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Performance and Emission Characteristics of Multi Cylinder Di Diesel Engine Operating on Jome and Diesel

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ABSTRACT:

Continuous rise in the conventional fuel prices and shortage of its supply have increased the interest in the field of the alternative sources for petroleum fuels. Biodiesel is one such alternative source which provides advantage of pollution control. In the present work, experimentation is carried out to study the performance, emission and combustion characteristics of JOME biodiesel and diesel. In this experiment a multi cylinder, four stroke, naturally aspired, direct injection, water cooled, eddy current dynamometer, TATA Indica V2 diesel engine is used at very low load condition. Crude oil is converted into biodiesel and characterization has been done. The experiment is conducted at low load condition. The engine performance parameters studied were brake power, brake specific fuel consumption, brake thermal efficiency.

The emission characteristics studied are CO, CO2, UBHC, mean gas temperature, exhaust gas temperature and smoke opacity. These results are compared to those of pure diesel. These results are again compared to the corresponding results of the diesel. From the graph it has been observed that, there is a reduction in performance, and emission characteristics compare to the diesel. This is mainly due to lower calorific value, higher viscosity and lower mean gas temperature. The present experimental results show that JOME biodiesel can be used as an alternative fuel in diesel engine.

Keywords:
Alternative fuel, Biodiesel, Combustion, Emission, JOME biodiesel, Performance, Transesterification.

I. INTRODUCTION:

For the social development, economic growth and welfare of human being of any country, the energy is critical input factor. Fossil fuels are the major source for the energy demand since from their exploration. India with high rate of economic growth and increase in population has an energy demand of 3.5% of world commercial energy demand and ranks sixth. The highest proved oil reservoirs including non conventional oil deposits are in Venezuela (20% of global reserves), Saudi Arabia (18% of global reserves), Canada (13% of global reserves) and Iran (9% global reserves). This inequality of petroleum reservoirs creates the dependency of other countries on the above mentioned countries. Political imbalances in these countries have the ability to shake the economy of dependant countries. The environmental impact of petroleum is often negative because its emission is toxic to all most all kinds of living beings.

The possibility of climate change exists due to the effect of green house gases emitted from the petroleum based products. An increased emission product creates the health related problems on living beings. To overcome this problem usage of biodiesel is the best solution, since the properties of these esters are comparable to that of diesel. But the production of biodiesel trend is originating recently to fulfill the energy demand and lots of data are required for the engine modification for optimum operation. In the whole world biodiesel production, Indian contribution is only 1.5% till today. The planning commission of India has launched a bio-fuel project in 200 districts from 18 states in India. It has recommended two plant species, viz. JOME (JOME curcas) and Karnaja

(Pongamia pinnata) for biodiesel production. Indian government has also started lot of programs like "National Mission on Biodiesel", "National Mission on JOME" etc to grow JOME and Pongamia in unused areas through aid from the government sectors and there by planned to enhance the production of biodiesel and its usage. The substitution of diesel oil by renewable fuels produced by the country generates higher foreign exchange savings, even for the major oil exporting countries. Therefore developing countries can use this kind of projects not only to solve their ecological problems, but also to increase their economy. In view of the several advantages, biofuels have potential to replace petroleum based fuels in the long run. In the recent years, systematic efforts have been made by several researchers to use the various vegetable oils as fuel in the compression ignition engines. The viscosity of vegetable oil is about ten times higher than that of diesel. The commonly employed method to reduce the viscosity of vegetable oils is transesterification. It is from the study by Dipak Patil et.al;[11] has conducted experiment on performance characteristics and analysis of JOME oil on multi-cylinder turbocharger compression ignition engine.

