Experimental Investigations of Performance Parameters on Direct Injection Diesel Engine with Alternative Fuels

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Abstract : Vegetable oils are a Promising substitute for diesel as their cetane number is close to that of diesel fuel. In the present study used cooking oil as well as its biodiesel was used as a total substitute on a 3.68kW, 1500RPM diesel engine at the recommended injection timing and pressures (27^{0}bTDC and 190 bar); and its performance parameters were analyzed in comparison to neat diesel operation. Though vegetable oils are comparable with diesel fuel, they have high viscosity and low volatility. These properties can be altered to some extent by converting vegetable oil to biodiesel by the process known as esterification. Biodiesel have high cetane number, low viscosity and contain presence of oxygen in its molecular composition causing good combustion in diesel engine. Peak brake thermal efficiency was higher for diesel fuel, followed by biodiesel and crude waste fried oil. Engine with biodiesel operation at full load decreased peak Brake thermal efficiency by 4%, increased Brake specific energy consumption by 5% , Exhaust gas temperature was found to increase by 13%, decreased Volumetric efficiency by 3%.

***IndexTerms* – Diesel engine, Direct Injection, Cooking oil, Injection Pressure.**

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1. INTRODUCTION

As conventional fuels are depleting at a faster rate and also the rise in number of vehicles using these fuels are contributing to more and more pollution levels, the alternative fuel research has gained prominence. Diesel is being used in Transport as well as in agricultural sectors. Hence substitute for diesel fuel will help mankind to a great extent. Suitable substitutes for conventional fuels will result in foreign exchange savings also, as our crude oil requirements are mostly met by imports.. The most promising substitutes for petroleum fuels are alcohols and vegetable oils. However, alcohols have low cetane number and hence engine modification is necessary if they are to be used as fuels in diesel engines. That too, most of the alcohol produced in India is diverted for Petro–Chemical industries. On the other hand, vegetable oils have high cetane number, comparable to diesel fuel.

The important substitutes for diesel fuel are alcohols (methanol and ethanol) and vegetable oils, which are renewable in nature. When alcohol is substituted for diesel fuel, engine modification is to be carried out to overcome the difficulty of low cetane number. Vegetable oils, both edible and non-edible, have high cetane number (in the range of 40—45), energy content comparable to diesel. Used cooking oil samples were collected from different hotels, restaurants (instead of throwing waste), and used for experimentation purpose in the present study.

Several researchers experimented the use of vegetable oils as fuel on conventional engines (CE) and reported that the performance was poor, citing the problems of high viscosity, low volatility and their polyunsaturated character causing the problems of piston ring sticking, injector and combustion chamber deposits, fuel system deposits, reduced power, reduced fuel economy and increased exhaust emissions [1-4].

The problem of high viscosity of waste fried cooking oil can be reduced to some extent by chemically converting (esterified) it into biodiesel which is renewable and biodegradable in nature. Several researchers carried out experiments with biodiesel on conventional diesel engines and they reported performance improved marginally, particulate emissions reduced and increased nitrogen oxide levels [5-9].

In this study instead of diesel fuel the used waste fried cooking oil as well as its biodiesel was tried as a total substitute in conventional engine and its performance was compared with that of neat diesel in conventional engine.

2. MATERIALS AND METHODOLOGY

Figure.1 represents the schematic diagram of Experimental setup employed for the investigations with neat diesel. The engine employed was of kirloskar make, Four-stroke, vertical, single-cylinder, constant speed, water- cooled diesel engine with a bore of 80 mm and a stroke of 110 mm. The rated output was 3.68 kW at a speed of 1500 rpm and the compression ratio is 16:1. The manufacturer has recommended an injection timing of 27^{0}bTDC at an injector opening pressure of 190 bar. The injector used has three holes of 0.25 mm size. The combustion chamber was direct injection type without any special arrangement for swirling motion of air. The brake power of the engine was measured by connecting it to an electrical dynamometer. Fuel consumption was determined using burette method and air-box method was employed for measuring air consumption. The various components of Fig.1 were listed below.

1.Engine, 2.Electical Dynamometer, 3.Load Box, 4.Orifice meter, 5.U-tube water manometer, 6.Air box, 7.Diesel tank, 8 Three-way valve, 9.Burette, 10. Exhaust gas temperature indicator, 11.AVL Smoke meter, 12.Netel Chromatograph NO_x Analyzer, 13.Outlet jacket water temperature indicator, 14. Outlet jacket water flow meter, 15.Piezo-electric pressure transducer, 16.Console, 17.TDC encoder, 18.Pentium Personal Computer and 19. Printer.

