EVALUATION OF PERFORMANCE AND EMISSION FEATURES OF JATROPHA BIODIESEL-TURPENTINE BLEND AS GREEN FUEL

by

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An experimental study was conducted to measure the suitability of jatropha biodiesel-wood turpentine blend as a replacement for diesel fuel in a compression ignition engine. Tests were performed in a 4-stroke, single cylinder, air cooled Diesel engine. The results show that the performance factors for various blends were found to be near to diesel, emission features were improved and combustion characteristics were found to be comparable with diesel. The brake thermal efficiency of the blends establishes 9.2% lower than that of diesel at 75% load. Brake specific fuel consumption increases for blends at part load and remains same at full load. The CO, HC, and smoke emissions were reduced by 75, 64-78, and 33-66%, respectively, compared to diesel at 75% load. Nitric oxides were increased. Jatropha biodiesel-wood turpentine blends offered comparable performance and combustion features, reduced emissions and it is capable of replacing standard diesel in compression ignition engines.

Key words: *engine, vegetable oil, turpentine, emissions, performance*

Introduction

The energy requirements of the world are growing faster than ever [1]. The depletion of fossil fuel reserves and the pollution level rising made vegetable oil viable as a fuel in Diesel engines in the practice [2-6]. Rudolph Diesel, the inventor of the Diesel engine performed experiments by using fuels from crushed coal to vegetable oil. Renewable fuels like plant oils take away more CO_2 from the atmosphere during their growth than it is added by burning them. Therefore, they reduce the growing CO_2 content in the atmosphere [7]. Numerous researchers tested the use of vegetable oils as fuel in conventional engines and described that their performances were reduced due to the higher viscosity and lower volatility [8-13]. To overcome these difficulties, several researchers recommended the usage of transesterified vegetable oils with reduced viscosity, which was termed as biodiesel [14-17]. This rigorous manufacturing and commercialization of biodiesel have raised some serious environmental issues. Its extensive production can lead to the global food market by radically raising consumption, oil prices, which largely affect emerging countries. In order to alleviate these ecological concerns, alternative oilseeds are being examined as substitute feedstocks. The claim for energy around the globe is constantly growing, precisely in the mandate for petroleum-based energy. Global warming is linked to the greenhouse gases which are typically discharged from the combustion of petroleum fuels [18-21]. To resolve both the energy alarm

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and environmental issue, the renewable energies with lower environmental impact should be considered.

Many experimental studies were conducted to study fuel properties, performance, and emissions of different blends of methyl ester of pongamia, jatropha, and neem with reference to diesel [22-25]. The results show that diesel blends displayed similar efficiencies, lower smoke, CO, and HC. The vegetable oil esters from edible oils may not be the right option for their substitution in Diesel engine due to an insufficient production of edible oil in India. Hence, attention has been diverted to test the suitability of non-edible vegetable oils for Diesel engine. Biodiesel is a substitute fuel that can be environmentally friendly, preserve energy and green protection. Biodiesel is biodegradable, non-toxic, and sulphur free [26-29]. The purpose of this work is to measure the performance and pollutant features of a Diesel engine running on selected fuels, jatropha biodiesel-wood turpentine (JWT) blends, in comparison to diesel without any engine modifications.

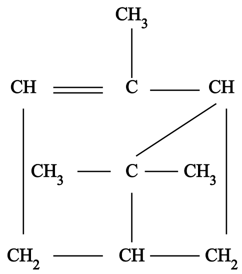
Biodiesel

Vegetable oil is one of several alternative fuels designed to extend the competence of petroleum, the flexibility, and cleanliness of Diesel engines. Vegetable oils and biodiesel have the potential to reduce the level of pollution and global warming. Biodiesel is described as a fuel that contains mono-alkyl esters of long chain fatty acids resulting from plant oils [30-32]. Biodiesel is a substitute fuel, cleaner than diesel and it could be used straight as fuel for compression ignition (CI) engines without modifying the engine system [33-35]. It has high biodegradability, excellent lubricity, and no sulfur content.

