Waste Cooking Oil as Fuel in CI Engine – A Review

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***Abstract*— There has been an increasing demand for clean energy in the recent days. Fuels used now days are non-renewable fuels, a major reason for environment pollution. Increasing urbanization, increase the demand and also increase the emission from the conventional fuels which created a demand for efficient and alternative energy source. 1/3rd fuel produced in the world is consumed by the transportation sector and a major contributor to greenhouse gases. Production process of energy should be developed which can cater the demand of environmentally safe, renewable and sustainable. Alternate fuels are being researched because of the increasing demand of the convention no-renewable fuel. There have been many renewable energy, but the immediate replacement is biodiesel. Biodiesel is a replacement of the diesel, which is the major fuel in the transportation sector and consists of alkyl esters. Biodiesel are majorly produced from food crops, a major disadvantage and at the same time it increase the production cost. Recent studies show that biodiesel could be produced from waste cooking oil, this does not pose any threat to the food crops. Use of waste cooking biodiesel in the CI engine reduces the HRR and in-cylinder pressure. Many researches also showed that CO, HC, NO_x emission reduces with increase in blend ratio. This paper gives a review of the use and characteristics of waste cooking oil biodiesel used in compression ignition engine.**

***Index Terms*— waste cooking oil, biodiesel, NOx, CO, HC**

I. INTRODUCTION

Requirement for energy has been increasing day by and also the need for clean fuel. As we are progressing the need for clean fuel is becoming crucial and it is a concern. The fuels that are being used now are nonrenewable and harmful to the environment. Because of the conventional fuels the pollution have been on a rise and it has a damaging effect on the environment and on the health of humans. 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. It is very important to have a cheap and cost competitive alternate fuels which can replace the arising demand of the conventional energy. It has been clearly seen that the transportation sector plays a curtail role in the use of consumption of crude oil. It was observed that 1/3rd crude oil is being consumed by the same and is the largest contributor of greenhouse gasses emission. In the period 2010 to 2040 it has been predicted by the many researchers that the demand for fossil fuels would increase by 40%, which would be because of the transportation sector. Alternate fuels are being researched because of the increasing demand of the convention no-renewable fuel. There have been many renewable energy, but the immediate replacement is biodiesel. biodiesel is a replacement of the diesel, which is the major fuel in the transportation sector and consists of alkyl esters [1].

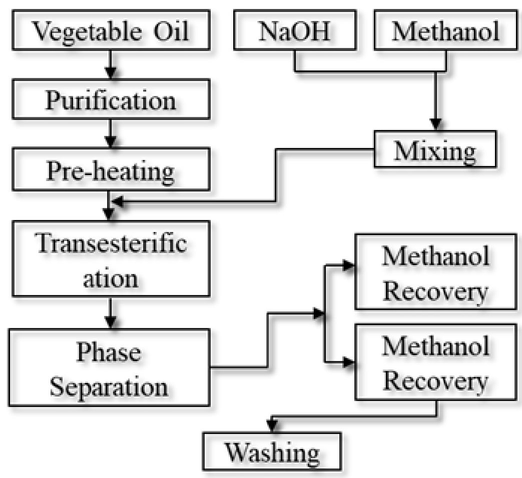

Figure 1. Biodiesel Production process [2]

Biodiesel is also known as methyl/ethyl esters which consists of long chain fatty acids. In the alternative fuels, biodiesel is a popular fuel because of being biodegradable, renewable, nontoxic and free from carbon. Because of similar physiochemical property of biodiesel, it can be replaced by diesel in a diesel engine with small modification or no modification. Biodiesel has a lot of advantages but production of biodiesel from crops is not wise. The process of making biodiesel is shown in Fig. 1. Use of waste cooking oil for production of biodiesel would be economical and a good research area. Gives an review on the use of waste cooking oil biodiesel and its advantages [2][3].

