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Combustion Characteristics of Inedible Vegetable Oil Biodiesel Fuels

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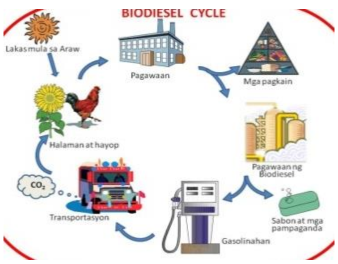
Graphical abstract



Abstract

Energy crisis and environmental issues related to fossil fuel consumption have emerged as a concern for scientific societies. Biodiesel has been introduced as an acceptable source of energy to substitute fossil fuels. In general, vegetable oils and their derivatives known as biodiesel have been applied successfully in energy generation purposes. Technically, biodiesel provides some advantages in terms of pollutant formation and power generation in comparison with conventional diesel fuel. In addition to being an indigenous and renewable supply, biodiesel reduces toxic emissions, and majority of engine performance and fuel consumption are comparable with the use of conventional fuels. In this paper various aspects of inedible oil utilization in engine and energy generation is studied. Economy, combustion characteristics and pollution formation of some inedible oil namely Jatropha, Karanja, Jojoba, Cottonseed, Mahua Oil and Rice bran Oil are investigated.

Keywords: Biodiesel; jatropha; cottonseed; jojoba; karanja; mahua; rice bran oil

1.0 INTRODUCTION

Application of vegetable oils for diesel engines is as old as the diesel engine itself. Rudolf Diesel is the diesel engine inventor and has been reportedly using peanut oil as fuel for the engine demonstration purposes in 1900[1]. Nowadays, the energy crisis and fossil fuel prices are among the most important topics particularly in view of the fact that petroleum is close to depletion[2]. Thus scientific and engineering communities are motivated to discover an alternative energy sources[3]. One of these sources is biofuel which can be derived from particular seeds oil. Since the combustion characteristics of the vegetable oil are similar to the petroleum, vegetable oils can be administered as an immediate candidate for replacing fossil fuels[4]. Therefore researchers have begun to demonstrate a renewed interest in vegetable oils, because of potential advantages as a fuel. Vegetable oils are environmentally friendly and renewable in nature and at the same time, which can be easily produced in rural areas[5]. There are two types of vegetable oils: edible or non-edible. Sunflower oil, palm oil, rice bran oil and cotton seed are some of the edible oils and Mahua oil, Jatropha oil, rubber seed oil are non-edible oils. Rice bran oil and cotton seed oil (CSO) are not widely used for cooking, which are used as substitutes for diesel ignition. Cottonseed oil has many properties closer to diesel, but certain features, such as high viscosity and low volatility creates problems when used as an alternative fuel for diesel engines[6]. This paper aims to investigate the properties of some inedible oils such as Jatropha oil, Karanja oil, Jojoba oil, Cottonseed oil, Mahua oil and Rice bran oil in terms of combustion characteristics and pollutant formation.

