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Experimental investigations on Diesel-Waste Cooking Oil Blends (V5, V10, V15, V20) on a Single - Cylinder 4-Stroke CI Engine

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This paper presents the performance investigation of V5, V10, V15, V20 waste cooking oil diesel blends on CI engine. This work evaluated the engine's efficiencies and emissions when operating on diesel- WCO blends, V5 (5% WCO and 95% diesel), V10 (10% WCO and 90% diesel), V15 (15% WCO and 85% diesel), and V20 (20% WCO and 80% diesel) fuel blends. This test is performed with the primary objective to evaluate the impact of these blends on engines performance indicators such as power output, fuel efficiency, and various emissions. The waste cooking oil various tests were conducted to analyze the combustion parameters, thermal efficiency, and exhaust emissions of the engine using these fuel blends. The results indicate significant variations in performance metrics, with the increase of blends showing good performance indications and less carbon based pollutions. This research provides valuable insights into the feasibility and benefits of using cooking oil diesel blends in CI engines, contributing to the development of sustainable effective fuel alternatives.

Keywords: Waste Cooking oil, diesel blends, V5, V10, V15, V20, CI engine, Performance analysis, Pollution analysis.

1. Introduction

The utilization of waste cooking oil (WCO) as a viable alternative to conventional diesel fuel has garnered considerable attention in recent years. This study aims to examine the performance and emission characteristics of a single-cylinder, four-stroke, Compression Ignition (CI) engine when fueled with various blends of waste cooking oil and diesel[1]. The research evaluated the engine's performance and emissions while operating on pure diesel, V5 (5% waste cooking oil, 95% diesel), V10 (10% waste cooking oil, 90% diesel), V15 (15% waste cooking oil, 85% diesel), and V20 (20% waste cooking oil, 80% diesel) fuel blends.

Additionally, previous studies have investigated the performance and exhaust emissions of an indirect-injection diesel engine using waste cooking oil and its blends with conventional diesel[2][3].

The engine tests were performed under full-load and varying speed conditions. The results indicated that torque, power, and thermal efficiency tend to decrease with higher proportions of waste cooking oil blends compared to pure diesel[4][5]. However, the specific fuel consumption increased when using waste cooking oil blends. The highest power, lowest specific fuel consumption, and maximum thermal efficiency were achieved with pure diesel fuel[6]. Notably, biodiesel significantly differs from diesel in exhaust emissions and plays a crucial role in reducing greenhouse gases and mitigating global climate change[7].

The amount of CO_2 emissions by biodiesel is similar to that emitted by fossil diesel. However, the key difference lies in the source of the carbon [8] [9]. For biodiesel, much of the CO2 released during combustion corresponds to the carbon absorbed by the crops used to produce the oil during their growth. In contrast, the carbon dioxide released by fossil diesel comes from oil deposits that have stored carbon for geological eras [10]. Therefore, while crops for biodiesel production contribute to a rapid reduction in emissions, fossil diesel does not, as its carbon re absorption occurs over millennia, making it a significant source of CO2 [11] [12]. CO2 presents in exhaust gases typically due to insufficient air or inadequate mixing. Biodiesel, which contains about 10% oxygen compared to the 2% in fossil fuels, significantly improves combustion quality, reducing carbon monoxide emissions by 15% for BD20 (20% biodiesel blend) and up to 40% for BD100 (pure biodiesel) [13][14].

Unburned hydrocarbons, which are harmful to human health and can be carcinogenic, particularly aromatic hydrocarbons, are also reduced by using biodiesel[15]. Emissions of unburned hydrocarbons decrease by about 15-20% for BD100, and the near absence of aromatic HC in biodiesel further reduces health risks [16]. Additionally, biodiesel does not contain sulfur, so it don’t produce sulfur dioxide emissions. However, nitrogen oxides (NOx) are a notable environmental concern with biodiesel. These pollutants, which contribute to photochemical smog and acid rain, increase by about 13% with biodiesel due to its higher oxygen content [17]. Despite this, some studies have observed NOx reductions of 4 to 26% compared to diesel [18]. In engines fueled by biodiesel, the formation of fine particulates is reduced by 20–60%, and these particulates are less [19] Biodiesel is better than diesel, as it had a better flash point, compared to diesel's 72 °C [20]. Additionally, biodiesel is 95% biodegradable, whereas diesel is only 40% biodegradable. However, the presence of double bonds in many fatty acid chains in biodiesel increases the potential for auto-oxidation, making it chemically unstable. For instance, biodiesel oxidation produces hydro peroxides [21].

