Journal of Green Engineering (JGE)

Volume-10, Issue-12, December 2020

Exhausted Edible Oil, Performance as Fuel, C.I Engine – A Review

[1]Adhirath Mandal and [2]HaengMuk Cho

[1] Doctorate Student, Dept. of Mechanical Engineering, Kongju National University, Republic of Korea.
E-mail: adhirath.mandal@gmail.com.
[2] Professor, Dept. of Mechanical Engineering, Kongju National University, Republic of Korea.
E-mail: hmcho@kongju.ac.kr

Abstract

Need for energy is increasing day by day and the use of clean fuel is becoming important. Everyone needs a clean environment and is an important concern. The energy source used conventionally is not nonrenewable. Use and extraction of such energy source increase pollution and also have a damaging effect on the environment. Increasing the urbanization, demand and emission from the conventional fuels created a demand for an efficient and alternative energy source. The production process of energy should be developed which can cater to the demand for environmentally safe, renewable and sustainable. To meet the growing demand, renewable energy should have cost-competitive and economical. The transportation sector plays a major role in the consumption of crude oil. It is almost 1/3rd of the total crude oil. Thus transportation is the major contributor to greenhouse gas emission. Demand for fuel is anticipated to rise by 40% because of the transportation sector in a period of 2010-2040. There are a lot of advantages of using biodiesel, but from a sustainability point of view, it was not advisable to produce biodiesel from food crops. Generation of biodiesel from used or waste cooking oil is a good idea as it does not pose any threat to the food crops. This paper gives a review of the use and characteristics of waste cooking oil biodiesel used in a compression ignition engine.

Journal of Green Engineering, Vol. 10_12, 12766-12784.

Keywords: Waste cooking oil, Biodiesel, NOx, CO, HC.

1 Introduction

Need for energy is increasing day by day and use of clean fuel is becoming important. Everyone need a clean environment and is an important concern. The energy source used conventionally are not nonrenewable. Use and extraction of such energy source increases pollution and also have a damaging effect on the environment. Increasing urbanization, increase the demand and also increase the emission from the conventional fuels which created a demand for efficient and alternative energy source. Production process of energy should be developed which can cater the demand of environmentally safe, renewable and sustainable. To meet the growing demand, renewable energy should be cost competitive and economical. The transportation sector plays a major role in the consumption of crude oil. Which is almost 1/3rd of the total crude oil. Thus transportation is the major contributor of greenhouse gas emission. Demand for fuel is anticipated to rise by 40% because of the transportation sector in a period of 2010-2040. Because of the increasing demand of fuel, devolvement of alternate fuel are being researched. The immediate replacement of a conventional fuel is, biodiesel which can replace diesel, consisting of fatty acid alkyl esters [1].

Methyl/ethyl esters of long chain fatty acids are known as biodiesel. Biodiesel is one of the alternate fuels which is popular. It has features of being non-toxic, biodegradable, carbon neutrality and renewable. Because of similar physiochemical property of biodiesel, it can be replaced by diesel in a diesel engine with small modification or no modification.

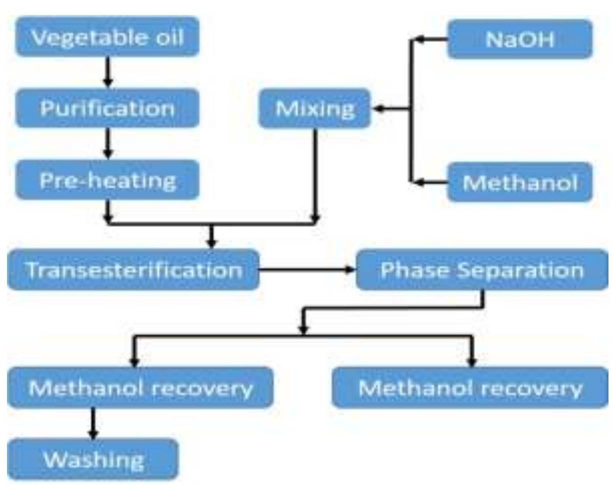

Figure 1 Yielding process of biodiesel [3]

There are a lot of advantages of using biodiesel, but from sustainability point of view it was not advisable to produce biodiesel from food crops. A general biodiesel production process is shown in figure 1. Biodiesel yielding from used or waste cooking, good idea as it does not poses any threat to the food crops. Utilization of waste or used cooking oil for the yield of biodiesel is economical [2][3].

2 Literature Review

Y. Zhang et al. [4] Discussed on the four different ways to yield biodiesel from waste/used cooking oil and virgin vegetable oil. It was developed under acidic or alkaline condition for commercial scale. A classification of the 4 processes was carried out to evaluate their advantages and disadvantages. The use of used cooking oil to create biodiesel reduced the raw material cost. The catalysatin process by acid using WCO witnessed to be executable with less ramification than the catalysed process by alkali-using used edible cooking oil. Therefore making it a competitive alternative to commercial biodiesel production by the alkali-catalysed process. **L. Wei et al. [5]** studied on the diesel engine run by waste cooking oil biodiesel. Probed on the particulate & gaseous emission and combustion in a diesel engine by the use of WCOB. A DI-diesel engine was used for the experimentation, 13-mode test cycle of Japanese, with 20%, 50% and 75%(B20, B50, B75) biodiesel on volume basis was used. With the use of biodiesel, in-cylinder pressure increases, maximum heat release rate is reduced and combustion & ignition delay in shortened. With the use of biodiesel the break specific fuel consumption also increased. There was no substantial change in break thermal efficiency. 1,3-butadiene, benzene, formaldehyde, ethane, propene and acetaldehyde increased the weighted brake specific emission but toluene and xylene reduced the weighted brake specific emission. The increase in weighted brake specific was because of the accelerated pyrolysis of long chain molecules in higher combustion temperature and in-cylinder high pressure. The decrease was reasoned as toluene and xylene have oxygen which encourages oxidation reaction. Ozone formation was not observed for any significant changes for the unregulated gaseous emissions for the test fuels. With use of biodiesel it was observed that weighted particle mass concentration and GMD was reduced but weighted total number concentration. Linear regression was conducted for particulate matter and weighted unregulated gases, results showed that correlation coefficient more than 0.9 was obtained which proven that biodiesel content was proportional to PM emission and unregulated gaseous.

