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Emission Analysis of Diesel Engine by Cooking Oil Waste as Part Substitute of Fuel

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Authors' contributions

This work was carried out in collaboration between both authors. Author MRP designed the study, performed the laboratory works, analyzed the data and, wrote the protocol and Author SPM wrote the first draft of the manuscript and managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Methyl ester as biodiesel is one clean energy sources for fueling diesel engines. The adverse effects of the conventional fossil fuels and rise in fuel price have made researchers to carry out their researches on various sources of biodiesels. The process of producing biodiesel from vegetable oil is not so economical due to cost of the raw materials though there are reductions in emission gases from automobile exhaust. The cooking oil as waste is not eco-friendly and difficult to dispose. The same can be used as a part substitute to diesel to run internal combustion engine to economize the fuel cost, reduce environmental pollution, ameliorate the difficulties of unburnt cooking oil disposal. Recent study envisages an attempt to convert the waste cooking oil to fatty acid methyl ester (FAME) as a supplement to diesel. An internal combustion engine was run with different proportion by substituting with FAME acquired from cooking oil waste. The analyses of the noxious gases released have been conducted to find the concentration of noxious gasses by using Exhaust Gas Analyzer. The percentage of toxic gasses exhausted on running the internal combustion engines with extracted biodiesel at 10%, 20% and 30% mix were analyzed. The results

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revealed that the percentage of emitted gases like Hydrocarbon (HC), and Monoxide of Carbon (CO) were reduced and it was found optimum at a blend of 20% of biodiesel when added with 80% conventional diesel but need further work on it.

Keywords: Cooking oil waste; esterification; emission analysis; diesel engine; biodiesel.

1. INTRODUCTION

The extensive use of petroleum fuels in automobile is the main reason behind air pollution in recent times. The emissions from the automobiles consists of lethal gases like oxides of carbon; CO_2 (Carbon dioxide), CO (Carbon monoxide), Oxides of Nitrogen (NOx), and Hydrocarbon (HC). This emission from automobiles is the reason behind global warming and possesses threat for the mankind. Hence use of alternate fuel is a wise option as the emission comes out as a result of burning these fuels [1]. Biodiesel, a liquid fossil fuel substitute, is an excellent option to be used as propellant in automobiles [2]. It is a long chain fatty acid alkyl ester which has similar properties resembling with conventional diesel. Moreover it can be used in automobile engines without or very little modification in engine. This biodiesel can be obtained from large variety of plants which are the sources of non-edible and edible oils. The non-eatable oils, manufactured from fruits, barks, flowers of plants like Microalgae, Jatropha (*Jatropha curcas*), Karanja (*Millettia pinnata*), Neem (*Azadirachta indica*), Mahua (*Madhuca longifolia*), Rubber seed (*Hevea brasiliensis*), seed pods of silk cotton (*Ceiba pentandra*), etc., are amply accessible in emerging countries. These non-edible oils are of low cost in comparison to the edible oils. The wastes of cooking oil are obtained as residue after use of edible vegetable matter that has been utilised during preparation of food and eatables. These edible oils after repeated use; are not recommended for further human consumption as it may cause health hazards. The free disposal without proper management of this cooking oil waste is noxious for environment. If disposed in large quantities, they may cause blockage in drains and pipe lines. However they can be recycled to some extent. Used cooking oil is used in manufacturing of soap and also in oleo chemical industries [3].

