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Pine oil–biodiesel blends: A double biofuel strategy to completely eliminate the use of diesel in a diesel engine

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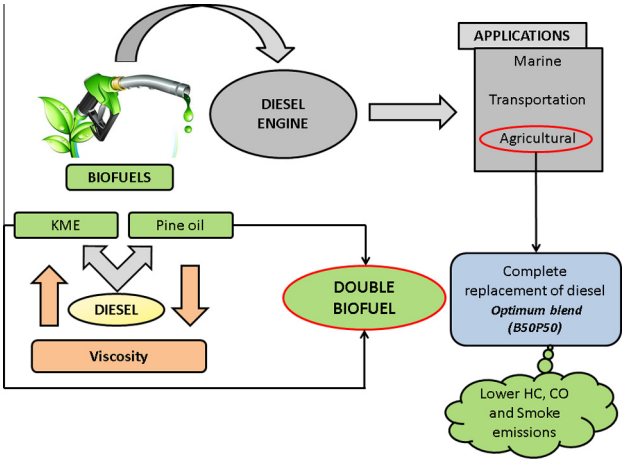
HIGHLIGHTS

- The concept of double biofuel is adopted to replace the use of diesel in a diesel engine.
- Less viscous pine oil and high viscous KME were used as two renewable biofuels.
- From the experimental outcome, B50P50 was regarded as optimum blend.
- HC, CO and smoke emission for B50P50 were reduced by 8.1%, 18.9% and 12.5% than diesel.
- The performance and combustion characteristics for B50P50 were in par with diesel.

GRAPHICAL ABSTRACT



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ABSTRACT

Pine oil, synthesized from pine oleoresin, is recently being viewed as a potential renewable source of fuel for diesel engine application. Significantly, the estimated physical and thermal properties of pine oil are suited for its use in diesel engine, with the notable advantages of lower viscosity, boiling point and comparable calorific value with diesel. In this study, we decidedly conceived a strategy to blend it with a biodiesel, instead of diesel, so as to look out for double biofuel, a measure aimed at complete replacement of fossil fuels. As such, in the current investigation, KME (kapok methyl ester), a biodiesel derived from kapok oil, was blended with pine oil in various proportions such as B25P75, B50P50 and B75P25. Significantly, up on blending pine oil with KME, the viscosity, boiling point, cetane number and other properties of the resultant blends were found to be appropriate, as the merits and demerits of one biofuel over the other are mutually balanced. Therefore, the reported blends were subsequently tested for its combustion, performance and emission characteristics in a single cylinder diesel engine. From the experimental investigation, B50P50 blend was found to be amenable for its use in diesel engine without any modification, as the performance and combustion characteristics of the engine was found to be comparable with diesel. Further, the major emissions such as HC (hydrocarbon), CO (carbon monoxide) and smoke for B50P50 were observed to be 8.1%, 18.9% and 12.5% lower than diesel at full load condition, while NO_X (oxides of nitrogen) emission was in par with diesel.

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1. Introduction

The demand for energy, excessive reliance on crude oil import and growing environmental devastation has fostered the research and development on alternate renewable source of fuels, known as biofuels. Most often, these biofuels are derived from biological raw materials and could be classified into two categories based on their viscosity, viz less and high viscous fuels. While vegetable oil and its derivatives, biodiesel, could be regarded as high viscous fuels, alcohols and ethers can be termed as less viscous fuels. Alcohol based fuels such as ethanol and methanol, are more amenable for its use in spark ignition engine, while the use of biodiesel and other ether based fuels are becoming more prominent in compression ignition engine [1,2]. However, in the past decade, researchers have contemplated on using alcohol based fuels in diesel engine too, due to demand for petroleum diesel and the fact that alcohols are also compatible for its use in diesel engine [3]. Though the use of pure alcohols in diesel engine is unfeasible, considering the insurmountable challenges with their poor ignition properties and lower calorific value [3], they can find their use in diesel engine by modifying the engine design, particularly the fuel injection systems [4]. However, they can be used as blend fuels such as alcohol–diesel blend and alcohol–diesel emulsion in a diesel engine without any modifications, which is regarded as the simplest and attractive method, though complete replacement of diesel in any case is impossible [5].

Research studies on the use of other less viscous fuel, in the likes of alcohols, such as eucalyptus oil and pine oil have also garnered much attention in the recent times [6–8]; as the fuel properties of them are conducive for their operation in diesel engine. Similar to alcohols, these fuels have lower viscosity; however, unlike alcohols, they have comparable caloric value with diesel. Notably, eucalyptus oil, which falls under the category of essential oil derived from plants, has been proven to be a potential substitute for diesel in the recent past [9]. In the same note, use of less viscous biofuel, pine oil, obtained from the resins of pine tree, has been investigated by Vallinayagam et al. [7,10] and its feasibility in a diesel engine is ensured. Typically, both these fuels were used in blends with diesel and are reported to have shown better performance, combustion and emission characteristics.

