats.
- (f) *Lubrication additive* – Because biodiesel is a better lubricant than current low-sulfur petroleum, fuel injectors and other types of fuel pumps can rely on biodiesel fuel for lubrication. With the right additives, engine performance can also be enhanced, making engines last longer. Other numerous applications can also make use of its lubrication properties, such as concrete forms and asphalt trucks. Its solvent properties also make it a safe parts-cleaner, reducing skin and eye irritation associated with other cleaners.
- (g) *Cleaner environment* – biodiesel reduces CO₂ exhaust emissions by up to 80%. Because of this, biodiesel has the potential to reduce air toxics and cancer causing compounds. If spilled, it will quickly degrade into natural organic residues, without polluting the environment.

Biodiesel limitations

Fuel energy content

Biodiesel has less energy content (lower heating value) than diesel fuel by about 8%. Complaints of low power may occur with B100 but rarely with B20 or less.

Cold flow

Specific compounds in diesel fuel and biodiesel tend to crystallize at low temperatures. This can cause filter plugging and eventually the fuel will become a solid mass. Certain varieties of algae, yeast, and fungi can also grow in the diesel fuel tanks.

Reaction completeness

The reaction of triglycerides to methyl esters frequently leaves partially reacted mono-, di-, and triglycerides in the final product. The monoglycerides of saturated fatty acids have very high melting points. Incompletely reacted fuel will often have suspended white flakes of saturated monoglycerides that can plug fuel filters. Unreacted oil can contribute to in-cylinder deposits [17]. Many engine companies indicate that use up to B20 is acceptable. Above that, they are trying to gain more experience. Engine Manufacturers Association says that B5 is not a problem [18].

Biodiesel life cycle

Energy demands

It is useful to compare the energy demands of the various stages in the above biodiesel production process with those of the conventional petrodiesel production process. A summary of the energy consumption is provided in tab. 3.

It is important to note here, that agriculture accounts for most of the energy demands in the biodiesel production process (more than 25%). Therefore, the overall energy demand is much lesser in the case of biodiesel, when compared to the demands of petrodiesel.

Table 3. Energy consumption in production stage

MJ per MJ fuel	Biodiesel production stage	Energy	Petrodiesel production stage	Energy
0	Soya bean agriculture	0.0573	Domestic crude conversion	0.0461
0.05	Soya bean transport	0.0034	Foreign crude-oil conversion	0.0223
0.1	Soya bean crushing	0.0794	Domestic crude transport	0.0033
0.15	Soya oil transport	0.0072	Foreign crude transport	0.0131
0.2	Soya oil conversion	0.0801	Crude-oil refining	0.1198
0.25	Biodiesel transport	0.0044	Diesel fuel transport	0.0063
0.3	Total	0.2318	Total	0.2009

The other important observation to be made here is that, crude-oil refining dominates energy demands of petrodiesel production and soy oil conversion dominates biodiesel production.

Energy balance

Biodiesel and petroleum diesel have very similar energy efficiencies [19]. The base-case model estimates life cycle energy efficiencies of 80.55% for biodiesel vs. 83.28% for petroleum diesel. The lower efficiency for biodiesel reflects slightly higher process energy requirements for converting the energy contained in soybean oil to fuel. In terms of effective use of fossil energy resources, biodiesel yields around 3.2 units of fuel product energy for every unit of fossil energy consumed in the life cycle. By contrast, petroleum diesels life cycle yields only 0.83 units of fuel product energy per unit of fossil energy consumed. Such measures confirm the renewable nature of biodiesel. The life cycle for B20 has a proportionately lower fossil energy ratio (0.98 units of fuel product energy for every unit of fossil energy consumed). For B20s the fossil energy ratio reflects the impact of adding petroleum diesel into the blend.

Emissions

Carbon dioxide emissions

The demand for fossil energy associated with biodiesel is low, so its life cycle emissions of CO₂ are, not surprisingly, much lower. Per unit-work delivered by a bus engine, B100 reduces net CO₂ emissions by 78.45% compared to petroleum diesel. B20's life cycle CO₂ emissions are 15.66% lower. Thus, replacing petroleum diesel with biodiesel in urban buses is an extremely effective strategy for reducing CO₂ emissions.

Total particulate matter and carbon monoxide emissions

The B100 life cycle produces 32% less total PM and 35% less CO than the petroleum diesel life cycle. This is mostly because of lower emissions at the tailpipe. PM emissions from an urban bus operating on biodiesel are 68% lower than those from an urban bus operating on petroleum diesel. Biodiesel reduces tailpipe CO emissions by 46%.

