Experimental Investigation of Engine Performance and Exhaust Emissions of Produced Biodiesel from Waste Cooking Oil

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Abstract: Availability of petroleum and environmental concern fuels has caused attention in the look for internal combustion engine alternative fuels. Various researchers have tried on many alternate fuels. Literature review depicts bio-diesel as most promising fuel for diesel engine. Pure biodiesel was produced from wasted cooking oil during trans-esterification, and by further processes, biodiesel is prepared. The properties of these were compared favorably with the characteristics essential for internal combustion engine fuels particularly diesel engine. The results obtained from testing demonstrates that without changing any component of the diesel engine, for all blend conditions engine performance is similar to the results with standard diesel. Moreover, the B10, B5 blend fuels (comprise 10%, 5% biodiesel respectively) led to reasonable emissions at variable load. These experimental results compared with standard diesel which depicts significant reductions in CO, and NO_x, with the increase of unburned HC. As biodiesel is sulphur free fuel, significant reductions in CO_2 is observed.

Index terms: *Biodisel, diesel engine, waste cooking oil, exhaust emission.*

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I. INTRODUCTION

Diesel engines are extensively used as power sources in medium and heavy-duty applications because of their lower fuel consumption and lower emissions of carbon monoxide (CO) and unburned hydrocarbons (HC) compared with gasoline engines. Rudolf Diesel, the creator of the diesel engine, ran an engine on groundnut oil at the Paris Exposition of 1900. Since after that, vegetable oils have been used as fuels when petroleum supplies were expensive or difficult to obtain. Research into vegetable oils decreased with the increased availability of petroleum in the 1940s. In view of the fact that, the oil crisis of the 1970s research interest has stretched out the area of alternative fuels. Biodiesel is produced from fatty acids triglycerides and can be used in diesel engines without serious problems. The cost of vegetable oils is the main handicap to commercialization of the product. Moreover, several chemical properties of oils like the high molecular weight and high viscosity basis the poor fuel atomization and low volatility which lead to incomplete combustion and severe engine deposits along with injector coking and piston ring sticking. Vegetable oil viscosity can be improved by pyrolysis, blending and emulsification but it fails to solve the problem completely. Thus, research has revealed that one way to improve the fuel properties of oils and fats which is trans-esterification. A process of converting vegetable oil into biodiesel fuel called as Trans-esterification. This process supplies a fuel that can be operated in unmodified diesel engines. Numerous vegetable oil esters have been tried as alternative to diesel fuel. A lot of researchers have reported that with the use of vegetable oil ester as a fuel in diesel engines, a diminution in harmful exhaust emissions as well as equivalent engine performance with diesel fuel were achieved. Several studies have observed that biodiesel seems to emit lower pollutants than standard diesel fuel. Decreasing of carbon dioxide (CO_2) by using biodiesel contributes to reduce greenhouse effect. In other sense, diminishes carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NOx). Although biodiesel has many advantages when it comes to fuel properties, it still has several properties that need to be improved, such as its lower calorific value, lower horse-power output, and its comparatively higher emission of nitrogen oxides. Monyem et al. [1] observed that fuel properties of biodiesel might be affected by oxidation after the biodiesel was stored for a period of time. Without modifying engine, biodiesel-diesel blends operate perfectly on supercharged vehicle diesel engines. Nor Hazwani Abdullah et al. [2] demonstrated the production of biodiesel as an alternative fuel from waste cooking oil. Blended B5 and B10 grade biodiesel extensively helped to protect environment and conversion of waste to useful energy. Kusmiyati et al. [3] investigated the waste fish oil biodiesel production and its performance in diesel engine. Study reported that waste fish oil biodiesel blends fuel have higher torque compared to those diesel oil, blending fuel has higher power engine as compared to diesel fuel at speed of 1200- 1450 rpm, and has a lower BSFC as compared to that of pure diesel oil. B.K. Barnwal and M.P. Sharma [4] studied the Prospects of biodiesel production from vegetable oils in India. Studies have revealed that biodiesel blends lead to a reduction in smoke opacity, emission of particulates, unburnt hydrocarbons, carbon dioxide and carbon monoxide, but cause slightly increase in nitrous oxide emissions. Ester blend with a concentration of 20% biodiesel gave maximum improvement in peak thermal efficiency, minimum brake specific energy consumption and minimum smoke opacity. Alpaslan Atmanlı et al. [5] studied engine performance and exhaust emissions of turbocharged direct injection diesel engine. Addition of n-butanol to diesel fuel-vegetable oil blends leads to increase NO, NO2 and CO formations, while decreasing CO2 and HC emissions. The blends of biodiesel with small content in place of petroleum diesel can help in controlling air pollution and easing the pressure on scarce resources without significantly sacrificing engine power and economy [6]. Mohamed Saied Shehata [7] prepared biodiesel from cotton seed oil, palm oil and flax oil and it biodiesel fuels give BP and brake thermal efficiency lesser than diesel fuel. Biodiesel pushes itself forward with reduction harmful emissions like unburnt hydro carbon, particulate matter and Carbon monoxide [8]. By using a common-rail diesel engine fueled with bio-ethanol as a fuel additive in coconut oil biodiesel blends, brake thermal efficiency and brake specific fuel consumption increases and NOx, smoke and CO emissions decreases[9]. Use of biodiesel resulted in lower emissions of CO (up to 58.9%), CO2 (up to 8.6%), NO (up to 37.5%), and SO2 (up to 57.7%), with increase in emissions of NO2 (up to 81%). Results revealed a slight increase in BSFC [10]. C.V. Sudhir et al. [11] studied the potential of waste cooking oils (WCO) as biodiesel feed stock. The results indicate that the thermal performance of esters of WCO closely resemble the performance of esters of fresh oil. At higher load operation of esters of WCO fueled engine suffers nearly 2 % brake thermal efficiency loss. HC emissions of WCO-biodiesel fuel were observed to be approximately 35% lower than baseline diesel operation. Wail M. Adaileh et al. studied the combustion characteristics and emissions of compression ignition diesel engine were measured using a biodiesel as an alternative fuel. The feed-stock for the biodiesel was the waste cooking oil. The experimental results compared with standard diesel shows that biodiesel provided significant reductions in CO, and unburned HC, but the NOx was increased. Using B20 and B5 diesel fuel gave better emission results but also high NOx emission and more brake specific fuel consumption [12]. Hadavi et al. [13] studied the Emissions from a HGV using Used Cooking Oil as a Fuel under Real World Driving Conditions. Used cooking oils were used as a fuel in Heavy Goods Vehicles. Biofuel produced less and lower CO spikes. CO emissions were reduced by half for the empty trailer tests and 25% for the loaded trailer tests respectively by the Biofuel compared to diesel. Shou-Heng Liu et al. [14] studied the Emissions of Regulated Pollutants and PAHs from Waste-cooking-oil Biodiesel fuelled Heavy-duty Diesel Engine with Catalyser. BSFC was higher for biodiesel blends as a consequence of biodiesel having a lower heating value. A high fraction of biodiesel blends resulted in lower PAH emissions. Blends had lower PM, HC, and CO emissions but higher CO2 and NOx emissions. Biodiesel increase combustion efficiency and reduce PM, HC, and CO emissions.

