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Lemon peel oil – A novel renewable alternative energy source for diesel engine

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ABSTRACT

The present research work has embarked on to exploit the novel renewable and biodegradable source of energy from lemon fruit rinds. A systematic approach has been made in this study to find the suitability of lemon peel oil for internal combustion engines and gensets applications. Extracted lemon peel oil is found to exhibit comparatively very low viscosity, flash point and boiling point than that of conventional diesel. Various blends of lemon peel oil have been prepared with conventional diesel with volumetric concentration of 20%, 40%, 50% and 100% and their physical and chemical properties are evaluated for its suitability in direct injection diesel engine. Lower cetane index of lemon peel oil significantly influences the ignition delay period and peak heat release rate that lead to the penalty in NOx emissions. Interestingly, the diesel engine performance characteristics have been improved to a remarkable level with higher proportions of lemon peel oil in the blends. In addition, the reduction of BSCO, BSHC and smoke emission is proportional to the lemon oil concentration in the blends. Overall diesel engine characteristics indicated that lemon peel oil can partially or completely replace the petroleum diesel usage to a great extent in developing countries like India.

1. Introduction

The modern economy is growing in a faster pace. Petroleum fossil fuels play a vital role in the transportation and power generation sector and have a great impact in the economy of any country. It is evident that the sources of petroleum resources are available only at few places across the globe which causes a monopoly in the trade market of petroleum fuel [1]. In addition, the harmful pollutant from hydrocarbon based fuels in automobiles causes the global warming and other environmental impacts [2]. Therefore, several renewable and biodegradable based alternative fuels had been considered as fuel sources across the globe in the past few decades. The biodiesel transesterification from all kind of available edible and in-edible vegetable oils and animal fats being the best choice for diesel engine application and it was also successfully implemented in many developed countries [3,4]. However, the biodiesel usage for diesel engine application had witnessed many operation difficulties such as higher viscosity, lower heat capacity, gum formation, auto oxidation and engine durability [5,6]. Apparently, biofuels synthesised from any parts of plants like leaves, wood, resins and grass also have unique properties similar to that of diesel fuels. These kinds of biofuels have very significant properties such as very low viscosity and low boiling point which can offer better atomization and enhanced evaporation. Furthermore, the heating values of all of this low viscous biofuels are almost comparable or equivalent to conventional diesel fuels [7]. The prominent sources of biofuels are eucalyptus oil, pine oil, lemon grass oil and turpentine oil.

Recent research on biofuels from peels of various fruits and vegetables have been the focus around the world to replace the conventional diesel fuel with these alternatives, renewable, biodegradable, eco-friendly fuel. The extraction of biofuel from peel of orange fruit was used as renewable biofuel in single cylinder diesel engine by Purushothaman and Nagarajan [8]. They had investigated the performance and combustion characteristics of diesel engine fuelled with orange peel oil and compared their results with conventional diesel fuel. The diesel engine operation

Abbreviations: BTDC, before top dead centre; BSFC, brake specific fuel consumption; BSEC, brake specific energy consumption; BTE, brake thermal efficiency; BMEP, brake mean effective pressure; DI, direct injection; BSHC, brake specific unburned hydrocarbon; BSNOx, brake specific oxides of nitrogen emission; BSCO, brake specific carbon monoxide; DEE, diethyl ether; LPO 20, 20% of lemon peel oil + 80% of diesel by volume; LPO 100, 100% of lemon peel oil by volume; ppm, parts per million; EGR, exhaust gas recirculation; IAN, isoamyl nitrate; DTBP, di-tertairy butyl peroxide; LVLC, less viscous and low cetane; GC–MS, Gas Chromatography–Mass Spectrometry; IT, injection timing; CA, crank angle; FSN, Filter Smoke Number; MT, Metric Tonnes.

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with neat orange oil has resulted in increased delay period and combustion duration and that enhanced the brake thermal efficiency to 31.7% compared to diesel fuel of 29.3%. The carbon monoxide and hydrocarbon emissions were decreased significantly for neat orange oil fuel than that of diesel fuel. However, higher NO_x emission was observed with orange oil fuel at all loads compared to diesel fuel. The above researchers Purushothaman and Nagarajan [9] had made attempts to reduce NOx by introducing diethyl ether to the blend of orange peel oil with diesel fuel. They have evaluated the influence of 36 mg/s of diethyl ether (DEE) with neat orange oil and compared the performance and emission characteristics to that of neat orange oil without DEE. The addition of DEE with orange oil, marginally increase the brake thermal efficiency and reduce the NOx emissions. However, the CO and HC emissions slightly increased with DEE addition which also lies within the acceptable limits.

The ignition improver paradise oil methyl ester was blended with biofuel namely eucalyptus oil in the volumetric proportion of 50:50 [10]. The brake thermal efficiency of 50% eucalyptus oil - 50% pure biodiesel was 2.4% higher than diesel fuel at 100% loading condition. The 50% addition of ignition improver paradise oil methyl ester resulted in 49% of smoke reduction, 34.5% reduction of hydrocarbon emissions and 37% reduction in carbon monoxide emissions with 2.7% increase in NOx emissions. The lower cetane number of eucalyptus oil was reduced by ignition improver and the same had been reflected in the combustion duration. The turpentine biofuel was produced from pine gum or pine wood and the same had been examined as renewable biofuel for diesel engine by Anand et al. [11]. They derived turpentine biofuel from pine tree through pyrolysis process in their research work. The physical and chemical properties of turpentine fuel were comparable to conventional petroleum diesel fuel. It was reported that the 30% of turpentine oil with diesel blend had shown improvement in brake power and heat release rate along with favourable emission whereas the concentration of turpentine oil beyond 30% resulted in decreased performance and emission characteristics.

