Removal of Deposit Formation using Emulsion Fuel in CIDI Engine

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Abstract

The Experiments on short-term engine operation have shown that waste cooking oil is a desirable replacement for compression ignition engines. The study used blends of waste cooking oil in a long-term endurance test. in order to determine the long-term effects of burning used cooking oil. The results of the study showed that the operating surface of the engine head had very little wear and tear. Nevertheless, the durability test using blends of waste cooking oil and diesel is carried out. Because it has the highest fuel oxygen content, the lowest cetane number, DF60WCO20Pe20, has the longest explosion delay and the shortest burning time. Deposits in engine heads are measured and contrasted with emulsion fuels. At the same locations, a qualitative investigation is carried out using scanning electron microscopy techniques. Visual inspection revealed certain deposits on engine heads when running on all fuels, according to the investigation's conclusions. According to the study, DF95WCO5 created more carbon deposits on the engine head than DF60WCO20Pe20 and DF when SEM and EDS are used.

***Keywords*:** Diesel Engine; Waste Cooking Oil; Ternary Blend; N-Pentanol, Engine Head Deposit.

Introduction

Stringent environmental regulations to limit harmful exhaust gas emissions from diferent combustion applications and the depletion of petroleum-based diesel fuel are major concerns worldwide (Azad et al., 2023). The modern world has a huge demand for energy because of the growing population and the growth of the automotive industry. The supply of fossil fuels is almost entirely depleted due to the massive demand for energy. The estimated 30% annual increase in energy consumption cannot

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be met by the nonrenewable fossil fuels currently in use (Gupta et al., 2015). Numerous environmental issues are also connected to the use of fossil fuels. It is believed that carcinogens specific to lung cancer are present in the diesel exhaust of vehicles that run on fossil fuels.

The use of petroleum-diesel contributes significantly to greenhouse gas (GHG) emissions, which are directly related to climate change and global warming (Chakraborty et al., 2023). It is well known that deposits forming around the injector can change the fuel flow rate and injection pattern in the combustion chamber, thereby reducing overall system performance. Deposit development is primarily driven by fuel impurities, soot, volatile lubricating oil, and reactive combustion products (Hoang and Le Anh, 2018). Rapid urbanization and global population growth have increased the demand for energy. This increase in energy demands has an effect on people's welfare, health, and social and economic development. Globally, the unchecked use of fossil fuels has led to environmental degradation and health hazards (Das et al., 2020).

Diesel reserves have declined, cost volatility has increased, and environmental impact and public health issues have escalated as a result of the increased demand and use of diesel for engine fuel (Capuano et al., 2017; Dabi and Saha, 2019). A study found that frying and cooking generate a large amount of waste cooking oil (WCO) worldwide (Gad and El-Seesy, 2021). About 23 million tons of waste vegetable oil are produced by India's food processing industry, per this study (Food and Agricultural Organization of the United Nations) (Hassen and Bilali, 2022). The disposal of waste cooking oil (WCO) has also resulted in environmental issues that call for reprocessing or consumption along with a financial incentive (Charpe and Rathod 2010; Ansari et al., 2025). Engine performance is then investigated after the results showed that WCO is transesterified to create biodiesel. There isn't much information available about using unmodified WCO as blend fuel with diesel for effluent classification and performance analysis when used in a CI engine. The first search for alternative fuel sources for internal combustion engines began in 1893 when Rudolf Diesel tested peanut oil as an engine fuel (Majhi and Ray 2015). Between 1930 and 1940, when engine power is supplied by vegetable oil derived from different food sources, it became necessary to investigate this issue, and research on alternating fuel oil is initiated at multiple locations (Can, 2014).

Every year, between 0.4 and 0.6 million tons of WCO are produced, according to research done in Japan. However, only 0.25 to 0.26 million tons are collected for industrial use; the rest is drained through home sinks, damaging the drainage system and placing needless strain on sewage systems. WCO has reached and affected the aquatic ecosystem

(Murugesan et al., 2009). Inadequate handling and disposal of this fluid waste can have detrimental impacts on the environment and human health (WCO). Based on the kinds of feedstocks used in the biodiesel manufacturing process, biodiesel generations are generally separated into three major groups. Sunflower seed, palm, coconut, rapeseed, canola, soybean, and peanut oil are among the vegetable oils that are directly used to make the first generation of biodiesel. According to Enagi et al. (2018), using first-generation biodiesel feedstocks has detrimental socioeconomic effects and affects food security. Animal fats, waste cooking oils (WCO), and non-edible oils (such as castor, jojoba, and jatropha oils) are used to make second-generation biodiesel (Bhuiya et al., 2016).