In the present study, post work has been carried out of paper entitled production of biodiesel from waste cooking oil [15]. In the previous work, the biodiesel was prepared from waste cooking oil. ASTM standard methods were used to characterize physical properties of biodiesel. The composition of final biodiesel was determined by taking considerations of physical properties such as density, viscosity, flash point and water content. All the measured properties met the ASTM criteria for fuel standard. This work represents engine performance analysis of prepared biodiesel with B5 and B10 blends. Also, engine emissions were also analyzed for biodiesel blends of B5 and B10 with pure diesel.

II. EXPERIMENTATION

It is Single cylinder Four stroke diesel engine make Kirloskar (TV1). It is water cooled constant speed engine with power 5HP at 1500rpm speed. It has 110mm stroke and bore of diameter 80mm. Engine capacity is 661cc with compression ratio of 17.5:1.

The system is used for the study of Single cylinder four stroke diesel engines. System is having unique feature of calculating different efficiencies of internal combustion engine including heat balance sheet. Figure 1 shows the diesel engine setup. The engine & dynamometer is mounted on base structure. The system is designed in such fashion that easily operates; demonstrates & requisite experimentation can be performed. It has facility of measuring Engine brake load, speed, consumption of air, consumption of fuel, temperature at different locations, and mass flow of water. It has unique feature of direct reading & automatic calculating all efficiency & heat balance sheet of internal combustion engine. The online graphical representation of important parameter is displayed on screen to visualize the effect of change in load or speed. System has facility of measuring engine brake load, speed, consumption of air, consumption of fuel, temperature at different locations, and mass flow of water

Figure 1: Diesel engine setup

III. ENGINE PERFORMANCE

The engine performance fueled with various blends of diesel and biodiesel are measured. Brake power is power available at crank shaft in engine. Mechanical Efficiency is the ratio of Break Power to Indicated power. Brake Specific Fuel Consumption (BSFC) is the rate of fuel consumption divided by the break power produced. Variation of specific fuel consumption of diesel and its blend with biodiesel at respective load are shown in table 1.

