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Experimental investigation of kapok (*Ceiba pentandra*) oil biodiesel as an alternate fuel for diesel engine

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ABSTRACT

This manuscript explores the possibility of using kapok oil as a source for biodiesel production and experimentally investigate it, KME (kapok oil methyl ester), as a diesel engine fuel. Distinctly, this manuscript is novel on the basis of adopting a different approach in extracting oil from kapok seeds and testing of the produced KME in a diesel engine, perhaps for the first time. Accordingly, kapok oil, an indigenous source, has been extracted from kapok seeds through steam treatment process followed by crushing in an expeller, which has not been considered so far by researchers. Significantly, this method is chosen with the intent to extract oil for its use in diesel engine. Typically, KME is synthesized by trans-esterification process, and the properties of it, evaluated by ASTM standard methods, are in concordance with biodiesel standards. Having ensured the feasibility of its use in diesel engine, KME is tested in a single cylinder diesel engine to appraise the performance, combustion and emission characteristics of the engine. The experimental investigation reveals that the thermal efficiency of the engine for B25 is superior to conventional diesel by 4%. In the same token, the emission and combustion results of lower blend of KME (B25), showed comparable results with diesel, making KME as one of the pertinent fuel for diesel engine.

1. Introduction

Our dependence on fossil fuel grows stronger each year and with the rapid industrial growth, the price of crude oil has been soared up to massive levels [1,2]. As a follow out of these uncertainties, the world has started moving towards the sustainable energy resources, with particular emphasis on renewable fuel derived from biological raw material. Recently, the use of alternate fuel is gaining immense popularity and it has been unanimously reported that biodiesel is one of the best alternate fuel in the realm of renewable sources of fuel [3,4].

The use of vegetable oils directly in diesel engine had been commemorated early since 1900, when Rudolf diesel tested peanut oil in a diesel engine [5,6]. Though the cost of vegetable oil is higher compared to diesel, it was used at times when there arose an imminent threat of petroleum based fuel deprivation. In the years gone by, the usage of vegetable oils directly in diesel engine is hindered by their own setbacks such as high viscosity, poor volatility and poor cold flow properties [7,8]. To alleviate the problem of high viscosity, the vegetable oil has to undergo a process called trans-esterification, whereby the triglyceride molecules are broken down into methyl ester (biodiesel) [9,10]. Biodiesel, mono alkyl ester of long chain fatty acid, derived from vegetable oil or animal fat [11,12], can be used in diesel engine without any modifications because of its potential benefits [13,14]. Its prevalence together with its renewability and bio degradability is accompanied by other advantages such as decreased HC (hydrocarbon), CO (carbon monoxide), and particulate matter emissions [15,16]. However, in the pursuit of using biodiesel in diesel engine, it suffers a setback of slightly higher NO_X (nitrogen oxide) emission owing to the presence of surplus oxygen [10,17].

In the process of selecting suitable oil for biodiesel production, there are several considerations such as availability, cost, stability and manufacturing method. In recent times, the demand for edible vegetable oil has increased and there are concerns such as high cost and negative impact on food chain [18]. Therefore, non-edible oils such as Jatropha (*Jatropha carcus*), Karanja (*Pongamia pinnata*), Nagchampa (*Callophyllum inophyllum*), rubber seed (*Hevca brasiliensis*), Neem (*Azadirachta indica*), Mahua (*Madhucha indica*), Jojoba (*Simmondsia chinensis*), and microalgae are being used as prominent source for biodiesel production as they are readily and abundantly available [14]. Moreover, non-edible plants can be grown in waste lands, which further benefits as green cover to waste land. In the current generation, researchers have forfeited using edible vegetable oil as source for biodiesel production and rather they have set their sight on non-edible oils for the reasons explained above.

In the wake of all contemporary issues pertaining to the choice of suitable feedstock for biodiesel production, various studies on

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the characterization of biodiesel form non-edible oils as substitute for diesel have been investigated by many researchers [7,14,19]. In this regard, the non-edible kapok oil (*Ceiba pentandra*) could be a potential alternative source for biodiesel production [20]. Kapok tree is grown in India, Malaysia and other parts of Asia, while it also has great economic importance for domestic and industrial use in Nigeria. The pods of the tree contain seeds surrounded by a fluffy, yellowish fiber, that is a mix of lignin and cellulose, and notably, about 120–175 seeds could be found inside each pod. The oil extracted from the seed is being considered as an indispensable source for synthesizing biodiesel and researchers are deliberating to harness it. The history of kapok seeds dates back to 1931, when Dr. C.L. Alsberg, happen to collect some kapok seeds, during his visit to Java and examined the fatty acid composition of the small quantity of oil extracted from the seeds [21]. Reportedly, from his study, the oil was found to contain 17.15% of saturated fatty acid and 76.32% of unsaturated fatty acid. Later, from 1964 to 1974, various studies disclosed the presence of more unsaturated fatty acid than saturated fatty acids, with variable proportions of cyclo-propenoid fatty acids [22]. At present, kapok oil has only limited application and the natural production of seeds remain underutilized. A recent study on the production of biodiesel from non-edible kapok (*C. pentandra*) oil has reported the use of soxhlet extractor and solvent, *n*-hexane, to extract oil from dried and powdered kapok seeds [23]. Subsequently, they synthesized the required biodiesel by trans-esterification process, presenting the results of reaction time, reaction constant and activation energies, during the conversion of raw oil into methyl ester. Another research work in connection with production of biodiesel from kapok oil has adopted the same approach to extract oil and have reported higher oxidative stability of kapok methyl ester than the standard values [24]. In the above works, only the chemistry part of the oil and biodiesel were discussed in detail, targeting the kinetics of biodiesel production form kapok oil.

