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Impact of oxy-additives on diesel engine performance and emission parameters using waste cooking oil biodiesel

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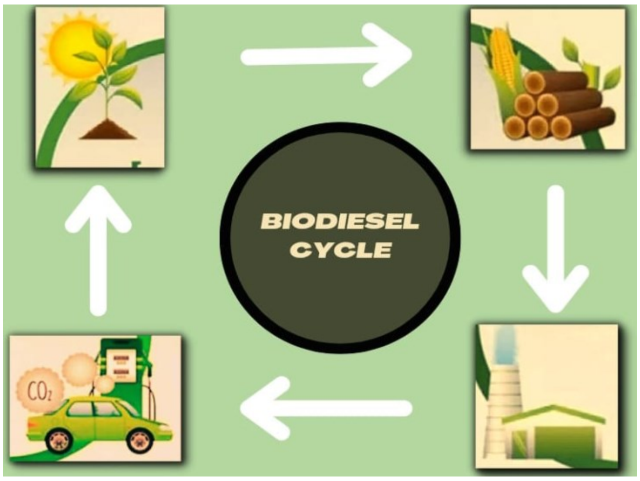
Graphical abstract



Abstract

From the last two decades, the amount of waste materials recycled into useable energy sources has grown in popularity due to the fast rise in energy demand caused by the world's population growth. In other words, the conversion of garbage into energy will undoubtedly become an essential topic in the near future. Biodiesel has garnered a great deal of interest recently to reduce pollution generated by the burning of petroleum fuels. Biodiesel is made from vegetable oils and animal-based oils in most cases. Waste cooking oil biodiesel (WCB) is the most suitable resource for biofuel development because it is cost-effective and environmentally friendly, minimizing the amount of waste generated. In order to reduce harmful pollutants from engines, the use of oxygenated fuels seems to be a realistic solution. To minimize the impact on air quality, it is important to use oxy-additives that are specifically formulated for biodiesel and comply with environmental regulations. It is also recommended to use biodiesel blends with lower percentages of oxy-additives and to properly maintain the engines and exhaust systems of vehicles that use biodiesel. The purpose of this exploration is to improve the outcomes of an engine running at various concentrations of methoxyethyl acetate (MEA) additives and WCB biodiesel. The findings were compared to pure diesel, and the results were optimized for different load circumstances and combinations of oxygenated additives for the assessment of emission characteristics.

Keywords: Waste cooking oil; air quality; diesel blend; emission; methoxyethyl acetate

1. Introduction

The two most pressing issues confronting humanity in the twenty-first century are the scarcity of clean energy and the effects of global warming. Energy demand has skyrocketed due to the world's expanding population and rising wealth. As a major factor in raising people's quality of life, efficient energy use is crucial to human civilization. Every country's economic growth is dependent on its ability to get enough energy. Agriculture, industry, transportation, retail, and residential use all need energy in some form (Kumar and Majid, 2020). Environmental contamination challenges have developed due to the increasing use of fossil fuels to fulfil the high energy needs of industrialized countries and the residential sector.

Using fossil fuels to generate electricity has a range of public health and environmental risks and may have long-term effects globally (Bach, 1981). Multiple investigators are now looking into supplies of sustainable fuels since environmental concerns have risen. Renewable energy sources include things like wind, hydropower, solar electricity, biomass, and biofuels, to name just a few. To meet both economic and environmental needs, all of these resources must contribute significantly, and biodiesels as a possible option (Sathish *et al*., 2023; Vinayagam *et al*., 2021) and a simple schematic are shown in Figure 1.