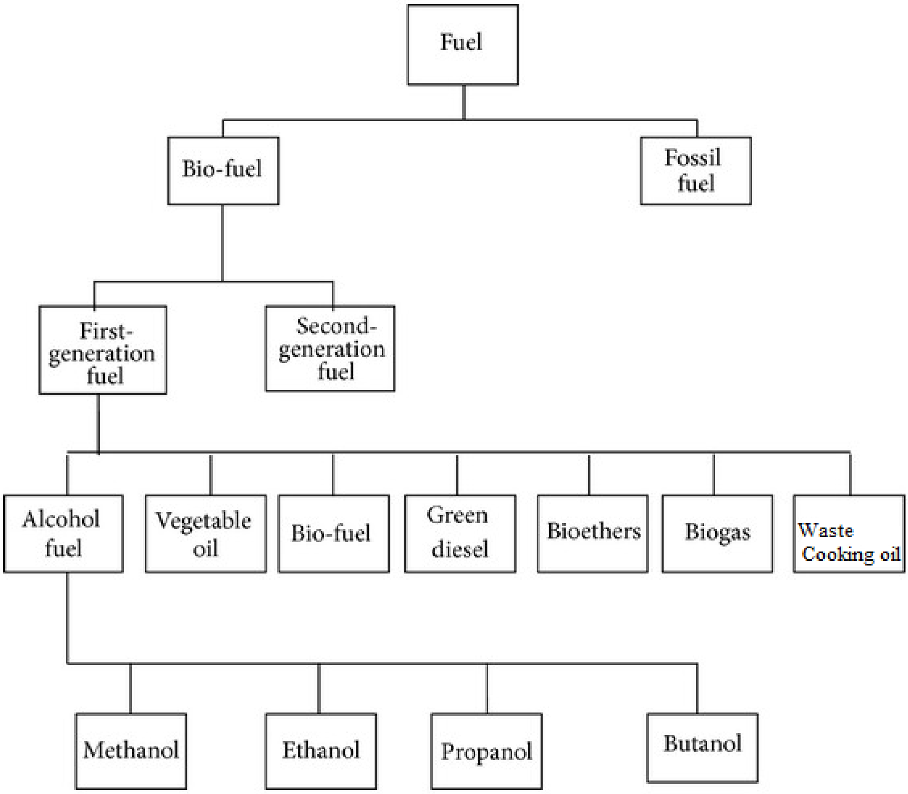


Figure 1. Types of fuels

1.1 About Waste Cooking oil

Waste cooking oil is primarily composed of triglycerides, which are esters of fatty acids and glycerol. The exact chemical composition can vary depending on the type of oil used for cooking and its processing history. There are various bio-fuels as shown in figure1. The study focuses on palm oil (heated 2-3 times), which is the most commonly consumed edible oil in India. Over 8 million tonnes were consumed in the 2023 marketing year. It also commands the highest revenue share in the edible oil market. Coming to the chemical composition of waste cooking oilriglycerides are the main constituents, comprising around 95-98% of waste cooking oil. Triglycerides consist of three fatty acid molecules esterified to a glycerol molecule[22][23]. Free Fatty Acids (FFAs) are fatty acids that have been released from the triglyceride molecules due to hydrolysis, especially if the oil has been used multiple times for frying. The presence of FFAs increases as the oil degrades. Mono glycerides and Diglycerides are intermediate products of triglyceride hydrolysis, where one or two fatty acids are still attached to the glycerol backbone.

Phospholipids are minor components that can be present in waste cooking oil. Phospholipids are amphiphilic molecules containing fatty acids, glycerol, and a phosphate group. Sterols are another minor component, typically found in small quantities in vegetable oils. Sterols include compounds like sitosterol and campesterol. Oxidation Products are waste cooking oil degrades through exposure to heat, light, and air, oxidation products such as hydroperoxides, aldehydes, ketones, and polymerized triglycerides may form. These contribute to the oil's degradation and decrease its quality. It's important to note that waste cooking oil can also contain contaminants such as water, food particles, and degraded oil components from repeated heating cycles. Therefore, while it still contains valuable triglycerides, its quality for reuse or recycling into biodiesel depends on its purity and chemical stability.

WCO is a low-cost feedstock compared to virgin vegetable oils, making the biodiesel production process more economical. Biodiesel production from WCO reduces dependency on imported fossil fuels and supports local energy production. The biodiesel industry creates jobs in collection, processing, and distribution.

