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INFLUENCE OF TURPENTINE ADDITION IN JATROPHA BIODIESEL ON CI ENGINE PERFORMANCE, COMBUSTION AND EXHAUST EMISSIONS

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ABSTRACT−The prospect of using turpentine oil as an additive for Jatropha biodiesel and using it as an alternative fuel for diesel in CI engines has been experimented in this work. Tests were carried out in a single cylinder, air cooled, constant speed, direct injection diesel engine. The results display that the performance of Jatropha-Mineral Turpentine (JMT) and Jatropha-Wood Turpentine (JWT) blends were found close to diesel, emission features were enhanced and combustion parameters were noticed to be comparable with diesel. Brake thermal efficiency of JMT20 blend found closer to diesel at 75 % load. BSFC increases for JMT and JWT blends at part load and maintains at full load. CO, HC and Smoke emissions were reduced with JMT and JWT blends at 75 % load. NOx emissions were on the raise. Furthermore, JMT and JWT blends offered comparable performance and combustion parameters, reduced emissions and both can substitute standard diesel in CI engines.

KEY WORDS : Diesel, Vegetable oil, Turpentine, Combustion, Emissions

NOMENCLATURE

CI : compression ignition
J100 : jatropha biodiesel
JMT : jatropha biodiesel-mineral turpine
JWT : jatropha biodiesel-wood turpine
BTE : brake thermal efficiency, %
BSFC : brake specific fuel consumption, kg/kW-hr
EGT : exhaust gas temperature, ^0C
CO : carbon monoxide, %
HC : hydrocarbons, ppm
CO_2 : carbon di-oxide, %
NO_x : nitrides of oxygen, ppm
HRR : heat release rate, kJ/m^3.deg
CA : crank angle, deg

1. INTRODUCTION

Vegetable oils are measured as substitute fuel, resultant from renewable natural sources and emit less regulated pollutants than the diesel fuel. The usage of vegetable oils, as an alternative to diesel fuel, has been increased promptly. However, due to technical absences, they are hardly used in unchanged diesel engines. Problems like poor atomization, injector sticking and engine deposits occurs when using pure vegetable oils in diesel engines. It has been reported by many researchers that use of crude vegetable oils as fuel, can decline engine performance parameters with reductions in emission (Varuvel *et al.*, 2012). Vegetable oils exhibit longer combustion duration with moderate rates of pressure rise, unlike petroleum derived fuels (Aydin, 2013). Biofuels have been gaining reputation lately as an alternative fuel for diesel engines. Biofuels can be used in any diesel engine, generally without any modifications and it boasts reduction in toxic emissions except NOx emissions.

In this work, jatropha biodiesel is blended with mineral turpentine and wood turpentine to develop an alternate and green fuel as a substitute for diesel in the CI engine and to measure the performance, combustion and emission characteristics.

2. VEGETABLE OIL-JATROPHA BIODIESEL

2.1. Jatropha Oil

Numerous claims states that a lot of complications may arise by translating edible oils into biodiesel (Kumar and Sharma, 2008). In order to astounded this problem, research has been steered to produce biodiesel by using non-edible oils like Jatropha.

Advantages with Jatropha.

- It is easier to harvest than large tree and has much shorter gestation period.
- It generates additional income for people in the slack agricultural season.
- It is resistant to common pests and not consumed by the cattle.
- The by-products of biodiesel are used as bio-fertilizer and

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glycerine.
- It require very few nutrients to survive and therefore can be grown on less fertile land.

In addition to being a source of oil, Jatropha also provides a meal that assists as a exceedingly nutritious and economic protein supplement in animal feed, if the toxins are removed (Becker and Makkar, 1998).

India has a enormous waste land space suitable for Jatropha cultivation and it can supply large volume of biodiesel for numerous states of India with the reserve a total of 1.72 million hectares of land for Jatropha cultivation (Chauhan *et al*., 2010). The current research is aimed at discovering technical feasibility of Jatropha oil in diesel engine without any modifications.

