Rubber Seed Oil: A Feasible Feedstock for Biodiesel Production in Sri Lanka

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Abstract

Alternative fuels can be used as a solution for the escalating price of petroleum fuels in transportation and stationary engines. Biodiesel produced from non-edible oil sources is one such alternative fuel. However, availability of sufficient quantities of feed stocks for the production of biodiesel is a matter of concern in the commercialisation. At present, Rubber Seed Oil (RSO) is the only non-edible oil feed stock available in Sri Lanka for the production of biodiesel at a reasonable scale. Although Sri Lanka has a large acreage of rubber cultivation, rubber seeds are not collected systematically for commercial utilisation, and therefore, a large amount of seeds go wasted on rubber plantations. Hence, seed collection has to be streamlined with a guaranteed good market price in order to utilise the oil in biodiesel production.

RSO contains high amount of free fatty acids (FFA) as in many seed oils, and therefore, a two-step esterification process has to be used to convert high FFA RSO to bio diesel which increases the production cost. Market price of biodiesel will largely depend on the price of oil feed stocks, price of other additives used and the production cost, which have great influence on the success of the biodiesel commercialisation and captivating consumers.

Introduction

The major part of all energy consumed in Sri Lanka comes from fossil sources (petrol, diesel and liquefied petroleum (LP) gas) that are being imported to the country spending huge sum of foreign exchange. However, these sources are limited and will be exhausted in the near future.

In Sri Lanka, diesel engines dominate commercial transportation (e.g., road, rail and sea) and power generation due to its ease of operation and higher fuel efficiency. The consumption of diesel oil was 1.8 Million tones in 2006 (Annual Report 2006. Central Bank of Sri Lanka). Due to the shortage of petroleum products and its increasing cost, it is imperative that systematic efforts need to be made to develop alternative fuels, especially to the diesel oil for at least partial replacement.

In the global context, biofuels have received a rapidly growing interest for reasons of energy security, diversity, and sustainability as well as for greenhouse gas mitigation. In recent years, many countries have enacted regulations – and adopted aggressive goals – to encourage increased usage of biofuels. *Ethanol production more than doubled between 2000 and 2005 to nine billion gallons, or 1.2 percent of global fuel use and in 2005, USA pledged to nearly double the ethanol production by 2012.. While corn-based USA. ethanol and sugarcane-based Brazilian ethanol account for nearly 90 percent of global production, other countries are rapidly expanding output using a variety of sugar and grain crops. Bio diesel production, which started from a smaller base, has quadrupled. Europe is currently the leading producer of bio diesel, which is processed from vegetable oils that are derived from soy beans, oil palm, and rapeseed, among other crops. Moreover European Community recently announced that bio fuels will meet 10 percent of their transportation fuel needs by 2020 (Global Biofuel Trends, 2007).* It is timely that Sri Lanka also takes initiatives to look at feasible alternative energies to face the energy crisis.

Biodiesel, an alternative to petroleum diesel is a biofuel, made from renewable biological sources such as vegetable oils and animal fats. Vegetable oils have comparable energy density cetane number[1], and low volatility with that of the petroleum diesel fuel (Ramadas *et al.* 2005a) Even Rudolph Diesel, the father of diesel engine, demonstrated the first use of vegetable oil in compression ignition engine. However, viscosity of vegetable oils is higher than that of petroleum diesel which could affect the flow properties of the fuel, such as spray atomisation, consequent vaporisation and air–fuel mixing in the combustion chamber. It could also cause poor cold engine start-up, misfire, and ignition delay (Ramadas *et al.* 2005a). Hence, it is necessary to bring their combustion-related properties closer to those of petroleum diesel. Blending (with petroleum diesel) and chemically modification by transesterification[2] are two commonly adopted methods to use vegetable oils and fat as fuel in diesel engines.

Biodiesel is derived from vegetable oils and animal fats. Different types of locally available vegetable oils can be converted into biodiesel. Coconut oil is a good source of raw material for the production of biodiesel that gives biodiesel comparable to petroleum diesel. However, the use of edible coconut for the production of biodiesel will contribute towards the 'food to fuel' accusation and is not a feasible solution for the fuel crisis. Nonedible seed oils like rubber seed oil, jatropha seed oil and neem seed oil as well as waste cooking oils and rendered fats are also potential feedstock to produce biodiesel.