Significant efforts have been made by using the extracted biodiesel in diesel engines as part addition for improved performance, and burning characteristics [4-6]. Several works have been carried out by different researchers on different biodiesels regarding their property and emission analysis. Madiwale and Bhojwani [7] have reviewed the production of FAME, properties as fuel, performance, and their emission analysis of different biodiesels. *Ismail et al.* [8] worked on the biodiesel extracted from simarouba oil, and examined its efficacy in propelling a diesel engine. However they have not studied their emission characteristics. Prasada Rao and Appa Rao et al., [9] carried out their research on performance properties, and emission analysis on various diesel engines consuming mahua biodiesel. *Padhi and Singh* [10] carried out their work towards the optimization of biodiesel from oil extract of mahua. Mahalingam et al. [11] verified through emission analysis by blending ethanol with locally available mahua (locally called Mahula) oil, and observed reduction in CO, NO_x and HC. Rathore & Pandey [12] studied the emission impact and performance on engine run by diesel with assorted karanja and coconut biofuel. At varied proportions. Jena et al. [13] carried out search for groundwork of extracting biodiesel from mahua oil and simarouba oil. Attempts were made to extract biodiesel from cooking oil waste and tried to substitute as fuel for diesel engines. Zhang et al. [14] produced biodiesel from waste cooking oil and studied its economic viability. Di et al. [15] carried out their investigation with waste cooking oil by blending with low sulphur diesel and found a reduction in HC and CO emissions and increase in NOx value. Sheinbaum-Pardo [16] studied the possible use of cooking oil waste as biodiesel in Mexico City.

Many other workers from different countries had worked to use blend the diesel fully or partly with biodiesel produced from used cooking oil by various procedures in the present 21st century and successfully proved the probability of supplementing diesel by waste oil processing and extractions of FAME, Birla et. Al., [17], Allah et. al., [18], Li et al., [19], Bali et al., [20], Digfie et al., [21], Erchami et al., [22].

1.1 Scope of Study

Ushering of bioenergy has been impinged in Indian green energy context by blending diesel with 5% biofuel. India used up 72.7 MMT of diesel in FY, 2021 even in the pandemic year. About 23MMT of edible oil (vegetable product) is expended annually and producing 3MMT of cooking oil wastes. The Government of India is in plan to Repurpose Used Cooking Oil (RUCO) which shall blend diesel with 5% to biodiesel to bridge the oil gap. http://www.businessworld.in/article/Diesel-Doped-With-Biodiesel-Made-From-Used-Cooking-Oil-Rolled-Out/05-05-2021-388664/

The present research envisages preparation of biodiesel on esterification of waste cooking oils followed by transesterification procedure. Then different blends of biodiesel were prepared by mixing with diesel in required proportions. The biodiesel blends were used to fuel a diesel engine and engine exhaust gases were analysed by means of a gas analyser. The amount of constituent gases of engine emission was found to be reduced as compared to engine emission using diesel fuel that makes it suitable to use without any modification in engine design.

2. MATERIALS AND METHODS

2.1 Properties of Waste Cooking Oil

The waste or used cooking oils mainly consisting of fats have already been used for cooking or frying purposes at homes, restaurants or in food processing industries. The properties of the cooking oil residuals considered are the acid value, viscosity, and density were observed and reported in Table 1.

2.2 Preparation of Biodiesel

The biodiesel could be extracted from used oil wastes by involvement of two steps. The first stage was esterification on acid catalyzed (H_2SO_4 acid as catalyst) and subsequent step was base catalyzed (KOH as catalyst) transesterification. Present study was the conversion of the cooking oil waste into similar biodiesel form by the bi-modal transesterification processes. Initially the free fatty acid (FFA) in the cooking oil waste was converted to methyl ester by esterification (acid-catalyzed), and later was the transesterification (base-catalyzed) using (KOH, base as catalyst). Esterification was done to moderate the FFA present in the used waste oil. At the beginning the temperature (≈60-64^{o}C) was maintained for a mixture of 200 ml methyl alcohol and 10gm of sulphuric acid (conc. $H_2SO_{4)}$ added with the waste oil. On continuous heating for 3 hours, the waste cooking oil with methanol and $H_2SO_{4,,}$ the product was filtered by a separating funnel. The product alcohol with scums was removed. Then the FAME evolved was collected to undergo transesterification process. The transesterification process was conducted by adding it with 10gm of KOH and 200ml of methanol then transferred to the flask. The fatty acid methyl ester (FAME) produced during the procedure have identical properties to that of normal diesel. The FAME evolved in the esterification process needs to be purified through different processes such as transesterification (undergo recovery of methanol), repeated washing by water, purification of FAME, removal of alkali, purification of evolved glycerine, and waste treatment. The chemical reaction for FAME production is in Fig. 1.

