

Analysis of *Prosopis juliflora* Methyl Ester as a Fuel in the CI Engine

Boopathi Duraisamy^{1,2}, Kandasamy Velmurugan¹,
V S Karuppannan Venkatachalapathy¹, Arumugam Thiagarajan¹

¹Department of Mechanical Engineering, Sri Manakula Vinayagar Engineering College, Pondicherry University, Puducherry, India

²Department of Automobile Engineering, SRM Institute of Science and Technology, Kattankulathur, India

Corresponding Author: Boopathi Duraisamy

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ABSTRACT

As the availability of fossil fuels continues to decrease, the quest for alternative fuels that can be utilised in place of conventional fuels is increasing rapidly. The *Prosopis juliflora* oil (JFO) is a potential fuel for diesel engines, and the rising availability of the seeds in India, makes it a realistic option for CI engine fuel. In a CI engine, the high viscosity of the oil decreases performance and increase the emission characteristics. Trans-esterification is used to improve the fuel characteristics and reduce the viscosity of the fuel oil. The name for trans-esterified JFO is *Prosopis juliflora* methyl ester (JFME). Fourier transform infrared spectroscopy (FTIR) and gas chromatography–mass spectrometry (GC–MS) are utilised to determine the species composition of this fuel. C-H stretching alkane group, C=O methyl ester group, CH₃ bending alkane group, and C-O stretching ester group are detected by FTIR. According to GCMS, methyl oleate is present at 43.34 percent whereas methyl palmitate is present at 28.99 percent. Both esters have great fuel qualities and JFME is the most suitable fuel for diesel engines. The performance findings demonstrate that JFME has a greater thermal efficiency than JFO and a lower thermal efficiency than diesel. This can be enhanced further by combining various fuels.

Keywords: *Prosopis juliflora* oil, Transesterification, FTIR, GCMS, performance

INTRODUCTION

The price of fossil resources is escalating daily, and energy demand rates are also rising sharply (1). Vegetable oil can be utilised as a renewable resource to meet the energy requirement (2). Vegetable oil as a fuel has a decreased thermal efficiency due to its higher viscosity, resulting in increased HC and CO emissions (3). The transesterification method is used to transform vegetable oil into biodiesel. The transesterified vegetable oil shows superior performance and emission characteristics compared to the unmodified fuel oil (4). Various approaches, including as engine modifications, blending of different fuels, injection pressure optimization, etc., are also employed to increase the efficiency of the fuel oil (2,3,4). Due to the availability of oxygen atoms in the biodiesel is helps the combustion process, resulting in a greater combustion chamber temperature, which increases NO emission (5). Blending biodiesel with diesel and alcohol improves the brake thermal efficiency and decreases NO emissions. This alcohol has a higher latent heat of evaporation, leading in a decrease in combustion chamber temperature, which increases the delay period. As a result of the increase in delay period, better mixture formation occurs, it leads to constant volume combustion (6). Micro-explosion of the fuel droplets in an emulsion of biodiesel and water in the

control range results in an increase in brake thermal efficiency and a decrease in emissions (7). By incorporating nanoparticles as additives into biodiesel, the fuel's qualities can be enhanced, and the engine performance is improved and emissions can be reduced (8). When the engine is operating in dual-fuel mode, a homogenous mixture is supplied; this promotes the complete combustion of fuels, resulting in great brake thermal efficiency and a decrease in smoke emissions (9). Biodiesel is manufactured from a range of non-edible plant seeds, and the qualities of the fuel vary according on the availability of the seeds. This difficulty is resolved by the availability of seeds that are simple to cultivate in all climates. The Prosopis juliflora tree is renowned for its copious availability; it can be found across India with the exception of the north-east and the Himalayas (10). The seeds of Prosopis juliflora are ideal for the large production of Biodiesel.