2.0 INEDIBLE OILS

2.1 Jatropha

Jatropha is an inedible plant that is used for production of bio energy[7]. As a fuel, Jatropha oil reduces the CO_2 emission by 80% without SO_2 production. Jatropha oil can be produced by both homogeneous and heterogeneous method[8]. Jatropha plants grow in tropical areas but originally come from Central America[9].To reduce the viscosity of the crude Jatropha oil, it is blended with diesel fuel. Another method of reducing the viscosity of Jatropha is to make a micro emulsion. Pyrolysis is another method of converting the Jatropha crude oil into biodiesel with heat or catalyst. Alcohol is a material which is widely used in the field of biofuel production. Triglyceride also presents in the reaction along with the catalyst to form esters[10]. Sahoo and Das[11] blended mono esterified filtered Jatropha, karanja and Polanga oils with diesel to produce a useful fuel for diesel engine. A 6 kW diesel engine is used. The peak pressure, time of occurrence of peak pressure and heat release rate is measured. The utilized diesel was 100% neat while the biofuel used are 20%, 50% and 100% volume blended. The maximum pressure from 77 to 84 bars is achieved for Jatropha oil concentration from 20% to 100%. Agarwal and Dhal[12] experimented performance of Jatropha blends in non-preheated condition in a DI-CI engine at 1500 rpm.The engine was tested in 200 bar fuel injection pressure with Jatropha concentration of 5%, to 100% (%v/v) with diesel. The cylinder pressure was the same for different fuel blends. Jatropha oil blends are showing relatively earlier pressure rise compared to mineral diesel for higher engine loads. For low loads, blends show higher peak pressure but at high engine loads, diesel gives higher peak pressure. For 80 and 100 percent rated load, 5% Jatropha blend shows slightly higher peak pressure compared to mineral diesel. The rate of pressure rise is slower for vegetable oil blends because of slower burning characteristics. Agarwal and Gangwar[13] studied the effect of reducing the viscosity and poor volatility of Jatropha oil by blending it with mineral diesel in transportation indirect injection diesel engine. An analysis of pressure rise, instantaneous and cumulative heat release was done. Jatropha blends of 5 to 50% by volume in a diesel engine were tested. Jatropha oil blends (50% and 20%) showed higher peak pressure than other blends. Peak cylinder pressure showed a direct relation with the amount of Jatropha oil in blend. The premixed combustion phase for all Jatropha oil blends shift towards top dead centre (TDC) and magnitude of premixed combustion phase for all fuel blends decreases with engine load increases, cause of pre-combustion chamber in indirect injection (IDI) engines. Sundaresan[14] studied the methyl ester of Jatropha oil (MEJ) in a single cylinder engine.The oil was blended 25 to 100% with diesel volume based. Rate of heat release, cumulative heat release and pressure were measured. The blends of MEJ and diesel showed in lower peak pressure compared to mineral fuel. The blends of MEJ and diesel have higher viscosity and lower fickleness. It may result in poor mixture formation and atomization. Pandey and Nandgaonkar[15] applied a 780 hp CIDI military engine to test diesel, Jatropha oil methyl ester (JOME) and karanja oil methyl ester (KOME) as fuel.They measured the power output, specific fuel consumption and heat release rates. A 12 cylinder, four stroke diesel engine with variable speed and equipped with a supercharger is used in the experiment. The brake specific fuel consumption (BSFC) with mineral fuel was lower than esters because of the decrease in heat value of esters. The BSFC values for mineral fuel, JOME and KOME at full load were 226, 231 and 234 g/kW-h respectively. The BSFC for KOME was higher as compared to JOME as the relative density of KOME is lower than that of JOME, and hence larger volume of KOME fuel is injected. It was concluded that JOME gave better soot free combustion (SFC) rather than KOME, but both ester fuels performed poorer than diesel. Chauhan[16] studied Jatropha oil on an agricultural engine and showed that the BSFC with Jatropha was more than mineral fuel. BSFC of Jatropha oil showed better result rather than mineral fuel. One possible reason could be the mixed effects of the relative fuel density, viscosity, and heating value. Ganapathy[17] studied the effect of injection timing, load torque and engine speed on a Jatropha biodiesel engine. BSFC, brake thermal efficiency (BTE), maximum cylinder pressure and maximum heat release rate were measured in this investigation. It was found that changing the injection timing could be effective in BSFC reduction and BTE augmentation.The results show that the BSFC increases as the injection timing is developed or retarded, using diesel as fuel. A rise In BSFC is observed at different load and speed.

2.2 Karanja

Karanja oil is obtained from seeds of Millettiapinnata tree that grows mostly in tropic countries like Malaysia, India and Indonesia[18]. The raw and processed oil is used as substitute for mineral fuel. Karanja oil is yielded about 200 metric ton. About 6% is used for biodiesel production[19]. Karanja oil is produced by the method of esterification. Alkaline and acid catalysts are used in this field[20]. The viscosity of the karanja oil is reduced by the methods of esterification, micro emulsion and pyrolysis[21]. Combustion characteristics of preheated Honge (Karanja) oil mixtures as fuel for an agricultural engine was investigated by Agarwal and Rajamanoharan[22]. The concentrations of Karanja oil were10 to 75 (% v/v) diesels. They investigated the relation between the temperature and viscosity of Honge oil. Thermal properties of Honge oil and its blends were compared with mineral fuel. These properties include density, viscosity, flash point, fire point and calorific values. It was stipulated that preheated fuels, reduces the viscosity and increases the volatility. BSFC for unheated Honge oil mixtures to 50 percent is less than mineral fuel. The main reason is the effect of the fuel density, viscosity and lower HV. BSFC is a good factor to compare the engine performance of fuels with different calorific values. They reported the BSFC of all Honge oil mixtures to be lower than that of diesel. Combustion properties of karanja oil and diesel and liquefied petroleum gas (LPG) fuel in an agricultural engine was experimented by Nazar[23]. At any given LPG share there is a considerable difference between low and high load conditions. The lean mixtures at low loads lead to poor combustion of the LPG air mixture. The larger equivalence ratios at high outputs lead to rapid combustion and knock. At full load the peak pressure increases with increase in the amount of LPG inducted. The combustion of the entrained LPG along with the pilot fuel at high loads is the reason for the high combustion rate particularly at the beginning of the combustion process. At loads below 100 % the induction of LPG reduces the initial combustion rate and lowers the peak pressure.