Vallinayagam et al. [12] have harvested the pine oil, a novel biofuel for diesel engine applications. The pine oil was blended with neat diesel in the concentration of 25%, 50%, 75% and 100% and study have been performed in a 5.2 kW, 4-stroke, direct injection diesel engine. The combustion characteristics of diesel engine in the form of peak cylinder pressure and heat release rate had shown that 100% pine oil produced higher peak pressure and heat release rate compared to pine oil blends and diesel fuel. The lower viscosity of pine oil accelerated the evaporation rate and mixing processes and thus produced prominent combustion. The brake thermal efficiency of diesel engine was 5% higher for 100% pine oil compared to neat diesel fuel. Moreover, the CO, HC and smoke emissions were reduced beyond 30% when the diesel engine was operated with 100% pine oil with significant penalty in NO_x formations. They reported that 100% pine oil may be directly utilized in the direct injection diesel engine with improved performance and combustion characteristics, if NOx emissions and knocking could be effectively controlled by other techniques.

The limitations of the above NOx emissions were addressed by the same authors Vallinayagam et al. [13] by introducing two different ignition improvers namely isoamylnitrate (IAN) and Di-Tertiary Butyl Peroxide (DTBP) on the performance, combustion and emission characteristics of 50:50% pine oil-diesel blend in a direct injection diesel engine. With the introduction of ignition improvers IAN and DTBP of 1.5% with pine oil blend had shown significant reduction in delay period thus resulted in 12.8% and 19.2% of NO_x reductions for the 50% pine oil-diesel blend. Thus they reported that the DTBP had shown superior performance in all aspects of engine characteristics comparatively to that of IAN as an ignition improver.

Vallinayagam et al. [14] have performed the engine testing with neat pine oil fuel in a direct injection compression ignition engine by preheating the inlet air using glow plug attachment. They reported that the diesel engine was running smoothly without causing knocking problem with the support of inlet air preheated with glow plug assistance. They also pointed out that the brake thermal efficiency for 100% pine oil fuel operation was comparable to diesel fuel when the inlet air was preheated to 60 °C under glow plug ignition. They also stated that 100% pine oil operation decreased the CO and smoke emissions up to 13.2% and 16.8% under the same mode of operation at 100% load condition. They also observed that the NOx emissions increases with increase in inlet air temperature by preheating at full load conditions and its value slightly decrease with decrease in inlet temperature of air.

Vallinayagam et al. [15] have formulated a new strategy by blending two biofuels namely pine oil and kapok methyl ester for complete elimination of fossil diesel fuel in a direct injection diesel engine. The kapok biodiesel concentration was varied in the proportion of 25%, 50% and 75% and 100% in the biofuel blends. The study indicated that the brake thermal efficiency of 25% and 50% biodiesel with pine oil were higher than diesel at all testing conditions. However, the addition of biodiesel beyond 50% reduced the brake thermal efficiency at all loads. They reported that 50% biodiesel blend with pine oil may be used directly in the diesel engine without any modifications as their engine characteristics were found to be equivalent to that of neat diesel. They also pointed out significant reductions in hydrocarbons, carbon monoxide and smoke for this blend combination with NOx emission similar to that of conventional diesel. Thus from their study, they concluded that 50% kapok biodiesel with 50% pine oil shows better engine characteristics compared to all other blends.

Alagumalai [16] had studied the possible utilization of lemongrass oil (*Cymbopogon flexuosus*) as a renewable fuel source under premixed charge mode in a diesel engine. The study revealed that the ignition delay period was shorter for neat lemongrass oil under premixed and normal mode of operation compared to neat diesel which significantly affected the combustion process. The performance assessment of diesel engine was investigated by Dinesh et al. [17] using *Cymbopogon flexuosus* as a renewable fuel. The lemongrass oil was extracted from lemon tree through steam distillation process and blended with diesel in the proportions of 10%, 20%, 30%, 40% and 100% for their experimental study. It was noted that the increase in concentration of lemongrass oil in the blend greatly reduced the performance characteristics with significant penalty in peak pressure and heat release rate beyond 20% concentration of lemon grass oil due to its reduced properties. At the same time, the CO, HC and smoke emissions were reduced with increase in richness of biofuel in the blend.

The light biofuels commonly known as less viscous and less Cetane rated fuels (LVLC) are getting wider and deeper attention in recent times because of its unique nature of low viscosity and low Cetane number than petroleum diesel. In addition, these renewable biofuels originates from various parts of the plants and other biomass through pyrolysis and steam distillation process. The carbon chain lengths of these LVLC fuels are comparatively low compared to conventional hydrocarbon fuels. Interestingly, the heat content of these LVLC fuels are equivalent or even slightly higher than petroleum diesel and that would not lead to power drop when the neat biofuel is used in diesel engine [18].

1.1. Novelty and motivation of the present study

The operational feasibility of low viscous and low cetane fuels as alternative energy sources has stimulated us to find a new alternative fuel for diesel engine applications. In this regard, a