Comparative Study on Performance of Straight Vegetable Oil and its FAME with respect to Common Diesel Fuel in Compression Ignition Engine

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Abstract: A comparative study has been carried out on the performance of compression ignition engine (CI) using common diesel fuel (CDF) blended with both refined soybean (Glycin max) and sunflower (Helianthus annuus) oil as straight vegetable oil (SVO) as well as their corresponding fatty acid methyl esters (FAME) with respect to CDF. Low cost methyl esters of vegetable oil were prepared using own patented technique where ultrasonic energy has been found to be beneficial. SVOs and corresponding FAMEs were blended with CDF separately at different proportion to act as fuel for research CI engine. Both engine performance and fuel combustion characteristics were evaluated from the present study at different loads with varying compression ratios. Graphical relationships of load (kg) in engine against various engine performance parameters such as: brake thermal efficiency (%), brake specific fuel consumption ((kg/kWh), brake mean effective pressure (bar), cumulative heat release (kJ) and emission characteristics have been plotted for each set of fuels with respect to CDF. The relationship developed identifies the advantages of using blended FAME prepared with the patented processes over their corresponding SVO and CDF in the CI engine.

Keywords: CI engine, Straight vegetable oil, FAME, Blended fuel, CDF

1. Introduction

The Energy and Environment will determine the fate of mankind in this century. The alarming rise of energy demand in the growing civilization is mainly met by fast depleting fossil fuel. The transport sector is the highest consumer of fossil fuel as common diesel fuel (CDF) requiring more than 29 per cent of its total consumption. Due to its high sulphur, aromatics and nitrogen content the CDF is considered to be the single largest polluter of the environment. As the agro based vegetable oil is carbon neutral of renewable energy source and free of sulphur as well as aromatics, it behaves environmental friendly biofuel. However, the straight vegetable oil (SVO) fails to act as ideal fuel primarily because of its high viscosity and poor atomization in fuel spray for its low volatility. It often leads to deposit and chocking of injector, combustion chamber and valves [1]. These hurdles are reduced to minimum by subjecting the vegetable oil mainly to the process of dispersion or Transesterification. Dispersion of SVO with common diesel fuel, also called blending is to provide a simple as well as cheap fuel for the CI engine.

1.1. Transesterification of vegetable oil and animal fats

Chemically, vegetable oil and animal fat are triglycerides in which one glycerol molecule is esterified with three molecules of different long chain fatty acids [2] each with 15-20 carbon numbers raising its average molecular mass over 800amu. This reason might be responsible to inherit high kinematic viscosity and lowers vapour pressure. The process adopted to transfer one heavier ester to three lighter esters (esters of three different fatty acids with lower aliphatic alcohols) is called Transesterification reaction. Combination of these different

FAME molecules with viscosity and carbon equivalent to CDF is able to replace fossil fuel as ideal fuel for CI engine, popularly called Biodiesel [3].

1.2. Fuel for the performance of Unmodified Compression Ignition Engine:

CDF is a mixture of hydrocarbon molecules with varying carbon chain of C_6 - C_{18} . The presence of smaller hydrocarbon chains with their high vapour pressure contributes to lower flash point of CDF to below 60°C which is ideal to start ignition under common compression. While FAME of particular fatty acid (biodiesel), a compound of fixed carbon number 15-18 acquires very low volatility is contributing high flash point ($>130^{\circ}\text{C}$) thus fails to get atomized in unmodified CI engine for early ignition. The hurdle is minimized by blending the biodiesel with CDF. A system known as the “B” factor is generally used to state the amount of biodiesel in CDF fuel mixture such as: 100% biodiesel is referred to as B100, while 20% biodiesel when mixed with 80% CDF is labeled B20 and so on. Obviously, the higher the percentage of biodiesel, the more eco-friendly is the fuel. Blended fuel up to B20 has successfully used in unmodified engines [4-7].

The aim of the article is to evaluate the acceptability of biodiesel prepared at reduced parameters by employing ultrasonication at various steps of the composite process such as the purification of crude vegetable oil, transesterification, separation of FAME from the reaction mixture and purification of crude FAME to make ASTM standard. An unmodified CI engine setup with variable compression ratio is adopted to study the engine performance and combustion of fuel for different fuel and evaluate brake power (kW), brake thermal efficiency (%), brake specific fuel consumption (kJ/kW-hr), brake mean effective pressure (bar), of engine against various engine loads (especially lower loads). A comparative statement would be prepared for each set of four combinations of SVO-CDF, their corresponding FAME-CDF in different ration against CDF to find out the most acceptable fuel for the CI engine.

