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Experimental investigations on jatropha biodiesel and additive in diesel engine

Y.V.Hanumantha Rao[1], Ram Sudheer Voleti[1], A.V.Sitarama Raju[2] and P.Nageswara Reddy[3]

[1]Dept of Mechanical Engg., Koneru Lakshmaiah College of Engg., Green Fields, Guntur-522502, AP, India.

[2]Dept. of Mechanical Engg., Jawaharalal Nehru Technol. Univ. College of Engg, Kakinada-533003, Andra Pradesh.

[3]Balaji Institute of Technolgy & Science, Narasampet-506331, Warangal Dt, Andhra Pradesh.

rao_yvh@yahoo.co.in, mechanicalmighty@yahoo.co.in, avsr_raju2005@yahoo.com, nageswara_pereddy@rediffmail.com

Abstract: The performance of single cylinder water-cooled diesel engine using Multi-DM-32 diesel additive and methyl-ester of Jatropha oil as the fuel was evaluated for its performance and exhaust emissions. The fuel properties of biodiesel such as kinematic viscosity, calorific value, flash point, carbon residue and specific gravity were found. Results indicated that B25 have closer performance to diesel and B100 had lower brake thermal efficiency mainly due to its high viscosity compared to diesel. The brake thermal efficiency for biodiesel and its blends was found to be slightly higher than that of diesel fuel at tested load conditions and there was no difference between the biodiesel and its blended fuels efficiencies. For Jatropha biodiesel and its blended fuels, the exhaust gas temperature increased with increase in power and amount of biodiesel. However, its diesel blends showed reasonable efficiencies, lower smoke, CO_2 and CO. Multi- DM-32 additive with methyl ester of Jatropha offer fuel conservation as well as reduce pollution.

Keywords: Jatropha oil, additive, transesterification, performance and emission characteristics

Introduction

Diesel engines are the most efficient prime movers. From the point of view of protecting global environment and concerns for long-term energy security, it becomes necessary to develop alternative fuels with properties comparable to petroleum based fuels. Unlike the rest of the world, India's demand for diesel fuels is roughly six times that of gasoline, hence seeking alternative to mineral diesel is a natural choice (Barnwal *et al*., 2005). The rapid depletion of petroleum reserves and rising oil prices has led to the search for alternative fuels. Non edible oils are promising fuels for agricultural applications. Vegetable oils have properties comparable to diesel and can be used to run CI engines with little or no modifications. Usage of biodiesel will allow a balance to be sought between agriculture, economic development and the environment (Altõn, 1998).

Jatropha curcas is non-edible oil being singled out for large-scale for plantation on wastelands. *J. curcas* plant can thrive under adverse conditions. It is a drought-resistant, perennial plant, living up to fifty years and has capability to grow on marginal soils. It requires very little irrigation and grows in all types of soils (from coastline to hill slopes). The production of Jatropha seeds is about 0.8 kg per square meter per year. The oil content of Jatropha seed ranges from 30% to 40% by weight and the kernel itself ranges from 45% to 60%. Fresh Jatropha oil is slow-drying, odorless and colorless oil, but it turns yellow after aging (Sarin *et al*., 2007). In Madagascar, Cape Verde and Benin, Jatropha oil was used as mineral diesel substitute during the Second World War. Forson *et al*. (2004) used Jatropha oil and diesel blends in CI engines and found its performance and emissions characteristics similar to that of mineral diesel at low concentration of Jatropha oil in blends. Pramanik (2003) tried to reduce viscosity of Jatropha oil by heating it and also blending it with mineral diesel.

Additives are abundantly manufactured and mixed with IC engine fuels to meet the proper performance of fuel in engine. Additives act like catalyst so that they aid combustion, control emission, control fuel quality during distribution and storage and reduce refiners operating cost. Now in India MFA's are sold in retail market for better mileage of the vehicles and keeping the engine components clean, for better performance and to decrease pollution. For a long time industry has been using various types of chemical additives which are corrosive, toxic and non- ecofriendly. Use of multi functional additives for diesel will lead better fuel conservation and emission control takes place. Awareness of multi functional additives marketing and there use to be given to the automobile owner's especially fleet owners and huge genset users (Ramana & Raghunadham, 2004). Tests were conducted with two commercially available bio-additives and results confirmed that pollution can be controlled by reducing CO and HC emissions and conserving fuel by high thermal efficiency (Raghunadham & Deshpande, 2004). Ethylene glycol mono-alkyl ethers as oxygenated fuel additives had taken and studied for performance parameters such as brake specific fuel consumption, brake thermal efficiency and emission levels. Significant reduction in particulate emission is observed with fuel additives (Suresh Shetty *et al*., 2007).