It is reliably learnt from the literature study that testing of KME (kapok methyl ester) in diesel engine has not come to light so far and only the production of it has been optimized. Further, for diesel engine applications, large quantity of oil is required to produce biodiesel and therefore, the Soxhlet extraction method, as reported in the past studies, would not be suitable. In this scenario, as a different attempt, this study has adopted steam treatment process followed by mechanical crushing technique, which extracts larger proportion of oil conveniently. Further, this study has focused on preparing the biodiesel from kapok oil (*C. pentandra*) by trans-esterification process and it has been used as substitute for diesel in a diesel engine for the first time. Finally, various blends of KME with diesel are prepared and the performance, combustion and emission characteristics of a diesel engine are investigated and analyzed.

2. Materials and methods

2.1. Extraction of oil from kapok seeds

The kapok pods were collected from a village in India on January 2013, which encompasses a large number of black color kapok seeds surrounded by silky fiber. Thus far, kapok oil is reported to have been extracted by Soxhlet extraction method using *n*-heptane as solvent [23,24]; however, this study has attributed to extract kapok oil by steam treatment process followed by mechanical crushing process. The outline of the steam treatment process followed by crushing of the hot seeds in an expeller has been depicted in Fig. 1. Firstly, the seeds, separated from the fibers, were noted to be in good physical condition and therefore, without subjecting it to any pretreatment process, these seeds were fed into a reactor of large capacity to hold bulk volume of them. After which, steam from a separate line is allowed to be passed into the reactor so as to soak the seeds with hot steam and help extract small fraction of raw oil. Subsequently, the left out oil in the seeds are recovered by crushing the hot seeds in a mechanical expeller and the total quantity of oil, as collected through these steps, is channelized into a separate tank as shown in Fig. 1. The extracted oil is then purified through a filter so as to remove any sediments or contaminants left out in it. After the extraction process, the total oil yield, which was calculated to be 21%, was ensured from the weight of seeds used and weight of total oil extracted using the following formula:

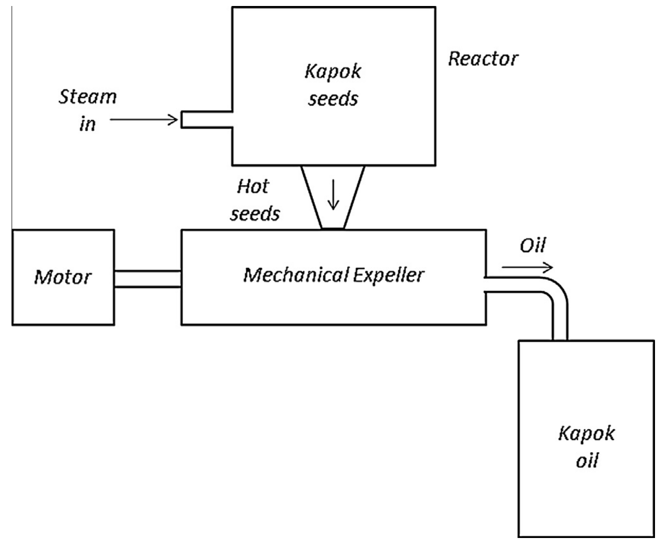

Fig. 1. Extraction of kapok oil from kapok seeds.

$$\text{Total yield } (\%\ \text{weight}) = \frac{\text{Weight of oil extracted}}{\text{Weight of seeds}}$$

For application like diesel engine, this method of oil extraction is reasonable, as it admits bulk extraction of oil in a single trail and makes the method economical. Further, this method is believed to enhance the recovery of oil than normal mechanical expulsion technique and would help improve the properties of the extracted oil. This is because, hot treatment of seeds by steam recovers some proportion of oil and this coupled by crushing in a mechanical expeller would help enhance maximum recovery of oil. Distinctly, the process of steam treatment followed by mechanical crushing has not been attempted by many researchers, when compared to other oil extraction techniques such as mechanical, solvent and enzymatic extraction methods [25]. The physical and thermal properties of the kapok oil, as evaluated by ASTM standard methods, have been shown in Table 1. The estimation of fuel properties reveals that the raw kapok oil has higher viscosity and boiling point, which does not support its direct use in a diesel engine. Therefore, it is essential to trans-esterify the extracted kapok oil to reduce its viscosity to permissible biodiesel standard level and make it feasible for operation in a diesel engine.

2.2. Trans-esterification of kapok oil

In the sample preparation of biodiesel, one liter of kapok oil is heated in a magnetic stirrer apparatus, containing a hot plate and stirrer. The oil is heated up to 65 °C and in parallel, KOH (potassium hydroxide) pellets were dissolved with methanol in a separate vessel to form potassium methoxide solution. The formed potassium methoxide solution is then poured in the heated oil and