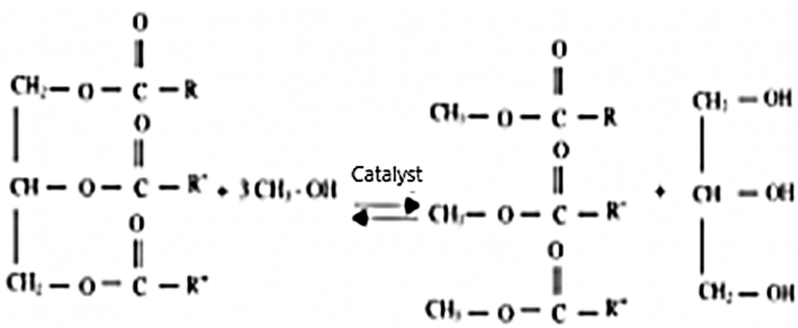
The mixture of the biodiesel sample prepared was heated to constant temperature (about 62^{o}C) and continuously stirred for 3 hours. After 3hours of heating, the hot mixture was decanted into a separator funnel for about 12 hours where formations of two layers occur. The topmost deposit delimited by methyl ester and the bottom sheet are deposits of glycerol, catalyst, extra methanol, and other products which were removed. The top biodiesel layer of the methyl ester was collected. The upper biodiesel layer was methyl ester which was collected and washed repeatedly by water to eliminate soppiness of the methyl ester. Finally it was filtered to take away scums and then it was heated up to 100^{0}C so that it was dried up to remove the residual water. The biodiesel was sealed and stored for further usage. The prepared waste cooking oil biodiesel was then added with diesel in in three different proportion and the various blends of biodiesel designated as B-10, B-20, and B-30. These biodiesel blends were utilised to run diesel engine and the exhaust gas ejected out from the exhaust pipe was analyzed by allowing to pass through a gas analyser. https://biofuels-news.com/news/the-conversion-of-used-cooking-oils-into-biodiesel.

2.3 Emission Test

The exhaust gas from diesel engine was analysed by means of gas analyser in pollution testing apparatus like exhaust gas analyzer was used, Fig. 2 (a), which was integrated with the testing diesel engine. The function of the exhaust gas analyzer and the variable compression rig from Centurion University and Technology and Management has been used to examine the different gases released through the exhaust pipe of the test engine to finally access the concentration of the most lethal CO gas (Fig. 2 b). The probe connected to the analyser was put in the exhaust pipe of the diesel engine to sense the exhaust gas. The composition of exhaust gases which mainly consists four major pollutants such as CO, CO_2, NO_x and HC were recorded during testing of different combinations of cooking oil waste employed as biodiesel. The comparison of exhaust emissions was shown in Table 2-5.

Table 1. Various physical and rheology properties of raw waste cooking oil

S.N	Properties	Raw waste cooking oil
1	Calorific value (KJ/kg)	40500
2	Density (kg/m^3)	890
3	Viscosity at 35^{o}C (mm^2/s)	4.8
4	Flash point (^{o}C)	176
5	Cetane number (CN)	63