Wood turpentine oil

Wood turpentine made history of use as a viable fuel reserve and can substitute the diesel and biodiesel. Turpentine had been made by man and used as a fuel in the 1700's for burning lamps, boilers, and furnaces. Turpentine oil derived by pyrolysis mechanism from the pine tree dissolved in a volatile liquid is admitted as a substitute to diesel in CI engines. Turpentine oil was used as an engine fuel, but was waived in detriment of the more easy availability of fossil fuels. The turpentine oil used for this work was procured from a neighboring saleable shop. Turpentine is a yellowish, impervious, gummy, unstable, flammable combination of HC isomers gained both from pine resin and wood. Turpentine has a smaller α-pinene content of 40% by mass. It comprises chemically of 58-65% γ-pinene, β-pinene, and added isometric terpenes. Turpentine mixes freely in any quantity with jatropha biodiesel and it is presumed that turpentine oil might be a decent contender for diesel fuel due to its high global production. The cost of turpentine oil is usually greater than that of diesel, but it is least cost substitute through the global emissions management cost [36, 37].

Wood turpentine is a combination of biological composites largely terpenes and its structure can differ significantly conferring to the kind of pine tree from which it was resultant. Oil of turpentine consists of HC (terpenes) of the formula $C_{10}H_{16}$. The search of oleoresin-derived terpenes from renewable pine woods as distinct fuels and in whole or limited standby of conservative fuel centered engines. Both qualitative and quantifiable features of oleoresin from pines provide backing to an extensive choice of aspirant terpenes for the growth of substitute biofuels. The molecular arrangement of turpentine is given:



Resin tapping methods:

(1) Bark chipping method – shaving of bark up to 5 cm wide along one-third of the tree's boundary,
(2) Borehole method – a closed collection apparatus captures the volatile oleoresin and prevents premature solidification of the resin acids.

The oleoresin thus obtained from the above processes is finally steam distilled to obtain turpentine oil. The physical and chemical properties of wood turpentine are given in the tab. 1

Table 1. Physical-chemical properties of wood turpentine

Formula	$C_{10}H_{16}$
Molecular weight	136
Physical state	Clear liquid
Melting point	–60 to –50 °C
Boiling point	150 °C
Flash point	35 °C
Specific gravity	0.864
Vapor density	4.7

Materials and methods

The key aspect of the present analysis is to assess the performance, combustion, and emissions of different alternative green fuels. In the current work, jatropha biodiesel was blended with wood turpentine oil. The different combination of jatropha biodiesel and jatropha turpentine blends used in this experiment are: J100 (jatropha biodiesel 100%), JWT10 (jatropha biodiesel 90% + wood turpentine 10%), JWT20 (jatropha biodiesel 80% + wood turpentine 20%), JWT30 (jatropha biodiesel 70% + wood turpentine 30%), JWT40 (jatropha biodiesel 60% + wood turpentine 40%), and JWT50 (jatropha biodiesel 50% + wood turpentine 50%). The properties of the blended fuels are given in tab. 2.

Table 2. Properties of fuel

Description	Diesel	Jatropha biodiesel	Wood turpentine	JWT 10	JWT 20	JWT 30	JWT 40	JWT 50
Density at 15 °C [kgm^{-3}]	860	890	880-900	895	893	891	888	886
Viscosity at 40 °C [mm^{2}s^{-1}]	4.25	5.65	3.89	5.37	5.19	5.04	4.87	4.71
Flash point [°C]	50	170	35-40	154	140	128	112	98
Cetane number	48	50	38	–	–	–	–	–
Calorific value [MJkg^{-1}]	43.50	42.25	44.00	42.43	42.60	42.78	42.96	43.13