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II. Literature Review

A. New Oil as Biodiesel

Peng Geng et al. 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-cooling direct-injection marine auxiliary diesel engine, emission and combustion characteristics was studied by using clean waste cooking oil biodiesel, B70 (diesel containing 70 vol.% of biodiesel), B90 and Ultralow Sulfur Diesel. Study on NOx 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. Maximum heat release rate was reduced, when the engine was operated 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. With increase in biodiesel content, temperature in the exhaust manifold reduces. Use of high substitution ratio of biodiesel, significantly reduces the NOx emission because of cylinder temperature reduction in the diffusion combustion mode. Increase in biodiesel content and engine load, NO2/No emission decreases [4]. **Mag ń Lapuerta et al.** studied the two different alcohol driven biodiesel, methyl ester and ethyl ester. Two different biodiesels and conventional diesel were examined on 2.2L CRDI engine in 100%, 70% and 30% volume basis. Pure biodiesel resulted in increase in fuel consumption compared to reference fuel. With use of biodiesel NOx emission was reduced slightly, but in case of smoke opacity, total hydrocarbon emission, particle emission there was sharp reduction, although volatile organic fraction of the particulate matter increased. Pure biodiesel resulted in increase in fuel consumption compared to reference fuel. With use of biodiesel NOx emission was reduced slightly, but in case of smoke opacity, total hydrocarbon emission, particle emission there was sharp reduction, although volatile organic fraction of the particulate matter increased [5]. **Lijiang Wei et al.** investigated on the emission reduction in a marine diesel engine by the use of biodiesel. Compression ratio, NOx emission and combustion process were studied by the experimental investigation on the use of waste cooking oil biodiesel. Four different types of bled were used in the experimentation, and was observed that increasing the blend ration would 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%. Rise in biodiesel blend, NOx emission decreased. NOx raised with decline in in-cylinder. 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 [6]. **X.J. Mana et al.** studied naturally aspirated direct injection engine and focused on the emission , 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 NOx increased with increase in biodiesel blend ratio. Increase in the biodiesel blend, xylene and toluene emission reduced as well as benzene emission also increased. As benzene increased was balanced by decrease in toluene and xylene, BTX emission was not changed. Emission were affected by the load and engine speed [7]. **Cheng Tung Chong et al.** 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 [8].

Y. Zhang et al. studied the production of biodiesel from fresh and waste cooking vegetable oil, 4 different production ways. The four unlike methods were implemented to assess the technological gains and limitations. It was observed that fresh vegetable cooking oil required less equipment for the process but the raw material cost was high, alkali-catalysed process. Conversion of waste cooking oil by acid catalysed process was comparatively easy compared to alkali catalysed, at the same time use of waste cooking oil was cost effective and reduces raw material cost. Which makes waste cooking oil biodiesel produced by alkali catalysis, a good alternate fuel [9]. **Emilio A. Viornery-Portillo et al.** compared the environmental impact on the use of ultra low sulphur diesel and B25 biodiesel in a power generator of 33kW. It was seen from the result that the use of waste cooking oil biodiesel (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% NOx emission, CO by 52% reduced, compared to ultra-low Sulphur diesel. Harmful emission would reduce by the use of Biodiesel [10]. **Jehad Yamin et al.** Researched on the engine performance and mapping. He used diesel and used cooking oil biodiesel fuel. For the test 1500cc CI engine testbed was used and performance parameter were measured. Load varied from no load to full load, speed of crankshaft was 35 & 60rps and constant temperature of the coolant at 70oC. With the help of the test results the simulation model was adjusted. With biodiesel fuel there was slight improvement in the operation of the engine. It was also observed that when using biodiesel combustion was in the mixing phase. Use of potassium hydroxide as catalyst in equivalent to sodium hydroxide, yield was more by 45% which resulted in lower viscosity by 10% and calorific value by 5%. Result from mapping showed that thermal efficiency was lower than diesel. Engine when fueled with diesel, fuel consumption was low of about 250-300 g/kWh at mean effective pressure value and higher power but for biodiesel the fuel consumption was 350 g/kWh at low engine speed, mean cylinder pressure and power. Biodiesel has higher cetane number so it burns earlier than diesel [11]. **Mohammed S. Edam.** Researched on the use of caster methyl ester with diesel in different proportions and examined the performance, combustion characteristics and emission of a single cylinder engine. Diesel-rk simulation program was used to study numerically about the biodiesel. With increasing percentage of CME, near the top dead center peak pressure was closer. With increased blending the, brake specific fuel consumption also increased. NOx emission was higher for all the biodiesel blends of CME and diesel. Smoke level also decreased with increasing the biodiesel blend ratio. For B10, B20, B30, B50, B70 and B100, smoke level were reduction were, 15.25%, 35.3%, 40.7%, 45.71%, 49.43% and 52.73% respectively. The best blend was B20, have reduced CO emission and slight variation in performance in comparison to conventional diesel [12]. **Alireza Shirneshana. [13]** Experimented on the use of alternative fuel (biodiesel) in a 4 cylinder direct injection diesel engine at different engine load, speed of 1800 rev/min with different. Four different fuel blends (B20, B40, B60 and B80) were used for the test in an engine. The biodiesel was prepared from waste fry oil. Emission was lower (HC and CO) & NOx, CO2 increased when used biodiesel at higher load. Contrary the CO and HC were higher at lower load. Study showed that biodiesel compared to diesel showed lower exhaust emission. Combustion improves with addition of biodiesel as it increases the oxygen level of the fuel [13].

