Experimental Study on the effect of Di-Ethyl Carbonate in Performance, Combustion and Emission Characteristics of CI Engine Fueled with Karanja Oil Blended

V Mathan Raj1, Chetan Bharadwaj, Yash Mandal, G Manikandaraja

Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur – 603203, Tamil Nadu, India

1Email: mathanrv@srmist.edu.in

Abstract: In today's world where the earth chokes on the pollution caused everyday by the human society the need for alternative means of fuels is now more than ever. We need to find alternative fuel sources as soon as possible as the health and environmental problems caused by the fossil fuels, we use on a daily basis now exceed the benefits provided by them. However, fuel sources which are clean in nature such as hydrogen have not been researched thoroughly enough for them to be implemented in practical use and power sources such as electric power though researched thoroughly and in current use cannot be implemented on a larger scale in such a short period of time. Hence biofuels i.e., fuels extracted from feed crops are our best chance to reduce the effect of pollution caused by fossil fuels. Vegetable oils are one such fuel source that can potentially replace the fossil fuels with none or minimal modifications to the existing engines. In this experimental study, performance, emission and combustion characteristics of Karanja oil blends (K-10, K-20, K-30) with mineral diesel and 5%DEC (Di-ethyl carbonate) additive were investigated in a CI engine at different engine loads and constant engine speed. Combustion analysis revealed that the combustion duration increased significantly even with smaller concentration of Karanja oil in the fuel blend.

Keywords: Alternative fuel, CI engine, Biofuels, Vegetable Oils, Emission.

1. Introduction

The current generation energy enthusiasts and researchers have resorted to various traits and techniques to find a potential alternative to the depleting fossil fuel resources which has been over exploited for many decades now. The drastic variations in the global climate are attributed to the CO2 emissions largely due to the combustion of these fossil fuels. The soaring prices of crude oil, climate change, scarcity of resources and global warming are all demeaning factors which may bring about a catastrophe in the energy sector in the near future. These factors have led to a large-scale innovative research on renewable energy options worldwide. Although numerous prospective energy options have been explored in a wide horizon of areas such as wind, solar, hydrogen and biomass, they have not come into prominent usage due to drawbacks such as financial constraints and shortages in supply.

In 1900 Rudolf Diesel, the inventor of CI engine suggested the usage of vegetable oils as an alternate fuel and experimentally demonstrated the proposal by using peanut oil. Straight vegetable oils (SVOs) such as soybean oil, sunflower oil and Non edible oils such as neem, mahua and tobacco seed oil have been tested several times on diesel engines earlier.[1] Conclusions from testing these oil-diesel blends showed satisfactory results relating to power output, thermal efficiency and lubricating oil data. [2-4] These studies also showed higher HC and CO emissions and lower NOX emissions with these oil diesel
blends while compared to that of mineral diesel. However, the engine showed deterioration in performance on continuous usage of these blends. The reasons cited during the study are injector coking, fuel filter plugging, ring sticking and formation of carbon deposits in combustion chamber and contamination of lubricating oils resulting primarily due to the high viscosities of these oils. These oils possess lower volatility, calorific value and cetane number compared to that of mineral diesel and also other disadvantageous properties such as reactivity of unsaturated hydrocarbon chains and the higher percentage of carbon residue. [5-8]. These problems can be overcome by subjecting the oil to dilution, micro-emulsification, pyrolysis and transesterification. On the contrary, the cost of edible and non-edible oils is on par with diesel itself therefore, apparently biodiesel production from these oils is not economically viable. Moreover, biodiesel conversion process requires various chemical and technological inputs that are inaccessible to rural areas. Hence blending serves to be a viable economical option. According to the Indian scenario, edible oils cannot be used as an alternative fuel source because it is an importer of vegetable oil. Non-edible oils like the one used in the study Karanja (Pongamia pinnata oil) can be used to serve this purpose. Pongamia pinnata is one of the nitrogen’s fixing trees, a species of the pea family and can be grown in large quantities on waste and non-cropped lands. These trees produce seed that contain 30 - 40% of oil. Adaptation of these oils as an alternative fuel source in India will lead to many advantages like support to farming and rural economy and reduction in dependence on imported crude oil. In this study blending process is adopted to lower the viscosity of Karanja oil. Experimental investigation aims to identify and analyze the properties of Karanja oil blends that affect the performance, emission and combustion characteristics of the CI engine and also checking its feasibility as an alternate fuel source by doing a comparative study with diesel.

