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Effect of Biodiesel and Their Diesel Blends on Performance and Emission Characteristics of CIDI Engine: A Review

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Abstract— The ever increasing raise of petro-diesel fuel rise, deterioration of fuel reserves and economically attractive biodiesel are competent to presently using fossil fuels. Biodiesel, produce by the transesterification of vegetable oils or animal fats with simple alcohols and catalyst attracts more and more attention recently. Biodiesels are one of the best available renewable energy resources that have come to the forerunner in the recent times. In this paper, a comprehensive review has been conducted to study the different research accomplishments on vegetable oils and animal fat oils that are used as biodiesels as an alternative fuel for a compression ignition direct injection (CIDI) engine. Impediments and advantages allied with vegetable oils, animal fat oils and their diesel blends are also take into account for the research review. The existing literature revealed that the transesterification process is a most appropriate and distinctive method used for preparation of biodiesels from plants and animal fats. From the experimental studies, it has been unveiled that the biodiesels typically causes the reduction in engine torque and power, but the lower smoke emissions, carbon dioxide, carbon monoxide, pollution and with the biodiesel as compared to neat diesel with a minor increased in NOx emissions. Although sufficient and significant work has been carried out to evaluate the characteristics of diesel engine using biodiesels produced from both edible and non-edible vegetable oils, from the literature it was observed that inadequate amount of work has been done to analyze the characteristics of CIDI engine fuelled with animal-fat based biodiesels especially fish oil. Hence the authors' research is focussed on evaluating the effect of fish oil methyl ester (FOME) on characteristics of CIDI engine and this paper is concerned to review of previous work related to FOME and its diesel blends used in diesel engine.
Keywords— Biodiesel; Renewable Energy; Fish Oil Methyl Ester, Vegetable oils, Edible and Non-edible oils

I. INTRODUCTION

World's energy crisis, global warming, diminishing fossil fuel reserves are raising concerns and inevitability to find more economic and more environmentally friendly solutions to satisfy the current energy consumption. Periodic increase in crude oil prices due to more demand, stringent emission norms, and feared shortages of crude oils due to rapid depletion and net production of carbon dioxide from combustion sources have rekindled interest in renewable vegetable oil fuels [1]. In the recent times, the diesel engines became predominantly used engine than petrol engines as technology has improved and the invention of turbo-charged direct injection engines in the 1980s played a vital role to extend the raise of its popularity in all sectors that includes personal automotives and agriculture machinery. The usage of biodiesel in CI engines is a promising move to cut down the fossil fuel use and alleviate the global warming because biodiesel are more eco-friendly than any other fossil fuel. Fuels that are derivatives of renewable biological and biodegradable resources and can be employed in diesel engines are established as biodiesel fuels. Animal fats, neat and recycled vegetable oils derived from plants can be used in the production of biodiesel fuels. The research on vegetable oils as biodiesel was started more than century ago and the research is remain the interesting topic among the researcher to find a suitable and economically feasible biodiesel and literature revealing that more research and technological developments are considered necessary. The major cost of production of biodiesel is feedstock and therefore, choosing the paramount feedstock is essential to ensure low production cost. It has also been found that the continuity in transesterification process is another choice to minimize the production cost. Biodiesel is currently not economically feasible, and more research and technological development are needed. Thus supporting policies are important to promote biodiesel research and make their prices competitive with other conventional sources of energy. Currently, biodiesel can be more effective if used as a complement to other energy sources. [2]

Currently, clean alternative renewable energy sources have been raising over time, but usage of fossil fuels has grown even faster.

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As shown in the fig 1, fossil fuels usage in the total world's energy consumption in 2013 is 87 percent and conversely, the alternative energy sources such as hydropower, solar, wind, nuclear, and bio-fuels made up just 13 percent. World-wide production of bio-fuels has increased by 6.1% in 2013 which was driven by Brazil +16.8% and US +4.6% and the ethanol production has increased 6.1% and biodiesel has increased 6.2%. It is also observed that the production of biofuels in America, and Asia Pacific is increasing every year and in contrary, declining in Europe and Eurasia.

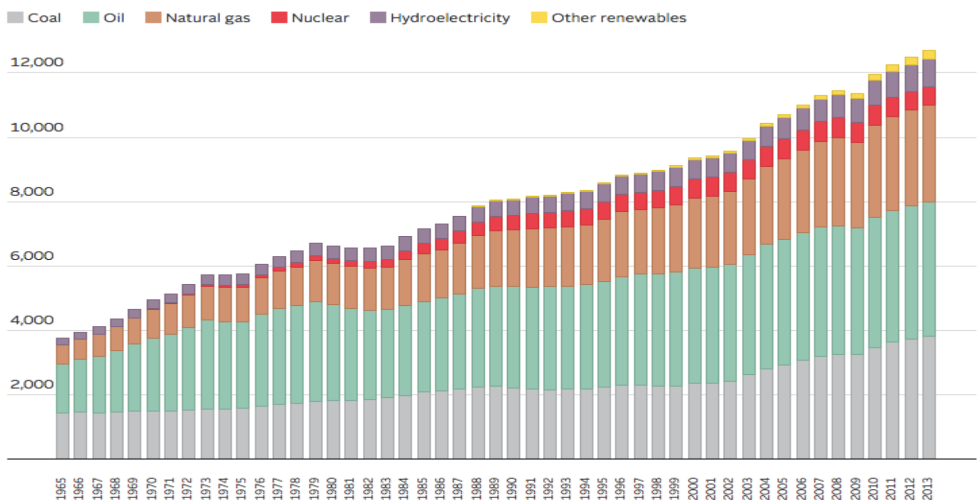

Fig 1. Global Energy Usage By Source (in Millions of Tons of Oil Equivalent)[3]