According to the printed and electronic media, there has been a considerable interest by both public and private sector organisations in planting oil-yielding seed plants such as *Jatropha curcas* and *Pongamia pinnata*. However, authors feel that growing rubber is more economical for a country like Sri Lanka with limited land and high population than growing other oil-bearing crops. The reason being the rubber gives multitude of benefits: rubber latex for the rubber industry, wood for furniture and energy and oil from seeds for biodiesel whereas the other crops would be dedicated only to produce oil for biodiesel.

Extensive studies have been carried out at the Department of Chemical Engineering, University of Moratuwa, Sri Lanka on biodiesel production using the above-mentioned feedstocks. Nevertheless, this article would focus on the feasibility of Rubber Seed Oil (RSO) in the production of biodiesel in Sri Lanka.

Availability of Rubber Seed

Rubber (*Hevea brasiliensis*) was introduced to Sri Lanka in 1876 during the colonial era, and since then, it has been grown as a commercial crop. At present, Sri Lanka has around 118,000 ha under rubber plantations. Nguyen van Hao and Duong Thanh Liem (2003) reported that an area of one hectare of rubber trees yield 300-500 kg of seeds. However, it is reported that modern high-yielding clones introduced by the Rubber Research Institute (RRI) of Sri Lanka produce a low seed yield compared to wild varieties planted decades ago (Tilakeratne, 2007). It is further reported that, if the demand for seed oil rises, RRI scientists are capable of producing new high-yielding clones with a potential to produce high seed yields. Nevertheless, what RRI scientists should consider at this juncture is the development of high yielding rubber seeds with high oil content without compromising on the quality of latex produced by the trees. Then, it will address both the natural rubber industry as well as the energy sector issues in the country.

Seed Collection and Storage

Little or no attention has been paid to the utilisation of rubber seed oil in Sri Lanka, and presently there is no proper mechanism for the collection of rubber seeds. Rubber seed production occurs once a year and the seeds are dehisced, released and dropped from trees. Sunshine is critical to the drying of the pods in order for them to dehisce and release the seeds. When there is rainfall during the seed maturing period, the seed pods will not dehisce to release the seeds. Collected seeds normally contain about 25-30% moisture, and high moisture content promotes rapid deterioration of seeds. Seed collection delay also leads to moisture pick up and deterioration, and therefore, seeds should be collected as soon as they drop from the trees (Nadarajah *et al.*, 1973). Unexpected rains were experienced in Sri Lanka during the harvesting period of 2008, and it is reported that all the rubber seeds were perished and good quality seeds are not available for extraction of oil. As a result of the climatic conditions in Sri Lanka, a greater proportion of rubber seeds deterioration occurs in storage mainly due to mould growth and germination, and hence, seeds should be spread out for aeration as soon as they are collected. By adopting this method, moisture content can be reduced and the storage period can be extended.

Rubber Seed Oil

The weight of fresh rubber seed varies from 3 to 5 g of which about 40 % is kernel, 35% shell and 25% moisture. The average oil content of the seed is around 25% on a moisture free basis (Nadarajah *et al.*, 1973) even though there can be variations in the oil content of the seeds from different countries. Two products are obtainable from rubber seeds, and they are the oil and the cake. The oil, which is semi-drying and yellowish in colour, consists of 17 – 22% saturated fatty acids and 17 – 82% unsaturated fatty acids (Ikuagwu *et al.*, 2000). Typical composition of RSO is given in Table 1 (extracted from Ramadhas *et al.*, 2005b).

Table 1
Composition of RSO

Property	Rubber seed oil
Fatty acid composition (%)	
(i) Palmitic acid $C_{16:0}$	10.2
(ii) Stearic acid $C_{18:0}$	8.7
(iii) Oleic acid $C_{18:1}$	24.6
(iv) Linoleic acid $C_{18:2}$	39.6
(v) Lonolenic acid $C_{18:3}$	16.3
Specific gravity	0.91
Viscosity (mm^2/s) at 40 °C	66.2
Flash point (°C)	198
Calorific value (MJ/kg)	37.5
Acid value	34

Source: Ramadhas et al.(2005b).

