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Investigations on Performance Parameters with fixed injection timing of Ceramic Coated Diesel Engine with Linseed Oil Biodiesel

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Abstract: *The uses of biodiesel are increasingly popular because of their low impact on environment. However, it causes combustion problems in conventional diesel engine [CE]. Hence it is proposed to use the biodiesel in low heat rejection (LHR) diesel engines with its significance characteristics of higher operating temperature, maximum heat release, and ability to handle the lower calorific value (CV) fuel etc. In this work, biodiesel from linseed was used as sole fuel in both versions of the combustion chamber. Engine with LHR combustion chamber was developed with ceramic coating on inside portion of cylinder head by partially stabilized zirconia of 0.5 mm thickness. The experimental investigations were carried out on a four stroke, single cylinder, DI, 3,68 kW at a speed of 1500 rpm. In this investigation, comparative studies on performance parameters was made on CE and engine with LHR combustion chamber with different operating conditions of biodiesel with varied injector opening pressure and fixed injection timing.*

Keywords: *Alternate Fuels, Vegetable Oils, Biodiesel, LHR combustion chamber, Performance parameters.*

1. INTRODUCTION

The world energy demand has, for the last three decades, witnessed uncertainties in two dimensions. Firstly, the price of conventional fossil fuel is too high and has added burden on the economy of the importing nations. Secondly, combustion of fossil fuels is the main culprit in increasing the global carbon dioxide (CO2) level, a consequence of global warming. The scarcity and depletion of conventional sources are also cases of concern and have prompted research world-wide into alternative energy sources for internal combustion engines. Bio-fuels appear to be a potential alternative "greener" energy substitute for fossil fuels [1].It is renewable and available throughout the world. The idea of using vegetable oils as fuel for diesel engines is not new .The problem of using neat vegetable oils in diesel engines relates to their high viscosity. The high viscosity will lead to blockage of fuel lines, filters, high nozzle valve opening pressures and poor atomization. One hundred percent vegetable oils cannot be used safely in DI diesel engines. The problems of high fuel viscosity can be overcome by using esters, blending and heating. Vegetable oils exhibit longer combustion duration with moderate rates of pressure rise, unlike petroleum derived fuels. The use of vegetable oils, such as palm, soya bean, sunflower, peanut, and olive oil, as alternative fuels for diesel is being promoted in many countries [2]. Besides, some species of plants yielding non-edible oils, e.g. jatropha, karanji and pongamia may play a significant role in providing resources. Both these plants may be grown on a massive scale on agricultural/degraded/waste lands, so that the chief resource may be available to produce biodiesel on 'farm scale'. The methyl ester (or biodiesel) produced from linseed oil was known as linseed oil biodiesel (LSOBD). The test fuels used in the experimentation were pure diesel and linseed oil based biodiesel.

2. LITERATURE REVIEW

Rudolph Diesel, the inventor of the diesel engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil. Several researchers [3-6] experimented the use of vegetable oils as fuel on diesel engine and reported that the performance was poor, citing the problems of high viscosity, low volatility and their polyunsaturated character. Viscosity can be reduced with preheating. Experiments were conducted [7-10] on preheated vegetable [temperature at which viscosity of the vegetable oils were matched to that of diesel fuel] oils and it was reported that preheated vegetable oils improved the performance marginally. The problems of crude vegetable oils can be solved, if these oils are chemically modified to bio-diesel. Bio-diesels derived from vegetable oils present a very promising alternative to diesel fuel since biodiesels have numerous advantages compared to fossil fuels as they are renewable, biodegradable, provide energy security and foreign exchange savings besides addressing environmental concerns and socio-economic issues. Experiments were carried out [11-15] with bio-diesel on direct injection diesel engine and it was reported that performance was compatible with pure diesel operation on conventional engine. Few investigators [16-19] reported that injector opening pressure has a significance effect [20] on the performance and formation of pollutants inside the direct injection diesel engine combustion.

