Feasibility analysis of admitting gasified waste vegetable oil and non-edible oil blends with diesel in CI engine

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Abstract: The disposal of used waste vegetable oil is a significant concern from the pollution point of view. Several studies have already been made to produce biodiesel/blending with diesel in CI engines. However, the cost benefit analysis makes this process non-viable. Also, several works of literature are available in the admitting of non-edible oil blends in CI engines. This paper analyses the admitting the gasified waste vegetable oil (WVO) with non-edible oil (NEO) in CI engine. The mixture of WVO and NEO has been auto-gasified before admitting them in CI engine. Auto gasification is converting the solid combustible waste into the gaseous product with bio-oxygen and catalytic ash. This way, the temperature of the gasification process is reduced and makes direct admission is feasible. From the various trails, it has been found that the optimised performance ratio for the WVO and NEO mixture is 50:50. The cost-benefit analysis of bio diesel production and usage in CI engine has been analysed and reported in this paper. The EIA of WVO disposal has also been carefully analysed and reported.

Keywords: waste vegetable oil; WVO; non-edible oil; NEO; CI engine.

Reference to this paper should be made as follows: Kumar, C.S., Karthikeyan, M., Premkumar, D., Walling, S. and Kirubakaran, V. (2022) 'Feasibility analysis of admitting gasified waste vegetable oil and non-edible oil blends with diesel in CI engine', *Int. J. Environment and Sustainable Development*, Vol. 21, No. 3, pp.312–326.

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This paper is a revised and expanded version of a paper entitled 'Direct admission of waste vegetable oil & non edible oil blends in CI engine' presented at 4th International Conference on Bio energy, Environment and Sustainable Technologies, Thiruvannamalai, 28–30 January 2019.

1 Introduction

Indian economy should depend upon the energy conservation policy because India's top importing product is crude oil from the Organization of Petroleum Exporting Countries (OPEC). The cost of the barrels is also increased, which will affect the GPD growth of the country. The fossil fuel used in vehicles emits CO_2, which triggers global warming and climatic changes. The demand for fossil fuel is increasing day by day due to the villages' urbanisation, population growth, and the increased usage of vehicles. The pollution caused by this fuel significantly impacts every living thing's lifecycle and causes global warming and climate change. The greenhouse effect is a natural phenomenon, keeping the earth's surface warm. Human activities, mainly burning fossil fuel, are responsible for increasing greenhouse gases such as carbon dioxide (CO_2), nitrous oxide (NO), sulphur dioxide (SO_2), and nitrous dioxide (NO_2) into the atmosphere. The solution to this kind of problem is going towards alternate fuel, i.e., bio-fuel, which will replace fossil fuel in the future. The whole world is found the excess crisis of fossil fuel and polluting the environment, so there is a need for going towards the biodiesel (Canakei and van Gerpen, 2003). It is also known that biofuel production is becoming extremely attractive to developing countries that cannot afford significant oil import (Agarwal, 1998).

2 Literature review

In Atabani et al. (2013), it has been identified that non-edible vegetable oil is highly used as a substitute for diesel. This oil has blended with different compositions to evaluate the engine performance characteristic. Oil cannot be directly used in the diesel engine because it's a high viscosity and less volatile matter. It can be rectified by doing the transesterification process. But the cost is high due to the various processes involved. It requires proper maintenance due to carbon deposition while it is used for some time.

In Fontaras et al. (2011), blending is done with different ratios of *Jatropha curcas* with diesel, and the blending is mainly to reduce the viscosity. It is found that 50% of oil blended with 50% of diesel to obtain the same viscosity as that of the diesel, but the cost is equal to the production of the diesel. It has been found that several methods are available, which include blending with pertocrops, pyrolysis, Micro emulsification (co-solvent blending), and transesterification process to produce biodiesel (Barnwal and Sharma, 2005).

