NIET JOURNAL OF ENGINEERING & TECHNOLOGY

ISSN 2229-5828

EXTRACTION, CHARACTERIZATION AND ENGINE PERFORMANCE OF JATROPHA CURCAS OIL

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Abstract

Global concern about escalating energy demand, depleting fossil fuel reserves and increasing environmental pollution has given an impetus to explore alternative fuels, preferably renewable. Plants oils are a renewable source of combustible material whose energy content can be beneficially utilized for transportation purposes. In this paper, the performance of a diesel engine running on pure Jatropha Curcas Oil (JCO) was experimentally investigated. JCO was supplied at two different temperatures- 35°C and 65°C. The important characteristic properties of JCO were found to be compatible with the requirement of diesel engine fuel. The comparison of fuels was made in terms of brake thermal efficiency, fuel consumption, pressure versus crank angle diagram and exhaust gas temperature. The test results show decrease in thermal efficiency and increase in fuel consumption and exhaust gas temperature for unheated JCO operation. Larger ignition delay and lower peak cylinder pressure was observed with it. However, engine performance was found to improve when JCO was preheated. This performance was in between that obtained with diesel and unheated JCO. On the whole, it can be concluded that for short-term usage, JCO (preheated to 65°C) can be directly used instead of diesel, without any operational difficulty and modification in engine design.

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Introduction

The increasing industrialization and motorization of the techno savvy world has led to a steep rise in the demand for petroleum-based fuel. These fuels are obtained from natural fossil oil reserves, which are very limited. These finite reserves are highly concentrated in certain regions of the world, which increases dependence on a few oil rich nations. Furthermore, these reserves are gradually depleting and burning of these fuels has a severe destructive impact on the environment. In the context of the above problem. The search for alternative fuels has become extensive. The energy used in different power sectors is based on diesel and it is, therefore essential that alternatives to diesel be developed. The need of the hour is to utilize renewable energy resources. For this reason, biofuels are being researched worldwide as alternative fuels. Vegetable oils are bio-origin based fuels. They are non-toxic and eco-friendly. They have rapid bio-degradability, their sources are renewable and they can be obtained easily. They operate in a diesel engine just like petrol-diesel, thereby they require no major modification in engine design [1-5]. Thus, vegetable oils hold great potential as an alternative fuel for diesel engines without any major modification. The partial or full replacement of diesel with these oils will relieve the pressure on existing fuel reserves as well as conserve a lot of diesel, thereby saving substantial money. As there is a tremendous demand for edible oils as food and they are far too expensive to be used as fuel at present, so the use of non-edible oils compared to edible oils is very significant.

In the present investigation, non-edible jatropha curcas oil (JCO) is used as an alternative fuel in unmodified diesel engines. Jatropha curcas is a widely occurring variety of tree born oil seeds. It grows practically all over India under a variety of agro-climatic conditions. Thus, it ensures a reasonable production of seeds with very little inputs.In this present study, it is observed that there are various problems associated with straight vegetable oils being used as fuel in diesel engines, mainly caused by their high viscosity [2,6-8]. Although short-term tests using neat vegetable oil showed promising results, longer tests showed various engine problems such as carbonization of injector, piston head and surfaces of cylinder, gum development, engine deposits, wear of vital parts, ring sticking and thickening of the lubricating oil etc [2,8-11]. These experiences led to the use of modified vegetable oil as a fuel. In order to use vegetable oils in existing engine design, their viscosity had to be reduced. Solution of the viscosity problem can be approached through various techniques such as blending with lighter oils [1,4-6,9], preheating (i.e. increasing fuel inlet temperature) [1,8,10-11] and transesterification i.e. conversion to methyl/ethyl esters referred to as biodiesel [2-5].

The objective of this experimental work is to study the effect of fuel preheating on performance of the diesel engine running on JCO. During this investigation, the engine was fuelled with JCO at two different fuel inlet temperatures- at 35°C (ambient temperature) and 65°C (elevated fuel inlet temperature). Diesel was used as a baseline fuel. For comparison purposes, the short-term performance tests have been carried out using three fuels.