The present research is aimed at exploring technical feasibility of Jatropha oil in direct injection compression ignition engine without any substantial hardware modifications. In this work the methyl ester of Jatropha oil was investigated for its performance as a diesel engine fuel. Fuel properties of mineral diesel, Jatropha biodiesel and Jatropha oil were evaluated. Three blends were obtained by mixing diesel and esterified Jatropha in the following proportions by volume: 75% diesel+25% esterified Jatropha, 50% diesel+50% esterified Jatropha and 25% diesel+ 75% esterified Jatropha. Also 0.4 mL/L Multi-DM-32 additive is added to methyl ester of Jatropha to study the performance and exhaust emissions of diesel engine. Performance parameters like brake thermal efficiency, specific fuel consumption, brake power were determined. Exhaust emissions like CO_2, CO, NO_X and

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smoke have been evaluated. For comparison purposes experiments were also carried out on 100% esterified Jatropha and diesel fuel.

Materials and methods

A lot of research work has been carried out to use vegetable oil both in its neat form and modified form (Agarwal *et al.*, 2008). Studies have shown that the usage of vegetable oils in neat form is possible but not preferable (Altõn, 1998). The high viscosity of vegetable oils and the low volatility affect the atomization and spray pattern of fuel, leading to incomplete combustion and severe carbon deposits, injector choking and piston ring sticking. The methods used to reduce the viscosity are

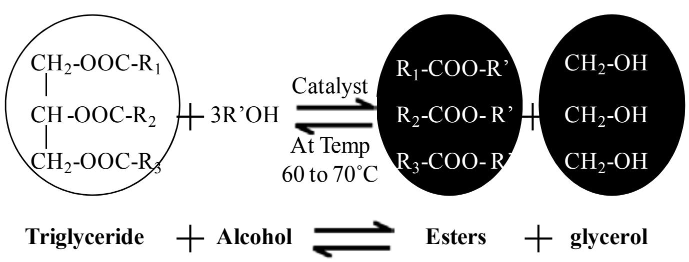
* Blending with diesel
* Emulsification
* Pyrolysis
* Transesterification

Among these, the transesterification is the commonly used commercial process to produce clean and environmental friendly fuel (Pramanik, 2003). However, this adds extra cost of processing because of the transesterification reaction involving chemical and process heat inputs.

Materials and transesterification process

The conversion of Jatropha oil into its methyl ester can be accomplished by the transesterification process. Transesterification involves reaction of the triglycerides of Jatropha oil with methyl alcohol in the presence of a catalyst Sodium Hydroxide (NaOH) to produce glycerol and fatty acid ester.

Mechanism of Transesterification Reaction



Catalyst Use in Transesterification Reaction:
KOH/NaOH

The production of biodiesel by transesterification of the oil generally occurs using the following steps:

1. *Mixing of alcohol and catalyst.* For this process, a specified amount of 450mL methanol and 10gr Sodium Hydroxide (NaOH) was mixed in a round bottom flask.
2. *Reaction.* The alcohol/catalyst mix is then charged into a closed reaction vessel and 1000mL Jatropha oil is added. Excess alcohol is normally used to ensure total conversion of the fat or oil to its esters.
3. *Separation of glycerin and biodiesel.* Once the reaction is complete, two major products exist: glycerin and biodiesel. The quantity of produced glycerin varies according the oil used, the process used, the amount of excess alcohol used. Both the glycerin and biodiesel products have a substantial amount of the excess alcohol that was used in the reaction. The reacted mixture is sometimes neutralized at this step if needed.
4. *Alcohol Removal.*
5. *Glycerin Neutralization.* The glycerin by-product contains unused catalyst and soaps that are neutralized with an acid and sent to storage as crude glycerin. In some cases the salt formed during this phase is recovered for use as fertilizer. In most cases the salt is left in the glycerin.
6. *Methyl Ester Wash*. The most important aspects of biodiesel production to ensure trouble free operation in diesel engines are complete reaction, removal of glycerin, removal of catalyst, removal of alcohol and absence of free fatty acids.

