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ORIGINAL PAPER

Performance and pollutants analysis on diesel engine using blends of Jatropha Biodiesel and Mineral Turpentine as fuel

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Abstract Performance and pollutants features of Jatropha–Mineral Turpentine blends along with diesel have been examined in a single-cylinder compression ignition engine. Vegetable oils have higher viscosities than diesel fuel, and it greatly disturbs the performance, durability, burning and discharge features of the compression ignition engine. The tests were performed with different blend combinations of Jatropha–Mineral Turpentine oil as fuel. The experimental outcome indicates that brake thermal efficiency of the blend of 80% Jatropha Biodiesel and 20% of Mineral Turpentine is nearby to diesel fuel at 75% load. Carbon monoxides, hydrocarbons and emission were reduced to the considerable amount, whereas the oxides of nitrogen increase with increase in part load and reduced with 75% and full load operations. The specific fuel consumption of Jatropha–Mineral Turpentine blends found to be slightly upper than diesel fuel. The heat release rate and cylinder pressure of Jatropha–Mineral Turpentine blends were closer to diesel fuel. The test results recommend that Jatropha–Mineral Turpentine blends might stay a decent auxiliary to diesel fuel in the near upcoming and it can be concluded that Jatropha–Mineral Turpentine oil blends could be utilized in a conventional compression ignition engine with no alteration.

Keywords Vegetable oil · Energy · Efficiency · Combustion · Emission

Introduction

The world is currently threatened with the several crunches like growing energy demand, diminishing mineral oil, industrialization and environmental pollution concern, and these factors were motivated many researchers to try out with vegetable oil as alternate for fossil fuel in diesel engines (Bala 2005; Sayin and Gumus 2011; Karikalan and Chandrasekaran 2013; Kasaby and Nemit-allah 2013). Researchers around the sphere have sightseen numerous substitute energy possessions for the increasing energy desire. Numerous biofuel energy assets discovered comprise biomass, biogas, alcohols, vegetable oils, biodiesel, etc. These unconventional energy assets are chiefly friendly to environment, but they requisite to be assessed on the base of their gains, drawbacks and precise claims. Several of these energies can be utilized straight, whereas others must be framed to get the pertinent possessions nearer to straight fuels.

Long-term use of vegetable oil causes deposit formation and lubricating oil contamination in the diesel engine, and the vegetable oils were forced to get transesterified to make the biodiesel and to resolve the issue and make viable for diesel engine (Kumar et al. 2003; Shivakumar et al. 2011). Numerous claims state that a slice of complications may ascend by translating eatable oils into biodiesel (Kumar and Sharma 2008). To astound this problem, exploration has been steered to yield biodiesel by spending non-eatable oils like Jatropha. In addition to the presence of a basis of oil, Jatropha also affords a meal that assists as an exceedingly healthy and profitable protein add-on in animal feed, if the contaminants are detached (Becker and

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Makkar 1998). Biodiesel has gained an attention to replace the diesel fuel as substitute energy source. Biodiesel can replace diesel without any major modification in the engine. It is biodegradable, renewable and produces hazardless gases (Mofijur et al. 2015; Rajasekar et al. 2010). It is expressed by several researchers that biodiesel and its blends could replace diesel fuel in compression ignition engines and provides a decent reduction of carbon monoxide, hydrocarbon and emission with no control over the oxides of nitrogen (Ozsezen and Canakci 2010; Chauhan et al. 2010; Ganapathy et al. 2011; Mistri et al. 2016; Jain and Sharma 2013; Mofijur et al. 2014; Shrivastava et al. 2012; Teoh et al. 2014).

Utmost of the substitute biofuels notorious currently are evidenced to be a restricted standby for the prevailing biofuel owing to its limited adverse fuel features (Gunea et al. 1998). The organically centered substitute fuels termed biofuels were acknowledged well in advance the search of further encouraging alternate fuels (Robert et al. 1995). These biofuels are renewable and eco-friendly. Largely, plants return two kinds of oils specifically triglyceride oil and turpene oil of which triglyceride oil is attained from the plant kernels, but turpene oil is gained from all portions of the plant. Triglyceride oils have upper viscosity than terpene oils. But, terpene oils display lesser viscosity and encouraging fuel features than triglyceride oils. Terpene oils are chiefly obtainable in certain plant types specifically eucalyptus, pine tree, etc.