Biodiesel as an alternative for diesel fuel fashioned by the transesterification process is being investigated as a solution for the depletion of fossil fuels and their impact on the environment. Since waste cooking oil is cheaper to produce than other biodiesel fuels, it has been recognized as a viable substitute in the market. WCB's biodiesel production is ecologically friendly (waste management) since it recycles WCB and produces less pollution than other techniques. It reduces the need for petrochemical oil imports while also lowering the cost of waste treatment, which is beneficial (Manikandan *et al*., 2023; Rocha-Meneses *et al*., 2023; Yaqoob *et al*., 2021). This research evaluated (Gad and Ismail, 2021) biodiesel generated from WCB and mixed it with fossil fuel at different ratios. The HC and CO emissions were reduced, but NOx emissions were increased by using a mix of gasoline. The turbocharged diesel engine's performance was shown to be impacted by WCB biodiesel blends, according to the findings.

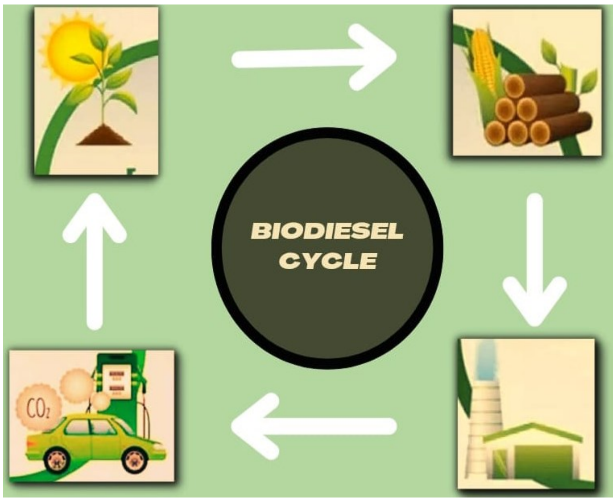


Figure 1. Biodiesel cycle

A larger fuel consumption compared to exhaust emissions was found in the combustion and emission tests; however, the use of WCB typically contributed to lower carbon and hydrocarbon emissions, and the nitrogen oxide generated by WCB was lower than that generated by diesel fuel in most operating settings (An *et al*., 2013). The exhaust gas temperatures of WCB blends rose due to increasing the quantity of WCB biodiesel in diesel blends. Higher SFC has been caused by the inferior heating value of WCB and its mixtures. For biodiesel blends, the efficiency drops as the percentage of biodiesel rises. Experimental research by (Can, 2014) examined the combustion analysis in a diesel engine using WCB at five and ten percent concentrations with diesel fuel. Nitrogen oxide emissions were found to have risen, but smoke and hydrocarbon emissions were found to have decreased. They found that the fatty acid content of discarded cooking oils from various restaurants in the exact location was variable, which they hypothesized would lead to a similar variation in biodiesel composition. (Abed *et al*., 2018) This work explored the impact of fuelling a diesel engine with WCB biodiesel on emissions at a particular engine speed. According to the results, biodiesel decreases the amounts of HC and CO but increases NOx concentrations.

During the performance testing, it was discovered that fuel consumption increased for di-ethyl ether, 10 and 20% blends, and thermal efficiency also increased (Raja *et al*., 2019). They evaluated (Rao and Reddi, 2017) the engine emissions through the GRA method to investigate the engine emissions while using Mahua methyl ester and additives in an engine. A diesel-waste plastic blend that had 10% additives had the best overall performance for the majority of engine loads when compared to all other fuels tested. The combustion start time was unaffected by changing the fuel type (Rajeshwaran *et al*., 2018). According to (Selvam *et al*., 2021), they have incorporated the agitator diethyl ether with waste plastic pyrolysis oil biodiesel into the study, and emission standards were assessed in it. This research (Joy *et al*., 2019) investigated combustion and showed improved performance with higher thermal efficiency and lesser fuel consumption and pollutants. They (Jayaprabakar *et al*., 2019) tried to estimate bio-neem seed oil in engine and emission analysis using the oxygenated additive. The findings showed that carbon, hydrocarbon, and nitrogen oxide emissions had all slightly decreased. The effectiveness and emission attributes of MEA, an improving additive, combined in varied proportions is the keynote of this study. In contrast to diesel, BTE increased slightly while HC and CO_2 decreased significantly and It barely reduces NOX and CO (Senthil *et al*., 2015). Diesel blended with neem methyl ester and rice wine alcohol enhanced oxygen along with decreased sulphur, enhancing performance and emission. Biofuel mixtures with additives boosted peak cylinder pressure and release of heat during ignition (Reang *et al*., 2020). The intention of this research is to examine the implications of methoxyethyl acetate ratio with diesel on WCB blended at 25% and 50%. The performance and emissions analysis are carried out on a 1- cylinder diesel engine under varying load conditions. The results of fuel consumption, emission of hydrocarbons, and carbon monoxide were optimized for blends of WCB and MEA by the design of the experiment tool.