B. Waste Cooking Oil as Biodiesel

Sahar et al. reduced the cost of producing biodiesel by utilizing waste cooking oil, but as free fatty acids are high transesterification process is difficult. Waste cooking oil had acid value was 5.5 mg KOH/g, this also showed that FFA was high. By the use of HCL, H3PO4, & H2SO4 (all acidic catalyst), esterification of waste cooking oil was carried out, this method reduced the FFA by 88.8% at 600C with methanol to oil molar ratio by 1:2.5. 90% efficiency was achieved by the presence of KOH and fatty acid methyl ester transesterification at 500C at 1% catalyst. 1:3 methanol to oil archived 94% FAME yield at 60 oC reaction temp and 1% catalyst. The main component to produce biodiesel were stearic acid, oleic acid, palmitic acid and linoleic acid. Pretreatment of waste cooking oil biodiesel by acid followed by catalyzed reaction was a good method for treatment of waste cooking oil [14]. **L. Wei et al.** investigated the particulate emission, gaseous emission and combustion of a diesel engine which was fuelled by used cooking oil biodiesel. Different test cycles were used on a DI diesel engine with 20%, 50% and 75% biodiesel. 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 [15]. **Xianbao Shen et al.** 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 waste cooking 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, NOx, CO and PM2.5 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, NOx, HC and PM2.5 were reduced by increasing blend ratio [16]**. Mangesh G. Kulkarni et al.** discussed on the use of biodiesel form waste cooking oil. Fatty acid methyl ester biodiesel is an alternative fuel which is biodegradable and nontoxic and produced form renewable source. The major difference in the commercialization of biodiesel 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 the production of biodiesel from waste cooking oil, 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 NOx and carbon residue [17].

Yuan-Chung Lin et al. 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 waste cooking oil. The investigation was carried out 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. 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.

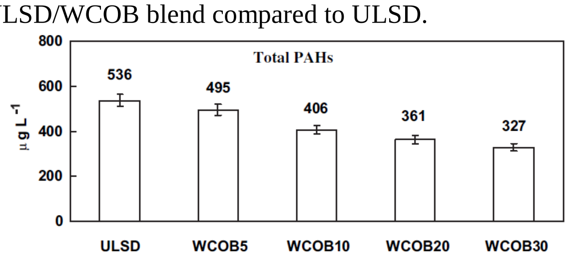

Figure 2. PAH emission for different blends [18]

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 [18]. **Joonsik Hwang et al.** investigated on the use of waste cooking oil biodiesel 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.

