Research article Available online www.ijsrr.org ISSN: 2279–0543

International Journal of Scientific Research and Reviews

Effect of Injection Timing on Performance and Combustion Characteristics of a Diesel Engine Fuelled with Diesel and Methyl Ester of Sunflower oil

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ABSTRACT

A great attention has been received by diesel engines due to their high power performance, thermal efficiency and low emissions in comparison with gasoline engines. Transportation systems sector consumes a large portion of non-renewable petroleum fuels. For a renewable fuel resource it is urgent look that will replace traditional fuels. Production of biodiesel from vegetable oils is one of promising resources. In this present work initially experiments are conducted using diesel and sunflower oil methyl ester (SME) with different injection timings at the rated speed of 1500 rev/min under variable load conditions. Load speed, air flow rate, fuel flow rate, exhaust gas temperature, and exhaust emissions of carbondioxide, nitric oxide and smoke are observed, cylinder pressure position signals are recorded for processing to obtain combustion parameters.

KEYWORDS: Diesel, Methyl ester, injection timing, transportation, emissions, performance.

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INTRODUCTION

The physical properties of the biodiesel fuel such as viscosity, flash point effect the different process occurring within the diesel engine cylinder; including fuel evaporation, fuel mixing with air, fuel atomization and fuel burning and engine performance. In metering the desired amount of fuel at correct time depending on engine operating conditions plays an important role is injection timing (IT). The increase of injection timing is recorded as one of the basic parameters that tend to reduce particulate matter emissions and fuel consumption in addition to other influences; including the increase of fuel portion burned by premixed combustion, the increase of mixture homogeneity, the increase of local A/F ratio, the decrease of combustion duration, the increase of the in-cylinder peak pressure, and the increase of NOx emissions. Kumar et al.[1] studied the effect of compression ratio, fuel atomization, Injection Timing, fuel quality, combustion rate, A/F ratio, intake temperature and pressure on engine performance parameters. Authors founded that, the increase in air motion into diesel engine improves the fuel atomization, the heat release rate and reduces the levels of exhausted emissions. Sayin et al.[2] studied the effect of fuel atomization and fuel distribution through combustion chamber using a single cylinder diesel engine operated with canola oil methyl esters (COME) and its blends with diesel fuel. The experimental results showed that, fuel exhibits different combustion and performance characteristics for different IT and engine loads. From their study, Sayin et al.[2] Kannan and Udayakumar[3] studied the effect of IT on performance and emissions from diesel engine. Authors concluded that, good performance and low emissions occur at high IP of 200 bar. Canakci et al. [4] observed the decrease of engine mechanical performance parameters and the increase of most engine emissions (smoke opacity, UHC and CO) except NOx and CO_2 when the injection pressure becomes lower than the engine original injection pressure. Nagaraju et al. [5] carried out an experimental study to determine the effect of using B20 (fuel blend containing 20% soybean methyl ester biodiesel and 80% neat diesel fuel) on the combustion process, performance and exhaust emissions of diesel engine. Their results indicated that, the emissions of NO_X, CO, UHC and soot for B20 are lower than those for diesel fuel, while BSFC and T_{exh} are higher for B20 than for diesel fuel. Krahl et al.[6] studied the effect of using biodiesel fuels on diesel engine performance and concluded that, the high BSFC and low brake power (BP) obtained with biodiesel are related to the biodiesel low heating value. Purushothaman et al. [7] investigated the effect of IP on the combustion process and the exhaust emissions of diesel engine fueled with orange skin powder diesel solution. The results indicated that orange skin powder-diesel solution gives superior combustion and emissions characteristics as compared to diesel fuel at IP of 235 bars. Monyem et al. [8] reported that the advance of injection timing of about 2.3 LC.A. is necessary for fueling neat biodiesel fuels in comparison with that for fueling a diesel fuel using the same fuel injection pump setting. The injection timing advance is attributed to the physical property differences between biodiesel and diesel fuel; higher viscosity, higher molecular weight and fatty acid contents and so higher bulk modulus for biodiesel than that of diesel fuel. This optimization can be achieved at the proper match between the IP and the combustion cylinder geometry. The aim of the present work is to investigate the effect of blended fuels on the engine Performance and Combustion Characteristics using diesel and methyl ester of sunflower oil with different injection timings.

