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Fuel injection pressure impact on diesel engine exhaust gas temperature and NOx emissions using Polanga biodiesel

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ABSTRACT

The present paper investigates about the production of biodiesel from neat polanga via base catalyzed transesterification and mixing of the biodiesel with a suitable additive (Dimethyl carbonate) in varying volume proportions in order to prepare a number of test fuels (B10, B20, B30, B40) for diesel engine application. In this experimental investigation, effect of different fuel injection pressure were evaluated for the assessment of different polanga biodiesel blends B10, B20, B30, B40 on engine exhaust gas temperature and NOx emissions on single diesel engine system. Higher fuel injection pressure is preferable for polanga biodiesel due to its higher viscosity for tested fuel. Fuel injection pressure of 240 bar results maximum exhaust gas temperature and NOx emissions. Up to 20% polanga biodiesel blends in a diesel engines improves thermal performance and reduces emissions, without any modifications in CI engine.

Keywords: *Polanga; Biodiesel; Injection Pressure; Engine*

I INTRODUCTION

1.1. Need for Alternative Petroleum Product

The modernization of human civilization from rural societies to affluent urban ones was made possible through the employment of modern technology based on multitude of scientific advances all of which is driven by energy [1]. Globalization and rapid economic growth have resulted in the exhaustive use of energy resources worldwide [2]. Degradation of environment is the other problem due to the use of petroleum based fuel. CI engine are extensively in use and are dominating power sources during road transportation due to operational stability, higher thermal efficiency and lower carbon monoxide and hydrocarbon emissions. Biodiesel has emerged as an alternative source to diesel as it does not need any significant changes in CI engine [3].

1.2. Limitations of Edible oil

There are limitations on the suitability of edible vegetable oil feedstocks due to the latest concerns like their involvement in the human food cycle and environmental degradation caused by the use of available cultivation land. Involvement of edible vegetable oil feedstock's could cause ecological imbalances due to the cutting down of forest land for plantation purposes. Therefore, non-edible plant oils are prominent for application as biodiesel in the diesel engine industry [4].

1.3. Availability and resources of Non-edible oil

350 oil bearing crops are available around the world [5]. Non- edible oils are the sustainable feedstocks's for the application in producing biodiesel since most of the plants can be grown on wastelands to reclaim them, not compete even higher yields of biodiesel and fuel properties as the edibles [6]. Crops bearing non-edible vegetable oil seeds are Jatropha curcas, Polanga, Karanja, Neem, Mahua, Castor, Jojoba, Coriander, Hingan, Mongongo. Other non-edible oils such as *Nicotiana tabacum* (tobacco), *Acrocomia aculeate* (macaúba), *Crambeabyssinica* (hochst), linseed oil, rubber seed oil, *Sapium sebiferum* (chinese tallow), *Sapindus mukorossi* (soapnut), *Euphorbia tirucalli* (milk bush), *Calophyllum inophyllum* (polanga) and nahor oil have been used as feedstocks [7]. Therefore, more emphasis is now given to non-edible seed oils as a source for biodiesel.

1.4. Polanga (Calophyllum Inophyllum): An alternative diesel fuel

Polanga is a perennial angiosperm. Its full botanical name is "*Calophyllum Inophyllum*" [8]. It is a non-edible oil seed. The tree bearing polanga seeds are medium sized and it grows well in exposed sea sands or deep soil. The rainfall requirement for this tree is 750–5000 mm/year. The expansion rate of the Polanga tree is 1.1m height per year in favourable locations. This plant is widely found in South-East Asia, East Africa, Australia and India [9]. Polanga tree yields 100-200 fruits/kg with each fruit having one large brown seed of 2-4 cm diameter. A single, large seed is surrounded by a shell (endocarp) a thin, 3-5 mm layer of pulp. The oil obtained from the seed is thick and tinted green. About 2000 kg/ha oil yield has been reported [10]. Looking at its omnipresence throughout the Indian coastline, it seems that its natural production potential is no less than Jatropha curcas. High oil content, extensive availability, non- edible nature, low water requirement, growth on non-arable lands, etc. makes this oil seed highly suitable for fuel applications in diesel engines. An integrated research and development approach to evaluate the potential of this oil seed to be a true alternative to mineral diesel is to be assessed [11].