2. Jatropha curcas oil

Jatropha curcas oil is non-edible oil, which is obtained from the dried ripe seeds of the Jatropha curcas plant. Jatropha curcas is a large shrub or tree native to the American tropics but commonly found and utilized throughout most of the tropical and subtropical regions of the world [9,12]. It is commonly known as Physic nut, Ratanjot, Jamalghota, Jangaliarandi or Kala-aranda [13]. It is a drought-resistant, perennial plant, and has the capability to grow on marginal/poor soils. It requires very little irrigation and grows in all types of soils [1].

The Jatropha curcas plants start yielding from the second year of plantation but in limited quantity. If managed properly, it starts giving 4-5 kg per tree seed production from 5th year onwards and seed yield can be obtained upto 50 years from the day of plantation. The oil content of Jatropha seed ranges from 30 to 50% by weight [13]. The oil can be combusted as fuel without being refined. It burns with a clear smoke-free flame, tested successfully as fuel in diesel engines. Jatropha oil cake contains nitrogen, phosphorus and potassium, so it can be used as organic manure. Jatropha seed press cake and Jatropha oil have insecticidal properties.

In spite of a number of advantages Jatropha also suffers from certain limiting factors, which need to be kept in mind while dealing with this species. Jatropha seeds are hard and possess toxicity. Thus, the de-oiled cake cannot be used as animal fodder . After extraction of oil from the seeds the detoxification of the seed cake is necessary so that the seed cake can be used as cattle feed. From several investigations it is found that de-acidification and bleaching could reduce the content of toxic phorbol esters to 55% [14]. The fatty acid composition of JCO consists of myristic, palmitic, stearic, arachidic, oleic and linoleic acids [9,15]. Fatty acid composition of JCO is shown in Table 1. The main benefits of jatropha are renewable energy, erosion control and soil improvement, promotion of employment and poverty reduction.

Table 1: Fatty acid profile of JCO [12]

Fatty Acid	Formula	Structure	Wt%
Myristic Acid	$C_{12}H_{28}O_2$	14:0	0.5-1.4
Palmitic Acid	$C_{16}H_{32}O_2$	16:0	12–7.0
Stearic Acid	$C_{18}H_{36}O_2$	18:0	5.0–9.7
Oleic Acid	$C_{18}H_{34}O_2$	18:1	37-63
Linoleic Acid	$C_{18}H_{32}O_2$	18:2	19-41

3.Extraction of oil

Before oil extraction, the jatropha seeds should be roasted for around 10 minutes or can be solar heated for several hours. The seeds should not be overheated. The process breaks down the cells containing the oil and eases the oil flow. The heat also liquefies the oil, which improves the extraction process. Oil can be extracted from the seeds by heat, solvents or by pressure. Extraction by heat is not used commercially for vegetable oils. The oil from Jatropha seeds can be extracted by three different methods. These are mechanical extraction using a screw press, solvent extraction and an intermittent extraction technique viz. soxhlet extraction. Although oil extraction can be done with or without seed coat, for Jatropha, utilization of a mechanical de hulling system (to remove the seed coat) can increase oil yield by 10%.Choosing efficient extraction methods can increase the yield by more than 5%. While in cold pressing (<60°C), around 86 – 88% efficiency is achieved, hot pressing (110 – 120°C) can increase it to around 90%. On the other hand, the solvent extraction method enhances the efficiency up to 99%.

A disadvantage with solvent extraction is that the quantity of phospholipids in solvent extracted oil is twice as high as compared to pressed oil. This necessitates a further step of oil de gumming before trans-esterification. Oil extraction methods are also being developed based on fermentation hydrolysis. In this process, cell walls of the oil plant seeds are destroyed followed by the release of the oil present within the cells [16]. This new method not only produces higher quality of oil and cake but also requires much less energy and results in lower levels of environmental pollution. The efficiency so far obtained is 86% and more research is needed to develop an effective enzyme system. In order to purify the extracted oil, the oil must undergo a series of steps. The first step is sedimentation which is the easiest way to get clear oil, but it takes about a week until the sediment is reduced to 20-25 % of the raw oil volume. In the second step the purification process can be accelerated tremendously by boiling the oil with about 20 % water. The boiling should continue for few hours until the water has completely evaporated and the oil then becomes clear. Then the raw oil is again filtered which is a very slow process.