3 Materials

3.1 Vegetable oil or edible oil

Vegetable oil is made up of a triglyceride molecule obtained from the plant, which is mainly used for cooking purposes. The usage of vegetable oil is less polluting than petroleum fuels (Ramadhas et al., 2004). Different types of vegetable oil are evaluated for CI Engine used as a substitute for diesel, but vegetable oil has some problems in flow, atomisation, and heavy particulate emission (Altin et al., 2001). Transesterification of vegetable oil is a common method for the production of bio-diesel has a longer production process (Saka and Kusdiana, 2001). The use of vegetable oil in diesel engines lower engine performance, and compared to the diesel engine, NOx emissions are relatively low while using vegetable oil (Yucesu et al., 2001).

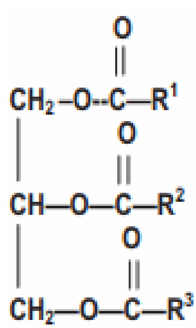
Figure 1 Oil seed production

Rabi Oilseeds Area & Crop								
	2017-2018			2016-2017			Change	
	Area Lakh Ha.	Crop Lakh Tons	Yield Kg. Ha.	Area Lakh Ha.	Crop Lakh Tons	Yield Kg. Ha.	Area Lakh Ha.	Crop Lakh
Groundnut	6.39	13.90	2175	11.47	15.49	1318	(-)5.08	(-)1.59
Rape/Mustard	66.88	63.80	946	66.52	65.00	1013	(+)0.36	(-)1.20
Sunflowerseed	1.74	1.50	862	2.11	1.73	820	(-)0.37	(-)0.23
Sesamseed	0.68	3.00	--	2.97	2.64	889	(-)2.29	(+)0.36
Safflowerseed	0.62	0.44	710	0.95	0.52	547	(-)0.33	(-)0.08
Linseed	4.01	1.55	386	3.84	1.65	429	(+)0.17	(-)0.10
Total	80.32	84.19	1045	87.86	87.03	991	(-)7.54	(-)2.84
As per GOI data as on 8th February, 2018. Source: The Solvent Extractors Association of India								

3.2 Waste vegetable oil

Waste vegetable oil (WVO) contains several fatty acids, mainly triglycerol, diglycerol, and monglyerides molecules. A large amount of waste vegetable oil is produced in the world due to food consumption, and they are disposed of in a harmful way (Ghassan et al., 2003). WVO is cheap, renewable, and disposed of inadequately (Al-Widyan et al., 2002). Even though economic and environmental standpoints, the usage of WVO as an alternative for diesel in engines (Yu, 2002). One way to reduce the cost of bio-diesel is the usage of waste oil as a lower-cost feedstock (Canakei and van Gerpen, 2003). Clean fuel reduces 20% of particulate emission while using the soybean blend used in DI engine (Akasaka et al., 1997). WVO are those oil which had been already used for cooking purpose at Homes, especially for frying also used at hotels, shops, restaurants, etc. WVO is not suitable for its eccentric purpose. Once the oil is used several times, it becomes contaminated, dirty, and inconvenient for this oil to be used again. The cost of Waste vegetable oil is competitive to the diesel and major concern in collecting the oil, avoid illegal dumping (Murayama et al., 2000). The disposing of WVO is a great concern to the environment and also to the human being. For the disposal of waste vegetable oil sustainably, the gasification process is used. WVO should be filtered to remove the unwanted, and scattered pieces of food particles and the quality of the oil is checked. Filtering of oil consists of two types of mechanical filtering and settling. In this process, the WVO (waste vegetable oil) has undergone settling in which the oil is kept for a few days or a period of a week; the fatty acids and water particles settle down, but some residue floated on the top layer should also be removed. The waste vegetable oil is then blended with the non-edible oil for gasification to produce carbon monoxide as a syn-gas to run the CI engine. The common structure of vegetable oil is shown in Figure 2.