Experimental setup

The engine used for this experimental investigation was a single cylinder 4-Stroke naturally aspirated water cooled diesel engine having 5 BHP as rated power at 1500 r/min. The engine was coupled to a brake drum dynamometer to measure the output. Fuel flow rates were timed with calibrated burette. Exhaust gas analysis was performed using a multi gas exhaust analyzer. The pressure crank angle diagram was obtained with help of a piezo electric pressure transducer. A Bosch smoke pump attached to the exhaust pipe was used for measuring smoke levels. The experimental set up is shown in Fig. 1.

1. Engine 7. Air Box
2. Brake Drum Dynamometer 8. Manometer
3. Fuel Tank (Biodiesel) 9. Air flow direction
4. Diesel Tank 10. Exhaust Analyzer
5. Burettes 11. Smoke Meter
6. Three way valve 12. Exhaust Flow

The specifications of diesel engine are given below:

Manufacturer	: Kirloskar engines Ltd, Pune, India
No of cylinders	: One
No. of strokes	: Four
Bore & Stroke	: 80 & 110 mm
Capacity	: 3.68 kW
BHP of engine	: 5
Speed	: 1500 r/min
Mode of injection	: DI
Cooling system	: Water

Experimental procedure

Experiments were initially carried out on the engine using diesel as the fuel in order to provide base line data (ISI, 1980). The cooling water temperature at the outlet was maintained at 70°C. The engine was stabilized before taking all measurements. Subsequently experiments were repeated with methyl ester of Jatropha oil for comparison.

Results and discussion

The fuels (Mineral diesel, Jatropha biodiesel and Jatropha oil) were analyzed for several physical, chemical and thermal properties and results are listed in Table 1.

Table 1. Fuel properties of mineral diesel, Jatropha biodiesel, Jatropha oil

Property	Mineral Diesel	Jatropha Biodiesel	Jatropha Oil
Density(kg/m^3)	840±1.732	879	917±1
Kinematic Viscosity at 40 °C (cst)	2.44±0.27	4.84	35.98±1.3
Pour Point (°C)	6±1	3±1	4±1
Flash Point (°C)	71±3	191	229±4
Conradson Carbon Residue (%,w/w)	0.1±0.0	0.01	0.8±0.1
Ash Content (%, w/w)	0.01±0.0	0.013	0.03±0.0
Calorific Value (MJ/kg)	45.343	38.5	39.071
Sulphur (%, w/w)	0.25	<0.001	0
Cetane No.	48-56	51-52	23-41
Carbon (%, w/w)	86.83	77.1	76.11
Hydrogen (%, w/w)	12.72	11.81	10.52
Oxygen (%, w/w)	1.19	10.97	11.06

Fig. 1. Experimental setup

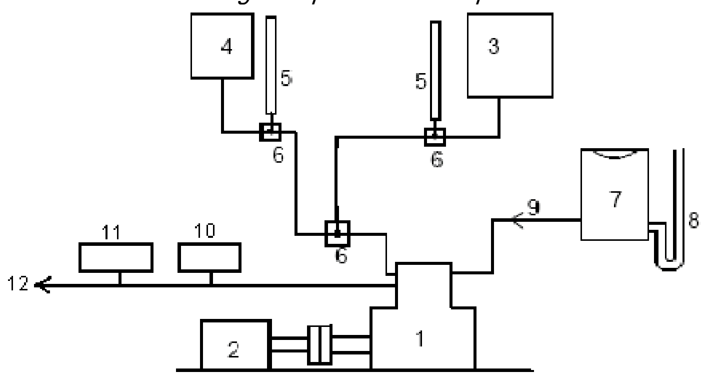
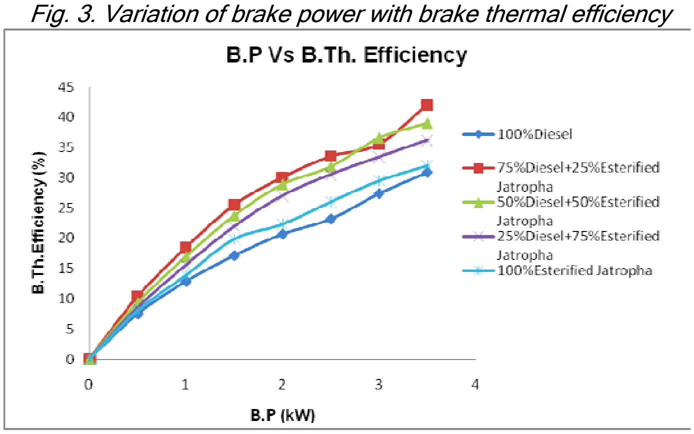