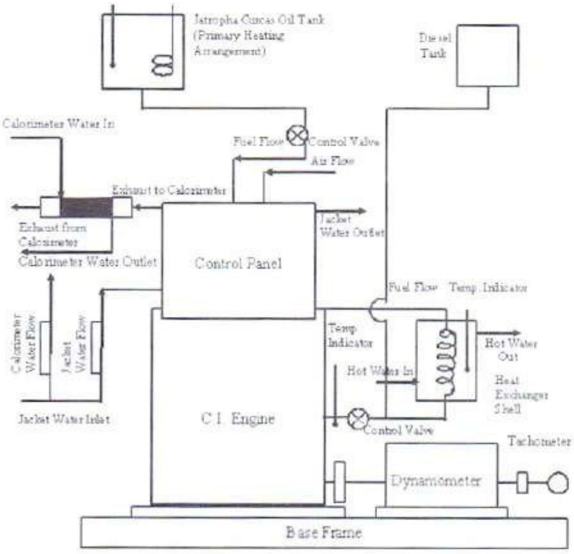

Figure 1: Experimental Setup

4. Experimentations

4.1 Experimental Set-up

The DI diesel engine (Kirloskar make) was used for conducting the experimentations. Fig.1 shows the engine test rig mounted on a rigid base frame. The specifications of the experimental set-up are given in Table 2. Engine is coupled to an eddy current dynamometer by cardon shaft. Experimental setup is provided with different equipments and instruments for the measurement of air flow, fuel flow, cylinder pressure, crank angle, speed, various temperatures and load. A rotameter is provided for engine cooling water flow measurement. Piezoelectric type pressure sensor is used for cylinder pressure measurement. The sensor is mounted in the cylinder head of the engine. The sensor is provided with a water-cooled adapter. These signals are interfaced to a control panel, which is connected to a computer to monitor the engine performance at different running conditions.

Table 2: Engine Specifications

Engine	Kirloskar (Model TV1), single cylinder, four stroke, water cooled diesel engine.
Bore x Stroke	0.0875 m x 0.110 m
Compression ratio	17.5:1
Rated power	5.2 kW @ 1500 rpm
Stroke volume	661 cc
Fuel and air measurement	Differential pressure unit
Speed measurement	Rotary encoder
Dynamometer	Eddy current
Load measurement	Strain gauge load cell, Range 0-50 kg
Water flow measurement	Rotameter
Fuel and air measurement	Differential pressure unit
Speed measurement	Rotary encoder

In order to use plant oil as fuel, a minor modification in the existing set-up was made. The fuel system was designed and held different tanks: a conventional fuel tank for the test fuel and a secondary fuel tank for diesel (used only for starting and stopping the engine). A fuel filter was provided at the outlet of the JCO tank. JCO was heated in the fuel tank by means of a thermostatically controlled immersion rod and was allowed to flow to the fuel pump through a fuel measuring unit. In order to compensate for temperature loss of vegetable oil, a heat exchanger was fitted between the fuel measuring unit and fuel pump. A tube-in-shell type of heat exchanger was designed and fabricated, which was cylindrical in shape. The fuel was passed through a copper tube, which was coiled within the heat exchanger shell. The heat exchanger, vegetable oil tank and hot water tank were mounted on a suitable stand. The heat exchanger shell was completely insulated to minimize heat losses. Three calibrated Copper-Constant temperature probes (of range -180°C to 390° C) were attached to a heating arrangement for measurement of different temperatures.

4.2 Experimental Procedure

Experiments were initially carried out on the engine with diesel as the fuel to obtain baseline data. The same test procedure was then repeated for JCO at different temperatures (35°C and 65°C). Then, comparative assessment of test fuels was made. Engine water flow rate and calorimeter water flow rates were adjusted at 350 LPH and 80 LPH respectively. The injection timing was optimized and set at 27° bTDC. Injection timing and injection pressure were not changed for all fuels. For carrying out tests with JCO, the engine was started with diesel and allowed to warm up and computer software was allowed to get fully loaded. Then, the diesel fuel valve was shut down and JCO valve was opened to run the engine. Instrument readings for a particular test case were recorded after a sufficiently long time that ensure steady state engine operation. The engine was tested under different load conditions for a constant speed of 1500 rpm. The comparison of two fuels was made in terms of thermal efficiency, fuel consumption, in-cylinder pressure and exhaust gas temperature. At the end of the experiment, the fuel was always switched back to diesel and the engine was run until all alternative fuel had been purged from the fuel lines, injection pump and injector in order to prevent engine deposits.