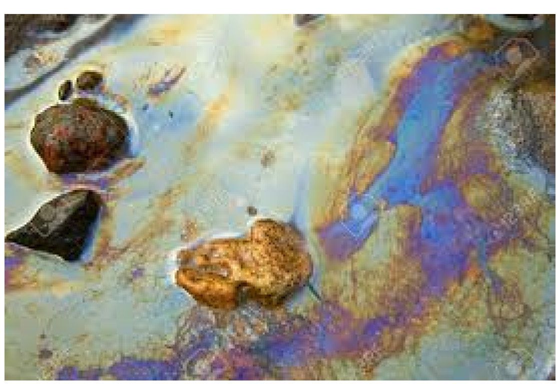
Figure 2 Chemical structure of WVO



3.3 *Impacts of waste vegetable oil*

According to the Food Safety and Standards Authority of India, it states that the total polar compounds of the oil should be in the permissible range of up to 25%. If it exceeds the limit, then the oil is unsafe for human consumption and may cause hypertension, cancer, liver diseases, and high-level cholesterol content. There is no correct method or standard protocol available for disposing of the WVO in the current situation.

Figure 3 Waste vegetable oil (see online version for colours)



3.4 Non-edible oil

Non-edible oil is that oil that cannot be used for human consumption. Edible oil is highly focused on biodiesel production, but, as a comparative analysis, non-edible oil uses bio-diesel production predominately cost very low and easily available (Gashaw and Lakachew, 2014). Pyrolysis of vegetable oil is a simple and effective method for fuel production (Lima et al., 2004). Bio-diesel produced from the transesterification of non-edible oil has cetane indices similar to the conventional diesel fuel (Alcantara et al., 2000). Trees such as *Pongammai pinnata*, *Jatropha curcas*, *Calophyllum inophyllum*, Mahua, para rubber tree, *Camelina sativa*, kneaf ricinus, Babasssu oil, Jajoba and rocket are some of the few trees used for the production of non-edible oil. The oil cannot be used for commercial purposes and does not have a huge market; therefore, they are readily used to produce biodiesel. In this research, we have taken Pongamai oil to blend with waste vegetable oil. These *Pongammai pinnata* trees are found in several parts of India, and it is also likely to grow in the tidal areas along the bank of the river. Punam is native to the humid and subtropical environments (Najafi et al., 2007). The maximum environment temperature ranging from 27°C to 38°C, and the minimum is 1°C to 16°C. The tree starts seeding and pods after 4 to 5 years. Pungum can grow in any kind of soil types from stony to sandy, even grow in the clayey sands, and well tolerate the salinity of the soil. Some of the fatty acids present in the pungam oil are given in Table 1.

