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THE EFFECT OF THERMAL BARRIER COATING ON EXHAUST EMISSIONS AND COMBUSTION CHARACTERISTICS OF DIESEL ENGINE WITH RICE BRAWN OIL BASED BIODIESEL

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ABSTRACT

Vegetable oils are promising substitutes for diesel fuel in the scenario of depletion of fossil fuels. Exhaust emissions and combustion characteristics at full load operation were determined with engine with ceramic coated low heat rejection (LHR) combustion chamber, with its significance characteristics of higher operating temperature, maximum heat release and ability to handle the lower calorific value fuel etc., with different operating conditions of rice brawn oil based biodiesel (ERBO) with varied injection timing and injector opening pressure and compared with conventional engine. Biodiesel increased nitrogen oxides and decreased particulate emissions with LHR combustion chamber when compared with conventional engine at similar operating conditions.

KEYWORDS: Alternate Fuels for Diesel, Biodiesel, Low Heat Rejection, Exhaust Emissions and Combustion Characteristics

INTRODUCTION

In the context of fast depletion of fossil fuels and ever increase of number of vehicles employing compression ignition engines, the research for alternative fuels which are renewable in nature is becoming more and more prominent.

Alcohols (ethanol and methanol) and vegetable oils are renewable in nature. However, alcohols have Cetane number. Hence they are directly used in diesel engines. On the other hand, vegetable oils have high cetane number and they can replace 100% of diesel fuel in diesel engine. When Rudolf Diesel first invented the diesel engine about a century ago, he demonstrated this principle by employing peanut oil and hinted that vegetable oil would be the future fuel in diesel engine. [1].

Vegetable oils were used in conventional diesel engine. It was reported that performance deteriorated with vegetable oils due to their high viscosity and low volatility. [2-5]. The high viscosity of vegetable oils cause problems in injection process leading to an increase in smoke levels and low volatility of the vegetable oils leads to oil sticking to the injector or cylinder walls resulting in deposit formation which interferes with the combustion. Preheating of the vegetable oils in order to equalize their viscosity to that of pure diesel may ease the problems of injection process [6-7]. Increased injector opening pressure may also result in efficient combustion in compression ignition engine [8-9]. Esterifiction of vegetable oil to its methyl ester reduces its molecular weight and viscosity and increases its cetane number. Studies were made with biodiesel with conventional engine and reported that biodiesel operation increased oxides of nitrogen and decreased particulate emissions. [8-9]. Vegetable oils and biodiesel need a hot combustion chamber to achieve efficient energy release rates and hence the concept of LHR combustion chamber was introduced with its significance characteristics of higher operating temperature, maximum heat release, and ability to handle lower calorific value fuel etc.

Engine with different versions of the combustion chamber were categorized depending on degree of insulation. Low grade LHR combustion chamber consisted of coating with partially stabilized zirconium of thickness 500 microns on inner side of cylinder head. Medium grade LHR combustion chamber consisted of air gap insulated engines, while high grade LHR combustion chamber contained the combination of low grade and medium grade LHR combustion chambers. Investigations were carried out with ceramic coated LHR combustion chamber and it was reported increase of NOx emissions and reduction of particulate emissions. [10-13].

Here, an attempt was made to determine exhaust emissions and combustion characteristics with engine with low grade LHR combustion chamber with biodiesel (rice brawn oil based) with change of injection timing and injector opening pressure and comparison was made with conventional engine with similar operating conditions.

MATERIALS AND METHODS

Due to very high free fatty acid, rice bran oil was converted into methyl ester by the two stage process [14]. The physic-chemical properties of the biodiesel in comparison to ASTM biodiesel standards are presented in Table 1.

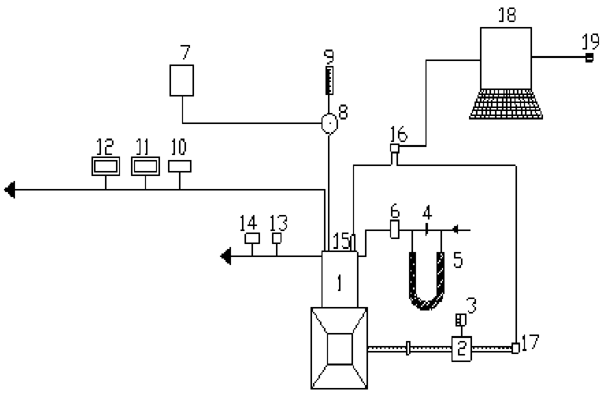
Table 1: Properties of Test Fuels [14]