3. MATERIALS AND METHODS

This section contains fabrication of engine with LHR combustion chamber, preparation of biodiesel, properties of biodiesel, description of the schematic diagram of experimental set up, specifications of experimental engine, specifications of sound analyzer and definitions of used values. The inner side portion of cylinder head was coated with partially stabilized zirconium (PSZ) of thickness of 500 microns in order to convert conventional diesel engine to low heat rejection (LHR) combustion chamber. The chemical conversion of esterification reduced viscosity four fold. Linseed oil contains up to 72.9 % (wt.) free fatty acids [22].The methyl ester was produced by chemically reacting the linseed oil with an alcohol (methyl), in the presence of a catalyst (KOH). A two-stage process was used for the esterification [23-25] of the waste fried vegetable oil. The first stage (acid-catalyzed) of the process is to reduce the free fatty acids (FFA) content in linseed oil by esterification with methanol (99% pure) and acid catalyst (sulfuric acid-98% pure) in one hour time of reaction at 55°C. In the second stage (alkali-catalyzed), the triglyceride portion of the linseed oil reacts with methanol and base catalyst (sodium hydroxide-99% pure), in one hour time of reaction at 65°C, to form methyl ester and glycerol. To remove un-reacted methoxide present in raw methyl ester, it is purified by the process of water washing with air-bubbling. The methyl ester (or biodiesel) produced from linseed oil was known as linseed oil biodiesel (LSOBD). The physic-chemical properties of the crude linseed oil and biodiesel in comparison to ASTM biodiesel standards are presented in Table-1. The test fuels used in the experimentation were pure diesel and linseed oil based biodiesel. The schematic diagram of the experimental setup with test fuels is shown in Figure 1.

Table.1. Properties of test fuels

Property	Units	Diesel	Biodiesel	ASTM D 6751-02
Carbon chain	--	C_8-C_{28}	C_{16}-C_{24}	C_{12}-C_{22}
Cetane Number		55	55	48-70
Density	gm/cc	0.84	0.87	0.87-0.89
Bulk modulus @ 20Mpa	Mpa	1475	1850	NA
Kinematic viscosity @ 40^{o}C	cSt	2.25	4.5	1.9-6.0
Sulfur	%	0.25	0.0	0.05
Oxygen	%	0.3	10	11
Air fuel ratio (stochiometric)	--	14.86	14.2	13.8
Lower calorific value	kJ/kg	42 000	38000	37 518
Flash point (Open cup)	^{o}C	66	180	130
Molecular weight	--	226	280	292
Preheated temperature	^{o}C	--	60	--
Colour	--	Light yellow	Yellowish orange	---

The specifications of the experimental engine are shown in Table-2. The combustion chamber consisted of a direct injection type with no special arrangement for swirling motion of air. The engine was connected to an electric dynamometer for measuring its brake power. Burette method was used for finding fuel consumption of the engine. Air-consumption of the engine was measured by an air-box method (Air box was provided with an orifice meter and U-tube water manometer). The naturally aspirated engine was provided with water-cooling system in which inlet temperature of water was maintained at 80^{o}C by adjusting the water flow rate. Engine oil was provided with a pressure feed system. No temperature control was incorporated, for measuring the lube oil temperature. Copper shims of suitable size were provided (to vary the length of plunger of pump barrel)

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in between the pump body and the engine frame, to vary the injection timing and its effect on the performance of the engine was studied, along with the change of injector opening pressure from 190 bar to 270 bar (in steps of 40 bar) using nozzle testing device. The maximum injector opening pressure was restricted to 270 bar due to practical difficulties involved. Exhaust gas temperature was measured with thermocouples made of iron and iron-constantan.

Table.2. Specifications of the test engine

Description	Specification
Engine make and model	Kirloskar (India) AV1
Maximum power output at a speed of 1500 rpm	3.68 kW
Number of cylinders ×cylinder position× stroke	One × Vertical position × four-stroke
Bore × stroke	80 mm × 110 mm
Method of cooling	Water cooled
Rated speed (constant)	1500 rpm
Fuel injection system	In-line and direct injection
Compression ratio	16:1
BMEP @ 1500 rpm	5.31 bar
Manufacturer's recommended injection timing and pressure	27^{o}bTDC × 190 bar
Dynamometer	Electrical dynamometer
Number of holes of injector and size	Three × 0.25 mm
Type of combustion chamber	Direct injection type
Fuel injection nozzle	Make: MICO-BOSCHNo- 0431-202-120/HB
Fuel injection pump	Make: BOSCH: NO-8085587/1