Experimental set-up

A Kirloskar-TAF1 model single cylinder, air cooled Diesel engine was used for the tests. The engine specifications are stated in the tab. 3. The engine is attached to a 240 V swing

Table 3. Engine specifications

Model	Kirloskar, TAF1
Type	4-stroke, air cooled, direct injection, constant speed
Number of cylinders	One
Bore	80 mm
Stroke	110 mm
Compression ratio	16.5:1
Power output	4.42 kW; 6 HP
Rated speed	1500 rpm
Nozzle pressure	200 bar
Fuel injection timing	23 °CA bTDC

field electrical dynamometer for loading the engine through a resistive load bank. Power-star (swing filed) electrical dynamometer is coupled with the test engine crankshaft on the right side. Crank angle Encoder AVL 365 C is connected to the crankshaft open end. The model 21-9 is having a maximum rating of 5 kW with the highest current rating of 21 A. Electrical resistance loading is used to load the engine from 0, 25, 50, and 100%, representing 1.1, 2.2, 3.3, and 4.4 kW, respectively. Loading can be easily done by switching on the required resistance bank, according to the testing requirements.

The measurement methods are detailed:

– Load and speed measurement

The engine was set to run at a constant speed of 1500 rpm. The load of the engine was obtained from load cell reading. The speed of the engine was monitored using sensor along with digital speed indicator.

– Temperature measurement

Temperature of the cooling water inlet, outlet and exhaust gas was measured with chromel alumel (k-type) thermocouples. A digital indicator with automatic room temperature compensation facility was used.

– Fuel consumption measurement

The fuel was supplied from a vessel weighing 5 kg (vessel weight plus fuel weight) placed nearer to the engine and the fuel to the engine will flow through a hose. The fuel flow rates were obtained by noting the time taken for 10 g of fuel consumption.

– Exhaust emission measurement

The smoke opacity was measured with the help of AVL 415 smoke meter and the pollutants like HC, CO, NO_x, CO_2, and O_2 were measured with the help of (AVL DI-GAS 444) five gas analyzer.

– The cylinder pressure

The cylinder pressure was measured with the help of a piezoelectric air cooled transducer. A hole was drilled vertically through the cylinder head to mount the pressure transducer. The pressure transducer is used to measure the dynamic pressure inside the cylinder.

– The heat release rate

The heat release rate was measured with the help of combustion analyzer.

The diagram of the experimental set-up for the current study is presented in figs. 1 and 2. The engine initially ran with jatropha biodiesel, and then it is changed to jatropha-wood turpentine oil blends.

The exhaust gas temperature (EGT) was quantified by a thermocouple mounted on the exhaust. To quantify the current and voltage delivered by the load bank, an ammeter and voltmeter were used. Smoke was measured using a smoke meter (AVL smoke meter 415). The exhaust gas was analyzed using an exhaust gas analyzer (AVL DI-GAS 444) to determine CO_2, CO, HC, NO_x, and O_2 absorptions. Tests were preceded by jatropha biodiesel and jatropha-wood turpentine oil blends were injected at a pressure of 200 bar. For testing purpose, some blends of different concentrations were arranged stretching from 100% (jatropha biodiesel) to 50:50 (jatropha-wood turpentine oil blends) through 10, 20, 30, 40, and 50%. These blends were then exposed to performance and pollutant tests on the engine. The performance, combustion, and pollutant data were examined for all tests and the outcomes are presented in the subsequent division.

