Research Article

Comparison of NO_x for Diesel and Waste Cooking Oil Biodiesel

Adhirath Mandal[a], HaengMuk Cho[b*]

[a]*Doctorate Student, Dept. of Mechanical Engineering, Kongju National University, Republic of Korea*
[b]**Professor, Dept. of Mechanical Engineering, Kongju National University, Republic of Korea*

Article History: Received: 10 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 28 April 2021

Abstract
Transportation, industrial, commercial, agricultural and domestic sector mainly relies and uses diesel fuel to produce mechanical energy or power. Alternative fuels have also been introduced and using alternative fuels, continues to be a challenge. Biodiesel being a part of the alternative fuel, obtained from animal fat and vegetable oil, good alternative to conventional diesel. Popularity of biodiesel all of the world have recently increased because of its renewability, biodegradability, non-toxic, easy availability and better emission. For the use of biodiesel, engine modification is not needed. It is also free from Sulphur and aromatics, which helps in reducing exhaust emission, compared to conventional gasoline and also renders same fuel efficiency. For the use of biodiesel, engine modification is not needed. It is also free from Sulphur and aromatics, which helps in reducing exhaust emission, compared to conventional gasoline and also renders same fuel efficiency. Biodiesel could be blended in any ratio with the diesel and can also be used directly in the engine. Generally the price of raw edible oil are high and using them to produce biodiesel increase the price of the biodiesel. Biodiesel costs, 75-90% of the raw biodiesel. Because of the increasing cost of production of the biodiesel, use of waste cooking oil in the production of biodiesel would help in reducing the cost and would be a sustainable solution. It is sad that the waste cooking oil is discarded in the drain. Disposal of the waste cooking oil can lead to blockage, smell and environmental pollution. This paper simulates the NOx emission for Diesel and waste cooking oil biodiesel.

Keywords: Waste cooking oil biodiesel, NO_x, Emission, combustion, CI engine

1. Introduction

Transportation, industrial, commercial, agricultural and domestic sector mainly relies and uses diesel fuel to produce mechanical energy or power. To improve the fuel economy and the emission, a lot of research have been carried out on internal combustion engine. Alternative fuels have also been introduced and using alternative fuels, continues to be a challenge. Biodiesel being a part of the alternative fuel, obtained from animal fat and vegetable oil, good alternative to conventional diesel. Popularity of biodiesel all of the world have recently increased because of its renewability, biodegradability, non-toxic, easy availability and better emission. For the use of biodiesel, engine modification is not needed. It is also free from Sulphur and aromatics, which helps in reducing exhaust emission, compared to conventional gasoline and also renders same fuel efficiency. Biodiesel could be blended in any ratio with the diesel and can also be used directly in the engine. But the specifications of the biodiesel should be with EN 14214 and ASTM D6751 limit. Because of the standard, the fuel complies with the emission limits and engine lastingness [1][2].
Biodiesel from vegetable oil have been widely examined in the recent years. Biodiesel production is mainly carried out in 4 ways, from fats and oil. The different ways of transesterification are:

- Base-catalyzed transesterification
- enzyme catalytic conversion of the oil into its fatty acids and then into biodiesel
- direct acid-catalyzed transesterification
- non-catalytic transesterification using methanol or methanol/co-solvent

But the preferred way of transesterification is Base-catalyzed to produce biodiesel. Most commonly used alcohol is methanol because of its low cost. Distillation is a common method to produce methanol from the different methods. Generally the liquid products are petroleum gas, wood, natural gas and coal are distilled. Generally the price of raw edible oil are high and using them to produce biodiesel increase the price of the biodiesel. Biodiesel costs, 75-90% of the raw biodiesel. Because of the increasing cost of production of the biodiesel, use of waste cooking oil in the production of biodiesel would help in reducing the cost and would be a sustainable solution. It is sad that the waste cooking oil is discarded in the drain. Disposal of the waste cooking oil can lead to blockage, smell and environmental pollution. Because of which some government has put taxes on disposal of these oils [2].
Waste cooking oil recycled as cooking oil can cause cancer as the oil is oxidized it produces toxic contents. Acquiring cooking oil in large amount still remains a challenge. Use of waste cooking oil should be increased by looking at the implementation, pro and cons and economic impact. It was observed that in London, 60% fresh

oil was returned by western restaurants and pubs. To ease the process of producing biodiesel from waste cooking oil, supplies had been trained to obtain maximum waste oil [3]. This paper compares the NO_x emission in a diesel engine fueled with waste cooking oil biodiesel and conventional diesel.