The reduced pilot quantity and lean LPG air mixtures are the reasons for the reduced peak pressure and rate of pressure rise at low loads. At 100% load the maximum rate of pressure rise soars to very high values indicating rough combustion.The results indicate that there was a significant difference between the neat Karanja oil mode and the Karanja oil–LPG mode. A sharp rise in the initial heat release, which is due to the combustion of the accumulated pilot and the entrained LPG, is seen at high outputs. This is the reason for the high NO, peak pressure and maximum rate of pressure rise. At low loads and low gas substitutions the initial combustion rate is not as sharp as the entrained LPG is less. Combustion of KOME in a DI diesel engine with the concentration of 20% to 80% was investigated by Kumar and Das[24]. The Honge oil is first converted to methyl ester by transesterification process. They got to the viscosity of IS 1448 at 15^0.The ignition time is extended and maximum gas pressure is decreased as the KOME is added to the diesel fuel. They reported the same max pressure for B20 and mineral fuel.They suggested that diesel fuel and KOME blend of 40% can be a suitable substitute for diesel fuel. Pandey and Nandgaonkar[25]experimented a military engine fueled with KOME and compared its performance to the diesel.They showed that the performance of biodiesel could be near diesel however the fuel consumption is higher but produces fewer emissions and slightly more NO_x. A 12 cylinders, 4 stroke and variable speed DI engine was used in this study. The engine was left to get to steady state condition after 10 minutes. The results indicate that BSFC of KOME is approximately 3.53% more than that of mineral fuel. The relative viscosity of biodiesel is more than 10% higher than mineral fuel. The result is in agreement with the results that other researchers achieved.

2.3 Jojoba

Jojoba is a name that is usually the extent of industrial crops in some countries. Currently, farmers do this dark and deserted bush in the United States America, South Africa, Latin America, and many other countries. In recent years, jojoba oil has become one of the Egyptians actual products. Jojoba oil properties are differing basically from other typical vegetable oils. Its chemical structure is linear long chain esters, and other common vegetable oilsare triglycerides. Conventional seed oil production glyceride, in Fatty acids, which are attached to a glycerol molecule. It is consists of fatty acids with fatty alcohols direct connection. No other plant is known for the production of this type of fluid. Jojoba oil especially its derivatives is widely used in cosmetics, pharmaceuticals and lubricants[26,27]. Radwan[28] applied shock-tube test that it was instrument for measurement of delay with two piezo-electric pressure transducers, electronic plotter, charge amplifiers and storage oscilloscope for Jojoba oil.In their studied the Jojoba methyl ester was mixed with methanol and gas oil at different mixing rate of 20, 40, 60, and 80%. Results show that increasing the temperature of ignition and ignition pressure reducing delay of ignition period of JME and its mixtures with methanol and gas oil. Indeed, Radwan[29] studied using a Ricardo E6/MS variable compression ratio spark ignition engine for Jojoba oil. A Ricardo E6/MS is an engine with a single cylinder, variable compression ratio, four-stroke, spark-ignition engine with a disc-type combustion chamber with a stroke of 110 mm and a bore of 76 mm. They expected the earlier times leads to a decrease in knock resistance due to increased use of gas desired final temperature. Results demonstrate that turbo diesel, with higher inlet pressure and temperature works with a higher resistance to detonation and pre-ignition with jojoba bio-fuel with gasoline. Sundaresan[30] investigated experimentally the applied potential of JME oil in the basis of combustion in a constant speed single cylinder, vertical, water-cooled, ambient diesel engine 8 hp @ 1500 rpm to provide diesel engine. For experimental purpose they prepared Methyl Esters of Jojoba with mixtures, 25, 50, 75, and 100, respectively by vol. After the beginning of 27° advanced before top dead center (BTDC) injection duration of the pressure drop in the curve of the combustion pressure obtained compared to the motoring curve. Result showed that The mixtures MEJ diesel are lower than diesel and can be due to the slow combustion of the mixture, due to the high viscosity, low volatility. Selim[31] used Ricardo E6 compression diesel was fully equipped with instrumentation to measure the pressure of combustion and the growth rate for Jojoba oil. The engine speed varied 1000-2000rpm, and engine load varies from 0.5 to 21 Nm. Test parameters were the percentage of the JME in a mixture, injection timing, speed, load, and compression rate. The result showed that the JME fuel produced proved to be a good standby for diesel fuel.