Microbes and microalgae are the source of third-generation biodiesel (Jacob et al., 2021). The disadvantages of making biodiesel from first-generation feedstocks are often solved by biodiesel feedstocks, depending on the second and third generations (Ananthi et al., 2021). Since feedstock selection is responsible for more than 75% of the expenditures associated with producing biodiesel, it is essential (Demirbas, 2009). By producing biodiesel using the WCO, environmental problems associated with water pollution may be avoided and a sustainable energy source and significant emission reduction can be achieved (Hassen et al., 2018). Emulsification, pyrolysis, and transesterification are a few well-known conventional processes linked to the manufacture of biodiesel (Enagi et al., 2018).

The most widely used of the three processes is conventional single-step transesterification, which produces biodiesel (mono-alkyl ester) and glycerol by reacting WCO (triglyceride) with methanol or ethanol (alcohol) in the presence of an acid or base catalyst (Attia et al., 2020). When used directly in compression ignition engines, vegetable oil may result in a number of issues, including increased engine scratching, lubricating oil clotting, carbon accumulation in machine components, fuel strainer blockage, and injector choking. Energy consumption has increased, leading to increased fuel consumption (mostly from fossil fuels) and the creation of environmental risk concerns. Changing to renewable energy sources would mitigate these problems by reducing the consumption of fossil fuels. Further, inexhaustible energy sources have the potential to meet future energy demands (Prabu et al., 2017).

In compression ignition (CI) engines, WCO's high viscosity can lead to issues like excessive fuel consumption at startup, poor atomization during injection, carbon settling in the burning cylinder, and filter blockage (Dey and Ray 2020). WCO shows a high viscosity and low volatility in terms of deprived atomization. Because leftover cooking oil doesn't contain any particles, it can be used as fuel for internal combustion engines, like diesel engines. Used cooking oil can be used as fuel to generate more power. As a result, handling WCO carefully is necessary when using it as an uncommon fuel for CI engines. Techniques such as trans-esterifying WCO to biodiesel or preheating WCO are common while many studies have looked at the emission and engine performance of different fuels, relatively few have looked at the effect of n-pentanol on compression ignition engine characteristics. In order to investigate the carbon deposition of an engine head from a compression ignition engine, this study used diesel, cooking oil, and n-pentanol as fuel samples.

Methodology

The engine's performance is examined under thermally stabilized steady state conditions. As is previously mentioned, studies showed that biodiesel may be produced from fossil fuels. Numerous biodiesel fuels are examined, as previously mentioned, and the results are also shared. Limited investigation had been done to determine the deposit formation attributions for WCO, which is regarded as an alternative fuel. However, it is crucial to properly treat WCO before using it. To make sure the WCO in the make-up tank is liquid, it is warmed to around 40 ^{0}C. The heating tank is simultaneously heated to the desired test temperature. Therefore, a treated WCO is used, along with diesel fuel and n-pentanol, to investigate performance and engine head deposition.WCO is collected from a nearby well-reputed restaurant to be used in our tests. In order to reduce the viscosity of the WCO, an additive named n-pentanol is found through a detailed literature survey.

The blend samples are then sent to a university laboratory for characterization. The WCO had been principally utilized for frying activities in a temperature range of 130 and 180 °C. Prior to mixing, the oil is strained and warmed to eliminate any foodstuff and water dribbles. This is necessary to modify the strength of the mixtures because diesel is water-abhorrent, and the occurrence of water may cause phase separation over a cycle of time. In order to filter WCO a 4 µm filter is used. Each test fuel blend (% vol) is prepared before the engine is fueled for operation. The engine under study is one that is currently in operation at QUEST University Nawabshah's thermodynamics lab, which is part of the Mechanical Engineering Department. The required fuel properties are listed in Table 1. The actual fuel sample and the experimental setup are shown in Figures 1 and 2, respectively. A four-stroke, one-cylinder diesel engine is selected and set up on a test bed. Two fuel tanks, one for mix fuels and the other for DF, provided the test engine's fuel. The engine is connected to an eddy current dynamometer. The engine is fueled with DF at first, and then with mix fuels to create baseline values. To obtain mean values, each test is conducted three times.

Table 1: Fuel properties.