BIO-DIESEL PRODUCTION

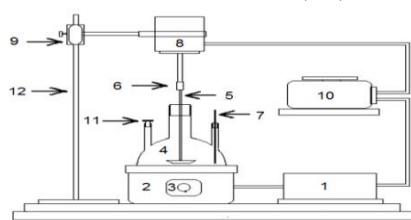
Preparation of biodiesel

Preparation of biodiesel from Prosopis Juliflora seed oil by trans-esterification, it is a process of using methanol (CH_3OH) in the presence of catalyst (Potassium hydroxide KOH) to chemically break there molecule of raw oil into ester and glycerol. This process is a reaction of the oil with an alcohol to remove the glycerine, a by-product of biodiesel production.

Transesterification process

Bio-diesel is produced by using trans-esterification Process in the laboratory. Setup having a stirrer, is connected to the DC motor, it was placed in the centre neck of the flask container to stir the reactants.

Thermometer is placed in the flask to continuously monitor the temperature of the reactants. The flask container is placed on a heater for heating the oil and maintaining the desired temperature of the oil. Potassium hydroxide as an alkaline catalyst (KOH) is 18 grams weighed and methanol 250 ml is taken in the beaker. The KOH and alcohol are combined, until completely dissolved. 1000 ml of Juliflora seed oil is placed in a container and swirled with a mechanical stirrer, while being heated with a heating coil. Minimum stirrer speed is required, and when the temperature of the raw Juliflora seed oil reaches $60\text{ }^\circ\text{C}$, the KOH-alcohol solution is put into the raw oil container, which is then tightly sealed. Now the solution is rapidly mixed (720 rpm). As methanol evaporates at temperatures above $60\text{ }^\circ\text{C}$, it is imperative that the temperature does not exceed $60\text{ }^\circ\text{C}$. Also, the KOH-alcohol solution is only mixed with the raw oil at a temperature of $60\text{ }^\circ\text{C}$, as heat is produced when KOH and alcohol are combined, and the temperature of the raw oil must be greater than this for the reactions to occur effectively. After two hours of stirring at $60\text{ }^\circ\text{C}$, the oil-KOH-alcohol solution is transferred to a glass container. Now, separation occurs, and biodiesel collects in the upper portion of the glass container, while glycerine collects in the lower portion. This glycerine is taken out of the container. The biodiesel is then cleaned with water. Once more, glycerine is separated from biodiesel and eliminated. The biodiesel is continuously washed with water until there is no glycerine remaining. Now, this biodiesel is heated to 100 degrees Celsius to evaporate its water content. The final product is biodiesel that is ready for use (15).



1. Power Supply; 2. Heater; 3. Thermostat; 4. Round Bottom Flask; 5. Stirrer; 6. Connector; 7. Thermometer; 8. Stirrer Motor; 9. Slider; 10. Speed Controller; 11. Cap; 12. Stirrer Stand.

Figure 1. Biodiesel Production setup

FUEL CHARACTERIZATION

FTIR

Fourier-transform infrared spectroscopy (FTIR) is a technique used to obtain an infrared spectrum of absorption or emission of a solid, liquid or gas. An FTIR spectrometer simultaneously collects high-spectral-resolution data over a wide spectral range. This confers a significant advantage over a dispersive spectrometer, which measures intensity over a narrow range of wavelengths at a time. In the FTIR results, the wave number 1500-500 cm⁻¹ is called fingerprint region and wave number 4000-1500 cm⁻¹ is called functional group region.

The spectral analysis of JFME shows that the existence of three different functional groups. The sharp peak at 2924.09 cm⁻¹ and 2854.65 cm⁻¹ signifies the presence of C-H stretching (alkane). Conversely, the absorbance at 1741.72 cm⁻¹ indicates the methyl ester group (C=O). In the fingerprint region wave number 1452.40 cm⁻¹ shows CH₃ bend, wave number 1363.67 cm⁻¹ is shows bending alkane group and wave number 1244.09 cm⁻¹ is a C-O-C stretch component. The wave number 1168.86 cm⁻¹ is a C-O stretching ester group and 721.38 cm⁻¹ is a C-H bending and rocking component.