2.4 Cottonseed

Cotton is both a fiber (cotton lint) crop and a food (cottonseed oil). Plant produces about 150 kg of cottonseed for each 100 kg of cotton fiber produced. Seed's production which varies directly with the production of cotton fiber is dominated by cotton fiber production factors. Cotton seed oil, original vegetable oil from America, dominates the USA vegetable oil market foralmost 100 years. The European and English vegetable oil industry was based on several fruit trees and oilseeds in their countries and colonies. But cottonseed was the main raw material for processors of vegetable oil in the United States until the mid-20th century. In just 50 years of research and experimentation have a chemical smell, taste light, creamy and delicate develops, cotton, white fat to define standards for fats and oils in the world. The developments of scientific and technological progress for the processing of cottonseed oil werepillarsof fats and oils industry, asitis known today. A number of methods have been developed especially for cottonseed oil, which is then used for other oils. Today, vegetable oil processors in the world, including the USA, have a wide range of products to choose from, but one of the pioneers of American cotton seed and vegetable oil[32]. Rakopoulos[33] evaluated the combustion characteristics of cotton seeds oil and biodiesel methyl ester of 20% by vol. of n-butanol or diethyl ether, fueling the standard, experimental, cylinder, high-speed direct injection, four-stroke, 'Hydra' diesel[33]. The tests were conducted in each fuel blends or pure cotton seed or pure oil bio-diesel with engine operating at three different loads. Result indicated that use of these mixtures in comparison with the corresponding cottonseed or pure biodiesel is referred to the injection pressure diagrams were delayed, ignition delays increase, and maximum cylinder pressures decrease. Daho[34] investigated the combustion of mixtures of domestic fuel–oil in Burkina Faso. For this test a special burner and an electric motor which drives both the combustion air fan and the fuel pump was applied. The volumetric nozzle and pump produce a spray in theair flow brought by the fan. Experimental results depict that mixture containing 30% cottonseed oil and 70% distilled fuel oil relative to the engine, depending on the chemical mechanism. Rakopoulos[35] studied the effect of pure cottonseed oil in direct injection, high speed; diesel engine at the authors' laboratory. The combustion chamber and the diagrams of injection pressure developed medium and high load, obtain the acquisition system and high-speed processing. The experimental heat release analyses obtain cylinder pressure diagrams is developed and used. The thermal analysis result, combined with of the most diverse physical and chemical properties of biofuels, which are used to support clean diesel with the correct interpretation of the observed behavior of the engine power. In the other experiment Rakopoulos[36] analyzed the effects of cottonseed oil utilization on combustion behavior of a fully instrumented, six-cylinder, heavy-duty, turbocharged and intercooled, direct injection of "Mercedes-Benz" diesel engine. Fuel in the combustion chamber and the pressure of injection cartridges are available in two speeds and three loads at speeds of 1200 and 1500 rpm. The analysis results fuel injection pressure regime virtually unchanged, and the ignition delay was essentially the same. Indeed, experimental evaluation of thecombustion characteristicsof cottonseed oil on a fueling a standard, high-speed direct injection, single-cylinder, four-stroke diesel engine was done by Rakopoulos[37]. The tests were performed in each of these fuel mixtures or pure cottonseed oil or bio-diesel, with the engine runs at three different loads. Fuel consumption and total unburned hydrocarbons were measured. The differences in the performance of the fuel compositions of the operating baseline of the diesel engine compared to the work of cottonseed oil or its neat biodiesel.

