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Technical note

# Experimental study on the performance and emission measures of direct injection diesel engine with Kapok methyl ester and its blends

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ABSTRACT

In this study, Kapok methyl ester was derived from Kapok seed oil by the two-step esterification process. The two-step process consists of acid-catalyzed pretreatment, followed by alkaline-catalyzed transesterification. The experimental investigation was carried out in a single-cylinder direct injection diesel engine, and the performance and exhaust emissions of the engine were also studied for the different blends of Kapok methyl ester. The results showed that the exhaust gas temperature and specific fuel consumption are increased for rich blends of Kapok methyl ester, but the brake thermal efficiency is decreased for the same blends. The $NO_x$ emission is higher than that of diesel at all load conditions of the engine. The lean blend of the Kapok methyl ester has appreciable engine efficiencies, lower values of smoke, and lower CO and HC emissions. Thus, the experimental results proved that the Kapok methyl ester is one of the most suitable alternatives to diesel fuel.



## 1. Introduction

In recent years, numerous attempts have been made by researchers to find out some new renewable and sustainable energy sources. The primary reasons behind in this are, the environmental concern, increasing fuel demand, fast depletion and limited availability of fossil fuels. Secondarily aiming for, energy security and local electricity generation, domestic market utilization, and transportation [1], also, the cost of petroleum products depends on the international market, which is reflected in the growth of a country. All the above factors jointly force mankind towards the study of renewable energy sources for the present as well as future benefits. Different types of energy sources such as water, wind, solar and biofuels have the potential to replace the fossil fuels [2]. At present, biodiesel and bio-ethanol are used successfully as alternative fuels in many countries, especially in Brazil, Germany, Malaysia, Indonesia, the USA, Spain, Argentina and India [3].

The government of India has launched a national mission on biofuels with the aim of achieving a target of 20% blending of biodiesel by 2012 [4]. To meet these expectations it would require 12 to 13 million hectares of biodiesel feedstock plantations. Hence, there is a need to identify some alternative local plant species, without affecting the needs of the rural poor, and encroaching upon fertile lands used for food production. India has rich forest resources with a variety of plants and oil seeds. Moreover, nearly 80-100 million hectares of wasteland are available, which can be utilized for the purpose of biodiesel feedstock plantations. The biodiesel feedstock plantations have the additional benefits of green cover to waste land, support to agriculture and rural economy, lower dependence on imported crude oil, and reduction in air pollution [5]. Biodiesel can be derived from any of the edible or non-edible oils like soybean, coconut, sunflower, *jatropha curcas*, *pongamia pinnata*, Kapok, neem, rubber seed oil etc., and also from animal fats. Some of the oil yielding Indian tree species and their oil content are given in Table 1 [6].

Biodiesel production from edible oils would not be viable for a developing country like India, even though India has large potential to be one of the leading world producers of biodiesel. Hence, as far as India is concerned, non-edible oil is the most suitable option for biodiesel production purposes.

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**Table 1**
Some of the oil yielding species and their oil content.

| Scientific name | Common name | Oil content in % |
|---|---|---|
| *Azadirachta indica* | Neem | 20–50 |
| *Simmondsia chinensis* | Jojoba | 50 |
| *Vateria* sp. | Dhupa | 20–27 |
| *Calophyllum inophyllum* | Undi | 50–73 |
| *Mesua ferrea* | Nahor | 40 |
| *Aleurites* sp. | Tung | 50–60 |
| *Schleichera oleosa* | Kusum | 34 |
| *Ceiba pentandra* | Kapok | 25–28 |
| *Simarouba glauca* | Lakshmi tharu | 60–75 |
| *Madhuca longifolia* | Mahua | 35 |
| *Garcinia indica* | Kokum | 33–44 |
| *Shorea robusta* | Sal | 12–13 |
| *Diploknema* | Aisandra | 60 |
| *Elaeis guineensi* | Oil palm | 56 |
| *Jatropha curcas* | Jatropha | 21–31 |
| *Pongamia pinnata* | Punga | 27–40 |

Biodiesel is defined as the mono-alkyl esters of long-chain fatty acids, and is obtained from vegetable oils or animal fats through a chemical process in the presence of alcohol with an acid or alkaline catalyst. Recently, there have been multiple efforts by many researchers to find out the feasibility to convert raw vegetable oil into biodiesel. Blending, emulsification, thermal cracking and transesterification are identified as the most common methods, and used widely to reduce the viscosity of vegetable oils [7]. The performance and emission characteristics of biodiesel of different vegetable oils have been presented by various authors in various papers, and they have been proved as successful alternative fuels, viz., rubber seed methyl ester [7], sunflower oil methyl ester [8], rapeseed methyl ester [9], canola and palm oil methyl ester [10], honge oil [11], preheated animal fats and animal tallow [12,13], chicken fat methyl ester [14] and waste cooking oil [15,16]. The most common phenomenon of different biodiesels are that there is not much variation in engine performance; there is a significant reduction in hydrocarbon (HC), carbon monoxide (CO) and smoke emissions; but the $NO_x$ emission is increased compared to diesel [17–21].

In this work, the Kapok methyl ester (biodiesel) was extracted and its different blend ratios with diesel were tested in a direct injection diesel engine. The various performance and emission measures of the engine were then analyzed. Moreover, this paper presents a comprehensive analysis of the engine performance and emission levels under different load conditions of the engine, for different blend ratios of Kapok methyl ester and diesel.

