Indian Journal of Geo Marine Sciences
Vol. 49 (07), July 2020, pp. 1286-1292

Studies on *Prosopis juliflora* methyl ester production and its effect on DI diesel engine

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Received 22 March 2019; revised 29 April 2019

Prosopis juliflora methyl ester (PJME) was produced from a non edible feedstock found in the arid and semi-arid regions all over the globe. The Biodiesel from this species was produced with respect to optimum transesterification process variables. An experimental investigation was done using the Methyl ester in a DI diesel engine to estimate the performance, combustion and emission characteristics at a brake power of 5.2 KW and an unvarying speed of 1500 rpm. Experimental studies on the methyl ester revealed that there was a decrease in the brake thermal efficiency by 8.34 % and increase in the emission of Carbon monoxide (CO), unburnt hydrocarbon (HC) and smoke by 10.7 %, 16 % and 11 %, respectively. PJME exhibited NO_x emission of 10.71 %, lower heat release rate (HRR) of 23 %, and 7 % peak pressure when compared to neat diesel under 100 % loading condition. From the successive experiments conducted with *Prosopis juliflora* methyl ester, B20 Biodiesel blend was found the best suitable blend for marine engines as the results almost matches with the neat diesel. Also, biodiesel from this non edible species proved that it was an inherent source for alternative fuel, with environmental benefits.

[Keywords: Biodiesel, Combustion, Emission, Performance, *Prosopis juliflora*]

Introduction

The increase in the energy demand leads to the exhaustion of fossil fuels, price hike of oil and gas. Augmentation in environmental pollution led the researchers and scientists to propose biodiesel to be the perfect choice amongst all the available alternative fuels[1]. Biodiesel can be produced from a wide variety of traditional edible and non edible oil seed crops such as ground nut, mustard, rape seed, Jatropha, Pongamia, Tobacco, Mahua, Rubber seed etc[2]. Though there is a production of large quantity of oils, still India is not self sufficient in the production of edible oils; and the possibility of production of biodiesel from edible oil is also very less. Using non edible feedstock for Biodiesel production was found to be economical than edible feedstock and also reduces the food-fuel conflict[3].

As per the Wasteland Atlas of India, 47.21 million hectare (14.92 % of total land area) are at present lying waste in India and is shown in Figure 1. The five largest wasteland are catagorized as: land area with dense scrub (2.94 % of total geographic area (TGA)), land area with open scrub (2.8 % of TGA), less utilized degraded forest – scrub dominated (2.72 % of TGA), barren rocky area (2.20 % TGA) and snow enveloped (or) glacial area (1.29 % of TGA)[4].

As *Jatropha curcas* can grow in low rainfall areas, our Government of India has planned to plant these species in waste lands[5]. Though this species has the advantages to grow in varied climatic conditions with less water and bearing pest attack, the presence of oil

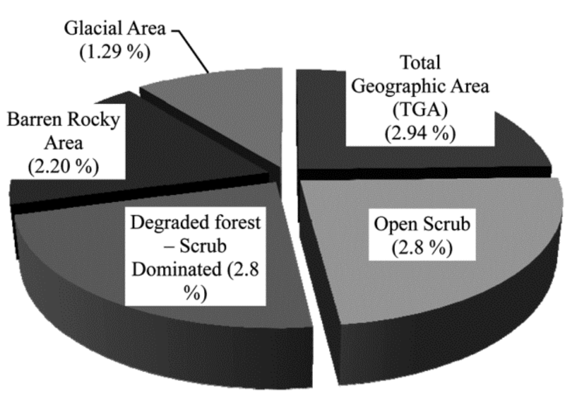

Fig. 1 — Distribution of waste land in India

content and nutrient requirements for the plant are found to be more critical. This criterion makes the plantation of these plants to be less viable in the waste lands. Hence, the afforestation of the waste lands with *Prosopis juliflora* will lead to fruitful results since these species require only less amount of water which is more suitable for dry and arid waste lands[6]. *Prosopis juliflora* grows up abundantly in India and seems to be originated about million years ago. In India it is called by several names such as Vilayati babul, Vilayati kikar, Vilayati khejra, Gando baval[7]. As non-edible oils are high viscous in nature, it causes the oil to be more sticky causing fuel atomization problem. Hence, by reducing the viscosity, biodiesel can be produced efficiently and can be used without modifying the diesel engines[8].