Nitrogen oxide emissions

At the same time, NO_x emissions are 13% higher for the B100 life cycle compared to the petroleum diesel life cycle. B20 has 2.67% higher life cycle emissions of NO_x. Again, this increase is attributed to higher NO_x emissions at the tailpipe. An urban bus run on B100 has NO_x emissions that are 8.89% higher than a bus operated on petroleum diesel.

Total hydrocarbons

It has been found that 35% higher life cycle emissions of total hydrocarbons (THC) using biodiesel as compared to petroleum diesel, but tailpipe THC emissions are 37% lower for B100 than for petroleum diesel. The increase results from hexane being released during soybean processing, and due to volatilization of agrochemicals applied on the farm.

Water and solid waste

Biodiesel life cycle waste-water flows are almost 80% lower than those of petroleum diesel. Biodiesel is also responsible for only about 5% of the hazardous waste generated by petroleum diesel.

Water consumption

On a life cycle basis, B100 uses water at a level that is three orders of magnitude higher than petroleum diesel [19].

Biodiesel economics

Present and future market

The global biodiesel industry is among the fastest-growing markets the chemical industry has ever seen. World capacity, production, and consumption of biodiesel grew on average by 32% per year during 2000-2005, and the industry looks set for even faster growth rates – 115% per year for capacity, and 101% per year for demand – in the years to 2008 and beyond [20].

The graph in fig. 3 shows recent and forecast growth in biodiesel capacity and demand.

The pie charts in fig. 4 show world production (which is the same as consumption) of biodiesel in years 2005 and 2010, and share of different regions in total production.

Used as a replacement for fossil diesel, the success of biodiesel hinges on government support through subsidies and tax relief. Without such subsidies, biodiesel would not be competitive with fossil diesel. The environmental credentials of biodiesel are impeccable. The use of biodiesel reduces greenhouse gas emissions compared with the use of fossil fuels. Biodiesel also has a favorable energy balance and can be made sustainably from renewable oilseed resources. The market potential for biodiesel is defined by the size of the existing fossil diesel fuel market. There is no major technical limitation on replacing fossil diesel with biodiesel. There is, however, a limitation on feedstock availability – vegetable fats and oils and animal fats – and this, in turn, depend on the availability of farmlands to grow the crops. The growth of biodiesel industry will be determined largely by government legislation and regulation. In general, governments

