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Simultaneous reduction of NOx and smoke emission of CI engine fuelled with biodiesel

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ABSTRACT

In the present work an attempt was made to reduce the NOx and smoke emission of CI engine fuelled with biodiesel through combined effect of fuel injection timing and EGR. Fuel injection timing was advanced to inject the fuel well before the manufacturers recommended injection timing and exhaust gases were introduced at this timing and their combined effect on performance and emission parameters of the engine were investigated. Significant reduction in smoke density was observed at the advanced injection timing with increased NOx emission. It was also observed that when exhaust gases were admitted at advanced injection timing, NOx emission of the engine was decreased with marginal increase in smoke density. This increased smoke density resulted from EGR was marginally higher than the smoke density of the engine at standard injection timing.

Keywords: *diesel engine, injection timing, EGR, NOx, smoke density*

1. Introduction

Compression ignition (CI) engines play an important role in energy sector of any country due to their higher thermal efficiency. However NOx and smoke emissions of these engines are comparatively higher than gasoline engines. When biodiesel was utilized as an alternate to diesel, smoke emission was reduced significantly with increase in NOx emission [1-5]**.** Investigations were carriedout to control the NOx and smoke emission of CI engine through modification of combustion process [6-13]. Combustion modification methods include modification of fuel injection timing (advance or retard), exhaust gas recirculation (EGR), fumigation etc.[14]. It was reported that NOx and smoke emission are indirectly proportional to each other. At higher temperature NOx emission will be higher with reduced smoke and at lower temperature it will be the reverse. NOx and smoke mission of CI engine were controlled with an increase of other one and loss in thermal efficiency. Hence there is a need of a method to reduce the smoke and NOx emission of the CI engine with less sacrifice on the other and thermal efficiency.

In the present work combined effect of advanced injection timing and EGR were investigated to reduce both NOx and smoke emission simultaneously. Fuel injection timing is advanced to inject the fuel before the manufactures recommended (standard) injection timing. As a result of this, NOx emission of the engine may increase. Exhaust gases were introduced at this advanced injection timing and its effect on NOx and smoke emission of the engine was investigated by admitting exhaust gases at different rates.

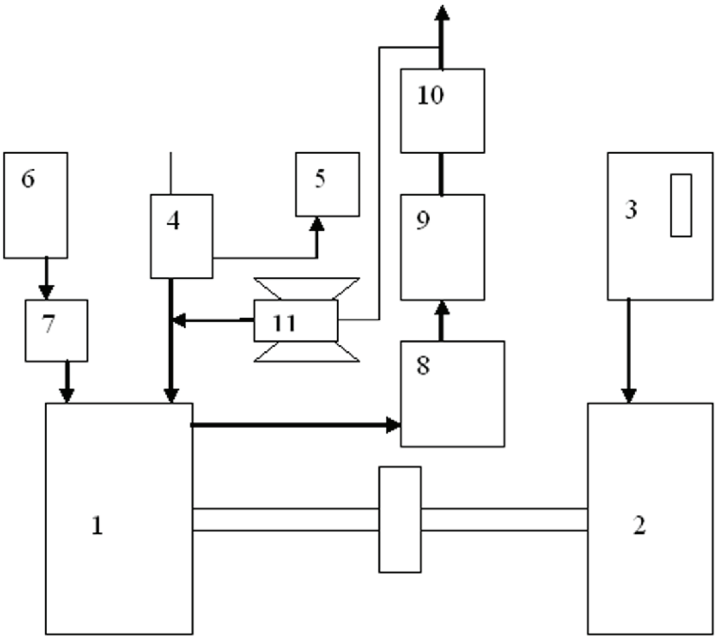
2. Materials and methods

2.1 Fuel injection timing

The start of fuel injection was determined at static conditions using spill method. Fuel injection pump outlet was disconnected and connected to a goose neck specially designed for this purpose. By slowly rotating the flywheel, the fuel was made to spill out from the tube. The flywheel was provided with divisions on its circumference. The distance of the spill out point from the top dead centre (TDC) position on flywheel was converted into degrees as start of fuel injection angle. By varying the number of shims under the fuel injection pump the static fuel injection timing was changed. To advance the fuel injection timing the shims under the fuel injection pump were removed. Maximum advance of fuel injection timing was taken as 2.5 degree of crank angle (CAD) from the standard injection timing. Further advancing the injection timing was resulted in increase of the NOx emission [7, 15].

2.2 Experimental setup

Tests were conducted on the engine incorporated with cooled EGR. The schematic of the experimental set-up is shown in Figure 1. The technical specifications of the engine used in the investigation are given in Table 1.