2. Material and methods

The use of waste cooking oils as a biodiesel source is becoming increasingly economically viable. Used cooking oil has the potential to be a more cost-effective bio-resource than edible vegetable oils since it does not interfere with the growth of food crops in any manner.

Waste cooking oil biodiesel, like bio-seed-based fuels, has a higher viscosity and density than standard diesel. However, it can fulfill the current fuel base requirements. Biodiesel may be enhanced using gasoline additives to make its qualities more comparable to diesel. Alcohols, on the other hand, have a low viscosity. As a result, alcohols are added to diesel-biodiesel blends in order to lower the viscosity of the fuel mix and make it more akin to diesel viscosity. Methoxyethyl acetate, an alcohol-based additive, is an oxygenated renewable fuel that can be produced from biomass. Trans-esterification converts any vegetable oil into biodiesel. During the chemical process, the vegetable oil components break down into new molecules. First, triglycerides are converted into alkyl esters, which are biodiesel. The product is methyl ester if methanol is used and ethyl ester if ethanol is used. These two biodiesel fuels have distinct chemical compositions. The chemical reaction produces glycerin, which must be removed from the biodiesel during transesterification. Due to the fluid's phase, glycerin may rise to the top or sink to the bottom. Transesterification produces biodiesel with a lower viscosity than conventional diesel fuel, making it suitable for engines. The properties of waste cooking biodiesel and methyl ethyl acetate are tabulated in Table 1.

Table 1. Waste Cooking Oil and MEA Properties

Sl.No	Property	Unit	Diesel	WCB	MEA
1	Calorific Value	kJ/kg	45000	34958	32451
2	Viscosity, at 40°C	cSt	2.87	4.87	0.21
3	Density, at 15°C	g/cm3	0.832	0.891	0.686
4	Flash Point	°C	61	159	46
5	Oxygen	wt%	0	12	41
6	Cetane Index	-	55	46	-

