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Impact of Alcohol and Gutter Oil Emulsion in Single Cylinder Compression Ignition Engine

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Abstract- Although the world's natural fossil fuel supplies are running low, the demand for fuel is rising due to rapid urbanization and population growth. The direct use of spent cooking oil in diesel engines has gained acceptance to lessen global reliance on fossil fuels, particularly in the transportation sector. As a result, carbon and lacquer deposits have worn down and damaged the engine. Furthermore, deposits on the piston crown may become extremely persistent due to the increased heat generated by contemporary diesel injection systems. In a single chamber CI engine, three distinct fuel tests were put through a 200-hour endurance test: DF83WCO7Pe10, which is a blend of 83% diesel, 7% waste cooking oil, and 10% n-pentanol, and DF93WCO7, which is a mixture of 93% diesel and 7% waste cooking oil. This review examined the effects of DF, the ternary fuel mix DF65WCO20Pe15, and the twofold fuel mixes DF93WCO7 on cylinder crown stores. Visual examination of the piston, while it was operating with all tested fuel types, showed some deposit deposition, according to the investigation. An engine powered by DF93WCO7 left more carbon deposits on and around the piston surface than one powered by DF83WCO7Pe10, according to SEM and EDX.

Keywords: Compression Ignition Engine, N-pentanol, Waste Cooking Oil, Deposit Formation

I. Introduction

Global population growth and the trend toward greater urbanization have raised energy demands. The rise in energy consumption is associated with the development of human society and its health, social, economic and welfare aspects. Unrestrained use of fossil fuels has resulted in significant health issues and widespread environmental degradation [1]. The use of oils, especially fossil fuels, has increased as a result of rising energy consumption and the emergence of more ecological risk factors. Reducing the use of fossil fuels and substituting them with renewable energy sources could mitigate these issues [2]. Worldwide, significant amounts of waste cooking oil (WCO), which is created during the cooking or frying process, are produced [3]. A UN Food and Agricultural Organization report estimates that India's food processing industry produces 23 million tons of waste vegetable oil [4]. Additionally, the environmental issues caused by the disposal of waste cooking oil (WCO) necessitate either reprocessing or use with a financial incentive [5]. The results of the study confirmed that waste cooking oil (WCO) could be converted into biodiesel through the transesterification process. Analysis was then done to determine how well the biodiesel produced from WCO performed in engines [6]. Vegetable oil has the potential to be a competitive alternative fuel due to its renewable nature, environmental friendliness, ease of production, and inherent biodegradability [7]. This study fills a glaring research gap by examining the use of unmodified waste cooking oil (WCO) as blended oil with diesel for the purpose of classifying effluents and evaluating their performance in a compression ignition (CI) engine [8].