Sahar et al. [6] researched on making biodiesel form used oil as it is a choice to make at less cost. Transesterification is difficult with high free fatty acids in waste oil which is a constriction for the process. WCO-biodiesel produced, having acid value was 5.5 mg KOH/g, this also showed that FFA was high. By the use of HCL, H_3PO_4, & H_2SO_4 (all acidic catalyst), esterification of languish cooking oil was carried out, this method reduced the FFA by 88.8% at 60^0C with methanol to oil molar ratio by 1:2.5. In the presence of KOH and fatty acid methyl ester transesterification, which yield 94% at 50 ^{0}C at 1% catalyst. Characterization was carried out on the basis of iodine value, viscosity, acidic value, specific gravity, calorific value, saponification value, pour point, cetane number and cloud point. Synthesized biodiesel was analyzed by gas chromatography. Method of producing biodiesel by alkali catalyzed transesterification, an efficient method of producing waste cooking oil biodiesel. 1:3 methanol to oil archived 94% FAME yield at 60 ^{o}C reaction temp and 1% catalyst. Biodiesel was made by linoleic acid, oleic acid, palmitic acid and stearic acid as the main component. Pretreatment of waste cooking oil biodiesle by acid followed by catalyzed reaction was a good method for treatment of waste cooking oil. **Peng Geng et al. [7]** studied on the use of biodiesel in large ocean going ships for production of electricity. For the production of electricity with the use of diesel produces a lot of harmful emission. Alternate fuel are being suggested to reduce the emission in the marine diesel engine. Emissions of a 6-cyclinder turbocharged, inter-cooled direct-injection marine diesel engine, emission and combustion characteristics was studied by utilizing clean Exhausted edible oil biodiesel, Biodiesel-70% diesel-30%, B90 and Ultralow Sulfur Diesel. Study on NO_x emission was studied with high biodiesel to diesel ratio at different loads of 25, 50 and 75% engine load at 1050to1500rpm speed situations. It was observed that with increase in biodiesel content the in-cylinder pressure decreased with reduction in ignition delay, advance in ignition and longer combustion duration. Max heat release rate was reduced, low load. The reduction was 14.3% and maximum HRR was 21.3% when the load was high. With increase in engine load, increase in peak heat release rate and cylinder pressure was observed. With increase in biodiesel content, temperature in the exhaust manifold reduces. Use of high substitution ratio of biodiesel, significantly reduces the NO_x emission because of cylinder temperature reduction in the diffusion combustion mode. Increase in biodiesel content and engine load, NO_2/No emission decreases. **Xianbao Shen et al. [8]** measured emission of on-road diesel vehicle which was fuelled with waste cooking oil biodiesel, with the love of portable emission measurement system. 2 LDDT truck and 2 HDDT truck was filled with 4 mixed fuels with different blend ratio. The ratio of blend was 0%, 5%, 20% and 100%. With the use of biodiesel + conventional diesel it was observed that there was no decrease in fuel consumption. Using exhausted edible oil biodiesel and mixing with diesel helps in reducing emission, gives energy security and food security as well. With increasing biodiesel content in the mixture it was observed that HC, NO_x, CO and $PM_{2.5}$ decreases. In all the blends, emission was lowest in highway condition than non-highway. Biodiesel blend which were below 12.5% showed better emission characteristics (especially B5) than neat diesel in non-highway conditions. CO, NO_x, HC and $PM_{2.5}$ were reduced by increasing blend ratio. **Mangesh G. Kulkarni et al. [9]** discussed on using biodiesel form waste edible oil. Fatty acid methyl ester biodiesel is an alternative fuel which is biodegradable and nontoxic and produced form renewable source. The major difference in making biodiesel available in the market is that the manufacturing cost and raw material cost is more than conventional diesel. The only low cost biodiesel production technique is by used cooking oil. As the cooking oil are being used for frying, which forms polymerized triglycerides and free fatty acid which affects the property of the biodiesel and transesterification reaction also. Transesterification process must be selected in the free fatty acid and water content. If FFA and water are <1 wt% and <0.5 wt% then alkaline catalyst is suitable, if FFA is more than 1 wt% than acidic catalyst should be selected. These catalyst were not recommended for transesterification because of high molar concentration, corrosion problem and high catalyst concentration, for waste cooking oil. Biodiesel processing would become costly if two-step (acid catalyzed and alkaline catalyzed step) process is adopted, which is also not friable. For chemical catalyzed reaction, enzyme-catalyzed transesterification is a good option which must be developed for commercialization. For making biodiesel from WCO, potential in catalyst-free supercritical methanol method was observed. But high molar ratio, pressure and temperature make it difficult for industrial scale. Emission are less and performance of the engine is better when commercial engine was run on waste cooking oil biodiesel, except NO_x and Conradson carbon residue.

Magín Lapuerta et al. [10] researched on two different biodiesel which were obtained from used edible oil. The two different biodiesel were methyl ester and ethyl ester, driven by alcohol. The biodiesel and conventional diesel were tested on a CRDI engine of 2.2L. Biodiesel was tested as pure and in a blend of 30% & 70% volume basis. European drive cycle was used to simulate the operation mode. Pure biodiesel resulted in increase in fuel consumption compared to reference fuel. With use of biodiesel NO_x emission was reduced slightly, but in case of smoke opacity, total hydrocarbon emission, particle emission there was sharp reduction, although volatile organic fraction increased. Alcohol used in the yield of biodiesel showed effect in the HC emission and PM composition. Volatile organic fraction of the particulate matter & Hydrocarbon emissions were noted to increase.