Fig. 3. Variation of brake power with brake thermal efficiency



Density, cloud point and pour point of Jatropha oil was found higher than diesel. Higher cloud and pour point reflect unsuitability of Jatropha oil as diesel fuel in cold climatic conditions. The flash and fire points of Jatropha oil was quite high compared to diesel. Hence, Jatropha oil is extremely safe to handle (Harrington, 1986). Higher carbon residue from Jatropha oil may possibly lead to higher carbon deposits in combustion chamber of the engine. Low sulphur content in Jatropha oil results in lower SO_X emissions. Presence of oxygen in fuel improves combustion properties and emissions but reduces the calorific value of the fuel (Yamane *et al.*, 2001). Jatropha oil has approximately 90% calorific value compared to diesel. Nitrogen content of the fuel also affects the NO_X emissions.

Higher viscosity is a major problem in using vegetable oil as fuel for diesel engines. In the present investigation viscosity was reduced by transesterification process. Viscosity of Jatropha biodiesel is 4.84 cst at 40 °C. It is observed that viscosity of Jatropha oil decreases remarkably with increasing temperature and it becomes close to diesel at temperature above 90 °C.

Experimental data

The experimental data includes the combustion parameters like fuel consumption (F.C), specific fuel consumption (S.F.C), brake power (B.P), brake thermal efficiency (Bth) and exhaust gas temperature. Before the actual tests are carried out the engine is checked for lubrication and fuel supply. If the engine starting is difficult for blends, then it is run on diesel initially.

Fig. 2. Variation of brake power with specific fuel consumption

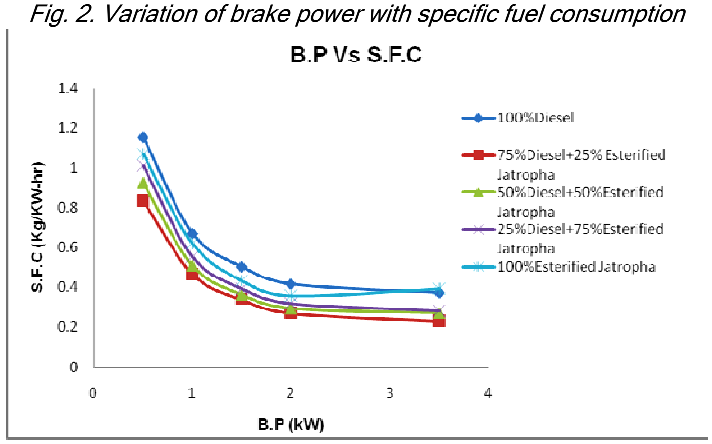
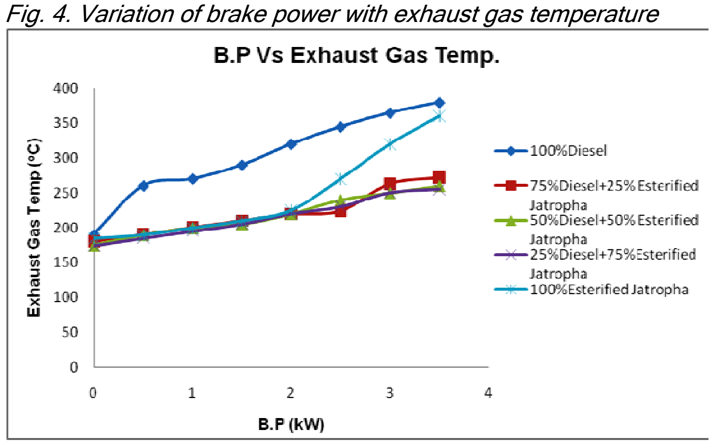


Fig. 4. Variation of brake power with exhaust gas temperature



Determination of fuel consumption: Fuel tank is attached with a graduated burette. The valve at the bottom of the tank is closed when fuel consumption rate is to be measured so that fuel is consumed only from the burette. The time taken for 'x' amount of fuel consumption is recorded to measure the fuel consumption rate.

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Determination of brake power: The equivalent load 'W' is recorded from the calibrated circular scale incorporated in the dynamometer setup. Brake power is obtained by using the formula: B.P= (πDWN)/60
Where D is diameter of the brake drum in mm
N is speed of the enginein r/min

Determination of brake thermal efficiency
Brake thermal efficiency= (B.PX3600)/ (m_fXC.V)
Where m_f is fuel consumption in kg/h
C.V is calorific value of the fuel used in MJ/kg

a dial thermometer. The indicator on a graduated dial directly reads the temperature in °C. All the combustion parameters of fuels that are used in the engine are obtained and indicated in the following Tables 2-7.

