An Overview of Performance, Emission and Combustion Characteristics of Biodiesel Tested in CI Engine

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Abstract— **Petroleum based fuels play a vital role in rapid depletion of conventional energy sources along with increasing demand and also major contributors of air pollutants. Energy demand is increasing drastically because of the fast industrial development, rising population, expanding urbanization, and economic growth in the world. This paper introduces different species of non-edible vegetables whose oils are potential sources of biodiesel. Various aspects of non-edible feedstocks, such as biology, distribution, and chemistry, the biodiesel's physicochemical properties, and its effect on engine performance and emission, are reviewed based on published articles. From the review, fuel properties are found to considerably vary depending on feedstocks. The performance parameters of the test engine vs. Brake thermal efficiency, Volumetric efficiency are decreased, Brake specific fuel consumption and exhaust gas temperature are increased for all neat oils compared to diesel. Emission parameters of engine such as Carbon monoxide, Carbon dioxide, Un-burnt hydrocarbons and Smoke are increased, but Nitrogen oxides are decreased for all neat oils and their blends compared to diesel. This variation is observed due to high viscosity coupled with lower heating value of the fuels. In this process, the performance parameters of engine such as Brake thermal efficiency and volumetric efficiency are slightly decreased, Brake specific fuel consumption and Exhaust gas temperature are increased compared to diesel for all bio-diesels. Emission parameters of engine such as Carbon monoxide, Carbon dioxide, Un-burnt hydrocarbons and Smoke are reduced, but Nitrogen oxides increased for all bio-diesels compared to diesel. This trend is observed due to complete combustion of the bio-diesels, as the viscosity is reduced. It is observed that 25% of neat oil mixed with 75% of diesel is the best suited blend, without heating and without any modification of the engine. Analysis of the performance results revealed that the biodiesel generally give higher brake thermal efficiency and lower brake-specific fuel consumption. Emission results showed that in most cases, NOx emission is increased, and HC, CO, and PM emissions are decreases. It is observed that the combustion characteristics of biodiesel are almost similar to that of diesel. It was reported that a diesel engine could be successfully run and could give excellent performance and the study revealed the most effective regulated emissions on the application of different oils biodiesel and their blends as fuel in a CI engine.**

Index Terms—**non-edible feedstock; biodiesel; blend; emission.**

I. INTRODUCTION

Biodiesel is one of the most important source of fuel for diesel engines. Studied have been carried out on different kinds of fuels such as non-edible oil, s gained momentum in recent years because of increasing environmental problems by fossil fuels and depletion of oil stock. Some problems such as high viscosity, low lower heating value and increase in NOx emissions due to oxygen content are limiting the scope of biodiesel. Biodiesel with different forms of energy have become essential for human beings to maintain a standard of living and to conserve economic growth. In the past few decades, fossil fuels, mainly petroleum-based liquid fuels, natural gas and coal have played an important role in fulfilling this energy demand. However, because of their non-renewable nature, these fossil fuels are projected to be exhausted in the near future [1]. Therefore, the demand for clean, reliable, and yet economically feasible renewable energy sources has led researchers to search for new sources. Based on the review works considered in this study, several trees that are naturally available can be exploited for the production of sustainable fuel for petrodiesel engine. The raw materials of the biofuel being exploited commercially and scientifically by several researchers are the non-edible oils derived from Jatropha, Mahua, Karanja, Rubber seed, Linseed, Neem, Tobacco seed, Polanga, cotton seed, castor, Jojoba, Desert date, Crambe, Mango and so forth [2]. The selection of non-edible oils as possible fuel for use in a diesel engine is based on the literature. Some of the non-edible vegetable oils that are promising substitutes for petroleum diesel and the acceptable non-edible biodiesel feedstocks for biodiesel production include Karanja, Polanga, Mahua, Rubber seed, cotton seed, Simmondsia chinensis (Jojoba), Tobacco, Neem, Linseed, Jatropha carcus, and so on. The objective of this paper is to present the various sources of non-edible oils that can replace edible oils and fossil fuels for biodiesel production as well as their fuel properties. This study also compares their physicochemical properties, engine performance, and emission characteristics in a diesel engine through a review [3, 4].