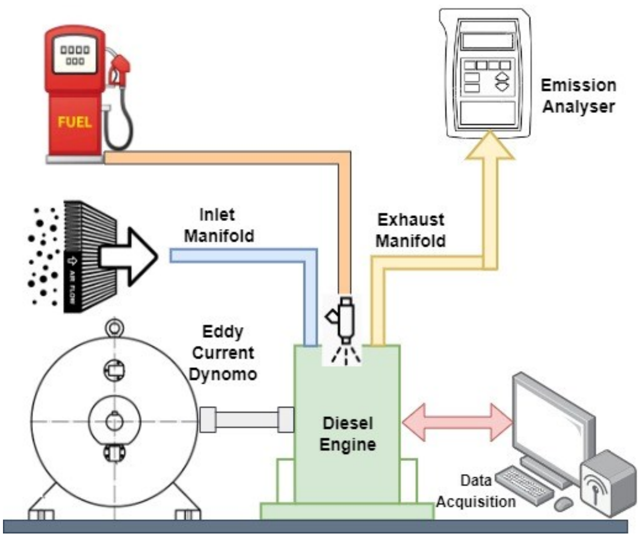


Figure 2. Representation of entire engine Schema

2.1. Experimental details

Waste cooking oil and its blends were assessed in a single-cylinder, constant-speed DI engine, as shown in Figure 2. Speed is maintained regardless of load and biodiesel mix percentages in the diesel engine. The engine was connected to eddy current dynamometer, which monitors current flow, and is used to adjust and alter the engine loads manually to varying KW. For each of the testing blends, the load is increased, according to the 4.4 kW power output of the engine. In this investigation, the airflow rate was measured using a calibrated orifice on an air drum, and the fuel flow rate was analyzed with a calibrated burette. Two fuel tanks were employed for the fuel flow measurement; one was filled with pure diesel and the other with esterified biodiesel, and the fuel flow was recorded. AVL software was put on the test rig, allowing for the collection of various readings and outcomes while the machine was in operation. Waste cooking oil acquired from the transesterification progressions of vegetable oil was blended at different volumetric ratios of 25% and 50% along with 10% and 20% oxygenated additives of methyl ethyl acetate. The biodiesel fuel named WCB25MEA10 is formed by the blends of 25% waste cooking oil biodiesel and 10% methoxyethyl acetate on a volume basis mixed with pure diesel of 65%, and the combination of blends is WCB50MEA10 (40% diesel + 50% WCB+ 10% MEA), WCB25MEA20 (55% diesel + 25% WCB+ 20% MEA), and WCB50MEA20 (30% diesel + 50% WCB+ 20% MEA). Since various uncertainties develop through the course of a large number of repeated trials, which is not taken into account in this study, uncertainty analysis is not performed for this the data collected.

3. Results and discussion

3.1. Performance characterizes

The Specific Fuel Consumption (SFC) reduces when engine load elevates with MEA ratios, and the results are displayed in Figure 3. The SFC values of the WCB50 blends were higher than those of the diesel. The greater the amount of fuel required by oil blends compared to diesel oil in order to provide the same output power, In consequence of the reduced viscosities of the oil mixes, the fuel injected into the combustion chamber had smaller droplet sizes, poorer fuel penetration, improper fuel-air mixing, and decreased combustion efficiency. WCB25MEA10 and WCB25MEA20 blends achieved a 16% and 19% reduction in SFC compared to standard diesel, and WCB50 blends achieved a 25% and 28% increase in fuel consumption compared to diesel. It can be observed in Figure 4 that the brake thermal efficiency (BTE) had an effect on the engine's maximum output power. The braking thermal efficiency of WCB50MEA10 and WCB25MEA20 was found to be about 6.2% and 6.4% higher than that of standard diesel when tested under varying load conditions, respectively. Thus increased MEA concentration in the mixture leads to increased viscosity and, thus, a slower combustion rate, resulting in a lower BTE compared to WCB50.

