Inedible Vegetable Oil as Substitute Fuel in Compression Ignition Engines-Jatropha Oil

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Abstract

The use of inedible vegetable oils as substitute for diesel fuel in compression ignition engine is of significance because of the great need for edible oil as food, and the reduction of biodiesel production cost etc. Jatropha curcas oil which is a leading candidate for the commercialization of inedible vegetable oils is selected in this study for reviewing the application in CI engine as an alternative fuel. The important properties of jatropha oil (JO) and JO biodiesel are summarized from the various sources in the literature. It is found that five different types of alternative fuel from JO such as neat JO, JO blends with diesel or other fuel, neat JO biodiesel, JO biodiesel blends with diesel or other fuel and degummed JO were extensively examined in the diesel engine. Two different application types of alternative fuels from JO such as preheating and dual fuelling were also tested. It should be pointed out that most of these applications are limited to single cylinder conditions. The systematic study for the selection of effective application method is required. It is clear that the blends of JOME and diesel can replace diesel fuel up to 10% by volume for running the existing common rail direct injection systems without any durability problems. The systematic assessment of spray characteristics of different types of JO and its derivatives for use as diesel engine fuel is also required.

Introduction

Nowadays, energy crisis due to depletion of resources and increased environmental problems accelerate the investigations of alternative fuel, which should be not only sustainable but also environmentally friendly. Alternative fuels for compression ignition (CI) engines include vegetable oils, biodiesel, Fischer-Tropsch diesel and DME (dymethyl ether). Of these four alternative fuels, vegetable oils can be divided into edible and non-edible oils. The different types of edible vegetable oils and biodiesels as substitutes for diesel fuels are considered in the different countries depending on the climate and soil conditions. For example, soybean oil in the USA, rapeseed (canola in Canada) and sunflower oils in Europe, palm oil in South-east Asia (mainly Malaysia, Indonesia and Thailand), and coconut oil in the Philippines are being produced[1]. The other edible vegetable oils include poppy seed, safflower seed, sesame seed, wheat grain, corn marrow, bay laurel leaf, peanut kernel, hazelnut kernel, walnut kernel, almond kernel and olive kernel[2].

The use of edible vegetable oil or biodiesel from it as substitutes to diesel fuels may lead to a problem of self-sufficiency in vegetable production. The use of non-edible vegetable oils is of significance because of the great need for edible oil as food. In addition the selection of non-edible vegetable oil can reduce the production cost of biodiesel due to the relatively high cost of edible vegetable oils.

Babu and Devaradjane[3] reviewed to find the prospects and opportunities of introducing vegetable oils and their derivatives as fuels in diesel engines. They selected 8 non-edible vegetable oils such as neem, karanja, mahua, jatropha, honne, castor, linseed and

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crambe oils, and 11 edible vegetable oils such as sunflower, soybean, sesame, safflower, coconut, cottonseed, olive, palm, peanut, corn and rapeseed oils for a survey of studies and research on vegetable oil based fuels. Their results show that compared to No. 2 diesel fuel, all of the vegetable oils are much more viscous, are much more reactive to oxygen, and has higher cloud point and pour point. They also found that vegetable oils and their biodiesels offer lower engine noise, and lower smoke, HC and CO, slightly higher NOx and higher thermal efficiency compared to diesel. In addition, 25/75 blend of vegetable oil with diesel fuel and 20/80 blend of biodiesel with diesel fuel offer better engine performance and lower emissions. However, they had concentrated mainly on the study of the performance and emission characteristics for edible vegetable oils and its derivatives.

Fatty acid profiles of seed oils of 75 plant species having 30% or more fixed oil in their seed/kernel were examined by Azam et al.[4]. They concluded that fatty acid methyl ester of oils of 26 species including jatropha, neem, polanga seed and karanja were found most suitable for use as biodiesel.

Achten et al.[5] recently reviewed the currently available information on the different process steps of the production process of biodiesel from *jatropha curcas* L., being cultivation and production of seeds, extraction of the oil, conversion to the biodiesel and the use of the biodiesel and the by-products. However, the use of jatropha oil in CI engine in this review was based on the limited number of papers in the literature.