Performance and emissions

The performance, combustion parameters and exhaust emissions of the engine with diesel and methyl ester of Jatropha oil are presented and discussed below.

The Specific Fuel Consumption was calculated by fuel consumption divided by the rated power output of the

Fig. 5. Variation of brake power with CO_2

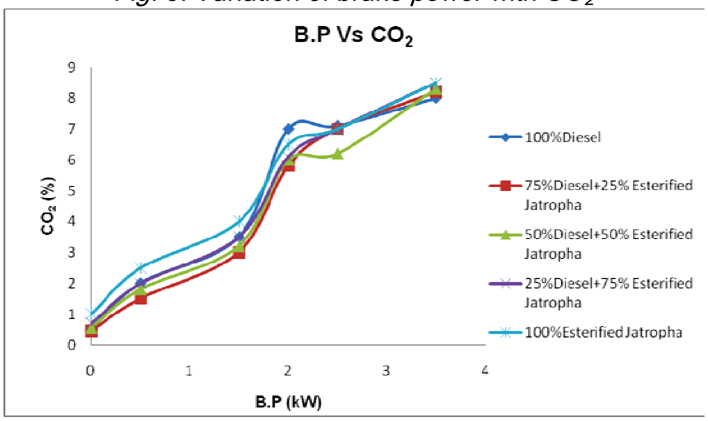


Fig. 6. Variation of brake power with CO

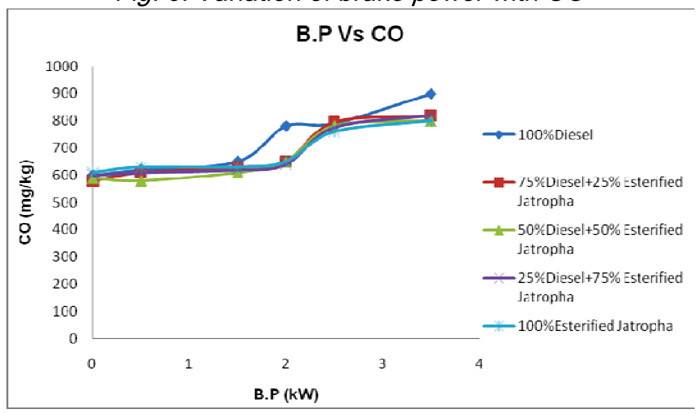


Fig.7. Variation of brake power with NOx

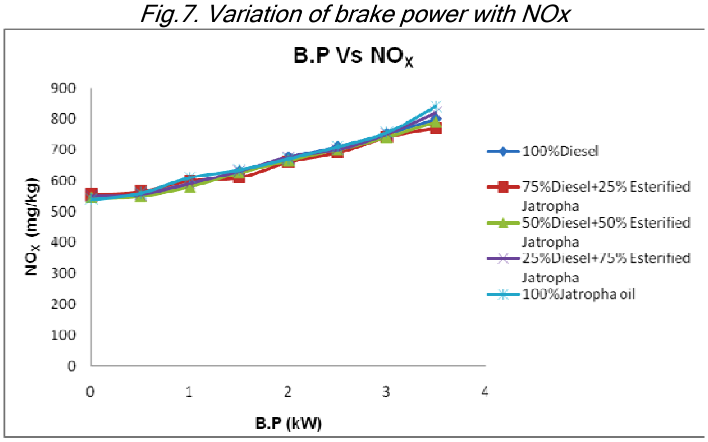


Fig. 8. Variation of brake power with smoke

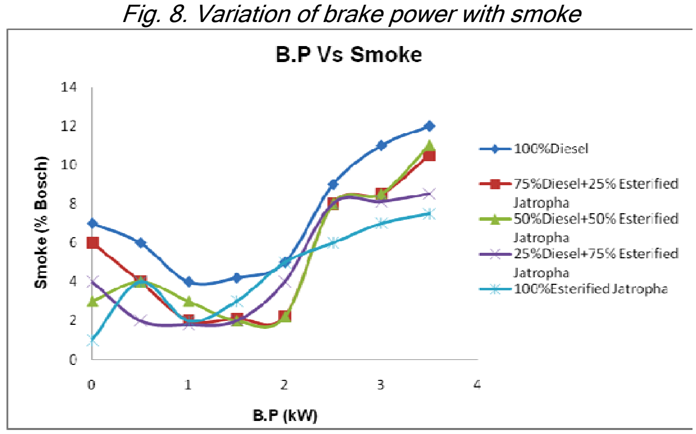


Fig. 9. Variation of brake power with specific fuel consumption

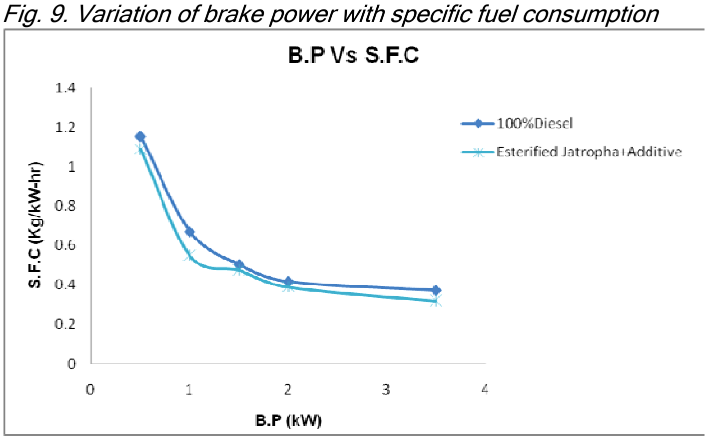
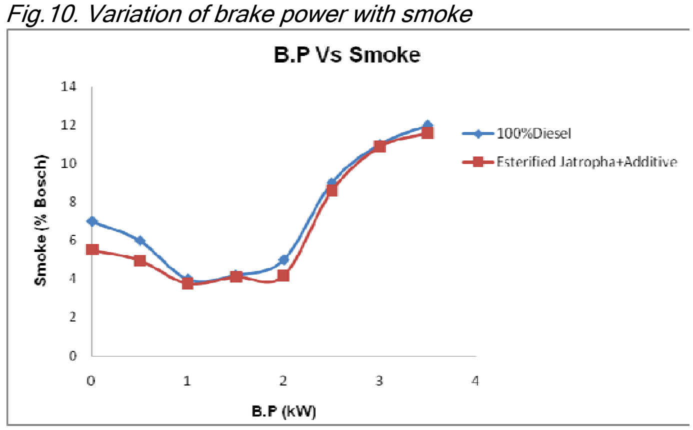


Fig.10. Variation of brake power with smoke



Specific fuel consumption was calculated by fuel consumption divided by the rated power output of the engine. The exhaust gas temperature is measured using

engine. In Fig. 2, it indicates that Specific Fuel Consumption is lower than the diesel for various proportions of Jatropha oil with diesel at constant operated conditions.

This is due to complete combustion, as addition oxygen is available from fuel itself. The percent increase in Specific Fuel Consumption was increased with decreased amount of diesel fuel in the blended fuels. This may be due to higher specific gravity and lower calorific value of the biodiesel fuel as compared with diesel fuel (Forson *et al*., 2004). The calorific value of the Jatropha biodiesel was about 7 % lower than that of diesel fuel.