2. Methodology

2.1 Preparation of blends

Several Operational difficulties, arises due to the direct application of plant oils are primarily due to their high viscosities. These problems can be overcome by subjecting the oil to dilution, micro-emulsification, pyrolysis and transesterification this study a viable cost-effective method blending is adapted to lower the viscosity of the Karanja oil. [19-21]. Six blends are prepared with diesel, Karanja oil and diethyl carbonate in varying volumetric proportions. The various blends and their constituents are as follows:

- K-10 With 10% Karanja oil and 90% diesel  
- K-20 With 20% Karanja oil and 80% diesel  
- K-30 With 30% Karanja oil and 70% diesel  
- K-10 5% DEC With 10% Karanja oil, 5% diethyl carbonate and 85% diesel  
- K-20 5% DEC With 20% Karanja oil, 5% diethyl carbonate and 75% diesel  
- K-30 5% DEC With 30% Karanja oil, 5% diethyl carbonate and 80% diesel.

The tests were conducted on single cylinder H.S. compression ignition Diesel engine. The setup consists of a Single Cylinder-four stroke Compression Ignition (CI) engine which is connected to eddy current dynamometer for the purpose of loading. Fuel to the engine was supplied from the fuel tank and air from the air chamber with an orifice plate coupled to the U tube manometer for measurement of the volume flow rate of air. Necessary instruments were provided for crank angle measurements and combustion pressure. The setup consists of a stand-alone panel comprising of air box, fuel measuring unit, transmitters for air, fuel tank, manometer, and fuel flow measurements, process indicator and engine indicator. A Thermocouple was used to measure the exhaust gas temperature in the exhaust gas pipe line. Calorimeter is used for water flow measurement and Rotameter is used for cooling water temperature. Emission parameters of NOx, CO, CO2 and HC were recorded using AVL gas bioanalyzer. The experimental setup allows us to calculate performance for brake power (BP),

indicated power (IP), brake thermal efficiency (BTE), indicated thermal efficiency (ITE) and specific fuel consumption (SFC).

To find variation in in-cylinder pressure with respect to crank angle we use a high-speed data acquisition system. The pressure signal from the pressure sensor is converted in a digital form while taking note of the transducer sensitivity and the charge amplifier setting during the experimentation. Transducers generally provide relative pressures; thus, it is necessary to determine the absolute pressure in the cycle, which can be taken as reference.

| No. of Cylinders | 1 |
|------------------|---|
| No. of Strokes   | 4 |
| Fuel             | H.S. Diesel |
| Rated Power      | 5.2KW @ 1500 RPM |
| Type of Load     | Electrical Load |
| Type of Dynamometer | Eddy Current Dynamometer |
| Cylinder Dia.    | 87.5mm |
| Stroke Length    | 110mm |
| Compression Ratio| 17.5:1 |
| Orifice Dia.     | 20mm |

A load cell is a transducer which converts a mechanical force into an electrical signal. A mechanical setup is provided which deforms the strain gauge due to the force produced. The strain gauge uses deformation as an electrical signal due to the resistance of the wire changes during deformation.

In our experimental study, a piezo sensor is used to record the fuel injection pressure. The piezo sensor is interconnected with a data acquisition system so that the pressure values are displayed on the computer screen. We require a high-speed data acquisition system to continuously get the pressure changes with respect to crank angle.

| Fatty Acid         | Molecular formula | Percentage | Structure                        |
|--------------------|-------------------|------------|---------------------------------|
| Palmitic acid      | C_{16}H_{32}O_{2} | 11.65 %    | CH_{3}(CH_{2})_{14}COOH         |
| Stearic acid       | C_{18}H_{36}O_{2} | 7.5 %      | CH_{3}(CH_{2})_{16}COOH         |
| Docosanoic acid    | C_{22}H_{40}O_{2} | 4.45 %     | CH_{3}(CH_{2})_{20}COOH         |
| Tetracosanoic acid | C_{24}H_{48}O_{2} | 1.09 %     | CH_{3}(CH_{2})_{22}COOH         |
| Oleic acid         | C_{18}H_{34}O_{2} | 51.59 %    | CH_{3}(CH_{2})_{16}(CH=CH) COOH |
| Linoleic acid      | C_{18}H_{36}O_{2} | 16.64 %    | CH_{3}(CH_{2})_{17}(CH=CH)_{2}COOH |
| Eicosanoid acid    | C_{20}H_{40}O_{2} | 1.35 %     | CH_{3}(CH_{2})_{20}COOH         |
| Residual           | ---               | 6.83 %     | ---                             |
3. Results and discussion