2. Literature Review

M.S. Gad et al. 2020. 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 NO_x 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. 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%, NO_x by 20% and smoke opacity by 30% compared to pure waste cooking oil biodiesel. It was observed that by blending biodiesel with gasoline in small dose, improves the physical [4].

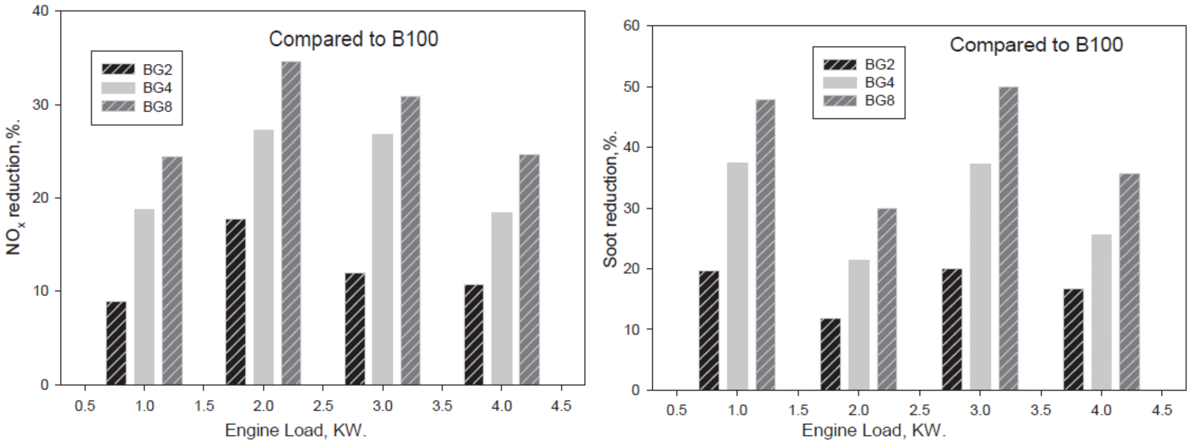

Figure 1: NO_x emission at different engine load [4]

JehadYamin et al 2019. 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 [5]. **Mohammed S. Edam. 2019**. 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. NO_x 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 [6]. **R. Selvaraj et al. 2019**. 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. Proton nuclear magnetic resonance, Fourier transformation infrared spectroscopy, carbon nuclear magnetic resonance and gas chromatography-mass spectrometry was use to examine FAME.

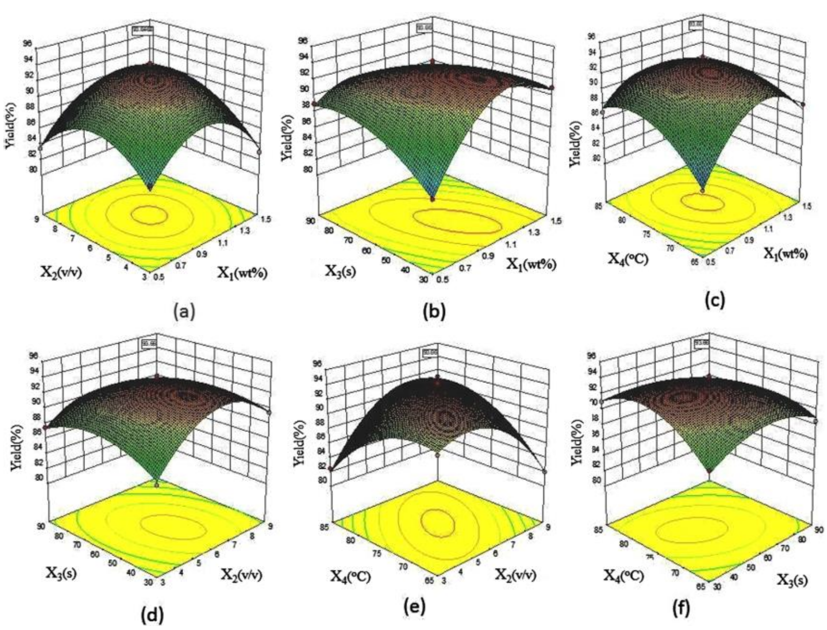

Figure 2: Response surface plots showing the effects on yield of FAME (%) (X1: Catalyst (wt %), X2: Alcohol: Oil ratio (v/v), X3: Time (s) and X4: Temperature (°C)) [7].