Using the Jojoba fuel with its improved properties has improved the dual fuel engine performance, reduced the combustion noise, extended knocking limits and reduced the cyclic variability of the combustion. Rakopoulos and Antonopoulos [5], Rakopoulos et al. [6] did an experimental study to evaluate and compare the use of Cottonseed oil, soybean oil, sunflower oil and their corresponding methyl esters. There conclusion is that, all tested biodiesel or vegetable oil blends, can be used safely. Venkateswara et al. [7] carried out an experimental study to examine properties, performance and emissions of different blends (B10, B20, and B40) of Methyl ester of Pongamia (PME), Jatropha (JME) and Neem (NME) in comparison to pure diesel. Results indicated that pure diesel blends showed reasonable efficiencies, lower smoke, CO and HC. Ravi Kumar et al. [8] investigated performance of diesel engine using blends of methyl esters of palm oil with diesel fuel. Acceptable brake thermal efficiencies and BSFC were achieved with the blends containing up to 50% methyl esters of palm oils. The search for alternative fuels has lead researchers to investigate more sustainable sources such as, Jojoba oils. This oil is rare in that is an extremely long (C36–C46) straight chain wax ester, and not a triglyceride, making Jojoba and its derivative Jojoba esters more similar to sebum and whale oil than traditional vegetable oils. Silem's team reveals that the Jojoba fuel matched pure diesel for torque and power and the Jojoba combustion gas took slightly longer to reach maximum pressure in the cylinder, which explain why the engine runs more quietly on the nut oil over the engine speeds they tested. Pure Jojoba oil has been also used and its blends with diesel fuel for diesel engines [9], the results indicated a negligible loss of engine power, a slight increase in brake specific fuel consumption and a reduction in engine NOX, and soot emissions using blends of Jojoba oil with pure diesel fuel as compared to pure diesel fuel. Radwan et al. [10] carried out an experimental study for measuring the thermal ignition delay of Jojoba methyl ester and its blends with pure diesel fuel and methanol. The results have shown that, Jojoba methyl ester has superior ignition characteristics compared to pure diesel fuel, methanol and their blends. They have shown that the new fuel oil has reasonable ignition delay characteristics as compared to gas oil. The Jojoba raw oil is now produced successfully in Egypt and the plant is being cultivated in many places in the Egyptian desert. Osayed [11] compared the values of the laminar burning velocity of pure diesel oil and iso-octane with values of two grades of Jojoba methyl ester, and the results reveal that the laminar burning velocity was lower in case of Jojoba methyl ester than those of diesel oil and iso-octane. Also, an effective way for reducing emissions may be accomplished by using EGR technology. The presence of inert molecules reduces the temperature and the combustion pressure inhibiting the formation of NOX by the thermal mechanism, as well as increases the detonation tolerance. This method, while effective in reducing NOX emissions, may lead to considerable losses in engine performance. Abd-Alla, [12] found that adding EGR to fresh air entering diesel engine, appears to be a more beneficial way of utilizing EGR. This way may allow exhaust NOX emissions to be reduced substantially. From lectures review of the previous researches works there is lack in the data of EGR effects on engine performance, emission, Twall and Texhaust when using biodiesel fuel as alternative fuel for diesel engine. So, the aim of the present work is to study performance, emission, cylinder pressure, Twall and Texhaust of a single cylinder DI diesel engine using S100 and B20 as alternate fuels at different engine speeds and also at different percentage of EGR. The results are compared with conventional pure diesel fuel**.**

Economic preparation of two grades of JME was achieved by Radwan et. al. [13] JME by using 4.6 mole of methyl alcohol per mole of raw oil. However, the fuel used in his work was prepared by using the most economical amount of methyl alcohol per mole of raw oil; which is 0.1 mole of methyl alcohol per mole of raw oil. This was found to give the highest yield with the smallest quantity of alcohol used. The effect of different ratios of methyl alcohol/raw oil on the physical and chemical properties of the JME produced. The objective of the present study, as a continuation of previous study by Radwan et al [13], is to compare the first use of pure Jojoba methyl ester and its blends with gas oil in an indirect injection diesel engine equipped with performance, combustion pressure and peak rate of pressure rise measurements; the later factor is of direct effect on engine operational roughness, combustion noise and vibration. The engine test variables included the percentage of Jojoba methyl ester in the blend, engine speed, load, injection timing and engine compression ratio. Many researchers have examined the combined analysis of the effect of biodiesel combustion on engine performance and emissions; and reduction of the NOx emissions but few of them attempted to review them. This paper presents a comprehensive review on the effects biodiesel combustion on NOx emissions of biodiesel fuelled engines, in order to provide useful information to engineers, policymakers, industrialists and researchers. Articles from highly rated journals as well as SAE technical papers are reviewed to discuss the notable factors affecting NOx emissions of biodiesel fuel. Finally, reduction techniques of the NOx emission are described for biodiesel fuelled engine [14]

II. PERFORMANCE OF CI ENGINE USING BIODIESEL

A. Cottonseed Biodiesel: Aydin H. et. al. [14] and Altin et. al. [15] experimentally investigated that cotton seed biodiesel gives poor engine performance results compared with other biodiesel fuels. BSFC is high in most test conditions, along with lower brake power and BTE and it gives high thermal efficiency in some specific conditions. The following conclusions can be made By analyzing the different experimental results they shows that using Cottonseed biodiesel engine power increases by about 2.2–2.3% in a full load operating condition but engine power decreases with the use of preheated biodiesel blend and higher injection pressure. BTE improves in both naturally aspirated and turbo-charged operations, the increment of which is about 6.34% with fuels at elevated temperature. BTE increases by about 6% with low biodiesel present in the blend and with high engine torque condition. If engine load increased and high percentage of biodiesel present in the fuel blend then BSFC increases by 3.7%. With the lower percentage of biodiesel BSFC decreases present in the fuel blend.