In this experimental study the performance, combustion and emission characteristics of Karanja oil blends (K-10, K-20, K-30 and K-10 5% DEC, K-20 5% DEC, K-30 5% DEC) when blended with mineral diesel in respective ratio were studied and experiments for the above-mentioned characteristics were conducted accordingly. The experiments were carried in unheated conditions on a direct injection CI engine at different engine load and a constant engine speed of 1500 RPM. The baseline data for mineral diesel was obtained by carrying out the experiments initially with mineral diesel as the fuel. To determine the above-mentioned baseline emission and performance of the engine the engine was run for a period of time with no load applied to above-mentioned results of the engine emissions, carbon monoxide (CO), hydrocarbon (HC), carbon dioxide (CO2), and oxides of nitrogen (NOx), at 200 bar injection pressure are shown in the respective graphs. The performance and combustion characteristics for all the blends are shown in the following graphs in comparison with mineral diesel as a fuel. A slight decrease in the emission characteristics can be observed when compared to mineral diesel. The decrease in these emissions can be attributed to the presence of oxygen in biodiesel leading to better utilization of fuel. [10,11] This reduction may be due to better combustion of fuel. Better emissions and performance characteristics.

3.1 Performance Characteristics

3.1.1 Brake Specific Fuel Consumption (BSFC):

The change in BSFC for the test fuels in comparison to mineral diesel is shown in Figure 2. The fuel consumption for each blend was measured by determining the volume of fuel used by the engine under the provided load conditions for working cycle of the engine. BSFC is determined by dividing TFC per hour by the power developed. This was done in order to determine how efficiently the engine can convert fuel into mechanical work. K-20 has the lowest BSFC for higher operating load condition of the fuel, while K-30 with 5%DEC shows a higher level at lower load. But at the higher load, it shows a drop in its level due to low oxygen content. K-20 has higher heating value than other fuels while K-10 and K-30 have the lowest. K-20 and K-30 show a minute value change at higher load conditions due to combined effect of calorific value and high oxygen content.
3.1.2 Brake Thermal Efficiency

The Figure 3 depicts the variation of brake thermal efficiency with respect to the load applied on the engine. The graph shows the rise in brake thermal efficiency with respect to load for all blends respectively, however at initial or lower loads the difference in BTE for all blends when compared to mineral diesel are almost negligible. K-20 blend rises high because of its higher calorific value and oxygen content than K-10 and K-30 blends but K-30 shows the highest value at the maximum load. BTE for K-30 is high at our maximum load, 36.8% while compared to diesel which is 33.9%. the higher calorific value of the blends is the major factor when determining the brake thermal efficiency of the engine when fueled with all the different blends.

3.2 Emission characteristics:

3.2.1 Carbon Monoxide:
Carbon monoxide is one of the most fatal gases known to mankind, it is the main cause of deaths by pollution in many highly populated countries. For this reason alone, we need to reduce the carbon monoxide emissions that are emitted from our engines as soon as possible. Carbon monoxide is known to be colorless, odorless and highly toxic in its elemental state. In this experiment we determine the Carbon Monoxide emissions from all the blends used experimentally with help of a gas analyzer fitted to the exhaust system of the experimental setup. The figure describes the changes in CO levels for all of the tested fuel blends with respect to the load applied to the test setup. It is observed that the change in Carbon Monoxide (CO) emissions for all blends and diesel is very small. This phenomenon can be
credited to the oxygen content present and C/H ratio present in the fuel blends that helps cause complete combustion. [12,15] However, from Figure 4 it is noted that the reduction on the Carbon Monoxide emissions does not depend on the oil percentage present within the fuel blends. 