Engine test were performed in the European drive cycle under medium load and under load conditions with 100% biodiesel and blends of ethyl ester and methyl blends. The results observed from these conditions showed that particulate matter, smoke opacity and hydro carbon emission was reduced to great extent by using waste cooking oil biodiesel fuel. In the event of use of methyl ester the potential was higher, but a good correlation was derived in the case of soot formation process with molecular oxygen concentration. **Lijiang Wei et al. [11]** reached on the use of biodiesel in the marine diesel engine. It was seen as an promising option to reduce the emissions. Experimental investigation on the use of used edible oil biodiesel, to study NOx emission, combustion process and the composition ratio. Biodiesel and diesel blends of 4 types were used. It was observed that with increase in ratio of biodiesel blend, there was decrease in peak of heat release rate. At 1050rpm and 1500rpm speed, PHRR reduction was 11.04% and 19.86%. with increase in biodiesel blend brake thermal efficiency changed little but brake specific fuel consumption increased. With 1050rpm and 1500rpm at B50, different engine load the max increment in brake specific fuel consumption were 7-8.3% and 5.1-6.1%. NOx emission decreased with increase in biodiesel blend and with decline in in-cylinder temp NO2/NOx slowly increased. With increase in load and engine speed, significant reduction in NO2/NO for in-cylinder cooler regions. Waste cooking oil biodiesel could be considered for auxiliary diesel engine in marine. **X.J. Mana et al. [12]** focused on the emission in a direct injection engine which was naturally aspirated, which were fueled with B10, B20, B30, B100 (Biodiesel 100%) & neat diesel. 13 mode test cycle was used to conduct the experiment for the diesel engine so that regulated and unregulated emission influenced by engine speed and engine loads could be identified. For the experimental observations it was seen that HC, particulate matter mass concentration and CO decreased whereas NO_x increased with increase in biodiesel blend ratio. By increasing the biodiesel content, emission of acetaldehyde and formaldehyde & unregulated emission also increased. In the case of ethene, propene and 1-3 butadiene the trend was same. Benzene emission increased by increase in the content of biodiesel but at the same time xylene and toluene emission reduced. As benzene increased was balanced by decrease in toluene and xylene, BTX emission was not changed. All the emission were affected by the load and engine speed. Some emission could increase like, ethane, 1,3-butadine, benzene, formaldehyde, propene & acetaldehyde with increase in biodiesel fuel , but reduce the hydrocarbon emission. **Cheng Tung Chong et al. [13]** experimented by using pool flames using extinction calibrated laser induced-incandescence (LII) and pre-vaporised diffusion jet flames under total carbon flow to compare and quantify the soot volume fraction of waste cooking oil biodiesel and its bled. Soot is formed highest at the flame and convected downstream for diesel fuel, but in the condition of biodiesel, soot volume fraction is the center of the flame was evenly distributed. Soot tendency reduced by increasing the biodiesel fraction which was visible in vapour flame and pool flame. SVF profiles for pool flame was noticed when radial profile of SVF was compared along the centerline, residence time for soot diffusion and growth compared to vapour flame was reflected, this showed that the pool burner had low mass flux. At higher temperature the diesel rich fuel flame soot was found which convert quickly upwards. 62.9nm (pool) for biodiesel and 51.6 for diesel. Soot produced was higher in the vapour flame than pool flame by a factor of two, mass consumption rate for same fuel. Soot volume fraction for waste cooking oil biodiesel was lowest irrespective of the flame type and owing to fuel chemistry and aromatic compound absent. The diameter of soot primary particle size was 1.5 lower mean diameter for waste cooking oil biodiesel than diesel produced soot. Large diameter particles of 22% was produced for diesel by pool flame and 8% for biodiesel. **Yuan-Chung Lin et al. [14]** discussed on the cost of commercialization of biodiesel. The costliest part of the biodiesel is the raw material. To reduce the cost of biodiesel, raw material cost has to be reduced, which could be reduced by the use of waste cooking oil. Another problem is solve, i.e waste disposal by the use of WCO. The investigation was accomplished on a heavy duty diesel engine to calculate brake specific fuel consumption, polycyclic aromatic hydrocarbons & carcinogenic potencies and regulated matter, under US-HDD transient cycle. The investigation was carried out on 5 different test fuels, 1. ultra-low sulfur diesel (ULSD), 2. WCOB5, 3. WCOB10, 4. WCOB20, and WCOB30.

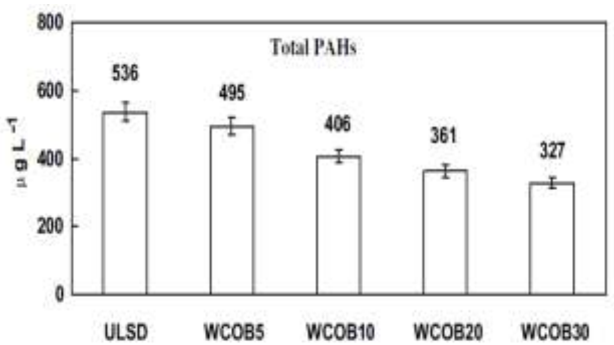

Figure 2 PAH Emission for Different Blends [14]

Results showed that blend of waste cooking oil biodiesel and ULSD showed reduced CO, PM and HC emission with respect to ULSD. CO lowered by 3.33%-13.1%, PAHs decreased by 7.53%-37.5%, HC reduced by 10.5%-36.0% and PM reduced by 5.29%-8.32% by use of ULSD/WCOB blend compared to ULSD. With the use of waste cooking oil CO, HC and PM reduced and at the same time combustion efficiency increased. PAH in WCOB is not present because of which the biodiesel blend with high fraction resulted in lower PAH emission as shown in figure 2. Volumetric consumption was smaller between biodiesel a diesel because volumetric injection was compensated by high density biodiesel. **Joonsik Hwang et al. [15]** investigated on biodiesel made from WCO in a CRDI single cylinder diesel engine to study the effect of injection timing and injection pressure on the emission and combustion characteristics and compared it with commercial diesel. Fuel property were compared to the conventional fuel including fatty acid composition.80 MPa and 160Mpa was the selected injection pressure in the test engine and 25 and 0 crank angle were selected for injection timing after top dead center at 2 different engine load. In casse of biodiesel the indicated specific fuel consumption in respect to injection timing was higher than diesel in all cases.