The 20% turpentine and 80% diesel mixture have an identical burning and performance features, lessened CO, UBHC and soot equated to diesel. In specific, about 45–50% emission lessening is gained with upper turpentine blends (Anandavelu et al. 2010; Mahalakshmi and Karthikeyan 2005). The effects of different blends of turpentine oil with diesel fuel have been investigated and noticed that the low heat rejection diesel engine with blended fuels shows the better performance, reduced oxides of nitrogen and heat release rate with decreased emissions when compared to diesel engine. The main objective of this study is to testify an untried biodiesel blend in the name of Jatropha Biodiesel–Mineral Turpentine (JMT) from 10 to 50% as substitute for diesel fuel in a single-cylinder compression ignition engine and to assess the performance, combustion and emission features against standard diesel fuel.

This research work has been carried out at Sri Venkateswara College of Engineering, Chennai, on August 8, 2015.

Vegetable oil–Jatropha Biodiesel

Lessons have revealed that the practice of vegetable oils in neat practice is thinkable but not desirable. The upper viscosity of plant oils and the lesser volatility shakes the atomization and spray form of fuel, principal to imperfect burning and severe carbon pledges, injector clogging and piston ring jabbing. India has an enormous unused land space appropriate for Jatropha farming, and it can source huge capacity of biodiesel for numerous states of India with the spare a total of 1.72 million hectares of plot for Jatropha farming (Chauhan et al. 2012). The transesterification practice is to lessen the viscosity of the oil. The transesterification response ensues fine in the existence of catalyst sodium hydroxide (Demirbas 2003; Schuchardt et al. 1998). Transesterification is the practice of switching the alkoxy set of an ester composite by an added alcohol. Jatropha Biodiesel is much cleaner than fossil-fuel diesel. It can be utilized in diesel engine without any alterations. Biodiesel is better for the environment because it is made from renewable resources and has lower emissions compared to petroleum diesel (Biswas et al. 2010; Mofijur et al. 2013; Jain and Sharma 2010; Ramesh and Sampathrajan 2008; Sundaresan et al. 2007).

Mineral Turpentine

Mineral Turpentine also known as white spirit is a petroleum-derived clear, transparent liquid used as a common organic solvent in painting and decorating. In industry, mineral spirits are used for cleaning, degreasing machine components, cutting oil and reaming lubricant. White spirit is a mixture of aliphatic and alicyclic C7 to C12 hydrocarbons with a maximum content of 25% of C7 to C12 aromatic hydrocarbons, a maximum benzene content of 0.1% by volume, a kauri-butanol value of 29, an opening boiling point of 145–17 °C and a density of 0.79 g/ml. Mineral Turpentine is chemically very different from turpentine, which largely consists of pinene, and it has inferior solvent properties. Mineral spirits have a characteristic unkind kerosene-like odor. White spirits are also a major constituent in some widespread automotive fuel/oil additives.

Materials and methods

The present analysis is to shrink the viscosity of Jatropha oil near to straight diesel in mandate to mark it proper for use in diesel engine and to assess the engine performance with different substitute fuels. Viscosity of test fuel was further reduced by blending the Jatropha Biodiesel with Mineral Turpentine oil. The different combinations of Jatropha Biodiesel and Jatropha Biodiesel–Mineral Turpentine blends used in this experiment are J100 (Jatropha Biodiesel 100%), JMT10 (Jatropha Biodiesel 90% + Mineral Turpentine 10%), JMT20 (Jatropha

Biodiesel 80% + Mineral Turpentine 20%), JMT30 (Jatropha Biodiesel 70% + Mineral Turpentine 30%), JMT40 (Jatropha Biodiesel 60% + Mineral Turpentine 40%) and JMT50 (Jatropha Biodiesel 50% + Mineral Turpentine 50%).