The performance characteristics and amount of emission from non edible species such as mahua oil, linseed oil and rice bran oil blended with diesel was determined and compared with neat diesel fuel. These oils were fed into the single cylinder, four strokes DI diesel engine. The performance as well as emission parameters like thermal efficiency, and smoke density for different fuel blends were found to be very close with some variations of diesel[8]. Various blends of diesel and *Jatropha* oil by volume like 97.4 %/2.6 %; 80 % /20 %; and 50 %/ 50 % was tested and evaluated on a single-cylinder direct injection engine. Studies reveal that 97.4 % of diesel and 2.6 % of Jatropha fuel blend produced higher brake power and brake thermal efficiency with lesser values of specific fuel consumption, exhaust gas temperature, carbon monoxide and carbon dioxide emissions[9]. Also when neat Jatropha oil blended with methanol resulted in an increase in brake thermal efficiency, decrease in exhaust gas temperature, smoke levels, HC and CO emissions, and increase in ignition delay[10]. The studies on the possibility of utilizing pure *Putranjiva roxburghii* oil in Ricardo Variable Compression Diesel Engine revealed that the performance parameters for the blends above 30 % v/v, the BTE and BSFC showed inferior quality[11]. When metal based additive ferric chloride was added to biodiesel at a dosage of 20 µmol/L and when it was tested with DI diesel engine operating at a constant speed of 1500 rpm, the results revealed that brake specific fuel consumption (BSFC) decreased while there was an increase in brake thermal efficiency by 6.3 %[12].

The prediction of various researchers in the latest literature surveys on production of Biodiesel makes clear that methyl esters from non edible oils is the best and it is evident that, there is no trace of work regarding the oil extraction from the pods (seed) of *Prosopis juliflora.* This non edible species has an enormous amount of potential for biodiesel Production, performance, combustion and emission. Also, optimization of *Prosopis juliflora* oil and Methyl ester was not yet reported so far.

The most important objective of the present investigation is Biodiesel to be derived from *Prosopis juliflora* will reduce the conflict between food and fuel as this is a non-edible feedstock. This drought resistant powerful species can be grown in the wastelands of India which will help to meet the economic needs of the poor people of our country. From the oil extracted, *Prosopis juliflora* methyl esters were obtained. The performance characteristics of various biodiesel blends (B25, B50, B75, and B100) were tested in a Direct Injection (DI) diesel engine with the intention of improving BTE and reducing emission characteristics. Hence the present study will help us to efficiently utilize *Prosopis juliflora* methyl ester as an alternative fuel in a Marine diesel engine.

Materials and Methods

Prosopis juliflora is a dicotyledon belonging to the Botanical family Fabaceae and sub-family Mimosoideae (Fig. 2). The flattened pods of *Prosopis juliflora* are 6-30 cm long, 5-16 mm wide and 4-9 mm thick. The production of pods approximately varied from 5 kg to 40 kg/tree. Also, 2300 kg/ha pods can be produced with *Prosopis juliflora* planted with a density of 20 kg/tree[6]. The dried fruits of *Prosopis juliflora* were gathered from the waste lands of Ramnad district in Tamil Nadu. *Prosopis juliflora*