Biofuels offers an attractive alternative to fossil fuels, but a consistent scientific framework is needed to ensure policies that maximize the positive and minimize the negative aspects of biofuels. Many countries are moving towards the partial and gradual replacement of fossil fuels with biofuels, majorly ethanol for petroleum replacement replacements. The countries that are using And biodiesel for diesel the increased move towards biofuels is spurred by global, political, economic and environmental events, especially due to rising rate of crude oil prices.

Table: 1 Biodiesel Production in Different Countries [50]

Country	Source of Biodiesel
USA	Soyabean
Europe	Rapeseed oil (>80%) and sunflower oil
Spain	Linseed and olive oil
Brazil	Soyabean
Canada	Vegetable oil/Animal fat
China	Guang pi
Australia	Animal fat, beef tallow and rapeseed oil
Malaysia	Palm oil
Ireland	Animal fat and beef tallow
France	Sunflower oil

II. TRANSESTERIFICATION FOR BIODIESEL PRODUCTION

Transesterification is a process of transforming the carboxylic acid ester into a different carboxylic acid ester. The most conventional method of transesterification is the reaction of the ester with ethyl/methyl alcohol in the presence of an acid catalyst. In organic chemistry, transesterification is the process of exchanging the organic group R″ of an ester with organic group R′ of an alcohol in the presence of an acid or base catalyst. Transesterification can be written as

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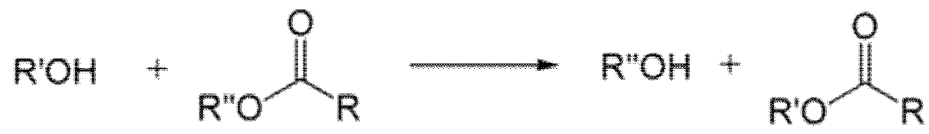

Alcohol + Ester → Different Alcohol + Different Ester

Fig 4. Transesterification - Chemical Reaction

Anitha A and Dawn S.S (2010) analysed the properties of raw vegetable oil and waste cooking oil. High viscosity and cloud point makes the vegetable oil is not compatible to be used raw in the engine and hence justifies the need for transesterification. The methyl esters are obtained from Waste cooking oil was originated to meet the ASTM standards for bio diesel. The methyl ester of waste cooking oil is produced by transesterification. The high catalytic activity, re-usability, lower emission rates, improved engine performance and environmentally benign nature makes it a promising candidate when compared with conventional catalysts. Filliers et al, (1995) insisted the pre treatment is not required if the reaction is carried out under the high pressure and high temperature. Under these conditions simultaneous esterification and transesterification take place. The maximum yield of esters occurs at a temperature ranging from 60 to 800C at a molar ratio of alcohol to oil as 6:1. Further rising the temperature, the yield of esters has a negative effect on the convention. Ma, F et al., were revealed that catalysts used for transesterification of triglycerides is classified as alkali, acid, enzyme or heterogeneous catalysts, among which alkali catalysts like KOH, KOME, NaOMe and KOMe are more effective. If the oil has high free acid content and more water acid catalyst is appropriate. The acids could be H2SO4, H3PO4, HCL or organic sulphonic acids. Methanolysis of beef tallow was studied with catalyst KOH and KOME comparing the two catalysts, KOH was considerably better than KOME.[48] Siva Kumar T et al (2009)reviewed that biodiesel is known as the mono-alkyl-esters of long chain fatty acids derived from renewable feedstock, such as, vegetable oils or animal's fats, for use in compression ignition engines. The different parameters for the optimization of biodiesel production were investigated and the performance test of a diesel engine with pure diesel fuel and biodiesel blends was carried out. Biodiesel was produced by the standard transesterification process. Cottonseed oil (CSO) was selected for biodiesel production and published that maximum of 76% biodiesel was produced with 20% methanol in presence of 0.5% sodium methaoxide.

III.HISTORICAL BACKGROUND

In 1853, many years before the first diesel engine became functional, two chemists E. Duffy and J. Patrick, were carried-out first experiments on transesterification of vegetable oils to distil out the glycerine which was used in the manufacturing of soap and in later time, the by-product of the soap manufacturing was used in running the motor engine, called 'biodiesel' after Diesel Engine was invented by Dr. Rudolf Diesel in 1895. In 1900 at the world fair organized by the French society in Paris, France a small version of a diesel engine was tested with peanut oil. Due to abundant supply of fossil fuel in those days, the research on vegetable oils was slowly relegated. In 1912, Diesel said, "The use of vegetable oils as engine fuel may seem negligible today. Despite the widespread use of fossil fuels, especially during the 1930s and the World War II, the interest on vegetable oils as bio-fuel for internal combustion engines was reported in several countries.