Property	Units	Diesel	Biodiesel (ERBO)	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	0.86	0.87-0.89
Bulk modulus @ 20Mpa	Mpa	1475	1800	NA
Kinematic viscosity @ 40^{o}C	cSt	2.25	3.5	1.9-6.0
Sulfur	%	0.25	0.0	0.05
Oxygen	%	0.3	11	11
Air fuel ratio (stochiometric)	--	14.86	13.8	3.8
Lower calorific value	kJ/kg	42 000	38500	37 518
Flash point (Open cup)	^{o}C	66	174	130
Molecular weight	--	226	261	292
Preheated temperature	^{o}C	--	65	--
Colour	--	Light yellow	Yellowish orange	---

Partially stabilized zirconium of thickness 500 microns was coated on inside portion of cylinder head by plasma spray technique. Schematic diagram of experimental setup used for the investigations on compression ignition diesel engine and LHR combustion chamber with biodiesel (ERBO) is shown in Figure 1.

The test fuels used in the experimentation were pure diesel and rice bran oil based biodiesel. The conventional engine had an aluminum alloy piston with a bore of 80mm and a stroke of 110mm. The rated output of the engine was 3.68 kW at a a speed of 1500 rpm. The compression ratio was 16:1 and manufacturer's recommended injection timing and injector opening pressure were 27^{o}bTDC and 190 bar respectively. The fuel injector had 3 holes of size 0.25mm. The combustion chamber consisted of a direct injection type with no special arrangement for swirling motion of air. The engine was connected to 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 air-box method. 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. The engine oil was provided with a pressure feed system. N temperature control was incorporated, for measuring the lube oil temperature. Copper shims of suitable size were provided in between the pump body and the engine frame, to vary the injection timing and its effect on the performance of the engine is studied. The injection pressures were varied from 190 bars to 270 bar (in steps of 40 bar) using nozzle-testing device. The maximum injector opening pressure was restricted to 270bars due to practical difficulties involved. The exhaust gas temperature (EGT) was measured with thermocouple made of iron and iron-constantan connected with exhaust gas indicator. Biodiesel was injected in conventional manner. There was provision for preheating the biodiesel (PT).

Exhaust emissions of particulate matter and NOx were recorded by AVL Smoke Meter and Netel Chromatograph NOx Analyzer respectively at the full load operation of the engine. The accuracy of the analyzers was 1%. The Piezo electric transducer, fitted on the cylinder head to measure pressure in the combustion chamber was connected to a console, which in turn was connected to Pentium personal computer. TDC encoder provided at the extended shaft of the dynamometer was connected to the consol to measure the crank angle of the engine. A special P-θ software package evaluated the combustion characteristics such as peak pressure (PP), time of occurrence of peak pressure (TOPP), maximum rate of pressure rise (MRPR) from the signals of pressure and crank angle at full load operation of the engine. The accuracy of the instrumentation was 1%.



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. AVL Smoke Meter, 12. Netel Chromatograph NOx 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

Figure 1: Schematic Diagram of Experimental Set-up

RESULTS AND DISCUSSIONS

Data of pure diesel (DF) was taken from reference [12]. The optimum injection timing with conventional engine was 31^{o}bTDC, while with LHR combustion chamber it was 30^{o}bTDC. The optimum injection timing with conventional engine with rice brawn oil based biodiesel was 31^{o}bTDC [14].

Performance Parameters

From Figure 2, it is noticed that improved performance was observed with engine with LHR combustion chamber at all loads with biodiesel operation in comparison with pure diesel operation on conventional engine. This was because of improved evaporation rate of biodiesel with reduction of ignition delay. The optimum injection timing was observed to be 30^{o}bTDC with LHR combustion chamber with normal bio-diesel as well as preheated biodiesel. With biodiesel operation, the optimum injection timing was obtained earlier with engine with LHR combustion chamber when compared with CE. This was due to reduction of ignition delay and combustion duration with biodiesel with LHR combustion chamber.