![Figure 4. CO Emissions Vs Load](image)

3.2.2 Carbon Dioxide Emissions:

In this study it was observed that the CO₂ emissions were found to be lower when compared to mineral diesel as the higher viscosity of the fuel plays a major role in this property which causes poor atomization of the fuel resulting in the reduced CO₂ levels. It can also be noted that increases in the blending ratio leads to lower CO₂ emissions and higher viscosity of the fuels but also leads to a lowered calorific value of the fuel. From Figure 5 it is observed that K-20 5% DEC displays a lowered CO₂ level because higher viscosity even among other tested fuel blends. [17]

![Figure 5. CO₂ Emissions Vs Load](image)

3.2.3 Nitrogen Oxide Emissions:

When it comes to diesel engines and their emissions, nitrogen oxide or NOx emissions are one of the biggest concerns when it comes to environmental impact of the fuel concerned. Hence the oil blends used in our study were also subjected to analysis of nitrogen oxide emissions and the following
observations were made. The Figure 6 depicts the variation of nitrogen oxide with respect to the load applied on the engine. The following observations were made from the graph:

At part loads, diesel is emitting more NOx emissions than the KO blends. At maximum load, KO blends show increased NOx emissions than mineral diesel by 13%. This could be attributed to the higher temperatures developed in the combustion chamber when using KO blends. This is also evidenced by the higher exhaust gas temperature from the KO blend fueled engine. The addition of diethyl carbonate in the blends have resulted in reduction of NOx emission (30-33%), at all engine load operations. The additives used in this study poses an oxygen content that makes the combustion process much more uniform this causes the reduction of any sudden pressure changes within the combustion chamber hence providing cooling by process of heat transfer providing localized gas temperatures Leading to reduced NOx levels. Hence K-10, K-20, K-30 with 5% DEC additive show very low NOx.

![Figure 6. NOx Emissions Vs Load](image)

3.2.4. Hydrocarbon Emissions

Hydrocarbon emission is also an important parameter for examining the emission characteristics of the engine using these respective blends. From the Figure 7 following observations were made. The emission has been found to be 17%, 18%, 19% and 22% with K-10, K-20, K-30 and mineral diesel respectively at 50% load. K-20 and K-30 blends show lower HC emission as compared to mineral diesel up to 75% load. However, at maximum load, K-30 shows higher HC emission than diesel and K-20’s HC emissions are on par with diesel. This may be due to poor atomization of the KO blends resulting from their high viscosity. The additives used in this study poses an oxygen content that makes the combustion process much more uniform this causes the reduction of any sudden pressure changes within the combustion chamber hence providing cooling by process of heat transfer providing localized gas temperatures Leading to reduced NOx levels. Hence K-10, K-20 and K-30 with 5% DEC show very low HC.

![Figure 7. HC Emissions vs Load](image)
3.3. Combustion Characteristics:

It is seen that when no load is applied, in-cylinder pressure for all the blends is almost similar. However, when engine load is increased it is observed that the in-cylinder pressure seems to significantly drop for the Karanja oil blends when compared to mineral diesel. It is observed that the peak cylinder pressure is higher for all the loading conditions. The higher volatility of the mineral diesel used in the study produces better air-fuel mixing hence a higher heat release rate is observed when the pistons near the TDC position within its cycle. This also means a higher thermal efficiency for mineral diesel when compared to other fuel blends. It is also observed that mineral diesel produces a higher peak cylinder pressure when compared to other Karanja oil blends. It is noted that even trace quantities of Karanja oil within the blend significantly alters the properties of the fuel such as fuel atomization and air-fuel mixing process.

The figures given below show the change in cylinder pressure when compared to the crank angle of the engine for all the different fuel blends used. It is revealed from the experiments that the fuel blends exhibit almost the same behavior as any other fuel under load conditions. It can be seen that as the load increases the maximum cylinder pressure for all the blends also increases. But it can be clearly observed that the peak pressure for K-30 is slightly higher by a margin of 2-3% when compared to other fuel blends.