Table 1 show that the Brake power is quite similar at same load for various blends. It is also observed that mechanical efficiency is quite similar at same load for various blends as mechanical efficiency depends upon Engine parameters, not on different types of blends. The BSFC initially decreases with increasing of engine load until it reaches a minimum value and then increases slightly with further increasing engine load for all kind of fuels. According to addition of biodiesel content in the blend, the BSFC initially decreases until it reaches a maximum value. Past studies shows that the maximum value of BSFC is at about B20 blend and then increases with more increase of the biodiesel content in blend. Using of blends B5 and B10, the BSFC of the engine is lower than that of diesel for all loads for the reason that, biodiesel includes oxygen which improves combustion of fuel. This may be due to improved combustion, low viscosity, high volatility of the test fuels using additive.

Table.1 Measurement of (a) Brake power, (b) mechanical efficiency and (c) BSFC at varying load conditions

(a)	Brake Power(kW)		
Load(kg)	**B0**	**B5**	**B10**
1	0.226	0.221	0.223
3	0.673	0.670	0.672
6	1.344	1.344	1.333
9	2.002	1.988	1.970
12	2.617	2.612	2.589
(b)	**Mechanical Efficiency (%)**		
Load(kg)	**B0**	**B5**	**B10**
1	12.660	12.409	12.515
3	30.131	30.030	30.102
6	46.274	46.274	46.086
9	56.200	56.028	55.804
12	62.653	62.603	62.404
(c)	**BSFC (kg/kW*h)**		
Load(kg)	**B0**	**B5**	**B10**
1	1.597	1.680	1.557
3	0.579	0.569	0.556
6	0.345	0.335	0.330
9	0.274	0.267	0.271
12	0.246	0.227	0.231

IV. EXHAUST EMISSION PERFORMANCE

The engine emission experiment setup consists the gas analyzer as shown in figure 2. Gas analyzer is an instrument used for determining the qualitative and quantitative composition of gas mixtures. Gas analyzer used here is automatic and sync with computer. The probe of gas analyzer is inserted in the exhaust pipe to take the emissions reading.

Figure 2: Gas analyzer

Following are the results of different biodiesel blends. Where B0 is pure diesel, B05 is 5% biodiesel and 95 % Diesel, while B10 is 10 % biodiesel and 90 % diesel.

Table.2 Measurement of NO_x Emission and CO Emission at varying load conditions

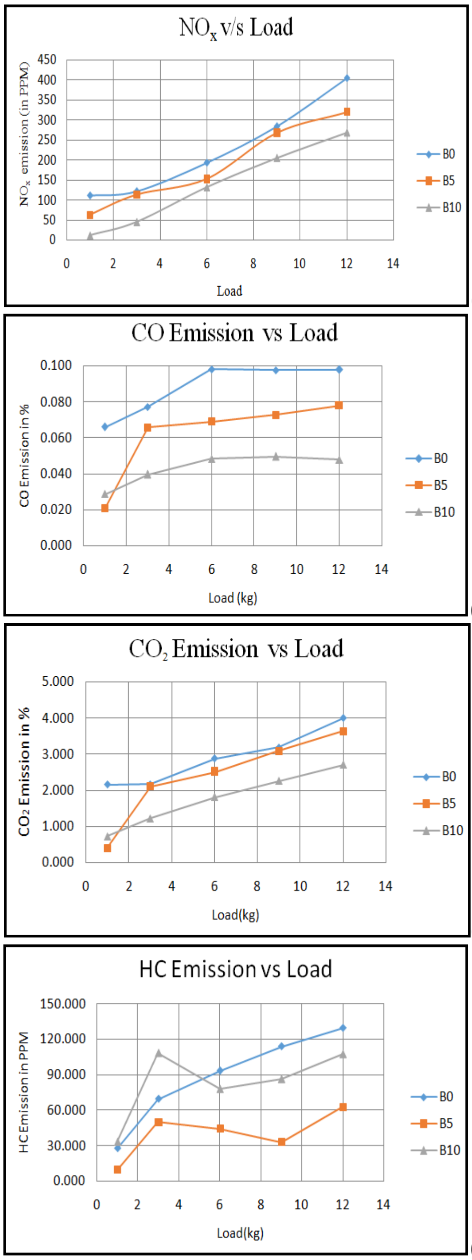
	NO_x Emission			CO Emission (%)		
Load(kg)	**B0**	**B5**	**B10**	**B0**	**B5**	**B10**
1	112	63.111	12	0.066	0.021	0.029
3	122.5	113.41	45.41	0.077	0.066	0.040
6	193.53	152.75	132	0.098	0.069	0.048
9	284.15	268	205	0.098	0.073	0.050
12	404.25	319.6	268.36	0.098	0.078	0.048