2.2. Jatropha Biodiesel

The drive of the transesterification practice is to lower the viscosity of the oil. The transesterification reaction ensues well in the existence of catalyst sodium hydroxide (Demirbas, 2003). Transesterification is the process of exchanging the alkoxy set of an ester composite by another alcohol. These reactions are habitually catalysed by the tallying of a base and acid. Bases can catalyse the reaction by eradicating a proton from the alcohol, thus constructing it more responsive, while acids can catalyse the reaction by offering a proton to carbonyl group, thus building it more reactive (Agarwal and Agarwal, 2007).

2.3. 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 alipahtic and alicyclic C7 to C12 hydorcarbons 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 °C to 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.

2.4. Wood Turpentine Oil

Wood Turpentine made history of use as a viable fuel resource and can still replace the diesel and biodiesels. Turpentine had been man-made and used as a fuel in 1700s for burning lamps, boilers and furnace. Turpentine oil derived by pyrolysis mechanism from the pine tree dissolved in a volatile liquid is admitted as substitute to diesel in compression ignition engines. Turpentine oil was used as an engine fuel and discontinued due to easy availability of fossil fuels. The turpentine oil used for this work was bought from a nearby commercial shop. Turpentine is a yellowish, opaque, sticky, volatile, combustible combination of hydrocarbon isomers gained either from pine gum or pine wood. Turpentine has a minimum alpha-pinene content of 40 % by weight. It consists chemically 58 ~ 65 % gamma-pinene along with beta-pinene and other isometric terpenes. Turpentine mixes freely in any proportion with jatropha biodiesel and it is assumed that turpentine oil could be a good contender for diesel fuel due to its high production in the world. The price of turpentine oil is slightly higher than diesel, but it would be least-cost alternative through the global emissions management cost (Prem Anand *et al*., 2010).

Table 1. Fuel properties of diesel, jatropha biodiesel and wood turpentine.

Description	Diesel	Jatropha biodiesel	Wood turpentine	Mineral turpentine
Density @ 15 °C, kg/m^3	860	890	880 ~ 900	790
Viscosity @ 40°, mm^2/s	4.25	5.65	3.89	3.8
Flash point, °C	50	170	35 ~ 40	36
Cetane number	45 ~ 55	50	38	-
Calorific value, MJ/kg	43.50	42.25	44.00	46.00

Table 2. Viscosities for blends of jatropha biodiesel, mineral turpentine and wood turpentine.

Description	J100	JMT10	JMT20	JWT10	JWT20
Viscosity @ 40°, mm^2/s	5.65	5.28	5.14	5.37	5.19

3. EXPERIMENTAL WORK

The key objective of the present analysis was to shrink the viscosity of Jatropha oil near to that of straight diesel in order to make it proper for use in a CI engine and to assess the performance of the engine with new alternate fuels. In the present study, viscosity was reduced by blending the Jatropha Biodiesel with Mineral Turpentine oil. The different combination of Jatropha biodiesel and Jatropha 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 %), JWT10 (Jatropha Biodiesel 90 % + Wood Turpentine 10 %) and JWT20 (Jatropha Biodiesel 80 % + Wood Turpentine 20 %).

A naturally aspirated direct injection diesel engine widely used in the farming sector has been selected for

Table 3. Specifications of the engine.

Make and model	KIRLOSKAR, TAF1
General details	Four stroke, compression ignition, constant speed, vertical, air cooled, direct injection
Number of cylinders	One
Orientation	Vertical
Bore	80 mm
Stroke	110 mm
Swept volume	553 cc
Clearance volume	36.87 cc
Compression ratio	16.5 : 1
Rated output	4.4 kW at 1500 rpm
Rated speed	1500 rpm
Nozzle opening pressure	200 bar
Fuel injection timing	23 ºCA BTDC
Type of combustion chamber	Hemispherical open combustion chamber

present experimental studies. A KIRLOSKAR-TAF1 model single cylinder, four stroke, constant speed, air-cooled, direct injection diesel engine was utilized for carrying out the tests. The technical specifications of the engines are given in Table 2. The engine run at a continual speed of 1500 rpm. Fresh lubricating oil was filled in oil sump before starting the experiments. The engine is attached through a single phase, 240 V swing field electrical dynamometer for loading the engine through a resistive load bank. The schematic layout of the experimental setup for the present investigation is shown in Figure 1. The engine is started by diesel and after warms up, it is changed over to Jatropha biodiesel and Jatropha biodiesel-Wood Turpentine blends.