IV.EFFECT OF EDIBLE OILS ON CHARACTERISTICS OF CIDI ENGINE

Many researchers have conducted experiments with vegetable oils with and without heating for diesel engine and found that the vegetable oils have higher viscosities, lower heating values, low volatility and moderately higher densities that instigate the engine problems such as nozzle coking, slow burning, massive deposits, high smoke emissions, erratic combustion and engine durability. Lin et al., have revealed from their experiments that the max and min differences in engine power and torque at full load between petroleum diesel and 8 kinds of vegetable oil methyl ester fuels were only 1.49% and −0.64%, 1.39% and −1.25%, respectively, due to higher viscosity, higher BSFC , higher oxygen content and higher combustion rate of biodiesel [73] . Based on the experimental analysis. Kusy et al., [4] were investigated and confirmed that engine torque and power dropped five percent when fuelled with soybean oil ethyl-ester and that visible smoke was similar to operation on diesel fuel. According to Ventura et al., [5] experimentally recorded parameters of the engine were normal during the engine testing. The engine lubricating system however, approached collapse since the lubricating oil started to thicken. Engine testing both in and out of the laboratory were needed to substantiate these visual observations. Murayama et al., [6] were carried out the experiments to evaluate performance, exhaust gas emissions, and carbon deposits in DI diesel engine fuelled with palm oil, rapeseed oil, methyl ester of rapeseed oil, and these fuels blended with ethanol or diesel fuel with different fuel temperatures and revealed for short term operation that both of vegetable oil generated an agreeable engine performance and exhaust gas emission levels, but they caused deposit of carbon build ups and sticking of piston rings after extended operation. Rakopoulos et al., [18] were conducted an experimental research study to estimate and compare the use of various vegetable oils such as corn oil, cotton seed oil, soybean oil, sunflower oil, rapeseed oil, palm oil, and olive kernel oil and their corresponding methyl esters at blend ratios of 10/90 and 20/80, in a standard, fully instrumented, 4-stroke diesel engine located at laboratory. The differences in the measured performance and exhaust emission parameters from the base line operation of the engine, i.e. when working with neat diesel fuel were determined and compared. Theoretical aspects of diesel engine combustion, combined with the widely differing physical and chemical properties of these diesel fuel supplements against the normal diesel fuel were used to aid the correct interpretation of the observed engine behaviour. Vellguth [7] have evaluated the CIDI engine's performance with vegetable oil and disclosed that diesel can be replaced with vegetable oils for but long term operation and unmodified engine coke up. Nwafor et al., [8] conducted experiment using rapessed oil blends as fuel in direct injection diesel engine and short-term engine tests indicated good potential for rapeseed oil blends and long-term endurance tests how serious engine problems such as ring sticking, gum formation, injector choking. Barsic et al., [9] carried-out investigations using vegetable oil to reduce the viscosity by heating it before injection and established that the preheated vegetable oil solves the problem of filter clogging. Schlick et al., [10] were conducted experiments and evaluated the performance of 2.59 L, 3 cylinder Ford diesel engine operating on soybean oil and sun-flower oil blended with no:2 diesel fuel on a 25:75 v/v basis and observed that the power persistently constant throughout 200 h of operation. Large amounts of carbon deposits on all combustion chamber parts prevent the use of above oil blends. Bhattacharya et al., [11] were used diesel-alcohol micro emulsions and identified that the SFC has increased due to their lower gross heat of combustion. The CO emissions were reduced almost 50% with different emulsions as compared to diesel. The hydrocarbon emission was marginally higher for all loads and NO emissions were lower. Hasimonglu et al., [12] were Srevealed in their investigations that, there was fall off engine power and torque with biodiesel due to higher viscosity. Higher SFC was observed due to lower heating values. The in-cylinder combustion temperature was lowered due to lower heating values of biodiesel, and less heat lost to engine parts. Mahanta et al., [13] were identified from their experiments using 15-20% Pongamia biodiesel blends and jatropha methyl ester blends with diesel in diesel engine shows increase in brake thermal efficiency and reduction in break specific fuel consumption especially at higher loads. There is a considerable reduction in CO and HC emissions for B15 and B20 at medium and higher power output. Agrawal et al., [14] have the performance of low heat rejection diesel engine operating with biodiesel of rice bran oil, it was observed that NOx emissions with bio diesel was higher due to presence of molecular oxygen. An exhaust gas recirculation was