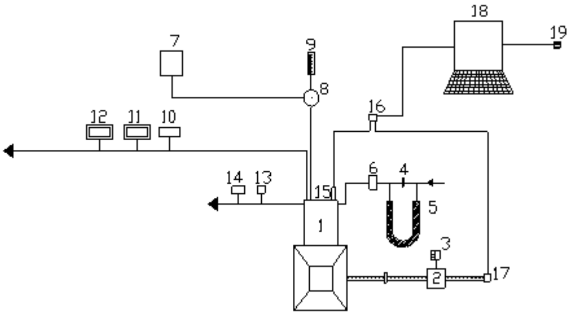

Fig.1 Experimental set-up for neat diesel operation

Water cooling system was provided for this naturally aspirated engine, and outlet temperature of water was maintained at 80^0C by flow rate adjustment. Pressure feed lubrication system was provided for engine oil.

2.1 WASTE FRIED COOKING OIL and ITS BIODIESEL OPERATION ON DIESEL ENGINE.

The experiment involves usage of waste fried cooking oil collected from various restaurants and canteens. In general the high viscosity of crude waste fried cooking oil was the major drawback to employ it directly as fuel in a diesel engine. Instead of biodiesel if crude vegetable oils and animal fats were employed as fuels in diesel engines, they creates operational problems such as piston ring sticking, formation of deposits in injection, fuel system and combustion chambers etc. These vegetable oils also cause reduced power, fuel economy and increase in exhaust emissions. All these effects may not be felt immediately but may occur over a period of time which in turn depends upon usage of the engine and design of fuel system. To convert waste fried cooking oil into biodiesel a process known as esterification was employed. The methyl ester was developed by chemical reaction of waste fried cooking oil with methanol in the presence of potassium hydroxide catalyst. A two stage esterification process was employed to convert crude waste fried cooking oil into biodiesel. In a duration of 60 min and at a temperature of 328K the initial phase(acid catalyzed) of the process was to decrease the free fatty acids content in waste fried cooking oil by esterification with methanol (99 % pure) and H_2SO_4 catalyst(98 % pure). The molar ratio of methanol to waste cooking oil was 1:9 and 0.5 % catalyst (w/w). In the final stage (alkali catalysed), the waste cooking oil triglyceride portion reacts with methanol and sodium hydroxide 99 % pure which was used as base catalyst in the reaction time of one hour at 338 K, to form glycerine and biodiesel (methyl ester). It was purified by air bubbling with water washing process to delete the unreacted methoxide present. Table.1 gives the properties of crude waste fried cooking oil along with its biodiesel obtained from M/s Indian Institute of Chemical Technology, Hyderabad.

Table-1
Properties of the test fuels

Property	Units	Diesel	Crude Vegetable oil	Biodiesel	ASTM D 6751-02
Carbon chain	--	C_8-C_{28}	C_{12}-C_{20}	C_{16}-C_{24}	C_{12}-C_{22}
Cetane Number		55	45	55	48-70
Density	gm/cc	0.84	0.90	0.87	0.87-0.89
Bulk modulus @ 20Mpa	Mpa	1475	2050	1800	NA
Kinematic viscosity @ 40^oC	CSt	2.25	5.2	4.2	1.9-6.0
Sulfur	%	0.25	0.4	0.0	0.05
Oxygen	%	0.3	0.2	11	11
Air fuel ratio (stochiometric)	--	14.86	15.5	13.8	13.8
Lower calorific value	kJ/kg	42 000	37500	37000	37 518
Flash point (Open cup)	^{0}C	66	190	174	130
Molecular weight	--	226	290	261	292
Preheated temperature	^{0}C	--	95	60	--
Colour	--	Light yellow	Dark yellow	Yellowish orange	---

The test fuels tried in the experiment were neat diesel; crude waste fried cooking oil and its biodiesel (WFVOBD). The terms 'waste fried cooking oil' and 'waste fried vegetable oil' (WFVO) were used interchangeably in the present article

3. RESULTS AND DISCUSSION

Figure.2 represents the bar chart showing the variation of peak BTE with test fuels in conventional engine at recommended injector opening pressure of 190 bar. From Fig, it was noticed that engine with crude waste fried cooking oil operation decreased peak brake thermal efficiency by 14% at 27^0TDC when compared with neat diesel operation. This was due to lower calorific value and higher viscosity of crude waste fried cooking oil.

From the Fig.2, it was noticed that engine with biodiesel operation decreased peak brake thermal efficiency by 4% at 27^0bTDC when compared with neat diesel operation. This was due to lower calorific value and moderate viscosity of biodiesel.

This was also due to higher calorific value and cetane rating of diesel causing efficient combustion leading to produce higher peak brake thermal efficiency.