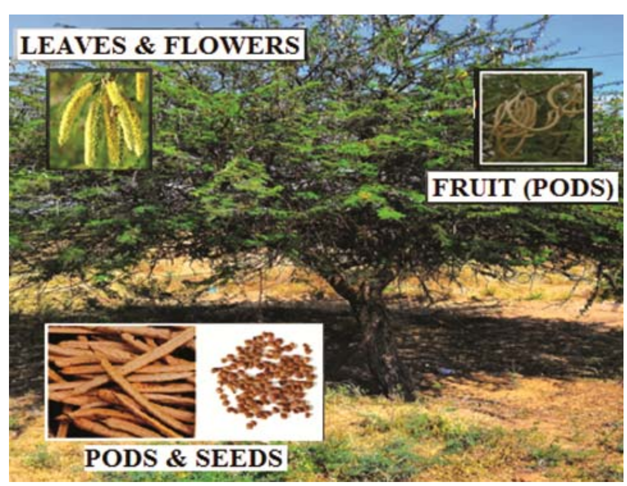

Fig. 2 — *Prosopis julifera*: tree with fruits and flowers

collected during the seasonal period were then cleaned and dried for removal of moisture content. The dried pods are crushed and powdered[7].

At first, KOH was dissolved in methanol by forceful stirring in a biodiesel reactor. Then, the catalyst/methanol mixture was mixed with 100 ml raw vegetable oil (*Prosopis juliflora*). The final mixture was stirred vigorously for one hour at 60 ˚C under the ambient pressure[13]. A successful transesterification should produce two different liquid phases, methyl ester and crude glycerine. Since Crude glycerine is a heavier liquid, it will accumulate at the bottom layer. In the present work separation of liquids was completed within 2-3 hours of settling. Complete settling of methyl ester can take as long as 8-10 hours. Washing the methyl ester is a two-step process. A water wash solution at the rate of 26 % by volume of vegetable oil and 1 gram of tannic acid / litre of water was added to the methyl ester and stirred. The above process was continued to get clear methyl ester. After transesterification, the viscosity of both methyl esters was found to be reduced and the value was nearer to the diesel fuel. Prepared methyl esters were then blended with neat diesel in different concentrations and that was used in the common rail diesel engine for conducting engine tests. The above said procedure was followed again for producing methyl ester using Sodium hydroxide as catalyst. Figure 3 shows the schematic diagram of biodiesel plant. The pictorial view of *Prosopis juliflora* methyl ester and its blend are shown in Figure 3.

The apparatus used for transesterification shown in Figure 3 consists of constant temperature water bath,

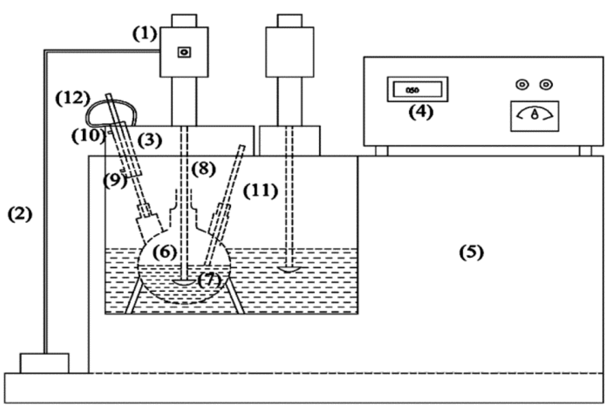

Fig. 3 — Schematic diagram of biodiesel production plant

reaction flask with condenser and digital rpm. Digital rpm was used for controlling the Mechanical stirrer and a constant agitation speed of 600 rpm was maintained for all the transesterification processes.

Pretreatment and transesterification

The pretreatment of oil before transesterification includes two steps: acid esterification followed by alkaline transesterification. After the second pretreatment step, if we intend to get the value of free fatty acid (FFA) as 1 mg KOH/gm, then in the first step, value of 5 mg KOH/gm should be obtained[13]. When there was a gradual increase in the reaction in the reaction time and Methanol/oil molar ratio, there was the reduction in the acid value from 43.7 to 39 mg KOH/gm (3:1 molar ratio, 0.5 hrs) and further it was reduced to 18.5 mg KOH/gm (3:1,2 hrs). In the pretreatment steps, the acid value of the oil was reduced from 43.7 mg KOH/gm to 8.6 mg KOH/gm under the optimum reaction conditions of 9:1v/v methanol/oil ratio and a minimum reaction time of about 120 minutes. The end products got from acid catalyzed pretreatment process was used for alkali catalyzed transesterification process. A series of experiments were carried out at various molar ratios, different proportion of catalyst, reaction temperature and extent of reaction time. From the findings optimum conditions for oil extraction was noted down.