2.5 Mahua Oil

Mahua is a large and tall tree abundant in India, which is from family of Sapotaceae, and one Mahua tree can grow up enough to have the height of over 20 meters. This type of trees has slow growing, as at the end of fourth year their average height is about 0.9 to 1.2 m. There is a spread of different types of Mahua tree all over the Indian sub-continent including India and Bangladesh, Mahua is valuable socially and economically and can be planted beside the roads, pavements and river banks in commercial scale. The drying yield 70% kernel on the weight of seed, oil comprise 50% of kernel of the seed, this oil has a yellow color in proper condition. Conventionally Mahua oil has been used in the soap industry in the small scale; also it can be used for production of moisturizer ointment to use in winter to prevent skin to crack. It is used for edible cooking oil for hair, lighting, lights, shiny and keeps the body warm. Mahua oil has similar properties as biodiesel specifications of different countries, such that these properties are comparable with conventional diesel the calorific value of Mahua blends are about 96.3% of diesel on a volume basis, this oil derivation can be easily substituted with diesel without any change in the engine, brakes and power and brake thermal efficiency will be almost identical to fossil diesel. All Mahua oils were shown to have the same thermal efficiency and 30% Mahua oil blend is found to have the ability to be the most thermally efficient[38]. For Mahua it was shown that energy consuming is similar to diesel fuel consumption at full load, and thermal efficiency diesel[39]. Kumar and Khare[40] utilized consumption of macro-emulsion of plants oil in engines to replace conventional diesel fuel as an alternative.These vegetable oils are non-edible including the macro-emulsion of Mahua and linseed oil while alcohol and neat diesel in composition with these vegetable oils have varying proportion, it can be seen that at low loads, macro-emulsion of Mahua oils tends to have by far more Brake Specific Energy Consumption (BSEC) in comparison with another case of study, namely macro-emulsion of linseed oil. There is a small difference in BSEC for different macro-emulsion, by growing alcohol concentration BSEC goes up, by increasing load the thermal efficiency increase and power output increases too, because during the complete combustion at higher loads, efficiency is higher. Moreover, it was found out that in general Mahua oil based blend has lower efficiency than linseed oil based fuel that this concluded methanol based macro-emulsions have higher efficiency than the ethanol based macro-emulsions, linseed oil blend has more smoke density than Mahua oil blend. It was stipulated that the macro emulsion of Mahua and another mentioned vegetable oil with 10 % concentration of alcohol gave satisfactory performance and there was not any knocks or noise during running the engine, so Mahua blends can substitute mineral diesel. An investigation was carried out by Godiganur to identify the emission characteristic and performance of Mahua Oil Methyl Ester (MOME) and its mixtures in turbo-charged engine and compare this blend with data of diesel fuel, by increasing the amount of B100 in composition with diesel[41]. The amount of the BSFC increases generally on weight basis at higher densities BSFC grows up, also the higher densities of Mahua mixture posed larger injection of mass at the identical injection pressure for the identical volume. It was concluded that the calorific value of biodiesel is less than diesel. The BSEC drops dramatically by increasing the percentage load for any fuel. In a recent study Mahua oil was transesterificated by using sulfuric acid as catalyst to produce Mahua oil ethyl ester (MOEE) and then the blend was tested in a 4-stroke direct injection natural aspirated diesel engine. The maximum thermal efficiency of diesel was achieved 26.36%, while for MOEE it was achieved 26.42% at 5.481 BMEP[42]. Bora, Das and Babu[43] investigated fuel properties of MOME and its mixtures with diesel blends from about 20% till about 80% per volume.At higher loads it is probable to reach to lower thermal efficiency, building up the amount of biodiesel in mixture increases BSFC and decreases brake thermal efficiency. It was shown that the injection opening pressure (IOP) of 200 bar leads to higher break thermal efficiency (BTE) in comparison with other IOPs except at 25% load. It can be seen that BTE of the biodiesel operated engine increases at higher injection pressure, at 25% load, the IOP of 180 bar leads to higher BTE and for MOB the BTE of the engine is slightly smaller than the diesel, this is caused by marginally larger viscosity and smaller volatility of the MOB[44].

2.6 Rice Bran Oil

Rice husk is the shell and skin of the rice seed that three-fourth of it is comprised with oil and rice bran has just 8% paddy weight. The three largest producers of rice are China, India and Indonesia. Rice husk oil has medical applications and also used as food for animals crude rice husk oil has free fatty acids including about 82% Triglycerids, 2.5% Diglycerides, 5.5% Monoglycerides, 2.5% free fatty acids, 0.3 % waxes, 0.8% glycolipids, 1.6% phospholipids. Rice bran oil and its blends can be used to produce biodiesel. This fuel can be substituted with mineral diesel, and there is not any need for modification in engine to consume this biodiesel. Anandram, Karthik and Ramakrishnan[45] have studied the feasibility of rice bran oil to apply for CI engine in its original and in its refined form, by increasing in load. It was shown that for all fuels there is an increase in performance, because when load and power increase there will be a reduction in heat loss, the thermal efficiency of an engine and its specific fuel consumption are inversely proportional, the specific fuel consumption were slightly higher than that of diesel fuel. By exerting all the loads thermal efficiency of the rice bran oil is lower than that of diesel.
Sinha and Agarwal[46] studied the application of rice bran oil non-edible grade in a direct injection diesel engine operating with diesel, rice-husk oil methyl ester and its mixtures and investigated the properties of combustion for these fuels. It was reported that engine creates slightly less power for more concentration of biodiesel in diesel that can be due to that biodiesel has smaller calorific value, BSFC for B05, B10 and B20 is lower in comparison with conventional diesel. When concentration of level biodiesel in the blends increases the BSFC is increased consequently. It was shown that for all blends of biodiesel efficiency curves follow conventional diesel curves; a decrease in thermal efficiency is caused by comparatively bigger viscosity of B100 that influences the chamber of spray combustion. Nagaraj[47]have studied the fuel properties of rice bran oil methyl ester for CI engine upon different operating condition.It was observed that the biodiesel blends with lower levels of concentration have a higher thermal efficiency in comparison with conventional diesel. Complete combustion can be result of the existence of oxygen in rice bran oil methyl ester compound. It was shown that maximum improvement in thermal efficiency belonged to rice bran oil blend with concentration of 20 percent. Sinha and Agarwal[48] studied the fuel properties of rice bran oil blends in a direct injection transportation diesel engine.It was illustrated that by increasing of engine load for B20 the amount of peak pressure increases and burning of fuel begins earlier compared to conventional diesel. Besides, for B20 maximumpressure and rate of pressure increase are higher at lower loads of engine whereas it gets lower by an increase in load. It was presented that peak pressure takes place ranging between 2 to 7 crank angle degrees for both bio diesel and mineral diesel, for B20 maximum pressure occurs later which shows that pressure rate rise is smaller at bigger loads for B20. For both diesel and bio diesel combustion duration increases by increasing the engine load that this is due to an increment in the level of fuel injected. Both fuels sustain quick premixed combustion caused by diffusion combustion as are typically of natural aspirated engines.