Trialkylglycerol (Triglyceride) Methanol FAME (Fatty acid methyl ester) Glycerol

Fig. 1. The trans-esterification reaction involved from triglyceride to FAME

Fig. 2 (a). The pollution testing exhaust gas analyzer apparatus

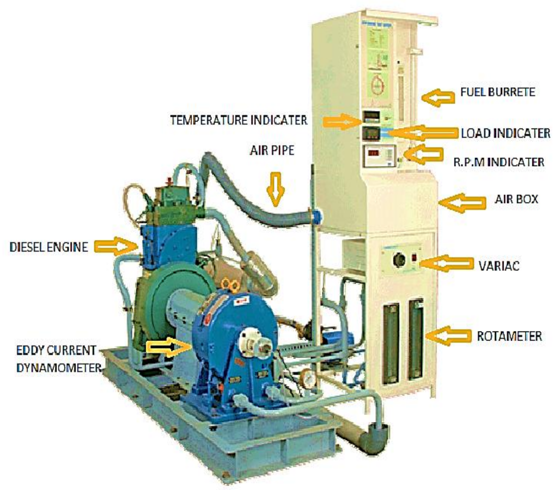
Equipment/Machine	Function/Use	Photo
VARIABLE COMPRESSION RATIO TEST RIG Specification • Single cylinder • 4 stroke Diesel engine • Water cooled • Power: 3.5 kW at 1500 rpm • Stroke: 110 mm • Bore: 87.5 mm • Displacement: 661 cc • CR: 17.5 (Modified to VCR engine CR range 12 to 18	To understand fuel performance and combustion analysis of I.C. Engines.	

Fig. 2(b). The variable compression rig, its standard specification, and function

3. THE RESULTS AND DISCUSSION

3.1 Carbon Monoxide (CO) Emission

The CO content of the engine emission by burning different composites cooking oil waste biodiesel is presented in Table 2 and graph is plotted by taking the results at different loads on the engine.

From Table 2, it is perceived that the cooking oil waste as biodiesel had given lower % of CO emission than conventional diesel. It is assigned to the extra oxygen content in the waste cooking oil biodiesel. The presence of high concentration of oxygen molecules helps in better combustion and reduction of % CO emission than conventional diesel fuel.

Fig. 3, envisages that when load increases with increasing biodiesel percentage, the CO emission of castor biodiesel blends decreases. This is because of the variation in air fuel ratio for the various operating conditions of the engine.

3.2 Oxides of Nitrogen (NO_X) Emission

The emission of NO_X increases as the quantity of leftover cooking oil increases in biodiesel blends than normally available diesel. It depends on the quantity of oxygen present inside the combustion chamber of cylinder, pressure, temperature and compressibility of fuel. The upsurge in NOx release can be attributed to higher content of oxygen in extracted biodiesel which raised the level of combustion chamber temperature.

Fig. 3 shows the emission of NO_X of conventional diesel with B10, B20 and B30. From the graph it was observed that with more biodiesel blend ratio the NO_X emission increases.

3.3 Hydrocarbon Emission

Table 4 shows that the hydrocarbon (HC) emissions from biodiesel extracted from cooking oil waste for all substitutes are a smaller amount as matched to available normal diesel for different loads which is a common trend in most substitute fuels due to high cetane number.

From Table 4, it was observed that in B30 the HC emission is less as compare to B20, B10 and the normally available diesel because in B-30 there is more biodiesel as compare to B20 and B10. As B30 contains more oxygen as compare to B20 and B10, it emits less HC. The reductions in HC emissions in waste cooking oil biodiesel can be attributed to thorough combustion of the fuel.

3.4 Carbon Dioxide (CO_2) Emission

The CO_2 emission in conventional diesel is more as it contain less oxygen. It was shown from Table 5 that the CO_2 emission of B30 was more as compare to B20, B10 and the diesel. The reasons can be complied with higher content of oxygen in cooking oil waste biodiesel than normal orthodox diesel fuel.

Table 2. CO emission of orthodox diesel vs. cooking oil waste as biodiesel at different loads

Load(kg)	CO (%)	CO (%)	CO (%)	CO (%)
	Diesel	B-10	B-20	B-30
2	0.08	0.05	0.05	0.04
4	0.07	0.05	0.04	0.03
6	0.06	0.05	0.04	0.04
8	0.05	0.04	0.04	0.03