FUEL INJECTION SYSTEM

The purpose of the fuel injection system is to deliver fuel into the engine cylinders, while precisely controlling the injection timing, fuel atomization, and other parameters. The main types of injection systems include pump-line-nozzle, unit injector, and common rail. Modern injection systems reach very high injection pressures, and utilize sophisticated electronic control methods. The performance of diesel engines is heavily influenced by their injection system design. In fact, the most notable advances achieved in diesel engines resulted directly from superior fuel injection system designs. While the main purpose of the system is to deliver fuel to the cylinders of a diesel engine, it is how that fuel is delivered that makes the difference in engine performance, emissions, and noise characteristics. The primary purposes of the diesel fuel injection system are graphically represented in plate 1.

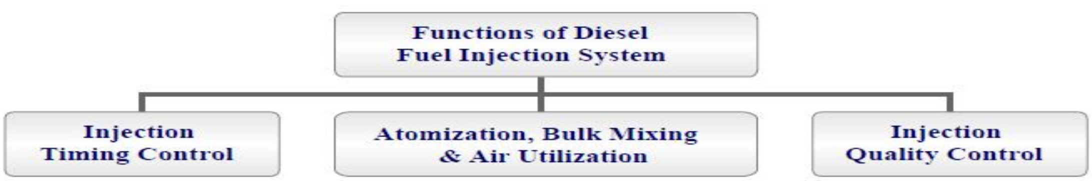


Plate 1: Main Functions of Diesel Fuel Injection System

EXPERIMENTAL SET UP AND PROCEDURE

***Experimental Set Up*:** The engine shown in plate 2 is a 4 stroke, PC Based vertical single cylinder, water cooled, diesel engine coupled to electrical dynamometer, specifications were written in table 1. Cooling water lines are fitted with temperature measuring thermocouples provided for engine cooling. A measuring system for fuel consumption consisting of a fuel tank, burette, and a 3-way cock mounted on stand and stop watch are provided. Air intake is measured using an air tank fitted with an orifice meter connected to a water U-tube differential manometer. A digital temperature indicator and a digital rpm indicator are provided for temperature and speed measurement on the panel board. A governor is provided to maintain the constant speed. All the experiments were conducted at the engine speed of 1500 rpm. Initially experiments are conducted using diesel and methyl ester of sunflower oil with different injection timings at the rated speed of 1500 rev/min under variable load conditions. Load speed, air flow rate, fuel flow rate, exhaust gas temperature, and exhaust emissions of carbon dioxide, nitric oxide and smoke are observed, cylinder pressure position signals are recorded for processing to obtain combustion parameters. In the second phase, methyl ester of sunflower oil is blended with diesel in different proportions. Performance, emissions and combustion parameters are analyzed and compared with neat diesel operation. All the test values were noted down thrice and average value was taken to avoid the errors in readings. Some of the properties of sunflower oil, sunflower methyl esters and its blends. It is very important to know the properties of fuel with blends. Different blends were tested and the properties are noted.

Table 1 Specifications of the Test Engine

Particulars	Specifications
Make	Kirloskar
Rated Power	3.7 kw(5hp)
Bore	80 mm
Stroke Length	110 mm
Swept volume	562 cc
Compression ratio 16.5:1	Compression ratio 16.5:1

Plate 2: diesel engine test rig

4. RESULTS AND DISCUSSION

The effect of bio diesel blend with diesel on the properties of the fuel has been discussed. Effect of variation of injection timing with diesel and bio diesel are also studied. It is also discussed in detail about the effect of biodiesel blend with diesel on the performance, emission and combustion parameters of the diesel engine. Optimum fraction of additive blended with diesel is also identified.

4.1 Fuel Properties of Diesel, Methyl Ester of Sunflower Oil and Biodiesel Blends

The properties are given in table 4.1. In sunflower biodiesel blended fuels, increase in amount of diesel fuel has shown no effect on specific gravity of fuel. The kinematic viscosity of sunflower biodiesel blended fuels increased with increase in amount of biodiesel level. The viscosity of B25 biodiesel blended fuel is 3.02 cst which almost closer to desirable viscosity of diesel fuel (2.47 cst). The calorific value of blended fuel improved by addition of diesel fuel in the biodiesel blends. The heating value increased with decease in biodiesel amount. The blended fuels had effect in reducing the flash point of the sunflower oil blended fuels, which indicated the improvement in the volatile nature of the fuels. The flash point of blended fuels increased with increase in amount of biodiesel in the fuels. Similar trend observed for ash content of blended fuels. The fuel properties of sunflower biodiesel blended fuels met the diesel fuel and biodiesel standards.