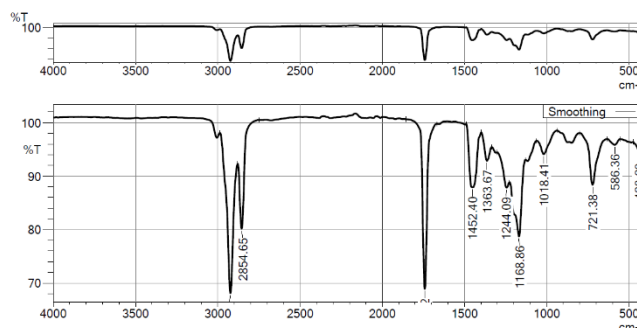
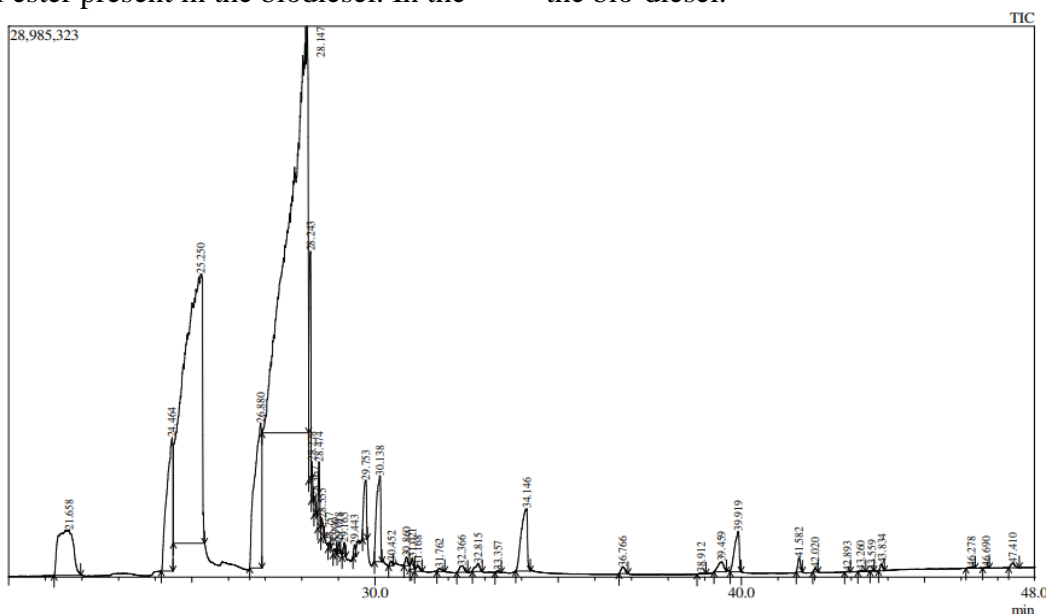


Figure 2. Wave number in cm-1 Vs Transmittance in percentage

GCMS

There are different types of fatty acid methyl ester present in the biodiesel. In the

Figure.3 showing 53 components present in the bio-diesel.



But the following seven components are majorly present in the biodiesel. In the

reaction time 28.147 is found that Methyl oleate (9-octadecenoic acid (z)-, methyl

ester), C₁₉H₃₆O₂ is about 43.35 percentage present in the biofuel. Molecular Weight of Methyl oleate is 296.5 g/mol, calorific value is 37,100 KJ/Kg, Cetane number is 56, Kinematic viscosity is 4.51 mm²/sec at 40 °C, Density is 852.3 kg/m³ at 50°C, Auto ignition temperature is 340°C. Methyl oleate in the engine application shows reduction in ignition delay, soot formation compare to diesel because the higher Cetane number, Peak pressure, gross heat release rate and specific fuel consumption is lower because of lower heating value, NOX is formed because of higher combustion temperate in the presents of excess oxygen. So NOX formation is also lesser because of lesser heating value of the Methyl oleate (11,12). In the reaction time 25.25, 24.464 is found that Methyl palmitate (Hexadecanoic acid, methyl ester), C₁₇H₃₄O₂ is about 33.6 percentage present in the biofuel. Molecular Weight of Methyl palmitate is 270.45g/mol. Methyl palmitate in the engine application shows reduction in NOX, CO, PM compare to base diesel, because of lone chain length and present of oxygen in the Methyl palmitate(13). So 30% of Methyl palmitate in the fuels showing good performance and emission results (14). In the reaction time 26.88 is found that Methyl linoleate (9,12-