Reduction in ignition delay is shown clearly, it is affected due to the higher compression ratio of the fuel. And peak cylinder pressure is absorbed for K-30 5% DEC for the higher loads compared with diesel and other fuel blends. It can be seen that for the blends (k-10, k-20, k-30) maximum cylinder pressure is almost identical. But, the peak pressure for K-30 at higher load is slightly higher when put up against other tested fuel. It can be observed that with increase in the loading conditions the ignition time delay is seen to reduce. This helps to attain the peak pressure far below the TDC. The blends show a higher viscosity and a higher cetane number again leading to peak cylinder pressure below the TDC.

![Figure 8. Crank Angle vs Pressure for 16kg load](image-url)
loading conditions. The maximum cylinder pressure is identical for K-10, K-20 and K-30 while compared to that of diesel. Also, another point recorded was that the ignition delay time decreases with increase in load conditions which in turn leads to reaching the peak pressure far from TDC when load is increased. This is due to the combined effect of high viscosity and cetane number for higher loading than lower loading conditions. Also, increase in combustion duration is also observed for all blends mixed with additives (5%DEC). This trend is observed because of high oxygen content present in the additive blends. K-10 with 5%DEC shows higher rise than K-20 and K-30 with 5%DEC at maximum loading condition but it is at par with K-20 and K-30 with 5%DEC at lower loading conditions.

4. Conclusion

Based on the experimental study the following conclusions are drawn:

- Brake thermal efficiency for the blend K-10 is found to be closer to diesel. Increasing the blending ratio decreases the brake thermal efficiency. K-20 blend rises high because of its higher calorific value and oxygen content then K-10 and K-30 but K-30 shows the highest value at maximum load.

- Brake specific fuel consumption was found to be lowest for K-20 under higher loading conditions. K-30 with 5%DEC shows higher level at lower load, but at higher load, there is a drop in its level due to low oxygen content. K-20 has higher heating value than other blends while K-10 and K-30 have the lowest.

- Variation in CO emission for all blends and diesel was found to be small at lower loading conditions and comparatively high at higher loading conditions. This is due to the oxygen content and C/H ratio of the fuel that causes complete combustion.

- CO₂ emission increases with increase in load because of increase in air fuel ratio which allows more oxygen for oxidation. K-20 is an exception in this case as it decreases with increase in load due to its low oxygen content. High viscosity and low atomization of the fuel results in less CO₂ emission, lower than diesel. This is the same reason why K-20 5%DEC also has lower CO₂ emission.

- HC emission was found to be quite high at half load conditions. But, at 75% load, K-20 and K-30 blends show lower HC emission as compared to diesel. At maximum load though, K-30 shows higher HC emission while K-20 is on par with diesel. Also, HC emission has been brought down drastically by the use of oxygenated additive (Diethyl Carbonate). This is due to the additive which increases the oxygen percentage in diesel and hence reduces the richness of air-fuel mixture. The K-10 5%DEC blend is recommended from this study as it shows low HC emissions over the entire range.

- At maximum load, oil blends show increase NOx emission than diesel than when at part loads, where diesel shows higher NOx emission. This is due to higher temperatures developed in the combustion chamber when oil blends are used. This can also be confirmed by the higher exhaust gas temperatures when the oil blends are used. The addition of Di-ethyl Carbonate (DEC) in the blends has resulted in reduction of NOx emission. This is due to the oxygen content in the additive which makes the combustion process more uniform hence providing more time for cooling through heat transfer and dilution. Hence K-10, K-20 and K-30 with 5%DEC show very low NOx emissions and the blend K-10 with 5%DEC is highly recommended from this study.
References:

[1] Md Nurun Nabi, S.M Najmul Hoque, Md Shamim akhter, “Karanja production, characterization and effect on diesel engine”, Fuel processing technology, Vol 90 (2009) 1090-1086.

[2] Girdhar Joshi, Devendra S Rawat, Bhawna Y Lamba, Kamal K Bisht, Pankaj, Nayan Kumar, “Study of transesterification of jetropa and karanja with metal oxides”, Energy conversion management, Vol 96 (2015) 258-267

[3] Arul Dhar, Avinash Kumar Agarwal, “Experimental investigating of the effect of pilot injection on performance, emission and combustion characteristics of karanja”, energy conservation management, Vol 93 (2015) 357-366

[4] Debabrata Barik, S Murugan, “Effects of DEE on Combustion performance and emission of karanja oil”, Fuels, Vol 164 (2016) 286-296

[5] Atul Dhar, Avinash Kumar Agarwal, “Effect of karanja blends on particulate emission from transport engine”, Fuel, Vol 141 (2015) 154-163

[6] Devendra S Rawat, Girdhar Joshi, Avanish K Tiwari, “Impact of additives on storage stability of karanja blends with conventional diesel”, Fuels, Vol 120 (2014) 30-37

[7] Vivek and A.K Gupta, “Production Biodiesel from Karanja Oil, Journal of scientific& Indian research”, Vol 63 (2004) 118–122.