A review on the performance and emission characteristics of five inedible vegetable oils, i.e. karanja, mahua, linseed, rubber seed, and cotton seed oils, as a substitute for diesel fuel was reported[6]. However, jatropha oil, one of typical non-edible vegetable oils, was not included in this review. Recently, Demirbas[7] reported the progress and recent trends in biodiesel fuels. The edible oils in use are soyabean, sunflower, rapeseed and palm. The inedible oil used as feedstock for biodiesel production includes *Jatropha curcas, Mahua indica, Calophyllum inophyllum, Pongamia pinnata,* neem, rubberseed, silk cotton tree, waste cooking and microalgae, etc. The main advantages of biodiesel include its domestic origin, its potential for reducing a given economy's dependency on imported petroleum, biodegradability, high flash point, and inherent lubricity in the neat form. The main disadvantages of biodiesel are its higher viscosity, lower energy content, higher cloud point and pour point, lower engine speed and power, injector coking, engine compatibility, and high price. Blends of up to 20% biodiesel mixed with petroleum diesel fuels can be used in nealy all diesel equipment and are compatible with most storage and distribution equipment. Neat biodiesel and biodiesel blends reduce PM, HC and CO emissions and slightly increase NOx emissions compared with petroleum-based diesel fuel used in an unmodified diesel engine.

Siriwardhana et al.[8] recently reviewed the potential and prospects of biodiesel in Thailand. In this review, we can find that the major sources of biodiesel production in Thailand are palm oil, jatropha oil and used cooking oil.

The advantages of non-edible vegetable oil as a diesel fuel are liquid nature portability, ready availability, renewability, higher heat content, lower sulphur content, lower aromatic content, and biodegradability. On the other hand, the disadvantage of non-edible vegetable oil as a diesel fuel are higher viscosity, lower volatility, the reactivity of unsaturated hydrocarbon chains, and higher percentage of carbon residue[9].

Based on the review works considered in this study, there are a lot of trees, shrubs and herbs in the world which can be exploited for substitute fuel as diesel fuel. The raw materials being exploited commercially and scientifically by many researchers constitutes the non-edible oils derived from jatropha, karanja (pongamia, honge), mahau, linseed, cottonseed, rubberseed, putranjiba, tobacco seed, pumpkin seed, polanga seed, neem, pilu, deccan hemp, nagchampa and crambe oils etc.

The review paper related to the performance characteristics and exhuast emissions of jatropha oil as a substitute for diesel fuel could not be found. The purpose of this study is to review the application of jatropha oil in CI engine and to suggest the future works related to spray characteristics of those oils.

2. Production of jatropha oil and jo biodiesel

Jatropha curcas L. is a genus comprising 70 species distributed in tropical and subtropical countries in the world. The jatropha oil yields of 37.4%(10), 30~40%(11) and 20~40%(12) respectively, were obtained from whole seeds. However, the kernel of the jatropha seeds contain 46~58%(11), 40~60%(13) and 46~48.6%(10), respectively. This is due to the selection of oil extraction method. Shah et al.(13) had evaluated the three phase partitioning for extraction of oil from *jatropha curcas* L. seeds.

The details about the jatropha planting, harvesting, oil pressing and purification as well as agronomy and uses can be found in the jatropha handbook(14), one of the series of monograph(15) and report(16).

Biodiesel can be produced from renewable feedstocks through simple refining processes such as transesterification, microemulsification, dilution and pyrolysis. The precise process for these techniques can be found in the work of Srivastava and Prasad(17). These techniques reduce the viscosity of vegetable oil. It is well known that out of the above four methods, transesterification is simple and cost effective.

Recently, degumming process which is easy, simple and less expensive process than transesterification is introduced for jatropha oil by Haldar et al.(18). Degumming is an economical process of acid treatment by which the gum of the vegetable oil is removed to improve the viscosity and cetane number of vegetable oil up to certain limit. Therefore, the evaluation and comparison between transesterification and degumming are required.