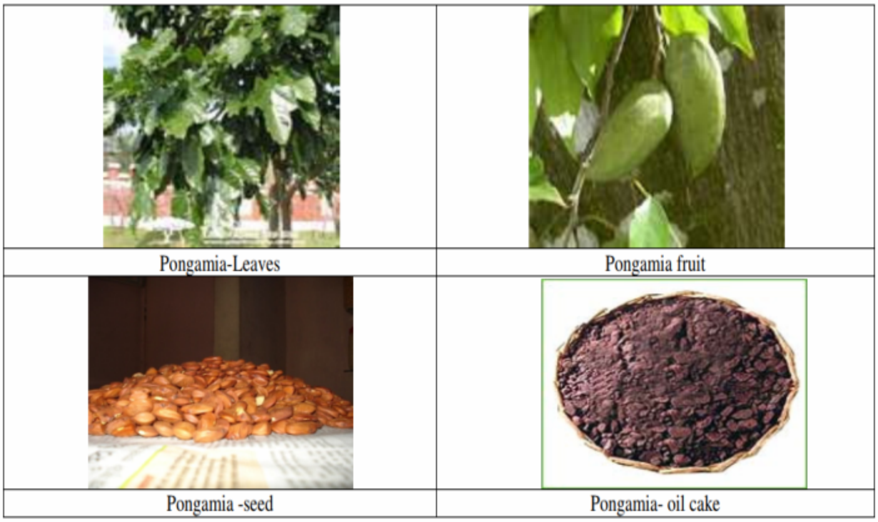
Table 1 Fatty acid in Pongamai Pinnaita

Fatty acid in Pungam oil	*Molecular formula*	*Structure*
Palmitic acid	$C_{16}H_{32}O_2$	$CH_3(CH_2)_{14}COOH$
Stearic acid	$C_{18}H_{36}O_2$	$CH_3(CH_2)_{16}COOH$
Oleic acid	$C_{18}H_{34}O_2$	$CH_3(CH_2)_{14}(CH{=}CH)COOH$
Linoleic acid	$C_{18}H_{32}O_2$	$CH_3(CH_2)_{12}(CH{=}CH)2COOH$
Eicosanoic acid	$C_{20}H_{40}O_2$	$CH_3(CH_2)_{18}COOH$
Dosocanoic acid	$C_{20}H_{44}O_2$	$CH_3(CH_2)_{20}COOH$
Tetracosanoic acid	$C_{24}H_{48}O_2$	$CH_3(CH_2)_{22}COOH$

3.5 Extraction of non-edible oil

There are three types of methods that are available for the extraction of oil from the pungamai seed. The first method is mechanical expeller; the second method is soxhelt extraction, also known as the solvent extraction method and the third, cold percolation method. The mechanical method is the oldest and widely followed, but it consumes more time. The cold percolation method is the gravitational method mainly used in the laboratory, and the oil can be extracted at room temperature. In soxhelt extraction method, the seed is granulated into fine particles from which the oil is obtained.

Figure 4 Karanja plan (see online version for colours)



3.6 Properties of raw material used

Table 2 Properties of standard diesel, WVO, NEO

Raw material	*Diesel*	*WVO*	*NEO*
Calorific value (MJ/Kg)	42.54	37.16	40.27
Density @ 15.56°C (kg/m^3)	843	912	922
Viscosity @ 40°C (mm^2/s)	2.4	41.7	37.12
Cetane number	46	-----	40
Cloud point °C	–5	0	3.5
Flashpoint °C	76	279	230
Pour point °C	–17	-39.7	-2.5

4 Methodology

4.1 Experimental setup and process

A gasifier for the blended oil has been designed and incorporated along with the engine. It contacts a flow chamber and heating source. The external heating source has been used only for trial purposes. The waste vegetable oil and pungam oil is blended at the ratio of 50:50 for gasification. This optimised ratio has been arrived based on the engine performance and run hours of the other blended ratio engine. The sample gasifier has been operated at a temperature of 380°C. The gasified gas passes through the condenser; the gas's moisture content is condensed into the water, which is collected in the collector. The gas is further continued to remove the dust particles. The quality of the producer gas can be monitored using an online producer gas analyser, where the carbon monoxide (CO) percentage has been recorded in the range of 34 to 38%. The producer gas, along with Diesel has been admitted into the IC engine. The ratio of diesel to gasified oil is 20:80. The detailed Specification of the engine is given in Table 3.

Table 3 Engine specification

Type	Four-stroke
No. of cylinder	1
Make	Kirloskar TAF1 HSD
Broke	87.5 mm
Stroke	110 mm
Cubic capacity	0.662 ltr
Compression ratio	17.5:1
Rated output	4.41 KW @ 1,500 RPM
Fuel tank capacity	6.5 ltr
Starting	Hand start
Rated speed RPM	1,500
Type of fuel injection	Direct injection

Figure 5 Prototype model (see online version for colours)

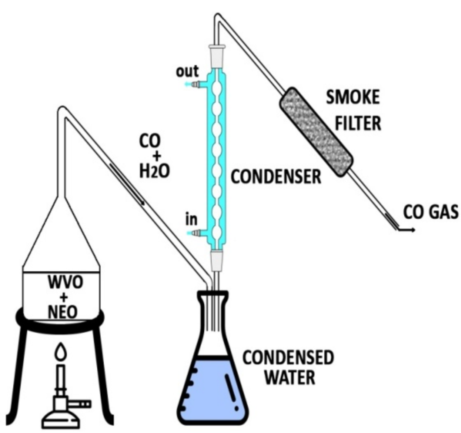


Figure 6 Schematic diagram of the process (see online version for colours)