Table 2. 100% Diesel combustion parameters

Load (kgf)	Manometer Reading (cm)	Time taken for 20cc of F.C (s)	F.C (kg/h)	S.F.C (kg/kWh)	B.P (kW)	Bth (%)	Exhaust Gas temp (°C)
0	2.5	135	0.416	-	0	0	190
2	2.5	98	0.573	1.154	0.496	7.45	260
4	2.5	85	0.661	0.670	0.992	12.83	270
6	2.5	75	0.750	0.503	1.488	17.1	290
8	2.5	68	0.826	0.416	1.984	20.65	320
10	2.5	61	0.921	0.372	2.480	23.15	345
12	2.5	60	0.936	0.314	2.977	27.35	365
14	2.5	58	0.968	0.279	3.473	30.85	380

Table 3. Esterified Jatropha oil combustion parameters

Load (kgf)	Manometer Reading (cm)	Time taken for 20cc of F.C (s)	F.C (kg/h)	S.F.C (kg/kWh)	B.P (kW)	Bth (%)	Exhaust Gas temp (°C)
0	2.6	128	0.523	-	0	0	185
2	2.6	126	0.531	1.071	0.496	8.0	190
4	2.6	109	0.614	0.619	0.992	13.84	200
6	2.6	104	0.644	0.432	1.488	19.84	210
8	2.6	95	0.705	0.355	1.984	24.84	225
10	2.6	69	0.970	0.391	2.480	21.92	270
12	2.6	53	1.263	0.424	2.977	20.2	320
14	2.6	49	1.370	0.395	3.473	21.73	360

Brake thermal efficiency is defined as actual brake work per cycle divided by the amount of fuel chemical energy as indicated by lower heating value of fuel (Senthil Kumar *et al.,* 2003). The brake thermal efficiency with biodiesel and its blends was found to be slightly higher than that of diesel fuel at tested load conditions. There was no difference between the biodiesel and its blended fuels on efficiencies. The brake thermal efficiencies of engine, operating with biodiesel mode were 22.2, 30.6 and 37.5 per cent at 2, 2.5 and 3.5 kW load conditions respectively (Fig.3).