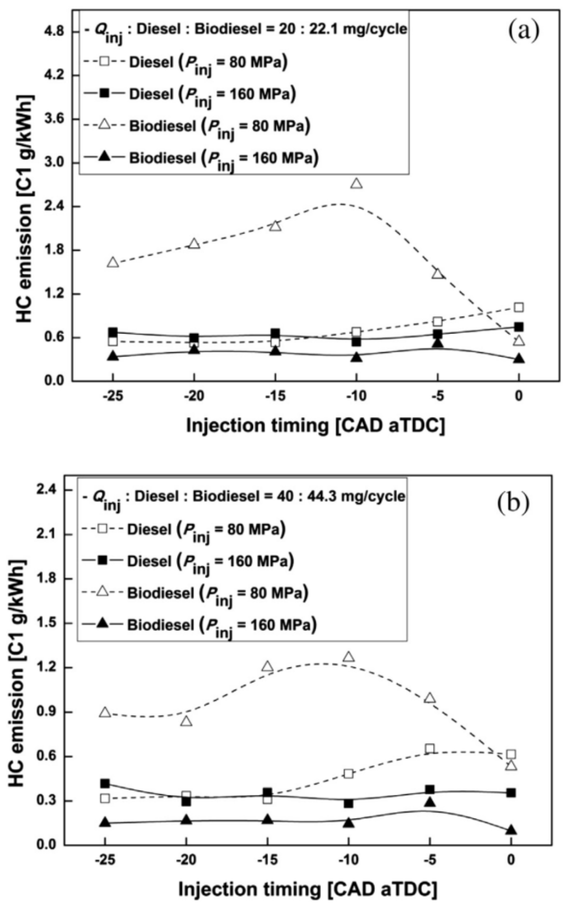

Figure 3. HC emission with injection timing at different load (a) low load, (b) high load [19].

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 Fig. 3. Hydrocarbon, carbon monoxide emission and smoke as reduced with the use of biodiesel especially at high injection pressure. NOx was comparatively higher for biodiesel compared to diesel [19]. **Ali M.A. Attia et al.** waste cooking oil methyl ester was produced by transesterification process. Different waste cooking oil biodiesel blends were tested on the engine performance. Soot tendency and viscosity analysis was carried out, by the use of waste cooking oil and its blend. In-cylinder peak pressure was determined by the engine load and blend ratio of biodiesel and diesel. 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% on use of 100% biodiesel, smoke opacity increased by 15%, NOx reduced by 10%, HC reduced by 15% and CO reduced marginally. 30% to 50% blending ratio was preferred for improvement in emission and engine performance [20]**. S. Senthur Prabu et al.** investigated on the use of hydroxyl-toluene and n-butanol additive with waste cooking oil. Exhaust emission and engine performance was evaluated. Sodium hydroxide, sulphuric acid and methanol was used as catalyst reaction for transesterification process of waste cooking oil to biodiesel. B0, B20, B30, B40 & B100 biodiesel blends were used to test the engine performance but the best blend was B30. Performance of B30 was meliorated than other blends because of the addition of n-butanol 20% & antioxidants of BHT 2000. BTE was 4.6% low and BSFC was 7.3% higher for B30 +butylated hydroxytoluene than diesel. 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. B30+n-butanol showed higher EGT (2.3%) & NOx (9%) compared to diesel fuel but Co emission was less by 37.5%. Compared to diesel, 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 Fig. 4 & Fig. 5. B30 showed better emission characteristics than diesel fuel.

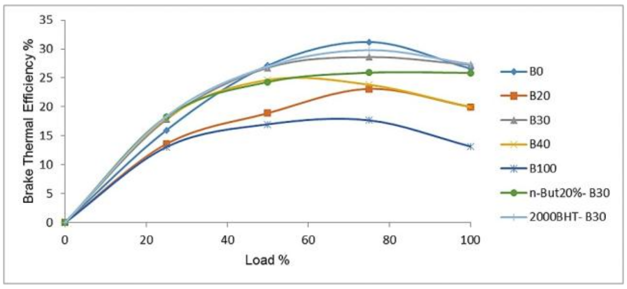

Figure 4. Brake thermal efficiencies of different blends at different loads [21].

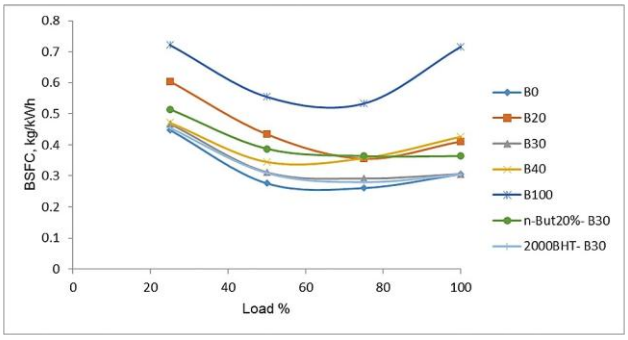

Figure 5. Brake specific fuel consumption of different blends at different loads [21]

A. Rajesh et al. discussed in the importance of alternative fuel, generated from waste and also help in reducing emission and environmental hazards. Investigation on waste cooking oil biodiesel was carried out to find the effect of anisole fraction. Compared result of biodiesel and baseline diesel with the waste cooking oil biodiesel 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 NOx 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 [22].