Deposition may negatively impact the overall efficiency of the system, whether it occurs along the outside of the injector tip or inside the injector nozzle's orifices [9]. The available literature states that the injector nose, the area of the combustion chamber with the lowest temperature, is where deposits in a diesel engine start to form. The deposits then spread to the throat and bands, then to the chamber walls, and finally to the chamber head, among other places [10]. In a thorough investigation, Diabya (2009) [11] contended that engine downsizing combined with severe engine operating conditions, such as the combustion chamber's operating temperature and pressure, the oil sump, or cylinder liner temperature could accelerate the deposits formation process in engines. To examine the effects of B50 and Indonesian biodiesel fuel (IBF: diesel fuel containing 10% palm oil biodiesel) on engine durability, Suryantoro (2016) [12] carried out endurance tests. According to the EDS results, there was a significant amount of calcium present in the deposits in the piston crown of the B50-powered engine. Additionally, this element is present in oil lubricants as a corrosion inhibitor or detergent. In contrast, the calcium content in the IBF-fueled engine was significantly lower. Studies have found a correlation between increased carbon deposits and certain properties of biodiesel, including its higher viscosity, decreased volatility [13], and the reactivity of unsaturated hydrocarbon chains, injector coking, and the formation of trumpet-like structures on injectors, among other effects, over long engine operating times. Based on the findings, SEM images demonstrated that the biodiesel-powered engine's injector nozzle width had decreased more noticeably. For unintended fuel instillation, existing common rail, and upcoming common rail structures, the study specifically looked at the formation of piston pledges when using RME (rape methyl ester) in a swirl hollow instillation unit. Because it is thought to be an effective alternative fuel for reducing the use of fossil fuels, waste vegetable oil (WO) is used in scientific research. After evaluating the engine's energetic performance metrics, the researchers concluded that palm biodiesel performed better energetically than Karanja biodiesel. comparative study of the effects of diesel and biodiesel fuel on two single-cylinder engines was part of the experimental analysis. The injector parameters and fuel injection pump pistons are identical for these engines. Following 200 hours of operation at 2000 revolutions per minute (rpm), a study of the injectors was conducted. This study employed EDS analysis and SEM (scanning electron microscopy) to provide a comparative comparison. Based on the findings, SEM images demonstrated that the biodiesel-powered engine's injector nozzle width had decreased more noticeably. For unintended fuel instillation, existing common rail, and upcoming common rail structures, the study specifically looked at the formation of piston pledges when using RME (rape methyl ester) in a swirl hollow instillation unit [14]. Because it is thought to be an effective alternative fuel for reducing the use of fossil fuels, waste vegetable oil (WO) is used in scientific research. The researchers came to the conclusion that palm biodiesel outperformed Karanja biodiesel in terms of energetic performance after analyzing the engine's energetic performance metrics. The machine's performance and characteristics of biodiesel emissions were examined through experiments [15]. Exhaust gas emissions and the effects of fuel deposits are closely related. The phenomenon of deposit formation has been extensively studied, especially about injectors [16-18]. Since reformulating WCO with alcohols is a simple, straightforward, and reasonably priced method of reducing the viscosity of vegetable oils, researchers have recently become interested in this approach. Studies have shown that ternary blends of used cooking oil, diesel, and alcohol have better cetane numbers, lower viscosities, and densities that are closer to diesel. Ternary blends are significant because they enhance energy security and environmental safety by partially substituting diesel with a recycled component, like WCO. Analyzing the composition and structure of the carbonaceous deposit found in a decommissioned engine was the aim of this experimental study.

The specific objective of this investigation was to identify the causes of the difficulties in eliminating carbonaceous pledges. This project's primary objective is to compare the piston pledges during a 200-hour endurance test using waste cooking oil (DF93WCO7), n-pentanol ternary blend fuel (DF83WCO7Pe10), and DF as the baseline fuel.

II. Material and Methods

When choosing the machine for this study, a diesel-powered four-stroke single cylinder engine was chosen. A detailed summary of the main requirements, including fuel specifications and other necessary conditions, is given in Table 1.

The engine was connected to a dynamometer that used eddy current. Three fuel specimens-DF, waste cooking oil (DF93WCO7), and n-pentanol (DF83WCO7Pe10) were used for the endurance test, which lasted 150 hours at a rotational speed of 1300 rpm and a load of 1 Newton meters (N-m). Table 1 contains the engine configuration.

Table .1: Engine Specification

Model	**Single-Cylinder, Four Stroke Pre-combustion Chamber**
Stroke	80mm
Bore	75mm
Mean Effective Pressure	576kPa
Cooling Water Consumption	1360 m/kW h
Injection Pressure	14.2 + 0.5 Mpa
Specific Oil Consumption	4.08 g/kW h
Output (12 hours rating)	4.4kW/2600r/min
Illuminator	Fly wheel driver

Piston ean Speed	6.93 m/s
Specific Fuel Consumption	278.8 m/kW h
Displacement	0.353L
Compression Ratio	21-23
Lubricating Oil Capacity	About 2L

The used cooking oil used in this investigation was bought from a nearby eatery. The fuel characterization completed prior to mixing is shown in Table 1. Table 2 lists the salient features of the fuels that were tested.

Table.2: Fuel Properties

Properties	**Test Method**	**D100**	**DF93WCO7**	**DF83WCO7Pe10**
Calorific Valve MJ/Kg	ASTMD5468	42.5	39.8	43
Viscosity Cst at 40c	ASTM D7042	2.28	2.388571	1.808706
Density g/ml	ASTM D7042	0.835	0.835281	0.834978
Flash Point °C	ASTM D93	78	85	94
Cetane Number	ASTMD6890	50	53	55.5

The Before starting the experiment, the engine was run for ten minutes to bring it to a steady state. Additionally, the engine was started and run for 10 hours every day for the duration of the endurance test. Frying operations at temperatures ranging from 130 to 180 degrees Celsius have been the main application for the WCO. Before mixing, the oil was strained and heated to remove any food particles and water dribbles. The strength of the mixtures had to be changed because diesel is water-abhorrent and water can cause phase separation over time. A 4 µm filter was used to filter WCO. Each test fuel blend (percent vol) was prepared prior to the engine being fueled for operation. A 200-hour endurance test was conducted on each test fuel (DF, DF93WCO7, and DF83WCO7Pe10). In order to assess the impact of using various test fuels, the development of pledges on the piston crown at different positions was examined using SEM and EDX. Scanning electron microscopy allows for the examination of objects at both macro and submicron sizes. once used with EDX in aggregate. Small material samples were subjected to elemental analysis using EDX. Photographs of the injector nozzle were taken at two different points in time: immediately following installation (zero hours) and following the completion of the endurance test for every piston sample.