used for controlling the NOx emissions. However, application of EGR resulted in higher BSFC, increased HC, CO and particulate emissions. Dhinagar et al., [15] were tested with three vegetable oils: neem oil, rice bran oil and karanji oil in the low heat rejection engine and revealed that without heating, the results indicated a lower brake thermal efficiency of 1- 4% when compared with the standard diesel engine. When these thick vegetable oils were heated and used in LHR engines the brake thermal efficiency improves. Spataru et al., [16] used soya methyl ester (SME) and canola methyl ester (CME) diesel blends in a Detroit Diesel engine. It was observed that the emissions of CO2, NOx, and particulate matter has increased and reductions in total hydrocarbons. It was also reported that the engine wear was within acceptable limits during durability tests conducted. Hemmerlein et al., [17] were conducted various modern diesel with respect to performance, fuel consumption, exhaust emissions and durability characteristics using neat (100%) rapeseed oil as fuel and observed that energy consumption and performance were almost same as diesel, and higher exhaust emissions with rapeseed oil. Hwang et al., were conducted experiment using biodiesel produced from waste cooking oil on the soot particles in a diesel engine was compared with neat diesel fuel and it shown that the diesel soot was mainly composed of carbon and hydrogen and WCO biodiesel soot contained high amount of oxygen species. [47] Kalam et al., were conducted experiments to investigate the exhaust gas emissions and deposit characteristics of a small diesel engine using preheated crude palm oil and its emulsions with 1%, 2% and 3% water. The results shown that preheated CPO reduced exhaust emissions such as containing less CO, HC and PM as compared to OD and CPO emulsified fuels and increased NO*x* emission as compared to OD and CPO emulsified fuels. [49] Grimaldi et al., have reported the results of a comparative analysis performed on a modern DI, common-rail, turbocharged engine using three different bio-derived fuels (rape seed, soybean, waste cooked oil) and conventional fossil diesel fuel. It was observed that NOx emissions of biodiesel fuels were same or marginally higher than fossil fuels. Smoke emission was further reduced by bio-fuels by a factor 3 to 4 and all the three bio-derived fuels performed in a very similar manner. HC and CO emissions were marginally affected by the fuel nature, with an appreciable decrease in HC emissions in bio-fuels, CO emissions revealed a moderate increase at part loads while at full load CO missions were lower for bio-fuels compared to fossil fuels probably due to temperature effects. [52] McCormick et al., were tested number of approaches for NOx reduction for 20% biodiesel blend (B20). Biodiesel produced from soybean oil and from yellow grease blended with 10% aromatic diesel, zero aromatic Fisher-Tropsch diesel with fuel additives was tested in a 1991 DDC Series 60 truck engine. Relative to base diesel, 20% lower PM emissions but NOx emissions for soybean and yellow grease based blends increased by 3.3% and 1% were exhibited by B20 fuels respectively. The 10% aromatic fuel exhibited 12% lower PM and 6% lower NOx. NOx emission was decreased by 6.5% for 20% blend of soybean with diesel [53]. Humke and Barsic were conducted an experiment on a single cylinder naturally aspirated direct injection diesel engine to evaluate the performance and emission characteristics of soybean oil and its blends with diesel and de-gummed soybean oil. In comparison to diesel, thermal efficiency lowered 1 to 2% and 1 to 2 g/kWh lower NOX, 2 to 20 g/kWh more CO, 1 to 2 g/kWh more hydrocarbons and 1 to 2 g/kWh more particulates with vegetable oils. High smoke level is also reported with soybean oil in comparison to diesel. During 25 hours of testing at 2200 rpm with vegetable oil, thermal efficiency losses ranged from 1 to 6% and particulate emissions increased from 2 g/kWh to 14 g/kWh due to nozzle deposits [54]. Fuls et al. Were tested a wide range of diesel engines used in agricultural tractors with degummed sunflower oil as fuel. In all cases they found the performance of the tractors was almost same as that of diesel fuel. They have observed the few problems such as carbon build up on injection nozzles, sticking piston rings and lubricating oil polymerization in direct injection diesel engines with prolonged use of raw sunflower oil. They concluded that vegetable oils can be directly used for short term engine operation without any modification and long term tests will affect the engine durability [55]. Alptekin were used methyl esters produced from five edible vegetable oils blended with two different fuels with different ratios. As methyl ester percentage in the fuel blend increased the viscosity and density of all blends were observed to be increased. With increase in the amount of ethyl esters in the blends boiling ranges were observed to be closer. The results showed that fuel properties of the blends were very close to those of diesel fuel at concentrations upto 20% of methyl esters [57].