The heat values of diesel and the blends of Jatropha Biodiesel are as follows:

For diesel = 43.50 MJ/kg, Jatropha Biodiesel = 42.25 MJ/kg, Mineral Turpentine = 46.00 MJ/kg, JMT 10 = 42.63 MJ/kg, JMT 20 = 43.00 MJ/kg, JMT 30 = 43.38 MJ/kg, JMT 40 = 44.13 MJ/kg and for JMT 50 = 44.50 MJ/kg.

The retail price of Jatropha Biodiesel is Rs. 50.00/L, and for bulk purchase, it ranges from Rs. 32.00 to Rs. 36.00/L. The retail price of conventional diesel fuel is Rs. 50.09/L. The price of Jatropha Biodiesel is lesser than the conventional fuel.

Experimental setup

A single-cylinder Kirloskar TAF1 model air-cooled DI diesel engine broadly used in the farm division has been designated for the current untried work. The fuel properties are specified in Table 1. The engine started after filling up fresh engine oil and allowed to operate at a continual speed of 1500 rpm. The engine is tied with a single-phase, 240-V swing-field electrical dynamometer for loading the engine through a resistive load bank. The diagram of test procedure is revealed in Fig. 1. The engine is started by diesel, and once warms up, it is transferred to Jatropha oil and Jatropha–Mineral Turpentine Oil blends.

A thermocouple was fitted in the exhaust route to size the temperature of the gases. The voltage and current disbursed in the load bank were quantified by voltmeter and ammeter. Emission was quantified using smoke meter (Make: AVL Austria, Model: 415). The exhaust gas was quantified by exhaust gas analyzer (Make: AVL India, Model: DIGAS 444) for analyzing CO_2, CO, HC, NO_x and O_2 absorptions.

The tests were piloted with diesel to create standard data with an ideal fuel injection pressure. In the subsequent phase, tests were steered by blends of Jatropha oil and Jatropha–Mineral Turpentine oil blends, though working the engine on optimal fuel injection pressure. For this persistence, some blends of different concentrations were arranged stretching from 100% (Jatropha Biodiesel) to 50:50 (Jatropha–Mineral Turpentine oil blends) by 10, 20, 30, 40 and 50%. These blends stayed and then exposed to performance and emission trials on the engine. The

Table 1 Fuel properties of diesel, biodiesel, Mineral Turpentine and biodiesel blends

Description	Diesel	Jatropha Biodiesel	Mineral Turpentine	JMT 10	JMT 20	JMT 30	JMT 40	JMT 50
Density @15 °C (kg/m^3)	860	890	790	878	866	857	847	839
Viscosity @ 40° (mm^2/s)	4.25	5.65	3.8	5.28	5.14	4.91	4.73	4.54
Flash point (°C)	50	170	36	152	138	125	110	96
Cetane number	45–55	50	–	–	–	–	–	–
Calorific value (MJ/kg)	43.50	42.25	46.00	42.63	43.00	43.38	44.13	44.50

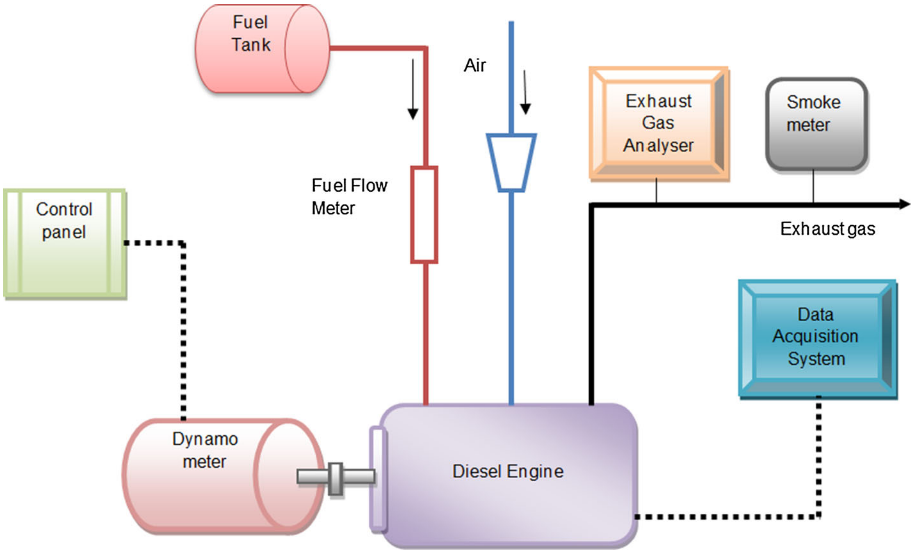

Fig. 1 Experimental setup line diagram

performance and pollutants data were explored for all experiments, and the outcomes are stated in the subsequent division.