According to the investigation he found that, it was observed that JBD20 shows less indicated 39.8% and brake thermal efficiency of 26.9% and 0.429 kg/kW-hr specific fuel consumption against diesel which are comparable. JBD20 is more suitable blend of JOME oil. Gvidonas Labeckas et.al;[15] conducted experiment on influence of fuel additives on performance of direct- injection diesel engine and exhaust emissions when operating on Shale oil and concluded that the brake specific fuel consumption at low loads and speeds of 1400–2000 rpm reduces by 18.3 to 11.0% due to the application of the Marisol FT. The additive SO-2E proved to produce nearly the same effect. The total NOx emission from the fully loaded diesel engine fuelled with the treated Shale oil reduces by 29.1% (SO-2E) and 23.0% (Marisol FT). The present work aims to investigate the variations of performance, emission and combustion characteristics of multi (four) cylinder diesel engine at different loads and speeds. The present investigations are planned after a thorough review of literature in this field. The combinations of JOME biodiesel, along with diesel are taken for the experimental analysis. In this article, the fuel properties, engine performance and emissions and combustion characteristics of the neat biodiesel and diesel will be investigated experimentally at variable load and speed. The engine will be operated once with fixed load and variable speed. At the second time engine will be operated with fixed speed and variable load. The engine gives 39 kW at 5000 rpm. In the beginning 75% of load will be fixed i.e. 29.25 kW and later speed variation of 1000, 1500, 2000, 2500 and 3000 rpm will be done. In the second step experiment will be conducted for varying load of 20%, 40%, 60% and 80% at a fixed speed of 2500 rpm. For the above mentioned experimental setup performance and emission characteristics will be recorded.

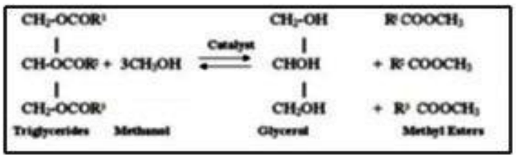
II. EXPERIMENTATION:

During the JOME oil is converted into biodiesel process it is necessary to find FFA, which gives the information about process conversion. Since the JOME oil FFA was around 12 transesterification process should be performed.

2.1 Transesterification process:

Transesterification reaction is the reaction of a fat or oil with an alcohol to form esters and glycerol. This reaction is also called alcoholysis.. A catalyst is usually used to improve the reaction rate and yield. Because the reaction is reversible, excess alcohol is used to shift the equilibrium to the products side. It can quickly react with triglycerides and sodium hydroxide (NaOH) which is used as the catalyst is easily dissolved in it. To complete a transesterification stoichiometrically, a 3:1 molar ratio of alcohol to triglycerides is needed. In practice, the ratio needs to be higher to drive the equilibrium to a maximum ester yield. The reaction can be catalyzed by alkalis, acids, or enzymes. The alkalis include sodium hydroxide (NaOH), Potassium hydroxide (KOH).

Alkali - catalyzed transesterification is always with R1 , R2 and R3 are long chain hydrocarbons which may be the same or the different for an alkali-catalyzed transesterification, the glycerides. The triglycerides can be purified by saponification (known as alkali treating) and then transesterified using an alkali catalyst. The transesterification reaction is shown in equation 2.1.



Equation 2.1.1 Chemical reaction of biodiesel

- **Parameters affecting on transesterification reaction system**

The transesterification is essentially a heterogeneous liquid-liquid system whether the catalyst is used or not. As a result, the reactor used must have intense level of turbulence to promote mass transfer. This can be achieved with the help of a mechanically agitated contactor or a static mixer. The process parameters affecting biodiesel production are discussed below.

- Catalyst: Transesterification is catalyzed by acidic or basic catalyst. For instance, H2SO4, HCl are the acidic catalysts while NaOH or sodium methoxide (NaOCH3) are basic catalysts.

The enzymes such as lipase have been also reported as catalyst for transesterification/esterification. The most popular catalyst is sodium methoxide. However, NaOH was also found to be suitable.

- Feedstock: The quality of feedstock plays important role. The free fatty acids (FFA) present in non -edible oil would destroy the basic catalysts and soap formation would take place. Thus, non-edible oil needs prior processing to remove FFA or one has to use acidic catalysts. The oil used must have as low moisture content as possible (moisture < 0.1%) so as to avoid hydrolysis of catalysts and triglycerides.