A thermocouple was fitted in the exhaust route to measure the temperature of the exhaust gases. Voltmeter and ammeter were used to quantity the voltage and current disbursed by the load in the load bank. Exhaust gas opacity was measured using smoke meter (Make: AVL Austria, Model: 415). The exhaust gas composition was measured using exhaust gas analyzer (Make: AVL India, Model: DIGAS 444) and it measures CO_2, CO, HC, NO_X and O_2 concentrations in the exhaust gas.

The tests were conducted with diesel to generate baseline data with optimum fuel injection pressure. In the second phase, tests were conducted using blends of Jatropha biodiesel and Jatropha biodiesel-Wood Turpentine blends, while operating the engine on optimum fuel injection pressure. These blends were then exposed to performance and emission tests on the engine. The performance and emissions figures were then analyzed for all experiments and the results are stated in the subsequent section.

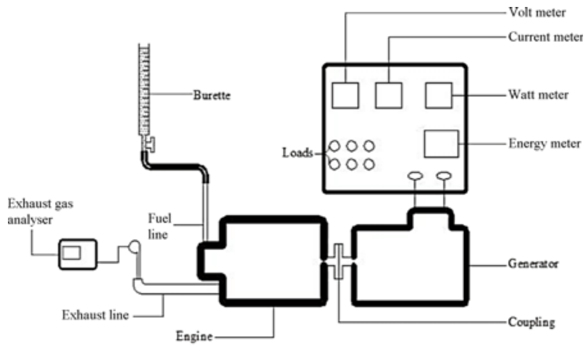

Figure 1. Experimental setup line diagram.

Figure 2. Experimental setup.

4. RESULTS AND DISCUSSION

4.1. Brake Specific Fuel Consumption

BSFC was found to increase with higher proportion of Jatropha-Mineral Turpentine (JMT) and Jatropha-Wood Turpentine (JWT) compared to diesel in the entire load range (Figure 3). The BSFC of JMT20 comes closer to diesel. Calorific value of Jatropha oil is lower compared to

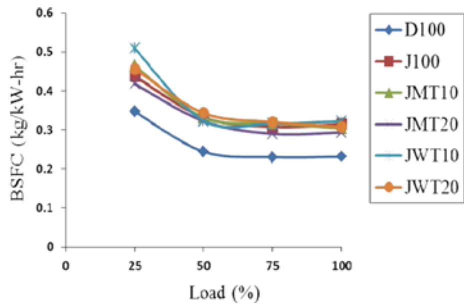

Figure 3. BSFC vs Load.

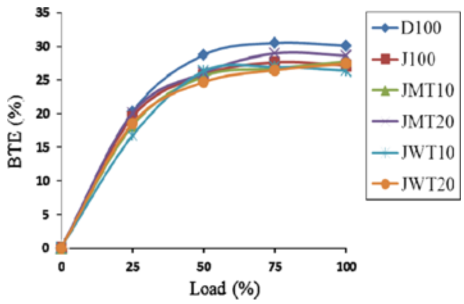

Figure 4. BTE vs Load.

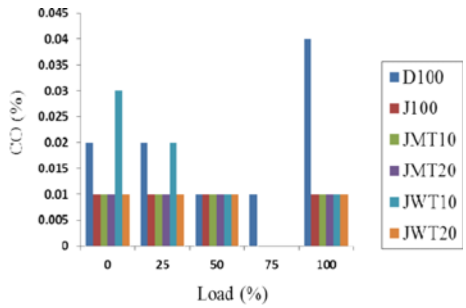

Figure 6. CO vs Load.

that of diesel, hence rising proportion of Jatropha oil in blend decreases the calorific value of the blend which results in increased BSFC.