M.S. Gad et al. researched on the use of waste cooking oil in conventional diesel engine. It was observed that, use of waste cooking oil biodiesel generated a lot of NOx emission. The biodiesel also had low volatility, high viscosity and high pour point. The impact of using gasoline with waste cooking oil biodiesel as an additive and its effect on combustion, emission, and exergy characteristics of a diesel engine run under various loads and a constant speed of 1500 rpm.

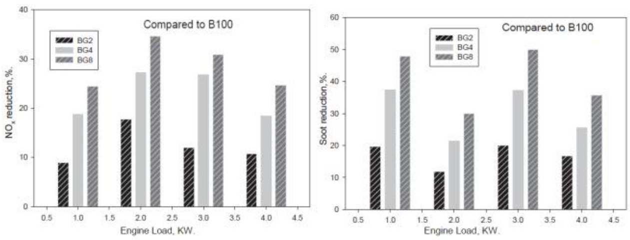

Figure 6. NOx emission at different engine load [23]

With the help of ultrasonic and mechanical dispersion, transesterification was carried out to produce waste cooking oil biodiesel and by applying GC-MS and FTIR the biodiesel was characterized. For BG2, BG4 and BG8 the viscosity was reduced by 5%, 11% and 21% respectively. Addition of gasoline with WCO, enlarges the Cylinder pressure and HRR. Reduction in emission was observed, CO by 25%, UHC by 30%, NOx by 20% and smoke opacity by 30% compared to pure waste cooking oil biodiesel as shown in Fig. 6. It was observed that by blending biodiesel with gasoline in small dose, improves the physical [23].

R. Selvaraj et al. Produced waste cooking oil biodiesel by transesterification with methanol. To increase the fatty acid methyl esters production, waste cooking oil was pre-treated and catalyst potassium methoxide 1% was used. Activated charcoal 2% was used to adsorb the free fatty acid. RSM method was used to optimize the process variables and Fame yield was predicted by ANN. Under the optimum condition the maximum conversion was 95%, time 60s, alcohol to oil ratio 6:1. Concentration of catalyst 1% and 75oC temperature. ANN predicted 0.99 and RSM 0.98 yield of biodiesel shown in Fig. 7. Proton nuclear magnetic resonance, Fourier transformation infrared spectroscopy, carbon nuclear magnetic resonance and gas chromatography-mass spectrometry was use to examine FAME. 13CNMR for FAME from WCO, agreed to the presence of methyl esters in biodiesel at 174.2 ppm and 51.4ppm [24].

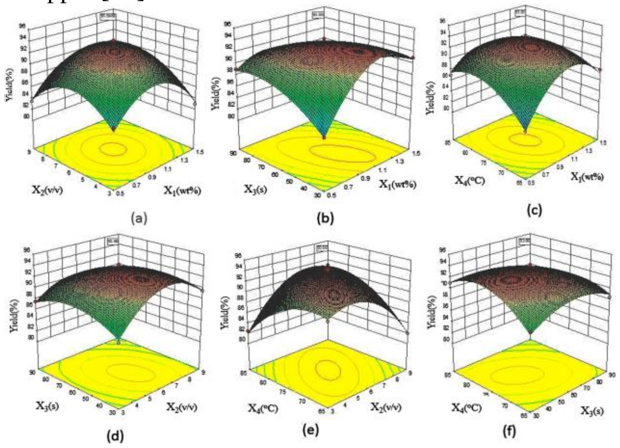

Figure 7. Response surface plots showing the effects on yield of FAME (%) (X1: Catalyst (wt %), X2: Alcohol: Oil ratio (v/v), X3: Time (s) and X4: Temperature (℃)) [24].