At present, biodiesel is commercially produced from the refined edible vegetable oils such as sunflower oil, palm oil and soybean oil, etc by one-step, alkaline-catalyzed esterification process. However, Ramadhas et al.(19) pointed out that this process is not suitable for production of biodiesel from many unrefined non-edible vegetable oils because of their high acid value. Even though two-step esterification method are suitable for jatropha oil for the production of biodiesel(20), further research on some advance methods such as supercritical methanol or ethanol, hydroprocessing, in situ alkaline transesterification and microwave method etc is required.

3. Fuel properties of jatropha oil and its biodiesel

The fuel properties of jatropah oil (JO) are shown in Table 1. The values from the different literatures are summarized as the minimum and maximum value as range for the fuel properties, respectively. For the comparison, the data from Achten et al.(5) are included. It can be found that there exists big difference between two data for the fuel properties, respectively. It should be pointed out that particularly the

Table 1. Fuel properties of jatropha oil

Property	Range	Achten et al.(5)
Density (kg/m^3, 40°C)	901~940	860~933
Viscosity (mm^2/s,40°C)	24.5~52.76	37.0~54.8*
Flash point (°C)	180~280	210~240
Pour point (°C)	-3~5	-3
Cloud point (°C)	8~10	2
Cetane number	33.7~51	38~51
Calorific value (MJ/kg)	38.20~42.15	37.83~42.05

*30°C

Table 2. Fuel properties of JO methyl ester

Property	Range	Patil and Deng[20]	ASTM D 6751-02
Density (kg/m^3, 40°C)	862~886	860~880	870~900
Viscosity (mm^2/s, 40°C)	3.0~5.65	2.35~2.47	1.9~6.0
Flash point (°C)	135~192	-	-
Pour point (°C)	2~6	-6~2	-15~10
Cloud point (°C)	4.0~10.2	-	-
Cetane number	43~59	60~63	min 47
Calorific value (MJ/kg)	37.2~43.0	39.7~41.6	-

difference in kinematic viscosities is due to the different base of temperature.

Table 2 shows the fuel properties of JO biodiesel. For the comparison, USA standards (ASTM D 6751-02)[20] and the data from Patil and Deng[20] are included.

It is found from Table 2 that the fuel properties of JO biodiesel are within the standards. Therefore, it is clear that JO biodiesel can be applied directly to CI engines.

4. Use of jatropha oil in CI engine

The oil content of jatropha seed ranges from 30 to 50% dry weight and the kernel itself ranges from 45 to 60%[21]. A dry seed of jatropha curcas contains about 55% of oil[22].

The jatropha oil and its derivatives can be used as a liquid fuel for CI engine. It can be classified with neat jatropha oil, fuel modification such as blending with other fuels, mostly with diesel fuel, biodiesel, biodiesel blends and degumming and engine modification such as dual fuelling and preheating.

4.1 Use of Neat Jatropha Oil(JO)

The performance of neat jatropha oil in the application for the single cylinder water-cooled direct injection diesel engine developing a power output of 3.7 kW at the rated speed of 1500 rpm at various output have been used as the basis for comparison with the blending, biodiesel and dual fuel operation techniques by Kumar et al.[23]. They found that jatropha oil resulted in a slightly, reduced thermal efficiency as compared to diesel. HC emission was higher with jatropha oil as compared to diesel. The maximum smoke level with jatropha oil was highest among that of its ester and diesel. Ignition delay was higher with neat jatropha oil. In addition, lower heat release rate are found with jatropha oil.

The test results on a single-cylinder direct-injection engine operating on neat jatropha oil as well as blends of diesel and jatropha oil were presented by Forson et al.[22] and Agarwal and Agarwal[24]. Their tests showed that jatropha oil could be conveniently used as a diesel substitute in a diesel engine.

Reddy and Ramesh[25] reported the experimental work on a compression ignition engine fuelled with jatropha oil. They found that when the injection timing is retarded with enhanced injection rate, a significant improvement in performance and emission was noticed. At full ouput, NO level and smoke with jatropha oil are 1162.5 ppm and 2 BSU, respectively, while they are 1760 ppm and 2.7 BSU with diesel. It was found that the brake thermal efficiency increases when the injection rate is lowered with jatropha oil. They concluded that a significant improvement in performance, emissions and combustion parameters can be obtained by properly optimizing the injector opening pressure, injection timing, injection rate and enhancing the swirl level when a diesel engine is to be operated with neat jatropha oil.