Figure 1. Experimental set-up

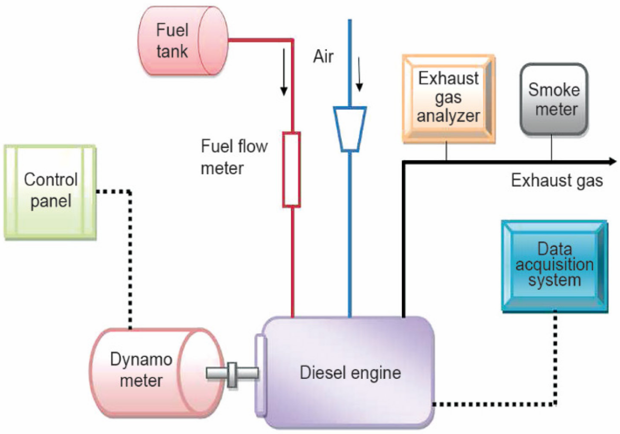


Figure 2. Experimental set-up line diagram

Results and discussion

Performance parameters

Brake specific fuel consumption

By running the engine with JWT instead of diesel fuel, the brake specific fuel consuption (BSFC) increases with the percentage of JWT for the entire load range, fig. 3. The BSFC of JWT30 is similar to that of diesel. Jatropha oil has an inferior lower calorific value and therefore higher content share of jatropha oil in mixture reduces the heating value of the mixture which leads to an increased BSFC. Other causes that lead to higher fuel consumption were: higher density as well as viscosity.

Brake thermal efficiency

The brake thermal efficiency (BTE) of JWT oil mixtures were lower than that of diesel. However, the thermal efficiency of blend JWT40 was very similar to diesel at 75%

load, fig. 4. The oxygen contained in the fuel improves the combustion quality, but higher viscosity and reduced volatility of plant oils. However, the higher viscosity and reduced volatility lead to poor atomization and combustion properties. It was determined that for higher wood turpentine concentrations, the BTE deceases as compared to mineral diesel.

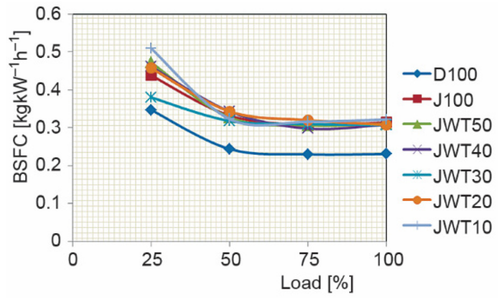


Figure 3. The BSFC *vs.* load

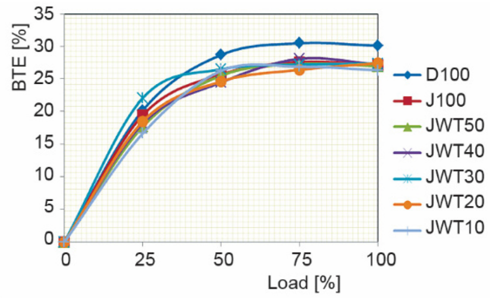


Figure 4. The BTE *vs.* load

Exhaust gas temperature

The EGT of jatropha, jatropha-mineral turpentine blends were comparable to those of diesel at all the loads, fig. 5. It was observed that the EGT increased with a rise in load in all cases. The highest value of the EGT of 422 °C was obtained when using the JWT10 blend. In the same case, the temperature value of D100 was found to be 410 °C.

Pollutant emissions

Carbon monoxide

The emissions of CO increase with load, fig. 6. The greater the load, the richer air--fuel mixture is burnt, and hence more CO is formed owing to the oxygen deficiency. The increase in CO emission at no load and part load may be due to the availability of less oxygen for the combustion. At 75% load, the CO emissions for J100, JWT30, JWT20, and JWT10 are negligible. In all other cases the CO increases when using JWT. This is considered to be the result of: (1) at the maximum engine load, the temperature inside the cylinder is higher, which favor the atomization of the blends, mix and then an improved burning can be accomplished and (2) oxygen content of the plant oil creates it at ease to burn at the upper temperature in the cylinder [9, 30].