3.0 CONCLUSION

Because fuel emissions of pollutants increase in global energy demand and competition edible oil sources for human consumption and for biofuels production, the non-edible oils have become the leading raw material for obtaining biodiesel. Mixing fuel from vegetable oils include changes petro-diesel and other fuels, thermal cracking, hydro deoxygenation and transesterification to decrease viscosity. This study involves vegetable oil mixed with conventional transesterification and discussion. Preheating fuel line and a dual delivery system for changing the injection and so on belong to modify the engine. Much of the research showed that 20% biodiesel with diesel showed better performance. The use of Jatropha oil to the engine with the ignition key as an alternative fuel may be categorized as Jojoba oil order, change of fuel such as Jojoba oil mixtures with diesel fuel, degumming Jojoba oil, JO biodiesel, JO biodiesel mixtures with diesel, and modification of engine such as dual fuelling and preheating. The application is necessary and infantile state areas limited to single cylinder. All methods of JO use as a substitute for inflammation CI engine give higher specific fuel consumption and lower brake thermal efficiency compared to diesel operation.

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References

[1] Nitske, W. R., Wilson, C. M. Rudolf . 1965. Diesel: Pioneer of the Age of Power. University of Oklahoma Press. 139.

[2] Hosseini, S. E., Andwari, A. M., Wahid, M. A., and Bagheri, G. 2013. A Review on Green Energy Potentials in Iran. *Renewable and Sustainable Energy Reviews*. 27: 533–545.

[3] Hosseini, Seyed Ehsan, and Mazlan Abdul Wahid. 2013. Feasibility Study of Biogas Production and Utilization as a Source of Renewable Energy in Malaysia. *Renewable and Sustainable Energy Reviews*. 19: 454–462.

[4] Hosseini, Seyed Ehsan, Mazlan Abdul Wahid, Saber Salehirad, and Mohsin M. Seis. 2013. Evaluation of Palm Oil Combustion Characteristics by Using the Chemical Equilibrium with Application (CEA) Software. *Applied Mechanics and Materials*. 388: 268–272.

[5] Hosseini, Seyed Ehsan, and Mazlan Abdul Wahid. 2012. Necessity of Biodiesel Utilization as A Source of Renewable Energy in Malaysia. *Renewable and Sustainable Energy Reviews*. 16(8): 5732–5740.

[6] Rakopoulos, D. C. 2012. Heat Release Analysis of Combustion In Heavy-duty Turbocharged Diesel Engine Operating on Blends of Diesel Fuel with Cottonseed or Sunflower Oils and Their Bio-diesel. *Fuel*. 96: 524–534.

[7] Yee, K. F., Wu, J. C. S., and Lee, K. T. 2011. A Green Catalyst for Biodiesel Production from Jatropha Oil: Optimization Study. Biomass and Bioenergy. 35: 1739–1746.

[8] Nahar, K., & Ozores, M. 2005. Jatropha: An Alternative Substitute to Fossil Fuel IFAS Extension: University of Florida.

[9] Openshaw, K. 2000. A Review of Jatrophacurcas L.: An Oil Plant of Unfulfilled Promise. *Biomass Bioenergy*. 19: 1–15.