For agricultrual applications where small amounts of fuel are consumed in every engine, use of neat vegetable oil is likely to be more attractive than the biodiesel[25]. Even though the neat jatropha oil is proper to apply for short- term use such as the agricultural machinery, pump operation etc., it is hardly find the test results on those engines.

4.3 Use of JO Blends

The application of jatropha oil blended with diesel fuel[21, 22, 25, 26] and methanol[23] to CI engine have been reported by many researchers in the literature.

Pramanik[21] reported the performance of the single cylinder CI engine using jatropha oil blended with diesel fuel and compared the results with the performance obtained with neat jatropha oil and diesel fuel. Among the various blends, the blends containing up to 30%(v/v) jatropha oil have viscosity values close to that of diesel fuel at the range of 35-40°C. They found that engine performance was significantly improved compared to that of neat jatropha oil. The specific fuel consumption and the exhaust gas temperature of the blends were reduced due to decrease in viscosity of the vegetable oil. The exhaust gas temperature, which is related to the formation of NOx, of 20:80 jatropha/diesel blend shows the very close to that of diesel fuel. They concluded that up to

50% jatropha oil can be substituted for diesel use in a CI engine without an major operational difficulties.

Forson et al.[22] presented the test results of blends of jatropha oil and diesel fuel in proportions of 97.4%/2.6%, 80%/20% and 50%/50% by volume on a single-cylinder direct injection engine and compared with the test results of diesel fuel and neat jatropha oil. They found that neat jatropha oil, neat diesel and blends of jatropha oil and diesel fuel exhibited similar performance and broadly similar emission levels under comparable operating condition. They concluded that the jatropha oil can be used as an ignition-accelerator additive for poor diesel fuels when 2.6% by volume of the jatropha is introduced into pure diesel fuel.

Agarwal and Agarwal[24] had measured the viscosity of jatropha oil blended with diesel fuel with blending ratio. They found that viscosities of jatropha oil blends up to 30% blending with diesel fuel was found close to diesel fuel. BSFC and exhaust gas temperatures for blends of jatropha oil and diesel were found to be higher compared to diesel fuel. Thermal efficiency was also found to be close to diesel for jatropah oil blends. CO_2, CO and HC were found to be increased with increasing proportion of jatropah oil in the blends compared to diesel fuel. They concluded that performance and emission characteristics were found to be very close to diesel fuel for lower blend concentration only.

Experimental investigations have recently been carried out by Gangwar and Agarwal[26] to examine the combustion characteristics of an indirect injection (IDI) CI engine operatig with jatropha oil blends with diesel (5, 10,20 and 50% by volume). Engine tests were performed at different engine loads ranging from no load to 100% rated load at constant engine speed of 2000 rpm. Combustion starts further earlier as the proportion of jatropha oil in the blend is increased. Combustion duration is observed to be almost similar for jatropha oil blends compared to diesel fuel. However, cylinder pressure rise for all jatropha oil blends was found to be higher than diesel. They concluded that jatropha oil blends up to 50% can be used in the CI engine without any hardware modification without any undesirable combustion features such as knocking.

Most approaches for blending jatropha oil with other fuel have been tried to introduce diesel fuel as same as discussed in the above. It is, however, known that vegetable oils offer the advantages of freely mixing with alcohols and these blends can be used in the existing diesel engines without modification.

Kumar et al.[23] found that blending of jatropha oil with methanol results in significant improvement in their physical properties. The viscosity and density are considerably reduced and the volatality is also improved. Results obtained from their experiments on a single cylinder diesel engine using a blend of jatropha oil and methanol showed improved brake thermal efficiency and reduced exhaust smoke emissions than neat jatropha oil. It was also found that the quantity of methanol that can be blended with jatropha oil is limited to 30% by volume due to the presence of water in alcohol and hence in turn the separation problem.

4.3 Use of JO Biodiesel

It is widely known that biodiesel generally causes an increase in NOx emission and a decrease in unburned hydrocarbon (UHC), carbon monoxide (CO) and particulate matter (PM) emissions compared to diesel fuel[6].

