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EMISSIONS AND PERFORMANCE STUDY WITH SUNFLOWER METHYL ESTER AS DIESEL ENGINE FUEL

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ABSTRACT

There is a need for innovative thinking to stabilize the fuel consumption pattern as well as depletion rate of crude oil and natural gas resources. Also, there are concerns ranging from environmental degradation as a result of tremendous noxious tail pipe emissions (CO, SO_x, NO_x, HC, SPM, aromatic compounds etc) to global warming due to emission of GHG (i.e. CO_2) from petrol & diesel driven vehicles. Thus there are strong incentives to adopt renewable energy in the form of biofuels-alcohols and biodiesels both, in transport sector in the service of the nation. In this research study 'Methyl ester of Sunflower oil' which is also popularly known as biodiesel, was prepared by employing transesterification of sunflower vegetable oil with methanol and catalyst KOH. Various blends of Sunflower methyl ester (SFME) were tested in 4-S, C.I. engine and engine performance results obtained were compared with data obtained from pure diesel (HSD). Study reported 1.5 to 4% increase in brake thermal efficiency (BTE) with SFME blends. The brake power (BP) values were comparable to those obtained from HSD. With biodiesel blends, significant reduction in emissions of hydrocarbons as well as smoke/ (particulates) was noticed. NO_x emissions with SFME blends were observed to be somewhat higher as compared to diesel. Since biodiesel is sulphur free fuel, no SO_x emissions were produced.

Keywords: fuel, engine, biodiesel, sunflower methyl ester, vegetable oil, performance, emissions.

INTRODUCTION

World's crude oil and natural gas reserves are finite and that of India are small (Table-1). India imports 65-75% of its petroleum fuel needs from Middle-East and other OPEC countries. Therefore, India has to depend upon foreign/imported petroleum fuels for the ever-increasing fuel supply needs. Besides, these supplies are subjected to unpredictable price hike and volatile interruptions and also are a colossal burden on India's economy.

Table-1. Oil and natural gas reserves of India.

Year	**Oil** (MMT)	**Natural gas** (BCM)
2000-2001	765	765
2005-06	765-780 [No major discoveries reported]; Cairn (Rajasthan)	850-860 [with new discoveries (Cairn in Rajasthan, and off the coast of Godawari basin in bay of Bengal) reserves increase by about 2% each year
Reserve to Production ratio (R/P ratio)	10-12 years	30-34 years

The adverse effects of fossil fuel based emissions on the environment and public health are well-known. Thus vegetable oils, used cooking oils and their methyl esters are excellent substitutes that are environmentally sustainable and provide energy security for the future Indian energy requirements [2,4,6,9,12,13,17,24].

Indian reserves and indigenous production

India's reserves of crude oil and natural gas are miniscule as compared with the rest of the world and some oil and gas rich countries (Middle East, Central Asia, Russia, North America, etc.). Therefore, indigenous oil and gas production is mostly consumed in automobiles and Indian transport sector.

Automotive engines in India

Of these, 7.4% vehicles were exported to other countries, remaining 7.838 million were sold in domestic market (this figure does not include vehicles imported from other countries). Of all the vehicles manufactured, an overwhelming 81% were 2-wheelers (scooter, m/cycles, and mopeds) and 3-wheelers. Share of 2-wheelers in overall pie was 76.5%, with 3-wheelers taking a marginal 4.5 % share only. Number of passenger vehicles (cars, utility vehicles, MPV) stood at 1.21 million with a 14.5% share, while LCV, MCV and HCV clocked 4.5%. This does not include about 7 million diesel gensets being used in agriculture sector and related work.

Similarly, in the year 2006-07, India produced 1.4 million vehicles whereas automotive vehicles produced by China and USA stood at 5 million and 10 million, respectively. It is estimated that by the year 2025 AD, the number of vehicles on Indian roads shall be more than 1 billion which will further aggravate the scenario in terms of fuel consumption and environmental pollution. India's diesel consumption is seven times that of gasoline and hence it can be safely stated that India is a diesel dominated economy. Therefore, it is all the more essential that biodiesel which is known for its clean burning characteristics, be adopted urgently. Besides, it can be produced indigenously from various sources such as tree-borne oilseeds.