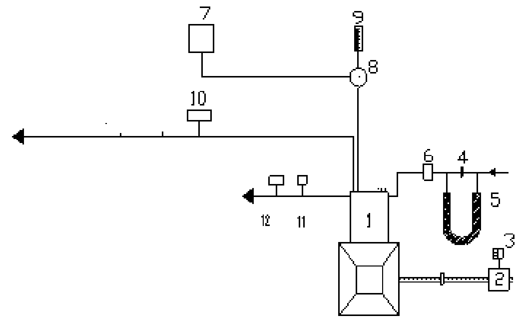

Figure 1: Schematic Diagram of Experimental Set-up

1..Engine, 2.Electical Dynamometer, 3.Load Box, 4.Orifice flow meter, 5.U-tube water manometer, 6.Air box, 7.Fuel tank, 8, Pre-heater, 9.Burette, 10. Exhaust gas temperature indicator, 11.Outlet jacket water temperature indicator, 12. Outlet-jacket water flow meter,

4. RESULTS AND DICUSSION

4.1 Performance Parameters

Table.3 indicates that at fixed injection timing, engine with biodiesel showed the compatible performance for entire load range when compared with the pure diesel operation. This may be due to the difference of viscosity between the diesel and biodiesel and calorific value of the fuel. The reason might be due to (1) higher initial boiling point and different distillation characteristics, (2) higher density and viscosity leads to narrower spray cone angle and higher spray penetration tip, leading to inferior combustion compared to neat diesel [35]. However, higher density of biodiesel compensates the lower value of the heat of combustion of the biodiesel thus giving compatible performance with engine. Biodiesel contains oxygen molecule in its molecular composition. Theoretical air requirement of biodiesel was low [Table.1] and hence lower levels of oxygen were required for its combustion. Brake thermal efficiency increased with the fixed injection timing with conventional engine with the biodiesel at all loads. This was due to initiation of combustion at earlier period and efficient combustion with increase of air entrainment [31] in fuel spray giving higher brake thermal efficiency. The increase of brake thermal efficiency at optimum injection timing over the recommended injection timing with biodiesel with conventional engine could be attributed to its longer ignition delay and combustion duration [31]. Similar trends were noticed with preheated biodiesel. Preheating of the biodiesel reduced the viscosity, which improved the spray characteristics of the oil, causing efficient combustion thus improving brake thermal efficiency.

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TABLE 3: DATA OF PEAK BRAKE THERMAL EFFICIENCY (BTE) AND BRAKE SPECIFIC ENERGY CONSUMPTION AT FULL LOAD OPERATION

Injection Timing (°bTDC)	Test Fuel	Peak BTE (%)						Brake Specific Energy Consumption at peak load operation (kW/kW)					
		Injection Pressure (Bar)						Injection Pressure (Bar)					
		190		230		270		190		230		270	
		NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT
27(CE)	DF	28	--	29	---	30	--	4.0	--	3.96	--	3.92	--
	LSOBD	27	27.5	27.5	28	28.5	29	4.02	3.96	3.96	3.94	3.94	3.96
27(LHR)	DF	27.5	--	28	--	29	--	4.3	--	4.2	--	4.1	--
	LSOBD	28	28.5	28.5	29	29	29.5	3.84	3.80	3.80	3.76	3.76	3.72

From Table 3, it is observed that LHR version of the engine at fixed injection timing showed the improved performance at all loads compared with CE with pure diesel operation. High cylinder temperatures [21] helped in improved evaporation and faster combustion of the fuel injected into the combustion chamber. Reduction of ignition delay of the vegetable oil in the hot environment of the LHR combustion chamber improved heat release rates and efficient energy utilization. Since the hot combustion chamber of LHR combustion chamber reduced ignition delay and combustion duration and hence the optimum injection timing was obtained [31] earlier with LHR combustion chamber when compared to conventional engine with the biodiesel operation.