The quality of WCO can vary, affecting the efficiency of the transesterification process and the quality of the biodiesel. Efficient collection systems and infrastructure are needed to gather WCO from dispersed sources. The cost of pre-treatment and purification can be high, requiring optimization to ensure economic viability. Research is ongoing to develop more efficient catalysts that can work with high free fatty acid content in WCO. The biodiesel preparation process and blending is shown in figure 4. Innovations in processing technologies aim to enhance the yield and quality of biodiesel from WCO. Governments are introducing policies and incentives to encourage the use of biodiesel and the recycling of WCO. Waste cooking oil can be composted or used as a soil amendment to improve soil structure and provide nutrients. It can help increase organic matter content and improve the soil's ability to retain moisture. Waste cooking oil has been used in artistic projects, such as making candles or as a medium for creating bio-based paints. Waste cooking oil is also used in research and development for testing and developing new technologies related to bio-fuels, bio products, and waste management.

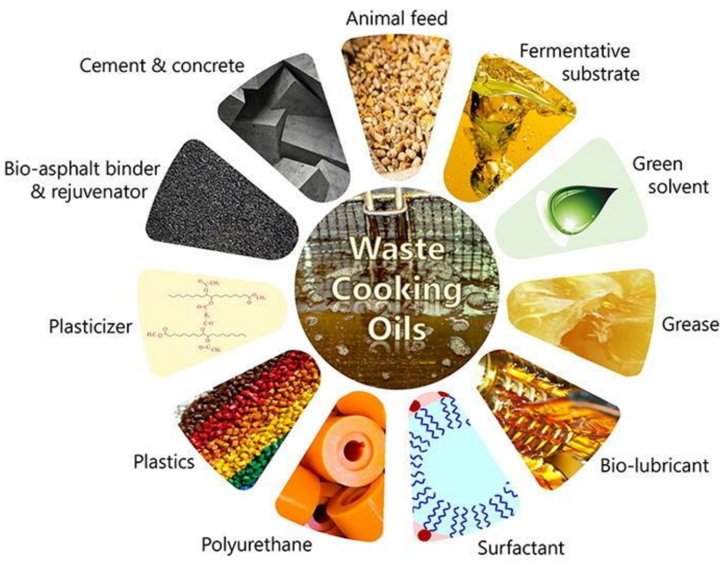


Figure 2 Waste cooking oil benefits

1.2 Engine Details: The diesel engine setup with the following specifications, It has asingle cylinder 4S- 1500 rpm engine. The engine is water-cooled and has a power output of 3.50 kW. Its cylinder bore measures ~ 87.50 mm, with a stroke length of ~110.00 mm, and a connecting rod length of 234.00 mm. The compression ratio is 18.00, and the engine's swept volume is 661.45 cc. Adiabatic Index (also known as Gamma or Ratio of Specific Heats): 1.41, The test setup is shown in figure 3. Air Density (kg/m³) is 1.17 (Air density refers to the mass of air per unit volume at a specific temperature and pressure. In this context, it is the density of the air entering the engine's combustion chamber, which affects the amount of oxygen available for combustion), Polytrophic Index (n) value is 1.18, Cylinder Pressure is 6.Orifice Diameter (mm): 20.00 (The orifice diameter is the diameter of a small opening or hole, typically used to measure the flow rate of a fluid, such as fuel or air, in the engine's system.

Figure3:Diesel Engine Test Rig

1.3 The Test Samples are as follows

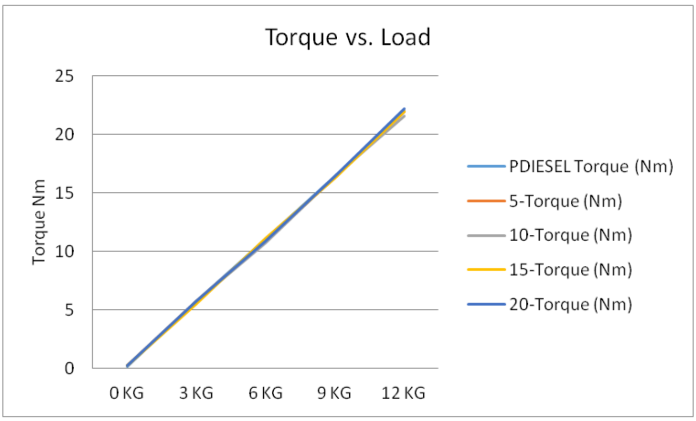
- Pure Diesel
- V5 (5% WCO and 95% Pure Diesel)
- V10(10% WCO and 90% Pure Diesel)
- V15(15% WCO and 85% Pure Diesel)
- V20(20% WCO and 80% Pure Diesel)