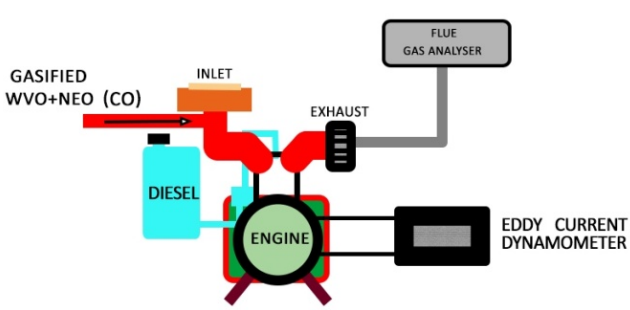


Figure 7 Experiment carried out (see online version for colours)

5 Results and discussion

5.1 Proximate analysis ultimate analysis and calorific value of the oils

The proximate analysis is widely used as a feed analysis method. It is done by using a hot air oven and muffle furnace to find out the moisture content, volatile matter, fixed carbon, and ash content for WVO and non-edible oil. Then the calorific value of both the oil is identified by using the Bomb calorimeter. By identifying the calorific value, the amount of energy production by the fuel is obtained and can be expressed in KJ/kg k or Cal/g. It is the heating value of the fuel.

Table 4 Proximate analysis and calorific value

Name of fuel	*WASTE VEGETABLE OIL*	*PUNGAM OIL*	*WVO + PUNGAM OIL*
Moisture content (%)	0.19	0.35	0.54
Volatile matter (%)	36.63	16.45	26.54
Fixed carbon (%)	61.52	83.18	72.35
Ash content (%)	0.66	0.035	0.345
Calorific value (cal/g)	15,091.7	11,556.7	13,324.2
Auto ignition temperature	320°C	265°C	290°C

Table 5 Ultimate analysis

GASES	*WVO*	*PUNGAM OIL*	*WVO + PUNGAM OIL*
% carbon	82.567	87.40	84.98
% hydrogen	5.40	4.34	7.57
% nitrogen	9.438	5.1288	7.28
% oxygen	2.59	3.037	2.81

5.2 Flue gas analysis

Flue gas analysis or producer gas analyser is an instrument used to analyse the composition of gases present in the flue gas. This gives the amount of CO, SO_2, NO, H_2S, and NOX released during the operation condition.

Table 6 Technical Specification

Sensor	*Max Range*	*Resolution*
Oxygen (O_2)	0–30% vol	±0.1% vol
Carbon monoxide (CO)	0–10,000 ppm	±1 ppm
Sulphur dioxide (SO_2)	0–5,000 ppm	±1 ppm
Carbon dioxide (CO_2)	----	±0.1% vol
Hydrogen sulphide (H_2S)	0–1,000 ppm	±1 ppm
Make – LANCOM III		

Table 7 Gases Composition

S. no.	*Name of gases*	*Diesel in PPM*	*WVO + non-edible oil in PPM*
1	CO	282.3	457.5
2	SO2	41.7	NIL
3	NO	1.9	NIL
4	H2S	NIL	1.8
5	NOX	1.9	0.5

5.3 Performance analysis

Performance analysis of diesel, waste vegetable oil, and diesel + gasified (WVO + NEO) is studied, and the graph is plotted for includes various performance results of BTE, BSFC, and volumetric efficiency. Each graph is interconnected with each other, but to understand it is plotted separately.

Figure 8 Brake power vs. brake thermal efficiency (see online version for colours)