Table 4.1 properties of diesel, methyl ester of sunflower oil and biodiesel blends

Fuel Properties	ASTM Methods	Diesel	B25	B50	B75	B100
Kinematic Viscosity cst at 40^{o}C	D445	2.47	3.02	3.59	4.00	4.23
Specific gravity at 15 ^{0}C	D1298-85	0.85	0.852	0.857	0.860	0.873
Heat of combustion, kJ/kg	D240-92	44,000	43,760	43,323	43,000	42,673
Cloud point, ^{0}C	D2500-91	6.5	6.9	7.3	8.1	10.2
Pour point, ^{0}C	D97-93	3.1	3.3	3.4	3.5	4.2
Flash point, ^{0}C	D92	76	88	113	126	148
Ash content,%	D482-91	0.21	0.21	0.22	0.24	0.24

4.2 Optimization of Injection Timing with Diesel and Methyl Ester of Sunflower Oil

In the first phase of this work, performance and emission studies carried out on the normal diesel engine using diesel and methyl ester of sunflower oil as fuels. At the rated speed of 1500 rev/min, variable load tests conducted at different blends B25, B50, B75, B100. Of all the blends B25 shows best results. B25 blend is preheated to 158°c conducted comparisons test between diesel, Biodiesel-B25, Preheated Biodiesel-B25, at base operating conditions shown in the table 4.2

Table 4.2 Comparison of performance and emission parameters of different test fuels (full load) at standard condition

Parameters	unit	Diesel	Sunflower oil	Sunflower oil BioDiesel B25	Sunflower Bio – Diesel with preheating(158ºc)
BSFC	Kg/kWh	0.291	0.355	0.350	0.335
BSEC	MJ/kWh	12.20	13.38	13.18	13.14
Brake Thermal Efficiency	%	29.5	26.7	27.1	27.1
Exhaust Gas Temperature	ºC	348	417	401	385
NOx	ppm	2048	1848	1898	1985
CO	Vol%	0.29	0.32	0.25	0.21
UBHC	ppm	197	207	189	164
Smoke	BSN	2.9	3.3	2.9	2.7

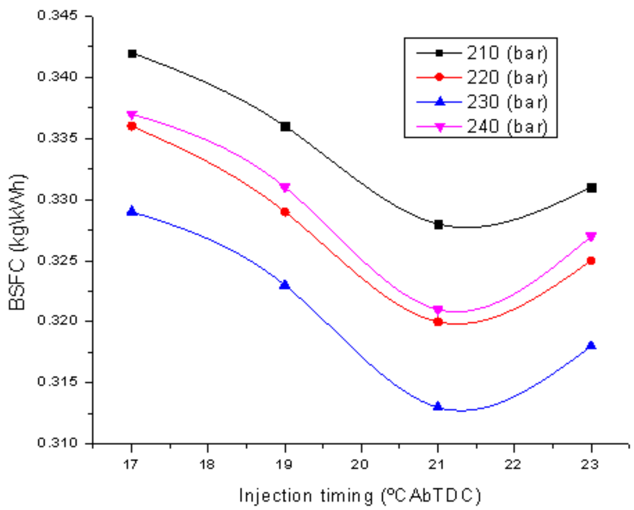
From the above discussion, it is observed that the emission values of Sunflower Bio Diesel are better compared to that of Diesel. Preheated Sunflower Bio Diesel is giving lower emissions compared to Sunflower Bio Diesel except NOx. Similarly, the performance parameters of Sunflower Bio Diesel are closer to that of pre heated Sunflower Bio Diesel and Diesel at standard Injection timing and pressure". "It also believed that the performance and emission parameters of Sunflower Bio Diesel would be improved further by optimizing Injection timing and pressure. with an objective to improve the performance and emissions". "As usual the comparison is considered for full load measurements only. The speed is kept constant that is at 1500 RPM. Initially keeping the Injection timing at the designed value i.e., 23°CA bTDC, the Injection pressure is varied as 210, 220, 230 and 240 bar and the measurements are taken and the computations are made and analysis of results are presented. Later the Injection timings are changed to 21, 19, 17 and experiments are repeated for variations of Injection pressure 210, 220, 230 and 240 bar". The Injection timing changed to different values (21, 19 and 17°CA bTDC) and at these values the Injection pressure varied and the tests repeated. Different test combinations of Injection timing and Injection pressure are listed in Table 4.3.The effect of Injection pressure (at a given Injection timing) on different combustion", performance, and emission parameters of Preheated Sunflower Bio Diesel is investigated. "Similarly for better understanding, the effect of Injection timing (at a given Injection pressure) on various combustion, performance, and emission parameters is also studied.