B. Jatropha Biodiesel: Chauhan BS et. al [16] and Sundaresan M et. al [17] carried out an experimental study of Jatropha biodiesel which gives high thermal efficiency with high fuel consumption. He observed that its blends give better brake power than diesel fuel in some cases. It also exhibits low BTE in some conditions. Engine performance results in different test conditions are observed. Some important deductions can be made by analyzing the results; A 20% biodiesel blend gives better engine power, which is about 0.09–2.64% higher, than diesel fuel. Engine power decreases with increased biodiesel percentage in the fuel blend. BTE slightly improves (percentage) in medium engine speed and improves by 0.1–6.7% in high engine speed. However, it decreases when a high biodiesel percentage is present in the fuel blend. BSFC increases by 6.8% with increased engine speed and high biodiesel percentage in the fuel blend.

C. Jojoba Biodiesel: Shehata M et. al. [18] and Saleh H. [19] carried out an experimental study to evaluate and compare the use of Jojoba oil which shows that Jojoba oil-based biodiesel can be considered a good alternative fuel because of its give higher brake power using in diesel engine. Its thermal efficiency and BSFC decrease at different speeds and in a full load condition. However, it gives higher BSFC in some specific conditions. Different engine performance results using Jojoba oil-based biodiesel in a diesel engine are compared. Various conclusions can be made from the analysis of the different experimental results such as with EGR operation engine power increases by 5% using Jojoba oil methyl ester. When the fuel blend used has a high percentage of biodiesel in the engine power slightly decreases. BTE slightly increases in a full load condition and with high engine speed but decreases by 6% with EGR operation. BSFC decreases about 8% when Jojoba oil methyl ester is used in EGR operation and with high engine speed.

D. Karanja Biodiesel: Jindal et al. [20] found that Karanja biodiesel blend gives better BTE and BSFC than other biodiesels. Karanja gives higher BTE at higher load condition and higher BSFC with the increase in blend ratio. However, the opposite trend was observed by some researchers experimented different Karanja biodiesel blends using a two-cylinder CI engine. They concluded that pure biodiesel gives lower BTE than diesel fuel, but biodiesel blend gives higher BTE than pure biodiesel. They show different experimental results of engine performance using Karanja biodiesel. The important points based on the result analysis are Engine power increases by about 6% with the presence of higher biodiesel percentage in fuel blend. Lower biodiesel concentration and higher engine speed gives higher power. BTE increases with higher engine load and decreases when a lower percentage of biodiesel is used in the fuel blend. BSFC decreases about 0.8% with used lower biodiesel blend ratio and higher engine speed. BSFC decreases significantly when pre-heated biodiesel fuel blends are used.

E. Linseed Biodiesel: Puhan S et. al. [21] carried out an experimental study to examine properties, performance and emissions of different blends (B10, B20, and B40) of Methyl ester of Linseed oil. The use of Linseed oil biodiesel in diesel engine gives excellent results, such as high BTE, high power output, and low BSFC. Some experimental results also show its high BSFC and low BTE. They show the engine performance results using Linseed oil-based biodiesel in a diesel engine in different conditions. Different conclusions can be made from the analysis of the experimental findings, Engine power increases with the presence of high engine load and high percentage of biodiesel in the fuel blend. BTE increases because of improved atomization and better mixing process at a high injection pressure. BTE increases by about 10–12% with increased biodiesel concentration in the fuel blend and high engine load condition. BSFC decreases by about 4–6% with high engine load and high biodiesel percentage in the fuel blend. It significantly increases with at a high injection pressure in the engine.

F. Mahua Biodiesel: Godiganur S et. al. [22] carried out an experimental study to improve performance of diesel engines by using Mahua biodiesel which gives poor results in terms of engine performance. Most researchers found that it has high BSFC and low BTE. However, some test conditions gave higher thermal efficiency. Different experimental results using Mahua biodiesel in different test conditions are studied. The conclusions can be made by analyzing the different experimental observations such as; a 20% biodiesel blend gives about 1–32.5% higher BTE at higher engine load condition than any other blend. BTE is reduced with the presence of a higher percentage of biodiesel in the fuel blend. BSFC increases by 4.1% with the increased proportion of biodiesel in the fuel blend.

G. Neem Biodiesel: Prasad L et. al. [23] compared the values of pure diesel oil and Neem biodiesel. It shows that Neem biodiesel generally gives slightly lower BTE and higher BSFC but gives higher BTE than diesel fuel in some conditions. Different experimental engine performance results are compared. Its low calorific value causes Neem biodiesel to give low BTE with high fuel consumption in most cases. BTE significantly increases with increased biodiesel percentage in the fuel blend and engine load. In a part load condition, the BTE of increases about 63.11% compared with that of diesel fuel. However, it decreases in a full load condition. BSFC decreases by about 8.25% at constant speed in a part load condition but significantly increases in a full load condition.