- Temperature: The transesterification reaction precedes best under atmospheric pressure at reflux temperature of about 64□ C in the case of FAME and could be higher in the case of FAEE.

The product recovery:

The reactor contents are thoroughly washed at the end to remove catalyst (caustic), methanol and glycerol. The residual methanol and water could be distilled out from Biodiesel to meet the desired specifications.

2.2 Properties of fuels used

Density

Fig 2.2.1 shows the hydrometer setup. Density is defined as the ratio of the mass of fluid to its volume. It is denoted by the symbol ρ(rho). The SI unit is given by kg/m^3. Density of diesel is 828 kJ/kg and density of JOME biodiesel is 864 kJ/kg.

Hydrometer

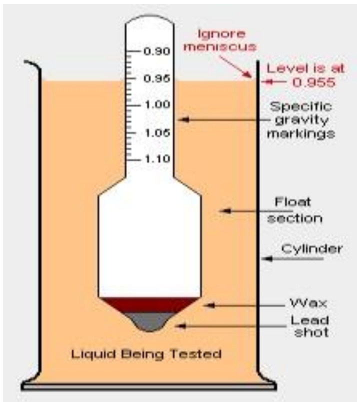


Fig 2.2.1

The total quantity of heat liberated by complete burning of unit mass of fuel. The calorific value of a substance is the amount of energy released when the substance is burned completely to a final state and has released all of its energy. It is determined by bomb calorimeter as shown in fig 2.2.2 and its SI unit in kJ/kg. The calorific value of diesel is found that 42,600 kJ/kg and JOME biodiesel is 40,800 kJ/kg.

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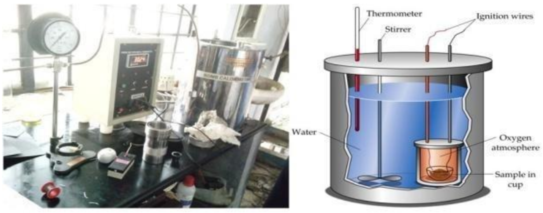

Fig 2.2.2 Bomb calorimeter

- **Kinematic viscosity**

The resistance offered to flow of a fluid under gravity. The kinematic viscosity is a basic design specification for the fuel injectors used in diesel engines. Kinematic viscosity determined by the instrument called Redwood viscometer as shown in fig 2.2.3 The value of kinematic viscosity is found that 4.6 Cst for diesel and 5.81 for JOME biodiesel.

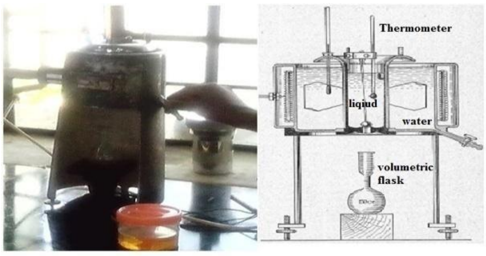

Fig 2.2.3 Redwood viscometer

Flash and fire point

Flash point of the fuel is defined as the temperature at which fuel gives off vapour to just ignite in air. Fire point of the fuel is defined as the temperature at which fuel will ignite continuously when exposed to a flame or spark. The flash point of biodiesel is higher than the petroleum based fuel. Flash point of biodiesel blends is dependent on the flash point of the base diesel fuel used and increase with percentage of biodiesel in the blend. Thus in storage, biodiesel and its blends are safer than conventional diesel. Determined by the instrument called Ables flash and fire point apparatus as shown in fig 2.2.4 The value of flash and fire point of diesel found that 51 ^{O}C and 57 ^{O}C respectively and JOME biodiesel is 160 ^{O}C and 175 ^{O}C respectively.

Fig 2.2.4 Ables flash and fire point apparatus

Table 2.1 shows the values of different properties such as density, kinematic viscosity, flash point, fire point and calorific value of diesel and neat JOME biodiesel.