Table 4.3 Different combinations of Injection timing and Injection pressure

S.No	Injection timing (°CA bTDC)	Injection pressure (bar)
1	23	210
		220
		230
		240
2	21	210
		220
		230
		240
3	19	210
		220
		230
		240
4	17	210
		220
		230
		240

4.2.1 Brake Specific Fuel Consumption

A graph is presented Fig.4.1, which shows the variation of BSFC while varying the Injection pressure for different Injection timings. For Injection pressure of 230 bar and 21°CA the BSFC is least compared to other combinations and is measured to be 0.315 kg/kwh. The reason for similar results is the better atomization leads to effective utilization of fuel-air mixture and better combustion can be realized which result a reduction in BSFC eventually. Whilst relatively a poorer mixing formation with lower Injection pressure consume more fuel quantity to generate same power output. It is observed from Fig.4.1 that the trend of BSFC versus Injection timing is similar to the trend of BSFC versus Injection pressure. At all Injection pressure, BSFC decreases with increase in injection advance, reaches a lower value and then start increasing with further increase in injection advance.



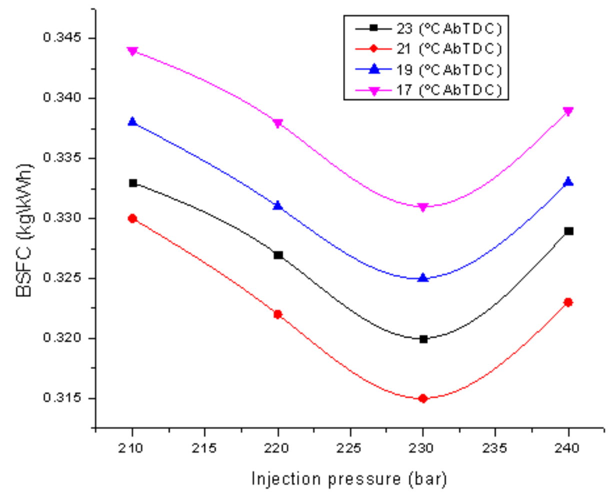
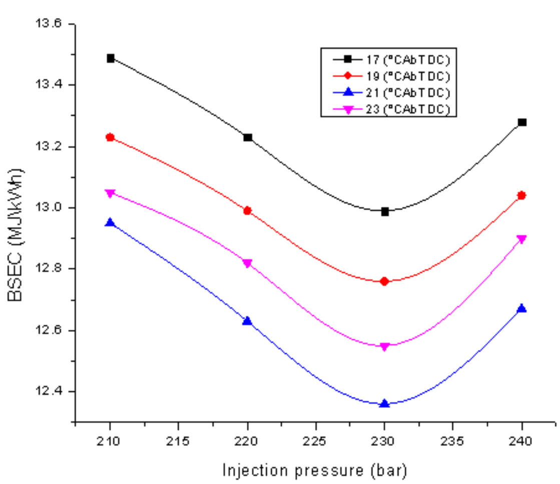


Fig.4.1 Brake Specific Fuel Consumption vs Injection pressure At different Injection timings

Fig.4.2 Brake Specific Fuel Consumption vs Injection timing at different Injection pressure

4.2.2 Brake Specific Energy Consumption:

The trend of variation of BSEC with Injection pressure at varied Injection timings and variation of BSEC while varying the Injection timing at varied Injection pressure are depicted in Fig.4.3 and Fig.4.4 respectively. It is clearly observed from Fig.5.24 and Fig.5.25 that the trend of BSEC with Injection pressure and Injection timing is as similar as the trend of BSFC.



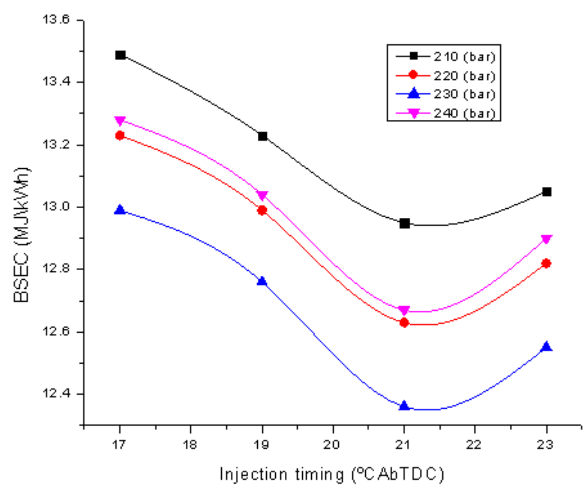
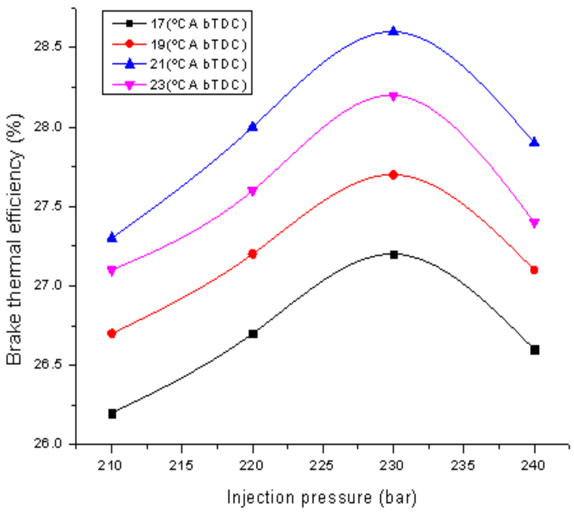