H. Polanga Biodiesel: Sahoo P et. al. [24] carried out an experimental study to investigate performance of diesel engine using blends of methyl esters of Polanga oil with diesel fuel. Polanga biodiesel usually gives high power output, high BTE, and low BSFC when used in a diesel engine. However, some researchers obtained the opposite trend. They presents the engine performance parameters using Polanga biodiesel in a diesel engine. Engine power is slightly reduced when a lower biodiesel fuel blend is used but increases when a medium percentage of biodiesel fuel blend is used. BTE increases with the use of higher biodiesel blend and added additives in the fuel. Lower BSFC is observed when the biodiesel blend has added additives and when the engine is operated at high speed.

I. Rubber Biodiesel: Ramadhas A et. al. [25] found that adding EGR to fresh air entering diesel engine appears to be a more beneficial way of utilizing EGR. Most experiments show that BSFC is higher when Rubber seed biodiesel is used in a diesel engine. However, higher BTE and brake power were observed with increased percentage of biodiesel in fuel blend and with engine load. They shows the engine performance when Rubber seed biodiesel is used in different test conditions. BTE increases at about 1.14–1.33% in a full load condition. Engine power increases with the increased percentages of biodiesel in the fuel blend and higher engine speed condition. A 20% biodiesel blend ratio and higher engine speed give higher BTE. Diethyl ether (DEE) injection with Rubber seed oil-based biodiesel blend shows high peak pressure and gives high BTE. BSFC increases with increased engine load and higher biodiesel percentages in the fuel blend.

J. Tobacco Biodiesel: Parlak A. et. al. [26] carried out an experimental Study of Tobacco oil biodiesel which shown excellent results in terms of engine performance, with high brake power and BTE, and low BSFC. However, it gives high BSFC in some specific conditions. Engine power increases by about 3.13% with high engine load and low biodiesel percentage in the fuel blend. At high engine speed and low biodiesel percentage, BTE increases by 2.02%. High engine load condition, high injection pressure, and biodiesel percentage affect the BTE of an engine. BSFC slightly decreases because of high brake power and low injection pressure. Engine load and speed also affect specific fuel consumption.

K. Thumba Biodiesel: Sunilkumar et al [33] carried out experiments by using dual biodiesel blends and compared it with diesel fuel characteristics. They investigated the performance characteristics of various dual biodiesel blends (mixture of biodiesel and diesel fuel) of Thumba biodiesel on a single cylinder variable compression ratio diesel engine. The biodiesel blends of B10 and B20 gave better brake thermal efficiency and lower brake specific fuel consumption than other biodiesel blends. At CR 18 BTE of Thumba B10 (36.31%) showed better performance than all other blends of Thumba biodiesel and pure diesel fuel (33.27%). At CR 18 BSFC of Thumba B10, B20 (0.23 kg/kwhr) showed better performance than all other blends of Thumba biodiesel and pure diesel fuel (0.25kg/kwhr). At CR18 BP of Thumba B40 (5.15 kw) showed better performance than all other blends of Thumba biodiesel and the pure diesel (5.07 kw).

III. EMISSION CHARACTERISTICS CI ENGINE BY USING BIODIESEL

A. Cotton seed Biodiesel: Aydin H et. Al. [14] studied the use of cotton seed as biofuel in a diesel engine, and they observed level of CO, NOx, HC, and smoke. Sometimes it also shows high emissions. They studied the different experimental results of emission characteristics using cotton seed biodiesel and its blends. By using cotton seed biodiesel the maximum reduction of CO, HC, and smoke emission is 45%, 67%, and 14%, respectively, with NOx decreasing by 25% compared with diesel fuel. From experimental results they show that as the fuel injection pressure increases CO and NOx emissions decreases. CO and HC emissions rapidly decrease with high BMEP and turbo charging operation. Depending on condition there is change in CO emissions about 4% to 45.66 %. With increase in biodiesel percentage HC emission increases. Because of high BMEP PM emission decreases (24 to 69%). Because of low engine load condition NOx emission is more (6 to 39.5%). At full load condition NOx emissions are 10 to 25% less. It increases with increased BMEP. Smoke increases in a high load condition. Low smoke emission is produced because of the low percentage of biodiesel present in the fuel blend. Low emission is produced with a high concentration of biodiesel present in the fuel blend.

B. Jatropha Biodiesel: Sundaresan M et. al. [17] observed less emissions of CO, HC, NOx, and smoke opacity by using Jatropha biodiesel. Engine emission decreases significantly in some specific conditions. Emissions of CO, HC, and smoke opacity decrease, with NOx emission decreasing in most cases. Emission decreases due to lower heating value of Jatropha biodiesel. As the percentage of biodiesel blend increases in fuel blends CO and HC emissions increase. CO emission decreases by 5.57 to 35.21% and HC emission decreases by 14.91to 32.28% due to high biodiesel content in fuel blends. NOx emission increases with increased engine load and biodiesel content in fuel blends. NOx emission increases by 3.29 to 10.75% in some conditions. It reduces in a full load condition. Smoke emissions increases with high engine load condition but decreases with the increase in biodiesel concentration in fuel blends.