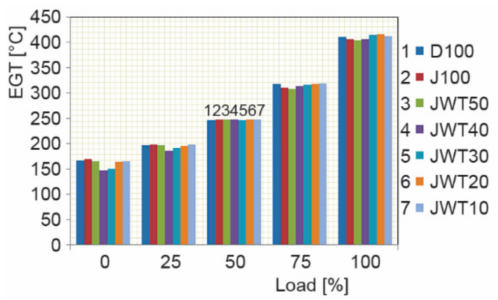


Figure 5. The EGT *vs.* load

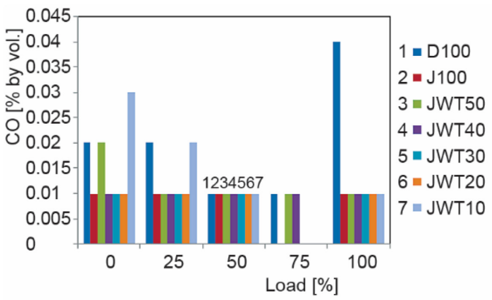


Figure 6. The CO *vs.* load

Hydrocarbons

Jatropha-wood turpentine oil blend JWT10, JWT20, JWT30, JWT40, and JWT50 exhibit lower HC emissions compared to diesel. The increase in HC emission for unloaded engine may be due to the availability of less oxygen during the combustion. At 75% load, HC emissions for J100, JWT10, JWT20, and JWT30 are 78.6, 42.8, 50, and 64.3% lower and at 100% load, HC emissions were 57.1, 61.9, 66.67, and 71.4% lower as compared to diesel, fig. 7. It could be observed that HC emissions rise with the percentage of wood turpentine in the blends. This is due to relatively more oxygen available for the reaction when added JWT10, JWT20, and JWT30 blends are injected into the cylinder at higher engine load. The plant oil fuel blend emits lower HC emissions than diesel, except for 50% of the plant oil with 50% diesel blend [9, 30].

Carbon dioxide

The lowermost CO_2 emission values were obtained for JWT20, fig. 8. The CO_2 emissions for lower blend concentrations were near to diesel. However, for higher mixture concentrations, CO_2 releases increased considerably, since plant oil contains oxygen portion. The carbon content is reasonably lower in the same volume of fuel consumed at the identical engine load, subsequently the CO_2 releases commencing the plant oil and its mixtures are lesser.

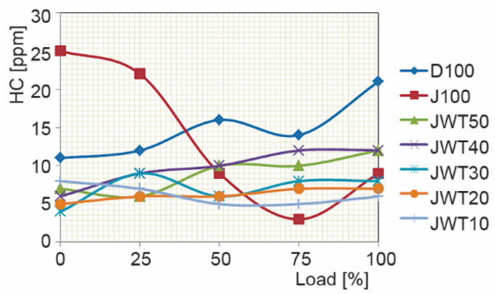


Figure 7. The HC *vs.* load

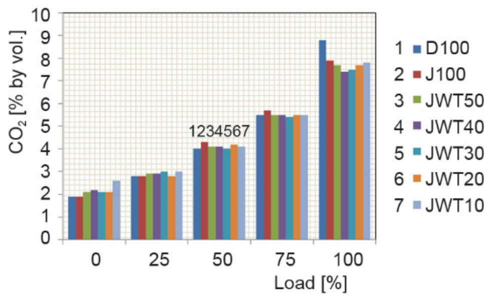


Figure 8. The CO_2 *vs.* load

Nitric oxides

The variation of NO_x emissions from jatropha biodiesel, JWT mixtures with respect to diesel are displayed in fig. 9. The NO_x emissions increased with the load for all JWT mixtures. The most important issue of the NO_x emissions is the burning temperature inside the cylinder and the confined stoichiometric ratio of the blend. The NO_x emissions at 75% of load for JWT10, JWT20, JWT30, JWT40, JWT50, J100, and neat diesel are 845, 877, 907, 924, 974, 867, and 802 ppm, respectively. At full load, the NO_x values for JWT10, JWT20, JWT30, JWT40, JWT50, J100, and neat diesel are 1035, 1071, 1052, 1066, 1129, 1084, and 964 ppm, respectively. The NO_x emission reduces with JWT blends due to the reduced com-