The same test procedure was repeated for preheated JCO. The fuel temperature was the only parameter that was changed and the changes in the performance of the engine must be due to these temperature changes.

5. Results and Discussions

The engine tests were carried out using JCO at two different temperatures (35°C and 65°C). The performance characteristics of JCO are then compared with diesel and shown here with suitable graphs. The results and related discussions are given below.

5.1 Fuel characteristics

Before the engine test, the important chemical and physical properties of JCO were experimentally determined as per standards methods. Table 3 shows the comparison of properties of JCO with diesel. Except cetane number determination of other properties was carried out in the laboratory by standard methods. Determination of flash point, calorific value, density, and kinematic viscosity were carried out using Pensky's Martin apparatus, Bomb calorimeter, Hydrometer and Saybolt viscometer respectively.

The flash point of JCO was observed to be much higher than that of diesel. Hence, it is safer in handling, transportation and storage. However, high flash point attributes to its lower volatility characteristics [5]. The calorific value of JCO is observed to be lower than that of diesel. The presence of chemically bound oxygen in vegetable oils improves combustion properties and emissions but lowers their calorific value [1-5]. The density of JCO is slightly higher than that of diesel. The cetane number of JCO is 38 as compared 50 for diesel. Thus, the propensity is higher for diesel knock in case of JCO operation. At 38°C, kinematic viscosity of JCO is very high in comparison to diesel. This is due to the large molecular mass and chemical structure of vegetable oil [1,9,11].

Table 3: Fuel Characterization [9]

Property/Fuel	JCO	Diesel	ASTM Method	Apparatus
Flash Point (C)	219	76	D 93	Pensky's Martin Apparatus
Calorific Value (MJ/kg)	39.73	42.01	D 240	Bomb Calorimeter
Density (g/cm3, at 30°C)	0.915	0.858	D 1298	Hydrometer
Cetane Number*	38	50	-	-
Kinematic Viscosity (cSt, at 38°C)	40.97	2.96	D 445	Saybolt Viscometer

5.2 Kinematic Viscosity vs Temperature

From the properties listed in Table 3, it has been observed that JCO has a higher kinematic viscosity compared to baseline fuel. The viscosity of JCO needed to be reduced more in order to make it suitable as fuel to be used in diesel engines. From the literature [9-11], it has been found that on heating, the viscosity of vegetable oils reduces. Therefore, efforts had been made to decrease the viscosity by heating JCO. For this, the kinematic viscosities were measured at varying temperatures in the range of 20-80°C.

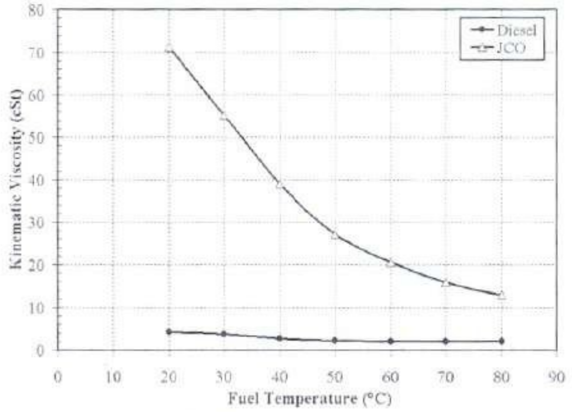

Fig. 2: Kinematic Viscosity Vs Temperature

Fig.2 shows that the kinematic viscosity of JCO is higher than that of diesel at all fuel temperatures. However, the viscosity of JCO reduced considerably with the increase in temperature, which is a result of decrease in

