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Influence of fuel injection pressures on *Calophyllum inophyllum* methyl ester fuelled direct injection diesel engine

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ABSTRACT

The trend of using biodiesels in compression ignition engines have been the focus in recent decades due to the promising environmental factors and depletion of fossil fuel reserves. This work presents the effect of *Calophyllum inophyllum* methyl ester on diesel engine performance, emission and combustion characteristics at different injection pressures. Experimental investigations with varying injection pressures of 200 bar, 220 bar and 240 bar have been carried out to analyse the parameters like brake thermal efficiency, specific fuel consumption, heat release rate and engine emissions of direct injection diesel engine fuelled with 100% biodiesel and compared with neat diesel. The experimental results revealed that brake specific fuel consumption of *C. inophyllum* methyl ester fuelled engine has been reduced to a great extent with higher injection pressure. Significant reduction in emissions of unburnt hydrocarbons, carbon monoxide and smoke opacity have been observed during fuel injection of biodiesel at 220 bar compared to other fuel injection pressures. However oxides of nitrogen increased with increase in injection pressures of *C. inophyllum* methyl ester and are always higher than that of neat diesel. In addition the combustion characteristics of biodiesel at all injection pressures followed a similar trend to that of conventional diesel.

1. Introduction

Energy is the vital ingredient in world economy and one of the fundamental requirements for human existence. The overwhelming rate of energy consumption throughout the globe leads to identify the novel energy sources and new alternate renewable technologies aimed for eco-friendly environment. Most of the transportation vehicles are fuelled by conventional diesel fuel and also used for power generation. Nowadays, biodiesel is found be feasible alternate to substitute the existing petroleum-based diesel fuels. The fuel properties of the biodiesel are almost similar in physical and chemical nature of the petroleum diesel and hence it is opted as a viable alternative fuel to neat diesel [1]. Biodiesel fuels are derived from various vegetable and animal fats which offer many advantages over conventional petroleum diesel like superior cetane number, better lubricity, and lower carbon monoxide and unburned hydrocarbons. Moreover biodiesel fuels are biodegradable, renewable and nontoxic in nature [2]. Non-edible oil is the most preferable choice of biodiesel source in India compared to edible oils like palm oil, soyabean oil, ricebran oil and sunflower oil etc. [3]. This is because of scarcity of edible oil for food preparation in India. *Calophyllum inophyllum* oil which is non-edible in nature could be used as a source for biodiesel esterification in India and is available in abundant quantities in places like, Southern east and East Asia, India and Australia.

Several methods have been followed in production of biodiesel such as micro-emulsion, pyrolysis, dilution and transesterification. Among these processes, trans-esterification is the most preferable method and economical one [4]. During this process of trans-esterification, the triglycerides present in the vegetable oil reacts with alcohol in the present of suitable alkaline or acidic catalyst to from ester and tri-hydroxy alcohol. This process of trans-esterification helps in reducing the high viscous vegetable oil to low viscous biodiesel [5]. Researchers in the past have suggested that presence of high free fatty acids in the vegetable oil results in formation of soap when treated with alkaline catalyst; thereby the yield of biodiesel diminishes [6]. The formation of soap during this process is known as saponification and can be avoided by replacing the alkaline catalyst with acidic one [7].

Numerous experiments have been performed with different biodiesels prepared from various feed stocks on compression ignition engine under various operating conditions. Sahoo et al. [8] reported that *Polanga* oil methyl ester could be an substitute for conventional diesel with minor modifications.

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Nomenclature

bTDC	before top dead center
BSFC	brake specific fuel consumption
BTE	brake thermal efficiency
CIME	*Calophyllum inophyllum* methyl ester
DI	direct injection
FFA	free fatty acid
UBHC	unburned hydrocarbons
NO_x	oxides of nitrogen
ppm	parts per million
CO	carbon monoxide
CO_2	carbon dioxide
CIME20	20% CIME and 80% diesel
CIME100	100% CIME and 0% diesel

Shehata et al. [9] has studied the impact of fuel injection pressures of 180 bar, 190 bar and 200 bar on direction injection compression ignition engine using 20% corn biodiesel, 20% soyabean biodiesel and conventional diesel. The experimental investigations explored that increase in injection pressure results in improvement in brake thermal efficiency and fuel economy.

Mohan et al. [10] analyzed the effect of injection pressures (225, 250 and 275 bar) and injection timing (19, 21, 23, 25, 27° bTDC) with 20% Mahua biodiesel blend in a DI diesel engine. It was observed that the increase in injection pressure helps in increasing the BTE up to 250 bar and no further improvement was noticed thereafter. Remarkable NO_x reduction was observed with increase in injection pressure. The value of UBHC and CO emissions were well below the standards at higher injection pressure of 275 bar. Puhan et al. [11] in their experimental investigations reported that the brake thermal efficiency of linseed oil methyl ester was marginally higher than conventional diesel at 240 bar injection pressure. It was also observed that the CO emissions were found to be lower than diesel fuel. A significant impact in delay period was noticed with an increase in injection pressure.