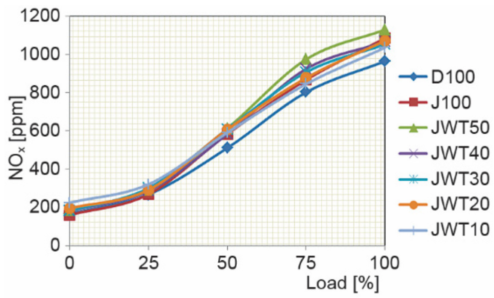


Figure 9. The NO_x *vs.* load

bustion temperature in the cylinder at 75% load and full load. Biodiesel premixes have greater oxygen absorptions at lower loads and therefore create more NO_x. This behavior has been linked with the non-linear nature of the chemical rate disparity with temperature. The NO_x creation and destruction is a kinetically-controlled system. The NO_x emissions decrease at higher loads as a concern of smaller residence periods of gases in the combustion chamber. The greater cetane number of biodiesel infers shorter ignition delay which diminishes the burning temperature as well as the residence time, consequently producing less NO_x formation at higher loads [10, 13].

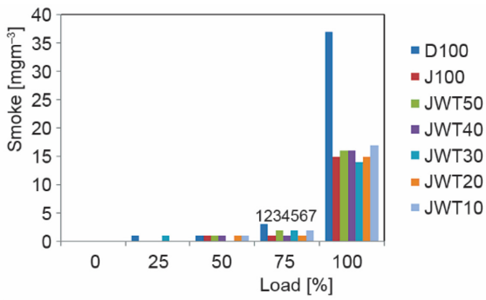


Figure 10. Smoke *vs.* load

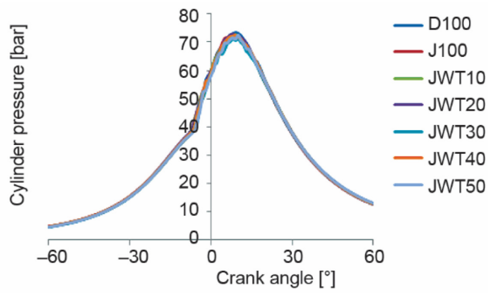


Figure 11. Cylinder pressure *vs.* crank angle

Smoke opacity

The smoke opacity rises with an increase in jatropha oil concentration in mixtures predominantly at upper loads, fig. 10. At 75% load, the smoke opacity for diesel, J100, JWT10, and JWT20 are 3, 1, 2, and 1 mg/m^3, while at 100% load the smoke opacity for diesel, J100, JWT10, JWT20, JWT30, JWT40, and JWT50 were 37, 15, 16, 14, 15, and 17 mg/m^3. Higher smoke opacity is considered to be a cause of the poorer atomization properties. Bulky fuel particles and higher viscosity of jatropha oil effect in poor atomization of fuel mixtures.

Combustion parameters

Cylinder pressure

The peak pressure established at maximum load is displayed in fig. 11. The magnitude of peak pressure depends on the quantity of fuel vaporized in ignition delay time, which is a distinctive of the fuel. The viscosity has a substantial role in the quantity of fuel vaporized. The peak pressure established for J100 is 72.33 bar at 8° aTDC, JWT10 is 72.76 bar at 8° aTDC, JWT20 is 72.97 bar at 8° aTDC, JWT30 is 71.17 bar at 8° aTDC, JWT40 is 72.51 bar at 9° aTDC, JWT50 is 72.55 bar at 10° aTDC, and for neat diesel it is 72.33 bar at 8° aTDC. It can be observed that the cylinder pressure of jatropha biodiesel, jatropha-turpentine blends are nearer to neat diesel due to better atomization and mixing. In a CI engine, the rate of pressure rise depends on the combustion rate in the early phases, which in turn is prejudiced by the volume of fuel taking part in the uncontrolled combustion. The uncontrolled combustion stage is influenced by the auto ignition delay as well as the fuel quantity injected during this time frame.