Octadecadienoic acid (Z,Z)-, methyl ester), C₁₉H₃₄O₂ is about 5.87 percentage present in the biofuel. In the reaction time 28.243 is found that Methyl stearate (Octadecanoic acid, methyl ester) C₁₉H₃₈O₂ is about 2.29 percentage and Molecular Weight is 298.5 g/mol. In the reaction time 21.658 is found that tetradecanoic acid, methyl ester, C₁₅H₃₀O₂, is about 3.96 percentage and Molecular Weight is 242.4 g/mol.

FUEL TESTING IN CI ENGINE

The tests were conducted in a single cylinder, water-cooled, four-stroke, direct injection, compression ignition engine, which develops 5.2 kW power at 1500 rpm coupled with eddy current dynamometer was used. Figure 4 illustrates the experimental setup and Table 3 displays the complete specifications of the engine used. A mechanical type fuel injection system with a pump and 3-hole nozzle – injector assembly is used. The fuel consumption is determined manually using a burette and stopwatch; measuring the time taken to consume 10 cc of fuel. From the time taken, engine performance parameters can be calculated.

Table 1 ASTM standards used for determination of fuel properties

Property	Test standards	Biodiesel standards		Method
		ASTM D6751 - 02	EN 14214/14213	
Kinematic viscosity,cST @ 40°C	ASTM D445	1.9-6.0	3.5-5.0	Redwood Viscometer
Density @ 15°C, g/cm ³	ASTM D1298	-	0.860-0.900	Pycnometer
Lower Heating value kJ/kg	ASTM D240	-	Min 35000	Bomb calorimeter
Cetane index	ASTM D976	Min 47	Min 51	Calculated based on API gravity & mid-boiling point
Flashpoint, °C	ASTM D93	Min 93	Min 120	Pensky Martens Apparatus [Closed Cup]

Table 2 Properties of diesel, JPO, JPME and Amyl alcohol

Properties	Diesel fuel	JPO	JPME	Amyl Alcohol
Kinematic viscosity,cST @ 40°C	3.6	37.87	6.8	3.69
Density @ 15°C, g/cm ³	0.830	0.930	0.875	0.801
Lower Heating value kJ/kg	42500	37600	38000	35370
Cetane index	45-55	45	49	20
Flash point, °C	74	181	128	49

Make and Model	Kirloskar AV1
Engine Type	Single Cylinder, Water cooled, direct injection, constant speed
Bore (mm)	87.5
Stroke (mm)	110
Compression Ratio	17.5:1
Rated power @ 1500rpm	5.2 kW
Injection Pressure (bar)	200
Injection timing	23°bTDC