2. Methodology

2.1. Materials

Refined Soybean oil of Nature fresh (India) and refined sunflower oil of Fortune brand (India) are collected from retail outlets and analysed to evaluate the free fatty acid (FFA), phospholipids and moisture content following ASTM 6751 method. Refined varieties of soybean oil and sunflower oil were found to contain such impurities within permissible limit to prepare biodiesel. Fatty acid methyl esters (FAME) of refined soybean oil and sunflower oils were prepared following in house patented process [8]. CDF collected found to have the acceptable range of fuel specification for CI engine [9]. Low energetic (1kW) Ultrasonic Processor Sonapros PR-1000 model (M/s Oscar Pvt. Ltd., Mumbai, India) was used for transesterification at various steps of the composite process.

2.2. Preparation of fuels for the comparative studies

Four sets each of both soybean oil and sunflower oil were prepared by blending 5% and 10% of the two SVOs and their corresponding FAMEs with rest quantity of common diesel fuel (CDF). Samples of soybean and sunflower oil blends (as shown in **Table 1**) were taken to evaluate the fuel properties in CI engine and make a comparative study with 100% CDF. Physical properties of this fuel were measured following ASTM 6751 method. Results within a range for both the fuels were reported in **Table 2**.

Table 1. Set of fuels for the comparative study in CI engine

Vegetable oil	CDF %	Percentage of SVO in blended common diesel fuel		Percentage of FAME in blended common diesel fuel	
		05% SVO	10% SVO	05% FAME	10% FAME
Soybean oil	100	SVO SB B05	SVO SB B10	FAME SB B05	FAME SB B10
Sunflower oil	100	SVO SF B05	SVO SF B10	FAME SF B05	FAME SF B10

Table 2. Physical properties for Common Diesel Fuel (CDF), SVOs (soybean and sunflower oil) and corresponding methyl esters (Biodiesel)

Sl. No.	Properties of Fuel	CDF	Vegetable oil	Biodiesel
01	Kinematic Viscosity(cSt) at 40 ⁰ C	2.5-5.5	35-65	5-8
02	Gross caloric value (kJ/kg)	42000	39,000-48,000	30000-39477
03	Density at 20 ⁰ C, kg/m ³	0.835	0.825-0.894	0.865-0.877
04	Flash Point (⁰ C)	38	>200	130-175
05	Cetane Number	45	40-50	40-58

A Research engine, make Kirloskar type, 1 cylinder, 4 strokes diesel, water cooled with variable compression ratio (VCR) of M/s Apex Innovation Pvt. Ltd., Sangril, Maharashtra, India was procured to study the CI engine performance. The engine is of constant speed (1500 rpm) type having maximum load 12kg with a capacity of 661.1cm³. The engine performance with various sets of fuels (shown in Table 1) was studied at lower loads of 2, 4, 6 and 8 kg under different compression ratios (16, 17 &18). The data acquisition system was used to create pressure-crank angle plot for both diesel and cylinder pressure. Also the pressure-volume plot was obtained to study the power generated by the engine at various compression ratios. Brake Specific Fuel Consumption and Brake Thermal Efficiency were obtained from load and fuel consumed etc. The engine Brake Power was measured by Eddy current dynamometer. Air inlet flow was measured using pressure transmitter and water flow by rotameter. Exhaust emission analysis was done with a multi gas analyser, M/s Netel (India) Ltd. under varying operating conditions.

3. Results and Discussion

3.1. Brake Specific Fuel Consumption (BSFC) of Soybean and Sunflower oil

Results on BSFC (i.e. the ratio of fuel mass flow of an engine to its output power) for all four sets of both soybean and sunflower fuel blends and CDF with engine loads of 2 to 8 kg against each compression ratio (16-18) are drawn but only CR 18 is shown in **Fig. 1** and **Fig. 2** respectively. It is observed that the BSFC(kg/kWh) is highest for B05 of both FAMEs when the engine load is only 2kg and CR 16, which further decreases linearly at higher CRs (17 and 18). BSFC for all fuels decrease uniformly when engine load increases to 8 kg because combustion improves due to increases in pressure and temperature.

Fig.1. BSFC (kg/kWh) vs variable engine loads (kg) plot at CR=18 for four fuel blends of soybean oil and CDF

Fig. 2. BSFC (kg/kWh) vs variable engine loads (kg) plot at CR=18 for four fuel blends of sunflower oil and CDF

On comparing the results of **Fig. 1** (soybean oil) with **Fig. 2** (sunflower oil) it is observed that BSFC values for both fuel sets are almost identical at engine load 8 kg. Values for B10 of both fuel blends are less than that of B05 but almost equal to CDF. With low gross calorific values of biodiesel, it is expected to have high BSFC for the B10 blended fuel. The presence of easily combustible linoleic and oleic acids with unconjugated and unsaturated fatty acids in respective FAME probably balanced such negative effect.

3.2. Brake mean effective pressure for soybean oil and sunflower oil

Brake mean effective power (BMEP) is the measure of the useful power output of the engine and may be represented by the equation (1).