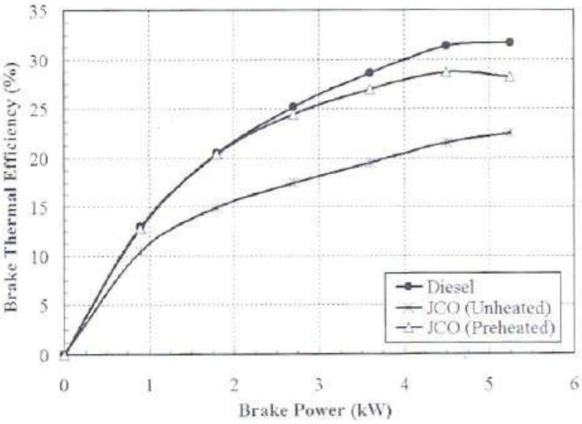

Fig. 3: Brake Thermal Efficiency vs Brake Power

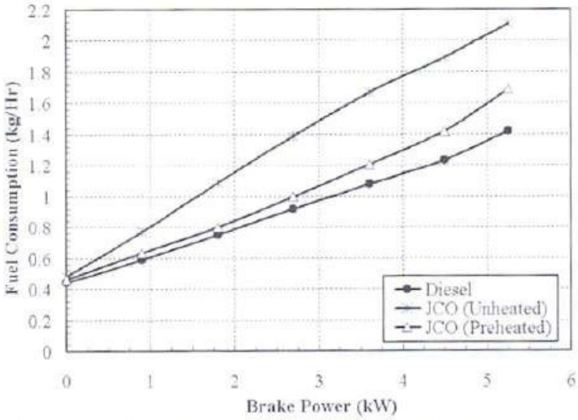

Fig. 4: Fuel Consumption vs Brake Power

intermolecular attraction due to expansion. For diesel, viscosity change with temperature was not so significant.

5.3 Performance characteristics

The results for the variation in the brake thermal efficiency with brake power for test fuels are presented in Fig.3. It can be seen that brake thermal efficiency with unheated JCO operation is quite low as compared to that of diesel operation. The maximum brake thermal efficiency with unheated JCO is 22.5% whereas it is 31.6% with diesel at maximum output power. Fig.4 shows the variation of engine fuel consumption with respect to brake power for test fuels. The fuel consumption in the case of unheated JCO is significantly higher as compared to diesel operation for the entire output power range.

The poor engine performance is a reflection of the high viscosity, low volatility, low cetane number and high density of JCO as compared to diesel. Kinematic viscosity of JCO is nearly 14 times higher than that of diesel. High viscosity and low volatility of vegetable oil based fuel greatly effects the fuel injection process and results in poor atomization of the fuel [1,17]. Also, cetane number of JCO is lower than diesel by approximately 12 units. These factors combine to increase delay period. Delay period is the time period between the start of fuel injection and onset of combustion. On the other hand, the high density of JCO leads to a larger mass injection of fuel particles for the same displacement of the plunger in the fuel injection pump [9]. On the other hand, when preheated JCO is used, increased brake thermal efficiency and reduced fuel consumption rate is obtained. This is due to reduction in viscosity and density and improved volatility. Further, brake thermal efficiency and fuel consumption values obtained with preheated JCO are still inferior to those obtained with baseline fuel operation.

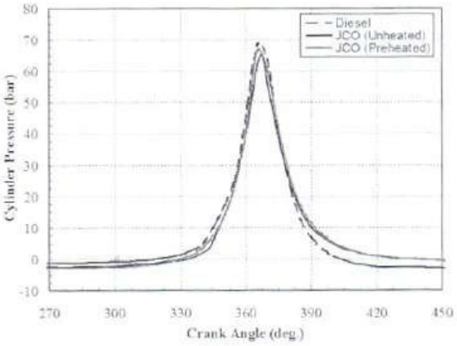

Fig. 5: Cylinder Pressure vs Crank Angle (Power 5.25 kW at 1500 rpm Injection Pressure 250 bar Injection Timing 27° bTDC)

In-cylinder pressure data was analyzed for change in pressure with respect to crank angle for test fuels. Fig.5 shows the pressure versus crank angle diagram for three fuels at an engine of 1500 rpm and maximum power output. From this diagram, it can be clearly seen that delay period of unheated JCO operation is largest. The start of fuel injection was the same for all fuels but the injection duration for unheated JCO is observed to be the largest. It is measured by the sudden change in the slope of pressure crank angle diagram. The possible reason for this is higher viscosity, lower volatility and lower cetane number of JCO and perhaps to compensate for the lower calorific value of fuel. Also, the maximum cylinder pressure with unheated JCO is the lowest. When preheated JCO is used, injection duration reduces while peak cylinder pressure increases. The preheated JCO showed reduction in delay period compared to unheated JCO. This improvement has resulted from decrease in oil viscosity and improved volatility. Further, we see that peak cylinder pressure value with preheated JCO lies in between those obtained with diesel and unheated JCO.