V. EFFECT OF NON-EDIBLE OILS ON CHARACTERISTICS OF CIDI ENGINE

Georgios Fontaras et al., [19] presented a detailed study conducted on a Euro-3-compliant diesel passenger car and a high injection pressure test bench engine using 10% cotton seed oil- 90% diesel blends as fuel. The test included fuel consumption and emission measurements. The aim of the experiment was to accurately evaluate the effect of bio-fuel on a common rail engine. The measurement protocol included the measurements of regulated emissions, fuel consumption and in-cylinder pressure at various operation modes. Results from the bench engine measurements were in line with those retrieved from the vehicle and indicate that under certain conditions it can be applied as automotive fuel in a broader scale. Recep Alton et al., [20] investigated the effects of vegetable oil fuels and their methyl esters (raw sun flower oil, raw cotton seed oil, raw soybean oil and their methyl esters, refined corn oil, distilled opium poppy oil and refined rapeseed oil) on a direct injected , four stroke, single cylinder diesel engine. The results show that from the performance point of view, both vegetable oils and their esters were promising alternatives as fuel for diesel engine. Because of their high viscosity, drying with time and thickening in cold conditions, vegetable oil fuels still have problems, such as low atomization and heavy particulate emissions. Stalin et al., [21] produced bio-diesel from Karanja oil by alkali catalysed transesterification process. The performance of I.C. engine using Karanja bio-diesel blended with diesel at various blending ratios has been evaluated. The test results indicated that the dual fuel combination of B40 can be used in diesel engine without making any engine modification. Masjuki et al., [22] presented an -experimental result, which was carried out to evaluate exhaust gas emissions and deposit characteristics of a small diesel engine when operated on preheated crude palm oil (CPO) and its emulsions with 1%, 2%, and 3% water. The test was conducted for 100 hrs using each of these test fuels at a constant speed of 2700 rpm and at 5.50 Nm load. The engine was disassembled after the test to scrape carbon deposits from the piston and cylinder walls. Ordinary diesel fuel (OD) scrape was used for comparison purposes. It was observed that the exhaust emissions such as CO, HC and PM were reduced, when the engine was operated with preheated CPO as compared to the OD and CPO emulsified fuels. This was mainly attributed to the fact that the preheating of CPO reduces its viscosity to the level of OD, which improves the fuel spray and atomization characteristics and produces complete combustion. However, preheated CPO increased the NO emission as compared to OD and CPO emulsified fuels. This was mainly attributed from the deposit characteristic result, which showed that the preheated CPO increased the highest fraction of ash deposit as compared to OD and CPO emulsified fuels and this was the reason for increased NO„ emissions. Deepak Agarwal et al., [23] has studied the effect of reducing the viscosity of Jatropha oil by increasing the fuel temperature using the waste heat of exhaust gases and thereby eliminating its effect on combustion and emission characteristics of engine. A single cylinder, four stroke, constant speed, water cooled, direct injection diesel engine typically used in agricultural sector was used for the experiments. The various parameters such as thermal efficiency, BSFC, smoke opacity, and CO_2, CO and HC emissions were estimated and the results revealed that performance and emission parameters were very close to mineral diesel for lower blend concentrations. However, for higher blend concentrations, the performance and emissions were observed to be marginally inferior. B20 blend has the finest performance than all other blends of Jatropha oil. Long run tests were conducted using optimized blend. It was found that the blend fuelled engine has higher carbon deposits inside combustion chamber than diesel fuelled engine. The utilization of these blends requires frequent cleaning of fuel filter, pump and the combustion chamber. Hence, it was recommended that the rubber seed oil and diesel blend fuel was more suitable for rural power generation. Agarwal Deepak et al., [24] revealed from their experiments that, the biodiesel fuelled diesel engines produce less carbon monoxide (CO), unburned hydrocarbon (HC) and particulate matter (PM) emissions compared to mineral biodiesel fuel, but higher NOx emissions. The drawback of higher NOx emission was overcome by employing EGR. The objective of the work was to investigate the use of bio-diesel and EGR simultaneously in order to reduce the emissions of regulated pollutants from the diesel engine. A two cylinder, air cooled, constant speed, direct injection diesel engine was used for the experiment. It was found that, the application of EGR with bio-diesel blends resulted in reductions of NOx emission without any significant penalty in PM emission or brake specific fuel consumption. Senthil et al. [25] have conducted experimental investigations on a Jatropha oil methanol dual fuel engine. In this work a single cylinder diesel engine was converted to use Jatropha oil as the pilot fuel and methanol as the inducted primary fuel. Tests were conducted at 1500 rpm and full load. Methanol and Jatropha oil were used in different quantities and experimental results revealed that brake thermal efficiency increased in the dual fuel mode when both Jatropha oil and diesel were used as pilot