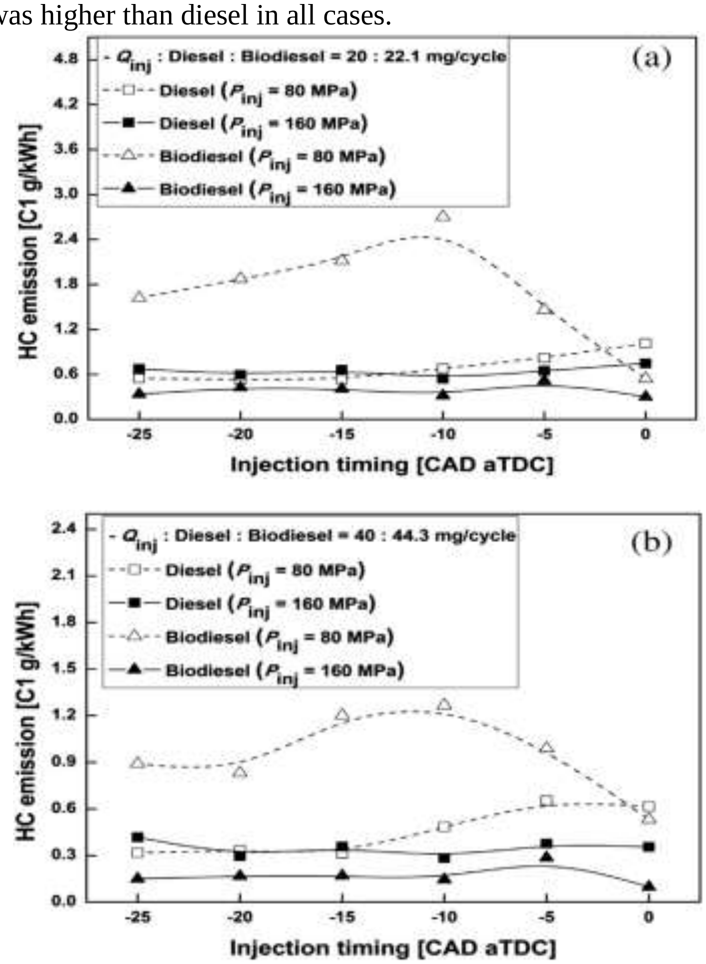

Figure 3 HC Emission with Injection Timing at Different Load (A) Low Load, (B) High Load [15].

For biodiesel, lower peak heat release rate and peak cylinder pressure was observed but longer ignition delay was seen in all conditions. HC emission comparison of different fuel with different load condition could be seen in Figure 3. Hydrocarbon, carbon monoxide emission and smoke as reduced with the use of biodiesel especially at high injection pressure. NO_x was comparatively higher for biodiesel compared to diesel. **Ali M.A. Attia et al. [16]** produced biodiesel from disposed cooking oil by transesterification process, waste cooking oil methyl ester. Experimental evaluation of engine performance on different WCOME and conventional diesel blend were tested. Effect on soot tendency and viscosity was investigated by the use of exhausted edible oil biodiesel and its blend with diesel. The performance of the engine was measured at an RPM of 1500 and at different engine load, in terms of engine and environmental aspect and in-cylinder pressure. It was observed that biodiesel blend ratio and engine load decides the in-cylinder peak pressure. Use of B20 showed best value of brake thermal efficiency and brake specific energy consumption. With blend ratio from B20 to B50, all were best for the engine environmentally. BSEC increased by 8% by the use of neat biodiesel fuel at different load of the engine, engine smoke opacity increased by 15% but NO_x emission decreased by 10%, unburnt hydrocarbons decreased by 15% and carbon monoxide decreased slightly. 30% to 50% blending ratio was recommended for better engine performance and emission improvement. With the biodiesel blend BSFC was 10% higher, η_{bth} had no change, BSEC had 3% change and T_{Exh} was lower by 2% where as smoke opacity was high by 20%, 6% reduced NO_x, Co lower by 25% and UHC by 20%. **S. Senthur Prabu et al. [17]** studied on disposed edible oil with hydroxytoluene and n-butanol additive. Exhaust emission and engine performance was evaluated. Sodium hydroxide, sulphuric acid and methanol was employed for catalyst reaction for transesterification process of WCO to biodiesel. B0, B20, B30, B40 & B100 biodiesel blends were used to test the engine performance. It was observed that B30 was the best blend between the other biodiesel blends. n-butanol 20% by volume and antioxidants of BHT 2000 was added to improve the performance of B30 fuel blend. Brake thermal efficiency was lower than diesel by 4.6% but brake specific fuel consumption was 7.3% higher for B30 +butylated hydroxytoluene. Heat release were same as diesel for B20,B40 and B30+BHT blend but B30+butanol at higher load showed higher heat release rate than diesel. Cylinder pressure for B30 was less by 4.5% where as for other blends the cylinder pressure were same as diesel fuel. B30+n-butanol showed higher EGT (2.3%) & NO_x (9%) compared to diesel fuel but Co emission was less by 37.5%.

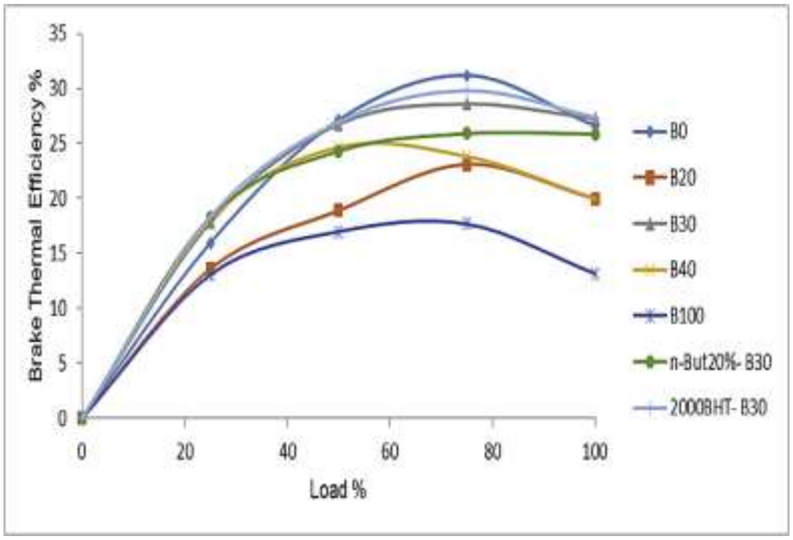

Figure 4 Brake Thermal Efficiencies of Different Blends at Different Loads.