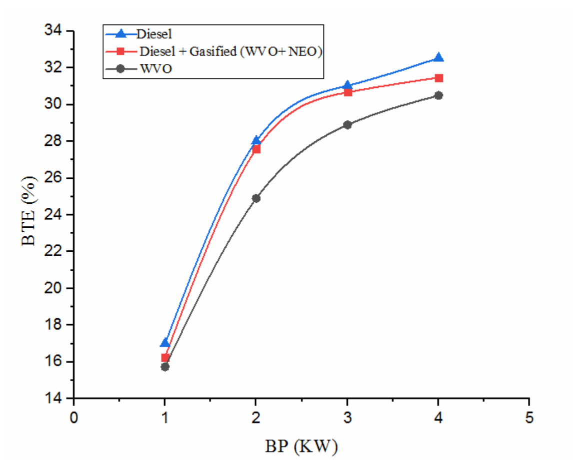


Figure 8 shows that brake thermal efficiency is calculated by variation in brake power for Diesel, Waste vegetable Oil, and blending of diesel with gasified (WVO + NEO). Due to the high viscosity of WVO has low BTE when compared to others.BTE is higher for the diesel with gasified (WVO + NEO) due to an increase in the fuel's calorific value. The term brake power is the amount of power utilised by the shaft. To calculate the brake power, the engine is operated at different load conditions. The formula calculates it

$$\eta_{bth} = BP/((\text{Mass of fuel})/s * \text{calorific value of fuel}))$$

where η_{bth} is the brake thermal efficiency.

Figure 9 Brake power vs. brake specific fuel consumption (see online version for colours)

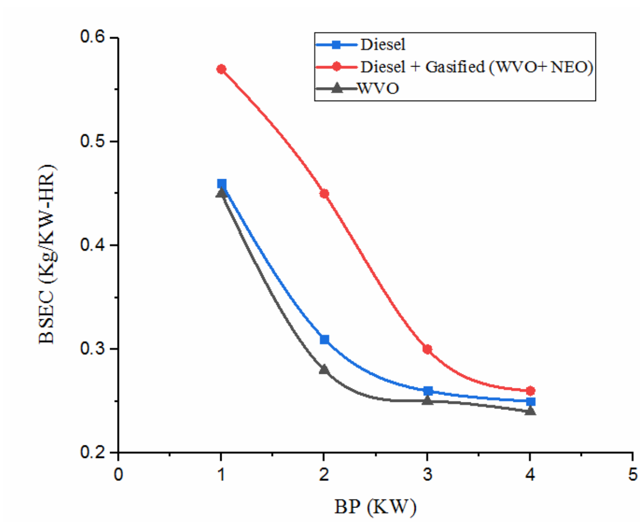


Figure 10 Brake power vs. volumetric efficiency (see online version for colours)

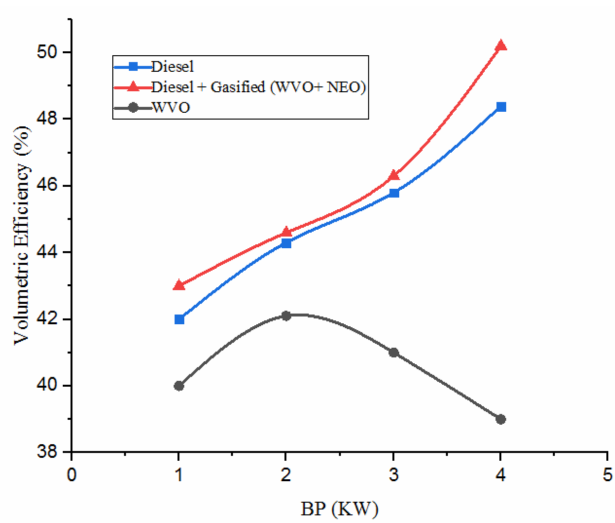


Figure 9 shows that, brake specific fuel consumption is determined by various brake power for diesel, waste vegetable oil, and diesel blending with gasified (WVO + NEO). BSFC further increase in load will decrease the SPFC. At full load condition, the diesel + gasified (WVO + NEO) has a lower value. BSFC is the number of fuel burns to produce rotational power.

Figure 10 shows that various brake power determines volumetric efficiency for diesel, waste vegetable oil, and diesel + gasified (WVO + NEO). Volumetric efficiency is the ratio of actual air steady-state mass airflow to calculated mass airflow into the engine.

5.4 Emission analysis

The gas analyser is used to estimate the amount of CO, CO_2, O_2, NOX emission from the CI engine is plotted on the graph for various brake power at different load conditions clear understanding exhaust gas emission for diesel, waste vegetable oil and diesel + gasified (WVO + NEO).