III. Results and Discussion

3.1. Piston Crown Photographic Inspection

Figure 1 shows the image of the piston top taken during a 150-hour endurance test on DF fuel. Both binary DF93WCO7 and ternary blend fuels, such as the DF83WCO7Pe10 mix, were used in the test. The formation of deposits on the piston liners and their upper surfaces is demonstrated by the visual examination of two fuel samples obtained during different operating hours, as shown in Figure 1.

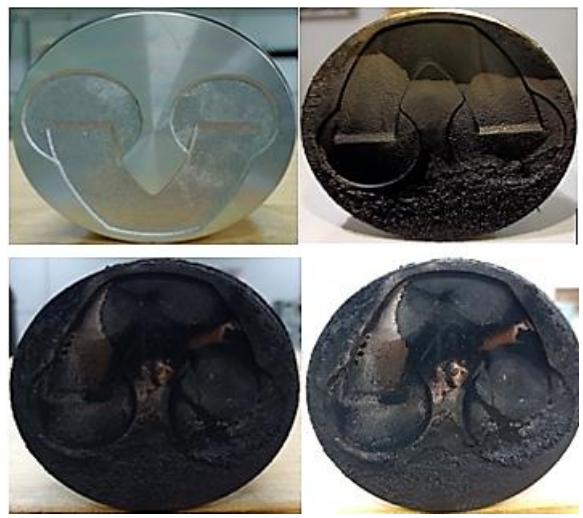

Figure.1 Visual inspection of engine piston during endurance tests.

The existence of deposit buildup was revealed by photographic documentation of pistons running on different fuel types (DF, DF93WCO7, and DF83WCO7Pe10). After analysis, it was found that the piston crown using DF93WCO7 had more dirt buildup than the piston crown using DF and DF65WCO20Pe15. Furthermore, it was noted that deposits on the piston when using diesel fuel (DF) appeared greasy or oily. However, compared to the piston operating on DF, the one operating on DF93WCO7 was muddier. DF83WCO7Pe10 has significantly less deposit when using ternary blend fuel than baseline fuel.

3.2. SEM and EDX Examination

The engine was partially disassembled to investigate the formation of deposits on the piston tops following a thorough 200-hour endurance test on the DF, DF93WCO7, and DF83WCO7Pe10 mix. Scanning electron microscopy (SEM) images of deposits on the piston top when fueled with DF, DF93WCO7, and DF83WCO7Pe10 are shown in Figure 2.

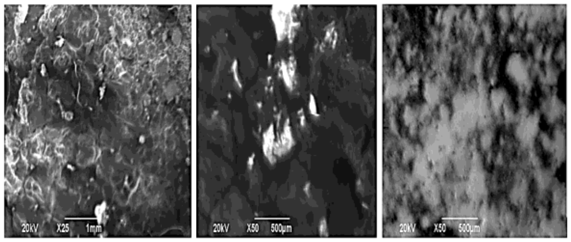

Figure. 2 SEM images of piston crown fueled by DF, DF95WCO5 and DF65WCO20Pe15.

The engine was disassembled for additional study following a 150-hour endurance test on the DF, DF93WCO7, and DF83WCO7Pe10 blends. In particular, SEM methods combined with EDS were used to analyze the deposit deposition on each piston top. The elemental makeup of the pledges and their relationship to the tested blends were the goals of this analysis. SEM micrographs at 25 exaggeration of deposits on the piston crown are displayed in Figure 3. On the upper layer of the piston crown, the carbon concentration was 56.17% on DF93WCO7 and 32.54% on DF. Darker areas were generally found to have higher levels of carbon. However, it was discovered that the carbon concentration on DF83WCO7Pe10 was 27.58 percent. Several additional metal elements were discovered in the spectrum during this investigation. This demonstrates that in the case of DF, the carbon layer that forms during deposition is not always thick. Carbon deposits are generally formed at high temperatures by either hydrocarbon breaking down into elemental carbon and hydrogen or hydrocarbon molecules aggregating and condensing into higher polynuclear aromatic hydrocarbons (PAHs), which then serve as nuclei for the development of carbonaceous deposits. The spectra from the resulting deposition showed the presence of several metallic elements.