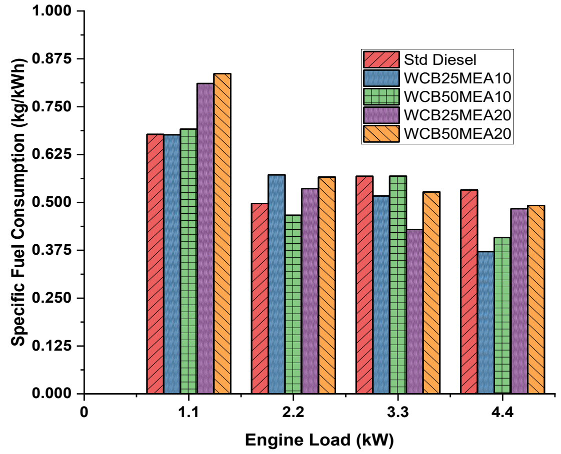


Figure 3. Study of SFC of MEA with WCB

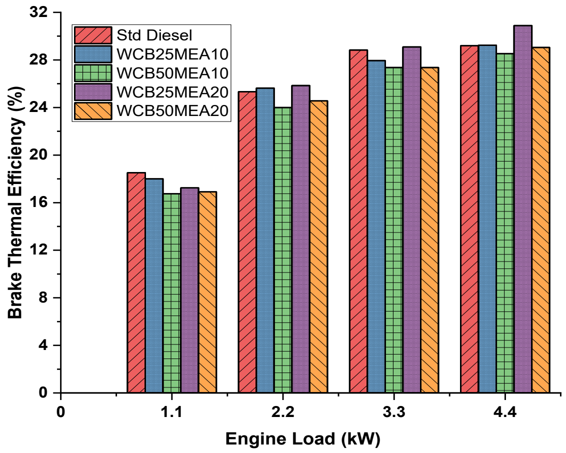


Figure 4. Study of BTE of MEA with WCB

3.2. Emission characteristics

Increased loads result in increased fuel consumption, which causes a shortfall in oxygen content and, as a consequence, increases carbon monoxide concentrations in the atmosphere. Figure 5 depicts the CO emissions from standard diesel and WCB and MEA blends. Low CO emissions are produced using a lower equivalency ratio in conjunction with greater in-cylinder temperatures for WCB25s. The generation of CO was found to be high at both the start and full load conditions, which was attributed to the rich fuel combination at WCB50 and MEA blends. The carbon monoxide emission drops progressively from low to half load for all of the WCB mixes and then climbs significantly from half load to maximum load for all of them. The WCB25MEA20 demonstrated a decrease in carbon monoxide emissions of between 6.3% and 10.26% compared to the diesel engine at various load levels. The decreased C/H ratio resulted in fewer carbon dioxide emissions. Carbon monoxide concentrations decreased when the mix ratio was increased. The greater oxygen concentration of MEA improved the atomization, combustion efficiency, and vaporization of the fuel compared to pure diesel, resulting in lower carbon emissions (Janarthanam *et al.*, 2020).