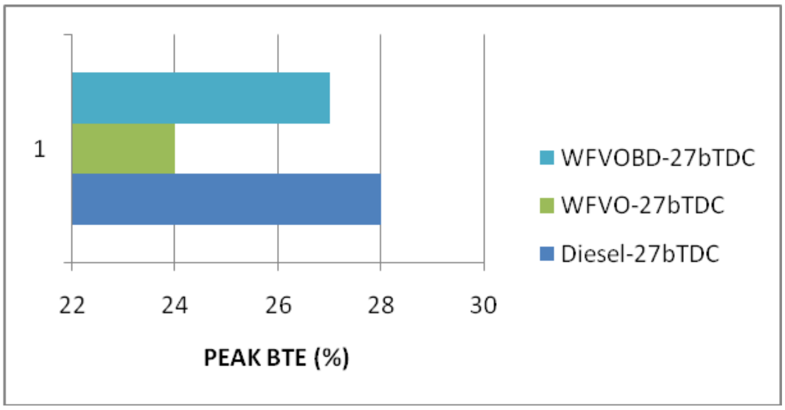

Fig.2 Bar chart showing the variation of Peak Brake Thermal Efficiency (BTE) with test fuels in engine

CE with biodiesel operation increased peak BTE by 8% at 27^0 bTDC when compared with crude waste fried cooking oil at 27^0bTDC. This was due to improved combustion with higher cetane value of biodiesel along with presence of oxygen in its composition.

Peak brake thermal efficiency was higher for diesel fuel, followed by biodiesel and crude waste fried oil. This was because of high calorific value and less viscous of diesel fuel. Similar observations were obtained by earlier studies [11].

Table 2

Data of peak Brake Thermal Efficiency (BTE) and BSEC at full load operation on CE

Injection Timing	Test Fuel	B.T.E	B.S.E.C(kw/kw)
27^0bTDC	DF	28	4.0
	WFVO	24	4.66
	WFVOBD	27	4.2

Generally brake specific fuel consumption(BSEC), is not used to compare the two different fuels, because their calorific value, density, chemical and physical parameters are different. Performance parameter, Brake Specific Energy Consumption (BSEC), is used to compare two different fuels by normalizing brake specific energy consumption, in terms of the energy consumed by the engine in producing 1 kW brake power. Lower the value of BSEC, the higher the performance of the engine. BSEC at full load of biodiesel is comparable to neat diesel fuel as shown in Table 2.

Figure.3 represents the bar chart showing the variation of brake specific energy consumption (BSEC) at full load operation with test fuels in conventional engine at recommended injection timings at an injector opening pressure of 190 bar. From the Fig it was noticed that CE with crude waste fried oil operation increased BSEC at full load by 17% at 27^0bTDC when compared with neat diesel operation. This was due to lower calorific value, higher viscosity, and poor volatility of crude waste fried oil leading to their poor atomization and combustion characteristics.

From the same figure, it was noticed that CE with biodiesel operation increased BSEC at full load by 5% at 27^obTDC when compared with neat diesel operation. Even though viscosity of biodiesel is slightly higher than that of neat diesel, inherent oxygen of the fuel molecules improves the combustion characteristics. This is an indication of relatively more complete combustion. Similar trends were noticed by earlier researchers [10, 12].

CE with biodiesel operation decreased BSEC at full load by 10% at 27^0bTDC when compared with crude vegetable oil. This was due to improved combustion with higher cetane value of biodiesel along with presence of oxygen in its composition.

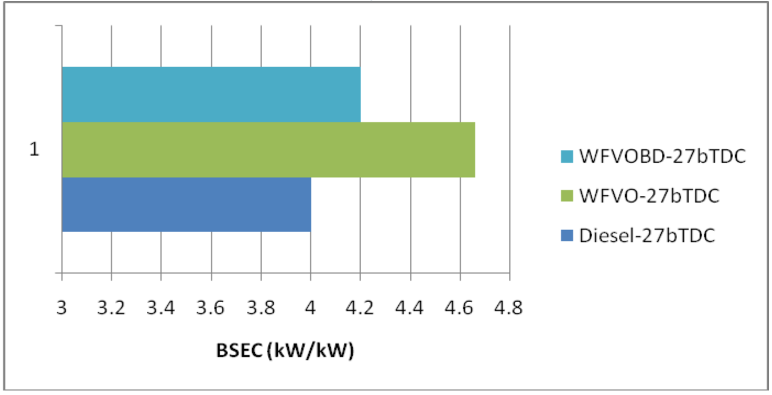

Fig.3 Bar chart showing the variation of Brake Specific Energy Consumption (BSEC) at full load operation

Esterification reduced the viscosity, molecular weight of the fuel and improved the cetane number, which reduced the ignition delay thus improving the performance of the engine, when compared to the crude waste fried oil.