Fuel samples Properties	Diesel	JOME Biodiesel	Apparatus used
Fuel density in kg/m^3	828	864	Hydrometer
Kinematic viscosity at 40°C in cSt	4.6	5.81	Redwood viscometer
Flash point in °C	51	160	Ables apparatus
Fire point in °C	57	175	Ables apparatus
Calorific value in kJ/kg	42600	40800	Bomb calorimeter

III. EXPERIMENTAL SETUP

3.1 Engine

The engine chosen to carry out the experimentation is multi (four) cylinder, four stroke, vertical, water cooled, computerised TATA make Indica V2 diesel engine. Fig 3.1.1 photograph taken from the IC engine laboratory, PDA College of Engineering shows engine connected with controlling unit. Table 3.3 shows the specification TATA Indica V2 engine.

Fig 3.1.1 Engine connected with dash board

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Table 3.1 Technical specification of TATA Indica V2 engine

Sl.No	Component	Specifications
1	Engine	Tata Indica V2, 4 Cylinder, 4 Stroke, water cooled, Power 39kW at 5000 rpm, Torque 80 NM at 2500 rpm, stroke 79.5mm, bore 75mm, 1405 cc, CR 22
2	Dynamometer	eddy current, water cooled
3	Temperature	eddy current, water cooled
4	Piezo sensor	Range 5000 PSI
5	Air box	M S fabricated with orifice meter and manometer
6	Load indicator	Digital, Range 0-50 Kg, Supply 230VAC
7	Engine Indicator	Input Piezo sensor, crank angle sensor, Input Piezo sensor, Communication RS 232, Crank angle sensor
8	Software	IC Enginesoft, Measurement and Automation
9	Temperature Sensor	Type RTD, PT100 and Thermocouple Type K
10	Fuel flow transmitter	DP transmitter, Range 0-500 mm
11	Air flow Transmitter	Pressure transmitter
12	Load sensor	Load cell, type strain gauge, Range 0-50 Kg

3.2 Exhaust emission testing machine

The emission test is done with AVL DITEST MDS 480 exhaust gas analyser modules. The product has additional features to save a vehicle and customer database, radio connected measuring chamber up to the option of designing the protocols individually. Due to the robust and intuitive application of the device, the tester can be used to get sophisticate and accurate emission measurements. This provides information motivation and modification. The computer is interfaced with engine. The engine soft is the software used to control the entire engine readings.

Fig 3.2.1 Exhaust gas analyser

3.3 Experimental procedure

For getting the base line data of engine first the experimentation is performed with diesel and then with biodiesel.

- Fill the diesel in fuel tank
- Start the water supply. Set cooling water for engine at 650 LPH and calorimeter flow at 150 LPH.
- Also ensure adequate water flow rate for dynamometer cooling and piezo sensor cooling.
- Check for all electrical connections. Start electric supply to the computer through the UPS.
- Open the lab view based engine performance analysis software package "engine soft" for on screen performance evaluation.
- Supply the diesel to engine by opening the valve provided at the burette.
- Set the value of calorific value and specific gravity of the fuel through the configure option in the software.
- Select run option of the software. Start the engine and let it run for few minutes under no load condition.
- Choose log option of the software. Turn on fuel supply knob. After one minute the display changes to input mode then enter the value of water flows in cooling jacket and calorimeter and then the file name (applicable only for the first reading) for the software. The first reading for the engine gets logged for the no load condition. Turn the fuel knob back to regular position.
- Repeat the experiment for different load and speed.
- All the performance readings will be displayed on the monitor.
- Using AVL smoke meter and exhaust gas analyser CO, CO2, NOx, UBHC, smoke opacity will be recorded.
- Now clear the diesel present in the engine and use neat biodiesel as a fuel, repeat the same procedure.
- At the end of the experiment bring the engine to no load condition and turn off the engine and computer so as to stop the experiment.
- After few minutes turn off the water supply.

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IV. RESULTS & DISCUSSION

4.1 Introduction

The experiment is conducted on TATA Indica V2 multi cylinder, direct ignition diesel engine to obtain performance and emission of multi-cylinder diesel engine using JOME biodiesel (J100) and diesel (D100) at low load condition i.e. up to 10% of maximum load.