REVIEW OF LITERATURE

Use of vegetable oils in diesel engines is not a new development; rather it is as old as the diesel engine itself. Dr Rudolph diesel (1858-1913), the inventor of **c**ompression ignition engine (1892 AD) used peanut oil as fuel to run one of the engines in Paris exposition in 1900 AD.

Biodiesel is new, alternate and green fuel which has the potential to replace petroleum diesel in near future. Biodiesel also known as 'vegetable oil methyl esters (VOME)', can help reduce our dependence on conventional/non-renewable fossil fuels as well as improve environment quality in metro cities, urban and rural sectors by reducing obnoxious automotive/vehicular emissions [2,3,6,10,11,13,17]. These biofuels which can be derived from vegetable oils- both edible and non-edible grade, waste vegetable oils (WVO) as well as animal fat offer many novel advantages that make BD in general an attractive proposition for unaltered C.I. engines. Some of the exceptional highlights of the biodiesel fuels are as follows:

- 100% green, renewable and biodegradable [5,6,13,14,24, 25];
- Superior cetane number of greater than 50 (range 49-54) as compared to petro-diesel [6,7,20];
- Relatively high flash point of g.t.150 ^{0}C which makes it safer to transport and handle [25];
- Biodiesel does not contain any aromatic compounds [6];
- Transesterification process employed to manufacture BD yields byproduct 'glycerol' which has many applications in industry, pharmaceuticals, cosmetics and food industries [3, 6,21];
- Biodiesels contain 10-11(wt)%. Oxygen which helps in better combustion of BD fuels in blended form or neat, in I.C. engines (as compared to diesel fuel which has no oxygen content) [6,21];
- In the absence of Sulphur, catalytic converter technology compliant with BS-III and BS-IV can be effectively used [11,24,25];

Gasoline (S content, ppm)		**Diesel** (S content, ppm)	
Year 2005	Year 2010	Year 2005	Year 2010
150 BS III	50 BS IV	350 BS III	50 BSIV

- Biofuels in general and biodiesels (methyl/ethyl/butyl esters vegetable oils) in particular, are clean burning fuels which are 100% carbon neutral fuels which provide energy security and promote sustainable development [2,6,24].

These above-said merits make biodiesel fuels a very attractive and benign alternative in comparison to petroleum based diesel with applications in railway locomotives, stationary agri-gensets, road transport such as long route trucks, city garbage trucks and school bus fleet, etc. [21,25].

Types of oilseeds

These vegetable oil based ester fuels can be derived from a number of edible, non-edible grade oil sources as described below:

Edible grade vegetable oils [2,4,5,6,8,11,14,16,17,21,22]

Such oils are used to produce biodiesel through transesterification and supercritical fluid (SCF) methods in various countries of the European Union, USA, Canada, Australia etc. However, in many countries of Asia, it won't be appropriate to use these for fuel as these are in short supply and highly in demand for food as well as cooking applications. These are: Peanut, Safflower, Palm, Soybean, Sesame, Rapeseed/Canola, Mustard, Sunflower, Linseed, Coconut, etc.

Non-edible grade vegetable oils [1,5,6,13,15,16,19,22]

A number of tree-borne vegetable oilseeds such as Jatropha curcas, Karanjia (Pongamia glabra), Pongamia pinnata, Mahua, Neem, Pine seeds, Tung seeds, Nagchampa, Kusum, Ark (Calotropis gigantia), Castor, Rubber, etc are ideally suited for production of biodiesel fuel for application in compression ignition engines. These are considered less energy intensive and more economical for biodiesel applications.

Waste cooking oils [6,21,25]

Waste oils from restaurants, hotels, hospital cafeterias etc in metro cities and urban areas/towns are, presently, being disposed of very carelessly and irresponsibly. Their use in diesel engines in suitable form such as transesterified oils can give us in Asia in general and South Asia in particular a never-ending source of biodiesel. Examples are used cooking oils, used frying oils, greases etc. In metropolitan cities of Asia where such waste oils are available in abundance, it will be very economical to produce biodiesel from these oils for the simple reason that these are available almost free of cost.

Table-2. Oilseed production in the World and India (1995-1996).

Oilseed type	**Production** (MMT)	
	World	India
Groundnut	19.3	5.12
Linseed	2.6	0.30
Sunflower	25.2	1.40
Soybean	123.2	4.50
Sesame	2.5	0.90

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PRODUCTION OF SUNFLOWER BIODIESEL

Transesterification

The most common method to produce BD is using 'tranesterification' which refers to a catalyzed chemical reaction involving vegetable oil-edible or non-edible origin, and an alcohol to yield fatty acid alkyl esters and glycerol i.e. crude glycerine [2,7,20].