Spectrum: Acquisition

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Carbon	K-series	32.54	37.42	60.97	4.0
Oxygen	K-series	16.14	18.56	22.70	3.2
Aluminum	K-series	1.19	1.37	0.99	0.1
Calcium	K-series	0.67	0.77	0.38	0.1
Chromium	K-series	0.68	0.78	0.29	0.1
Iron	K-series	33.77	38.83	13.61	0.9
Zinc	K-series	1.06	1.21	0.36	0.1
Sulfur	K-series	0.47	0.54	0.33	0.0
Silicon	K-series	0.45	0.52	0.36	0.0

Spectrum: Acquisition

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Carbon	K-series	56.17	56.17	65.15	17.6
Oxygen	K-series	37.81	37.81	32.92	12.3
Sulfur	K-series	1.17	1.17	0.51	0.1
Calcium	K-series	1.42	1.42	0.49	0.1
Iron	K-series	0.87	0.87	0.22	0.1
Zinc	K-series	1.92	1.92	0.41	0.1
Phosphorus	K-series	0.45	0.45	0.20	0.0
Silicon	K-series	0.18	0.18	0.09	0.0

Spectrum: Acquisition

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Carbon	K-series	27.58	36.65	69.16	3.4
Oxygen	K-series	3.18	4.22	5.98	1.6
Magnesium	K-series	0.28	0.37	0.34	0.0
Aluminum	K-series	0.78	1.03	0.87	0.1
Silicon	K-series	0.35	0.47	0.38	0.0
Chromium	K-series	0.74	0.99	0.43	0.1
Iron	K-series	42.35	56.27	22.84	1.2

Figure.3 EDS elemental examination of piston crown fueled by DF, DF93WCO7 and DF83WCO7Pe10.

The wear, erosion, and tribe-corrosion processes that take place inside engine parts (such as piston rings and pistons) are responsible for the presence of a variety of metallic substances in deposits, including Chromium (Cr), Aluminum (Al), Copper (Cu), Zinc (Zn), Lead (Pb) and Iron (Fe). Lubricating oil can be replaced by metallic elements. Some of this oil was probably inadvertently added to the fuel supply because engine oil is used to lubricate the high-pressure pump. In this regard, the presence of Sulfur (S) and Zinc (Zn) in every location suggests a link between the deposit and likely metal-adulterated lubricant. A magnified scanning electron microscope image of the deposits discovered on a piston crown fueled with three different fuel compositions-DF, DF93WCO7, and DF83WCO7Pe10 is shown in Figure 2. Furthermore, the elemental analysis results from EDX at different locations on the surfaces where the deposits were observed are shown in Figure 3.

IV. Conclusion

Following the 150-hour endurance test, the results of SEM and EDS analyses showed that using DF83WCO7Pe10 fuel significantly reduced the amount of piston deposits compared to using the DF93WCO7 mix. The carbon layer's thickness varied throughout the deposition. On the other hand, deposits that were comparatively thick and overlapped were observed at the top of the piston of an engine that was running on a blend of DF93WCO7 fuel. Moreover, deposits that seem to be identical completely seal the piston crown. All of the locations where the layer was deposited had higher carbon concentrations.

Future Recommendation

This study suggests that WCO is a potential fuel substitute, but it has the disadvantages of being highly acidic and viscous. Pentanol, which has been found to have a higher alcohol content, can assist with the use of any WCO oil in CI engines with performance, emissions, and combustion comparable to diesel. Further investigation into the application of various types of WCO oils can shed important light on this issue and mitigate the environmental impact.

References

[1] N. G. Mengistu, M. W. Mekonen, Y. G. Ayalew, L. F. Demisie, and T. Nega, "Experimental investigation on diesel engine performance and emission characteristics using waste cooking oil blended with diesel as

biodiesel fuel," *Discover Energy*, vol. 4, no. 1, p. 26, 2024.