Fuel properties of *Prosopis juliflora* methyl esters

The Methyl Esters of *Prosopis juliflora* were tested and its fuel properties matched with the values as prescribed in the ASTM standard D6751-02. The obtained fuel properties of Methyl esters of *Prosopis juliflora* oil were summed up and presented in Table 1.

Engine setup and measurements

To investigate the performance characteristics of *Prosopis juliflora* Methyl ester, a series of experiments were conducted on Kirloskar TV-1, single cylinder, four stroke, and air-cooled direct injection (DI) diesel engine. The experimental Engine setup is shown in Figure 4. The rated power of the Kirloskar engine is 5.2 kW at rated speed of 1500 rpm. The direct injection (DI) diesel engine was operated at a standard injection pressure of 200 bar pressure and constant running speed of 1500 rpm. The Hatridge smoke meter was utilised for measuring the smoke density. The exhaust gas temperature was measured using K–Type thermocouples.

Table 1 — Properties of biodiesel produced from non-edible feed stocks

Properties	Test Procedure	ASTM standard D6751-02	DIN EN 14214	Diesel	*Prosopis juliflora* methyl ether (PJME)
Density, Kg/m^3	ASTM D4052	875-900	860–900	847	893
Viscosity at 40^{0}C (mm^2/sec)	ASTM D445	1.9–6.0	3.5–5.0	2.85	4.9
Calorific value (MJ/kg)	ASTM D240			43.4	39
Cetane number	D613	47 min	51 min	46	49
Flash point (^{0}C)	ASTM D4052	>130	>120	68	120
Cloud point (^{0}C)	ASTM D2500	-3 to 12	--	--	4
Acid value (mg KOH/g of oil)	ASTM D4052	>0.8	>0.50	0.35	2.7
Saponification value (mg KOH/g of oil)	--	--	--	--	92
Iodine value (I_2g 100/g of oil)	--	--	--	--	87
Lauric acid	$C_{12}H_{24}O_2$	Dodecanoic acid	C_{12}	0.2	
Myristic acid	$C_{14}H_{28}O_2$	Tetradecanoic acid	C_{14}	0.1	
Palmitic acid	$C_{16}H_{32}O_2$	Hexadecanoic acid	C_{16}	10.6	
Stearic acid	$C_{18}H_{38}O_2$	Octadecanoic acid	C_{18}	5.2	
Oleic acid	$C_{18}H_{34}O_2$	Cis-9- Octadecanoic acid	$C_{18:1}$	34.7	
Linoleic acid	$C_{18}H_{32}O_2$	Cis-9-cis12-Octadecanoic acid	$C_{18:2}$	43.4	
Arachidice acid	$C_{20}H_{40}O_2$	Eicosanoic acid	C_{20}	0.13	
Behenic acid	$C_{22}H_{44}O_2$	Docosanoic acid	C_{22}	0.1	

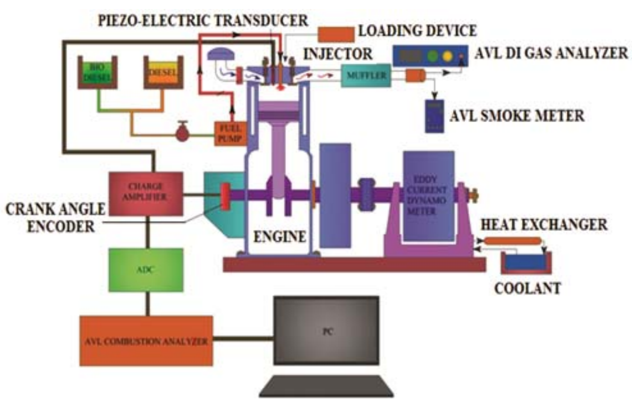

Fig. 4 — Schematic diagram of the engine setup

Hydrocarbon, carbon monoxide, NO_x emissions coming out from the exhaust of the Disel engine were measured by using AVL Di – gas analyzer. Combustion parameters like cylinder pressure and heat release rate were measured by using AVL Combustion Analyzers.