After transesterification, viscosity of vegetable oil methyl esters (VOME) is reduced by 85-90% of the original oil value. VOME, also called fatty acid methyl esters (FAME), are therefore products of transesterification of vegetable oils and fats with methyl alcohol (MeOH) in the presence of a suitable catalyst. The process of 'transesterification' is sometimes named 'methanolysis or alcoholysis'. During the reaction, high viscosity vegetable oil reacts with methanol (or ethanol/ butanol, as the case may be) in the presence of a catalyst (NaOH or KOH) to form an ester by replacing glycerol of triglycerides with a short chain alcohol.

[Triglycerides (veg oil) + Methanol = Veg oil methyl ester + Glycerol]
Methanol/methyl alcohol is preferred for transesterification as it provides better separation of methyl ester and crude glycerin thus facilitating the post-reaction steps of obtaining biodiesel.

The stoichiometry of transesterification reaction requires 3 moles of alcohol per mole of triglyceride to yield 3 moles of fatty esters and I mole of glycerol (crude glycerine). The reaction is reversible in nature and therefore, it is necessary to use excess of alcohol to favorably shift the reaction to the product side. When 2 to 3 time's excess methanol is used, the reaction rate is the highest.
Taking reactants in the ratio as follows:

Methanol: Refined oil :: 6 : 1,
Wt of catalyst/ KOH = 0.5 to 1% of wt of oil.,
Temp of reactor vessel maintained at 65 ^{0}C
and, the contents stirred to expedite the process.

The yield was noted to be more than 99.7 (vol) %; i.e. for every one litre of refined sunflower oil, the yield of BD was 997.4 ml. Upon transesterification, colour of refined sunflower oil changed from deep transparent yellow to light pale yellow (SFME).

Properties of blends

Properties of various fuels used were determined and are presented in Table-3:

Table-3. Physico-chemical characteristics of sunflower biodiesel blends.

Fuel type	C.V. (MJ/kg)	Kin Visc. cSt @40 ^{0}C	Density @ 15^{0}C (kg/m^3)	Flash Point (^{0}C)	Fire point (^{0}C)	Cloud point (^{0}C)	Pour point (^{0}C)
B0/D100	43.50	2.6803	0.846	54	64	-1	-6
B25/D75	41.925	3.184	0.8540	81	89.5		
B30/D70	41.610	3.284	0.8556	94.5	101.5		
B100/D0	37.20	4.693	0.8780	191	197	+1	

B100 : 100% SFMC (pure biodiesel); D100 : Pure diesel fuel; B25, B30 : blends of biodiesel and petro-diesel.

EXPERIMENTAL SET-UP

The study was performed on 4-stroke, single cylinder, DI diesel engine [model DAF-8], manufactured by Kirloskar Oil Engines Ltd.

Make: Kirloskar Oil Engines Ltd, Pune (Maharashtra)
Model: DAF -8
Type: Single acting, totally enclosed, high speed, 4 stroke, vertical, C.I. engine
Rated speed: 1500 RPM
Rated brake power: 5.9/8 (kW/BHP)
Brake mean effective pressure: 6.15 (kg/ cm^2)

RESULTS AND DISCUSSIONS

Engine Performance

Brake thermal efficiency vs. (%) Load

Brake thermal efficiency (BTE) vs. (%) Load graph represents very similar trends for all the fuels i.e. HSD and B25 & B30-fuels with biodiesel as blended component (Figure-1). At part loads, diesel fuel thermal efficiency (BTE) is superior however at peak loads (near full load condition), BTE of SFME blends B25 and B30 is better by 1.5% to 4% points. At peak loads, engine combustion of biodiesel blended fuels is better due to better oxygen availability and more mass of fuel injected for equal load conditions.