Purushothaman and Nagarajan [12] used 30% of finely grounded orange skin powder and 70% diesel solution to study the heat release rate and exhaust emissions of diesel engine under various injection pressures of 215 bar, 235 bar and 255 bar. The study reported higher heat release rate, higher incylinder pressure and significant reductions in smoke, hydrocarbon and CO emissions at 235 bar at 100% load compared to the other injection pressures. However the heat release rate was lower for the same diesel solution at 255 bar injection pressure due to increase in spray angle. Fuel particles could not penetrate deeper into the combustion chamber with increase in spray angle thus resulting in higher HC and CO emissions at 255 bar injection pressure.

Ong et al. [13] optimized the biodiesel production of high free fatty acid *C. inophyllum* oil through neutralization and transesterification process. Higher yield of biodiesel was obtained when methanol is mixed with oil in the ratio of 9:1 with the addition of alkali catalyst sodium hydroxide of 1% by weight at an temperature of 323 K by heating continuously for 120 min. The performance and emission studies of *C. inophyllum* biodiesel blends (CIB10, CIB20, CIB30 and CIB50) were carried out under different speed and full load conditions and the results were compared with conventional diesel. Performance parameters like BSFC, BTE and emission characteristics like, unburned hydrocarbon, oxides of nitrogen, carbon monoxide and smoke opacity were investigated. It was found that the brake thermal efficiency of CIB10 was substantially higher among the tested fuels. Better fuel economy was also noted for CIB10 compared to the conventional diesel fuel.

Rahman et al. [14] investigated the performance and emission characteristics of palm and *C. inophyllum* based biodiesel blends operated at high idling conditions without modifying the existing diesel engine. The engine was tested at 1000 rpm, 1200 rpm and 1500 rpm. The investigation revealed that higher the biodiesel percentage, higher the fuel consumption. In addition, 20% of palm biodiesel and *C. inophyllum* biodiesel blends produced higher NOx emissions and lower HC and CO emissions than diesel fuel. Further the exhaust gas temperature decreased with increase in concentration of biodiesel in blends for palm biodiesel and *C. inophyllum* biodiesels. The specific energy consumption of *C. inophyllum* biodiesel blends was lesser than the corresponding palm biodiesel blend due to its higher calorific value.

Sajjad et al. [15] experimentally studied the gas to liquid (GTL) fuel influence on combustion and emission characteristics on a four cylinder, four stroke diesel engine blended with *C. inophyllum* and conventional diesel. They used three different types of fuels namely: (i) 20% of GTL diesel blend (ii) 20% of *C. inophyllum* biodiesel blend and (iii) 50% of conventional diesel with 30% of *C. inophyllum* biodiesel and 20% of GTL for their investigations. Significant reduction in CO, HC and smoke opacity were observed for all fuel blends compared to conventional diesel fuel. The study also revealed that possible usage of above three fuels for commercial applications due to their better combustion and performance characteristics, which would meet the stringent emission norms.

Muthukumaran et al. [16] replaced conventional transesterification process by synthesis cracking method using fly ash as catalyst for *C. inophyllum* oil. It was found that remarkable improvement was noticed with respect to viscosity and heating value of the biodiesel. Further the experimental investigations showed that emissions like underburned hydrocarbon, CO, smoke and NO_x were comparable with conventional diesel for B25 blend. Fattah et al. [17] presented the effect of anti-oxidants on performance, emission characteristics of *C. inophyllum* biodiesel blends by experimental studies. They reported that higher brake power and lower BSFC were achieved with 3.5% reduction in NO_x by the addition of anti-oxidants in the CIB20 blend.

Belagur and Chitimi [18] characterized the various physical and chemical properties of untapped *C. inophyllum*. This oil was blended with diesel under various proportions. Experiments were carried out for various blends of *C. inophyllum* vegetable oil mixed with conventional diesel as per the ASTM standards. It has been concluded that 50% of *C. inophyllum* oil at 60 °C can be used as a substitute for diesel fuel for short term applications.

The objective of the present study arises from the various literatures surveyed and it is found that very minimal work have been carried out using *C. inophyllum* biodiesel as an alternate fuel for conventional diesel. It is also found that the effect of variation in injection pressure using *C. inophyllum* biodiesel has not been reported. Further it is also noticed that the usage of neat *C. inophyllum* biodiesel (CIB100%) is still missing. Hence this research work concentrates on the effect of variation in injection pressures of 200 bar, 220 bar and 240 bar for 100% *C. inophyllum* methyl ester and the results are compared with conventional diesel. The influence of fuel injection pressures of 200 bar, 220 bar and 240 bar for 100% CIME is performed to study the performance, combustion and emission characteristics of a four stoke, single cylinder, air cooled, compression ignition diesel engine and the results are critically analyzed with that of diesel fuel.