The exhaust gas temperature gives an indication about the amount of waste heat going with exhaust gases. The exhaust gas temperature of the different biodiesel blends is shown in Fig. 4. The exhaust gas temperature of blended fuels and biodiesel at 3.5 kW load condition was 19 % higher than that of 2 to 2.5 kW load conditions.

The exhaust gas temperature increased with increase in load and amount of blended biodiesel in the fuel. The exhaust gas temperature reflects on the status of combustion inside the combustion chamber (Takeda, 1982). The reason for raise in the exhaust gas temperature may be due to ignition delay and increased quantity of fuel injected. The exhaust gas temperature can be reduced by adjusting the injection timing/injection pressure in to the diesel engine.

The carbon dioxide emission from the diesel engine with different blends is shown in Fig. 5. The CO_2 increased with increase in load conditions for diesel and for biodiesel blended fuels. The Jatropha biodiesel followed the same trend of CO_2 emission, which was higher than in case of diesel. The CO_2 in the exhaust gas was same for Jatropha biodiesel blended fuels and Jatropha biodiesel.

The CO emission from the diesel fuel with biodiesel blended fuels and biodiesel is shown in Fig. 6.

The CO reduction by biodiesel was 17.5, 17, 16, 14 and 14 per cent at 1, 1.5, 2, 2.5 and 3.5 kW load conditions. With diesel fuel mode the lowest CO was recorded as 610 mg/kg at 1.5 kW load and as load increased to 3.5 kW, CO also increased to 898 mg/kg. Similar results were obtained for biodiesel blended fuels and Jatropha biodiesel with lower emission than diesel fuel. The amount of CO emission was lower in case of biodiesel blended fuels and biodiesel than diesel because of the fact that biodiesel contained 11 per cent oxygen molecules. This may lead to complete combustion and reduction of CO emission in biodiesel fuelled engine (Senthil Kumar *et al*., 2003).

Fig. 7 shows the variation of NOx with respect to brake power. At higher power output conditions, due to higher peak and exhaust temperatures the NOx values are relatively higher compared to low power output conditions.

A slight increase in NOx is observed for blends of Esterified Jatropha Diesel compare to diesel. The reason may be due to late burning of blends of MEJ-Diesel during expansion (Forgiel & Varde, 1981). The reason for increase in NOx with respect to Esterified Jatropha Diesel may be due to sustained and prolonged duration of combustion associated with reduction in combustion temperature.

Fig. 8 represents the variation of Smoke with respect to brake power. Smoke increases with increase in brake power. Smoke emission was lesser for blends of Esterified Jatropha Diesel compared to diesel. This may be due to late burning in the expansion and exhaust. When percentage of blend of biodiesel increases, smoke density decreases, but smoke density increases for B50 and B75 due to insufficient combustion. It requires changes in injection pressure and combustion chamber design (Yukitsugu *et al*., 1987).

Table 4. 75%Diesel+25% esterified Jatropha oil combustion parameters

Load (kgf)	Manometer Reading (cm)	Time taken for 20cc of F.C (s)	F.C (kg/h)	S.F.C (kg/kWh)	B.P (kW)	Bth (%)	Exhaust Gas temp (^oC)
0	2.6	160	0.368	-	0	0	180
2	2.6	142	0414	0.835	0.496	10.3	190
4	2.6	127	0464	0.467	0.992	18.4	200
6	2.6	117	0.503	0.338	1.488	25.44	210
8	2.6	110	0.535	0.270	1.984	31.86	219
10	2.6	103	0.571	0.230	2.480	37.3	224
12	2.6	74	0.795	0.267	2.977	32.2	263
14	2.6	60	0.981	0.283	3.473	30.4	272

Fig. 9 represents the variation of specific fuel consumption with respect to brake power. With the addition of additive there is better atomization of fuel takes place, leads to improved combustion hence fuel consumption was decreased with increase in power.