Results and discussion

Brake specific fuel consumption (BSFC)

BSFC was established to increase the upper segment of Jatropha–Mineral Turpentine oil likened to diesel in the complete load variety (Fig. 2). The BSFC of JMT50 is close to diesel. Jatropha oil is inferior when equated to that of diesel for calorific value; hence, upward share of Jatropha oil in blend drops calorific value of the blend which has effects in enlarged BSFC.

Brake thermal efficiency (BTE)

Brake thermal efficiency of Jatropha–Mineral Turpentine oil mixtures was lesser than diesel. Conversely, thermal efficiency of blend JMT50 was very nearby to diesel at 75% and full loads (Fig. 3). Oxygen existing in the fuel particles progresses the combustion features, but upper viscosity and deprived volatility of vegetable oil had clue to their reduced combustion features. Hence, thermal efficiency was established as lesser for upper mixture concentrations matched to mineral diesel.

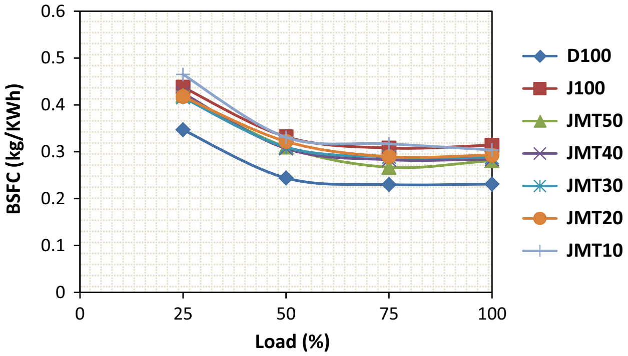

Fig. 2 BSFC versus load

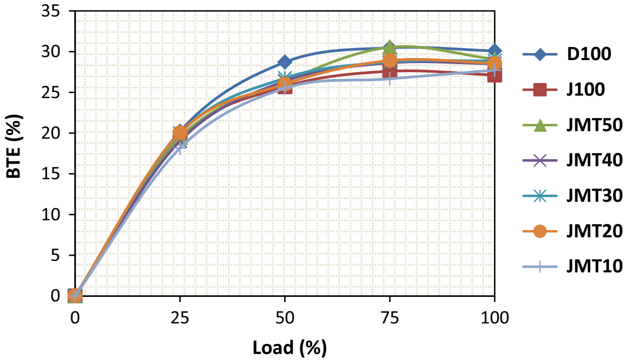

Fig. 3 BTE versus load

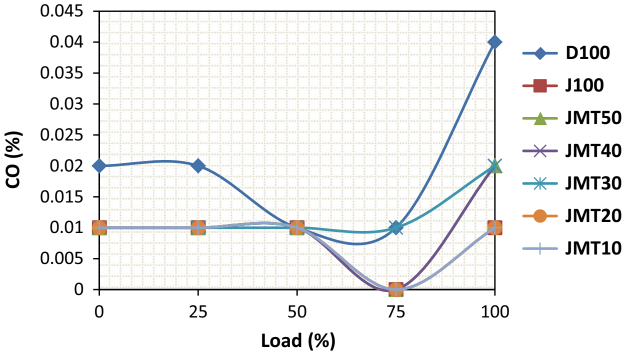

Fig. 4 CO versus load

Carbon monoxide (CO)

The emission of CO escalates with rising load (Fig. 4). Greater load, richer fuel–air mix is burned, and hence, CO is formed owing to deficiency of oxygen. At 75% loads, CO emissions for J100, JMT50, JMT40, JMT20 and JMT 10 are negligible. Only at maximum load, the CO emissions of Jatropha–Mineral Turpentine mixtures were all lesser than diesel fuel. This is probably owing to two elements: (1) at full engine load, the temperature inside the engine cylinder is greater, which creates the vegetable oil blends easier to atomize and mix, and then, an improved combustion was accomplished; (2) the oxygen substances in the vegetable oil create easier to burn at upper temperature in the cylinder (Agarwal and Agarwal 2007; Wang et al. 2006).