4.2. Brake Thermal Efficiency (BTE)
Brake Thermal efficiencies of JMT and JWT blends were lower than that with diesel. However, thermal efficiency of blend JMT20 was very close to diesel at 75 % and full loads (Figure 4). Oxygen present in the fuel molecules improves the combustion features but higher viscosity and poor volatility of vegetable oils lead to their poor atomization and combustion features. Thus, thermal efficiency was found to be lower for higher blend concentrations compared to that of mineral diesel.

4.3. Exhaust Gas Temperature
The exhaust gas temperatures of Jatropha biodiesel, JMT and JWT blends were comparable to that of diesel at all the loads (Figure 5). It shows that the exhaust gas temperature increases with increase in load in all cases. The highest value of exhaust gas temperature of 422 ºC was observed with the JMT10 blend, whereas the corresponding value with diesel was found to be 410 ºC.

4.4. Carbon Monoxide (CO)
The emissions of CO increase with increasing load (Figure 6). Higher the load, richer fuel-air mixture is burned, and thus more CO is produced due to lack of oxygen. At 75 % loads CO emissions for J100, JMT10, JMT20, JWT10 and JWT20 are negligible. Only on the point of engine full load, the CO emissions of JMT and JWT blends were all lower than that of diesel fuel. This is probably owing to two factors: (1) at the engine full load, the temperature in the cylinder of engine is higher, which makes the vegetable oil and it blends easier to atomize, a better air/fuel mixture and then a enhanced combustion can be achieved; (2) the oxygen contents in the vegetable oil makes it easier to be burnt at higher temperature in the cylinder (Agarwal and Agarwal, 2007; Wang *et al*., 2006).

4.5. Hydrocarbons (HC)
JWT blends JWT10 and JWT20 exhibit lower HC emissions compared to diesel at all loads. At 75 % loads HC emissions for J100, JWT10, JWT20 and JMT20 are 78.6 %, 42.8 %, 50 % and 64.3 % respectively less and at 100 % loads HC emissions were 57.1 %, 61.9 %, 66.67 % and 61.9 % respectively less as compared to diesel (Figure 7). It can be observed that HC emissions increase with increasing proportion of JMT and JWT blends. The HC emissions of JWT10 and JWT20 blends are lower with increased at higher engine load. This is due to relatively more oxygen available for the reaction when more JWT10 and JWT20 blends are injected into the engine cylinder at higher engine load. The HC emissions of vegetable oil and vegetable/ diesel fuel blends are lower than that of diesel fuel, excluding 50 % of the vegetable oil with 50 % diesel fuel blend is a little higher than that of diesel fuel (Agarwal and Agarwal, 2007; Wang *et al*., 2006).

4.6. Carbon Dioxide (CO_2)

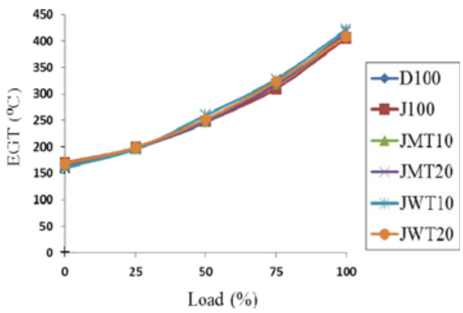

Figure 5. EGT vs Load.

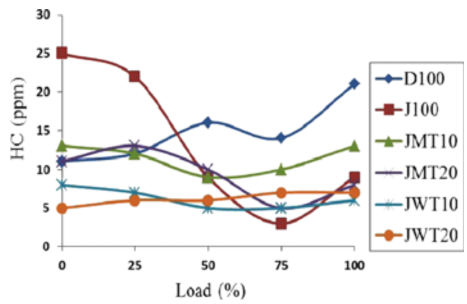

Figure 7. HC vs Load.

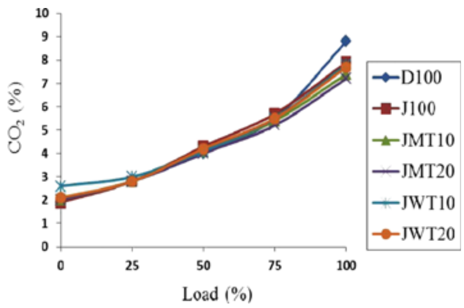

Figure 8. CO_2 vs Load.