13CNMR for FAME from WCO, agreed to the presence of methyl esters in biodieselat 174.2 ppm and 51.4ppm. [7]. **Majid Mohadesi et al.** produced biodiesel by transesterification of waste cooking oil with KOH as catalyst. Biodiesel was produced by micro-reactor of 5L/h, having 50 tube of 0.8mm diameter. Use of methanol reduced the acidity of oil, less than 1mgKOH/g in the presence of 1% sulphuric acid and at 60 °C. Catalyst weight, methanol to oil molar ratio and reaction time were studies by using Box-Behnken design. Highest content of biodiesel was 98.26% with 120s residence time [8]. **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. NO_x emission was also reduced with the use of methyl ester waste cooking oil. B20 was best ratio in terms of performance of the engine [9].

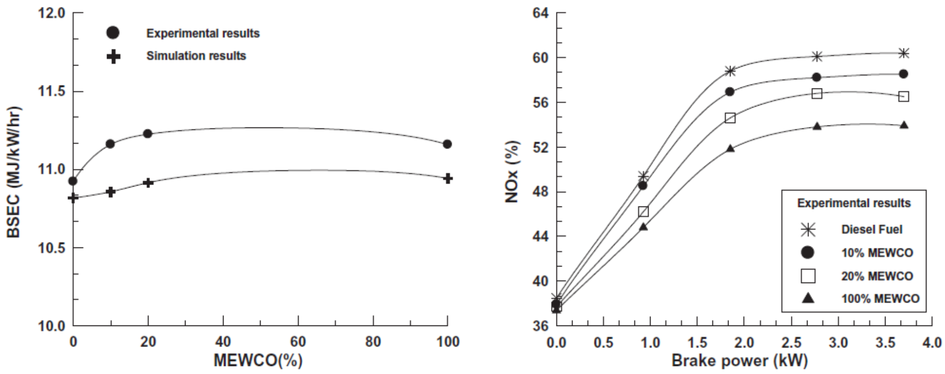

Figure 3: (a) MEWCO% v/s BSEC, (b) Load v/s NO_x emissions [9]

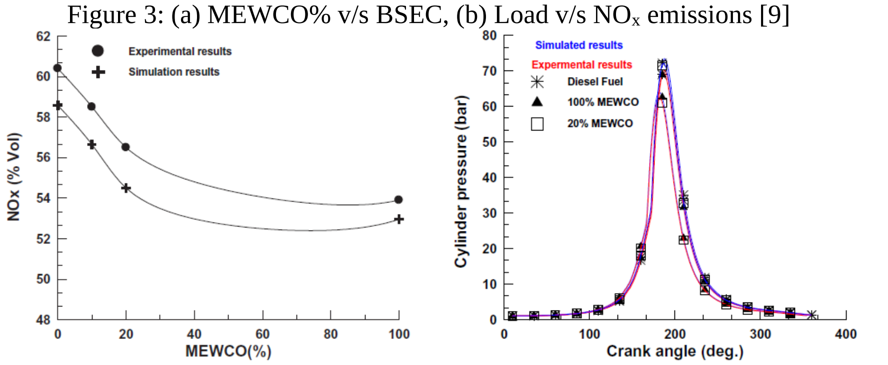

Figure 4: (a) MEWCO% v/s NO_x emission, (b) Crank angle v/s cylinder pressure [9]

MohdAffandiMohd Ali et al. 2020. 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 NO_x was reduced compared to diesel [10]. **C.C. Enweremadu et al. 2010.** Researched on the use of waste cooking oil as biodiesel, it would reduce the burden on sewage treatment plants and would be economically cheaper also. It was observed that after the oil was being used for frying, transesterification reaction was affected because of free fatty acids and polymerized triglycerides, this also affected the biodiesel properties. It was observed that with increasing biodiesel blend, ignition delay decreased. Peak pressure was higher for used cooking oil. As UCO blend increased the exhaust temperature also increased.