C. Jojoba Biodiesel: Huzayyin A et. Al. [9] conducted experiments for the use of Jojoba biodiesel in a diesel engine, and Jojoba biodiesel has been found to give higher emission than diesel fuel. The emission characteristics of Jojoba biodiesel are studied. Jojoba biodiesel produces high CO, HC, and NOx emissions in most cases but produces low CO emission in some specific conditions. CO emission increases (12 to 14%) with the increase in biodiesel percentage in the fuel blend and with EGR operation. It decreases in a high engine speed condition. CO emission decreases rapidly because of high engine speed. HC emission decreases significantly in a low engine speed condition and increases with EGR operation. NOx emission (14 to16%) increases with increased engine speed but decreases by about 11 to13% when Jojoba methyl ester is used without EGR operation.

D. Karanja Biodiesel: Agarwal Krak [27] tested biodiesel for CI Engine with different operating condition and Karanja biodiesel percentage in the blend. It significantly affects engine emission characteristics. Results show high CO and NOx emissions, in some cases low CO, HC, and smoke emission are observed. CO emission decreases by approximately 4 to 46.5% in a high load condition but increases with the presence of a high percentage of biodiesel in the fuel blend. HC emission decreases with a low percentage of biodiesel present in the fuel blend and in a high load condition. PM decreases with increased biodiesel content in the fuel blend. NOx emission increases by 4.15 to 14.18% with increased biodiesel percentage in the fuel blend. However, it decreases by 4 to 39% with the presence of low biodiesel percentage in the fuel blend. Smoke level is reduced (20 to 43%) with a high engine load and high biodiesel concentration in the fuel blend.

E. Linseed Biodiesel: Puhan S et. Al. [21] studied emission behavior of Linseed oil-based biodiesel used in a diesel engine depends on the engine's operating condition. It shows low emissions of CO, HC, NOx, and smoke, But it produces a high emission in some specific cases. They observed that, CO decreases when a high content of biodiesel is present in fuel blends and in a high engine load condition. Linseed biodiesel produces higher HC emission when higher biodiesel content is present in the fuel blends and in a higher load condition. HC emission rapidly decreases with the increase in fuel injection pressure. NOx emission generally increases when used high biodiesel percentage in the fuel blend. Smoke level decreases but NOx emission increases with increased fuel injection pressure.

F. Mahua Biodiesel: Puhan S et. Al. [28] experimentally investigates results for engine operation using Mahua oil based biodiesel which gives low CO, HC, NOx, and smoke. Emission characteristic of the experimental results using Mahua biodiesel shows that CO emission decreases by 0.02 to 0.16% with the increase in biodiesel concentration in the fuel blend. HC emission dramatically decreases by 35 to60% with the increase in biodiesel percentage in the fuel blend and in high engine load condition. NOx emission increases (6 to16%) with increased engine load and high biodiesel percentage in the blend. Smoke level decreases (5 to 46%) in a full load condition and with high biodiesel percentage present in the fuel blend.

G. Neem Biodiesel: Sivalakshmi S et. Al. [29] used Neem biodiesel in a diesel engine and has found low emission characteristics. Some specific condition show high emissions of CO, HC, NOx, and smoke opacity. They made different conclusions such as CO decreases with increased percentage of ethanol content in the fuel blend. At higher BMEP and engine load, CO emission increases by about 20 to 40%. Engine operation with dual mode condition produces high CO emission. HC emission increases by 24 to 54% with the increase in engine load and decreases by 2.59 to 5.26% in full load and half load conditions. HC emission is higher with the addition of ethanol in fuel blends in all operating load conditions. NOx emission decreases by 3.2 to 6.06% in half load and full load conditions. NOx emission decreases by 37% when pure oil is used and by 19% when methyl ester is used in a full load condition. Smoke opacity decreases by 18.39% with the addition of ethanol in fuel blends and high load condition. However, it increases significantly when a high percentage of biodiesel is present in the blend.

H. Polanga Biodiesel: Sahoo P et. Al. [30] conducted experiments using Polanga biodiesel in a diesel engine. They found that it gives low-criteria engine emission. In different operating conditions biodiesel blends greatly affect emission. They made different conclusions such as higher biodiesel blend ratio gives higher CO emission. HC emission significantly decreases with the presence of high biodiesel percentage in the fuel blend. Polanga biodiesel produces a low reduction of PM at about 9.88 to 42.06% with increased biodiesel percentage in the fuel blend. NOx emission increases when a fuel blend is used with high biodiesel percentage. It decreases by 4% in a high load condition. Smoke level decreases at a maximum of 35% at high biodiesel blend and high engine speed condition.