A performance evaluation of JO biodiesel had been carried out by Prasad et al.[27] on an low heat rejection diesel engine and compared with the pure diesel operation of a conventional diesel engine. They found that JO biodiesel was found to be an effective substitute for use in CI engine, except for higher smoke levels.

To reduce NOx emission from CI engines running on JO biodiesel, EGR system was tested by Suryawanshi and Deshpande[28] and Pradeep and Sharma[29]. They found that NOx emissions were decreased with the application of EGR with minor effect on fuel consumption rate, brake thermal efficiency and cylinder pressure etc. In the experimental work by Pradeep and Sharma[29], EGR level was optimized as 15%

based on adequate reduction in NO emissions, minimum possible smoke, CO, HC emissions and reasonable brake thermal efficiency.

Mandepe et al.[30] introduced common rail direct injection diesel engine to determine the effects of JO biodiesel on performance and emission characteristics. They found that HC and NOx emissions are comparable to those of fossil diesel fuel. However, CO emissions tend to increase and PM emissions were significantly lower than those of diesel fuel.

The performance and emission characteristics of single cylinder direct injection CI engine operated with neat methyl esters of Jatropha oil, Karanja oil, and sesame oil respectively were reported by Banapurmath et al.[31]. They found that all the methyl esters tested in this study result in a slightly reduced thermal efficiency and increased smoke, HC and CO level. It was also observed that NO emissions were lower for biodiesel operation compared to diesel.This tendency is not coincident with the general emission characteristics of biodiesel[6].

Puhan and Nagarajan[32] presented the effect of biodiesel molecular weight, structure and number of double bond on performance and emission characteristics of diesel engine. They found that more unsaturated biodiesel fuels have higher CO, HC and smoke emissions compared to highly saturated biodiesel fuel. More NO was observed in case of highly unsaturated biodiesel fuel due to higher ignition delay and advanced fuel injection timing.

4.4 Use of JO Biodiesel Blends

Subramanian et al.[33] tested jatropha oil biodiesel (jatropha oil methyl ester: hereafter JOME) blended with diesel in 5, 10, 15, 20 and 100% in the IDI diesel engine with EGR. Best fuel economy was observed with 10% biodiesel blended fuel in their study. In addition, NOx emissions increased while smoke emission was reduced at all speed ranges in two test modes.

The blends of 25, 50, 75 and 100% by volume of JOME and diesel was tested in single cylinder diesel engine by Sundaresan et al.[34]. They found that brake thermal efficiency of JOME blends was comparable with diesel fuel at all loads. For pollutant emissions, NOx emission from the blends of JOME was comparatively higher, smoke emission was lower and CO emission was also lower at peak load than diesel fuel.

Engine performance and exhaust emission in a single cylinder direct injection diesel engine fueled with neat JOME and its blends (B10, B20, and B50) with diesel fuel was investigated by Reksowardojo et al.[35]. The results obtained from this study in terms of engine performance and exhaust emissions are nearly similar with the other studies.

Acceptable brake thermal efficiency, brake specific energy consumption and emission characteristics in a single cylinder CI engine were obtained up to B25 of JOME and diesel fuel by Dhananjaya et al.[36]. With the increased injector opening pressure and advancing the injection timing, B20 JOME blend fuel with semi-adiabatic engine showed better combustion performance and lower exhaust emissions compared to other blends.

The blends of JOME and diesel fuel (B10 and B20) were tested in the sports utility vehicle equipped with a common rail direct injection system by Bhardwaj and Abraham[37]. It should be noted that this study is different with other investigations up to now in terms of the applicability of vegetable oils and its derivatives to the very high injection pressure system which is very sensitive to the fuel type and its quality. They concluded that the blends of JOME and diesel can replace the diesel fuel up to 10% (by volume) content for running existing common rail direct injection system without any durability problems.

It is known that stability of biodiesel is inferior compared to diesel fuel and therefore doping of biodiesel in diesel fuel will affect the stability of fuel significantly. Jatropha biodiesel has poor oxidation stability with good low temperature properties. On the other hand, palm biodiesel has good oxidative stability, but poor low temperature properties. To obtain an additive effect on these two critical properties of biodiesel by combining of jatropha and palm biodiesels, Sarin et al.[38] have examined blends of jatropha and palm biodiesel to study their physico-chemical properties. They suggested that for achieving better low temperature properties with improved oxidation stability, palm oil biodiesel blended with jatropha biodiesel at around 20-40% concentration will be an optimum mix of them. However, it is required to investigate the performance and exhaust emission characteristics of the optimum mix of jatropha-palm biodiesel when it is applied to CI engines.