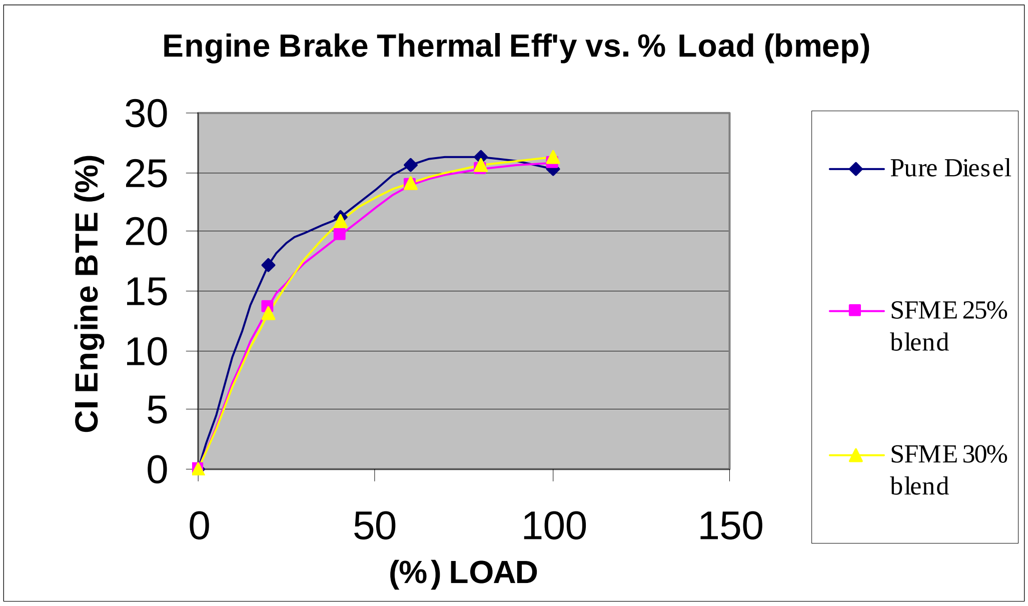

Figure-1. Trend of engine brake thermal efficiency at different load conditions.

Brake power (BP) vs. (%) **Load**

Brake power is the useful energy at the output shaft. The BP vs. (%) Load plot shows that as the percentage load increases from 0%, 20%, 40% and up to 100% i.e. full load, BP increases for all the fuels used in the engine (Figure-2).

At small and peak loads, there is a gain of 2% and 0.75% respectively. However, at medium loads, there is a loss of about 3 to 4%. The reason is that at medium loads due to higher C.V. and normal rates of heat release (ROHR), power generated by generated by diesel is better whereas at peak loads, BD fuels (B25 and B30) exhibit better combustion characteristics and perform better.

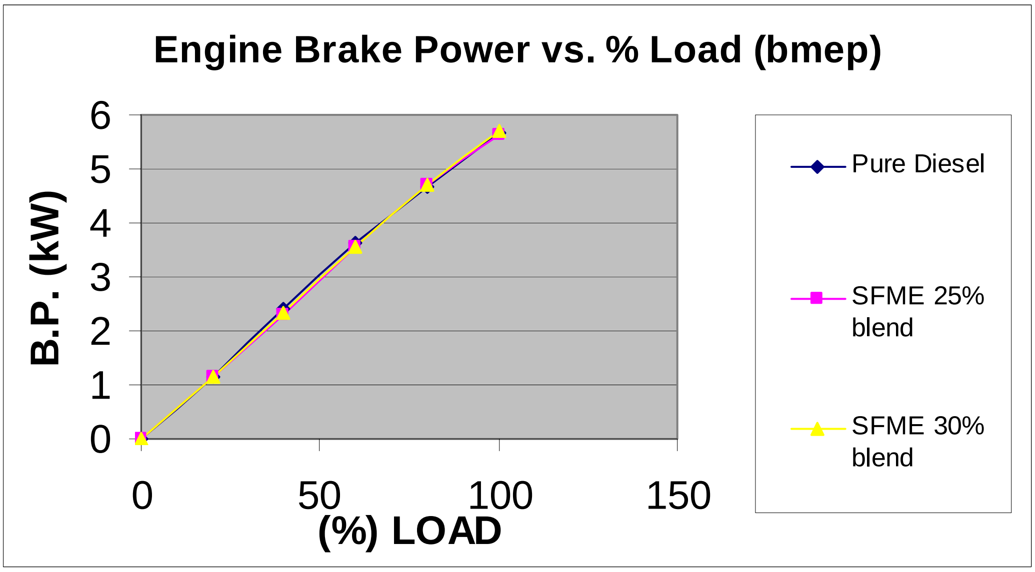

Figure-2. Trend of engine brake power at different load conditions.