Figure 11 BP vs. CO emissions (see online version for colours)

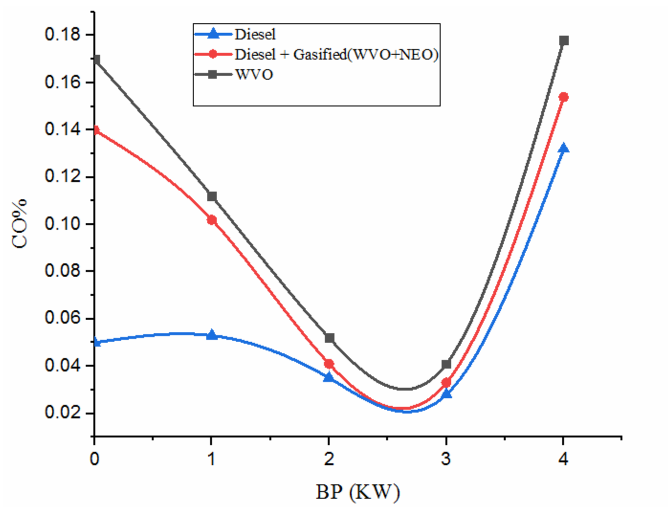


Figure 11 shows that CO emission of diesel, waste vegetable oil, and diesel + gasified (WVO + NEO) as the load increases CO emissions increase. Initially, the emission increases at the starting of the CI engine, reducing to a certain extent. In this graph, WVO had less CO emission when compared to others. Gasification of WVO +NEO increases the combustion rather than oxygen.

Figure 12 BP vs. CO_2 emissions (see online version for colours)

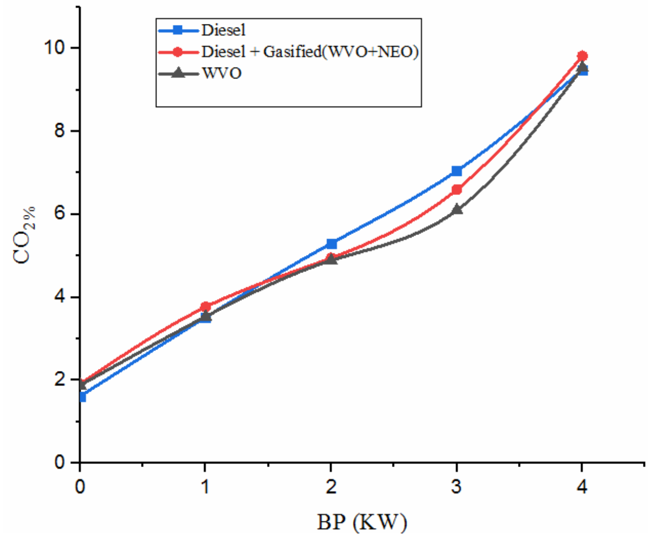


Figure 12 shows that CO_2 emission of diesel, waste vegetable oil, and diesel + gasified (WVO + NEO). At different load conditions, the CO_2 emission values are very close to each other. Above 40% load, the CO_2 emission is high for diesel and WVO. At lower load, the fuel is less due to the availability of a higher air-fuel mixture. The CO_2 is low in waste vegetable oil and diesel + gasified (WVO + NEO).

Figure 13 BP vs. NOX emissions (see online version for colours)

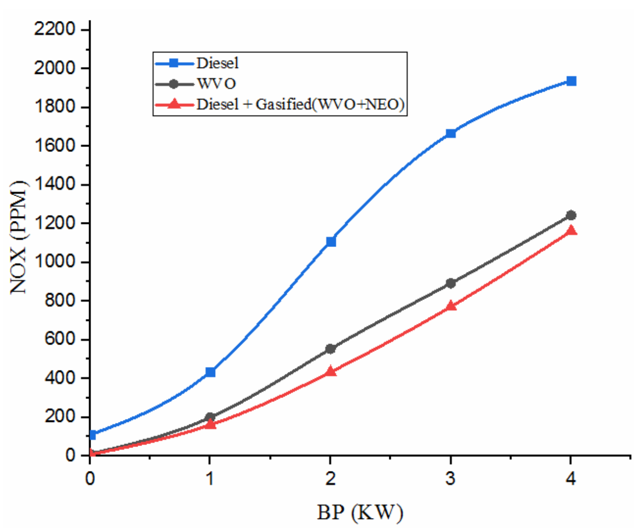


Figure 13 shows that NOX emission of diesel, waste vegetable oil, and diesel + gasified (WVO + NEO). As the load increases, the NOX emission in the CI engine is very high for diesel. NOX emission highly depends on the combustion temperature. Due to the higher cetane number, there will be ignition delay, and NOX emission is reduced.