Results and Discussion

Brake thermal efficiency

In any experimental investigation, Brake thermal efficiency (BTE) helps to determine the performance of biodiesel fuel. In Figure 5(a), it is shown that BTE increases with increase in load. Upto part load it increases and then BTE decreases as the combustion of fuel was not complete[8,12]. It was also found that there was a gradual decrease in BTE as *Prosopis juliflora* methyl ester added with diesel fuel. Higher viscosity and lower heating value of the *Prosopis juliflora* methyl ester may also be the reason for the decrease in BTE. A number of researches have been carried out and found to report that the brake thermal efficiency decreased when biodiesel was used as a fuel in diesel engine[11]. The percentage of Brake thermal efficiency of B25 blend was nearly same as that of diesel fuel. The BTE for neat diesel fuel is 24.21 %, B25 is 24.17 % where it is 23.10 % for B50, 22.27 % for B75 and 22.18 % for B100 under full load conditions. From Figure 5, it can be inferred that BTE decreases with the increasing proportion of *Prosopis juliflora* biodiesel fuel. The maximum decrease of BTE was found in B100 by about 1.96 %.

Emission Characteristics

Hydrocarbon (HC) emission

The variation of hydrocarbon (HC) emissions with respect to brake power is shown in Figure 5(b). It is clear that the hydrocarbon emission decreases up to part load and suddenly increases with rise in the value of brake power[8]. The *Prosopis juliflora* methyl ester and its blends with diesel fuel considerably increase the HC emissions while comparing with pure diesel fuel. Methyl esters had higher viscosity which

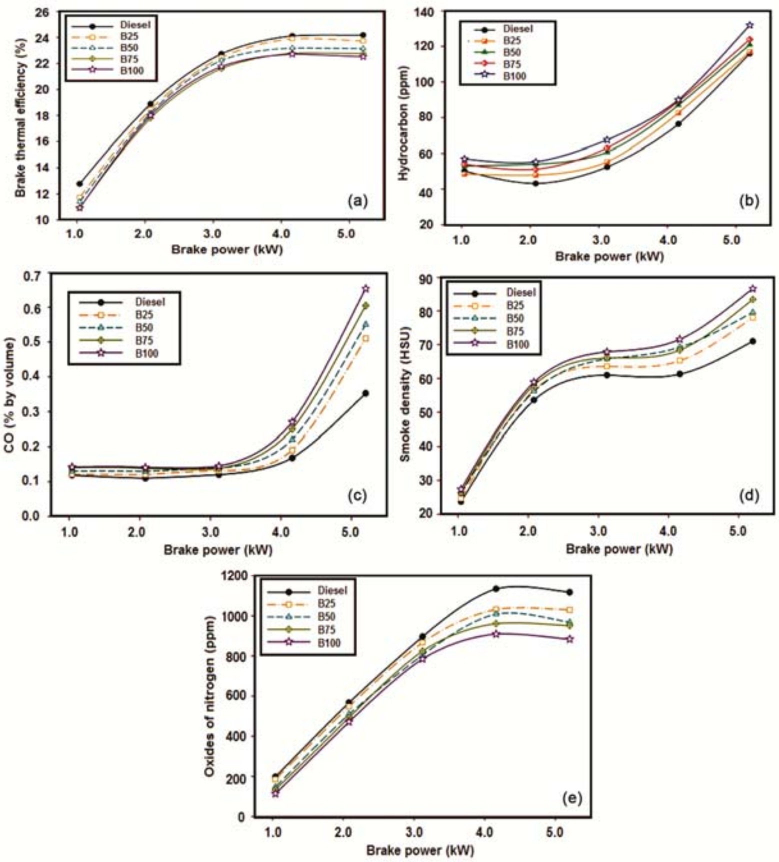

Figure 5 — a) Brake thermal efficiency, b) HC Emissions, c) CO Emission, d) Smoke Density, and e) NO_x Emission; against brake power