At present, RSO is not used for any edible purpose. However, studies have shown that RSO has many areas of potential applications amongst which are: the production of alkyd resin, paints and coatings, soap and bio diesel and as a lubricant. Yet in Sri Lanka, RSO does not find any major application and remains underutilised.

Oil Extraction

The two common methods of seed oil extraction are solvent extraction and mechanical pressing.

Solvent extraction uses a solvent such as hexane which is highly inflammable. It also requires highly skilled personnel to operate the process, and initial capital investment and operating costs are also high. On the other hand, the mechanical method of extraction is safe, initial capital investment is low, it does not require much skill to rate and is suitable for small- and even industrial-scale use. Mechanical pressing is recommended for large-scale production of RSO for the production of biodiesel due to the economics and the safety in operation.

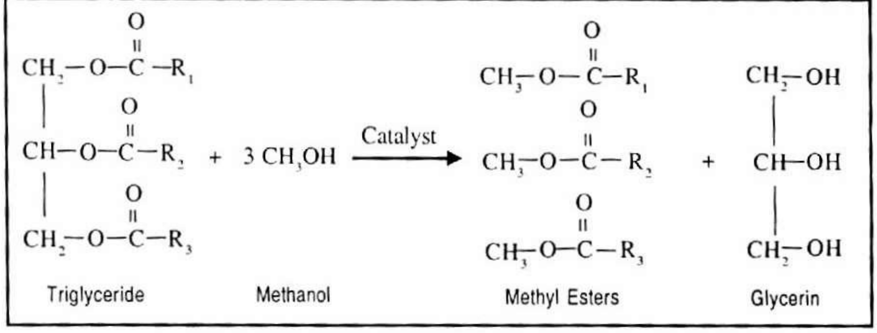
Storage of RSO

During storage, free fatty acids present in rubber seed oil may increase rapidly and produce unpleasant odour or taste thereby reducing the acceptability of the oil. The factors that affect degradation of oils are light, air, temperature, heavy metals, natural oxidative enzymes, pro-oxidants present in the oil and the degree of unsaturation of the oil. However, the main factors that affect the degradation of rubber seed oil are light and air (Iyayi *et. al.,* 2008). If the oil is stored in light proof, airtight and moisture-proof containers, the shelf life can be extended for several months. Since rubber seed is a seasonal product and also can deteriorate with time, it is sensible to extract the oil immediately after they are collected and the oil is stored appropriately so that it does not become inferior in quality.

Biodiesel Chemistry and Properties

Biodiesel is produced commercially by transesterification (alkaline esterifcation) of oils (triglycerides[3]) with alcohol. Methanol and ethanol are the commonly used alcohols for this process.. Triglycerides are reacted with alcohols to transform to monoesters (methyl ester or ethyl ester depending on the alcohol used) and glycerin in the presence of an alkaline catalyst[4]. The properties of monoesters that are formed are comparable to petroleum diesel. Figure 1 shows the transesterification reaction scheme.

Figure 1
Transesterication Reaction



Alkaline-catalysed transesterification of triglycerides is possible only if the Free Fatty Acid (FFA) content of oil is less than 2% (w/w). Higher percentage of FFA in the oil reduces the yield of the esterification process. The FFA content of non-edible RSO is high. It has been established that the monoester (or biodiesel) yield decreases with increase in FFA since the catalyst used for the transesterification process (Potassium hydroxide (KOH) or Sodium hydroxide (NaOH)) neutralises FFA by converting it into soap. In order to produce biodiesel from high FFA oils, FFA value has to be reduced to a value below 2% to avoid soap formation. Therefore, production of biodiesel from oils with high FFA involves two steps; FFA reduction step or the acid-esterification step and the biodiesel production step or the alkaline-esterification step.

How to Produce Biodiesel?

1. **Step 1:** Determination of the FFA content in the oil

   FFA% of oil is half the value of the acid value (AV) of the oil. AV of the oil can be determined according to the American Society for Testing and Materials (ASTM) standards(ASTM, 1972).