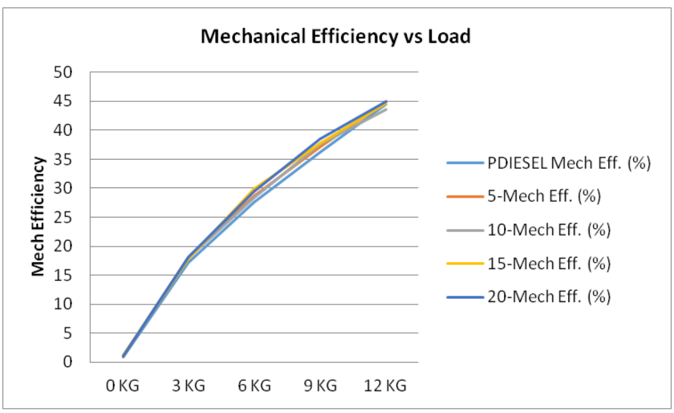
The test is performed by blending the sample with diesel in the desired proportions. The mixture of sample and diesel is used in a single cylinder CI Engine and several tests are performed under controlled atmospheric conditions. Prepare a blend of biodiesel, for instance, a V05 blend that includes 50 ml of WCO and 950 ml of diesel. The pure diesel and other blends such as V05, V10,V15 and V20 are tested on engine and the emissions are calculated for sustainability.

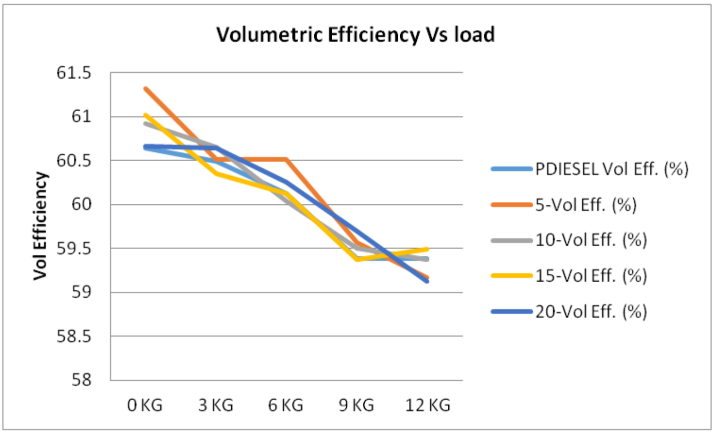
Figure 4: Biodiessl

2. Results and Discussions:

Graph i: Torque, Mechanical & Volumetric Efficiency





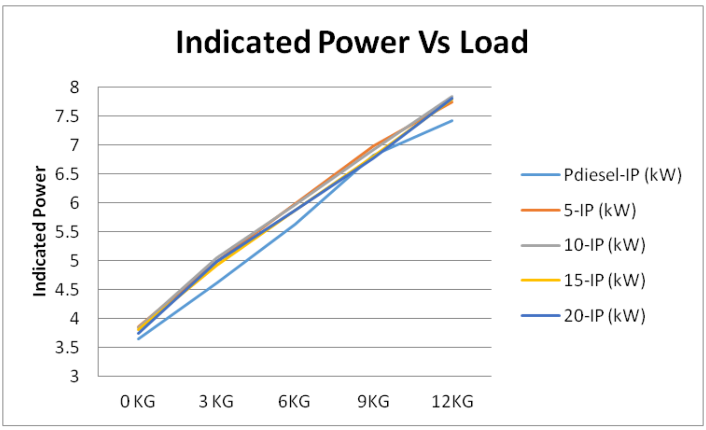


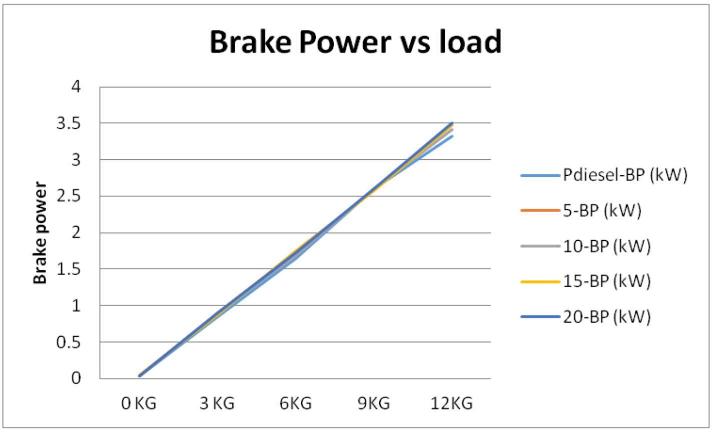
Torque: The torque output when using waste cooking oil can vary compared to diesel fuel due to differences in combustion characteristics, viscosity, and energy content. The pure diesel torque and V15 Torque under 12 kg load is recorded same, where as V20 torque is more than all values at maximum load. For better torque the maximum amount of blend is recommended, the V15 also recommended at average loads.