As the combustion chamber was insulated to greater extent, it was expected that high combustion temperatures would be prevalent in LHR combustion chamber. It tends to decrease the ignition delay thereby reducing pre-mixed combustion as a result of which, less time was available for proper mixing of air and fuel in the combustion chamber leading to incomplete combustion, with which peak BTE decreased. More over at this load, friction and increased diffusion combustion resulted from reduced ignition delay. Peak BTE with LHR combustion chamber with biodiesel operation was higher in comparison with conventional engine at recommended and optimized injection timings.

This was due to higher degree of insulation provided in the piston, liner (with the provision of air gap with superni-90 inserts) and cylinder head reduced the heat rejection leading to improve the thermal efficiency. This was also because of improved evaporation rate of the biodiesel. High cylinder temperatures [21] helped in improved evaporation and faster combustion of the fuel injected into the combustion chamber. Reduction of ignition delay of the vegetable oil in the hot environment of the engine with LHR combustion chamber improved heat release rates and efficient energy utilization.

Injector opening pressure was varied from 190 bar to 270 bar to improve the spray characteristics and atomization of the test fuels with fixed injection timing for CE and LHR combustion chamber. As it is observed from Table.1, peak brake thermal efficiency increased with increase in injector opening pressure at different operating conditions of the biodiesel. For the same physical properties, as injector opening pressure increased droplet diameter decreased influencing the atomization quality, and more dispersion of fuel particle, resulting in turn in better vaporization, leads to improved air-fuel mixing rate, as extensively reported in the literature [16-18][25]. In addition, improved combustion leads to less fuel consumption.

Performance improved further with the preheated biodiesel when compared with normal biodiesel. This was due to reduction in viscosity of the fuel. Preheating of the biodiesel reduced the viscosity, which improved the spray characteristics of the oil causing efficient combustion thus improving brake thermal efficiency. The cumulative heat release was more for preheated biodiesel [25] than that of biodiesel and this indicated that there was a significant increase of combustion in diffusion mode [25]. This increase in heat release [25] was mainly due to better mixing and evaporation of preheated biodiesel, which leads to complete burning.

Generally brake specific fuel consumption, is not used to compare the two different fuels, because their calorific value, density, chemical and physical parameters are different. Performance parameter, BSEC, is used to compare two different fuels by normalizing brake specific energy consumption, in terms of the amount of energy released with the given amount of fuel. From Table 3, it was evident that brake specific energy consumption with LHR combustion chamber with pure diesel operation was higher in comparison with conventional engine at recommended (8%)and optimized injection timings (6%). This was due to reduction of ignition delay with pure diesel operation with LRH engine as hot combustion chamber was maintained by engine with LHR combustion chamber. With biodiesel operation, BSEC was lower with LHR combustion chamber at recommended injection timing (5%) and at optimized injection timing (3%) in comparison with conventional engine.

BSEC was higher with conventional engine due to due to higher viscosity, poor volatility and reduction in heating value of biodiesel lead to their poor atomization and combustion characteristics. The viscosity effect, in turn atomization was more predominant than the oxygen availability [25] in the blend leads to lower volatile characteristics and affects combustion process**.** BSEC was improved with LHR combustion chamber with lower substitution of energy in terms of mass flow rate. 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 [25]. From the Table.3 it is noticed that BSEC at full load operation decreased with increase of injector opening pressure with different operating conditions of the test fuels. This was due to increase of air entrainment [25] in fuel spray giving lower BSEC. BSEC decreased with the preheated biodiesel at full load operation when compared with normal biodiesel. Preheating of the biodiesel reduced the viscosity, which improved the spray characteristics of the oil.

5. CONCLUSIONS

Peak BTE with LHR combustion chamber with biodiesel operation was higher in comparison with conventional engine at recommended and fixed injection timings. BSEC was lower with LHR combustion chamber with biodiesel operation in comparison with conventional engine at recommended injection timing (5%) and fixed injection timing (3%).

6. RESEARCH FINDINGS AND FUTURE SCOPE OF WORK

Investigations on study of performance parameters with engine with ceramic coated LHR combustion were systematically carried out with varied injector opening pressure and varied injection timing with different operating conditions of the test fuels with various configurations of the combustion chamber.

Degree of insulation can further be increased in order to study performance parameters as low viscous fuels can be efficiently burnt in LHR combustion chamber.

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