2. **Step 2:** Acid-esterification step

   The required amount of concentrated sulphuric acid (H_2SO_4) is added as the acid catalyst to methanol, and the mixture is added to the RSO, and then preheated to the required temperature. The oil-methanol mixture has to be kept at room temperature for at least 12 hours for the reaction to continue and also for the separation of layers. After 12 hours, the bottom layer has to be separated and the upper layer which contains methanol and water has to be discarded. The FFA content of the separated bottom layer should be checked. If FFA is less than 2%, the treated oil can be used for the production of biodiesel (alkaline esterification), otherwise the above procedure has to be repeated until the FFA content falls below 2%.

3. **Step 3:** Alkaline-esterification step

   In this step, triglycerides are transesterified to mono esters. Oils which have been pretreated as described in the second step are used for this reaction.

   The amount of catalyst - potassium hydroxide (KOH)- required for the reaction can be found by a titration technique. Stoichiometric quantity of methanol required for the reaction is generally 12.5% volume of oil, however, it varies from 11.3% to 16.3% depending on the oil. Excess amounts of methanol are added to drive the reaction forward towards completion. This excess amount is usually 60% - 100% of the stoichiometric amount of methanol. Thereby, KOH is mixed with methanol (20% v/v methanol to oil ratio) to prepare potassium methoxide.

   Pretreated oil is heated to a temperature of 50 - 55 °C, and the methoxide as prepared above is added to the heated oil. Then heating and mixing has to be continued for 90 minutes in a closed vessel (Chitra *et al.*, 2005). Then the mixture should be allowed to settle at room temperature for 24 hours, and the top layer which contains methyl ester of the rubber seed oil can be separated from the glycerin bottom layer.

4. **Step 4:** Biodiesel washing

   The methyl ester has to be washed with water until the pH of the ester reaches 7. This removes excess methanol, acids and soap formed during the reaction.

A detailed description of the materials and the methods used is given in Sampath *et al*, (2008).

Results of Biodiesel Studies

Biodiesel produced from RSO at the Department of Chemical and Process Engineering, University of Moratuwa, was tested for some important chemical and physical fuel properties. The comparisons of properties of RSO with that of Biodiesel from RSO, Standard biodiesel and Petroleum diesel are given in Table 2.

Table 2.
Comparison of Chemical and physical properties of RSO, Biodiesel from RSO, Standard biodiesel and Petroleum diesel

Properties	Rubber seed oil (RSO)	Biodiesel from RSO (washed)	ASTM Standards on Biodiesel	Petroleum Diesel
Specific Gravity (kg/m³) at 30° C	0. 820	0.877	0.880	0.826-0.859
Viscosity (Stock)	0.311	0.057	0.037-0.058	0.02-0.045
Flash Point (° C)	140	110	130	65
FFA %	23	0	0.25-0.4	0.25

Source: Department of Chemical and Process Engineering, University of Moratuwa.

Table 2 shows that, transesterication improved the important fuel properties of the RSO. The transformed methyl ester (biodiesel) has relatively closer fuel properties to diesel than that of original RSO. The high viscosity of RSO (about 0.311 Stocks) as against 0.057 Stocks for biodiesel at 30 °C further explains the need to convert RSO to a less viscous liquid through transeterification to avoid problems in pumping and atomisation in the injection system of a diesel engine. The flash point[5] of RSO biodiesel is higher than that of petroleum diesel. Hence, this fuel is safer to store and transport compared to that of petroleum diesel.

Engine Performances

Ramadas *et al.*, (2005a) reported the use of RSO, biodiesel from RSO and its various blends with petroleum diesel in engines. They showed that the lower blends of biodiesel improved the thermal efficiency with applied load and for all the blends tested, brake specific fuel consumption decreased with increase in the load. However, the specific fuel consumption of RSO is higher than that of biodiesel or petroleum diesel due to the combined effects of higher viscosity and lower calorific value of RSO. It is further reported that the gas emissions such as carbon monoxide, carbon dioxide and smoke density were reduced compared to petroleum diesel with increase in biodiesel concentration in the blend.