Mohamed F. Al-Dawody et al. investigated on the use of methyl ester of Waste cooking oil collected from different restaurants. Different blend ratio of B10, B20 and B100 on volume basis was used for testing in a diesel engine at constant speed. Diesel-rk simulation software was used to verify the experimental data and was found that both the data agree with each other. It was observed that with increasing the ration of methyl ester of waste cooking oil, maximum pressure reduced due to reduction in heating value of the fuel. NOx emission was also reduced with the use of methyl ester waste cooking oil. B20 was best ratio in terms of performance of the engine as show in Fig. 8 & Fig. 9 [25].

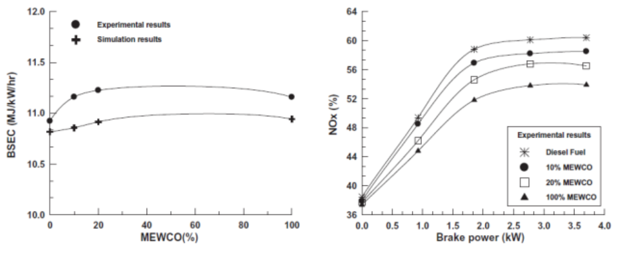

Figure 8. (a) MEWCO% v/s BSEC, (b) Load v/s NOx emissions [25]

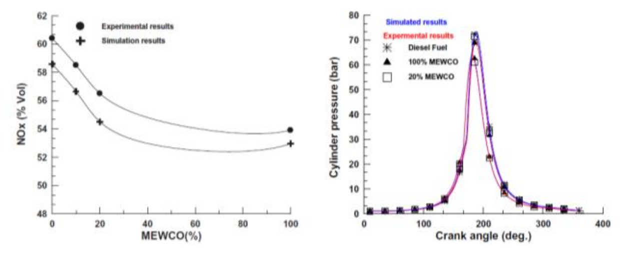

Figure 9. (a) MEWCO% v/s NOx emission, (b) Crank angle v/s cylinder pressure [25]

Mohd Affandi Mohd Ali et al. Used waste cooking oil as biodiesel which was produced by transesterification by microwave irradiation and activated limestone was used as catalyst. The screening was carried out by using response surface methodology and two level factorial design. Wet-impregnation was used to prepare the catalyst, which was characterized for porosity, surface element, surface area and surface morphology. Continuous microwave assisted reactor was used to execute the reaction and conversion was measured by gas chromatography. Waste cooking oil conversion was affected by methanol to oil molar ratio, catalyst loading and reaction time. At 5.47 wt% catalyst loading, methanol to oil molar ratio was 12.21:1 with reaction time of 55.26min, oil to biodiesel conversion was 96.65%. Time for transesterification was reduced by 77% by the use of CMAR. The biodiesel produced showed that particulate matter and NOx was reduced compared to diesel [26]. **Mohamed Shameer et al.** Investigated on the combustion, emission and performance characteristics of a diesel which was fueled by waste cooking oil biodiesel, animal fat biodiesel and camphor oil. All the alternate fuel were mixed in the ratio of This research paper aims at investigating the performance, emission and combustion characters of diesel engine with 20% volume concentrations of animal fat based biodiesel (AFO20), waste cooking oil biodiesel (WCO20), camphor oil (CMO20) and also including pure diesel fuel (D100). The peak cylinder pressure and heat release rate of biodiesel was about 4.82% higher and 13.49% lower than those of diesel fuel on average respectively. Start of combustion of alternate blends happened at earlier crank angles compared to base fuel. Combustion duration of all alternate fuel blends is higher than those of diesel at all load conditions. While fueling CMO20, AFO20 and WCO20, the NOx concentration in the emission shows 7.52%, 10.352% and 16.405% increment respectively with the biodiesel addition to diesel. However, significant reduction in NOx of about 43.8% was observed for camphor oil - diesel blend when compared to other biodiesel blends. The correlation between NOx emission level and in-cylinder temperature was premeditated by a novel procedure using thermal imager. The result shows that the increase in incylinder temperature contributed to the augmentation in NOx concentration. The main aim of this paper is to present the performance, emission and combustion characteristics of fuel blends obtained from camphor oil and bio-waste resources like animal fat residue oil and waste cooking oil. Also a novel procedure of usage of thermal imager to validate the impact of in-cylinder temperature on NOx formation in the compression ignition direct injection diesel engines fuelled with various blends has been insisted. Performance analysis resulted in lower BSFC of CMO20 among the other biodiesel blends. BTE scale for all biodiesel blends shows declining trend than those of diesel. AFO20, WCO20, CMO20 recorded 14.63%, 23.8% and 7.953% lower BTE when compared to diesel. On the whole camphor oil blend displays better performance than other blends, due to its lower viscous property. Combustion analysis depicted that all alternate fuel blends exhibit the start of combustion at earlier crank angles. Ignition delay period decreases with increase in load for all blends. Camphor oil blends resulted in 3.61% lower PCP, 19.32% lower HRR and 22.22% lower ID than those of diesel fuel at full load condition. Combustion duration of all fuel blends is higher than the duration period of diesel, among which camphor oil presents the lowest CD due to its better atomization attributed to its lower viscosity. According to the emission results, NOx increased with increasing biodiesel concentration in all fuel blends. Camphor oil shows the lowest NOx values among the alternate fuels; meanwhile biodiesel obtained from waste cooking oil contributed higher NOx emission due to its higher oxygen content. On an average, NOx concentration for AFO20, WCO20 and CMO20 are 12.08%, 18.24% and 7.52% higher than those of diesel fuel respectively. On an average, the cylinder head temperature (CHT) for AFO20,WCO20 and CMO20 are 3.75%, 7.16% and 1.08% higher than those of diesel fuel respectively. Thus the increment in CHT communicates with higher NOx. Hence it could be concluded that Camphor oil blend shows more positive results in all performance, combustion and emission aspects than the other biodiesels derived from animal fat residue oil and waste cooking oil. Camphor oil blend at 20% volume concentration is appropriate for diesel engine without any engine modification. A novel procedure of emission investigation has been proposed by incorporating NOx emission concentration with cylinder head temperature measured by thermal imager. Future scope of this work is calibration and optimization of cylinder head temperatures from thermal imager for measuring NOx emission variation of different biodiesel [27].