1.5. Performance of Biodiesel on CI engine

It is important to evaluate the influence of fuel injection pressure on comparative performance, emissions and combustion characteristics of biodiesel and diesel for operative application of biodiesel in modern CI engines. Mass of fuel injected into the cylinder depends on the density of the fuel [12]. [13] Produced biodiesel by transesterification in the presence of a catalyst. It was observed that transesterification process was influence depending upon the temperature, quality of catalyst, reaction time and verity of alcohol with the molecular ratio to the oil. Another mode of production of biodiesel from other filtered non-edible Karanja, Jatropha, and Polanga oil were also explained in this research. Chakraborty et al. [14] evaluated some relevant properties, the prospect of terminalia oil for biodiesel production. The fatty acid results of oil extorted from terminalia was found more suitable with respect to other seed oils tried. Terminalia oil contained 28.7% linoleic acid, 32.9% palmitic acid and 31.4% oleic acid. The kinematic viscosity and calorific value of terminalia oil were 25.50 cSt and 37.40 MJ/kg respectively, and lie within acceptable limits of the EN 14214 standard. However, the flashpoint of terminalia was found 90 °C which is relatively lesser than the required standard for diesel engine. Finally, these fuel properties conformed that biodiesel obtained from terminalia seed fulfil breathing biodiesel properties. [15] Recommends crude polanga oil as a possible feedstock for biodiesel production. The above mentioned oil had a high acid value which is 59.30 mg KOH/g. Therefore, the degumming, esterification, neutralization and transesterification process were carried out to decrease the acid value to 0.34 mg KOH/g. The optimum yield was obtained at 10:1 methanol to oil fraction with 1 wt. % and NaOH catalyst at 50^{o}C for 2 h. On the other hand, the C. Inophyllum biodiesel properties fulfilled the specification of ASTM D6751 and EN 14214 biodiesel standards. After that, the C. Inophyllum biodiesel, diesel blends were tested to evaluate the engine emission and performance characteristic. Also, from the literature survey, it has been observed that effect of injection pressure on Polanga oil based biodiesel does not exist in the literature.

II. MATERIAL AND METHODS:

2.1. Biodiesel production from Polanga seeds

Polanga (Calophyllum inophyllum) oil was extracted from good quality seeds using a screw press. The oil so obtained was pressure filtered and heated at 120°C for 20 minutes to remove moisture. The oil was then preserved in an airtight screw cap bottle. Figure 1 shows neat Polanga (Calophyllum inophyllum) oil and the seeds. The FFA of the oil was found to be 23.52%.

Biodiesel is basically formed by the transesterification process from raw Polanga oil feedstock. Transesterification has been identified as the best way to manufacture biodiesel from non-edible raw oil in the company of an acid or base catalyst. Normally, sulfuric acid is considered as the suitable catalyst for this reaction, however a good range of acids may be considered for the same purpose. Oil feedstocks with more than 2% free fatty acid contents are generally transesterified in two stages. In the first stage the FFA reacts with the alcohol in the existence of an acid catalyst, when the FFA is reduced below 2%, then it is transesterified in the presence of alkaline catalyst. As mentioned in the previous section, the FFA of Polanga (Calophyllum inophyllum) oil was as high as 23.52%. Therefore, it has to pass through a two stage transesterification process to produce biodiesel. Such type of reaction is generally very much time consuming and consumes large amounts of catalyst. Therefore, an optimization of process parameters like catalyst concentration, reaction time, etc. shall lead to commercially competitive production of biodiesel from Polanga oil.

Figure 1: Polanga seeds and the oil produced after extraction.

2.2. Diesel engine set up for the performance study

In this study Kirloskar make single cylinder, 4-stroke and water cooled diesel engine was selected. Such types of small engines are generally used for agricultural activities and decentralized power generation purposes across the India. Figure 3 shows the schematic image of the engine set up used for the study. Steady state test of the constant full load at 1500 RPM engine speed using B10, B20, B30 and B40 Polanga biodiesel blends at a different fuel injection pressure between 160-240 bars at an interval of 20 bars. The complete specification of the diesel engine is provided in Table 1.