Figure.4 represents the bar chart showing the variation of Exhaust Gas Temperature (EGT) at full load operation with test fuels in conventional engine at recommended injection timings at an injector opening pressure of 190 bar. From Fig.4, it was observed that CE with crude waste fried cooking oil operation increased EGT at full load by 22% at 27^0bTDC when compared with neat diesel operation. This was due to retarded ignition delay because of high duration of combustion of crude vegetable oil. Though the calorific value (or heat of combustion) of fossil diesel is more than those of test fuels, the density of these test fuels were higher therefore greater amount of heat was released in the combustion chamber leading to higher exhaust gas temperature.

From the same fig, it was noticed that CE with biodiesel operation increased EGT at full load by 13% at 27^0bTDC when compared with neat diesel operation as in case of crude vegetable oil. This was due to higher duration of combustion of biodiesel due to its moderate viscosity. CE with biodiesel operation decreased EGT at full load by 8% at 27^0bTDC when compared with crude waste fried cooking oil. This was due to improved combustion with presence of oxygen in the composition of biodiesel causing conversion of more heat into work and thus reducing heat rejection.

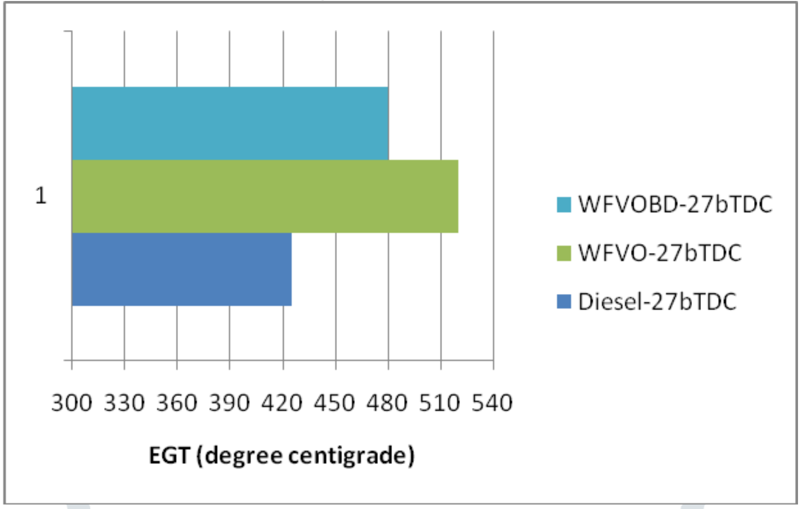

Fig.4 Bar chart showing the variation of Exhaust Gas Temperature (EGT) with test fuels in CE

Table 3
Data of EGT and coolant load at full load operation on CE

Injection Timing	Test Fuel	Exhaust Gas Temperature (EGT) (Degree Centigrade)	Coolant Load (kW)
27^0bTDC	DF	425	4.0
	WFVO	520	4.8
	WFVOBD	480	4.2

Figure.5 represents the bar chart showing the variation of Coolant Load at full load operation with test fuels in conventional engine at recommended injection timings at an injector opening pressure of 190 bar. From this Fig., it was noticed that CE with crude waste fried oil operation increased coolant load at full load by 20% at 27^0bTDC when compared with neat diesel operation. This was retarded ignition delay because of high duration of combustion of crude vegetable oil. This was due to concentration of un-burnt fuel at the walls of combustion chamber. Similar trends were observed with earlier researches [11,14]

From the same fig, it was observed that CE with biodiesel operation increased coolant load at full load by 5% at 27^obTDC when compared with neat diesel operation. This was because of efficient combustion of biodiesel with improved cetane rating. Similar trends were observed with earlier researcher [10, 13]

CE with biodiesel operation decreased coolant load at full load by 13% at 27^0bTDC when compared with crude Waste fried cooking oil. This once again established the fact that combustion improved with biodiesel operation, which reduced un-burnt fuel concentration at combustion chamber walls.