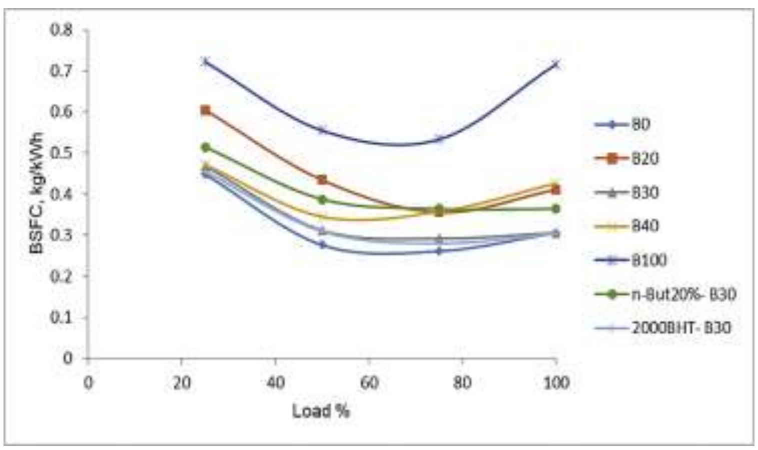

Figure 5 Brake Specific Fuel Consumption of Different Blends at Different Loads [17].

Compared to diesel fuel the 100% biodiesel had 51% lesser exhaust gas temperature. Performance of the engine on BTE and BSFC reduces steadily as the biodiesel fraction increase in the blend as shown I figure 4 & figure 5. B30 showed better emission characteristics than diesel fuel. **Emilio A. Viornery-Portillo et al. [18]** compared the environmental impact of the ultra low sulphur diesel and the production and use of B25 biodiesel. Which was used at a load of 100% in a power generator of 33kW. Impact was derived by the use of life cycle methodology, on the process and use of the biodiesel. It was clear from the result, use of WCOB (B25) showed better performance than ultra-low sulphur diesel. Abiotic depletion by 39.48%, acidification potential by 38.73%, eutrophication potential by 39.24%, human toxicity by 39.44% and global warming by 35.77% were the major reduction. 41.54% NO_x emission decreased and at the same time CO decreased by 52% when it was ecaluated to ultra-low Sulphur diesel, in the experiment. Power generator would reducing the harmful emissions by using Biodiesel. **A. Rajesh et al. [19]** discussed on the use of alternative fuel which could be generated from waste and also reduce the emission and environmental hazards. Investigation on waste edible oil biodiesel was accomplished to find the effect of anisole fraction. Compared result of biodiesel and baseline diesel with the WCOB with 30% vol. anisole blending. Ignition delay period is extended by increasing the anisole content in the biodiesel and also the heat release rate and in-cylinder pressure increase with increase in anisole fraction. Waste cooking oil biodiesel 90% and anisole 10% test fuel showed better brake thermal efficiency than biodiesel. At peak load NO_x emission was lowest when the engine was fueled with W90A10 biodiesel, but with Diesel and biodiesel it decreased by 17% and 11%. Biodiesel had highest smoke opacity, soot was suppressed with the addition of anisole. Anisole also helped in reduction of CO and HC emission. Waste cooking oil methyl ester blend with anisole 10% was efficient.

P. Santosh Babji et al. [20] use IDI diesel engine and replaced diesel fuel with disposed edible oil. Hydrated methanol employed as an additive which changed the combustion propensity. The diesel was replaced with inexpensive waste edible oil biodiesel with 6% hydrated methanol as additive, improve NO_x, exhaust temperature and smoke. For using biodiesel blends with super charging, peak pressure were same as compared to conventional diesel. BTE and BSFC was bettered. NO_x emission and smoke was also improved. **Lei Zhu et al. [21]** investigated the the use of biodiesel-pentanol blend in diesel engine at different engine load to check the particulate emission, combustion and gases. In the observation it was noticed that there was a delay in start of combustion with increase in pentanol fraction. From Crank Angle 10 to 90, biodiesel blend demonstrated faster combustion as equated to diesel & biodiesel fuel. Brake thermal efficiency was also higher for biodiesel–pentanol blend compared to diesel and biodiesel fuel. Addition of pentanol in biodiesel reduces the number concentration and particle mass, which is because of high oxygen concentration was observed which led to longer ignition delay and lower viscosity improving atomization. Brake Specific fuel consumption was also high for biodiesel-pentanol. But in comparison to diesel and biodiesel HC and CO emission was higher, when engine load was low (0.008Mpa to 0.24MPa). NO_x emission was low for thee blend as compared to biodiesel. But at a blend of B30, the NO_x emission was higher. **S. Sharbuddin Ali et al. [22]** produced biodiesel from waste cooking oil, tested with 1-octanol (OCT), 2-ethyl hexanol (TEH), di-n butyl ether (DBE) and diesel in a CRDi engine. Blends wear created WCOME15-OCT5, D80-WCOME15-TEH5 and D80-WCOME15-DBE5, its effect on performance, oxygenates on the combustion and emission characteristics was investigated and compared with D80-WCOME20 blend and conventional diesel. Combustion characteristics was improved by using 5%vol waste cooking oil methyl ester with oxygenates. HRR peak was high with oxygenates 1-octanol blend. BTE was higher than diesel for all blends but dropped for ternary blends, compared to waste cooking oil biodiesel 20%vol. NO_x emission was higher for the 3 blends, it was seen that for THE it was high by 1.75%, DBE by 0.02% and OCT by 4.07% form the reference fuel. DBE and THE for 1-octanol blend showed low smoke opacity by 25.03% and 22.03% respectively. CO and HC was also reduced. For all the blends CO_2 increased. Diesel 20%-waste cooking oil biodiesel 20% reduced smoke opacity by addition of oxygenates, 75% smoke emission lower with octanol blend. CO and HC emission also declined. CO_2 emission increased. **Jatinder Kataria et al. [23]** investigated on conversion of disposed edible oil to biodiesel by the process of transesterification. For production of biodiesel in an optimal way, mass ratio of catalyst to oil and molar ratio of alcohol to oil for catalysed transesterification was studied for different proportion. Catalysed transesterification, waste cooking oils optimum condition was determined, zinc doped calcium oxide by 5wt% and 12:1. The different biodiesel blends which produced were comparable with conventional diesel and were observed that they comply with the ASTM biodiesel standard. Test were conducted at injection pressure of 200bar, 1500 rpm speed, different load conditions and compression ratio of 15:1 & 17.5. HC emission was reduced, NO_x was higher except B40 blend. 1168PPM at CR17.5 and 1212PPM at CR 15 at full load for B40 blend NO_x emission was lowest. Smoke opacity decreases as the load is increased. **Olawole Abiola Kuti et al. [24]** investigation on waste edible cooking oil biodiesel was executed to observe the spray combustion characteristics and compare it with Reynolds Averaged Navier Stokes model simulated diesel oil. For the simulations of waste cooking oil biodiesel and diesel alternate was used. As an alternate to diesel, n-heptane (C7H16) & N-tetradecane (C14H30) was used. Methyl-9-decenoate, methyl decanoate, and n-heptane mixture was used as surrogate for WCO. Combustion process and spray was simulated in CFD by enforcing reaction kinetic and thermochemical data (460 reactions & 115 species). Ignition delay, soot formation spray liquid length & flame lift-off length was validated with previous experimental results. Data of the injection pressure were simulated and experimental data. Heat release rate occurs in the first stage ignition which is because of the formation of formaldehyde at low temp before the main ignition. OH radical are formed in the main ignition process, high temp. downstream lifted flame was stabilised by cool flame for both fuels. Cool flame location was because of increase in injection pressure which pushed it further downstream. **C. V. Manojkumar et al. [25]** studied the use of exhausted edible oil biodiesel /n-pentanol in an internal combustion engine for a reduced reaction mechanism was proposed for chemical kinetic simulation. 506 reactions and 146 species were consisted in the mechanism. There are a lot of advantages of waste cooking oil biodiesel and n-pentanol. Properties like viscosity, cetane number etc are similar for diesel fuel and waste cooking oil biodiesel fuel. Boiling temp, heating value is high and vaporization and auto ignition temp is low for n-pentanol as shown I table 1.