Lowest CO_2 emissions were observed for JMT20 (Figure 8). CO_2 emissions for lower blend concentrations were close to diesel. But for upper blend concentrations, CO_2 emissions enlarged significantly. This is because vegetable oil contains oxygen component; the carbon content is comparatively lower in the same volume of fuel consumed at the same engine load, subsequently the CO_2 emissions from the vegetable oil and its blends are lower (Agarwal and Agarwal, 2007; Wang *et al*., 2006).

4.7. Nitrides of Oxygen (NO_X)

The variation of NOx emissions from Jatropha biodiesel, JMT and JWT blends with respect to diesel fuel are shown in Figure 9. The NOx emissions increases with increasing load for all Jatropha biodiesel, JMT and JWT blends except JMT20 blend. The most important factor for the emissions of NOx is the combustion temperature in the engine cylinder and the local stoichiometric of the mixture. The NOx emissions at 75 % of load for JMT10, JMT20, JWT10, JWT20, J100 and neat diesel are 830 ppm, 794 ppm, 845 ppm, 877 ppm, 867 ppm and 802 ppm respectively. The NOx emissions at full load for JMT10, JMT20, JWT10, JWT20, J100 and neat diesel are 995 ppm, 954 ppm, 1,035 ppm, 1,071 ppm, 1,084 ppm and 964 ppm respectively. It can be seen that with the part load, the NOx emissions from the JMT and JWT blends are lower than that of diesel fuel. The NOx emissions are getting increased with JMT and JWT blends at 75 % load and full load.

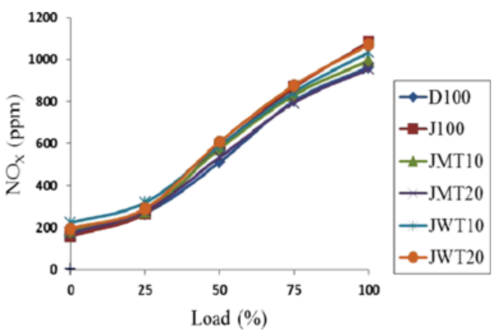

Figure 9. NO_X vs Load.

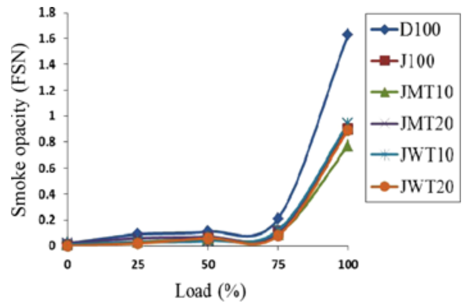

Figure 10. Smoke opacity vs Load.

4.8. Smoke Opacity

The smoke opacity increases with increase in Jatropha biodiesel, JMT and JWT blends particularly at higher loads (Figure 10). At 75 % loads smoke opacity for J100 JMT10, JMT20, JWT10 and JWT20 are 47.6 %, 57.1 %, 52.4 %, 33.3 % and 66.6 % respectively less and at 100 % loads smoke opacity were 44.8 %, 52.8 %, 42.3 %, 54 % and 59.4 % respectively less as compared to diesel. Greater smoke opacity might be due to poor atomization of the Jatropha oil. Bulky fuel molecules and higher viscosity of Jatropha oil result in poor atomization of fuel blends.

4.9. Cylinder Pressure

The highest pressure established at full load for the fuels used is shown in Figure 11. The magnitude of peak pressure based upon the amount of fuel evaporated in ignition delay period which is a characteristic of the fuel. Generally the viscosity plays a significant role in the amount of fuel evaporated. The peak pressure developed for J100 is 72.33 bar at 7 deg ATDC, JMT10 is 73.46 bar at 8 deg ATDC, JMT20 is 75.02 bar at 7 deg ATDC, JWT10 is 72.76 bar at 8 deg ATDC, JWT20 is 72.97 bar at 8 deg ATDC and for neat diesel it is 72.33 bar at 8 deg ATDC. It is clear that the cylinder pressure of Jatropha biodiesel, JMT and JWT blends are closer to neat diesel due to better atomization and mixing. In a compression ignition engine, the amount of pressure increase depends up on the combustion rate in the initial stages, which in turn is prejudiced by the quantity of fuel taking amount in the uncontrolled combustion. The uncontrolled or premixed