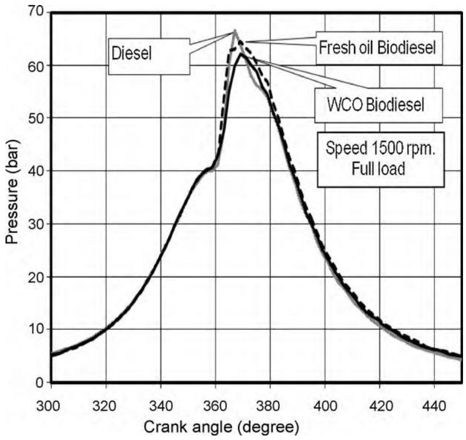

Figure 5: Crank angle V/S pressure diagram of 3 test fuels [11].

At higher loads, it was observed that there was slight increase in NO_x, this was because of the higher content of oxygen in the biodiesel fuel and the advanced injection process. Particulate matter and smoke, sharply reduced with UCO blend. The reduction in smoke and particulate matter was because of the oxygen content in the fuel which reduces the soot formation and increases soot oxidation. BSC and BSFC increased with increasing blend ratio. It was concluded that biodiesel form cooking oil is economically cheap and has good engine performance [11]. **C.S. Cheung et al. 2015.** Investigated on a 4 cylinder direct-ignition diesel engine which was fueled with puree diesel, pure biodiesel and biodiesel blends (B20 and B30). Five different engine loads were used to conduct the experiment, corresponding to brake mean effective pressures of 0.1650.33, 0.496, 0.661 and 0.753MPa at 1800rpm constantly. Hydrocarbon, carbon monoxide and PM concentration was reduced by the use of biodiesel but with increasing biodiesel NO_x emission increases. Diluted exhaust were collected the particulate samples and thermogravimetric was used to analyse by scanning calorimetry (TGA/DSC). Decrease in ignition temperature of the soot was because of the decrease in engine load and volatile mass fraction of the particulate increase, by increasing the biodiesel load [12].

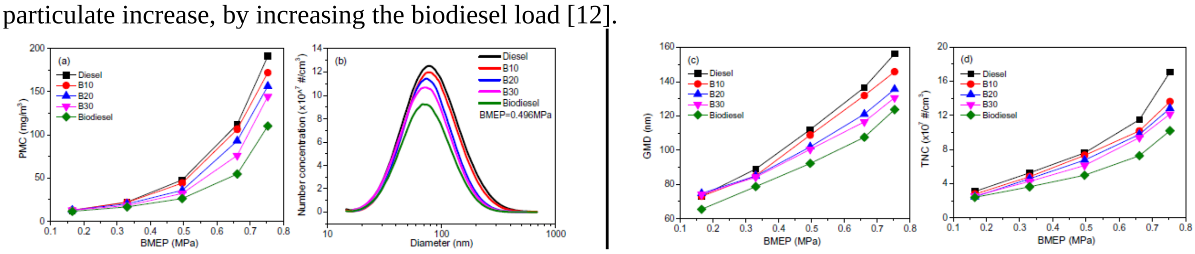

Figure 6: Biodiesel effect on (a) PMC, (b) particulate size-number distribution, (c) GMD and (d) TNC [12]

AlirezaShirneshana. 2013. 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) & NO_x, 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].

P. Mohamed Shameer et al. 2017. 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 fuelling 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 [14]. **Shou-Heng Liu et al. 2012.** Used waste cooking oil because of its economic cost and easy availability. Polycyclic aromatic hydrocarbon emission was analyzed on a heavy duty diesel engine with catalyzer which was fueled with waste cooking oil biodiesel and blends of biodiesel and ultra-low sulfur diesel. From the experiment it was observed that ULSD/WCOB blend showed lower CO, PM and HC but NO_x & CO emission was higher, compared to conventional diesel. PAHs was decreased by 14.1% - 53.3%, 6.76% - 23.5% HC, 6.80% - 15.1% PM and 0.962% - 8.65% CO but NO_x and CO_2 increased by 0.384–1.15% and 0.318–1.43% respectively [15].