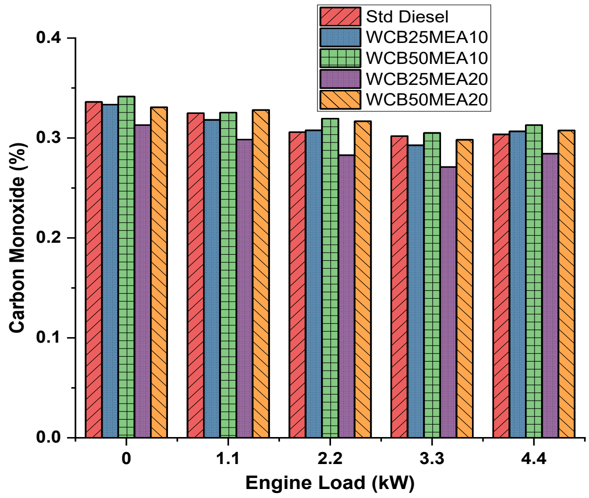


Figure 5. Study of Carbon Monoxide emission of MEA with WCB

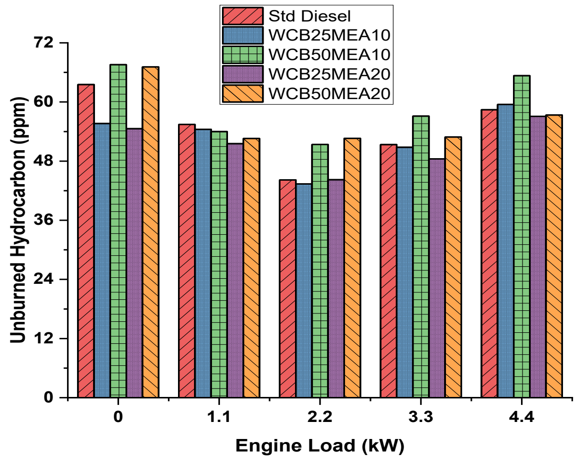


Figure 6. Study of Unburned Hydrocarbon emission of MEA with WCB

Figure 6 depicts engine load and the correlation with unburned hydrocarbon emissions for WCB and MEA blends. At all blending ratios from 0 to 100%, the rise in HC emissions associated with increased engine load is attributable to a larger volume of fuel being pumped into the engine. Due to the rise in in-cylinder temperatures, the flame quench has increased, which has resulted in this. The increased blending ratio of the oil, on the other hand, resulted in a rise in HC concentrations as a result of the detrimental effect of the extremely low viscosity of the oil, which resulted in smaller droplet sizes and decreased diffusion (Bhanu Teja *et al.*, 2022; Priyadarshi and Paul, 2018). The inefficient fuel-air mixing resulted in lower combustion efficiency and greater HC emissions as a consequence of the problem. The better viscosity of the WCB50 blends resulted in poor vaporization, spray penetration, and greater HC emissions as a result of the process. WCB25 blends reduced HC emissions by 2% to 14% contrasted to standard diesel, while WCB50 blends increased HC emissions by 11% to 16% compared to diesel.

As revealed in Figure 7, the oil mixes' nitrogen oxide levels fluctuated with engine load changes. Oxides of Nitrogen emission of WCB25 and WCB50 blends increase by 6.6% to 19.9% over diesel. Several factors affect NOx emissions, including oxygen concentration in the air, nitrogen content in the fuel, combustion temperature, and duration (Man *et al*., 2015; Joshi and Thipse, 2019; Chiatti *et al*., 2018). Oxygen and nitrogen react to produce NOx, which is the primary source of the pollutant. When the oxygen concentration is higher, higher combustion temperatures are caused by the increasing NOx quantities that are produced (Hwang *et al*., 2016; Kumar *et al*., 2022). The amount of NOx produced depends on a number of factors, including the temperature of the combustion chamber, the amount of oxygen present, the amount of extra air present, and the timing of the combustion process (Sureshbabu *et al*., 2023).

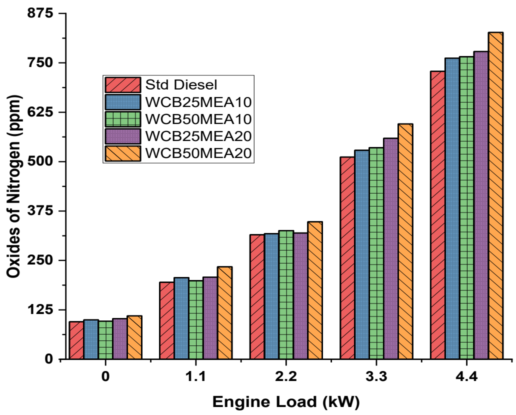


Figure 7. Study of Oxides of Nitrogen emission of MEA with WCB

3.3. Optimization of wcb and mea blend ratio on emission

In order to deliver the most complete solution to a solvable problem, process improvement practitioners frequently employ the Design of Experiments (DOE) method. This method differs from the norm in that it makes use of statistical data acquired from a limited number of trials to foresee the outcomes of a process that is both complicated and changeable (Venkatesh *et al*., 2022; Vicente *et al*., 1998). The design of experiments is the most prevalent numerical technique for maximizing outcomes, in contrast to any other research approach. The full factorial design is an analytical and methodical procedure for assessing the major effects and interactions of research studies. Even if the design is sound, the increased importance given to a particular element or set of variables leads to a rise in the total number of test points (Hossain *et al*., 2016). In this work, WCB and MEA blends the emissions of carbon monoxide and hydrocarbons, as well as SFC, were studied.