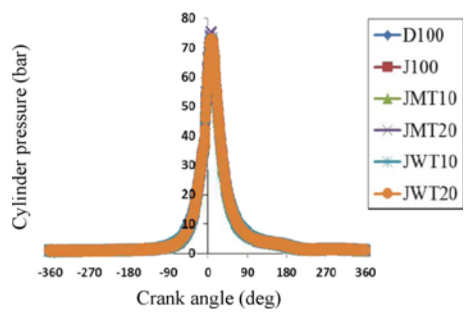

Figure 11. Cylinder pressure vs Crank angle.

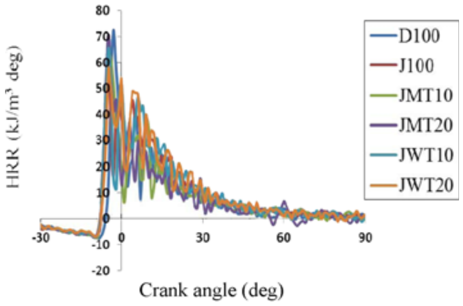

Figure 12. HRR vs Crank angle.

combustion phase is inclined by the delay period and the mixture preparation during the delay period.

4.10. Heat Release Rate (HRR)

The heat release rates for neat Diesel, Jatropha biodiesel, JMT blend and JWT blends are shown in Figure 12. The heat release rate at 50 % of load for diesel is 72.44 kJ/m^3deg.CA, for JMT10 blend it is 63.29 kJ/m^3deg.CA, for JMT20 blend it is 70.7 kJ/m^3deg.CA. The heat release rates at 75 % of load for J100 biodiesel is 66.27 KJ/m^3deg.CA, for JWT10 blend it is 65.7 kJ/m^3deg.CA and for JWT20 blend it is 57.03 kJ/m^3deg.CA. The heat release rate of diesel fuel and JMT20 blends are comparable. The peak heat release rates for diesel and JMT20 blends are 72.44 kJ/m^3deg.CA and 70.7 kJ/m^3deg.CA respectively. With the increase of JMT and JWT blends it is observed that the crank angle of peak heat release rate is advanced.

5. CONCLUSION

The prime objective of the present analysis is to search for an alternative and green fuel to standard diesel in CI engine by blending the Jatropha biodiesel, Mineral Turpentine and Wood Turpentine in order to make it proper for use in a CI engine and to assess the performance, combustion and emissions characteristics of JMT and JWT alternate fuels.

(1) BSFC was found to increase with higher proportion of mineral turpentine and wood turpentine in Jatropha biodiesel blends.
(2) Brake Thermal efficiency (BTE) of blend JMT20 was close to diesel at 75 % and full loads.
(3) The exhaust gas temperatures of Jatropha biodiesel, JMT and JWT blends were comparable to diesel and EGT increases with increase in load in all cases.
(4) CO emissions for J100, JMT10, JMT20, JWT10 and JWT20 are negligible at 75 % load.
(5) JMT and JWT blends exhibit lower HC emissions at 75 % and full load operation compared to diesel.
(6) CO_2 emissions for lower JMT and JWT blend concentrations were close to diesel.
(7) The NOx emissions increased with the part load and getting reduced with JMT and JWT blends due to reduced combustion temperature in the cylinder at 75 % load and full load.
(8) The smoke denseness increases with rise in Jatropha oil concentration in blends predominantly at higher loads.
(9) The peak heat release rates for diesel and JMT20 blends are 72.44 kJ/m^3deg.CA and 70.7 kJ/m^3deg.CA respectively.
(10) With the increase of mineral turpentine in the Jatropha biodiesel blend it is observed that the crank angle of peak heat release rate is advanced.

From the above study, it is very clear that JMT an JWT blends offered comparable performance and combustion parameters, reduced emissions and both can substitute standard diesel in CI engines.

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