Hydrocarbons (HC)

Jatropha–Mineral Turpentine oil blend JMT20 and J100 exhibit lower HC emissions compared to diesel. At 75% loads, HC emissions for J100 and JMT20 are 78.6 and 64.3%, respectively, less, and at 100% loads, HC emissions were 57.1 and 61.9%, respectively, less than diesel (Fig. 5). It can be perceived that HC emissions increase with growing share of Jatropha–Mineral Turpentine oil blends. The HC emissions of JMT 10 and JMT20 blends are lower with enlarged at upper engine load. This is owed to supplementary oxygen existing for the response when extra JMT 10 and JMT20 blends are injected into the cylinder at upper engine load. The vegetable oil and vegetable/diesel fuel blend emit HC emissions lower than diesel, except for 50% of the vegetable oil with 50% diesel fuel blend (Agarwal and Agarwal 2007; Wang et al. 2006).

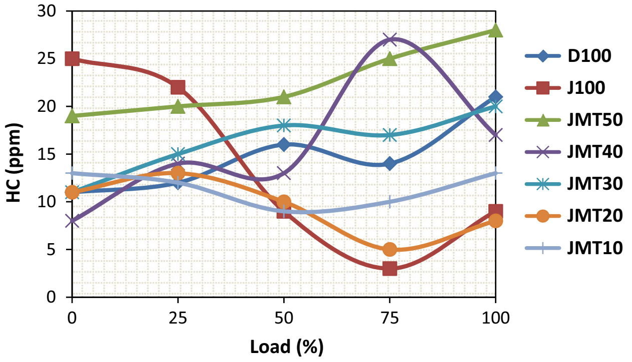

Fig. 5 HC versus load

Nitrides of oxygen (NO_x)

The variation of NO_x emissions from Jatropha Biodiesel and Jatropha–Mineral Turpentine blends with respect to diesel fuel is displayed in Fig. 6. The NO_x emission enlarged by the part load starts reducing at 75% and full load for all Jatropha–Mineral Turpentine blends. The utmost vital aspect for the emissions of NO_x is the burning temperature in the cylinder and the confined stoichiometric of the mix. The NO_x emissions at 75% of load for JMT10, JMT20, JMT30, JMT40, JMT50, J100 and neat diesel are 830, 794, 771, 754, 716, 867 and 802 ppm, respectively. The NO_x emissions at full load for JMT10, JMT20, JMT30, JMT40, JMT50, J100 and neat diesel are 995, 954, 893, 829, 805, 1084 and 964 ppm, respectively. It can be seen that with the 75% of load and full load, the NO_x emissions of the Jatropha–Mineral Turpentine blends are lesser than diesel. The NO_x emissions are getting diminished with Jatropha–Mineral Turpentine blends due to reduced burning temperature in the cylinder at 75% load and full load. Biodiesel premixes have greater oxygen absorptions at lesser loads and therefore create more NO_x. This behavior has been linked with the nonlinear nature of the chemical rates disparity with temperature. NO_x creation and devastation are a kinetic-controlled system. NO_x emissions declined 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 residence time, and consequently less NO_x formation at higher loads (Nabi 2010; Palash et al. 2013).

Emission opacity

The emission opacity surges with rise in Jatropha oil absorption in blends mainly at upper loads (Fig. 7). At 75% loads, emission opacity for J100, JMT20 and JMT10 is 47.6, 52.4 and 57.1%, respectively, less, and at 100% loads, emission opacity was 44.8, 42.3 and 52.8%, respectively, lesser as equated to diesel. Upper emission denseness might be owed to deprived atomization of the Jatropha oil. Massive fuel particles and upper viscosity of Jatropha oil has effect in reduced atomization of fuel blends.