The exhaust gas emissions of engine fuelled with various blends of diesel and biodiesel are measured and studied. The measurement of exhaust gas emissions of NOx and CO with respect to different loads are shown in Table 2. The measurement of exhaust gas emissions of CO_2 and HC with respect to different loads are shown in Table 3.

Table.3 Measurement of CO_2 Emission and HC Emission at varying load conditions

	CO_2Emission (%)			HC Emission (PPM)		
Load (kg)	**B0**	**B5**	**B10**	**B0**	**B5**	**B10**
1	2.15	0.40	0.72	27.60	9.55	33.50
3	2.17	2.10	1.22	69.50	49.58	108.08
6	2.88	2.50	1.80	93.38	44.25	77.90
9	3.19	3.09	2.25	114.07	32.91	86.25
12	4.00	3.64	2.70	129.62	62.60	107.18

Fig. 3 depicts the variations of exhaust gas emissions under different loading conditions. Nitrous Oxides (NOx) are reported by several researchers to be increased with Biodiesel. However, data observed under this study shows a reduction in nitrous oxides, very consistently. This may be due to the fact that the fuel was lacking in stearic and plasmatic acids. Due to incomplete combustion which is result of lack of oxidants, lower oxidation temperature. Formation of CO takes place. The lower percentage of biodiesel blends emits very low amount of CO in comparison with diesel.



(a) (b) (c) (d)

Figure 3: (a) NOx emission v/s Load; (b) CO emissions v/s Load; (c) CO2 emission v/s Load (d) HC emissions v/s Load

After the addition of biodiesel in the blended fuel, CO emissions decrease due to improved combustion with oxygen enrichment of the fuel. The reason that amount of oxygen content in biodiesel helps for the complete combustion. However, with increase in additive percentage CO decreases for all the prepared test fuels because of good spray characterization, good air-fuel ratio and proper combustion. As shown above, the amount of CO_2 emission decreases as amount of Bio-Diesel increases for particular load. Reason behind this is adequate amount of oxygen presence in rich blends and due to that complete combustion takes place. The HC emissions increase with increasing in load. HC emissions decrease with increasing biodiesel percentage in the blend. This is also due to oxygenated nature of biodiesel where more oxygen is available for burning and reducing hydrocarbon emissions in the exhaust. However, with increase in percentage of additive HC emission increases with respect to load because of low cylinder pressure and temperature causing a comparatively lower burning rate.

CONCLUSION

Following conclusions were drawn from the experimental results:

1. The biodiesel was prepared from waste cooking oil sample collected from a local restaurant in Gandhinagar, India. ASTM standard methods were used to characterize physical properties of biodiesel.
2. The composition of final biodiesel was determined by taking considerations of physical properties such as density, viscosity, flash point and water content. From the various tests, the flash point temperature was obtained as 97˚C, water content was 0.01% of biodiesel, and viscosity at 40˚C was 5.69 mm^2/sec, density 880 kg/m^3 and calorific value of 39719 KJ/kg. All the measured properties met the ASTM criteria for fuel standard.
3. It is harmful to use recycled waste cooking oil and due to stringent norms, it is advisable, not to dispose WCO directly to environment without proper treatment.
4. Moreover, considering economical point of view it is much cheaper to convert WCO into biodiesel than to extract diesel from petroleum through conventional refining process. Considering all these factors, it is preferable to use biodiesel as substitute for diesel engines.
5. Engine performance fuelled with pure diesel and various blends were measured. Mechanical efficiency is similar at same load for various blends. As load increases BTE increases for all biodiesel blends. Using of blends B5 and B10, the BSFC of the engine is lower than that of diesel for all loads.
6. Amount of NOx (in PPM) decreases with the increasing amount of Biodiesel in blends. It has been observed that lower percentage of biodiesel blends emits very low amount of CO in comparison with diesel.
7. The amount of CO2 emission decreases as amount of Bio-Diesel increases for particular load. The HC emissions increase with increasing in load. HC emissions decrease with increasing biodiesel percentage in the blend

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