Environmental Impact

Rubber is considered an environmentally friendly plantation where it acts as a sink for carbon dioxide absorption. Moreover, the carbon cycle time for fixation of carbon dioxide (CO_2) and its release after combustion of biodiesel produced from plant seed oil is quite small (few years) as compared to the carbon cycle time of petroleum oils (few million years).

Biodiesel exhibits several environmental benefits when compared to that of the existing petroleum fuels. Many researchers have shown that particulate matter, unburned hydrocarbons, carbon monoxide, and sulphur levels are significantly less in the exhaust gas. However, an increase in the levels of oxides of nitrogen is reported with bio diesel (NREL/TP-580-30004).

Development and Sustainability

In the Sri Lankan context, the demand for RSO could be created by the setting up of small-scale biodiesel production plants that could make a livelihood for the low-income communities in the rubber plantation areas. A market-driven sustainability could be achieved for the collection and extraction of oil which is essential for the continuous production of biodiesel. However, the cost of collection of seeds will be a critical factor in determining the price of oil.

If 75% of the seeds in Sri Lankan plantations are collected, extracted with 20% efficiency and converted into biodiesel with 65% efficiency, then 5000 tonnes of biodiesel can be produced annually. (In this calculation, present uses of rubber seed oil have not been taken into consideration since quantitative estimation of such uses are not documented). This is equivalent to 0.3% of the total diesel consumption in the country or 14% of the fuel consumption in the railway sector alone. This reveals an opportunity to retain around US$ 6 million worth of foreign exchange in the country that is spent on petroleum diesel imports.

Economics of Biodiesel Production

Presently, the cost of production of biodiesel is not comparable with petroleum diesel, mainly due to the high cost of oil and the cost of chemicals used. However, if bulk quantities of chemicals are purchased from the international market rather than from the local retail market, the cost would reduce drastically. If proper mechanisms are in place for the collection, extraction and storage of oil, RSO cost could also be reduced.

Moreover, if correct technology is applied, a large percentage of excess methanol could be recovered and reused by bringing down the cost of production further. Glycerol which is produced as a by- product in the process, if properly purified, can be an additional income generator in the biodiesel manufacture.

Adaptability

Blends of 20% biodiesel and 80% petroleum diesel, commonly known as B20 can be used in unmodified diesel vehicles however; adapted vehicles are required when the biodiesel component rises above 20% in the blend. Common method for blending fuels is known the "splash blending" in which biodiesel is added over petroleum diesel with little agitation. Blends at any percentage can be prepared, and obviously a richer blend of biodiesel maximises environmental benefits.

The consumer acceptability is the key to the success of the biodiesel industry as any other industry. The price of the fuel should be attractive enough to induce significant changes in entrenched consumer behaviour. In the early stages of the biodiesel fuel program, the biodiesel has to be sold at a price less than the conventional fuel prices to persuade consumers to adopt the new product. This has been practised in Brazil during the early stages of their fuel ethanol program and has worked satisfactorily. In addition to fuel price, the market should offer attractive modified diesel vehicles for higher biodiesel blends, and a product delivery infrastructure that convinces consumers that biodiesel is a useable and permanent alternative to conventional fuel.

Conclusion

In the present investigation, the rubber seed oil, a non-edible vegetable oil is chosen as a potential alternative for producing biodiesel for diesel engines. Using oil derived from rubber seeds instead of other types of edible oils could easily avert the debate of a conflict between food and fuel. Rubber seed oil after chemical modification is a proven replacement for diesel to be used in motor vehicles. The properties of biodiesel produced are comparable with petroleum diesel. However, use of higher blends of biodiesel in engines requires engine modifications. Since biodiesel can be produced within the country, its use may decrease the dependence on imported fuel, contribute to the country's economy and also to a cleaner environment. Moreover, the success of biodiesel as a fuel largely depends on the consumer acceptability where the price of the fuel is a main factor of concern.

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Footnotes

[1] Cetane number is a measurement of the combustion quality of diesel fuel during compression ignition.

[2] Transesterification- Transforming one type of ester into a different type of ester.

[3] A triglyceride means that three (tri) acids are bonded to an alcohol, in this case three fatty acids bonded to a glycerin.

[4] A substance that facilitates or enables a reaction between other substances.

[5] The temperature at which the fuel gets ignited