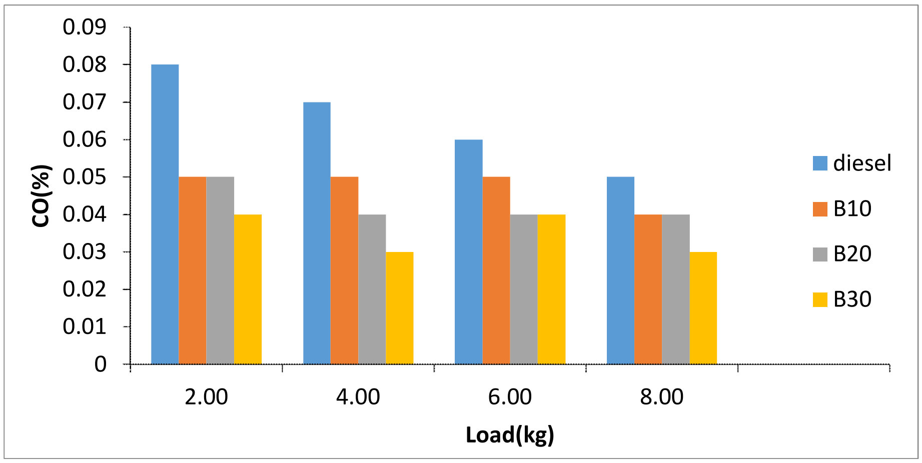


Fig. 3. CO Vs load for different blends of cooking oil waste as biodiesel

Table 3. NO_X emission of conventional diesel and waste cooking oil biodiesel at different loads

Load(kg)	NO_X(ppm)	NO_X(ppm)	NO_X(ppm)	NO_X(ppm)
	diesel	B10	B20	B30
2	37	45	68	89
4	107	118	149	162
6	156	160	178	191
8	201	216	237	253

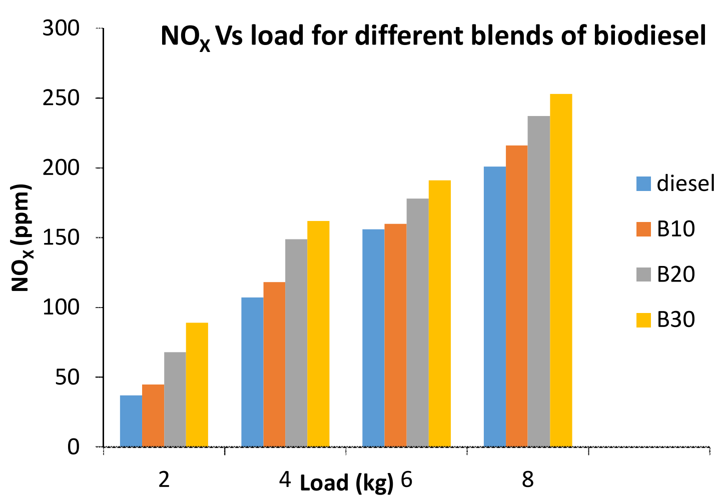


Fig. 4. NO_X Vs load for different blends of cooking oil waste as biodiesel

Table 4. HC emission of conventional diesel and cooking oil waste biodiesel at different loads

Load(kg)	HC(ppm)	HC(ppm)	HC(ppm)	HC(ppm)
	Diesel	B10	B20	B30
2	19	18	17	15
4	30	19	18	16
6	40	21	18	17
8	42	24	21	19

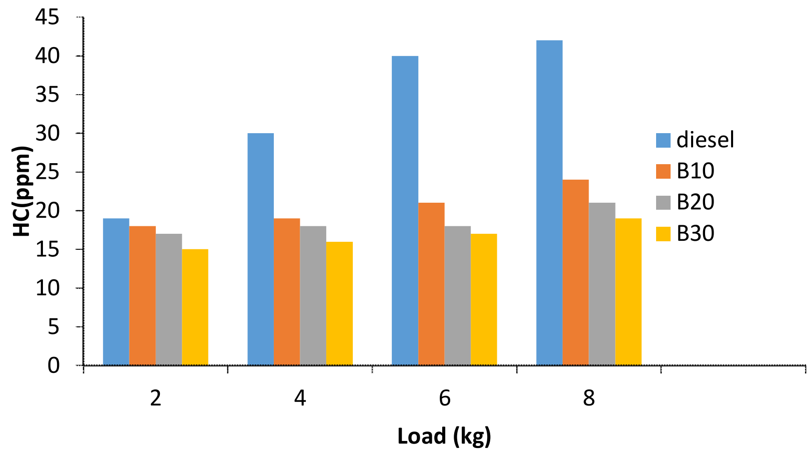


Fig. 5. HC emission Vs load for different groupings of cooking oil waste as biodiesel.