I. Rubber seed Biodiesel: Ramadhas et. Al. [31] shows that Rubber seed biodiesel produces lower emission than diesel fuel. The emission characteristics of Rubber seed biodiesel are presented from which different deductions can be made such as CO emission decreases by about 0.13 to 1.13% with a low biodiesel concentration in the blend and a high load condition. With high load, and low biodiesel percentage concentration, CO and HC emission is considerably decreased. NOx emission increases by about 13% with a high biodiesel percentage in the blend and a high load condition. Smoke opacity decreases by 37.09% with a low load condition and high biodiesel concentration present in the fuel blend. The presence of oxygen and the better mixing of DEE with air lead to an improved combustion rate.

J. Tobacco Biodiesel: Usta N [32] investigate Tobacco biodiesel in diesel engine can produce better emission performance compared with diesel fuel in most studies. Different blends of Tobacco biodiesel reduce CO and increase HC and NOx emissions. HC and NOx emissions significantly decrease in some special conditions. They concluded various important points such as with the increase in engine load and biodiesel content in the fuel blend, CO and HC emissions decrease. However, increase with high injection pressure. With a full load and in a high injection pressure condition, NOx increases by about 5 to 6% but significantly decreases with low content of biodiesel in the fuel blend. Smoke emission slightly decreases with a full load and in high engine speed condition.

K. Thumba Biodiesel: Sunilkumar et. Al. [33] experimenter on Thumba biodiesel blends and observed that Thumba B50 showed better emission performance of HC at all compression ratios than B10, B20, B30, B40 blends of Thumba biodiesel. Thumba B40 showed better emission performance of CO at CR 14 and for other compression ratios Thumba B100 Showed better emission performance. Thumba B100 showed better emission performance of CO2 than other blends of Thumba biodiesel at all compression ratios. As load and compression ratio increased ppm of NOx coming from exhaust increased. For all the compression ratios ppm of NOx coming from pure diesel was less than all other blends of Thumba biodiesel. At CR 18 ThumbaB20 Showed better emission than other blends of Thumba biodiesel. The blends of B10% and B20% have superior emission characteristics than other blends and closer to diesel values. Their shows that Thumba oil blends are found to be a promising alternative fuel for compression ignition engines. At CR 18 BTE and BSFC of Thumba B10, B20 and BP of Thumba B40 showed better performance.CO, HC, CO2 of B100 of Thumba biodiesel showed less emission percentage/ppm, for NOx emission B10 and B20 of Thumba, biodiesel showed less emission ppm.

IV. COMBUSTION CHARACTERISTICS OF CI ENGINE BY USING BIODIESEL

Detailed combustion analysis such as rate of heat release, cumulative heat release, rate of pressure rise, etc., was done for all biodiesel blends with diesel and the results are discussed in detail by different researchers. Biodiesel and its blends exhibited similar combustion stages to diesel fuel.

A. Cottonseed Biodiesel: Basavaraj et. Al. [34] studied combustion of cotton seed biodiesel in a compression ignition engine where cylinder pressure gives the information about the combustion efficiency. The cylinder pressure and crank angle data are taken by averaging 100 cycles at 75% load. The results show that the peak pressure of the methyl esters in engine is lower compared to that of diesel fuel in normal engine. At 75% load, peak pressure reaches up to the maximum of 59.27 bar. This is due to higher viscosity and lower volatility of CSOME, which leads to poor atomization. The net heat release for CSOME in engine is lower compared to that of diesel fuel in normal engine. The reason for this is the lower calorific value of the methyl esters. The premixed combustion phase with CSOME in LHR is shorter compared to that of diesel in normal engine, and this has resulted in lower heat release rate. This is the reason for lower brake thermal efficiency with methyl esters of cotton seed oil in LHR engine. At 75% load, the maximum heat release rate reaches up to a maximum of 26.49 J/deg CA and 33.31 J/deg CA respectively with CSOME engine and diesel fuel in normal engine. The rate of pressure rise is directly related to engine life and noise of the engine. The rate of pressure rise is higher for diesel in normal engine compared to that of CSOME in LHR engine. The reason for this could be the higher viscosity and lower volatility of methyl ester. The maximum rate of pressure rise for CSOME in LHR engine and diesel in normal engine are 2.8 bar/^{0} CA and 3.04 bar/^{0} CA respectively at 75% load. The rate of pressure rise should be low as far as possible to reduce the engine noise and to increase the engine life.

B. Jatropha Biodiesel: Chauhan et al. [35] studied the combustion characteristics of Jatropha biodiesel (JME100) in a diesel engine and compared with diesel fuel. The results showed that Jatropha biodiesel has lower peak cylinder pressure and lower heat release rate compared to diesel fuel. Moreover, premixed combustion heat release is higher for diesel, which is responsible for higher peak pressure and higher rate of pressure is in comparison to Jatropha biodiesel. This is attributed to the higher cetane number of Jatropha biodiesel resulting in shorter ignition delay and more fuel burnt in diffusion stage.