[10] Koh, M. Y., & Ghazi, T. I. M. 2011. A review of Biodiesel Production from Jatrophacurcas L. oil. *Renewable and Sustainable Energy Reviews*. 15: 2240–2251.

[11] Sahoo, P. K., Das. L. K. 2009. Combustion analysis of Jatropha, Karanja and Polanga Based Biodiesel as Fuel in a Diesel Engine. *Fuel*. 88: 994–999.

[12] Agarwal, A. K. Dhar. A. 2009. Performance, Emission and Combustion Characteristics of Jatropha Oil Blends in a Direct Injection CI Engine. *SAE International*. 01.1-12.

[13] H. K. Gangwar and A. K. Agarwal. 2008. Combustion Characteristics of Jatropha Oil Blends in a Transportation Engine. *SAE International Journal*. 1383: 1–11.

[14] Sundaresan M, Chandrasekaran S, Poral PT. 2007. Analysis of Combustion, Performance and Emission Characteristics of Blends of Methyl Esters of Jatropha Oil (MEJ) in DI Diesel Engine. SAE paper 2007-32-0066.

[15] A. K. Pandey, M. R. Nandgaonkar. Comparison and Evaluation of Performance,Combustion and Emissions of Diesel, Jatropha and Karanja Oil Methyl Ester Biodiesel in a Military 780 hp CIDI Engine. SAE paper 2010-01-2138.

[16] B. S. Chauhan, N. Kumar and H. M. Cho. 2009. Performance and Emission Studies on an Agriculture Engine on Neat Jatropha Oil. *Journal of Mechanical Science and Technology*. 24(2): 529–535.

[17] Ghadge S, Raheman. 2005. Biodiesel Production from Mahua (Madhucaindica) Oil Having High Free Fatty Acids. *Biomass & Bioenergy*. 28: 601–5.

[18] Duke, A. 1985. Handbook of Energy Crops. Unpublished. Available at: www.hort.purdue.edu.

[19] L. C, M. N., Meherb, S. N., &Naikb, L. M. D. 2008. Production of Biodiesel from High Free Fatty Acid Karanja (Pongamiapinnata) Oil. *Biomass and Bioenergy*. 32: 354–357.

[20] Freedman, B., Pryde, E. H. 1982. Fatty Esters From Vegetable Oils for the Use as a Diesel Fuel. In: Fargo ND, editor. Vegetable oils Fuels. Proceedings of the International Conference On Plant And Vegetable Oils as Fuels, St. Joseph, MI: ASAE. 117–22.

[21] Das, L. M., Bora, D. K., Pradhan, S., Naik, M. K., &Naik, S. N. 2009. Long-term Storage Stability of Biodiesel Produced from Karanja Oil. *Fuel*. 88: 2315–2318.

[22] Agarwal, A. K. Rajamanoharan. K. 2009. Experimental Investigations of Performance and Emissions of Karanja Oil and Its Blends in a Single Cylinder Agricultural Diesel Engine. *Applied Energy*. 86–112.

[23] Agarwal, A. K. Rajamanoharan. K. 2009. Experimental Investigations of Performance and Emissions of Karanja Oil and Its Blends in a Single Cylinder Agricultural Diesel Engine. *Applied Energy*. 86–112.

[24] Kumar, C., Babu, MKG, Das, L. M. 2006. Experimental Investigations on a Karanja Oil Methyl Ester Fueled DI Diesel Engine. SAE paper 2006-01-0238.

[25] A. K. Pandey, M. R. Nandgaonkar. Investigation of Esterified Karanja Oil Biodiesel Fuel For Military Use on a 38.8L Diesel Engine. SAE paper 2009-01-2806.

[26] A. S. Huzayyin, A. H. Bawady, M. A. Rady, A. Dawood. 2004. Experimental Evaluation of Diesel Engine Performance and Emission Using Blends of Jojoba Oil and Diesel Fuel. *Energy Conversion and Management*. 45: 2093–2112.

[27] M. Y. E. Selim, M. S. Radwan, H. E. Saleh. 2007. On the Use of Jojoba Methyl Ester as Pilot Fuel for Dual Fuel Engine Running on Gaseous Fuels. *SAE International*. 2007-24-0121.

[28] M. S. Radwan, S. K. Dandoush, M. Y. E. Selim, and A. M. A. Kader. 1997. Ignition Delay Period of Jojoba Diesel Engine Fuel. *SAE International*.

[29] M. S. Radwan, Soliman M S Elfeky and Osayed Sayed Mohamed Abu-Elyazeed. 2012. An Investigation on Abnormal Combustion, Emissions and Performance of Novel Jojoba Bio- Gasoline and Its Blends with Gasoline in a Spark- Ignition Engine. *SAE International*. 2012-01-1599.