Table 5. 50% Diesel+50% esterified Jatropha oil combustion parameters

Load (kgf)	Manometer Reading (cm)	Time taken for 20cc of F.C (s)	F.C (kg/h)	S.F.C (kg/kWh)	B.P (kW)	Bth (%)	Exhaust Gas temp (^oC)
0	2.6	153	0.402	-	0	0	175
2	2.6	134	0.459	0.926	0.496	9.3	190
4	2.6	122	0.505	0.509	0.992	16.9	200
6	2.6	114	0.540	0.362	1.488	23.7	205
8	2.6	106	0.58	0.293	1.984	29.32	220
10	2.6	93	0.662	0.270	2.480	31.8	240
12	2.6	88	0.700	0235	2.977	36.53	250
14	2.6	84	0.733	0.210	3.473	40.9	260

Table 6. 25% Diesel+75% Esterified Jatropha oil combustion parameters

Load (kgf)	Manometer Reading (cm)	Time taken for 20cc of F.C (s)	F.C (kg/h)	S.F.C (kg/kWh)	B.P (kW)	Bth (%)	Exhaust Gas temp (^oC)
0	2.6	151	0.426	-	0	0	174
2	2.6	128	0.502	1.012	0.496	8.5	185
4	2.6	117	0.550	0.223	0.992	15.5	195
6	2.6	110	0.584	0.392	1.488	21.9	205
8	2.6	102	0.630	0.317	1.984	27.0	220
10	2.6	92	0.699	0.282	2.480	30.5	230
12	2.6	84	0.765	0.257	2.977	33.4	250
14	2.6	78	0.824	0.237	3.473	36.2	255

The variation of smoke density with brake power of diesel-biodiesel with additive is shown in Fig.10. It is observed that smoke density reduced in case of Esterified Jatropha with additive when compared to diesel. This reduction in smoke density is mainly due to presence of internal availability of additive content in the biodiesel. It is observed that the reduction smoke density decreased up to 2kW, theirby smoke density gradually increased at higher loads.

Table 7. Esterified Jatropha oil with additive (0.4 mL/L) combustion parameters

Load (kgf)	Manometer Reading (cm)	Time taken for 20cc of F.C (s)	F.C (kg/h)	S.F.C (kg/kWh)	B.P (kW)	Bth (%)	Exhaust Gas temp (^oC)
0	2.6	120	0.489	-	0	0	183
2	2.6	118	0.506	1.02	0.496	9.11	187
4	2.6	110	0.543	0.547	0.992	16.99	199
6	2.6	105	0.569	0.382	1.488	24.33	206
8	2.6	98	0.619	0.307	1.984	30.29	221
10	2.6	70	0.853	0.343	2.480	27.03	268
12	2.6	55	1.086	0.364	2.977	25.4	317
14	2.6	50	1.185	0.341	3.473	27.25	351

Conclusions

A single cylinder compression ignition engine was operated successfully using methyl ester of Jatropha oil as the soul fuel with additives. The following conclusions are made based on the experimental results.

- Engine works smoothly on methyl ester of Jatropha oil with performance comparable to diesel operation.
- Methyl ester of Jatropha oil results in a slightly increased thermal efficiency as compared to that of diesel.
- The exhaust gas temperature is decreased with the methyl ester of Jatropha oil as compared to diesel.
- CO_2 emission is low with the methyl ester of Jatropha oil.
- CO emission is low at higher loads for methyl ester of Jatropha oil when compared with diesel.
- NO_X emission is slightly increased with methyl ester of Jatropha oil compared to diesel.
- There is significant difference in smoke emissions when the methyl ester of Jatropha oil is used.
- Multi-MD-32, Bio-additive possesses many attributes as Multi-Functional fuel additive. Its ability to reduce the surface tension between two or more interacting immiscible liquids helped the fuel to flow better through injector and better atomization of fuel, which improved the combustion and performance of the engine at all variable loads.
- Multi-DM-32 also improved the pollution control.
- With proper adjustments at fuel injection pump settings bio-additives will improve performance of IC engine.
- Use of bio-additives for diesel will lead to better fuel economy and reduced emissions and should be used by Indian refineries.
- Automotive industry and oil industry must work closely to find solutions for lower emissions and conserving fuel.

This methyl ester of Jatropha oil along with diesel may reduce the environmental impacts of transportation, reduce the dependency on crude oil imports, and offer business possibilities to agricultural enterprises for periods of excess agricultural production. On the whole it is concluded that the methyl ester of Jatropha oil will be a good alternative fuel for diesel engine for agricultural applications.

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