Cylinder pressure

The decisive pressure established at maximum load is shown in Fig. 8. The extent of decisive pressure hangs on the extent of fuel vaporized in ignition delay time which is a distinctive of the fuel. Largely, the viscosity shows a noteworthy role in the quantity of fuel evaporated. The decisive pressure established for J100, JMT10, JMT20, JMT30, JMT40 and JMT50 is 72.33 bar, 73.46 bar, 75.02 bar, 73.54 bar, 74.48 bar and 74.21 bar at 7° ATDC, 8° ATDC, 7° ATDC, 8° ATDC, 9° ATDC and 10° ATDC, and for neat diesel, it is 72.33 bar at 8° ATDC. It is clear that the cylinder pressure of Jatropha Biodiesel and Jatropha–Mineral Turpentine blends are nearer to neat diesel due to better atomization and mingling. In a CI engine, the degree of pressure escalation rests on the burning level in the early phases, which in turn is inclined by the quantity of fuel enchanting share in the uncontrolled burning. The

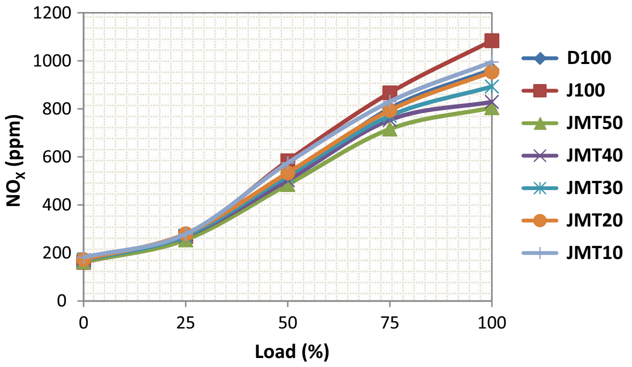

Fig. 6 NO_x versus load

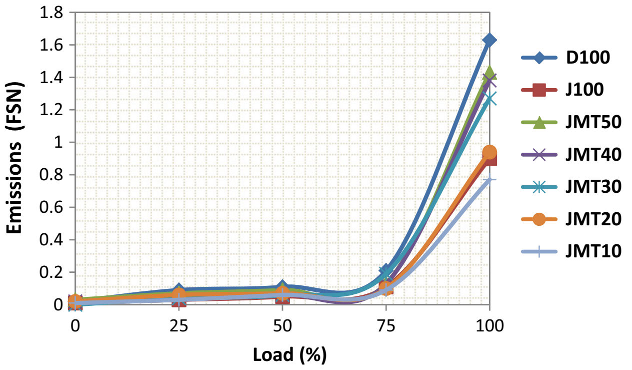

Fig. 7 Emissions versus load

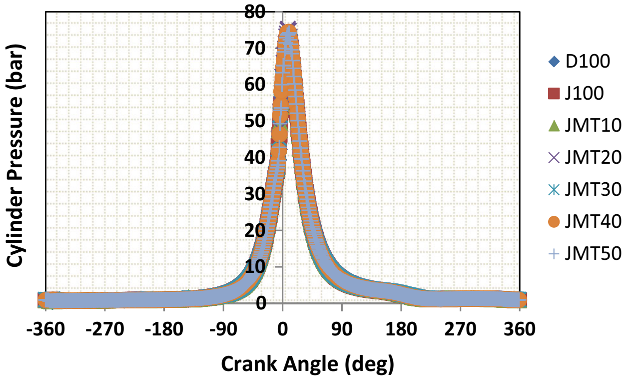

Fig. 8 Cylinder pressure versus crank angle

uncontrolled or premixed burning stage is inclined by the delay time and the mixing provision in the delay time.