fuel. The max. BTE was 31% with Jatropha oil and 32% wit, diesel. The smoke was reduced from 4.4 BSU to 1.6 BSU with pure Jatropha oil operation in the dual fuel mode. Hydrocarbon and carbon monoxide emissions were higher in the dual fuel mode with both fuels. Ignition delay and combustion duration were increased with jatropha oil and diesel in dual fuel operation. Heat release with neat jatropha oil indicates higher diffusion burning and lower premixed burning rates as compared to diesel. These phases were not distinguishable in the dual fuel mode. Pugazhvadivu et al., [26] were carried-out an experimental investigation on waste frying oil and disclosed that the waste frying oil requires heating temp of 135°C to bring down the viscosity like diesel at 30°C. It was also observed that the performance was improved and carbon monoxide and smoke emissions were reduced using preheated waste frying oil and concluded that the waste frying oil preheated to 135° C could be used as a biodiesel for short term engine operation. Murayama et al., [27] were conducted experiments and evaluated the engine performance and emission characteristics of a waste vegetable oil as biodiesel using direct injection and indirect injection diesel engines. The research results revealed that, for engine performance, the esterified fuel was at par with light oil. For the emission of particulates, with the IDI diesel engine there was no significant difference between the light oil; however, the DI engine proved to emit a much larger quantity of particulates in the low to middle range. The research also revealed the necessity of countermeasures against solidification of the fuel during the winter months. Wang et al., [28] carried out experiments to evaluate the performance and gaseous emission characteristics of a diesel engine when fuelled with vegetable oil and its blends of vegetable oil with diesel fuel separately. A series of tests were conducted and repeated for six times for each of the test fuels. The experiment was carried out at different loads and at a fixed speed of 1500 rpm. The experimental results showed that the basic engine performance and power output and fuel consumption were comparable with diesel when fuelled with vegetable oil and its blends. The emission of NOx from vegetable oil and its blends were lower than that of pure diesel fuel. The results from the experiments proved that vegetable oil and its blends were potentially good substitute fuels for diesel engine. Venkateswara Rao et al [29] conducted experimental investigation of Pungamia, Jatropha and Neem methyl esters as bio-diesel on C.I. Engine. Experimental investigations were carried out to examine properties, performance and emissions of different blends (B10, B20 and B40) of pungamia methyl ester, Jatropha methyl ester and Neem methyl ester in comparison to diesel. Results indicated that B20 have closer performance to diesel and B100 had lower brake thermal efficiency mainly due to its viscosity compared to diesel. However, its diesel blends showed reasonable efficiencies, lower smoke, CO and HC. Pungatnia methyl ester gave better performance compared to Jatropha and Neem methyl esters. Kalbande et al., [30] prepared the Karanja bio-diesel using alkali catalyzed tranesterfication and utilized it in diesel engine generator for power production. Bio-diesel produced using developed bio-diesel processor and its specified blends with diesel were used to run electric generator for power generation. Karanj bio-diesel and its specified blends as B20, B40, B60, B80 and B100 by volume were used to run electric generator. The generator was operating very smoothly without any noise and knocking on pure bio-diesel and its blends. It was observed that the overall efficiency of B20 and B100 blend proportions were found more than other blending proportions. The engine was run more efficiently on B20 and B100 fuel proportions for the production of 6000 watt electricity. G. Lakshmi Narayana Rao et al.,[31] studied the combustion and emission characteristics of a diesel engine fuelled with used cooking oil methyl ester (UCME) and its diesel blends. In this study, used cooking oil was dehydrated and then transesterified using an alkaline catalyst. Tests were conducted on a 4.4 kW, single cylinder, naturally aspirated, direct injection, air cooled stationery diesel engine. It was observed that, the ignition delay of UCME and its blends was found to be lesser as compared to that of diesel. The peak pressure of UCME-diesel was higher than that of diesel. With increase in percentage of UCME in the blend, the maximum rate of pressure rise and maximum heat release rate decrease. A minor decrease in thermal efficiency with significant improvement in reduction of particulates, carbon monoxide and unburnt hydrocarbons was observed compared to diesel. The NOx emissions of the UCME and its diesel blends were noted to be slightly higher than diesel. Lakshmi Narayana Rao et al., [32] studied the combustion and emission characteristics of diesel engine fuelled with Rice Bran oil methyl ester (RBME) and its diesel blends. The RBME is prepared through transesterification and the properties attained will match with ASTM Bio-diesel standards. Tests were conducted on a 4.4 kW, single cylinder, naturally aspirated, direct injection, air cooled stationary diesel engine to evaluate the feasibility of RBME and its diesel blends as alternate fuels. The ignition delay and its peak heat release for RBME and its diesel blends were found to be lower than that of diesel and the ignition delay decreases with