1.Diesel Engine 2.Electrical dynamometer 3.Dynamometer controls 4.Air Box
5.U Tube Manometer 6.Fuel tank 7.Fuel measurement 8.Exhaust gas analyzer
9.AVL smoke meter 10.Pulse reducer 11.EGR control value

Figure 1 Experimental set up

A piping arrangement was provided that connected the exhaust pipe and inlet air flow passage. The length of the piping arrangement was 8 m and the starting point of the arrangement in the exhaust pipe was 10 m away from the engine. This reduced the temperature of the exhaust gases approximately equal to that of the ambient air without any additional cooling arrangement. This was ensured by measuring the temperature of the recycled exhaust gases by using a thermocouple**.** The flow rate of the exhaust gases through the pipe was controlled by a control valve which regulates the quantity of exhaust gases. The temperature of the mixture was measured by using a K type thermocouple. Pressure difference in the ‘U’ tube manometer was used to obtain the volume of air replaced by exhaust gases from which the percentage EGR was calculated on volume basis. The percentage EGR was calculated using equation (1)

$$\text{Percentage EGR} = \frac{\text{volume of air without EGR} - \text{volume of air with EGR}}{\text{volume of air without EGR}} \text{X100} \quad (1)$$

From the earlier research work it was found that beyond 15 % EGR, smoke emission of the engine increases [6, 9, 10, 12]. To reduce the increase in smoke emission resulted from EGR the maximum percentage of EGR was limited to 15 %. To critically analyse the effect of EGR on NOx and smoke emission tests were conducted with 10 % of EGR also.

Table 1 Specifications of engine

Make	Kirloskar
Model	TAF 1
Type	Direct injection, air cooled
Bore × Stroke (mm)	87.5 × 110
Compression ratio	17.5:1
Cubic capacity	0.661 lit
Rated power	4.4 kW
Rated speed	1500 rpm
Start of injection	23.4° bTDC
Injector opening Pressure	200 – 205 bar

2.3 Test procedure

Tests were conducted on the engine fuelled with biodiesel. Biodiesel prepared by using used cooking oil was utilized as a fuel for the present investigation. Measured properties of used cooking oil methyl ester (UCME) and diesel are shown in Table 2. Fatty acid profile of the UCME taken from the literature is given in Table 3.

Table 2 Properties of UCME compared with diesel

Fuel property	Diesel	UCME	ASTM D 6751-07b
Viscosity at 40°C (mm^2/sec)	3.522	4.73	1.9 - 6
Flash point (°C)	70	142	130min.
Calorific value (kJ/kg)	43356	38650	~38912.7
Specific gravity	0.8	0.89	0.88

Table 3 Fatty acid profile of UCME [16]

Fatty acid	Percentage by volume
Palmitic	7.4
Stearic	3.4
Oleic	41.4
Linoleic	46.6
others	1.2

The engine was operated with the combination of injection timing and EGR as given in Table 4. The tests were conducted at a constant speed of 1500 rpm. In each trial, the engine was tested at various loads starting from no load to full load and at each load the responses (NO_x emission in ppm, smoke concentration in mg/m^3, mass flow rate of fuel in kg/sec) were measured. NO_x emission was measured with MRU(manufacturer name) 1600 exhaust gas analyzer and the smoke concentration was measured with AVL(manufacturer name) smoke meter.

Table 4 Combination of injection timing and EGR

Exp.No	Injection timing	Percentage EGR
1	Standard Timing (23.4 bTDC)	0
2	Advanced Injection timing (25.9 bTDC)	0
3	Advanced Injection timing (25.9 bTDC)	10
4	Advanced Injection timing (25.9 bTDC)	15

3. Results and discussion

Combined effect of injection timing and EGR on the performance and emission characteristics of CI engine fuelled with UCME was presented by comparing the same with normal operating condition (performance and emission measured at standard injection timing (std. timing) without EGR).

3.1 Brake thermal efficiency

Variation of brake thermal efficiency (BTE) with load at advanced injection timing and at different percentage of EGR for UCME is shown in Figure 2 by comparing them with the BTE at standard injection timing. As the load on the engine increases BTE also increases. A marginal decrease in BTE was observed for UCME at advanced injection timing. Advancing the injection timing initiates the combustion earlier than standard injection timing which may lead to a significant pressure rise before top dead centre (TDC) and may also contribute to increased compression work and heat loss resulting in a decreased BTE [17]. It was also observed that as a result of EGR, the BTE of the engine was increased by about 7 % at the advanced injection timing. This increase in BTE was due to the re-burning of unburnt hydrocarbons present in the EGR [10].