Fig.4.3 Brake specific energy consumption vs Injection timing at different Injection pressure

Fig.4.4 Brake specific energy consumption vs Injection pressure at different Injection timings

2.3 Brake Thermal Efficiency

The Brake Thermal Efficiency of Sunflower Bio Diesel with Preheating at different test conditions illustrate the variation of Brake Thermal Efficiency with varied Injection pressure and Injection timing respectively.



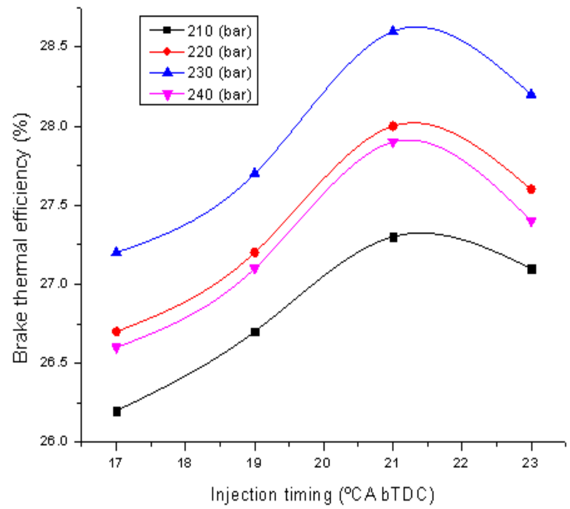


Fig.4.5 Brake specific energy consumption vs
vs Injection pressure at different Injection
Injection pressure

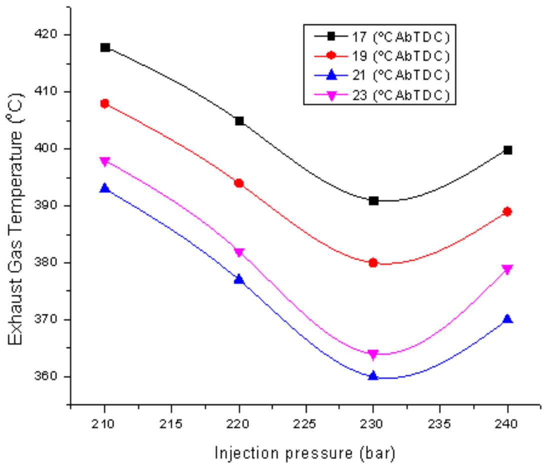
Fig.4.6 Brake specific energy consumption
Injection timing at different
timings

It is observed from Fig.4.6 that the efficiencies compared at 230 bar Injection pressure are 27.2%, 27.7%, 28.2% and 28.6% for the variation of Injection timings 17 deg bTDC, 19 deg bTDC, 23 deg bTDC and 21 deg bTDC respectively. Maximum thermal efficiency is possible for 21 deg bTDC and 230 bar Injection timing only which are obviously the optimized values for the use of Sunflower Biodiesel with preheating.

4.2.4 Exhaust Gas Temperature

Exhaust Gas Temperature is measured to have an idea on the amount of energy utilization by the engine from the burning of fuel. Higher the value of Exhaust Gas Temperature the lower the Brake Thermal Efficiency. The change in Exhaust Gas Temperature with change in Injection pressure at varied Injection timings is presented in Fig.4.7 It is observed from Fig.4.8 that the trend of temperature of exhaust gas with Injection pressure is exactly opposite to trend of Brake Thermal Efficiency with Injection pressure. As stated the lower Exhaust Gas Temperature indicates a higher thermal efficiency due to more energy utilization and vice versa. And therefore the Exhaust Gas

Temperature decreases with Injection pressure, reaching a lowest value and increases with successive increase in Injection pressure.