Fig. 3. BMEP (bar) vs variable engine load s(kg) plot at CR=18 for four fuel blends of soybean oil and CDF

Fig. 4. BMEP (bar) vs variable engine loads (kg) at CR=18 plot at CR=18 for four fuel blends of sunflower oil and CDF

$$BMEP = 2\pi T n_c / V_d \quad (1)$$

where T = torque(Nm), n_c = number of revolution per cycle and for 4 stroke engine it is 2, and V_d = displacement in volume.

Experimental results of brake mean effective pressure for each fuel of soybean set are drawn against engine load of 2-8 kg for each CR values of 16-18. The power outputs for all fuels are increasing with rise of engine load but shows same trend for all compression ratios. The BMEP comparison plots with respect to CDF at CR 18 for soybean and sunflower fuel blends are shown in **Fig. 3 & 4** respectively. BMEP is found to be much high for B10 of both soybean-FAME and sunflower-FAME at compression ratio 18 with 8 kg engine load.

3.3. Brake thermal efficiency

The variation of brake thermal efficiency with engine load of 2-8 kg at compression ratio 18 for both soybean and sunflower fuel sets are presented in **Fig. 5** and **6** respectively. It increases with increase in load under all compression ratios for both the fuel systems along with that of CDF. This may be due to the reduction in heat loss and increase in power with increase in load. The brake thermal efficiency for B05 and B10 for both fuel systems are less than that of CDF. This lower brake thermal efficiency obtained could be attributed to lower GCV values of biofuels. Hence it may be concluded that the performance of the unmodified CI engine with biodiesel prepared [10] with less operating parameter is comparable with conventional common diesel fuel.

Fig. 5. BTHE (%) vs variable engine loads (kg) plot at CR-18 for four fuel blends of soybean oil and CDF

Fig. 6. BTHE (%) vs variable engine loads (kg) plot at CR-18 for four fuel blends of sunflower oil and CDF

3.4. Brake power

The power output for all fuels increase with rise of engine load but shows same trend for all compression ratio at higher loads. **Fig. 7** shows FAMEs give slightly better power with respect to SVOs.

Fig.7. Brake power (kW) vs various engine loads (kg) plot at CR-18 for SVO and FAME (Biodiesel 10) fuel blends of soybean and sunflower oil with respect to CDF

3.5. Cumulative Heat Release

From **Fig. 8** it is clear that heat release of CDF is more than soybean SB B10 and slightly lower than sunflower SF B10 since biodiesels have less calorific value whereas out of these two biodiesels sunflower derivative is easily combustible than that of soybean.

Fig.8. Cumulative heat Release (kJ) vs Crank angle (degrees) at 8kg engine load with CR-18 for CDF, soybean B10 and Sunflower B10

3.6. Exhaust emission characteristics

Exhaust emission profile for Common Diesel Fuel (CDF), and methyl esters (Biodiesel) of soybean and sunflower (B10) at CR 18 were studied and the results are given in Table 3. Combustion efficiency of these fuels under study increases with rise in engine load. It is seen that the combustion efficiency of B10 of both soybean and sunflower FAME are much better than that of CDF. SB B10 FAME is found to be more efficient fuel than SF B10. However, NO_x emission increases at higher loads due to rise in temperature in the compressor.

Table 3. Exhaust emission characteristics for Common Diesel Fuel (CDF), and methyl esters (Biodiesel) of soybean and sunflower (B10) at CR 18

Engine Load (kg)	CDF			Soybean (SB B10)			Sunflower (SF B10)		
	% CO ₂	% O ₂	NO _x (ppm)	% CO ₂	% O ₂	NO _x (ppm)	% CO ₂	% O ₂	NO _x (ppm)
2	1.7	18.2	72	2.9	16.1	144	2.4	17.2	106
4	2.0	17.5	116	3.5	15.6	235	2.8	16.6	162
6	2.6	16.8	161	3.9	15.0	290	3.1	16.1	226
8	2.9	16.2	208	4.6	14.0	321	3.4	15.7	269

4. Conclusion

The fatty acid methyl esters prepared from soybean and sunflower oil with own patented composite process employing ultrasonication has been successfully tested in unmodified compression ignition engine. Amongst various engine performance data evaluated, the BSFC parameters although suggest biofuel to be inefficient than CDF, however, considering the exhaust emission factor biofuel is acceptable. SVOs possess better performance, but taking the viscosity into account FAMES look better fuel from the present study. From BMEP studies biofuels show better performance than CDF. With reference to the studies on BTHE, brake power and emission characteristics B10 soybean-FAME fuel is most acceptable fuel amongst the all studied nine fuels including CDF for the CI engine with lower load up to 8 kg at compression ratio 18. Hence it may be recommended as renewable fuel and prominent replacement for CDF in unmodified compression ignition engine.

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