Heat release rate

The heat release rate (HRR) for straight jatropha biodiesel, JWT mixture and diesel are displayed in fig. 12. The HRR at 50% of load for diesel is 72.44 kJ/m^3 °CA, for JWT30 blend it is 65.41 kJ/m^3 °CA, and for JWT40 blend it is 68.39 kJ/m^3 °CA. The HRR at 75% of load for J100 biodiesel is 66.27 kJ/m^3 °CA, for JWT10 blend, it is 65.37% and for JWT20 blend it is 57.03 kJ/m^3 °CA. The HRR at full load for JWT50 biodiesel is 67.83 kJ/m^3 °CA.

The HRR of diesel, JWT40 and JWT50 blends is similar. With the increase of turpentine in the jatropha biodiesel mixture it is observed that the CA of peak HRR is advanced.

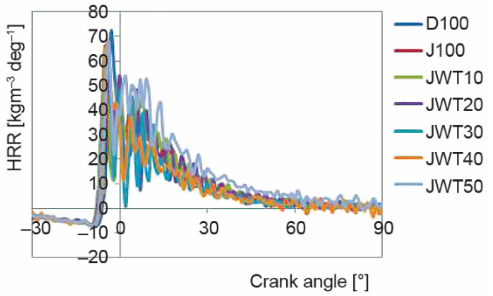


Figure 12. The HRR *vs.* load

Conclusions

The main objective of this work is to search a green fuel as a replacement for diesel for CI engines. The performance, combustion and pollutant features of JWT blends have been explored and equated to the standard diesel.

- The BSFC increases with a higher proportion of JWT blends as compared to diesel in the entire load range due to lower calorific value. The BTE of JWT50 blend was similar to diesel at 75% and 100% loads. The EGT of J100 and JWT blends were similar to diesel at all the loads and EGT increases with the rise in load.
- The emissions of CO rise with increasing load. At 75% load, CO emissions for J100 and JWT blends were negligible. The HC emissions of JWT blends were lower at 75% of load due to more oxygen available for the reaction in the cylinder. The CO_2 for lower blend concentrations were similar to diesel, but for higher blend concentrations, CO_2 increased significantly. The NO_x emissions increased with the load for all JWT blend. At 75% and 100% loads smoke opacity for JWT blends were lower than that of diesel.
- The peak pressure developed for J100 is 72.33 bar and JWT20 is 72.97 bar at 8° aTDC. The degree of peak pressure depends on the quantity of fuel vaporized over ignition delay time. The peak HRR observed for JWT40 blend is 68.39kJ/m^3 °CA. With the rise of turpentine in the jatropha biodiesel mixture it is witnessed that the CA of peak HRR is progressive.

The experimental results prove that JWT blends can be substituted for diesel in CI engines.

Nomenclature

aTDC	– after top dead centre
BTE	– brake thermal efficiency, [%]
BSFC	– brake specific fuel consumption, [kgkW^{-1}h^{-1}]
bTDC	– before top dead centre
CA	– crank angle, [°]
CI	– compression ignition
EGT	– exhaust gas temperature, [°C]
HRR	– heat release rate, [kJm^{-3}deg^{-1}]
J100	– jatropha biodiesel
JWT	– jatropha biodiesel-wood turpentine
JWT 10	– jatropha biodiesel (90%) + wood turpentine (10%)
JWT 20	– jatropha biodiesel (80%) + wood turpentine (20%)
JWT 30	– jatropha biodiesel (70%) + wood turpentine (30%)
JWT 40	– jatropha biodiesel (60%) + wood turpentine (40%)
JWT 50	– jatropha biodiesel (50%) + wood turpentine (50%)

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