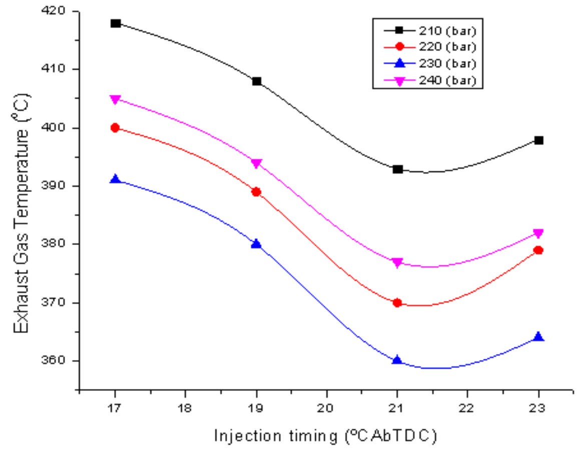
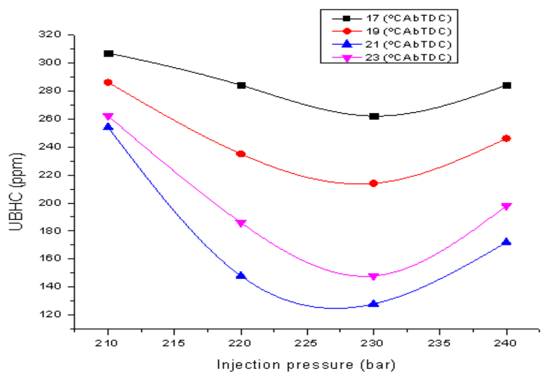


Fig 4.7 Exhaust gas temperature at different timings injection pressure

Fig 4.8 Exhaust gas temperature at different injection

4.2.5 Oxides of Nitrogen

The formation of NOx is favored by higher combustion temperatures and availability of more oxygen. The variation of Nox with Injection pressure at different Injection timings is shown in Fig.4.9. Similarly, Fig.4.10 illustrates the variation of Nox with Injection timing at varied Injection pressure. From the Fig. 4.9 it is noted that the Nox emissions are 1709 ppm, 1801 ppm, 1882 ppm and 2015 ppm for varied Injection timings 17 deg bTDC, 19 deg bTDC 23 deg bTDC and 21 deg bTDC respectively. A similar trend can be found from the Fig.5.31 for variation of Nox with Injection timing at different Injection pressure. Nox increases with increase in injection advance.



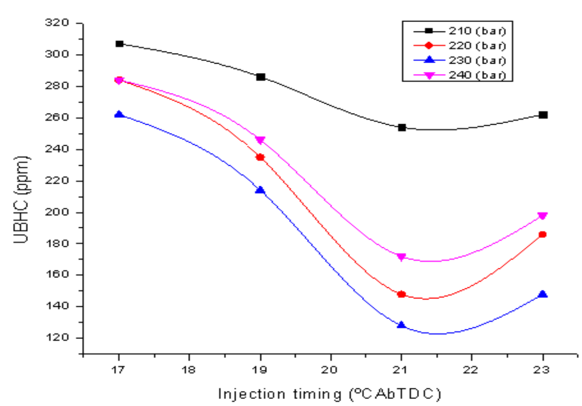


Fig 4.10 nox vs injection pressure at different injection pressure

Fig. 4.11 nox vs injection timing at different timings

4.2.6 Unburned Hydrocarbons

Figure 4.12 illustrates the variation of Un Burned Hydro Carbons with Injection pressure at varied Injection timing. The change in Un Burned Hydro Carbons with Injection timing at varied Injection pressure is depicted in Fig.4.13.