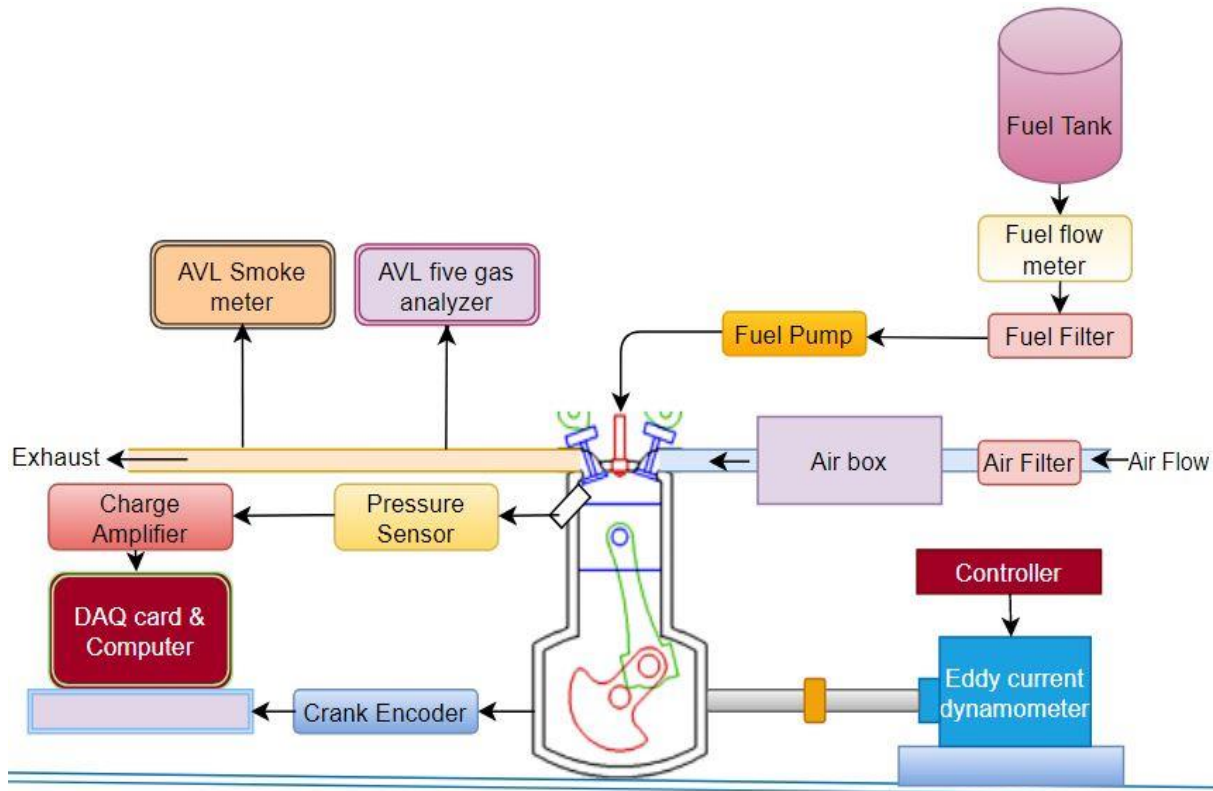


Figure 4. Schematic diagram of the experimental setup.

Brake thermal efficiency (BTE)

Figure 5 illustrates the change in BTE for diesel, JFO and JFME at various Break power. BTE is a ratio between energy developed by the engine (BP) and energy supplied (Fuel thermal energy) to the engine. Increasing the BP of the engine, BTE is increased. Because BP increases, the in cylinder temperature increases. Increase in the cylinder temperature, helps the combustion process, so better combustion take place, resulting in improvement in BTE. When engine is developing the full power, the BTE of diesel is 30.7% and JFO is 28.3%. The reduction in the BTE of JFO

is due to poor physical properties of the fuel. The higher viscosity of JFO leads to poor atomization and mixture formation resulting in incomplete combustion. So to generate the power more amount of fuel is consumed compare to diesel. BTE of JFME is improved to 29.3% in compare with the neat JFO. The transesterification helps the reduction in the viscosity of JFME, resulting in better fuel atomization leads to better mixing of fuel with air. So combustion process is improved, leads to better efficiency compare to JFO. But efficiency of JFME is lesser compare to diesel, due to the heating value of the fuel.