4.5. Use of Degummed JO

It is clear that neat vegetable oil has to be processed to take care of viscosity, cetane number and the removal of gummy materials for the utilizaton in diesel engine. It is well known that transesterificatin of neat vegetable oil is an effective way for proper use in diesel engine. Instead of it, an economical chemical process of acid treatment by which the gummy materials of vegetable oil are removed, namely, degumming is recently suggested. By degumming process, the viscosity and cetane number of vegetable oil can be improved up to certain limit so that the blends of vegetable oil with diesel can be used in diesel engine satisfactorily. The acid-caustic degumming process is schematically explained by Reksowardojo et al.[12].

A study has been conducted to investigate the performance and emission characteristics of degummed jatropha oil (DJO hereafter) and its blend with diesel (DJO10) in single cylinder DI diesel engine by Reksowardojo et al.[11]. In their study, diesel fuel, untreated jatropha oil (JO100) and its blend with diesel (JO10) were also included for the comparison purpose. Thermal efficiency of JO10 and DJO100 was found to be comparable with diesel at full loads. JO10 and DJO10 showed the slightly higher brake specific fuel consumption compared to diesel fuel. HC emissions of JO10 and DJO10 are higher than diesel fuel due to the higher viscosity of blends and in turn incomplete combustion. In addition, HC emission of JO100 and DJO100 are much higher than that of JO10 and DJO10. CO emission characteristics was very similar with HC emission trends. NOx emissions of JO10 and DJO10 were higher and comparable to diesel fuel, respecitively. They pointed out that the lower cetane number causes to increase the NOx emission of JO10 and DJO10. NOx emission of JO100 and DJO100 were much lower than that of diesel fuel. The cylinder pressure and rate of heat release of neat JO and DJO are lower than diesel fuel. This means that they have lower combustion temperature than diesel fuel and results in lower NOx emission. For smoke emission, JO10, DJO10, JO100 and DJO100 showed the lower value than that of diesel fuel. Even though they concluded that DJO10 is the very satisfactory blending ratio in terms of performance and exhaust emissions, the experimental results for the other blending ratios are essentially required.

A study on the comparison of performance and emission characteristics of a diesel engine fueled with three degummed non-edible vegetable oils was recently undertaken by Haldar et al.[18]. Blends of degummed oils (10, 20, 30 and 40%) such as jatropha, karanja and putranjiva oils with diesel were introduced in a single cylinder, variable compression diesel engine at different loads and injection timings. It was observed that 20% blend of three non-edible vegetable oils with diesel give quite satisfactory performance related to brake specific fuel consumption and brake thermal efficiency. Comparing the emission characteristics such as CO, HC, NOx and particulate matter using the three non-edible vegetable oils, jatropha oil was very encouraging. They also emphasized that the degumming method offers a potentially low-cost method with simple technology for producing an alternative fuel for CI engines. However, around 3% reduction of viscosity for the degummed jatropha and putranjiva oils, and around 5% reduction of viscosity for the degummed karanja oil are too small value compared to 10 to 12 times reduction of viscosity through transesterification.

5. Dual fuelling

To solve the problems with the use of neat vegetable oil in diesel engine such as the increased smoke emission and reduced brake thermal efficiency, Kumar et al.[39] investigated the jatropha oil as pilot fuel in a dual engine with methanol being used as the primary fuel. Tests were conducted at 1500 rpm and full load with single cylinder CI engine. The brake thermal efficiency was lower when JO is used as the pilot fuel as compared to diesel being used as the pilot fuel. The smoke level with JO was higher than that with diesel even in the dual fuel mode. HC and CO emissions are higher with JO as compared to diesel and futher increased in the dual fuel mode. However, it was found that JO leads to lower NO levels as compared to diesel, even in the dual fuel mode. In addition, they discussed the experimental results on combustion characteristics such as ignition delay, cylinder peak pressure, pressure rise rate, combustion duration, and heat release rate.