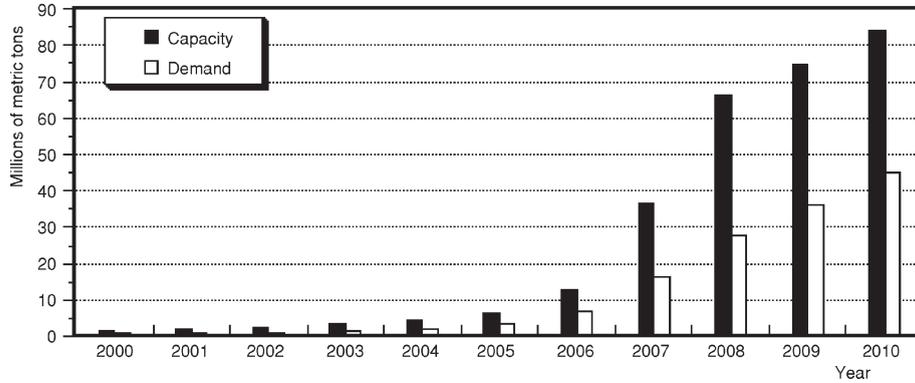


Figure 3. World capacity and demand for biodiesel

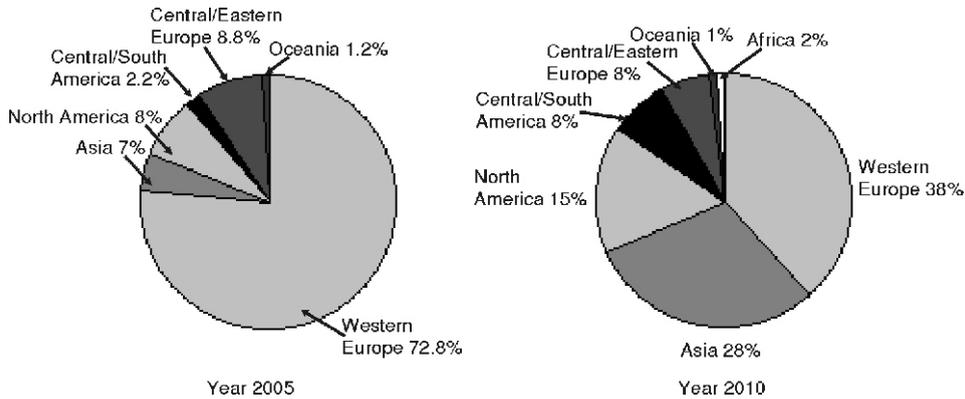


Figure 4. World production/consumption of biodiesel

use a variety of subsidies and tax breaks to stimulate demand growth. In doing so, governments have three major concerns that influence their biofuel policy:

- (1) securing energy supply and reducing dependence on fossil fuel imports,
- (2) obtaining environmental benefits, including cutting greenhouse gas emissions, but also reducing sulfur emissions compared with those of fossil diesel, and
- (3) creating jobs in rural regions and boosting the agricultural sector.

The build up in capacity will be particularly strong in North America and Asia, and the total growth in capacity worldwide will far exceed expected consumption growth rates. This will result in intensified competition, lower capacity utilization rates, squeezed profit margins, a war for raw materials, and, probably, the closure of small-scale producers and those in less strategically important regions. A shift in global biodiesel production patterns is expected to occur during years 2007-2010. While Western Europe accounted for more than three-quarters of worldwide biodiesel production in 2005, its share is expected to diminish to below 40% through 2010. This is mainly because production is expected to grow at much higher rates in all other regions, headed by Asia, which is expected to become the second-largest biodiesel producing region, right behind Western Europe, and followed by North America. Looking at world biodiesel consumption, 61% of the world total in 2005 was accounted for by Germany, where market conditions were highly favorable. Other countries with significant biodiesel markets in 2005 in-

cluded France, the United States, Italy, and Brazil. All other countries combined accounted for only 11% of world consumption. By year 2010, the United States is expected to become the largest single biodiesel market, accounting for roughly 18% of world biodiesel consumption. New and large single markets for bio diesel are expected to emerge in China and India. The share of all other countries will increase to 44% through the forecast period.

On a global scale, the biodiesel industry was highly fragmented in 2005, with the top ten producers accounting for roughly a quarter of worldwide installed production capacity, and with the largest producer having 857 thousand metric tons of installed production capacity. By 2010, the largest biodiesel producers will have grown dramatically in size. The six largest producers will have a combined capacity equivalent to the current total installed and operational capacity.

Glycerin is the by-product of biodiesel production. Traditionally, biodiesel producers sell this raw glycerin to processors, or purify it on-site to make pharmaceutical-grade glycerin. With the biodiesel production boom, the glycerin market has become flooded with huge amounts of both crude and refined glycerin. The traditional supply/demand pattern for glycerin has moved into a period of severe imbalance.

Pricing

The cost of biodiesel fuels varies depending on the base stock, geographic area, variability in crop production from season to season, and other factors. Although the cost may be reduced if relatively inexpensive feedstock, such as waste oils or rendered animal fat, is used instead of soybean, corn or other plant oil, the average cost of biodiesel fuel nevertheless exceeds that of petroleum-based diesel fuel. That said users considering conversion to an alternative fuel should recognize that the relative cost of converting an existing fleet to biodiesel blends is much lower than the cost of converting to any other alternative fuel because no major engine, vehicle, or dispensing system changes are required.

Biodiesel in CI engines

The use of biodiesel in the automotive industry has been continuously increasing in the last years, especially in France (where blends with diesel oil are widely used) and Germany (where many engines can be fuelled with pure biodiesel).

Power

When the brake power at different loads is compared for diesel and different combinations of dual fuels, it is noted that the brake power is higher for the dual fuel combinations from B5 to B30 than diesel. In case of B40 the brake power is more or less equal to that of diesel. For the dual fuel combinations from B50 to B100, the brake power is less than that of diesel. Hence it can be concluded that the dual fuel combination of B40 can be recommended for use in the diesel engines without making any engine modifications [21].