Properties	Diesel Fuel	WCO	n-Pentanol
Viscosity 40 ◦C Cst	2.28	52	2.89
Right Density g/mL	835	900	814.4
Flash point ºC	78	271	49
Oxygen (wt %)	0	20	8.47
Calorific valve MJ/Kg	42.5	37.68	34.75

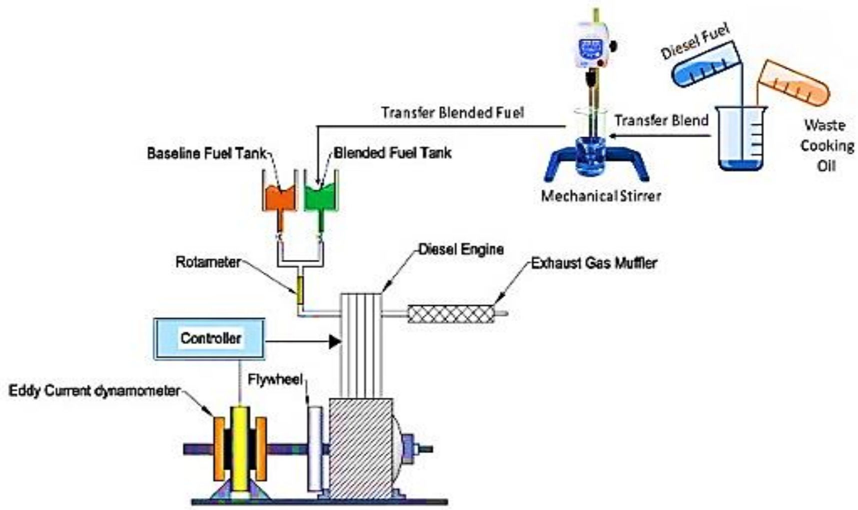

Figure 1: Engine experimental setup.

Figure 2: Physical postures of test fuels (a) DF (b) DF95WCO5 (c) D60WCO20Pe20.

To examine their influence on performance and emission characteristics, several fuel samples are created and mixed. In accordance with ASTM rules, the characteristics of diesel oil and its mixes are weighed. Experiments are conducted on a single-cylinder, 4-stroke, water-cooled, direct injection diesel engine (layout in Figure1), which had been extensively exploited in the agronomic region to pull water to ward irrigate grounds.

Results and Discussion

To evaluate deposition on engine parts, particularly the engine head, an endurance test is conducted in a compression ignition engine. The studies used n-pentanol (DF60WCO20Pe20), diesel (D100), and waste cooking oil (DF95WCO5). After 200 hours of operation, each sample's engine piston is swapped out for a deposition analysis. Prior to running on alternative fuels, the engine is warmed up with diesel petroleum for ten minutes. To maintain consistency throughout the test, the engine is run at a constant load and speed after the warm-up phase is finished. Determining the amount of elemental deposition on the engine head for each of the three fuels under evaluation is the primary objective of this investigation. Elemental deposition is observed on the surface of three distinct engine heads after 200 hours of testing. Table 2 show the nomenclature of the blended fuel.

Table 2: Nomenclature of the blended fuel.

WCO	Waste cooking oil
DF	Diesel Fuel
DF95WCO5	Diesel 95% + Waste cooking oil 5%
DF60WCO20Pe20	Diesel 60% + Waste cooking oil 20%+ n-Pentanol 20%
HD	Head Deposition

Using microscopic and visual inspection tests at various engine head locations, a deposition study is carried out to determine the elements deposition on the valve surface. The test also measured the loss of film viscosity to determine how the gasoline affected engine performance. The analysis revealed that the endurance test resulted in the accumulation of aromatic chemicals on the surface of the engine head piston for all three fuels. The microscopic test using the energy-dispersed X-ray method showed elemental deposition of aromatic compounds on the engine head's surface. Compared to diesel and biodiesel blended fuel, the gasoline sample with the n-pentanol mix had a larger residue. Additionally, more deposit is discovered on the piston's exhaust side than on its intake. The deposit is also found to be unevenly distributed across the engine head surface, with more deposition in some areas than others, when examined under a microscope. The unequal distribution of fuel in the engine cylinder is found to be the cause of the unequal deposition, resulting in localized combustion and increased deposition in certain areas. Additionally, compared to the other two fuels, clove oil is found to have a greater loss of cinematic viscosity, indicating that fuel viscosity affects both engine performance and deposition on the engine head surface. During the first ten hours of the endurance test, the loss of cinematic viscosity peaked for all three fuel samples before stabilizing.

Visual Inspection of Engine Head Deposit

Upon completion of the long-term 200 h endurance test on DF and the DF95WCO5 blend, the engine is partly disassembled and deposit formation on each engine head is studied. Advanced diesel injection systems are characterized by higher temperatures in the area of the head depositions that can lead to particularly stubborn deposits (Solangi et al., 2024). Engine head pictures are taken during a 200-hour endurance test on DF, DF95WCO5, and the DF60WCO20Pe20 mix, as shown in Figure 3. Visual inspection after different operating hours showed some deposit deposition on the injector liners and head surfaces for both fuel types.