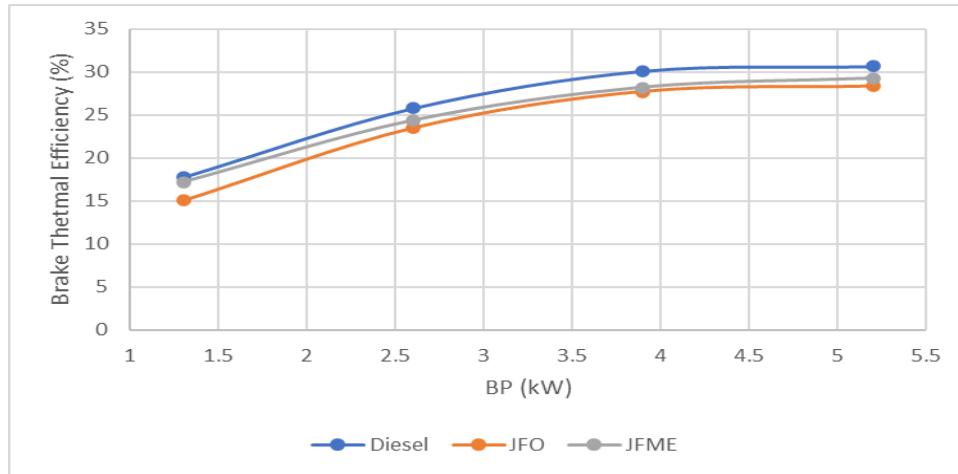


Figure 5. Variation of brake thermal efficiency at different BP

Brake Specific energy consumption (BSEC)

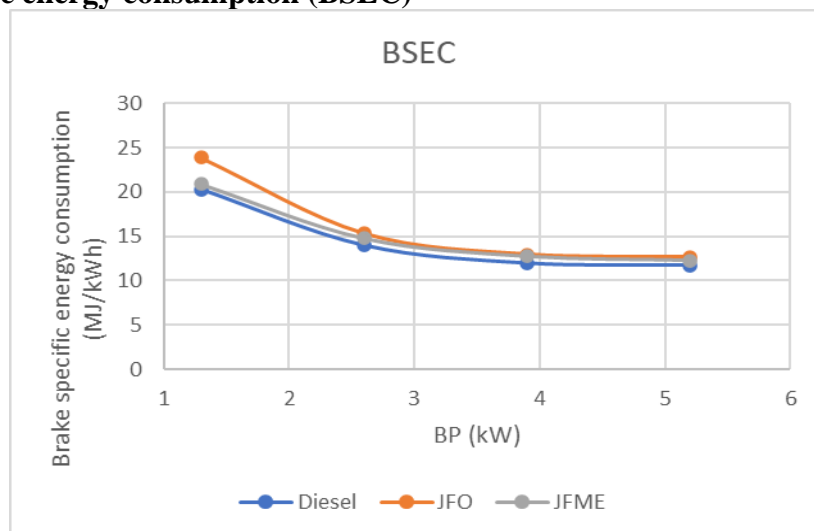


Figure 6. Variation of BSEC at different BP

Figure 6 shows the change in BSEC for diesel, JFO and JFME at various Brake power. BSEC is an amount of fuel thermal energy required to produce per kW BP in one hour operation of the engine. Increase in the BP of the engine BSEC is depressed. At maximum BP, BSEC of diesel, JFO, JFME IS 11.7, 12.7 and 12.3 MJ/kWh. Higher energy consumption of JFO is found, it is due to the poor fuel properties like viscosity, and density leads to poor combustion. BSEC is lesser for JFME compare to JFO, due to the reduction in the viscosity of the fuels resulting in better combustion.

CONCLUSIONS

Based on the experimental data and literature following conclusions have been made.

1. Maximum yield of biodiesel received 88% in the trans-esterification process.
2. In the Biodiesel, methyl oleate and Methyl palmitate contributing about 43.35 percent, 33.6 percentage. Both methyl ester enhances fuel properties. The carbon to hydrogen ratio shows near to the diesel. So this fuel can be used a diesel fuel.
3. Performance result shows the JFME shows better efficiency than JFO and lesser compare to diesel. Brake thermal efficiency of JFME at maximum brake power output is 29.3% and BSEC is 12.3 MJ/Kwh.

Conflict of Interest: None

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