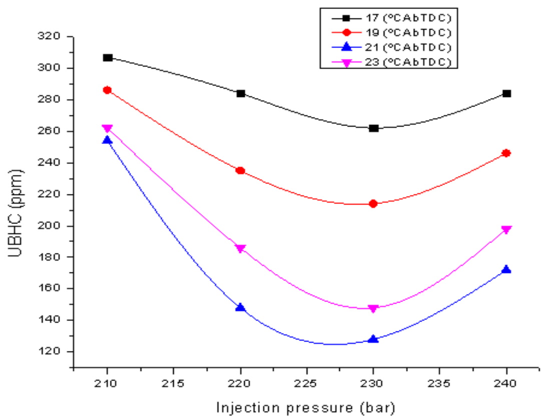


Fig.4.12 UBHC vs Injection pressure at different Injection Pressure

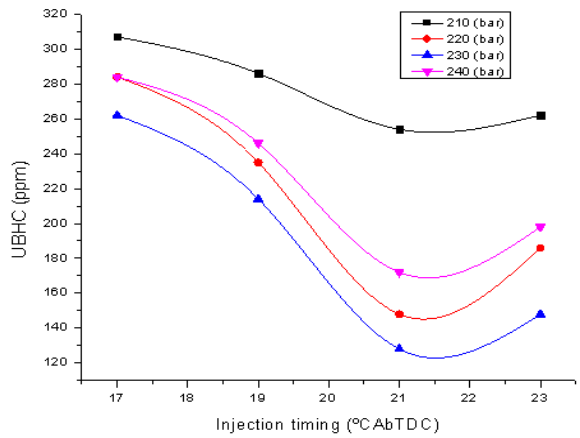
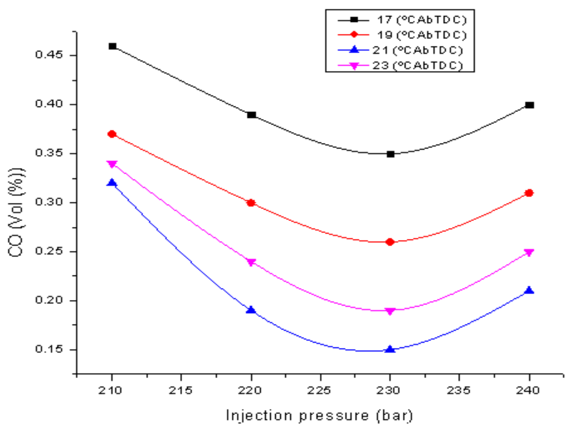


Fig.4.13 UBHC vs Injection timing at different Injection timing

The effect of Injection pressure on Un Burned Hydro Carbons at a given Injection timing for Sunflower Bio Diesel is investigated. The Hydrocarbon descends with increase in Injection pressure for all the attempted Injection timings. Depending on the increase in Injection pressure, fuel droplet size becomes smaller and air fuel mixture formation becomes better. Hence reduction in Hydrocarbon s is obtained when the Injection pressure is increased. The unburned Hydrocarbon emission starts increasing from 230 to 240 bars.

4.2.7 Carbon Monoxide

The CO is minimum i.e., 0.15 % by volume for the optimum design parameters of Injection timing (21 deg bTDC) and Injection pressure (230 bar)", "The trends of CO with Injection pressure and Injection timings are similar to the trend of unburned Hydrocarbon s with Injection pressure and Injection timing respectively.



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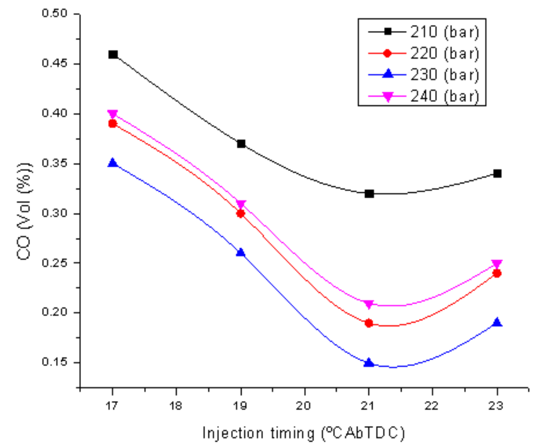

4.13 CO vs Injection pressure at different Injection timings **Fig.4.14 CO vs Injection timing at different Injection pressure**

It is observed from Fig. 4.14 that CO decreases from 210 to 220 bar, and reaches minimum at 230 bar of Injection pressure . This is believed due to larger rich mixture regions that results in increased CO eventually. In sprays, both fuel lean and rich regions may contribute to CO emission.

4.2.8 Smoke

Smoke is emitted as a product of the incomplete combustion process, particularly at higher loads. Smoke particles are formed from the fuel deposited on walls, especially under elevated loads. The variation of smoke with varied Injection pressure and varied Injection timings is presented in Fig.4.15 and Fig.4.16 respectively. The smoke is found to be lowest i.e., 2.0 BSU for the optimum values reffered. Hence by optimizing these parameters a reduction of 0.7 BSU of smoke is noticed compared do the use of preheated Sunflower BioDiesel in the engine with standard operating Injection timing and pressure.

The Smoke decreases with increase in Injection timing and reaches to a minimum value as like with the Injection pressure, and subsequently increases with advance in Injection timing. from the discussions of the results it is desirable to arrive at the suitable Injection timing and also the Injection pressure to get the best performance of the engine as well as to minimize the emissions. For this purpose combustion, performance, and emission parameters at different Injection timing and Injection pressure presented in the matrix. Table4.4 tabulates qualitative results on the characteristics of performance, combustion, and emissions for varied Injection timings and Injection pressure.