C. Jojoba Biodiesel: Selim et al. [36] studied the combustion characteristics of an indirect Ricardo E6 compression swirl diesel engine using biodiesel from Jojoba methyl ester (JME) and its blend (B25, B50 and B75). The authors studied the effects of engine speed (1000–200rpm), load (0.5–21Nm), injection timing (20–451 BTDC), and compression ratio (22and18) on maximum combustion pressure and maximum pressure rise rate. Additional tests have been carried out for pure diesel and pure JME to check the cyclic variability of maximum pressure and maximum pressure rise rate. The main finding of this study indicates that the pressures and pressure rise rates for pure JME are almost similar to those of gas oil. However, JME exhibits slightly lower pressure rise rate than gas oil which may be attributed to the slightly increased heating value of the JME. This appears to be advantageous with the new fuel. The maximum pressure rise rate for JME is similar to that of pure gas oil at the middle range of injection timing, e.g.from251 to 351 BTDC. However, for very early injection, 451, or very late injection, 201, the JME produced higher rate of pressure rise.

D. Karanja Biodiesel: Anand et al. [37] studied the combustion characteristics of Karanja biodiesel and its blend with methanol in a turbocharged, direct injection, multicylinder truck diesel engine at different load conditions and constant speed without altering injection timings. The min results of the experimental investigation indicate that the ignition delay, the maximum rate of pressure rise and energy release rates increase at all the loads. However, the peak pressure and the peak energy release rate decrease significantly at higher load conditions while the changes are insignificant at lower loads. Compared to neat biodiesel, it was observed that the ignition delay for biodiesel–methanol blend is slightly higher and the maximum increase is limited to1^0 CA. At no load condition, it was observed that the cylinder pressure trends of biodiesel–methanol blend and neat biodiesel are similar. Whereas at full load condition, there is a decrease in cylinder pressure with biodiesel–methanol blend operation. This is because of the lower cylinder gas temperature on account of higher latent heat of vaporization and higher specific heat as well as due to lower heat of reaction of the blend compared to neat biodiesel. The results of energy release rates indicate that the addition of methanol to biodiesel has not resulted in any change in energy release rate at no load condition, whereas the peak energy release rate decreases at full load for the blend compared to neat biodiesel due to its lower energy content.

E. Linseed Biodiesel: Puhan et al. [21] studied the combustion characteristics of Linseed biodiesel in a direct injection diesel engine at different injection pressures (200,220and240bar). The combustion analysis shows that when the injection pressure increases the ignition delay reduces. This may be due to lower sauter mean diameter, shorter breakup length, higher dispersion and better atomization. At full load, it was observed that the ignition delay is lower at higher injection pressures compared to diesel and the peak pressure is also higher. The test results show that the optimum fuel injection pressure is240 bar. The combustion duration was almost the same at all the injection pressures. The maximum heat release takes place during the premixed combustion phase. This is attributed to the higher injection pressure, which improves atomization and mixing leading to better combustion.

F. Mohua Biodiesel: Vibhanshu et al [38] show the combustion result ignition lag for the blends of Mahua oil methyl ester. Ignition delay for D100 is found at 10.5° while for neat Mahua oil methyl ester it is 7°. However for M10 and M20 ignition delay varied from 7.3°, and 8° respectively. By analysis it can be concluded that up to 20 % (v/v) of diesel can be easily substituted by Mahua oil biodiesel and can be run on an unmodified single cylinder diesel engine.

G. Neem Biodiesel: Dhar et al. [39] studied the combustion characteristics of Neem oil biodiesel and it blends (B5, B10, B20 and B50) in a direct injection (DI) diesel engine at various engine loads. In this study, various combustion parameters such as pressure–crank angle history, rate of cylinder pressure rise, heat release rate, cumulative heat release and mass fraction burned were analyzed. The results of the maximum cylinder pressure at different loads showed that at all loads, the peak pressure for B20 is higher than mineral diesel. Peak pressure for B5 and B10 is significantly lower than mineral diesel. The peak pressure for B20 is higher because of the shorter ignition delay and fast burning of the accumulated fuel as a consequence of optimum oxygen content in the fuel and comparatively lower viscosity due to small concentration of biodiesel in the fuel. The authors also reported that the combustion started earlier for higher biodiesel blends; however, start of combustion was slightly delayed for lower biodiesel blends in comparison to mineral diesel. The rate of heat release trends for all the biodiesel blends was almost identical to mineral diesel.