Mechanical Efficiency: The mechanical efficiency of an engine running on waste cooking oil can different from diesel fuel. Factors such as combustion efficiency, lubrication, and wear patterns may influence mechanical losses and overall efficiency. The maximum mechanical efficiency is achieved at V20 at maximum load. The mechanical efficiency is increased with increase in blending the same pattern is observed at 9 kg load and 12kg load.

Volumetric Efficiency: Volumetric efficiency is affected by the physical properties of waste cooking oil, such as its viscosity and combustion characteristics. Proper atomization and mixing with air are critical for achieving optimal volumetric efficiency. The vol. efficiency is decreased with increase of blending and load. The total average of all samples vol. efficiency is comes out to be 60.094. when the load increases the volumetric efficiency is decreasing. There is no significant variation in the results.

Graph II: Comparison of IP, BP of Waste cooking oil

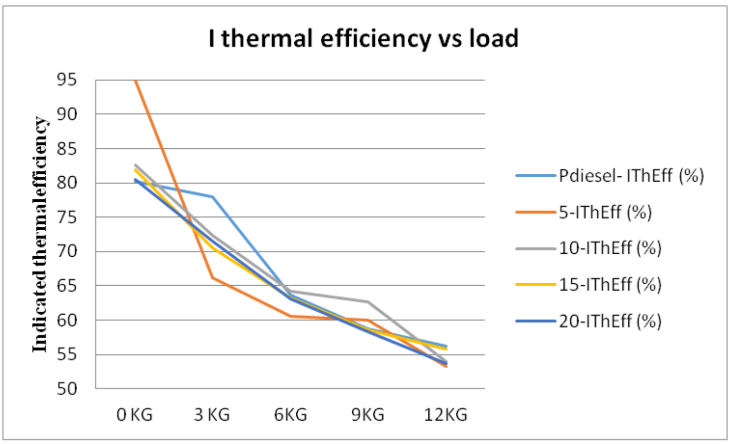


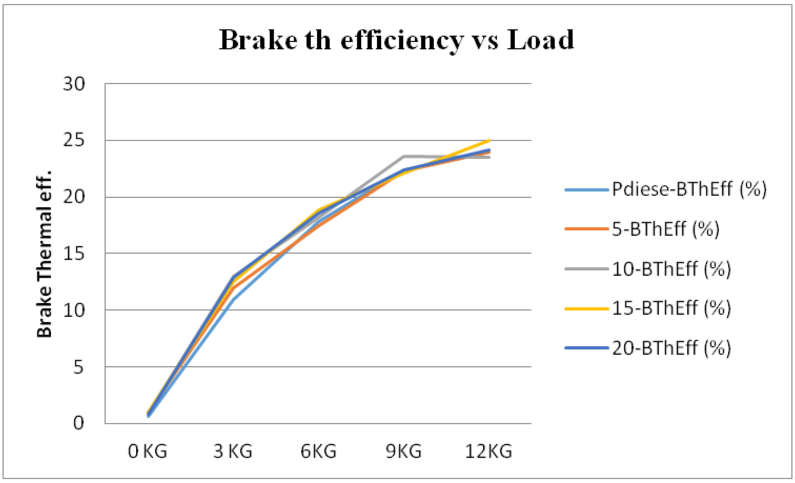


Discussions: The indicated power for the test is ranging from 3.7 to 7.8 based on various load s and blends. There maximum IP is achieved in case of pure diesel is 7.8 and V20 blend also same amount of IP achieved in case of remaining loads it is observed that the average blends and average loads are shows optimal results. The V10 and 6 kg load have 5.97 IP which is an optimal value. Overall average value of indicated power is 5.8724.

The Brake power is gives the exact measure of the useful power the overall average BP of all tests are recorded as 1.746. The maximum value recoded is at V20 and 12 kg load, at V20 the frictional losses are less compared to other blends the increase in blend is shows the complete combustion and less losses which leads to high brake power. At 12kg loads the other blends such as V5,V10,V15 recorded poor results, where as there is not much variation in the 9 and 6kg load. Overall there are not many variations in with the bio diesel blends when compared to Pure diesel. It is recommended to add V20 blend to gert maximum brake power.