4.2 Performance characteristics of multi cylinder diesel engine.

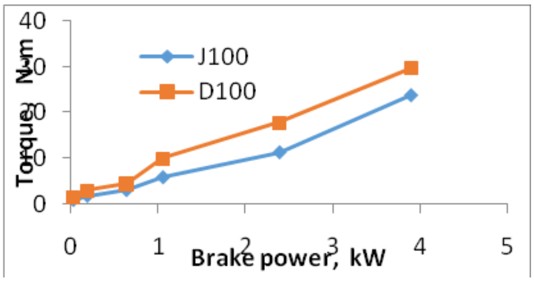

Fig 4.2.1 Variation of torque with brake power

Variation of torque with brake power is shown in fig 4.2.1 at low load condition. Torque obtained for the biodiesel is less as compare to the diesel. The maximum torque recorded for biodiesel is 23.6 N-m and diesel is 27.9 N-m at 3.9 kW brake power. Torque generation for biodiesel is low mainly due to higher viscosity.

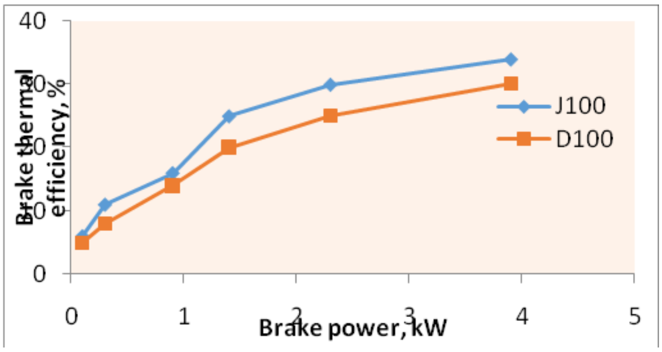

Fig 4.2.2 Variation of brake thermal efficiency with brake power

Variation of brake thermal efficiency with brake power shown in fig 4.2.2. Brake thermal efficiency increases with increase in brake power for both biodiesel and diesel. Maximum brake thermal efficiency of 46% for biodiesel and 83.31% for diesel is obtained. Biodiesel yields lower brake thermal efficiency compare to diesel because of higher viscosity and lower mean gas temperature.

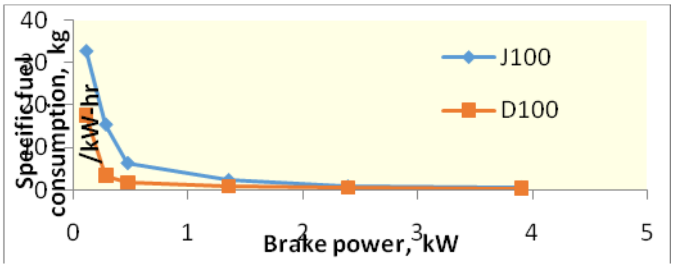

Fig 4.2.3 Variation of specific fuel consumption with brake power

Variation of specific fuel consumption with brake power is shown in fig 4.2.3. At the beginning specific fuel consumption is more and becomes constant with increase in brake power. In the idling condition specific fuel consumption of biodiesel is 32.76 kg/kW-hr at 0.11 kW and of diesel is 17.58 kg/kW-hr at 0.11 kW. Biodiesel consumption is more because of higher viscosity which produces improper air fuel mixture and hence poor combustion. Higher viscosity of biodiesel lowers the maximum temperature. So consumption of biodiesel is more for same power output.

4.3 Emission characteristics of multi cylinder diesel engine.

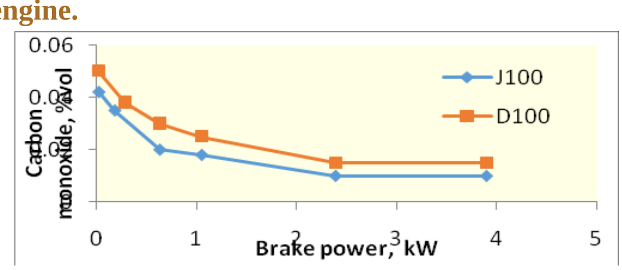

Fig 4.3.1 Variation of carbon monoxide with brake power

Variation of carbon monoxide with brake power is shown in fig 4.3.1. As brake power increases, carbon monoxide emission decreases at low load condition. At maximum power of 3.9 kW carbon monoxide recorded for biodiesel is 0.01 % volume and for diesel it is 0.015 % volume.