Table 1 Waste Cooking Oil Biodiesel and N-Pentanol Properties [25]

property	*n*-pentanol	WCO biodiesel
formula	$C_5H_{11}OH$	$C_{17.92}H_{33}O_2$ (RME)
molecular mass (kg/kmol)	88.149	~300
density (kg/L)	0.7392	0.876
boiling temperature (°C)	138	320−345
heat of vaporization (kJ/kg)	503	300
lower heating value (kJ/kg)	34791	37500
autoignition temperature (°C)	300	240
oxygen content (wt %)	18.2	11
hydrogen content (wt %)	13.61	11.78
carbon content (wt %)	68.24	76.78
solubility in water at 20 °C (wt %)	2.2	
cetane number	20	51

Knock resistance was lowered by mixing n-pentanol which is of high molecular weight which was mixed with diesel/biodiesel because of its high reactivity at high temperature as well as at low temperature.

Joonsik Hwang et al. [26] investigated the combustion characteristics and comprehensive spray of the conventional diesel and waste cooking oil biodiesel. Bosh method was used to measure the injection rate and under non-evaporating condition in a constant volume, performed the spray test. Injection pressure of 80 and 160MPa and 625,140Is was the injection duration for the injected fuel. Injection delay was longer for biodiesel because of high viscosity. Because of oxygen content in the biodiesel fuel molecule, air-fuel ratio was lean. Test was performed on common rail compression ignition engine. At an engine speed of 1400 r/min the indicated mean effective pressure of 0.16-0.93MPa was tested. Generally the fuel injection is at a crank angle of 60^0 but was changed to 0^0 before the top dead centre by 5^0 CAD. In comparison to diesel fuel, the fuel efficiency and in-cylinder pressure for waste cooking oil biodiesel was slightly lower because of lower heating value. Smoke emission, unburned hydrocarbon and carbon monoxide emission was reduced compared to diesel and was a benefit of waste cooking oil biodiesel. But as the engine load and injection time was increased, emission characteristics was deteriorated. Oxygen content in the waste cooking oil biodiesel were high, this enhances the combustion even though the properties of biodiesel was less favourable. Visible flame was shorter and Low flame luminosity was visible in the combustion image for waste cooking oil biodiesel as shown in figure 6. **Jassinnee Milano et al. [27]** produced W70CI30 biodiesel by alkaline catalysed transesterification assisted by microwave irradiation from Calophyllum inophyllum and waste edible cooking oil. RSM was applied for optimizing reaction time, concentration of the catalyst, ration of methanol to oil & stirring speed to maximize biodiesel production. Yield was 97.40% with methanol/oil ratio 59.60%, catalyst concentration 0.774 (w/w)%, reaction time 7.15min and stirring speed 600rmp. Oxidation stability of W70CI30 was 18.03h, which was higher than waste cooking oil biodiesel (4.61h). microwave irradiation-assisted transesterification helped in boosting the yield of biodiesel, which also reduces the transesterification time.

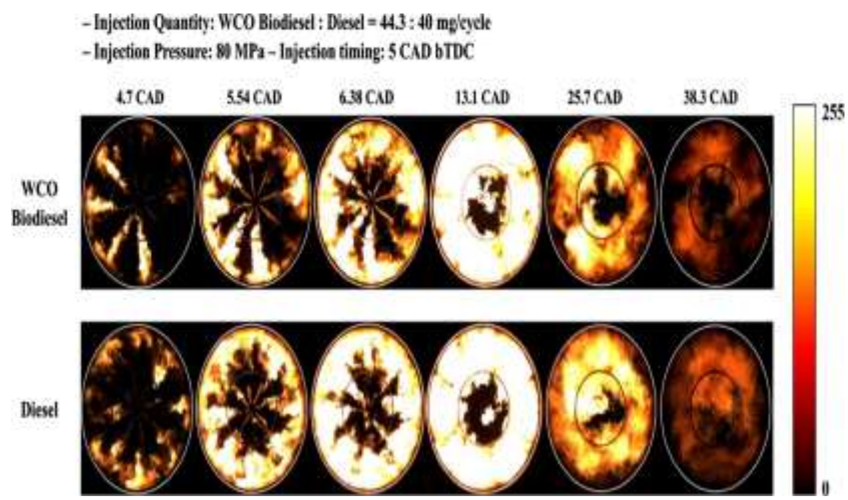

Figure 6 Waste Cooking Oil Biodiesel and Diesel Combustion Flame Image, Injection Pressure 80 Mpa [26].