[8] Vismaya, W. Sapna Eipesona, J. R. Manjunatha, P. Srinivas and T.C. Sindhu Kanya, “Extraction and Recovery of Karanjin: A Value Addition to Karanja (Pongamia Pinnata) Seed Oil”, Industrial Crops and Products, Vol 32 (2010), 118–122.

[9] P.K. Srivastava and Madhumita Verma, “Methyl Ester of Karanja Oil as An Alternative Renewable Source Energy”, Fuel, Vol 87,( 2008), 1673–1677.

[10] P.K. Sahoo and L.M. Das, “Process Optimization for Biodiesel Production from Jatropha, Karanja and Polanga Oils”, Fuel, Vol 88, (2009), 1588–1594.

[11] K.V. Thiruvengadaravi, J. NANDAGOPAL, P. BASKARALINGAM, V. SATHYA SELVA BALA and S. SIVANESANA, “Acid-Catalysed Esterification of Karanja (Pongamia Pinnata) Oil with High Free Fatty Acids for Biodiesel Production”, Fuel 98, 2012, 1–4.

[12] Avinash Kumar Agarwal and K. Rajamanoharan, “Experimental Investigations of Performance and Emissions of Karanja Oil and Its Blends in A Single Cylinder Agricultural Diesel Engine”, Applied Energy Vol 86, (2009),106-112.

[13] Malaya Naik, L.C. Meherb, S. N. Naik and L.M. Das, “Production of Biodiesel from High Free Fatty Acid Karanja (Pongamia Pinnata) Oil, Biomass& Bioenergy”, 2008, 354 – 357.

[14] Y.C. Sharma and B Singh, “Development of Biodiesel from Karanja, Tree Found in Rural India”, Fuel, Vol 87, (2008), 1740–1742.

[15] H. Raheman and A.G. Phadatare, “Diesel Engine Emissions & Performance from Blends of Karanja Methyl Ester and Diesel”, Biomass and Bioenergy, Vol 27, (2004), 393 – 397.

[16] Venkata R. Mamilla, M. V. Mallikarjun, Dr. G. Lakshmi and N. Rao, “Preparation of Biodiesel from Karanja Oil”, International Journal of Energy Engineering, DOI 10.5963/IJEE0102008.

[17] Md. Nurun Nabi, S.M Najmul Hoque and Md. Shamim Akhter, “Karanja (Pongamia Pinnata) Biodiesel Production in Bangladesh, Characterization of Karanja Biodiesel and Its Effect on Diesel Emissions”, Fuel Processing Technology, Vol 90, (2009), 1080–1086.

[18] L.M. Das, Dilip K. Bora, Subhalaxmi Pradhan Malaya K. Naik and S.N. Naik, “Long-Term Storage Stability of Biodiesel Produced from Karanja Oil”, Fuel, 88, 2009, 2315–2318.

[19] Sara Pinzi, Paul Rounce, Jose M. Herreros, Athanasios Tsolakis and M. Pilar Dorado, “The Effect of Biodiesel Fatty Acid Composition on Combustion and Diesel Engine Exhaust Emissions”, Fuel, Vol 104 (2013), 170–182.

[20] H.J. Berchmans and S. Hirata, “Biodiesel Production from Crude Jatropha Curcas Seed Oil with High Content Free Fatty Acids”, Bioresource Technology Vol 99, (2008), 1716–1721.

[21] H. Sharon, R. Jayaprakash, M. Karthigai selvan, D.R. Soban kumar, A. Sundaresten and K. Karuppasamy, “Biodiesel Production and Prediction of Engine Performance Using SIMULINK Model of Trained Neural Network”, Fuel, Vol 99, (2012),197–203.