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Initially carbon monoxide emission is high since engine is at idling condition due to poor combustion. Biodiesel gives less carbon monoxide compared to diesel with increase in brake power. Since biodiesel contains intrinsic oxygen, it gives additional oxygen for the combustion leads to better combustion of biodiesel compared to diesel.

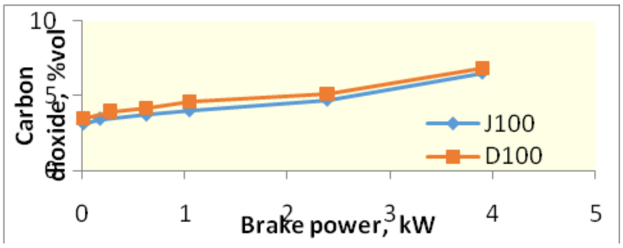

Fig 4.3.2 Variation of carbon dioxide with brake power

Variation of carbon dioxide with brake power is shown in fig 4.3.2. Carbon dioxide increases with brake power for both biodiesel and diesel. At 3.9 kW brake power, carbon dioxide value recorded for diesel is 6.82% volume and for biodiesel is 6.53% volume. Carbon dioxide emission for biodiesel is less compared to diesel with increase in brake power at lower load condition. Even though biodiesel gives additional oxygen for complete combustion, because of lower calorific value of biodiesel, that is carbon molecule percentage in biodiesel is less as compared to diesel per unit volume leads to lower CO_2 emission.

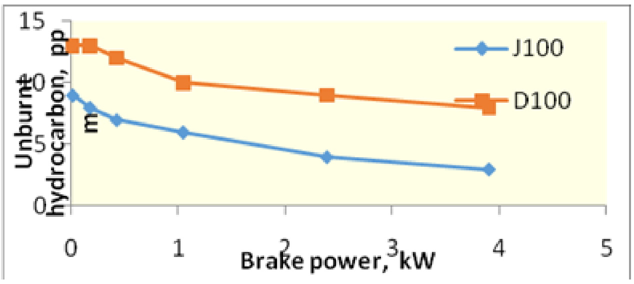

Fig 4.3.3 Variation of variation of unburnt hydrocarbon with brake power

Variation of unburnt hydrocarbon with brake power is shown in fig4.3.3. At the idling condition unburnt hydrocarbon percentage is more in exhaust due to poor combustion results. As the brake power increases percentage of unburnt hydrocarbon is decreases. At 3.9 kW brake power recorded for diesel is 8 ppm and the biodiesel is 3 ppm of unburnt hydrocarbon. Biodiesel recorded lower unburnt hydrocarbon compared to diesel, because of intrinsic oxygen present in the biodiesel gives additional oxygen to the combustion leads to better combustion. Hence biodiesel produces lower unburnt hydrocarbon percentage in the emission.

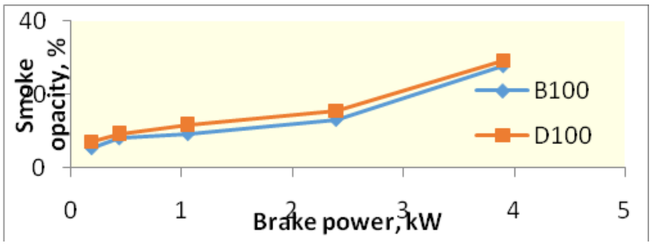

Fig 4.3.4 Variation of smoke opacity with brake power

Variation of smoke with brake power is shown in fig 4.3.4 at low load condition. To understand the pollution aspect of biodiesel the variation of smoke with brake power is studied. At 3.9 kW of brake power the value of smoke opacity recorded for is J100 27.8 % and for D100 is 29.1 %. Smoke value is lower for J100 comp ared to D100 because of intrinsic oxygen present in the biodiesel gives additional oxygen, leads to better combustion. Lower CO, CO_2 and UBHC also supports the lesser smoke value of J100.