## 2. Characteristics of Kapok seed oil

Kapok (Ceiba Pentandra) which is also known as silk-cotton, is a native of America and West Africa, and the seeds were introduced to Southeast Asia via India [22]. The Kapok tree grows 60–70 m tall, and the adult tree produces between 1000 and 4000 seed pods at a time, with each pod containing nearly 250 seeds surrounded by a fluffy and yellowish fiber. The seed contains 25–28 % oil content and the oil color is yellow with a pleasant mild odor. The important properties of Kapok seed oil compared with other oils, are given in Table 2 [7,23].

Triglycerides are the basic and major constituents of any vegetable oils, they around 90 to 98%, and remains are small amounts of mono- and diglycerides. Triglycerides are esters of three fatty acids and one glycerol, and these all are having a considerable amount of oxygen molecules in its structure. The common fatty acids available in vegetable oils are stearic, palmitic, oleic, lenoleic, lenolenic and etc. The fatty acid composition of Kapok seed oil is given in Table 3 [23,24].

**Table 2**
Comparison of Kapok seed oil with other oils.

| Property | Kapok | Rubber | Rapeseed | Cotton | Soybean | Sunflower |
|---|---|---|---|---|---|---|
| Specific gravity | 0.921 | 0.91 | 0.914 | 0.912 | 0.92 | 0.9161 |
| Kinematic viscosity at 40 °C in cSt | 30.2 | 66.2 | 39.5 | 50 | 65 | 58 |
| Flash point (°C) | 262 | 198 | 280 | 234 | 230 | 220 |
| Cloud point (°C) | −2 | 4 | −3.9 | 1.7 | −3.9 | 7.2 |
| Pour point (°C) | −5 | −8 | −31.7 | −15 | −12.2 | −15.0 |
| Calorific value (MJ/kg) | 39.59 | 37.5 | 37.6 | 39.6 | 39.6 | 39.6 |
| Acid value | 21 | 34 | 1.14 | 0.11 | 0.2 | 0.15 |
| Cetane number | 37 | 37.5 | 37.6 | 41.8 | 37.9 | 37.1 |
| Carbon residue wt.% | 0.15 | 0.30 | 0.30 | 0.24 | 0.27 | 0.23 |
| Ash wt.% | <0.001 | 0.020 | 0.054 | 0.010 | <0.010 | <0.010 |
| Sulfur wt.% | 0.12 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |

The kinematic viscosity of Kapok seed oil is several times higher than that of diesel fuel, and this higher viscosity can create problems, such as trouble in starting the engine, in the pumping and atomization of the injection system and combustion related problems. Thus, a fuel with very high viscosity is not good for the engine, and also this can result in reducing the volume of fuel injection with low pressure buildup. The volatility, that is vapourization capacity of a fuel is measured by 90% distillation temperature. During distillation of Kapok seed oil, 10% of volume is recovered at 288 °C, 50% at 314 °C, and 90% at 346 °C, whereas, diesel fuel has obtained the temperatures 215 °C, 274 °C and 340 °C for recovery of volume 10%, 50% and 90% respectively. The evaporation point explains that the Kapok oil has low volatile characteristic, which may also increase in hydrocarbon emission and smoke density. So, the suitable modifications can be incorporated in the raw Kapok oil in order to overcome the aforesaid deficiencies.

## 3. Esterification of Kapok seed oil

In the converting process of high free fatty acid (FFA) feed stock into biodiesel, the addition of excessive catalysts may create more problems than it solves. It can also prevent the separation of the glycerol from the ester. So that the following well known techniques like, enzymatic method, glycerolizes, acid catalysis and followed by alkali catalysis can be used, to obtain the satisfactory yielding of biodiesel by a chemical process [7,25]. The acid value of raw Kapok seed oil is 21.0, whereas that of FFA is approximately half the acid value of Kapok oil [26]. The maximum amount of FFA acceptable in a base catalyzed system is less than 2%, and preferably less than 1% [8]. The acid catalyzed pretreatment followed by the alkali catalyzed transesterification technique has been selected for the Kapok seed oil, due to its high FFA, and its being the most suitable technique for biodiesel conversion. This technique consists of the following two parts:

**Table 3**
Fatty acid composition of Kapok seed oil.

| Fatty acid | Systematic name | Structure[a] | Formula | % wt. |
|---|---|---|---|---|
| Myristic | Tetradecanoic | 14:0 | $C_{14}H_{28}O_2$ | 0.25 |
| Palmitic | Hexadecanoic | 16:0 | $C_{16}H_{32}O_2$ | 24.0 |
| Stearic | Octadecanoic | 18:0 | $C_{18}H_{36}O_2$ | 5.0 |
| Arachidic | Eicosanoic | 20:0 | $C_{20}H_{40}O_2$ | 1:0 |
| Behenic | Docosanoic | 22:0 | $C_{22}H_{44}O_2$ | 0.5 |
| Oleic | *cis*-9-Octadecanoic | 18:1 | $C_{18}H_{34}O_2$ | 22.0 |
| Linoleic | *cis*-9, *cis*-12-Octadecanoic | 18:2 | $C_{18}H_{32}O_2$ | 32.5 |
| Linolenic | *cis*-9, *cis*-12, *cis*-15-Octadecanoic | 18:3 | $C_{18}H_{30}O_2$ | 6.3 |
| Sterculic | *n*-octylcycloprop-1-enyl-octanoic | 19:2 | $C_{19}H_{34}O_2$ | 8.6 |

[a] xx:y indicates xx carbons with y double bonds in the fatty acid chain.