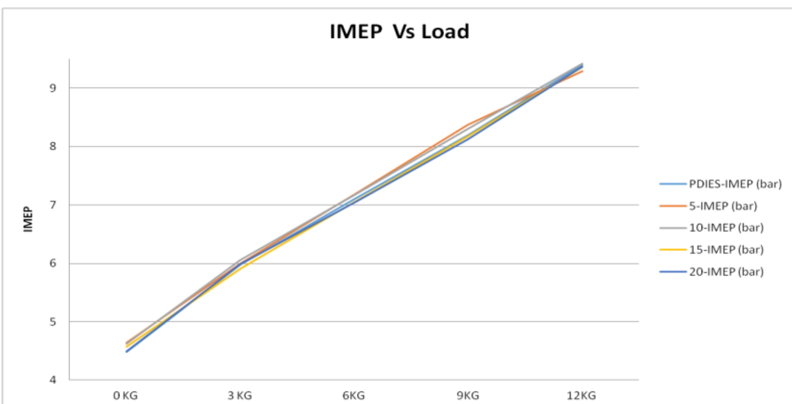
Graph III : Indicated & Brake Thermal Efficiency

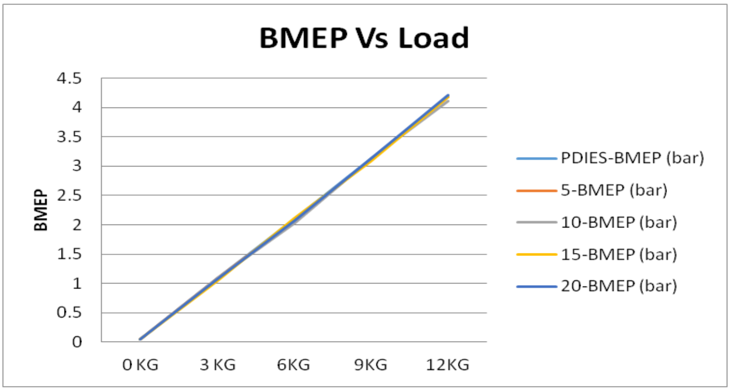




Discussion: Indicated Thermal Efficiency (ITE) and Brake Thermal Efficiency (BTE) are critical performance metrics for internal combustion engines, especially when assessing alternative fuels like waste cooking oil (WCO). ITE is the ratio of the power generated inside the engine cylinder to the energy input in the form of fuel. ITE is the ratio of Indicated Power and Fuel Energy Input. WCO typically has a lower calorific value compared to conventional diesel, which might reduce the ITE. Higher viscosity and different combustion characteristics of WCO can affect the completeness of combustion, influencing ITE. BTE is the ratio of the useful mechanical power output (brake power) to the energy input in the form of fuel. Adjustments to injection timing and other engine parameters can partially mitigate these effects but may not fully equalize the efficiencies with those of conventional diesel. Despite potentially lower ITE and BTE, WCO can reduce the overall carbon footprint and contribute to waste management, making it a more sustainable option. ITE for WCO is typically lower due to less efficient combustion and lower calorific value. BTE is also generally lower for WCO due to increased mechanical losses and the lower energy content of the fuel. The average value of IThEff is 66.5896 and BThEff is 15.808, with the increase in blend percentage the Ith value increased maximum value recorded at 5 percentage blend. The maximum value of bth recorded at V15 blend at 12 kg load.

Graph IV: Comparison of IMEP, BMEP, FMEP of Waste cooking oil



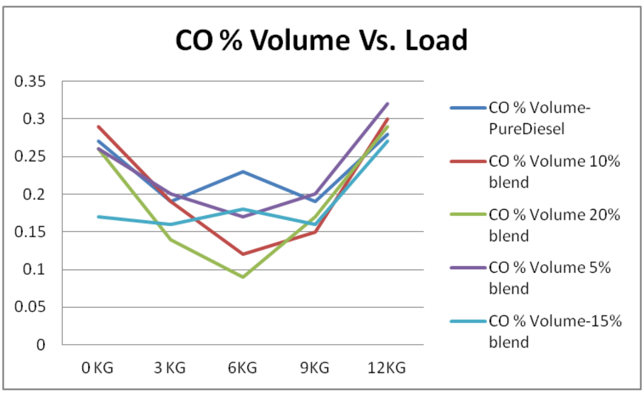


Discussion: The comparison of IMEP, BMEP, and FMEP for engines using waste cooking oil (WCO) involves understanding how this alternative fuel impacts each of these metrics. IMEP is the ratio of Displacement Volume to Indicated Work per Cycle. WCO typically has different combustion properties compared to diesel, which can result in lower IMEP due to incomplete combustion or delayed combustion phases. The lower calorific value and higher viscosity of WCO can lead to less efficient energy conversion and thus lower IMEP.

BMEP is the average pressure exerted on the pistons during the power stroke that results in the useful work output of the engine. BMEP is the ratio of displacement volume to brake work per cycle. WCO may lead to lower IMEP due to less efficient combustion and lower calorific value compared to diesel. The average IMEP value is 7.0528, BMEP is 2.0988 and FMEP is 4.9598. Maximum IMEP is recorded at V05 at all loads.