H. Polanga Biodiesel: P.K. Sahoo et. Al. [40] shows significant features related to combustion aspects of Polanga biodiesel. The peak pressure achieved using diesel, Polanga biodiesel and their blends at full load condition is studied. The peak pressure, heat release rate at no load and half load are analyzed, which gives very significant information on the ignition delay in case of biodiesel, diesel and their blends. The Polanga biodiesel (PB100) had an 8.5% higher peak pressure than that of neat diesel. The same trend is observed during the entire range of engine operation at no load and half load conditions for all the test fuels. The peak pressure for PB100, PB50 and PB20 is 85.31 bar occurring at 5^0 CA after TDC, 84.1 bar occurring at 5.1^0 CA after TDC and 80.9 bar occurring at 5.2^0 CA after TDC, respectively, while in the case the peak pressure is 78.7 bar occurring at 5.8^0 CA after TDC. Therefore, the peak pressure for PB100, PB50 and PB20 is 6.61 bar, 5.4 bar and 2.2 bar higher than that of diesel, respectively. The early peaking characteristics warrant careful attention to ensure that, while running with biodiesel and their blends, the peak pressure takes place definitely after TDC for safe and efficient operation. Otherwise, a peak pressure occurring very close to TDC or before that causes severe engine knock, and thus affects engine durability. So they concluded PB100 which gives maximum peak cylinder pressure (6.61

bars higher than that of diesel) is the optimum fuel blends as far as the peak cylinder pressure is concerned. The maximum heat release rate of biodiesel and their blends is lower than that of diesel, specifically, 68.37 J/deg CA for PB100 compared with 90.96 J/deg CA for diesel. This is because, as a consequence of the shorter ignition delay, the premix combustion phase for biodiesel and their blends is less intense.

I. Rubber Biodiesel: Ramadhas A et. Al. [25] investigated the combustion of Rubber seed biodiesel in CI engine. It shows a quick carbon build-up of carbon deposits on the injector nozzles. Incomplete combustion promoted the formation of additional solid residues, which were deposited on the combustion chamber walls and cylinder head. Also the carbon deposits on the piston surface of diesel-fueled engine and blend-fueled engine, respectively. Throughout the tests no sign of knocking was observed. The piston with blend usage shows a slightly larger carbon deposits in comparison to that of the diesel. The higher carbon deposits occurred due to the incomplete combustion of the Rubber seed oil blends. Because of the gumming nature of Rubber seed oil, the carbon particles were deposited on the wall of the combustion chamber.

J. Tobacco Biodiesel: B. SUBBA RAO et. Al. [41] carried out experiment to study the exhaust emissions and combustion of Tobacco oil seed biodiesel. They observed the peak pressure and maximum rate of pressure rise increased and time of occurrence of peak pressure (TOPP) decreased with low heat rejection LHR engine with crude Tobacco seed oil in comparison with pure diesel operation on CE.

K. Thumba Biodiesel: Rajesh Govindan et. Al. [42] studied the Thumba biodiesel in CI engine. They find that Thumba biodiesel blends lower heat release rate compared to diesel during premixed combustion phase. The peak of heat release rate for diesel during premixed stage is about 35.03 % and during mixing stage is about 1.09 % higher compared to B20. The heat release for Thumba biodiesel always starts nearly 2º to 3º crank angle earlier compared to pure diesel.

V. CONCLUSION

According to the review of the above literature we can conclude that, The non-edible oil is a promising source that can sustain biodiesel growth. In most cases, cotton seed and jatropha biodiesels gave higher BSFC but had better thermal efficiency than other biodiesels. Their brake power and torque were closer to those of diesel fuel because of their calorific value. Karanja, rubber seed, jojoba, and tobacco biodiesels had higher BTE and power and lower BSFC than other biodiesels. Moreover, the low percentage of biodiesel blends (<20%) caused high brake power and reduced fuel consumption because of complete combustion. Therefore, biodiesels with high calorific value and low viscosity are more suitable for the improvement of engine performance. Even though 350 oil-bearing crops are identified, only few are potential biodiesel. It is observed that biodiesel has similar combustion characteristics as diesel. The emission of unburnt hydrocarbon from the engine was found to be more on the all the fuel blends as compared to diesel. The emission of NOx from the engine found to be higher on the all fuel blends as compared to diesel. The studies reported that biodiesel can improve the combustion in the engine and hence has higher BTE. Some studies reported that the power of diesel engine increases with using of biodiesel–diesel blends (1.15–16.7%). It is reported by most of the authors that using biodiesel as a fuel in diesel engines significantly reduces HC (7.4–45%), and CO emissions (8.6–40%). This is occurred due to the higher cetane number and higher oxygen contents in biodiesel. The difference in in-cylinder peak pressure between diesel and diesel–biodiesel blends is not significant and is within 1%. The ignition of the biodiesel is earlier than that of diesel by about1–21^{0}CA.The instantaneous and cumulative heat release rates of biofuels are quite close to each other. In general, the combustion characteristics of biodiesel fuel blends and neat biodiesel have resulted in the same characteristics as for normal diesel combustion. It can be concluded that biodiesel production from different feedstocks have potential as an alternative energy and the use of biodiesel can lower the dependency on fossil fuel.

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