resulted in poor atomization during the combustion. From the Figure 6, it can be seen that the value of HC emission increased with an increase in percentage of methyl esters added to the diesel fuel. Hydrocarbon emissions for various diesel blends such as B25, B50, B75 and B100 were 109, 113, 117, 121 and 130 ppm, respectively. Compared with B100, B25 reduces the HC emissions effectively.

Carbon monoxide emission

The variation in the values of carbon monoxide (CO) emission when running DI diesel engine using different *Prosopis juliflora* methyl ester blends with neat diesel fuel is shown in Figure 5(c). Experimental studies reveal that CO emission was initially less at inferior loads up to 40 % and after that with a notable increase for all the *Prosopis juliflora* methyl ester-diesel blended fuels. Increased viscosity of biodiesel blends, the more chance of fuel-rich zones formation, generally related to CO emission[11]. From the perception of higher viscosity in the *Prosopis juliflora* biodiesel and their blends, tends to rich fuel combustion zones when evaluated with combustion of neat diesel fuel and causes the higher CO emission in

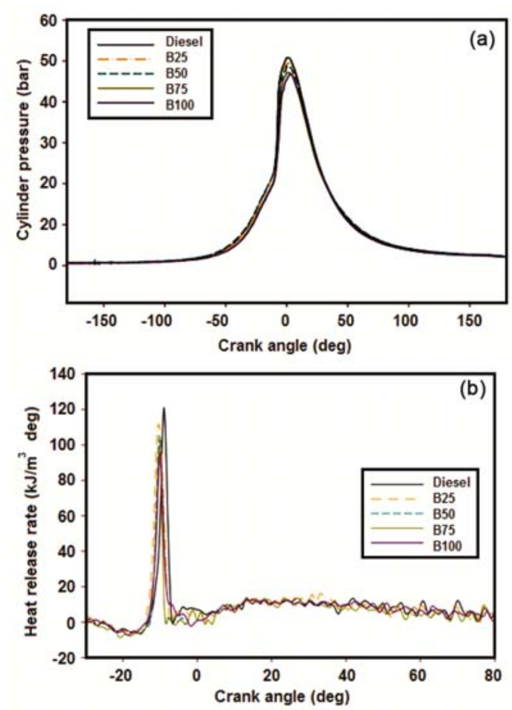

Figure 6 — a) Cylinder pressure, and b) Heat release rate; against crank angle

the cases of biodiesel and its blends. From the results, it is found that the CO emission for 100 % biodiesel (B100) is higher when compared with other biodiesel blends. In Figure 5(c), it can be noted that using biodiesel blends instead of using pure diesel resulted in a 38.77 %, 45.45 %, 57.81 % and 65.14 % average increase of CO emission when fuelling with the B25, B50, B75 and B100 blends, respectively. Increase in the rate of emission may be due to the higher air/fuel ratio and weak combustion mixture[12].

Smoke emission

The collection of unburnt tiny carbon particles due to the partial burning and incompletely reacted carbon present in the fuel leads to the smoke emission[8]. Figure 5(d), depicts the variant of the amount of smoke for *Prosopis juliflora* methyl ester blends and pure diesel fuel. As it is given in Figure 5(d), the smoke emission increased by the rise in biodiesel percentage. The improper mixing of biodiesel with air produces a lean oxygen mixer which will lead to formation of smoke[9]. The extent of smoke emission over the constant speed rpm increased to 75.2 HSU, 78.7 HSU, 83.2 HSU and 85 HSU for the B25, B50, B75 and B100 biodiesel blends respectively when it is compared with neat diesel fuel.