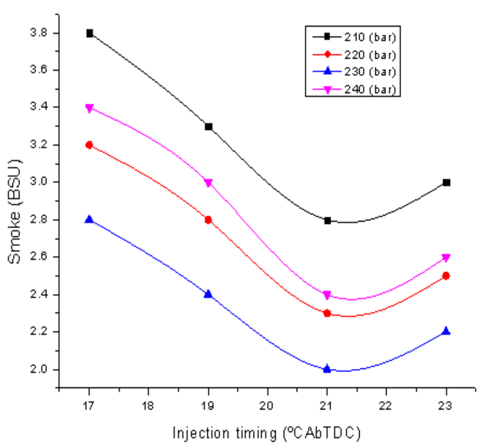

Fig.4.15 smoke vs injection pressure at different injection timings

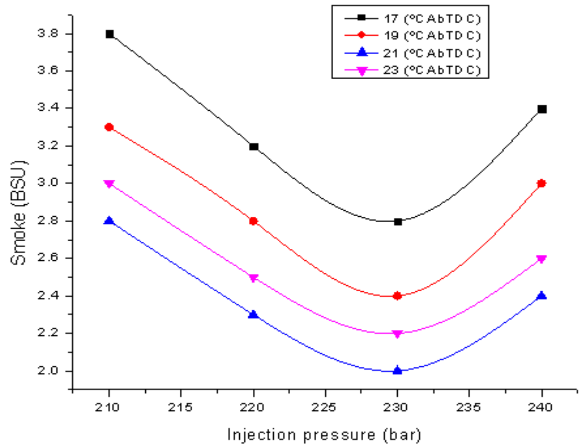

Fig.4.16 smoke vs injection timing at different injection pressure

Parameters	Desired value	Minimum value at	Maximum value at
Ignition delay	Lower	17ºCA bTDC 240bar	21ºCA bTDC 210bar
Peak pressure	Higher	17ºCA bTDC 210bar	21ºCA bTDC 230bar
BSFC	Lower	21ºCA bTDC 230bar	17ºCA bTDC 210bar
BSEC	Lower	21ºCA bTDC 230bar	17ºCA bTDC 210bar
Brake Thermal Efficient	Higher	17ºCA bTDC 210bar	21ºCA bTDC 230bar
Exhaust Gas Temperature	Lower	21ºCA bTDC 230bar	17ºCA bTDC 210bar
NOx	Lower	17ºCA bTDC 210bar	21ºCA bTDC 230bar
UBHC	Lower	21ºCA bTDC 230bar	17ºCA bTDC 210bar
CO	Lower	21ºCA bTDC 230bar	17ºCA bTDC 210bar
Smoke	Lower	21ºCA bTDC 230bar	17ºCA bTDC 210bar

Lower ignition delay is desirable for the sake of avoiding accumulation of unburned fuel towards the end of combustion which is the main cause for detonation.

CONCLUSIONS

Experimental investigation has been carried out to study the combustion characteristics of a diesel engine and the results were compared with injection timing. Based on this experimental work the following conclusions are made.

- Brake thermal efficiency of diesel is observed to be 30.25%, 32.5%, 31.1% and 31% at peak power output when the injection timing was maintained at 25^{o} BTDC, 27^{o} BTDC, 29^{o} BTDC and 31^{0}BTDC.

- Smoke emission of diesel is observed to be 12%, 10.59%, 11.24% and 11.38% at peak power output when the injection timing is maintained at 25^o BTDC, 27^o BTDC, 29^o BTDC and 31^o BTDC.
- Brake thermal efficiency of methyl ester of sunflower oil is observed to be 30.25%, 32.3%, 33.1% and 32% at peak power output when the injection timing is maintained at 25^o BTDC, 27^o BTDC, 29^o BTDC and 31^o BTDC.
- Smoke emission of methyl ester of sunflower oil is observed to be 7.19%, 7.55%, 7.21% and 7.2% at peak power output when the injection timing is maintained at 25^o BTDC, 27^o BTDC, 29^o BTDC and 31^o BTDC.
- CO emissions do not vary much different injection timings.
- NO_X emission is observed to increase with advancement of injection timings.
- Hence, it is concluded that the optimum injection timing may be taken as 27^o BTDC for diesel and 29^o BTDC for methyl ester of sunflower oil for better performance in CI engine.

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