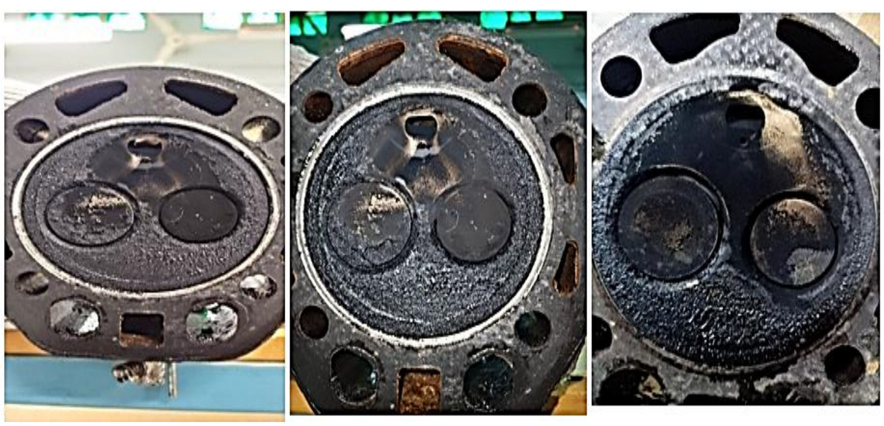

Figure 3: Visual inspections of DF, DF95WCO5 and DF60WCO20Pe20.

However, the engine head running on DF95WCO5 is dirtier than the engine head running on DF. There are reports of similar results. In another study, Hassan et al. (2022) discovered that waste cooking oil increased the amount of deposit development in the engine head. Additionally, it is observed that deposits on the engine head running with the DF95WCO5 mix are dry, while deposits on the engine head running with DF are greasy and oily. The engine head has less deposit when using the mix fuel sample DF60WCO20Pe20.

Scanning Electron Microscopy (SEM)

Following the completion of the 200-hour endurance test on DF, DF95WCO5, and the DF60WCO20Pe20 mix, the engine is partially disassembled and the deposit formation on each engine head is inspected. High temperatures surrounding the injector tip, which can result in extremely persistent deposits in and around the engine head, are a characteristic of improved diesel injection systems (Guan et al., 2019; Yaman and Yesilyurt, 2021).

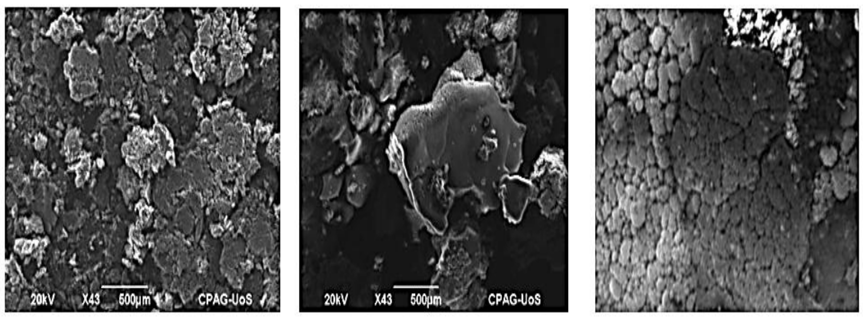

Figure 4: SEM running 200h on diesel fuel DF100, DF95WCO5 and DF60WCO20Pe20

Figure 4 shows the SEM micrographs of deposits on engine heads that are fuelled with DF and DF95WCO5, respectively, at 43 magnifications. Deposits containing DF are clearly much lower than those containing the DF95WCO5 mix. Figure 3 and Figure 3a show the SEM of deposits on an engine head that is fuelled with DF (diesel fuel), waste cooking oil (DF95WCO5), and n-pentanol (DF60WCO20Pe20) at 43 magnifications.

Conclusion

The engine head deposition endurance test using blend fuels like DF100, DF95WCO5, and DF60WCO20Pe20 is examined in this work and contrasted with diesel fuel. Minor deposit deposition is found in the engine head of both fuel-running engines (DF DF95WCO5 and DF60WCO20Pe20) upon visual inspection. However, the engine head using DF95WCO5 is found to be dirtier than the engine head using DF and DF60WCO20Pe20. After the endurance test, SEM and EDX analysis revealed that deposits on the engine head are considerably less when the engine is run with DF and DF60WCO20Pe20 than when it is run with the DF95WCO5 mix. A uniformly thick layer of carbon is not deposited. Moreover, deposits on or near the engine head did not significantly impair it.

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