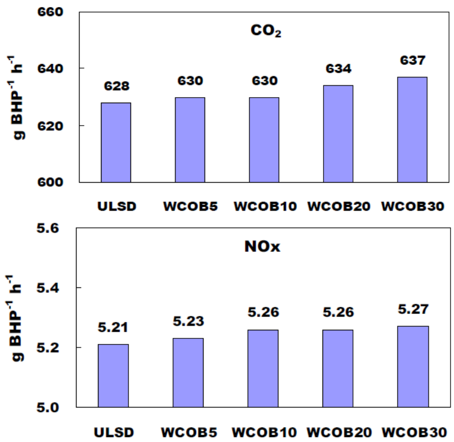

Figure 7: Emission of CO_2 and NO_x from the HDDE [15]

Sehmus ALTUN. 2011. Analysed the exhaust and performance emission of two biodiesel (animal tallow and waste cooking oil) in a direct injection diesel engine. The inedible animal tallow was trans-esterified by alkaline catalyst and methyl alcohol to get inedible animal tallow methyl ester. Waste cooking oil was biodiesel was produced by trans-esterification by methyl alcohol. Different engine speed and full load conditions was used to investigate the exhaust emission and performance. It was observed that BSFC increased and brake torque reduced. NO_x emission was higher for waste cooking oil and lower for inedible animal tallow. Where as in case of CO, emission from both the fuels were less [16].

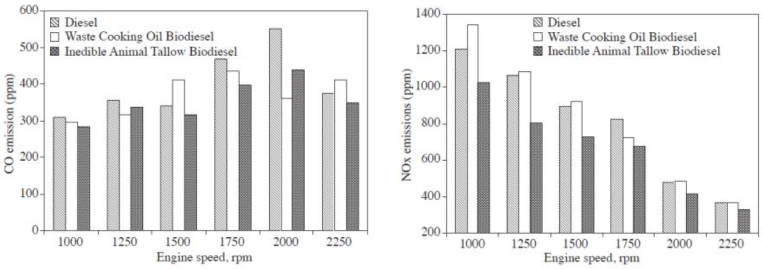

Figure 8: change in CO and NO_x emission with speed [16]

Stefano Cordiner et al. 2014. Investigated on the use of waste cooking oil biodiesel for a non-road application. The blend of waste cooking oil biodiesel and conventional diesel was in the ratio of 6-30% v/v. in the experiment it was observed that PM emission was low and NO_x emission was higher. PM/NO_2 ratio was the focus in presence of diesel oxidation catalyst. NO_x/NO_2 was unaffected by the raw exhaust & NO-NO_2 light-off temperature shows slight reduction by the used of biodiesel. Diesel Particulate Filter ensured more favorable conditions. It was also observed that the higher value of BSFC was because of the lower heating values of biodiesel. B30 blend had higher BSFC and more NO_x. PM was reduced because of higher oxygen content [17].

ArashMohebbi et al. 2102. Researched on use of waste cooking oil biodiesel and its blend in tractor diesel engine and investigated on heat release rate, engine torque and power, cylinder pressure, brake specific fuel consumption, oxides of nitrogen, brake thermal efficiency and particulate matter emission. It was noticed that advanced the injection and the combustion process, heat release rate was increased and ignition delay was shorter. Reduction in PM and increase in NO_x was observed because of higher temp and cylinder peak pressure. Engine power and engine torque was reduced with increasing blend ratio. BSFC was increased because of increasing the heating values of WCO but no change in brake thermal efficiency. To reduce $NO_{x,}$ effective was is to use EGR (exhaust gas recirculation). With EGR, PM values reduces significantly. EGR helps in reducing the NO_x and PM of the WCO biodiesel and has lower negative effect in engine performance [18].

3. CAD MODEL

A 2D model of the combustion cylinder was made in Ansys 16. The dimension of the cad model was same as the CI engine specification. The diameter of the cylinder was 89.90mm whereas the length of the cylinder was 110mm.