increase in RBME in the blend. Maximum heat release was found to occur earlier for RBME and its diesel blends than diesel. It was also observed that, as the amount of RBME in the blend increases the HC, CO and soot concentrations in the exhaust decreased when compared to mineral diesel. The NOx emissions of the RBME and its diesel blends were slightly higher than diesel. Forson et al., [33] conducted an experimental study of Jatropha oil-diesel blends on a single cylinder air cooled Lister model direct injection diesel engine. It was found that 2.6% Jatropha oil with 97.4% of diesel was the optimum blend to give higher thermal efficiency and power output and lower CO and CO2 emissions at all loads. Reddy et al., [34] carried out experiments to study the effect of variation of injection system parameters such as injection rate, injection timing, injector opening pressure, and swirl level on the performance and emission of Jatropha oil fuelled small, single cylinder, air cooled direct injection diesel engine used for agricultural purposes. They reported the optimum injection parameters for higher thermal efficiency and lower emissions as: static injection timing 33.5° BTDC, injector opening pressure 220 bar, injection rate corresponding to 9 mm plunger diameter. They also demonstrated the effect of injection system parameters on the heat release diagram and on various stages of combustion. They employed swirl enhancement to determine its effects on performance and emissions and found that the thermal efficiency has not been improved, but HC and smoke levels were decreased significantly with swirl. However it increased NO level considerably. Chollacoop et al., have been investigated the effects of high quality biodiesel, namely, partially Hydrogenated Fatty Acid Methyl Ester or H-FAME, on 50,000km on-road durability test of unmodified common-rail vehicle. They concluded based on the assessment on the use of B10 from Jatropha H-FAME in unmodified common-rail vehicle over 50,000km shown no substantial difference from the normal diesel criteria. Maximum torque and power were within 3% variation from rated values throughout 50,000km. Euro III emission regulation was clear for NOx and HC+NOx while CO and PM can beneficially clear Euro IV emission regulation. [44] Kumar et al., has conducted experiment on CI engine using Jatropha Oil Methyl Ester (JME) and observed that brake thermal efficiency (BTE) was found to increase with increase in volume fraction of n-butanol in vegetable oil based fuels. Also brake specific energy consumption was found to decrease with increased amount of n-butanol. The reduction in smoke opacity, oxides of nitrogen (NOx) and carbon monoxide (CO) emissions was observed with addition of n-butanol, however, hydrocarbon emissions increased with substitution of n-butanol [50]. Vallinayagam et al., were studied the Combustion performance and emission characteristics using pine oil in a diesel engine and revealed at full load condition, neat pine oil reduces CO (carbon monoxide), HC (hydrocarbon) and smoke emissions by 65%, 30% and 70%, respectively. The brake thermal efficiency and maximum heat release rate increase by 5% and 27%, respectively. However, the NOx (oxides of nitrogen) emission is higher than that of diesel fuel at full load condition. The experimental work reveals that 100% pine oil can be directly used in diesel engine and potential benefits of pine oil bio-fuel have been reaped. [51] Huzayyin et al., were conducted experiments using jojoba oil instead of diesel engine fuel and blending of jojoba oil with gas oil has been shown to be an effective method to reduce engine problems associated with the high viscosity of jojoba oil. Experimental measurements of different performance parameters of a single cylinder, naturally aspirated, direct injection, Diesel engine have been performed using gas oil and blends of gas oil with jojoba oil. Measurements of engine performance parameters at different load conditions over the engine speed range have generally indicated a negligible loss of engine power, a slight increase in BSFC, a reduction in NOX and soot emission using blends of jojoba oil with gas oil as compared to gas oil. The reduction in engine soot emission has been observed to increase with the increase of jojoba oil percentage in the fuel blend. Further enhancement in the engine performance parameters are expected using minor modifications in the engine operating conditions, such as injection timing and pressure that can be optimized as a function of the jojoba–gas oil blend ratio [56]. Matheaus et al., conducted experimental investigation of PCCI-DI combustion on a four cylinder light duty diesel engine with ultra-low Sulphur (less than 10 ppm) diesel fuel. Electronic control unit (ECU) of the engine was replaced with custom designed controller for obtaining the premixed charge with early pilot injections (up to three). The study reveals the potentional for reducing NOx emissions with PCCI-DI combustion at light loads (below 30%) and medium to low speeds. The test results indicated NO_x reduction of 9 to 15% under various operating conditions [58]. Lu-Yen Chen et al., were developed correlations for the calorific heat, cold filter plugging point, density, kinematic viscosity, and oxidation stability of Jatropha oil methyl esters (JOMEs) blended with diesel at various volumetric percentages. The results revealed higher brake thermal efficiency at higher power output. The concentration of CO_2 and NO were observed to increase with load while the concentration of O_2 and CO decreased[61].