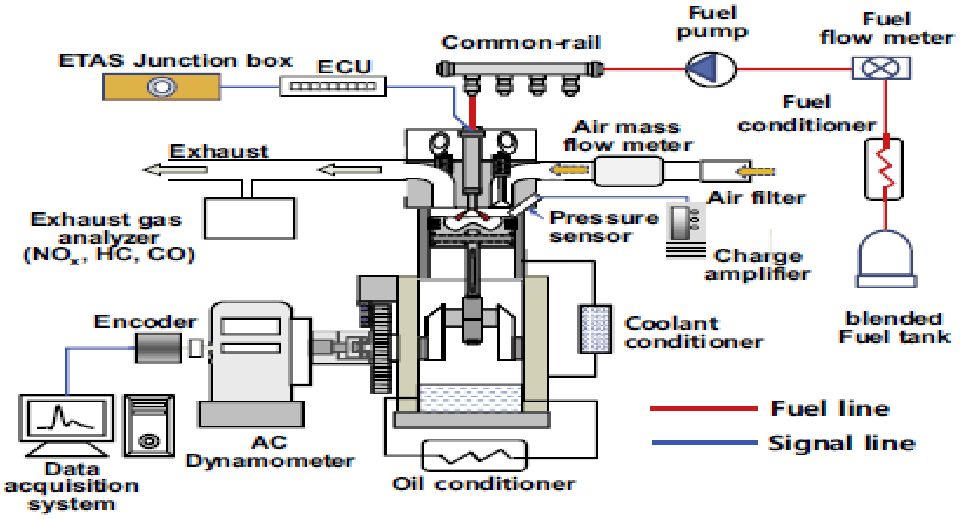

Figure 2: Schematic image of the experimental engine set up.

Table 1: Test Engine Specification

Make	Kirloskar
No. of cylinder	1
Strokes	4
Rated Power	3.5 kW@1500rpm
Cylinder diameter	87.5mm
Stroke length	110mm
Connecting rod length	234mm
Compression ratio	17.5:1
Orifice diameter	20mm
Dynamometer arm length	185mm
Inlet Valve Opening	4.5°BTDC
Inlet Valve Closing	35.5°ABDC
Exhaust Valve Opening	35.5°BBDC
Exhaust Valve Closing	4.5°ATDC
Fuel injection timing	23^0BTDC

III. RESULTS AND DISCUSSION

3.1. Exhaust gas temperature

Fig. 3 shows variation of EGT with respect to fuel injection pressure for different test fuels. It is observed that EGT increases with increase in load for all test fuels and diesel. It can also be seen from the graph that diesel exhibit low EGT when compared with other test fuels. Biodiesel exhibit highest EGT at all loads due to high combustion temperature of biodiesel because of higher oxygen content. The variation of EGT with the fuel injection pressure at constant full load for polanga biodiesel blends is given in Figure 3. In general, EGT increase with load, at elevated injection pressure the EGT is higher due to the increased combustion duration, increased heat loss, etc.