Nitrogen oxide emission

The Nitrogen oxide (NO_x) emissions of any diesel engine mostly depend on the flame temperature and presence of excess oxygen content in the fuel. Initially combustion was found to be delayed with the *Prosopis juliflora* methyl ester-diesel blends. The reason may be due to the decrease in mean peak temperature. As seen in Figure 5(e), the NO_x emissions all the way through the same rpm band decreased 1083 ppm, 985 ppm, 972 ppm and 967 ppm for the B25, B50, B75 and B100, respectively, compared with the neat diesel fuel. From Figure 5(e), it can be found that oxides of Nitrogen emissions for *Prosopis juliflora* methyl ester blends were lowest when it is compared with neat diesel fuel. It can also be inferred that the NO_x emissions of B25 biodiesel blend and neat diesel fuel were nearly similar.

Combustion Characteristics

Cylinder pressure

The peak pressure of *Prosopis juliflora* methyl ester blends and diesel fuel under full load condition is shown in Figure 6(a). Since due to shorter ignition delay, the peak cylinder pressure occurred in advance for *Prosopis juliflora* methyl ester blends when compared with neat diesel. In the early stage of combustion, high oxygen content present in methyl ester is good enough to make complete combustion of the fuel and also maintain to burn in the main combustion phase[12]. From the Figure 6(a), it can be seen that B100 had a 45.1 bar lower peak cylinder pressure than that of neat diesel fuel followed by 46.7 bar for B75, 47.3 for B50 and 50.2 bar for B25. In the series of experiments conducted, for all the test fuels, the same phenomenon was observed during the entire operation with different loading.

Heat release rate

Heat Release Rate (HRR) values determined with respect to the ignition delay for biodiesel blends was smaller than HRR for neat diesel. Many researchers in their research mean that the combustion process is earlier. The reason is due to the advanced injection and the physical properties of methyl esters like density, compressibility and viscosity[3]. The calorific values of *Prosopis juliflora* methyl esters and its blends in various proportions were lower than that of neat diesel fuel. For the above reason, the HRR shown in figure 6(b), was lower for methyl ester 113.69 kJ/m^{3}deg for B25, 107.09 kJ/m^{3}deg for B50, 100 kJ/m^{3}deg for B75 and 95.47 kJ/m^{3}deg for B100 compared with 124.01 kJ/m^{3}deg for pure diesel fuel. This is because of the result of the premix combustion phase and the longer ignition delay for methyl ester blends.

Conclusion

Biodiesel was obtained from *Prosopis juliflora* oil by the process of transesterification. The following points are concluded from the present work. BTE for B25 blend matched with diesel. With the increase in *Prosopis juliflora* blend, BTE decreased and it was observed to be about 1.96 % decrease for B100 Biodiesel blend. Increase in the amount of Biodiesel blend with diesel showed increased HC (Hydrocarbon), CO (Carbon monoxide) and smoke emission. At maximum load conditions, these values were found to be 16 %, 10.7 % and 15 %. NO_x emission value was decreased by 17.71 % when comparing it with NO_x emission values of neat diesel. B100 had a 7 % lower peak pressure than diesel fuel. Due to the presence of lower calorific values in biodiesel blends, the Heat Release Rate was 23 % lower for *Prosopis juliflora* biodiesel when compared with neat diesel fuel.

From the above studies, it can be concluded that B25 *Prosopis juliflora* methyl ester blend showed significant results which clearly imply that this blend will surely be an ideal source of fuel for marine diesel engines.

Conflict of Interest

I hereby disclose all of my conflicts of interest and other potentially conflicting interests, including specific financial interests and relationships and affiliations relevant to Indian Journal of Geo-Marine Science (e.g., employment/affiliation, grants or funding, consultancies, honoraria, stock ownership or stock options, expert testimony, royalties, or patents filed, received, or pending). This applies to the past 5 years and the foreseeable future.

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Author Contributions

MR contributed to conceptualization; formal analysis along with PM; funding acquisition along with VM; investigation; handling of resources, software and in general supervision along with PM, VM, and RP; and to drafting, editing and in reviewing of manuscript along with PM.

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