VI. EFFECT OF ANIMAL FAT OILS ON CHARACTERISTICS OF CIDI ENGINE

In general, the fish waste parts such as fins, viscera, tails, eyes are substantially discarded and those were mostly used as fish meal for livestock and have very modest economic value. However, the crude waste fish oil extracted from these discarded parts may provide profuse, inexpensive, and stable source of raw oil to allow the countries like India which have vast coastal area to produce biodiesel and thus help to reduce dangerous emissions. Kerihuel et al., were evaluated the performance of the diesel engine with micro emulsions of animal fat with water and methanol and recorded higher volumetric efficiency with micro emulsions and lower exhaust gas temperature when compared to neat diesel. Lower carbon monoxide, unburnt hydrocarbon, Nitrogen oxide emissions were also found with micro emulsions[35] . Metin et al., were studied the fat of chicken as biodiesel with synthetic Mg additive used in a single-cylinder diesel engine and its effects on performance and exhaust emissions. The results revealed that there was not considerable change in engine torque with the addition of 10% chicken fat biodiesel, while the specific fuel consumption increased due to the lower heating value of biodiesel, but smoke emissions and CO has decreased, and NOx emission has increased [36]. Cengiz Oner et al., were conducted investigations using biodiesel that was produced from inedible animal tallow and identified that viscosity and density of fatty acid methyl ester are very close to that of diesel where as the calorific value of biodiesel is found to be slightly lower than that of diesel. Due to lower heating value of biodiesel, the addition of biodiesel to diesel fuel decreases the thermal efficiency of engine and increase specific fuel consumption. However, the effective engine power was comparable to diesel fuel. They also revealed that B20, lowest CO, NOx emissions and the highest exhaust temperature were obtained among all other fuels and B100 were reduced emissions of CO, NOx, SO2 and smoke opacity [37]. Cherng-Yuan et.al., were prepared fish oil by using the discarded parts of mixed fish species as the raw material and transesterified fish oil methyl ester to produce biodiesel and identified that biodiesel from waste cooking oil has a larger gross heating value, higher cetane index, elemental carbon and hydrogen content, higher NOx emission, exhaust gas temperature and black smoke opacity and a lower elemental oxygen content, fuel consumption rate, brake-specific fuel consumption rate when compared with fish oil [38] . Lin & Li., [39] used the discarded parts of mixed marine fish species as the raw material to produce biodiesel and tested the same in direct-injection, four-cylinder, four stroke, and naturally aspirated diesel engine. The results revealed that compared with commercial biodiesel from waste cooking oil, marine fish-oil biodiesel had a larger gross heating value, elemental carbon and hydrogen content and cetane index. The marine fish oil conversion efficiency, NOx and black smoke opacity and lower elemental oxygen content, brake specific fuel consumption rate and CO emission compared to waste cooking oil biodiesel. Preto et al., [40] carried-out investigations on combustion properties of fish oil as biodiesel for conventional boilers and furnaces and highlighted that emissions were lower than burning pure fuel oil except that of NO which was higher for blends and it indicated good combustion properties, considerable economical benefits. NO emission was recorded to increase with increase of additional air, while emissions of SO_2 and carbon monoxide did not verify substantial reliance on excess air. Godiganur et al., [41] tested methyl ester of fish oil and its blends with diesel fuel on a Kirloskar diesel engine at constant speed of 1500 rpm under variable load conditions and the max thermal efficiency for B20 was higher than that of diesel. BTE obtained with B40, B60, B80 and B 100 was less than that of diesel due to higher specific energy consumption at various brake power outputs. It was reported that 20% blend gave the optimum results. CO and HC emissions were decreased and NOx, increased as the percentage of methyl ester in the blend increased. B100 which was less than that of diesel due to the intrinsic oxygen content of biodiesel. The NO produced with B10 to B 100 varied between 157-509 ppm as compared to 124 and 425 ppm for diesel due to the oxygen content in fish oil methyl ester which facilitated NOx formation. Sakthivel et al., has prepared biodiesel using waste parts of fish parts using ethyl and studied various properties such as viscosity, density, calorific value and flash point of biodiesel and biodiesel-diesel blends of different proportions. The properties of biodiesel were found to be similar to that of diesel. Engine performance and emission characteristics were examined in a single-cylinder, constant speed, and direct injection engine under variable load conditions. The test results showed no significant change in the engine performance and reduction of main noxious emissions such as CO, HC, NOx and smoke with the marginal increase of CO_2. Ultimately, fish oil can indeed become the appropriate source for biodiesel, with environmental benefits [42].

VII. OPTIMZATION OF BIODIESEL USED IN CIDI ENGINE

Meher et wl., were investigated for optimization of alkali catalyst methanolysis of Pongamia Pinnata oil and recorded that 97 – 98% of yield with 6:1 molar ratio of MeOH to oil, 65 °C temperature, and 360 rpm stirring speed within two hours[62] . Sun Tae et al. (2010) were used Taguchi method for optimization of process parameters for rapeseed methyl ester production and revealed that 96.7% yield of biodiesel was achieved using Potassium hydroxide as the catalyst and 60°C of reaction temperature as optimized parameters values [63]. Jindal et al., were evaluated the diesel engine fuelled with 100% Jatropha methyl ester for best performance and emission characteristics and concluded that a compression ratio of 18 and injection pressure of 250 bar were the optimum working conditions to run the engine without any compromise on engine performance and emission characteristics [64] .

VIII. CONCLUSIONS

The comprehensive research review on biodiesels categorically confirming that edible oils such as soybeans oil, coconut oil, sunflower oil, palm oil etc., non-edible oils such as neem oil, mahua oil, jatropha oil, cotton seed oil, pungami oil etc., and animal fats such as animal tallow, chicken fat, crude fish oil and their esters can be used as complete or partial substitute for diesel as renewable energy sources. The transesterification process will help to improve the quality of the biodiesels by reducing the viscosity, boiling point, flash point, pour point and completely removing the glycerides which make the vegetable and animal fat oils compatible with diesel. It also corroborating that the usage of edible oils in the preparation of biodiesels is not preferable, because it competes with food products and creates food crisis in extremely populated countries like India, China and other Asian countries. Instead, non-edible oils and animal fat oils are other best options for biodiesel preparation. The non-edible oil plants are less expensive to cultivate with little amount of water, requires less maintenance, can grow on all types of weather conditions and soils with high crop yield and has the ability to cultivate well on infertility soils.

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