Many studies on the performances and emissions of compression ignition engines, fuelled with pure biodiesel and blends with diesel oil, have been performed and are reported in the literature [2, 4-6]. Even if based on different engine architectures, that may influence the generalization of the results, all the tests showed a slight reduction of the performances (*e. g.* 5% decrease of the power over the entire speed range) and a significant increase of fuel consumption (+15%). There appears to be little difference in performance between regular diesel and the B20 mixture. The B100 displays about a 5% reduction in power from diesel, actually less than the ex-

pected 10% reduction [22]. When biodiesel was used as the fuel, acceptable changes occurred in the performance values. The maximum brake mean effective pressure obtained with the biodiesel was 16% lower than that obtained with the diesel fuel, with the difference being 7.5% under maximum power [23]. Raheman *et al.* [24] reported that the torque produced for B20 and B40 were 0.1-1.3% higher than that of diesel due to complete combustion of fuel. In case of B60-B100, it was reduced by 4-23% when compared with diesel fuel for single cylinder, four stroke, direct injection, water-cooled engine produced 7.5 kW power at 3000 rpm.

Emissions

The presence of oxygen in biodiesel leads to more complete combustion processes, resulting in lower emissions of CO, particulates, and visible smoke. However, an increase in NO_x emissions has been measured, due to higher temperatures. Neat vegetable oil poses some problems when subjected to prolong use in CI engines. The problems are attributed to its high viscosity and low volatility. Biodiesel from refined palm oil stearin is a promising alternative for using in diesel engines brake specific fuel consumption of biodiesels at various mixing ratios. A comparison of exhaust emissions showed that CO emissions of biodiesel are lower than those of diesel fuel. The difference between the obtained minimum values was around 70%. In terms of hydrocarbon emissions, diesel fuel has produced better results than the biodiesel fuel. Biodiesel resulted in higher NO_x emissions than diesel fuel when the engine operation range was considered. The difference was about 13-15% in the maximum power region [23].

Fuel consumption

The brake specific fuel consumption of biodiesel is decreased with the increase of mixing ratio of biodiesel. There appears to be little difference in performance between regular diesel and the B20 mixture. The B100 displays about a 5% reduction in power from diesel, actually less than the expected 10% reduction. While biodiesel reduced the maximum engine power by 8.6%, it increased the brake specific fuel consumption by 9.6%. In 2007, Daimler-Chrysler indicated intention to increase warranty coverage to 20% biodiesel blends, if biofuel quality in the United States can be standardized. The cylinder heads of the B20 engines contained a heavy amount of sludge around the rocker assemblies that was not found in the diesel engines. Nevertheless, the B20 tractors had essentially the same maintenance costs as the petroleum diesel tractors. All the engines exhibited normal wear for their mileage, independent of fuel [25]. The brake-specific fuel consumption for B20 and B40 was 0.8-7.4% lower than diesel. In the case of B60-B100 the brake-specific fuel consumption was 11-48% higher than diesel because of a decrease in the calorific value of fuel with an increase in biodiesel percentage in the blends.

Limitations

One of the most important biodiesel drawbacks is the deterioration of the lubricant properties: in fact, because of the high boiling point, the biodiesel that flows into the crankcase as a result of blow-by, dilutes the lubricant progressively, modifying its additive properties. Since biodiesel has detergent characteristics, it may bring in suspension fuel tank sludge that may block fuel-ways in the fuel injection system. Moreover, biodiesel is not compatible with some plastic materials used in pipes and seals, which must be changed. The brake thermal efficiency was 26.79 and 29.19% for B20 and B40, respectively, which was higher than that of diesel (24.64%). The maximum brake thermal efficiency obtained from B60, B80, and B100 was

24.26, 23.96, and 22.71%, respectively. This is due to the reduction in calorific value and increase in fuel consumption compared to B20. These results are in accordance with [26-29].

Conclusions

Disclaimers aside, biodiesel is a significant sustainable energy resource and is used all over the world. Biodiesel B20 and less can be used as an alternative fuel without much modifications of diesel engine and almost the same performance of a diesel engine with a petrodiesel fuel. The production, economics, and suitability of biodiesel varies from country to country. A detailed study basing on the feed stock availability, related oil extraction process and production of biodiesel, government policies and subsidies can only decide the impact on the public usage, and thus the reduced dependence on depleting fossil fuel resources. Environmental regulations have had, and will continue to have a significant impact on the formulation of diesel fuel. The introduction of new fuels and engine designs to meet new emission regulations has created a need to address a number of fuel properties in the order to guarantee acceptable emission performance while avoiding excessive engine maintenance.

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