Table 5. CO_2 emission of usual diesel and cooking oil waste as biodiesel at different loads

Load(kg)	**CO_2(%)**	**CO_2(%)**	**CO_2(%)**	**CO_2(%)**
	Diesel	B10	B20	B30
2	2.7	2.8	3.1	3.3
4	3	3.3	3.7	3.9
6	3.2	3.4	3.8	4
8	3.4	3.6	3.8	4.1

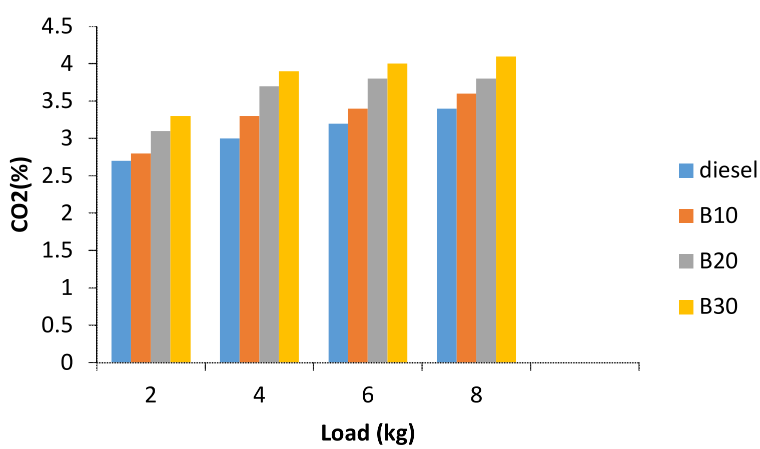


Fig. 6. CO_2 Vs load for different waste cooking oil biodiesel blends

It is also apparent from the Fig. 5 that the carbon dioxide (CO_2) emission is increasing with increasing loads and is least at a load of 2 kg. The reason is due to higher fuel entry as the load increases (Fig. 6).

3.5 Inference

The analysis from above results shows that there is considerable reduction in Hydrocarbon (HC) and Carbon Monoxide (CO) emission for waste cooking oil biodiesel as compared to diesel fuel while the percentage of Nitrogen Oxide (NO_x) increases for biodiesel blends. The increase in NO_x is obvious due to more oxygen content in biodiesel which results high combustion chamber temperature as compared to diesel and it is in accordance with literature. NO_x emission may be reduced by applying other techniques like Exhaust Gas Recirculation (EGR). Though there is a rise in Carbon Dioxide (CO_2) percentage in biodiesel but it is limited to 5% only and CO_2 is less pernicious than CO. This justifies our attempt to use cooking oil waste as biodiesel.

4. CONCLUSION

The biodiesel extracted from waste cooking oil has upright intrinsic properties than the normally available conventional diesel and many of its properties bear a resemblance to that of normal diesel. The results obtained can be concluded that the biodiesel extracted from waste cooking oil by transesterification can be blended to diesel as an alternative (part substitute) fuel for use as diesel substitute and save the cost of waste disposal, ecofriendly, and shall enhance economy. As the extracted biodiesel contains more oxygen promotes complete combustion in diesel engine which leads to less formation of Hydrocarbon (HC) and Carbon Monoxide (CO). However, there is an increase in the percentage of Carbon Dioxide (CO_2). This problem may be overcome by adding suitable additives which left for future investigation. The lower HC and CO emission of biodiesel blends of waste cooking oil has also a scope to check the overall performance of engine. As waste cooking oil biodiesel has lower emission than the normally available conventional diesel, the biodiesel can not pollute the environment and can be considered as a green fuel. Present study need further researches and wide field applications for its economy and environmental prospective.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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