2.1 Pollution analysis: When comparing the volume of carbon monoxide (CO) emissions from engines running on waste cooking oil (WCO) to those running on conventional diesel, several factors come into play, including combustion characteristics, fuel properties, and engine tuning.

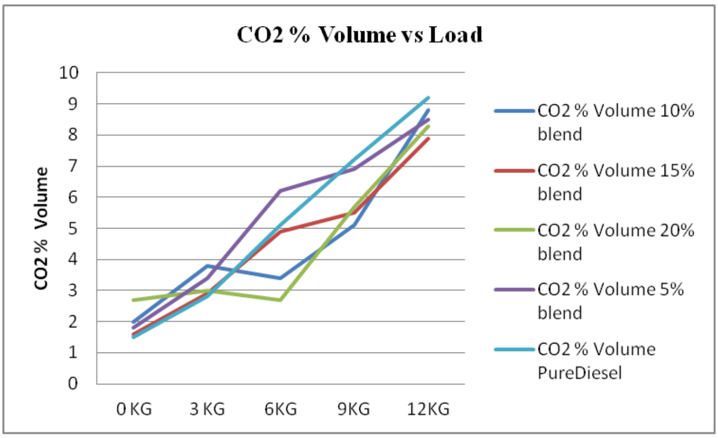
Graph V- Carbon Monoxide comparison with load



CO is a harmful pollutant produced during incomplete combustion of fuel in IC engines. It is typically measured in parts per million (ppm) or as a percentage of exhaust gas volume. The presence of oxygen in the fuel can affect combustion completeness. The energy content of the fuel influences the combustion process. Higher viscosity can affect atomization and mixing with air, leading to incomplete combustion. WCO often contains micro and nano residual food particles and impurities that can affect combustion.

WCO generally has a higher oxygen content compared to diesel, which can promote more complete combustion and potentially reduce CO emissions. However, the presence of free fatty acids and other compounds in WCO can lead to irregular combustion patterns, sometimes increasing CO emissions. From the graph V it is clear that the cp emissions are decreased at V05 and V10 blends. And the increase of blends to V20 is exhausting almost same emissions as pure diesel. The depletion of ozone layer is mainly due to carbon monoxide and its allied gases. From the above graph we can conclude that the V05, V10 and V15 diesel blends are best suited to reduce emissions also conclude that the medium loads are best suited for less CO emissions. WCO's higher viscosity compared to diesel can lead to poorer atomization and mixing with air, resulting in incomplete combustion and higher CO emissions. Pre-heating WCO or blending it with diesel can improve atomization and reduce CO emissions. WCO's higher oxygen content can enhance combustion efficiency, leading to potentially lower CO emissions compared to diesel. In engines not optimized for WCO, higher viscosity and incomplete combustion can lead to higher CO emissions. Presence of impurities and irregular combustion patterns in WCO can also contribute to increased CO emissions. Waste Cooking Oil produce lower CO emissions due to higher oxygen content, but this is highly dependent on the engine's tuning and the quality of the WCO. Pre-treatment and blending with diesel can help reduce CO emissions by improving combustion efficiency.

Graph –VI Carbon dioxide vs. Load

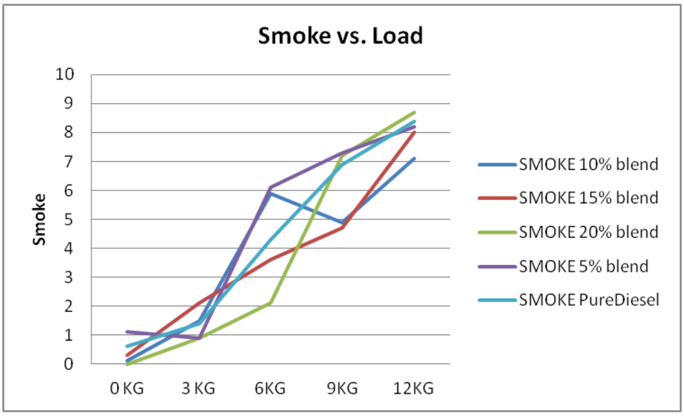


The Results of carbon dioxide in the emission with load and respective blends are drawn on bar chart. Carbon Dioxide (CO_2) nature is a colorless, odorless gas at room temperature. The carbon compounds in the exhaust gas mainly due to unburnt carbons. Using waste cooking oil (WCO) as a biodiesel blend can help in reducing overall CO_2 emissions. Biodiesel burns cleaner than conventional diesel because it contains oxygen, which allows for more complete combustion.