Volumetric efficiency depends on density of the charge which in turn depends on temperature of combustion chamber wall. Figure.6 represents the bar chart showing the variation of Volumetric Efficiency (VE) at full load operation with test fuels in conventional engine at recommended injection timing, at an injector opening pressure of 190 bar. From Fig, it was noticed that CE with crude waste fried cooking oil operation decreased volumetric efficiency at full load by 6% at 27^0bTDC when compared with neat diesel operation. This was due to increase of EGT at full load with waste fried oil operation due to accumulation of un-burnt fuel concentration. Similar trends were observed with earlier researches [11, 13]

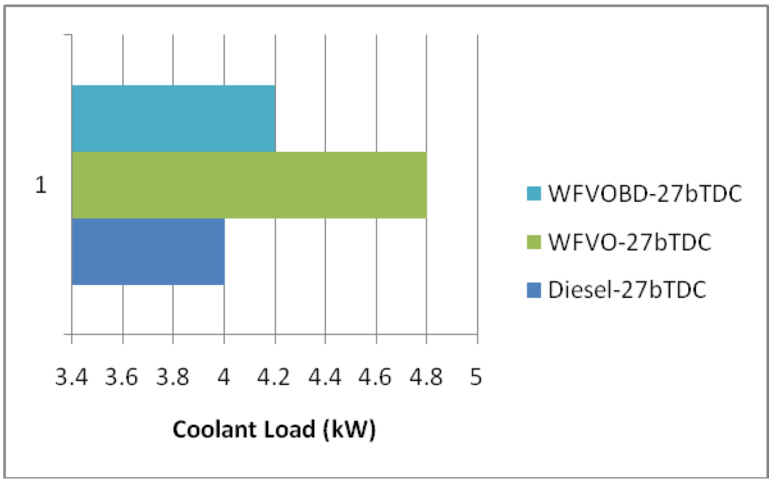

Fig.5 Bar chart showing the variation of Coolant Load at full load in CE with test fuels

From the same fig, it was observed that CE with biodiesel operation decreased volumetric efficiency at full load by 3% at 27^{0}bTDC when compared with neat diesel operation as in case of crude waste fried oil operation. Similar trends were observed with earlier researcher [10,13].

CE with biodiesel operation increased volumetric efficiency at full load by 2% at 27^{0}bTDC when compared with crude waste fried cooking oil. This was due to reduction of EGT with biodiesel operation with efficient combustion in comparison with crude vegetable oil operation. However, volumetric efficiency depends on valve overlap, speed of the engine rather than fuel composition. Hence marginal variation of volumetric efficiency was observed between crude waste fried oil operation and biodiesel operation on CE.

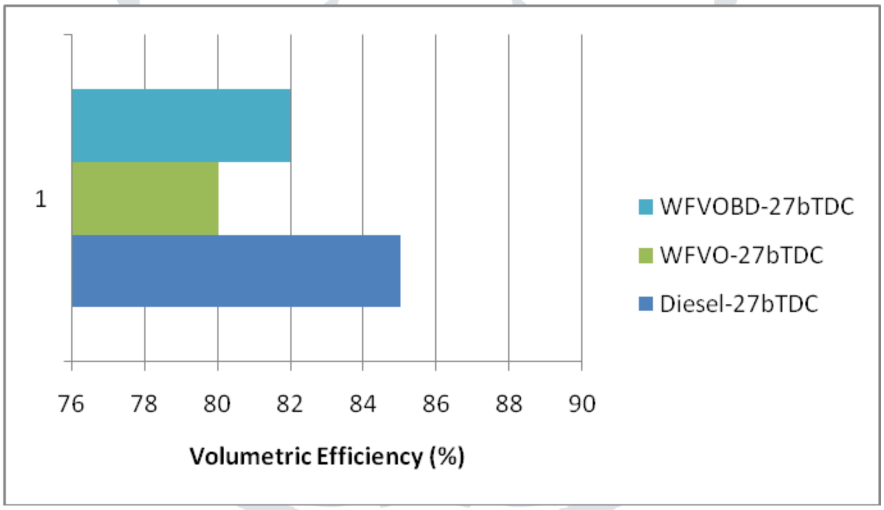

Fig.6 Bar chart showing the variation of Volumetric Efficiency at full load with test fuels in CE

Volumetric efficiency was higher with diesel operation followed by biodiesel and crude vegetable oil. This was due to clean and efficient combustion with high cetane value of diesel. Also exhaust gas temperatures were lower with pure diesel operation in comparison with crude vegetable oil and biodiesel.

Table 4

Data of volumetric efficiency at full load on CE

Injection Timing	Test Fuel	VE
27^{0}bTDC	DF	85
	WFVO	80
	WFVOBD	82

4. CONCLUSIONS AND FUTURE SCOPE OF WORK

Bio-diesel showed improved performance on the aspects of Brake thermal efficiency, Brake specific energy consumption, Exhaust gas temperature, Coolant load and volumetric efficiency in comparison with crude vegetable oil.

Injection timing and injection pressure may be varied in order to improve performance and further, Preheating can also be employed.

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