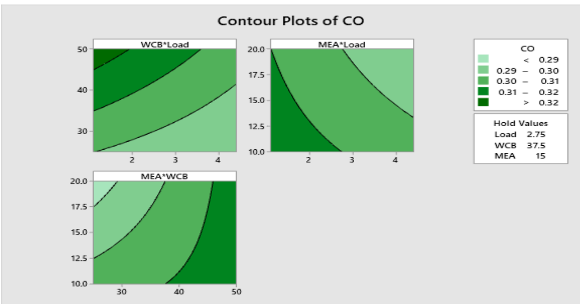


Figure 8. Impact of WCB, MEA blend on CO

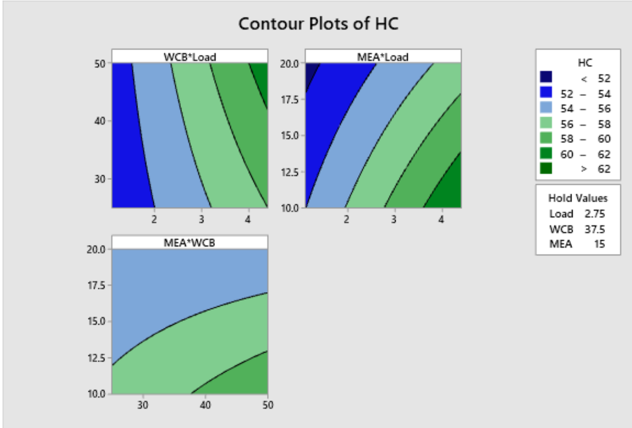


Figure 9. Impact of WCB, MEA blend on HC

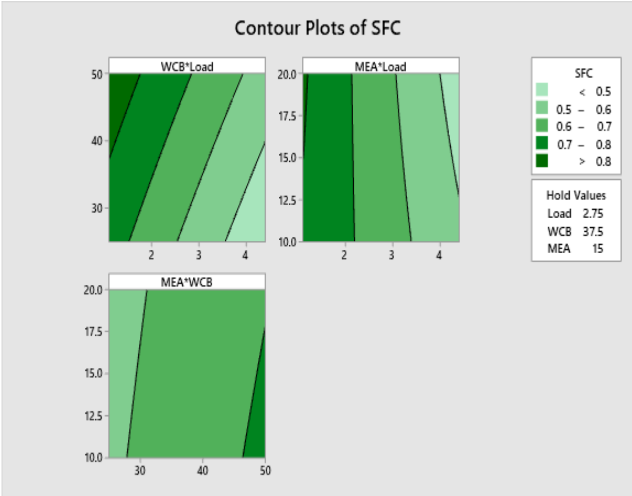


Figure 10. Impact of WCB, MEA blend on SFC

The MEA also has a favourable influence on consumption of fuel and pollutants, with the lowest value reached at 20% MEA mix, which is assumed to be connected to a faster combustion rate due to higher oxygen levels. Figures 8–10 shows the contour plots. Furthermore, because of the higher viscosity of WCB, emissions have increased when the blend ratio has been increased, resulting in a reduction in the burning effect. With an increase in the MEA ratio, it can be noticed that emissions decrease, with the lowest levels of CO and HC pollutants formed at 20% of the MEA ratio, which is owing to a higher combustion pace being the most significant. When a 25% blend of WCB and MEA is used, the amount of CO and HC produced is reduced as a result of a more oxygenated mixture that assists in complete combustion. Because WCB fuel has a higher viscosity than traditional fossil fuel, the quantity of harmful emissions released increases as the WCB ratio increases. Because of improper fuel combination and spray formation, which leads to incomplete combustion as the blend ratio rises, this phenomenon occurs. According to the contour plots the MEA blend at its highest concentration and the minimum blend of WCO have the most significant influence on the engine's ability to operate at the lowest possible emission and effective fuel usage.

3.4. Response optimization of SFC, CO and HC

As a method of improving the quality of an answer or a collection of replies, response optimization analyses the relationship between various input variables and the best possible combination of those parameters (Sivakumar *et al.*, 2022; Venkatesan *et al.*, 2022). The response optimizer function in statistical analysis software provides an ideal answer for the variable input combinations and a visual optimization plot. Possibly, the optimization graphic will be interactive. An optimization problem may be improved by experimenting with different input variable values (Uslu, 2020).