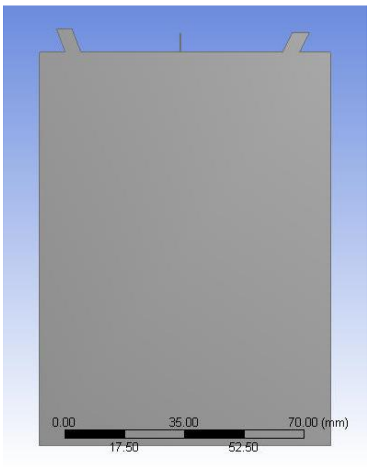

Figure 9: CAD design for analysis

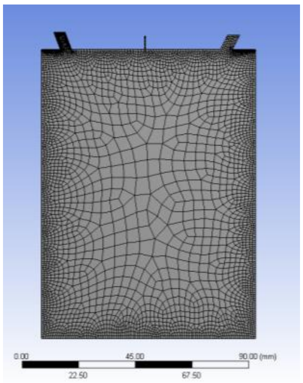

Figure 10: Meshed file

Analysis was carried out in Fluent module of Ansys 16. Species transport model was used with eddy-dissipation. The fuel used of analysis was Diesel and waste cooking oil biodiesel. The properties of the biodiesel have been listed in the table below.

Table 1: Properties of produced biodiesels

Property	Unit	Biodiesel	ASTM D6751
Density at 15 °C	g/cm^3	0.880	0.86 to 0.90
Kinematic viscosity at 40 °C	cSt	4.6	4 to 6
Pour point	°C	5	−15 to 10
Cloud point	°C	6	−3 to 12
Water content	%	0.03	0.05
Total glycerin	%	0.13	0.24

4. Result & Discussion

The analysis was solved by Ansys Fluent module. Two different types of fuel were considered for the analysis, Conventional Diesel and waste cooking oil biodiesel. The combustion condition for both the fuel were kept same so that we could compare the difference in the NO_x emission because of the fuel.