[30] M. Sundaresan, S.Chandrasekaran, P. Tamil Porai. 2007. Analysis of Combustion, Performance and Emission Characteristics of Blends of Methyl Esters of Jatropha Oil (MEJ) in DI Diesel Engine. *SAE International*. 2007-32-0066.

[31] M. Y. E. Selim, M. S. Radwan, S. M. S. Elfeky. 2003. Combustion of Jojoba Methyl Ester in an Indirect Injection Diesel Engine. *Renewable Energy*. 28: 1401–1420.

[32] R. D. O'Brien, L. A. Jones, C. C. King, P. J. Wakelyn, and P. J. Wan. *Oil and Fat Products*. 1: 173.

[33] D. C. Rakopoulos. 2012. Combustion and Emissions of Cottonseed Oil and Its Bio-diesel in Blends with Either n-butanolor diethyl ether in HSDI Diesel Engine. *Fuel*.

[34] T. Daho, G. Vaitilingom, O. Sanogo. 2009. Optimization of the Combustion of Blends of Domestic Fuel Oil and Cottonseed Oil in a Non-modified Domestic Boiler. *Fuel*. 88 1261–1268.

[35] C. D. Rakopoulos, D. C. Rakopoulos, E. G. Giakoumis, A. M. Dimaratos. 2010. Investigation of the combustion of neat cottonseed oil or its neat bio-diesel in a HSDI diesel engine by experimental heat release and statistical analyses. *Fuel*. 89: 3814–3826.

[36] D. C. Rakopoulos. 2012. Heat Release Analysis of Combustion in Heavy-duty Turbocharged Diesel Engine Operating on Blends of Diesel Fuel with Cottonseed or Sunflower Oils and Their Bio-diesel. *Fuel*. 96: 524–534.

[37] D.C. Rakopoulos." Combustion and emissions of cottonseed oil and its bio-diesel in blends with either n-butanol or diethyl ether in HSDI diesel engine", Fuel (2012).

[38] D. Agarwal, L. Kumar, and A. K. Agarwal. 2008. Performance Evaluation of a Vegetable Oil Fuelled Compression Ignition Engine. *Renewable Energy*. 33(6): 1147–1156.

[39] N. Saravanan, G. Nagarajan, and S. Puhan. 2010. Experimental Investigation on a DI Diesel Engine Fuelled with Madhuca Indica Ester and Diesel Blend. *Biomassand Bioenergy*. 34(6): 838–843.

[40] N. Kumar and U. Khare. 2004. Use of Macro-Emulsion of Vegetable Oil In Compression Ignition Engine. *SAE International*. 28: 0040.

[41] S. Godiganur, C. H. Suryanarayana Murthy, and R. P. Reddy. 2009. 6BTA 5.9 G2-1 Cummins Engine Performance and Emission Tests Using Methyl Ester Mahua (Madhucaindica) Oil/Diesel Blends. *Renewable Energy*. 34(10): 2172–2177.

[42] S. Puhan, N. Vedaraman, G. Sankaranarayanan, and B. V. B. Ram, 2005. Performance and Emission Study of Mahua Oil (madhucaindica oil) ethyl ester in a 4-stroke Natural Aspirated Direct Injection Diesel Engine. *Renewable Energy*. 30(8): 1269–1278.
[43] D. K. Bora, L. M. Das, and M. K. G. Babu. 2009. Experimental Evaluation of Mahua based Biodiesel as Supplementary Diesel Fuel. *SAE International.* 01: 0479.
[44] N. Kapilan, T. P. A. Babu, K. Janardhan, and R. P. Reddy. 2009. Effect of Injector Opening Pressure on Performance and Emission Characteristics of Mahua Oil Methyl Ester in a DI Diesel Engine. *SAE International.* 01: 2901.
[45] V. Anandram, J. Karthik, S. Ramakrishnan, S. Saravanan, and G. L. N. Rao. 2006. Effect of Refining Rice Bran Oil in its Performance and Emission Characteristics as a Fuel in D. I. Diesel Engine. *SAE International.* 01(724): 3366.
[46] S. Sinha and A. K. Agarwal. 2008. Ricebran Oil Biodiesel's Performance. Emission and Endurance Test on a CIDI Transport Engine. *SAE International*. 28: 0066.
[47] A. M. Nagaraja, G. P. Prabhukumar, and B. I. E. T. Davangere. 2004. Characterization and Optimization of Rice Bran Oilmethylester for CI Engines at Different Injection Pressures. *SAE International.* 28: 0048.