Table 2. Response Optimized results of CO, HC and SFC

Solution	Load	WCB	MEA	CO Fit	HC Fit	SFC Fit	Composite Desirability
1	4.4	25	20	0.28	57	0.35	0.829827

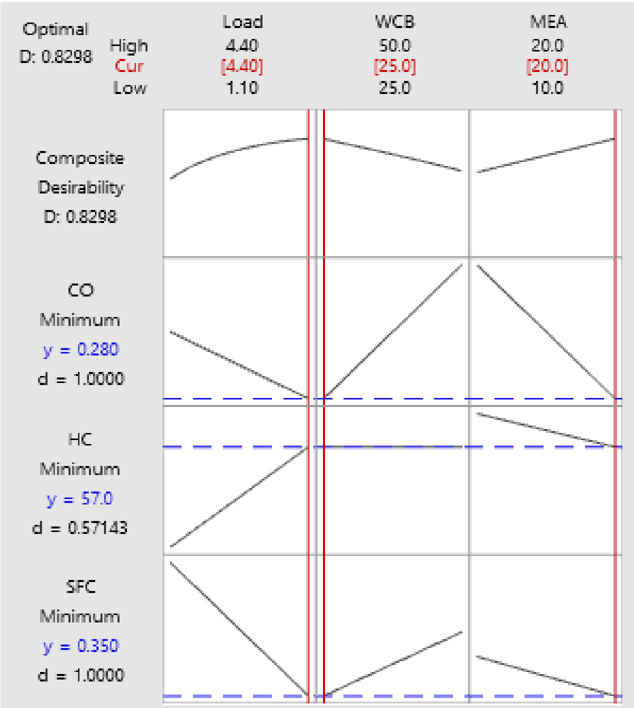


Figure 11. Optimization plot for CO, HC and SFC

The observations, as shown in Table 2 and Figure 11, confirms the finding that the lowest blending ratio of WCB at the greatest MEA ingredient is ideal for achieving reduced exhaust emissions and the lowest fuel usage under maximum loading situations. At these blend ratios, total combustion occurs as a result of a faster combustion rate and a higher oxygenated mixture, resulting in incomplete combustion. The best conditions for achieving these results are when the engine is filled with fuel and a combination of 25% WCB and 20% MEA with the diesel fuel blend, respectively. When operating at maximum load, the ideal minimal emissions generated by a 25% WCB and 20% MEA mix are CO at 0.28% and HC at 57 ppm and the lowest feasible fuel usage of 0.35 kg/kWh were accomplished.

4. Conclusion

Biodiesel has lately gained popularity to reduce pollution from fossil fuel combustion. Waste cooking oil is the greatest resource for biodiesel conversion since it is cheap and reduces waste. Using oxygenated fuels to minimize diesel emissions is feasible. In this study, a diesel engine ran with varied amounts of Methoxyethyl acetate additives and waste cooking oil biodiesel. The following observations were made for the waste cooking oil biodiesel's investigation,

WCB25MEA10 and WCB25MEA20 blends achieved a 16% and 19% reduction in SFC compared to standard diesel, and WCB50 blends achieved a 25% and 28% increase in fuel consumption compared to diesel.

The braking thermal efficiency of WCB50MEA10 and WCB25MEA20 was found to be about 6.2% and 6.4% higher than that of standard diesel when tested under varying load conditions.

The WCB25MEA20 demonstrated a decrease in carbon monoxide emissions of between 6.3% and 10.26% compared to the diesel engine at various load levels.

WCB25 blends reduced HC emissions by 2% to 14% correlated to standard diesel, while WCB50 combinations climbed hydrocarbon emissions by 11% to 16% compared to standard diesel.

Oxides of Nitrogen emission of WCB25 and WCB50 blends increase by 6.6% to 19.9% over diesel.

When operating at maximum load, the ideal minimal emissions generated by a 25% WCB and 20% MEA mix are 0.28% of CO and 57 ppm of HC. Under identical operating conditions, the minimal feasible fuel consumption attained is about 0.35 kg/kWh.

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