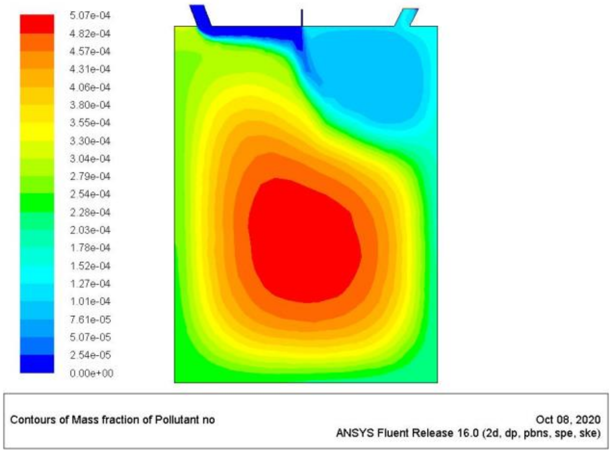

Figure 11: Diesel NO_x Density

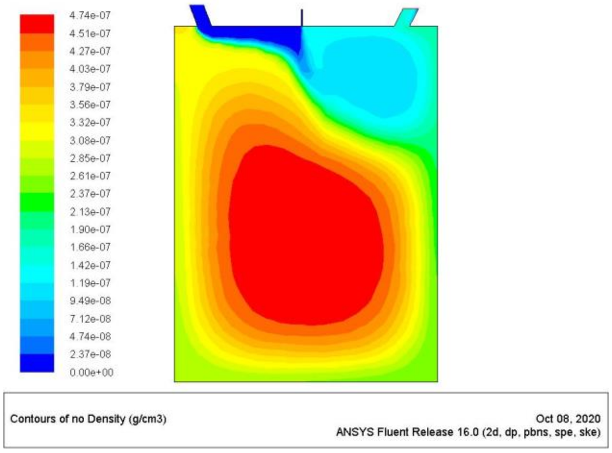

Figure 12: Diesel NO_x mass Fraction

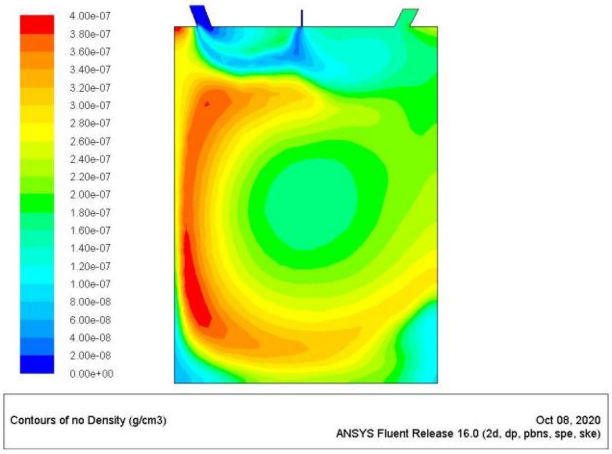

Figure 13: Waste cooking oil biodiesel NOx density

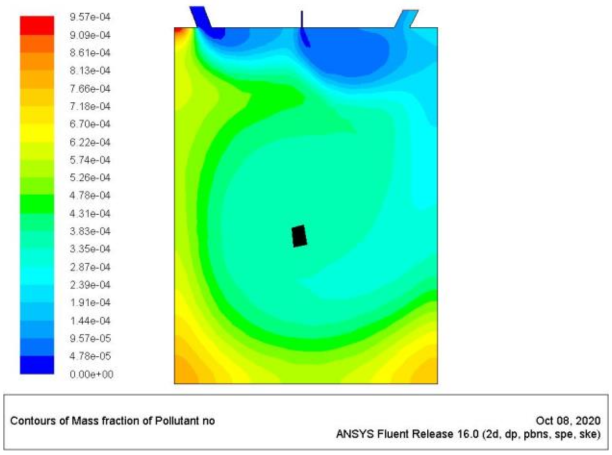

Figure 14: Waste cooking oil biodiesel NO_x Mass Fraction

It was observed from the simulation that, in the condition of diesel the NO_x concentration was at the center of the combustion chamber. NO_x density and NO_x mass fraction both were at the center of the combustion chamber as shown in figure 11 and figure 12. But in the case of waste cooking oil biodiesel, the NO_x concentration was shifted to the side of the combustion chamber. NO_x density was at the side were as NO_x mass fraction was at the top corner of the combustion chamber. This was because of the change in density of the fuel. Waste cooking oil biodiesel has more density than conventional diesel. NO_x was also formed more because of the oxygen content are more in the waste cooking oil biodiesel.

5. Conclusion

To improve the fuel economy and the emission, a lot of research have been carried out on internal combustion engine. Alternative fuels have also been introduced and using alternative fuels, continues to be a challenge. Biodiesel being a part of the alternative fuel, obtained from animal fat and vegetable oil, good alternative to conventional diesel. Popularity of biodiesel all of the world have recently increased because of its renewability, biodegradability, non-toxic, easy availability and better emission.

Biodiesel costs, 75-90% of the raw biodiesel. Because of the increasing cost of production of the biodiesel, use of waste cooking oil in the production of biodiesel would help in reducing the cost and would be a sustainable solution. It is sad that the waste cooking oil is discarded in the drain. Disposal of the waste cooking oil can lead to blockage, smell and environmental pollution. Therefore use of waste cooking oil as biodiesel would help in reducing the waste in the environment. In the paper waste cooking oil was simulated in the same conditions as the conventional diesel and was found that waste cooking oil biodiesel produces more NO_x emission than diesel. Which was because of the higher concentration of oxygen in the biodiesel. The results matched with the literature review.

Acknowledgement

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (NRF-2019R1A2C1010557)