In their continued research, they had introduced the hydrogen to enhance the performance characteristics of a vegetable oil fuelled compression ignition engine[40]. By introducting small amount of hydrogen along with air, a single cylinder CI engine was operated successfully. In the case of diesel being used as the pilot fuel instead of JO, the brake thermal efficiency was always higher. HC,CO and smoke emission were also lower with diesel as compared to JO. However, NO levels were higher with diesel than JO. In addition, combustion characteristics such as cylinder peak pressure, heat release rate and maximum rate of pressure rise were also higher with diesel than JO.

The various methods of applying jatropha oil and methanol such as blending, transesterification and dual fuel operation to CI engine were investigated experimentally and compared by Kumar et al.[23]. A single cylinder CI engine at constant speed of 1500 rpm with varying power output was used.

Table 3 shows the effect of different methods of using JO on performance and exhaust emission characteristics. All data are at maximum power output 37 kW. CO emission showed the same tendency with HC emission in Table 3. NO emission shows the highest in dual fuel mode and the lowest in diesel operation. It can be summarized that dual fuel operation in diesel engines leads to reduced smoke levels with improved performance. However, dual fuel engine gives poor part load performance and HC and CO emissions are higher[25].

Table 3. Effect of application methods of JO on performance and exhuast emission charateristics

	JO	Blends	Dual fuel	JOME	Diesel
BTE(%)	27.4	28.1	28.7	29.0	30.3
EGT(°C)	428	410	412	415	402
SL(BSU)	4.4	4.1	3.4	4.0	3.8
HC(ppm)	130	110	150	110	100
NO(order)	3	4	5	2	1

BTE: brake thermal efficiency, EGT: exhaust gas temperature
SL: smoke level, BSU:Bosch smoke unit

6. Preheating

The effect of preheating of neat JO and a blend of equal volume of JO and the diesel fuel on diesel engine performance was investigated by Forson et al. [22]. However, the effect of preheating on the performance and exhaust emissions on a diesel engine was not precisely explained, To evaluate the performance of CI engine with preheated JO, Agarwal and Agarwal [24] carried out the experiment on the measurement of viscosity of JO at different temperatures in the range of 40-100. The application of waste heat of the exhaust gases for preheating JO is adequate to bring down the viscosity in close range to diesel fuel. BSFC and exhaust gas temperatures for preheated JO was found to be lower compared to neat jatropha oil. Thermal efficiency was higher for heated jatropha oil compared to neat jatropha oil. CO_2, CO, HC and smoke opacity for preheated jatropha oil were found to be close to diesel fuel. They concluded that heating the JO can be used in CI engines in rural areas for agriculture, irrigation and electricity generation.

According to the experimental results by Prasad et al.[28], smoke levels were found to be higher with preheating of the inedible vegetable oils compared with diesel operation. In addition, preheating results in improved energy efficiency and higher NOx emissions with inedible vegetable oils in comparison with diesel fuel.

7. Discussion and summary

For the production of JO biodiesel, further research on some advanced methods such as supercritical methanol or ethanol, hydroprocessing, in situ alkaline transesterification and microwave method etc. is required.

There exists a big difference in the fuel properties of Jatropha oil between the literatures considered in this study. It may be due to the different climate with the production site of them. Even though the widely different fuel properties of JO biodiesel are reported, most of them are within the American standards.

The application of jatropha oil to CI engine as alternative fuel can be classified as neat JO, fuel modification such as JO blends with diesel fuel, JO biodiesel, JO biodiesel blends with diesel, degummed JO, and engine modification such as preheating and dual fuelling. It should be noted that most of these applications are limited to the single cylinder condition.

All the application methods of JO as a substitute for CI engine give the lower brake thermal efficiency and higher specific fuel consumption compared to diesel fuel operation. It can be found that JO biodiesel and its blends with diesel fuel generally lead to an increase in NOx emission and a decrease in HC,CO, and PM emissions compared to those of diesel fuel. In dual fuel operation with JO in diesel engine, HC,CO and NOx emissions are higher and smoke level is lower than those of dual fuel operation with diesel.

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