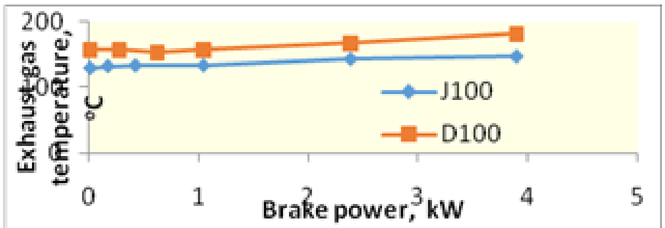

Fig 4.3.5 Variation of exhaust gas temperature with brake power

Variation of exhaust gas temperature with brake power is as shown in fig 4.3.5 at low load condition. Exhaust gas temperature increases with brake power. For 3.9 kW brake power values recorded for diesel is

182 oC and for biodiesel is 148 oC. The exhaust gas temperature of biodiesel is less compare to diesel because of lower mean gas temperature. Viscosity is also influences the exhaust gas temperature by affecting the rate of reaction.

V. CONCLUSION:

The purpose of this chapter is to summarize the preparation; characterization of biodiesel and the results of experiment have been carried out. The following section contains specific conclusions that have been drawn from the project work.

The conclusions of the project are as follows.

- Neat JOME oil is converted into biodiesel using transesterification process.
- Characterization of JOME biodiesel is carried out, the specific gravity and calorific value of biodiesel is less than that of diesel.
  Viscosity of the neat JOME oil is at higher values. However viscosity of biodiesel is well comparable with diesel.
- Engine is producing the desired brake power at different speed compared with that of diesel.
- Brake thermal efficiency of biodiesel is lower than diesel.
- In the load range of 0 to 2.2 kW specific fuel consumption of biodiesel is higher, as load increases biodiesel comparable with that of diesel.
- Mean gas temperature of combustion chamber for a complete cycle for burning of biodiesel is lower than that of diesel.
- Smoke, unburnt hydrocarbon, carbon monoxide, carbon dioxide emissions are a little lower than that of diesel due to low temperature of mean gas temperature.

REFERENCES

[1].Ministry of Petroleum and Natural Gas, Government of India, New Delhi, (Economic Division) report, Basic Statistics on Indian Petroleum & Natural Gas, 2012-13, Available at www. http://petroleum.nic.in/petstat.pdf, Accessed on 04-05-2014.

[2].CERA report on total world oil". Cera.com. November 14, 2006. Retrieved August 29, 2010.

[3].Greenergy - Providing Environmentally Friendly Fuels". PetrolPrices.com. 2006-10-24. Retrieved 2009-10-17.

[4].Deepak Agarwal and Avinash Kumar Agarwal, 2007, Performance and Emissions Characteristics of JOME Oil (Preheated And Blends) in A Direct Injection Compression Ignition Engine, Applied Thermal Engineering; 27: pp 2314–2323.

[5].M.L.Mathur and R.P. Sharma. Internal combustion engine. Dhanpathrai publication, publication year2010.

[6].S.Choudhury, P K Bose., 2008 JOME derived Biodiesel and its Suitability as C. I. Engine Fuel, SAE International; paper no. 28-0040.

[7].O.D. Hebbal, K.Vijaykumar Reddy and K.Rajagopal "Performance characteristics of diesel engine with deccan hemp oil" Science direct fuel 85 (2006) 2187-294.

[8].Suthar Dinesh Kumar L.a, Dr. Rathod Pravin P.b, Prof. Patel Nikul K.C, the performance of multi cylinder diesel engine fuelled with blend of diesel and neem oil biodiesel, International Journal of Advanced Engineering Research and Studies E-ISSN2249–8974.