References

1. Özer Can, “Combustion characteristics, Performance and exhaust emissions of a diesel engine fueled with a waste cooking oil biodiesel mixture,” Energy Conversion and Management,Vol. 87, pp. 676–686, August 2014
2. AyhanDemirbas,“Biodiesel from waste cooking oil via base-catalytic and supercritical methanol transesterification,” Energy Conversion and Management, Vol. 50, pp. 923–927, January 2009
3. ZahiraYaakob, Masita Mohammad, Mohammad Alherbawi, ZahangirAlam, KamaruzamanSopian, “Overview of the production of biodiesel from Waste cooking oil” Renewable and Sustainable Energy Reviews,Vol. 18, pp. 184–193, November 2012
4. M.S. Gad, Ahmed I. EL-Seesy, Ali Radwan, Zhixia He, “Enhancing the combustion and emission parameters of a diesel engine fueled by waste cooking oil biodiesel and gasoline additives,” Fuel,Vol. 269, pp. 1-13, March 2020
5. JehadYamin, Ahmad Jehad Abu Mushref,“Performance and mapping of direct injection diesel engine using waste cooking oil biodiesel fuel” Advances in Mechanical Engineering, Vol. 11(5),pp 1–11, September 2020
6. Mohammed S. Edam, Mohamed F. Al-Dawody, “Numerical Simulation for the Effect of Biodiesel Addition on the Combustion, Performance and Emissions Parameters of Single Cylinder Diesel Engine,” Al-Qadisiyah Journal For Engineering Sciences, Vol. 12, pp 072–078, June 2019
7. R. Selvaraj, I. Ganesh Moorthy, R. Vinoth Kumar, V. Sivasubramanian,“Microwave mediated production of FAME from waste cooking oil: Modelling and optimization of process parameters by RSM and ANN approach,” Fuel, Vol. 237, pp. 40–49, October 2018
8. Majid Mohadesi, BabakAghel, Mahmoud Maleki, Ahmadreza Ansari,“Production of biodiesel from waste cooking oil using a homogeneous catalyst: Study of semi-industrial pilot of microreactor,” Renewable Energy,vol. 36, pp. 677-682, January 2019
9. Mohamed F. Al-Dawody, Ali A. Jazie, Hassan Abdulkadhim Abbas,“Experimental and simulation study for the effect of waste cooking oil methyl ester blended with diesel fuel on the performance and emissions of diesel engine,” Alexandria Engineering Journal, vol. 58, pp. 9–17. January 2019
10. MohdAffandiMohd Ali, JoliusGimbun, Kun Lu Lau, Chin Kui Cheng, Dai-Viet N. Vo, Su Shiung Lam, RosliMohdYunus, “Biodiesel synthesized from waste cooking oil in a continuous microwave assisted reactor reduced PM and NOx emissions,” Environmental Research, vol. 185, pp 1-10, April 2020
11. C.C. Enweremadu, H.L. Rutto, “Combustion, emission and engine performance characteristics of used cooking oil biodiesel—A review,” Renewable and Sustainable Energy Reviews, vol. 14, pp 2863–2873, July 2010
12. C.S. Cheung, X.J. Man, K.W. Fong and O.K. Tsang, “Effect of waste cooking oil biodiesel on the emissions of a diesel engine,” in Proceedings of The 12th International Conference on Combustion & Energy Utilisation – 12ICCEU, vol. 66, pp. 93 – 96, Lancaster, UK, 2014
13. AlirezaShirneshana, “HC, CO, CO2 and NOx Emission evaluation of a diesel engine fueled with waste frying oil methyl ester” in Proceedings2nd International Conference on Leadership, Technology and Innovation Management. Vol. 75, pp. 292 – 297. Istanbul, Turkey, October 2013
14. P. Mohamed Shameer, K. Ramesh,“Experimental evaluation on performance, combustion behavior and influence of in-cylinder temperature on NOx emission in a D.I diesel engine using thermal imager for various alternate fuel blends,” Energy, vol. 118, pp. 1334-1344, November 2016
15. Shou-Heng Liu, Yuan-Chung Lin, Kuo-Hsiang Hsu, “Emissions of Regulated Pollutants and PAHs from Waste-cooking-oil Biodiesel fueled Heavy-duty Diesel Engine with Catalyzer,” Aerosol and Air Quality Research, vol. 12, pp. 218–227, April 2012

16. Sehmus ALTUN, “Performance and exhaust emissions of a DI diesel engine fueled with waste cooking oil and inedible animal tallow methyl esters,” Turkish J. Eng. Env. Sci, vol. 35, pp. 107 – 114. April 2010
17. Stefano Cordiner, Vincenzo Mulone, Matteo Nobile, Vittorio Rocco, “Effects of Waste Cooking Oil Biodiesel Use on Engine Fuel Consumption and Emissions: a Study on the Impact on Oxidation Catalyst and Particulate Filter,”in Proceedings of The 6th International Conference on Applied Energy – ICAE2014, vol. 61, pp. 953 – 957, Taipei, Taiwan, june 2014
18. ArashMohebbi, Mohammad Hassan Komarizade, SamadJafarmadar, JafarPashai, “Use of waste cooking oil biodiesel in a tractor DI diesel engine,” Journal of Food, Agriculture & Environment,vol. 10:(2), pp. 1290-1297, April 2012