Figure 14 BP vs. O_2 emission (see online version for colours)

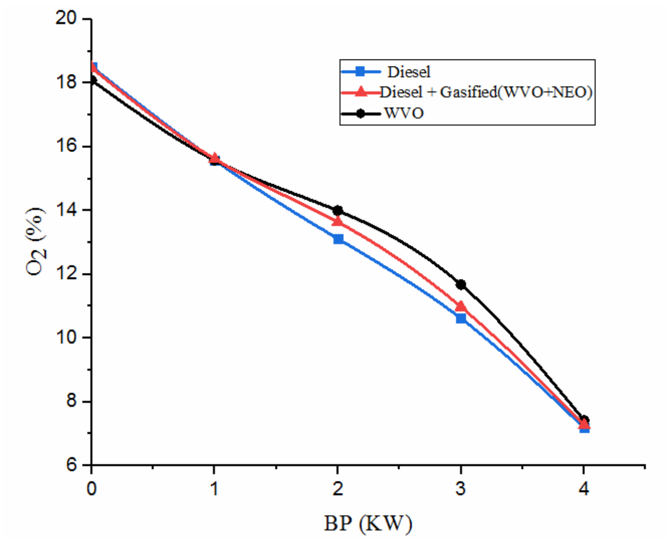


Figure 14 shows that O_2 emission of diesel, waste vegetable oil, and diesel + gasified (WVO + NEO). O_2 emission is high in WVO due to fatty acid present in the oil when compared to other fuel at different load conditions.

5.5 Cost-benefit analysis

The cost of biodiesel per litre is coming around Rs.44.00 to Rs.48.00. However, the price of non-edible oil per litre comes around Rs.22.00 to Rs.28.00, and waste vegetable oil per litre is Rs.8.00 to Rs.10.00. The gasified mixture has the 4,800 kJ/m^3 and gives equal break power as that of diesel. Considering the capital and operating cost of the gasifier, the payback comes within 8 to 10 months.

6 Conclusions

In this paper, the performance and emission characteristic of diesel, WVO, and gasified (WVO + NEO) (50:50) with diesel is compared. Based on these results, the following conclusion has arrived:

1 the present gasification technology gives the pathway for waste vegetable oil disposed of in an eco-friendly manner

2 the gasified mixture admission, along with diesel, increases the efficiency of the CI engine

3 the blend of 50 % of WVO and 50% of NEO is used for the gasification of oil to enhance the engine's performance

4 from the exhaust gas analysis, it has been observed that NO_X emissions are less when compared to diesel as base fuel

5 the volumetric efficiency and brake thermal efficiency are high for gasified (WVO + NEO) blend with diesel compared with diesel and WVO

6 the performance of the gasification has been improved by recovering the waste heat from the engine, which makes further improvement in the payback period.

Waste vegetable oil disposal's major challenge has been attempted in an eco-friendly manner along with energy generation. Even though the diesel's 20% dependency still exists, further investigation and engine modification will solve this dependency. Hence this paper attempts to find a solution from the waste for a sustainable environment without liberating any hazardous gases to the environment.

7 Future scope

Further investigation has to be done in the following areas:

- the ratio of the WVO may further increase by a suitable catalyst for the thermal cracking
- a gasifier should be redesigned by incorporating a waste heat recovery system so that the cost economics will be achieved significantly.

Acknowledgements

The authors wish to thank the Ministry of New and Renewable Energy, Govt. of India, for funding the Laboratory Upgradation Programme for carrying out this research work.

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