[9].Rakopoulos DC, Rakopoulos CD, Hountalas DT, Giakoumis EG, Andritsakis EC. Performance and emissions of bus engine using blends of diesel fuel with biodiesel of sunflower or cottonseed oils derived from Greek feedstock. Fuel J 2008;87:147–57.

[10]. Dipak Patil1 , Dr. Rachayya.R2. Arakerimath3, Performance Analysis of Multi-cylinder C.I. Engine

by using Karanja Bio-diesel, International Journal of Engineering Research and Applications, ISSN: 2248-9622, Vol. 1, Issue 4, pp.1755-1763.

[11].Haiter Lenin, Bawady HA. Experimental evaluation of diesel engine performance and emission using blends of jojoba oil and diesel fuel energy. Energy Convers Manage 2004;45:2093–112.

[12].Gvidonas Labeckas, Stasys Slavinskas, Influence of fuel additives on performance of direct-injection Diesel engine and exhaust emissions when operating on shale oil. Energy Conversion and Management 46 (2005) 1731–1744.

[13]. K. Anand, R.P. Sharma, Pramod S. Mehta Experimental investigations on combustion, performance and emissions characteristics of neat karanji biodiesel and its methanol blend in a diesel engine. Biomass and bioenergy 35 (2011) 533e541.

[14]. Ahmet Necati Ozsezen a,b, Mustafa Canakci a,b, The emission analysis of an IDI diesel engine fueled with methyl ester of waste frying palm oil and its blends. Biomass and bio energy 34 (2010) 1870e1878.

[15]. Mustafa Canakcia.b, Ahmet Necati Ozsezena,b, Ali Turkcana,b . “Combustion analysis of preheated crudesunflower oil in an IDI diesel engine biomass and bio energy 33(2009) 760 –767.

[16]. Mario Luciano Randazzo a, Jose Ricardo Sodre b, “Cold start and fuel consumption of a vehicle fuelled with blends of diesel oil–soybean biodiesel–ethanol”. Fuel 90 (2011) 3291–3294.

[17]. Ahmet Necati Ozsezen a,b,1, Mustafa Canakci a, Ali Turkcan b, Cenk Sayin c. Performance and emission and combustion characteristic of a multicylinder DI diesel engine running on diesel–ethanol–biodiesel blends of high ethanol content. Elsevier, Volume 88, Issue 12, December 2011, Pages 5042–5055.

[18]. S.M. Palash, M.A. Kalam, H.H. Masjuki, M.I. Arbab, B.M. Masum, A. Sanjid. Impacts of NOx reducing antioxidant additive on performance and emissions of a multi-cylinder diesel engine fueled with JOME biodiesel blends. Energy Conversion and Management Volume 77, January 2014, Pages 577–585.

[19]. J.H. Zhou, C.S. Cheung, C.W. Leung. Combustion, performance and emissions of ULSD, PME and B50 fueled multi-cylinder diesel engine with naturally aspirated hydrogen. International Journal of Hydrogen Energy. Volume 38, Issue 34, 13 November 2013, Pages 14837–14848.

[20]. M. Mofijura, H.H. Masjukia, M.A. Kalama, A.E. Atabania, M.I. Arbaba, S.F. Chengb, S.W. Goukb. Properties and use of Moringa oleifera biodiesel and diesel fuel blends in a multi-cylinder diesel engine. Energy Conversion and Management. Volume 82, June 2014, Pages 169–176.

[21]. Md. Mofijur Rahman, , Masjuki Hj. Hassan, Md. Abul Kalam, Abdelaziz Emad Atabani, Liaquat Ali Memon, S.M. Ashrafur Rahman. Performance and emission analysis of JOME curcas and Moringa oleifera methyl ester fuel blends in a multi-cylinder diesel engine. Journal of Cleaner Production. Volume 65, 15 February 2014, Pages 304–310.

[22]. C.D. Rakopoulos, E.G. Giakoumis. Speed and load effects on the availability balances and irreversibilities production in a multi-cylinder turbocharged diesel engine. DOI: 10.1016/S1359-4311(96)00014. Applied Thermal Engineering. Volume 17, Issue 3, March 1997, Pages 299–313.