III. Conclusion

Clean environment is a need of every one and is the major concern. The energy source used nowadays are non-renewable. Increasing urbanization, increase the demand and also increase the emission from the conventional fuels which created a demand for efficient and alternative energy source. In the Alternate fuels, Biodiesel is extremely popular because of non-toxic, biodegradable, carbon neutrality and renewable and same properties like diesel, it could be replace conventional fuel little 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. Generation of biodiesel from the food crops would not be a good idea and at the same time it would not be economical. Therefore use of waste cooking oil to generate biodiesel would be economical and at the same time reduce the waste from the environment. Following could be concluded on the use of waste cooking oil biodiesel in compression ignition engine:

- 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.
- Biodiesel blend increase, in-cylinder pressure decreased, reduced ignition delay, advance in ignition and longer combustion duration.
- Maximum heat release rate reduced, at low loads. The reduction in maximum HRR was 21.3% at high load. Engine load increases the peak heat release rate and cylinder pressure.
- The CO, HC, NO_X and $PM_{2.5}$ emissions for all vehicles reduced with increasing biodiesel blend.
- CO reduced by 13.1%, PAHs decreased by 37.5%, HC reduced by 36.0% and PM reduced by 8.32% by use WCOB blend compared to ULSD.
- BSEC increased by 8% when 100% biodiesel fuel was used, at different load.
- Engine smoke opacity increased by 15% but NOx reduced by 10%, unburnt HC reduced by 15% and CO reduced marginally.
- Addition of oxygenates to Diesel 20% - WCO biodiesel 20% reduces the smoke opacity, 75% smoke emission lower with octanol blend. CO and HC emission also declined.

It was clearly visible from the survey that the use of waste cooking oil biodiesel blend helps in reducing different emission but in some conditions increase the BSEC. Maximum heat release rate also increases at high loads. It would be recommended to develop biodiesel from waste cooking oil with higher fatty acids. Use of Waste cooking oil as biodiesel has to be researched in detail. Though the use of waste cooking oil reduces the emission but was to reduce the engine load and BSEC. In many conditions NO_x emissions increases. There for use of additives with waste cooking oil biodiesel would be an interesting topic and is an unexplored area. Impact of additives on the emission and engine performance has to be studied. hence, this review paper provides relevant knowledge on the waste cooking biodiesel to be used in CI engine.

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Conflict of Interest

The authors declare no conflict of interest.

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