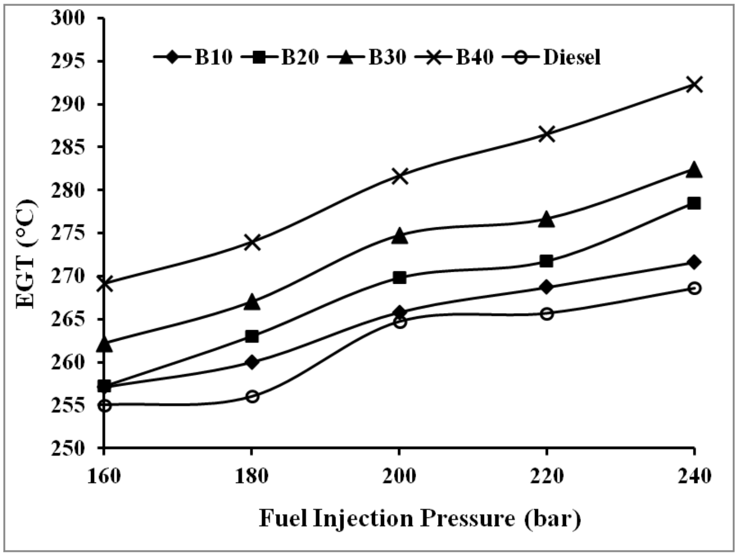

Figure 3: Variation of EGT with Injection pressure

3.2. NOx emissions

From the literature it is revealed that NOx is directly proportional to power output of the engine because NOx emission increases with increase in combustion and exhaust temperature [16]. The present test results show that NOx emission increases almost linearly with increase in engine load which is because of higher cylinder pressure and temperature at higher loads [16,17,18]. It is found highest for pure biodiesel because of high oxygen content which results in complete combustion causing high combustion temperature. Results also reveal that NOx decreases with higher additive percentage because of reduction in engine in-cylinder temperature because of smooth combustion, causing reduction in EGT [19, 20]. Figure 4 gives NOx values for various polanga biodiesel blends with diverse fuel injection pressures at full load condition. As seen from the figure, at elevated fuel injection pressure, NOx emissions are higher. At an elevated fuel injection pressure smaller test fuel particle diameter caused to vaporize quickly.

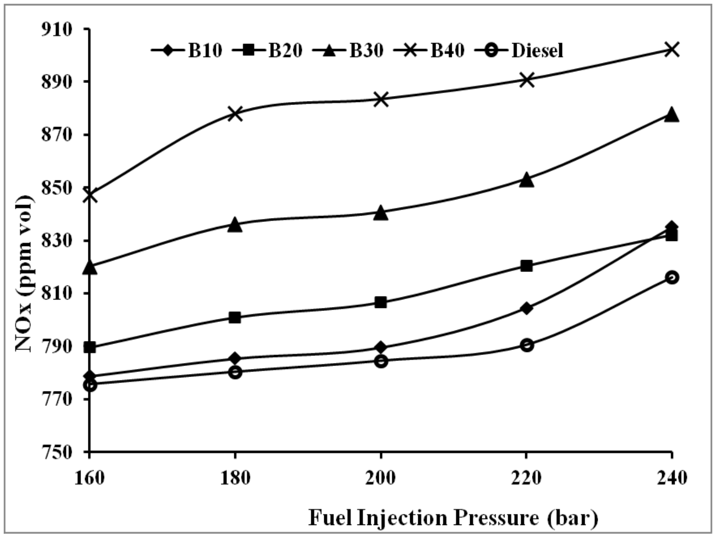

Figure 4: Variation of NOx with Injection pressure

However, the fuel particle cannot go through deep into the engine combustion chamber. So, at an elevated fuel injection pressure firstly produces quicker fuel combustion rates, resulting in a higher EGT as discussed previously section as an end result, NOx start to increase at elevated fuel injection pressure. Maximum NOx emissions were recorded to be 835, 832, 878 and 902 ppm vol for B10, B20, B30 and B40 respectively at 240 bar of fuel injection pressure.

IV. CONCLUSION

The experimental study is accomplished on a four stroke, single cylinder Kirloskar diesel engine using polanga biodiesel and its blends with diesel. The exhaust gas temperature and NOx emissions characteristics are evaluated by running the engine at injection pressures of 160 bar, 180, 200, 220 bars and 240 bar and varying loads from no load to full load at a percentage increase of 20% in each step. Based on the experimental studies, following are the important observations made and the conclusions drawn thereon.

1. A single cylinder, four stroke CI engine originally designed to operate on diesel as fuel may be operated on Polanga biodiesel blends without any system hardware modifications. Based on the experimental study, it can be concluded that at higher fuel injection pressure, the exhaust gas temperature using polanga biodiesel blends are more as compared to that of diesel oil.
2. Higher fuel injection pressure is preferable for Polanga biodiesel due to its high viscosity of polanga biodiesel test blends.
3. Polanga biodiesel blends B40 give the maximum NOx emissions as compared to all other blends at a higher

fuel injection pressure of 240 bar.

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