3 Conclusion

There is an increasing need of energy every day and use of clean energy is important. Clean environment is a need of every one and is the major concern. The energy source used conventionally are not non-renewable. Use and extraction of such energy source increases pollution and also have a damaging effect on the environment. Increasing urbanization, increase the demand and also increase the emission from the conventional fuels which created a demand for efficient and alternative energy source. Biodiesel is one of the alternate fuels which is popular. It has features of being non-toxic, biodegradable, carbon neutrality and renewable. Because of similar physiochemical property of biodiesel, it can be replaced by diesel in a diesel engine with small modification or no modification. There are a lot of advantages of using biodiesel, but from sustainability point of view it was not advisable to produce biodiesel from food crops. Yielding biodiesel from disposed edible oil possesses no threat to food crops & is environmentally friendly. Following could be concluded on the use of used edible oil in compression ignition engine:

- Use of biodiesel, in-cylinder pressure increases, maximum heat release rate is reduced and combustion & ignition delay in shortened.
- Transesterification process must be selected in the free fatty acid and water content. If FFA and water are <1 wt% and <0.5 wt% then alkaline catalyst is suitable, if FFA is more than 1 wt% than acidic catalyst should be selected.
- With increase in biodiesel content the in-cylinder pressure decreased with reduction in ignition delay, advance in ignition and longer combustion duration. Maximum heat release rate was reduced at low load. The reduction was 14.3% and maximum HRR was 21.3% when the load was high. With increase in engine load, increase in peak heat release rate and cylinder pressure was observed.
- As blend content increased, CO,NO_x, HC and $PM_{2.5}$ reduced.
- CO lowered by 3.33%-13.1%, PAHs decreased by 7.53%-37.5%, HC reduced by 10.5%-36.0% and PM reduced by 5.29%-8.32% by use of ULSD/WCOB blend compared to ULSD.
- BSEC increased by 8% by the use of neat biodiesel fuel at different load of the engine, engine smoke opacity increased by 15% but NO_x emission decreased by 10%, unburnt hydrocarbons decreased by 15% and carbon monoxide decreased slightly
- Diesel 20%-waste cooking oil biodiesel 20% reduced smoke opacity by addition of oxygenates, 75% smoke emission lower with octanol blend. CO and HC emission also declined. CO2 emission increased.

Acknowledgement

This work was supported by The National Research Foundation of Korea (NRF) grant funded by the Korea Government (MIST)(NRF-2019R1A2C1010557)

References

[1] Alex Tangy, Indra Neel Pulidindi, Nina Perkas, Aharon Gedanken, "Continuous flow through a microwave oven for the large-scale production of biodiesel from waste cooking oil", Bioresource Technology, Vol. 224, pp. 333–341, 2017.
[2] Mortaza Aghbashlo, Meisam Tabatabaei, Soleiman Hosseinpour, "On the exergoeconomic and exergoenvironmental evaluation and optimization of biodiesel synthesis from waste cooking oil (WCO) using a low power, high frequency ultrasonic reactor", Energy Conversion and Management, Vol. 164, pp. 385–398, 2018.
[3] Arvind Kumar Madheshiya, Ajitanshu Vedrtnam, "Energy-exergy analysis of biodiesel fuels produced from waste cooking oil and mustard oil", Fuel, Vol. 214, pp. 386–408, 2018.
[4] Y. Zhang, M.A. Dub, D.D. McLean, M. Kates, "Biodiesel production from waste cooking oil: 1. Process design and technological assessment", Bioresource Technology, Vol. 89, pp. 1–16, 2003.
[5] L. Wei, C.S. Cheung, Z. Ning, "Influence of waste cooking oil biodiesel on combustion, unregulated gaseous emissions and particulate emissions of a direct-injection diesel engine", Energy, Vol. 127, pp. 175-185, 2017.
[6] Sahar, Sana Sadaf, Javed Iqbal, Inam Ullah, Haq Nawaz Bhatti, Shazia Nouren, Habib-ur-Rehman, Jan Nisar, Munawar Iqbal, "Biodiesel production from waste cooking oil: An efficient technique to convert waste into biodiesel", Sustainable Cities and Society, Vol. 41, pp. 220–226, 2018.
[7] Peng Geng, Hongjun Mao, Yanjie Zhang, Lijiang Wei, Kun You, Ji Ju, Tingkai Chen, "Combustion characteristics and NOx emissions of a waste cooking oil biodiesel blend in a marine auxiliary diesel engine", Applied Thermal Engineering, Vol. 115, pp. 947–954, 2017.
[8] Xianbao Shen, Jiacheng Shi, Xinyue Cao, Xin Zhang, Wei Zhang, Hui Wu, Zhiliang Yao, "Real-world exhaust emissions and fuel consumption for diesel vehicles fueled by waste cooking oil biodiesel blends", Atmospheric Environment, Vol. 191, pp. 249–257, 2018.
[9] Mangesh G. Kulkarni, Ajay K. Dalai, "Waste Cooking Oils-An Economical Source for Biodiesel: A Review", Ind Eng Chem Res, vol. 45, pp. 2901-2913, 2006.
[10] Magín Lapuerta, José M. Herreros, Lisbeth L. Lyons, Reyes García-Contreras, Yolanda Briceño, "Effect of the alcohol type used in the production of waste cooking oil biodiesel on diesel performance and emissions", Fuel, Vol. 87, pp. 3161–3169, 2008.
[11] Lijiang Wei, Rupeng Cheng, Hongjun Mao, Peng Geng, Yanjie Zhang, Kun You, "Combustion process and NOx emissions of a marine

auxiliary diesel engine fuelled with waste cooking oil biodiesel blends", Energy, Vol. 144, pp. 73-80, 2018.