Over the past few years, investigation on the use of less viscous fuels such as ethanol, methanol and eucalyptus oil with biodiesel, instead of diesel, have also been reckoned. In this regard, Anand et al. [11], as a measure to completely eliminate the use of diesel, studied the combustion, performance and emission characteristics of a diesel engine fueled by a blend of 90% karanja methyl ester and 10% methanol. The study reported an increase in maximum thermal efficiency by 4.2% at 80% load, with the simultaneous reduction in NO_X (oxides of nitrogen) and smoke emission. Soon after the realization of improved performance with alcohol–biodiesel blends, Yilmaz and Sanchez [3] compared the performance and emission characteristics of a diesel engine fueled by biodiesel–ethanol and biodiesel–methanol blends, and the outcome of their work implied that biodiesel–ethanol blends are more effective than biodiesel–methanol blends in respect of engine performance and emission. To help enhance the combustion characteristics and exclude the use of conventional diesel as fuel, Kasiraman et al. [12] demonstrated the use of less viscous camphor oil with CSNO (cashew nut shell oil), a high viscous vegetable oil, in various proportions (10–30%) and showed better engine characteristics. In a recent study, Devan and Mahalakshmi [8] blended methyl ester of paradise oil with eucalyptus oil and used them as alternate renewable fuel for diesel engine, eluding the use of diesel completely, and reported better performance and emission than diesel.

Deeper scrutiny of all available literatures shows some endeavors, in the recent past, to use less viscous fuels in blends with either diesel or biodiesel. Further, it has been reliably construed that lower alcohols such as methanol and ethanol could be blended with either diesel or biodiesel only in lower proportions due to its lower heating value and higher latent heat of vaporization [13,14]. Nonetheless, the other contemporary less viscous bio derived fuel, eucalyptus oil, could be added in higher percentages with diesel/biodiesel, as it is reported to have comparable calorific value with diesel [15]. Distinctly, the blending of eucalyptus oil kind of fuels with biodiesel would give a priority of complete replacement of diesel, without compromising on the engine performance and emission.

Despite the immense benefits of blending fuels having lower viscosity and better calorific value with biodiesel, little consideration has been shed to develop blends of such kind, known as double biofuels, and investigate them in a diesel engine. To fulfill this limitation, in the current study, pine oil biofuel, endowed with lower viscosity and comparable calorific value with diesel, has been chosen to be blended with high viscous biodiesel, KME (kapok methyl ester). The benefits of double biofuel, which is to completely replace diesel, has been reaped thoroughly and distinctly, blending of pine oil with biodiesel has not been investigated so far. As such, pine oil was blended with KME in various proportions such as B25P75 (pine oil – 75% and KME – 25%), B50P50 (pine oil – 50% and KME – 50%) and B75P25 (pine oil – 25% and KME – 75%), by stirring them in an ultrasonic agitator so as to keep the integrity of the blend intact. Finally, pine oil–KME blends were tested in a single cylinder diesel engine without any modification and the performance, combustion and emission characteristics of the engine were analyzed and compared.

2. Pine and kapok oil – overview of feedstock

Currently, this study has used two feedstock viz pine oil and kapok oil, both come under the category of biofuel, but the origin of the former is from the resins of pine tree while the latter is from the seeds of kapok tree. Both the feedstocks, by virtue of their nature, are indigenous in their own way and do have all the probability to qualify as an alternate fuel for diesel engine [6,16]. Pine oleoresin, the raw material for pine oil synthesis, is tapped from pine tree and is subjected to steam distillation, before being treated with acids to synthesize the required pine oil. Typically, pine oil, by its appearance and nature, can be regarded as one of the less viscous fuels in the likes of eucalyptus oil, ethanol and methanol. Chemically speaking, pine oil, an alicyclic hydrocarbon, consists of mainly cyclic terpene alcohols, known as terpineol ($C_{10}H_{18}O$) along with alpha-pinene ($C_{10}H_{16}$). Further, from its molecular structure, it is evident that it possesses inherent oxygen, with lower molecular weight and shorter carbon chain length than diesel or biodiesel. Notably, pine oil, despite being a higher alcohol, does not produce any cooling effect like methanol and ethanol as the latent heat of vaporization of it is not higher like lower alcohols. On the other hand, kapok oil, the other feedstock chosen in this study, is extracted from kapok seeds by steam treatment process followed by mechanical crushing and the extracted oil is subjected to trans-esterification process to synthesize the required biodiesel, KME. Among the different fatty acids present in kapok oil, linoleic acid was found to be its major constituent with 18 carbon atoms and 2 oxygen atoms.

The thermal and physical properties of pine oil–KME blends, estimated by ASTM standard methods, are portrayed in Table 1. It is evident that pine oil has lower viscosity, flash point and boiling point, and higher calorific value than its counterpart, KME. On the contrary, pine oil is deemed to have lower cetane number than KME, affecting the auto-ignition of it. However, after blending pine oil with KME, some of the properties of the resulting blends are

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