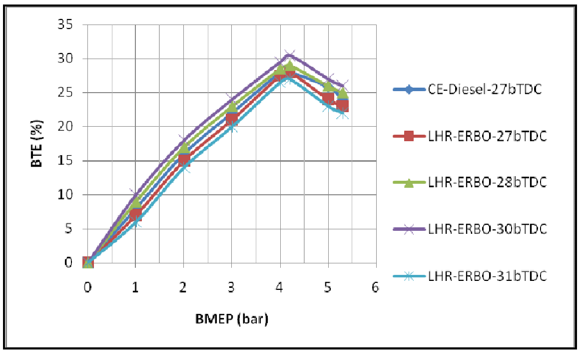


Figure 2: Variation of Brake Thermal Efficiency (BTE) with Brake Mean Effective Pressure (BMEP) in Engine with Ceramic Coated Insulated Combustion Chamber with Biodiesel (ERBO) at Different Injection Timings at an Injector Opening Pressure of 190 Bar

The effect of varied injection timing, injector opening pressure and preheating on the exhaust emissions and combustion characteristics were discussed with the help of Tables.

Exhaust Emissions

From Table 2, it is noticed that biodiesel operation on conventional engine increased particulate emissions at full load operation, in comparison with pure diesel (DF) operation. This was because of higher value of ratio of C/H (C= Number of carbon atoms and H= Number of hydrogen atoms in fuel composition. (C10H14N2),) of crude vegetable oil, when compared with pure diesel [14]. This was also because of reduction of air fuel ratios and volumetric efficiency with conventional engine. Particulate emissions decreased with engine with LHR combustion chamber when compared with pure diesel operation on conventional engine. This was because of efficient combustion with improved air-fuel ratios. Particulate emissions decreased at the optimum injection timing with test fuels due to early initiation of combustion.

Particulate emissions decreased with different operating conditions of the biodiesel with increase of injector opening pressure. This was because of improved atomization characteristics at higher injector opening pressure. Particulate emissions decreased with preheating. This was due to i) the reduction of the viscosity, density, and diffusion combustion proportion. Data of particulate emissions of diesel and biodiesel in conventional engine at recommended injection timing and optimum injection timing were taken from Reference [14].

Table 2: Data of Particulate Emissions at Full Load Operation

Injection Timing (bTDC)	Test Fuel	Particulate Emissions (Hartridge Smoke Unit) at Full Load Operation											
		Conventional Engine						Engine with Ceramic Coated LHR Combustion Chamber					
		Injector Opening Pressure (Bar)						Injector Opening Pressure(Bar)					
		190		230		270		190		230		270	
		NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT
27	DF	48	--	38	--	34	--	50	--	45	--	40	--
	ERBO	60	55	55	50	50	45	45	40	40	35	35	30

Table 2: Contd.,

30	DF	--	--	--	--	--	--	50		45		40	
	ERBO	--	--	--	--	--	--	40	35	35	30	30	25
31	DF	30	--	35	--	40	--	-	-	-	-	-	-
	ERBO	45	40	50	45	55	50	-	-	-	-	-	-

NOx levels were higher with biodiesel operation when compared with diesel operation on both versions of the combustion chamber due to presence of oxygen molecule in the composition of biodiesel and long chain unsaturated fatty acids. NOx levels increased with conventional engine and decreased with LHR combustion chamber with advanced injection timing. This was due to increase of residence time and gas temperatures with conventional engine and decrease of gas temperatures with LHR combustion chamber. From the Table 3, it is noted that these levels increased with increase of injector opening pressure with different operating conditions of biodiesel with CE, while they deceased with engine with LHR combustion chamber. This was because of increase of gas temperatures with increased rate of mixing with conventional engine and reduction of the same with engine with LHR combustion chamber with improved air fuel ratios with increase of injector opening pressure.

Preheated biodiesel decreased NOx levels in comparison with normal biodiesel as observed from the Table 3. With preheating, physical properties will affect two burning processes (premixed and diffused) which have different emission formation characteristics, This was also due to reduction of bulk modulus of the biodiesel.[15].

Data of NOx emissions of diesel and biodiesel in conventional engine at recommended injection timing and optimum injection timing were taken from Reference [14].