[12] X.J. Mana, C.S. Cheung, Z. Ning, L. Wei, Z.H. Huang, "Influence of engine load and speed on regulated and unregulated emissions of a diesel engine fueled with diesel fuel blended with waste cooking oil biodiesel", Fuel, Vol. 180, pp. 41–49, 2016.

[13] Cheng Tung Chong, Bo Tian, Jo-Han Ng, Luming Fan, Shiyao Ni, Kang Yao Wong, Simone Hochgreb, "Quantification of carbon particulates produced under open liquid pool and prevaporised flame conditions: Waste cooking oil biodiesel and diesel blends", Fuel, Vol. 270. pp. 1-10. 2020.

[14] Yuan-Chung Lin, Kuo-Hsiang Hsu, Chung-Bang Chen, "Experimental investigation of the performance and emissions of a heavy-duty diesel engine fueled with waste cooking oil biodiesel/ultra-low sulfur diesel blends", Energy, Vol. 36, pp. 241-248, 2011.

[15] Joonsik Hwang, Donghui Qi, Yongjin Jung, Choongsik Bae, "Effect of injection parameters on the combustion and emission characteristics in a common-rail direct injection diesel engine fueled with waste cooking oil biodiesel", Renewable Energy, Vol. 63, pp. 9-17, 2014.

[16] Ali M.A. Attia, Ahmad E. Hassaneen, "Influence of diesel fuel blended with biodiesel produced from waste cooking oil on diesel engine performance", Fuel,Vol. 167, pp. 316–328, 2016.

[17] S. Senthur Prabu, M.A. Asokan, Rahul Roy, Steff Francis & M.K. Sreelekh, "Performance, combustion and emission characteristics of diesel engine fuelled with waste cooking oil bio-diesel/diesel blends with additives", Energy, Vol. 122, pp. 638-648, 2017.

[18] Emilio A. Viornery-Portillo, Brenda Bravo-Díaz, Violeta Y. Mena-Cervantes, "Life cycle assessment and emission analysis of waste cooking oil biodiesel blend and fossil diesel used in a power generator", Fuel, Vol. 281, pp. 1-10, 2020.

[19] A.Rajesh, K. Gopal, De Poures Melvin Victor, B. Rajesh Kumar, A.P. Sathiyagnanam & D. Damodharan, "Effect of anisole addition to waste cooking oil methyl ester on combustion, emission and performance characteristics of a DI diesel engine without any modifications", Fuel, Vol. 278, pp. 1-10, 2020.

[20] P. Santosh Babji, B. V. Appa Rao & Aditya Kolakoti, "Performance and Emission Analysis of Supercharged IDI Diesel Engine Fuelled with Waste Cooking Oil Biodiesel", International Journal of Engineering Science and Computing, Vol. 7, No. 10, pp. 15126-15129, 2017.

[21] Lei Zhu, Yao Xiao, C.S. Cheung, Chun Guan, Zhen Huang, "Combustion, gaseous and particulate emission of a diesel engine fuelled with n-pentanol (C5 alcohol) blended with waste cooking oil biodiesel", Applied Thermal Engineering, Vol. 102, pp. 73–79, 2016.

[22] S. Sharbuddin Ali, M.R. Swaminathan, "Effective utilization of waste cooking oil in a diesel engine equipped with CRDi system using C8 oxygenates as additives for cleaner emission", Fuel, Vol. 275, pp. 1-11. 2020.
[23] Jatinder Kataria, S.K. Mohapatra, K. Kundu, "Biodiesel production from waste cooking oil using heterogeneous catalysts and its operational characteristics on variable compression ratio CI engine", Journal of the Energy Institute, Vol. 92, pp. 275-287, 2019.
[24] Olawole Abiola Kuti, S. Mani Sarathy, Keiya Nishida, "Spray combustion simulation study of waste cooking oil biodiesel and diesel under direct injection diesel engine conditions", Fuel, Vol. 267, pp. 1-13. 2020.
[25] C. V. Manojkumar, Justin Jacob Thomas, V. R. Sabu, G. Nagarajan, "Reduced Chemical Kinetic Mechanism for a Waste Cooking Oil Biodiesel/n‑Pentanol Mixture for Internal Combustion Engine Simulation", Energy Fuels, Vol. 32, pp. 12884−12895, 2018.
[26] Joonsik Hwang, Choongsik Bae, Tarun Gupta, "Application of waste cooking oil (WCO) biodiesel in a compression ignition engine", Fuel, Vol. 176, pp. 20–31, 2016.
[27] Jassinnee Milano, Hwai Chyuan Ong, H.H. Masjuki, A.S. Silitonga, Wei-Hsin Chen, F. Kusumo, S. Dharmaa, A.H. Sebayang, "Optimization of biodiesel production by microwave irradiation-assisted transesterification for waste cooking oil-Calophyllum inophyllum oil via response surface methodology", Energy Conversion and Management, Vol. 158, pp. 400–415. 2018.

Biographies

Adhirath Mandal He has completed his bachelors in Mechanical & Automation Engineering from Guru Gobind Singh Indraprastha University, Delhi, India. After his graduation he has worked in a water RO Company for 1 year. He completed his M.Tech (masters) in production engineering from Delhi Technological University, Delhi, India. He has worked as Assistant Professor in engineering colleges in Delhi NCR. He has teaching experience of 3.5 year. He is pursuing his doctoral degree from Kongju National University, Cheonan, Korea in mechanical engineering. His area of interest is

Biodiesel and electric vehicles. He has published papers in national and international journals. The papers are indexed in Scopus.

HaengMuk Cho He is a renowned professor in South Korea. He is working as professor at Kongju National University in South Korea. He did Post Doctorate Fellowship from Department of Automotive Engineering of Loughborough University in UK and North Texas University in USA. He earned his PhD from Hanyang University, South Korea in 1997 and completed his M.D. in Environment Engineering from Yonsei University in S Korea. He is working on national and international projects in the field of Bio-fuels for IC engines and renewable energy. Professor HaengMuk Cho is working in the field of Renewable Energy and Biofuels. He is also a member of many societies, like Korea Society of Automotive Engineers, Korean Society of Energy (Korea), Korea Society of Marine Engineering (Korea) & Korea Society of Environment Engineer (Korea). He has published many national and internal research papers. Most of his papers are indexed in Scopus and SCI**.**