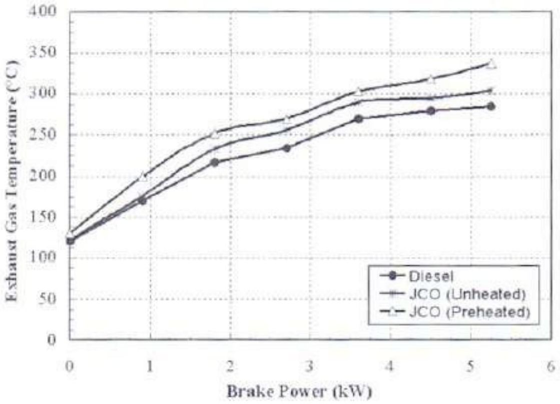

Fig. 6: Exhaust Gas Temperature vs Brake Power

The variation of exhaust gas temperature using diesel, unheated JCO and preheated JCO is presented in Fig. 6. The exhaust gas temperature obtained with unheated JCO is quite higher than that with diesel. The maximum temperature of exhaust gas at maximum output power is 304°C with unheated JCO and 285°C with diesel. In case of JCO operation, higher delay period results in slow combustion. Because of this, injected vegetable oil particles may not get enough time to burn completely before TDC, hence some fuel mixtures tend to burn during early part of expansion stroke (after-burning occurs). It can be further seen that with the increase in fuel inlet temperature (preheating), the exhaust gas temperature tends to increase. This is due to increase in combustion gas temperature [11].

6. Conclusions and Recommendations

In this investigation, JCO was tested as an alternative diesel engine fuel. The short-term performance test was carried out on a diesel engine separately with diesel and JCO (unheated and preheated). In order to evaluate engine performance no modification in the existing engine design was made. It was found that JCO had a good potential as an alternate for diesel. The most important advantage of this non-edible oil is that it is a renewable source of energy compared to petroleum fuel.

The engine performance with unheated JCO was found to be poorer in comparison with baseline fuel. Unheated oil exhibits a larger delay period and longer combustion duration with moderate rate of pressure rise and lower peak cylinder pressure. Higher exhaust gas temperature was also observed with it. The reason for this difference may be attributed to high viscosity, high density, low cetane number, low calorific value and poor volatility of JCO. Due to these inferior properties, JCO produces poor engine performance. The properties can be improved through various methods like transesterification, blending (with lighter oils) and preheating.

In the present study, improvement in properties was achieved by preheating the oil. When preheated JCO was used, engine performance was found to improve. Acceptable values of brake thermal efficiency and fuel consumption rate were observed with oil preheated to 65°C. The heated JCO showed a comparative reduction in a delay period over the unheated JCO. Also, higher peak cylinder pressure was observed with it. This performance was still slightly inferior as compared with baseline fuel operation. A series of experimentations must be carried out using preheated JCO. Continued engine performance, emission, combustion and durability of engine will increase consumer and manufacturer confidence. Studies are also needed on economic feasibility of this energy sources.

A thorough investigation is required in order to establish long-term durability of diesel engine running of pure JCO. A comprehensive work is needed to conclude that vegetable oil based fuels can be completely substituted for diesel in existing diesel engine designs.

Acknowledgements

The authors of this paper are grateful to the Department of Mechanical Engineering, Z. H. College of Engineering and Technology, Aligarh Muslim University, Aligarh for kindly providing the facilities to conduct the engine test. Further, the authors would like to thank M/s. Mohd. Ali and Rahis Beg for their technical help in conducting experiments.

Nomenclature

JCO	Jatropha Curcas Oil
DI	Direct Injection
LPH	Litre Per Hour
TDC	Top Dead Center
bTDC	Before Top Dead Center
rpm	Revolutions per minute
cSt	Centi Strokes
kW	Kilo Watt

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