[2] T. Mahmood, S. Hassan, A. Sheikh, A. Raheem, and A. Hameed, "Experimental investigations of diesel engine performance using blends of distilled waste cooking oil biodiesel with diesel and economic feasibility of the distilled biodiesel," *Energies*, 2022. [Online]. Available: https://doi.org/10.3390/en15249534

[3] M. D. F. Al-Aseebee, A. A. Khudhur, S. M. A. Alsaady, S. J. Al-Khafaji, and R. A. Hamzah, "Modeling of waste vegetable oil biodiesel for tractor engine utilization," *Journal of Ecological Engineering*, vol. 24, no. 12, pp. 293–303, 2023. [Online]. Available: https://doi.org/10.12911/22998993/173564

[4] S. Manigandan, P. Gunasekar, J. Devipriya, and S. Nithya, "Emission and injection characteristics of corn biodiesel blends in diesel engine," *Fuel*, vol. 235, pp. 723–735, 2019.

[5] N. Yilmaz, A. Atmanli, and F. M. Vigil, "Quaternary blends of diesel, biodiesel, higher alcohols and vegetable oil in a compression ignition engine," *Fuel*, vol. 212, pp. 462–469, 2018.

[6] M. K. Yesilyurt, "The effects of the fuel injection pressure on the performance and emission characteristics of a diesel engine fuelled with waste cooking oil biodiesel-diesel blends," *Renewable Energy*, vol. 132, pp. 649–666, 2019.

[7] H. Canton, "Food and agriculture organization of the United Nations—FAO," in *The Europa Directory of International Organizations 2021*, Routledge, pp. 297–305, 2021.

[8] K. R. Varun and G. Harish, "Comparative study of waste cooking oil with diesel for performance and emission analysis," *Journal of Emerging Technologies and Innovative Research*, vol. 8, no. 10, p. 111, 2021.

[9] A. Al-Ghafis and M. S. Basha, "Experimental trails on diesel engine performance and emission characteristics of waste cooking oil combinations at varying injection pressures," *American Journal of Applied Sciences*, vol. 18, no. 1, p. 15, 2021.

[10] P. K. Chaurasiya, S. K. Singh, R. Dwivedi, and R. V. Choudri, "Combustion and emission characteristics of diesel fuel blended with raw jatropha, soybean and waste cooking oils," *Heliyon*, vol. 5, no. 5, e01564, 2019.

[11] K. Copec, K. Celina, D. Filipovic, V. Jurisic, and I. Kovacev, "Effect of Waste Cooking Oil Blending with Diesel Fuel on Tractor Engine Performances and Exhaust Gases Emission," *Polish Journal of Environmental Studies*, vol. 32, no. 1, 2023.

[12] M. T. Suryantoro, B. Sugiarto, and F. Mulyadi, "Growth and characterization of deposits in the combustion chamber of a diesel engine fueled with B50 and Indonesian biodiesel fuel (IBF)," *Biofuel Research Journal*, vol. 3, no. 4, pp. 521–527, 2016.

[13] F. Jikol, M. Z. Akop, Y. M. Arifin, M. A. Salim, and S. G. Herawan, "Deposits Formation, Emissions, and Mechanical Performance of Diesel Engine Fuelled with Biodiesel: A Review," *International Journal of Nanoelectronics & Materials*, vol. 15, 2022.

[14] F. Jikol, M. Z. Akop, Y. M. Arifin, M. A. Salim, and S. G. Herawan, "Comparison of deposit development on heated surface using B10 and B20 biodiesel," in *Proceedings of Mechanical Engineering Research Day 2022*, pp. 12–13, 2022.

[15] D. Capuano, M. Costa, S. Di Fraia, N. Massarotti, and L. Vanoli, "Direct use of waste vegetable oil in internal combustion engines," *Renewable and Sustainable Energy Reviews*, vol. 69, pp. 759–770, 2017.

[16] A. I. El-Seesy, H. Hassan, and S. Ookawara, "Performance, combustion, and emission characteristics of a diesel engine fueled with Jatropha methyl ester and graphene oxide additives," *Energy Conversion and Management*, vol. 166, pp. 674–686, 2018.

[17] H. Xu, C. Wang, X. Ma, A. K. Sarangi, A. Weall, and J. Krueger-Venus, "Fuel injector deposits in direct-injection spark-ignition engines," *Progress in Energy and Combustion Science*, vol. 50, pp. 63–80, 2015.

[18] A. Ansari, L. Memon, F. Solangi, M. Ghannam, and M. Selim, "Influence of Alcohol Blend Fuels on Performance and Noise Emission in Spark Ignition Engine," *International Journal of Thermofluids*, vol. 26, p. 101120, 2025.