Engine emissions

Unburnt hydrocarbons (UBHC) vs. (%) **Load**

UBHC vs. (%) Load graph indicates UBHC emissions for all blends of sunflower methyl ester (SFME) are consistently on lower side as compared to diesel (Figure-3). The results are in compliance with findings of other research studies. With biodiesel blends, there is less of wall quenching and bulk quenching and hence less hydrocarbon emissions.

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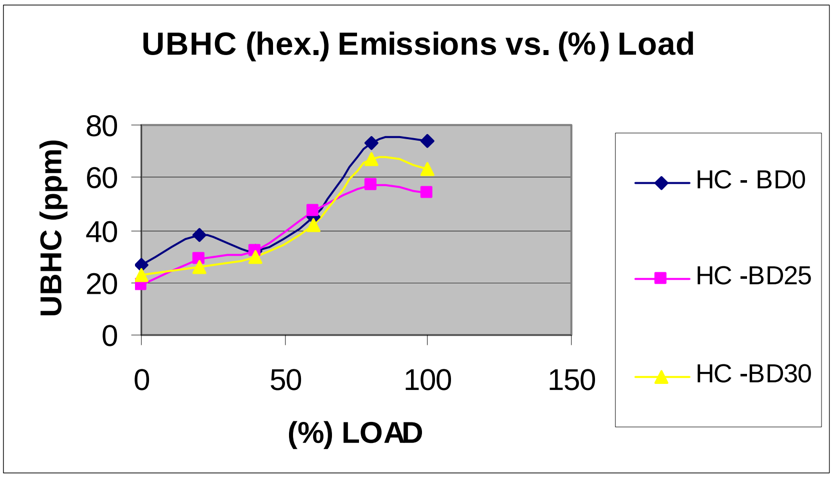

Figure-3. Trend of unburnt hydrocarbons at different load conditions.

Oxides of nitrogen (NO_x) vs. (%) **Load**

NO_x formation is heavily influenced by prevailing temperatures in combustion process and oxygen availability. Generally in diesel engine, excess air is present (with N_2 and O_2 making up 78.7% and 21.3% by volume).

NOx formation is higher in SFME blended fuels due to higher temperatures during combustion in diffusion burning phase and better access to oxygen. Biodiesel blends contain 2.6-3.1(wt) % oxygen, have more density and more amount of fuel (m_f) is injected. Mixture preparation is delayed but good, peak temperatures are higher in diffusion burning phase which means slightly more of NOx formed with biodiesel blends (Figure-4).

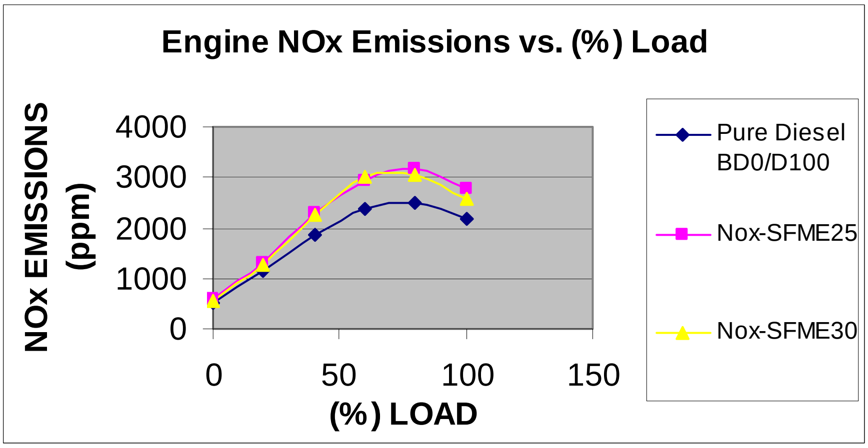

Figure-4. Trend of oxides of nitrogen emissions at different load conditions.

CONCLUSIONS

- Combustion of sunflower methyl ester (SFME) blended fuels-also known as biodiesel fuel, in DI diesel engines is trouble free and engine operation smooth.
- Performance characteristics of sunflower methyl ester (SFME) blended fuels are similar with higher BTE and BP values at full/peak load conditions.
- UBHC emissions are less as compared to diesel (HSD) but NOx emissions are higher. These results are on expected lines.
- Sunflower methyl ester (SFME) fuel prepared via transesterification is of superior quality.

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