The CO_2 emitted from burning biodiesel is partially offset by the CO_2 absorbed by the plants (typically palmoil or canola) used to produce the original cooking oil, making it more carbon-neutral compared to fossil diesel. Higher proportions of WCO biodiesel in the blend generally lead to lower CO_2 emissions. Common blends like V20 (20% biodiesel, 80% diesel) and V10 (10% biodiesel, 90% diesel) have shown favorable reductions in CO_2 emissions.

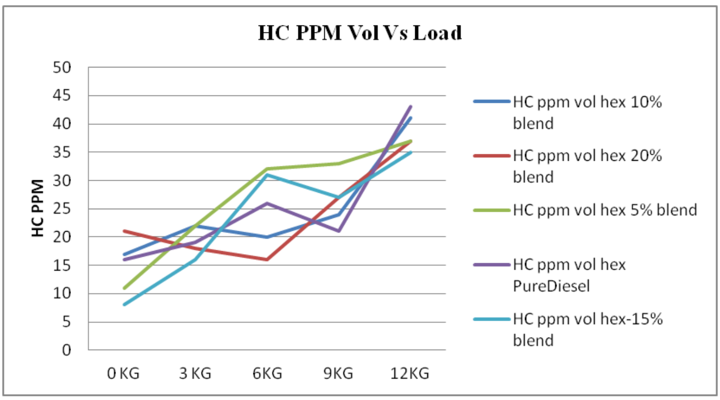
The economic impact of CO_2 is multifaceted. While reducing emissions may involve significant costs, such as investing in renewable energy infrastructure, there are also economic opportunities in the development of new technologies and industries related to carbon management. The amount of carbons in the atmosphere creates many pollution based problems. The CO_2 Volume is increasing with biodiesel blend but interestingly at the maximum blend i.e. 20% of blend it is decreased for 6kg of load. The V10 blend also shows less volume of CO_2 emissions. Using waste cooking oil as a biodiesel blend in single-cylinder diesel engines can lead to reductions in CO_2 emissions due to better combustion and the renewable nature of the fuel.

Graph –VII Smoke vs. Load



The smoke is a major pollutant the smoke value is decreased with theV10 and V15 blends at 9 and 12kg load. At 3 kg load V05 blend recorded less smoke.

Graph –VIII HC PPM vs. Load



In the context of studying the effects of waste cooking oil (WCO) diesel blends on a single-cylinder diesel engine, plotting hydrocarbon (HC) emissions in parts per million (PPM) against different loads can provide valuable insights. Typically, HC emissions tend to increases as the engine load increases. This is due to decreased combustion efficiency at higher loads where the combustion temperature is higher, leading to more incomplete burning of the fuel. The low emissions are recorded with blends are at V20 at 3kg and 6kg. Maximum emissions are observed at V10 at maximum load. WCO contains oxygen, which can enhance the combustion process, leading to lower HC emissions compared to pure diesel. Thus, as the WCO content in the blend increases, HC emissions are generally lower across maximum loads with maximum blends. At lower loads with less blend there is Slight reduction in HC emissions compared to pure diesel. Increasing WCO-diesel blends not only helps in waste management by recycling used cooking oil but also contributes to lower HC emissions, which are beneficial for reducing air pollution and improving air quality.

3. Conclusions:

The power output and torque of the engine generally decreased with increasing concentrations of waste cooking oil (WCO) in the blends compared to pure diesel. However, the reduction was relatively minor for lower blend ratios (V5, V10), indicating that these blends can be used without significant variation. BSFC increased with higher WCO content in the blends, suggesting that more fuel was required to produce the same power output. This could be attributed to the lower calorific value of WCO compared to diesel. CO emissions showed a decreasing trend with higher WCO content in the blends. This reduction could be due to the presence of oxygen in WCO, which promotes more complete combustion. HC emissions were observed to decrease with the increase in WCO content, likely due to the better combustion characteristics of the oxygenated fuel. NOx emissions increased with higher WCO content, which could be attributed to the higher combustion temperatures resulting from the oxygen content in WCO.

The overall combustion efficiency was slightly reduced for higher WCO blends, but the blends still exhibited reasonable combustion performance, making them a viable alternative to pure diesel. Using WCO as a fuel blend can be cost-effective due to the lower cost of WCO compared to diesel. It also provides an avenue for waste valorization. WCO-diesel blends offer environmental benefits by reducing waste disposal issues associated with used cooking oil and decreasing emissions of CO and HC. However, the increase in NOx emissions needs to be managed through after-treatment technologies or blend optimization. Based on the performance, emission, and combustion characteristics observed, V10 (10% WCO and 90% diesel) emerged as an optimal blend ratio, providing a good balance between maintaining engine performance and achieving environmental benefits.

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