Heat release rate (HRR)

The HRR for straight Jatropha Biodiesel, Jatropha–Mineral Turpentine and diesel are displayed in Fig. 9. The HRR at 50% of load for diesel, JMT10, JMT20, JMT40, and JMT50 blends is 72.44, 63.29, 70.7, 86.23 and 102.9 kJ/m^3deg.CA. The heat release rates at 75% of load for J100 diesel and JMT30 blend is 66.27 and 74.49 kJ/m^3deg.CA. The HRR of diesel, JMT20 and JMT30 blends are similar. The decisive HRR for JMT40 and JMT50 blends is 86.23 and 102.9 kJ/m^3deg.CA, respectively. With the rise of Mineral Turpentine in the Jatropha Biodiesel, it is witnessed that the crank angle of decisive heat release rate is progressive.

Conclusion

The significant objective of the current analysis is to shrink the Jatropha oil viscosity which was nearby to straight diesel by blending the Jatropha Biodiesel with Mineral Turpentine oil in directive to make it proper for practice in a diesel engine and to assess the enactment of the engine through different substitute fuels.

BSFC was established to increase upper share of Jatropha–Mineral Turpentine oil equated to diesel in the whole load choice owing to inferior calorific value. Brake thermal efficiency (BTE) of Jatropha–Mineral Turpentine oil was lesser than diesel. However, BTE of blend JMT50 is very near to the diesel at 75 and 100% loads but it is poorer for upper blend concentrations when equated to the diesel.

The emissions of CO increase with increasing load. At 75% loads, CO emissions for J100, JMT50, JMT40, JMT20 and JMT 10 are small. Jatropha–Mineral Turpentine oil blends JMT20 and J100 reveal lower HC emissions equated to diesel. It could be witnessed that HC emissions rise with growing share of Jatropha–Mineral Turpentine oil. The NO_x emissions enlarged with the part load and getting reduced with Jatropha–Mineral Turpentine blends due to reduced burning temperature in the cylinder at 75% load and full load. The emission denseness upsurges with rise in Jatropha oil absorption in blends chiefly at upper loads. At 75% loads and 100% loads, emission opacity for J100, JMT20 and JMT10 is less as compared to diesel. Upper emission denseness might be owed to deprived atomization of the massive fuel particles and upper viscosity of Jatropha oil.

It is perfect that the cylinder pressure of Jatropha Biodiesel and Jatropha–Mineral Turpentine blends is closer to neat diesel due to better atomization and mixing. The extent of peak pressure is influenced by the quantity of fuel vaporized in ignition delay time, which is a distinctive of the fuel. The decisive HRR for JMT40 and JMT50 blends is 86.23 kJ/m^3deg.CA and 102.9 kJ/m^3deg.CA, respectively. With the rise of Mineral Turpentine in the Jatropha Biodiesel blend, it is perceived that the crank angle of decisive HRR is advanced.

The above experimental results prove that Jatropha Biodiesel-Mineral Turpentine blends can be substituted for standard diesel in CI engine.

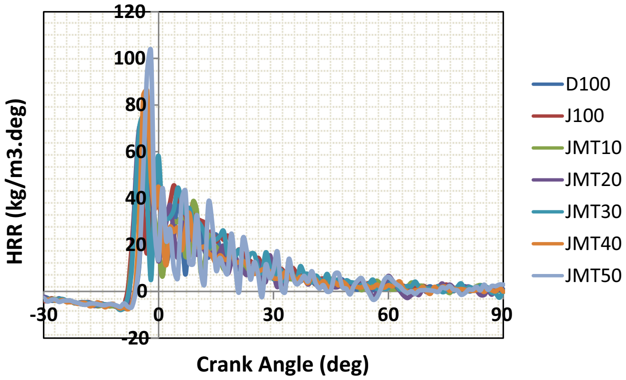

Fig. 9 HRR versus crank angle

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Abbreviations

C.I	Compression ignition
J100	Jatropha Biodiesel
JMT	Jatropha Biodiesel–Mineral Turpentine
BTE	Brake thermal efficiency (%)
BSFC	Brake specific fuel consumption (kg/kW-h)
EGT	Exhaust gas temperature (°C)

CO	Carbon monoxide (%)
HC	Hydrocarbons (ppm)
CO_2	Carbon dioxide (%)
NO_x	Nitrides of oxygen (ppm)
HRR	Heat release rate (kJ/m^3.deg)
CA	Crank angle (°)
ATDC	After top dead center
BTDC	Before top dead center

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