Table 3: Data of NOx Levels at Full Load Operation

Injection Timing (bTDC)	Test Fuel	NOx Levels at Full Load Operation (ppm)											
		Conventional Engine						Engine with Ceramic Coated LHR Combustion Chamber					
		Injector Opening Pressure (Bar)						Injector Opening Pressure (Bar)					
		190		230		270		190		230		270	
		NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT
27	DF	850	----	890	----	930	---	1175	--	1125	--	1075	--
	ERBO	950	900	1000	950	1050	1000	1250	1200	1200	1150	1150	1100
30	DF	--	--	--	--	--	--	1125		1075		1025	
	ERBO	--	--	--	--	--	--	1220	1170	1170	1120	1120	1070
31	DF	1100	-	1150	-	1200	--	-	-	-	-	-	-
	ERBO	1200	1150	1250	1200	1300	1250	-	-	-	-	-	-

Combustion Characteristics

From the Table 4, it is noticed that though calorific value of biodiesel was less than that of diesel fuel, peak pressure for normal biodiesel was comparable to diesel fuel due to its higher bulk modulus.

However, the peak pressures of preheated methyl ester were less than that of normal biodiesel due to its lower value of bulk modulus and shorter ignition delay.

Peak pressures increased with the advancing of the injection timing with the test fuels with conventional engine while they decreased marginally with engine with LHR combustion chamber. This was due to accumulation of the fuel and sudden explosion of the fuel in combustion chamber in conventional engine. Reduction of peak pressures in engine with

LHR engine with advanced injection timing was due to improved combustion with improved air fuel ratios. Peak pressure increased with test fuels in conventional engine and decreased in engine with LHR combustion chamber with increase of injector opening pressure. This may be due to improved spray pattern in conventional engine and improved combustion with improved air fuel ratios in engine with LHR combustion chamber. Diesel operation showed maximum rate of pressure rise (MRPR) (Table 4) as it has high calorific value. MRPR followed similar trends as those of PP.

The value of time of occurrence of peak pressure (TOPP) decreased with the increase of injector opening pressure with advanced injection timing at different operating conditions of the test fuels. Preheated biodiesel showed lower value of TOPP, in comparison with biodiesel at normal temperature. This once again confirmed by observing the lower TOPP, the performance of the engine improved with the preheated biodiesel compared with the normal biodiesel.

Data of combustion characteristics of diesel and biodiesel in conventional engine at recommended injection timing and optimum injection timing were taken from Reference [14].

Table 4: Data of Combustion Characteristics at Full Load Operation

Injection Timing (bTDC)	Test Fuel	PP (Bar)				MRPR (Bar/Deg)				TOPP (Deg)			
		Injector Opening Pressure				Injector Opening Pressure				Injector Opening Pressure			
		190		270		190		270		190		270	
		NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT
27(CE)	DF	50.4	--	53.5	---	5.3	--	5.9	--	10		9	
	ERBO	49.6	48.4	52.5	51.5	5.0	4.0	5.3	4.3	11	10	10	9
27(LHR)	DF	60.4	--	58.5	--	5.8		5.6		11	10	10	9
	ERBO	62.2	60.2	60.2	58.5	5.6	5.4	5.4	5.2	10	9	10	9
30(LHR)	ERBO	60.5	58.5	58.5	56.5	5.4	5.2	5.2	5.0	8	8	8	8
	DF	57.4	-	55.4	--	5.6		5.4		8		8	
31(CE)	DF	62.2	--	61.9	--	6.2	--	6.8.	--	8		8	
	ERBO	66.4	64.1	68.5	65.5	5.7	4.5	6.1	4.9	8	8	8	8

CONCLUSIONS

At an injector opening pressure of 190 bar,

- Particulate emissions at full load operation decreased by 25% and 9% with engine with LHR combustion chamber with biodiesel operation at recommended and optimized injection timings when compared with CE.
- NOx emissions increased by 32% and comparable with engine with LHR combustion chamber with biodiesel operation at recommended and optimized injection timing when compared with CE.
- Peak pressures increased by 25% and decreased 9% with engine with LHR combustion chamber with biodiesel operation at recommended and optimized injection timings when compared with CE.
- Maximum rate of pressure rise increased by 12% and comparable with engine with combustion chamber with biodiesel operation at recommended and optimized injection timings when compared with CE.

Research Findings and Suggestions

Comparative studies were made on exhaust emissions and combustion characteristics with low grade LHR combustion chamber combustion chamber and conventional engine with different operating conditions of the rice brawn oil based biodiesel with varied injector opening pressure and injection timing. Complete studies which include performance parameters, exhaust emissions and combustion characteristics on low grade LHR combustion chamber with crude vegetable oil and biodiesel is to be conducted. Control of nitrogen oxides from insulated engines is necessary.

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