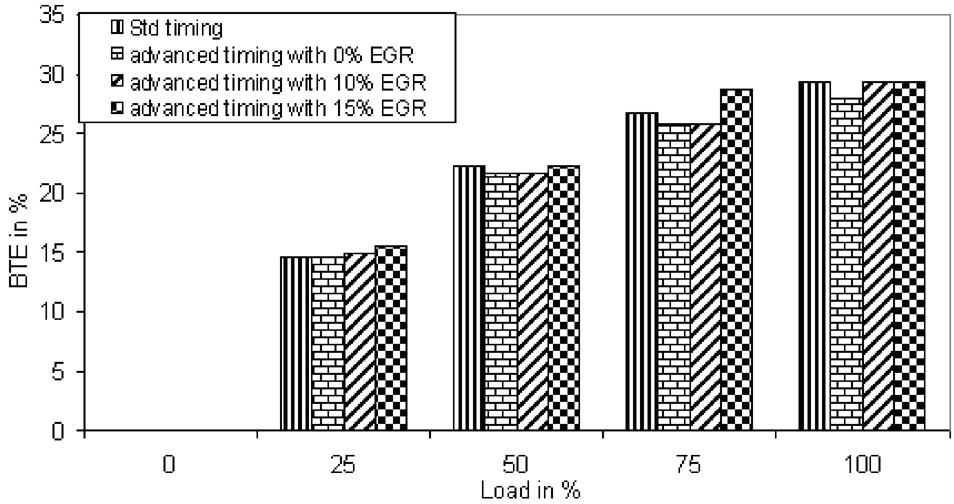


Figure 2 Effect of advanced injection timing with EGR on brake thermal efficiency

3.2 Nitrogen Oxides (NOx)

Variation of NOx with load at advanced injection timing and at different percentage of EGR for UCME is shown in Figure 3 by comparing them with the NOx at standard injection timing. It can be observed that NOx emission of the engine was increases with load. This is due to the increase in richness of the mixture with increase in load as a result of increased fuel injection quantity with constant air supply. It can also be observed that NOx emission at the advanced injection timing was significantly higher than that of the standard injection timing. When the injection timing is advanced it also advanced the start of combustion which increases the peak combustion temperature and hence the NOx emission. When EGR is introduced at this timing, considerable reduction in NOx was observed. Introducing exhaust gases reduced the availability of oxygen and reduced the temperature of the burned gases which resulted in lower NOx emission. From the figure 3 it is clear that the reduction in NOx emission is inversely proportional to the percentage of EGR. It is also clear that the increase in NOx emission resulted from the combined effect of injection timing and EGR is marginal when compared to the NOx emission of UCME at standard injection timing.

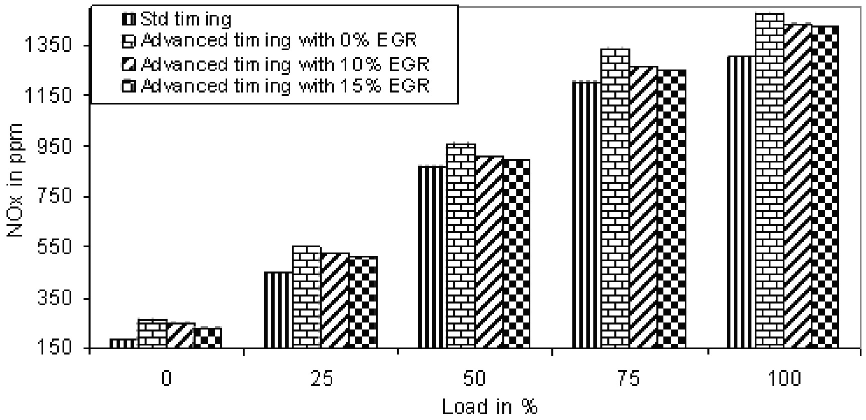


Figure 3 Effect of advanced injection timing with EGR on NOx emission

3.3 Smoke density

Figure 4 shows the variation of smoke density with respect to load at advanced injection timing and at different percentage of EGR by comparing them with that of standard injection timing. As the load on the engine increases smoke density also increases. It was observed that when compared to standard injection timing the smoke density of the UCME was lower by about 48 %. As a result of a earlier combustion due to the advanced fuel injection, the duration of the compression stroke after initiation of combustion is longer than that of standard injection timing. This causes compression of combustion products which increase the peak temperature attained in the cylinder [18]. Since the fuel vapourization is a function of temperature, better fuel vapourization at this higher temperature resulted in lower smoke density at advanced injection timing. Introducing exhaust gases at the advanced injection timing reduced the peak temperature of the cylinder and hence increased the smoke density of UCME. It was also observed that when compared to standard injection timing the percentage increase in smoke density resulted from EGR at the advanced injection timing is marginal.

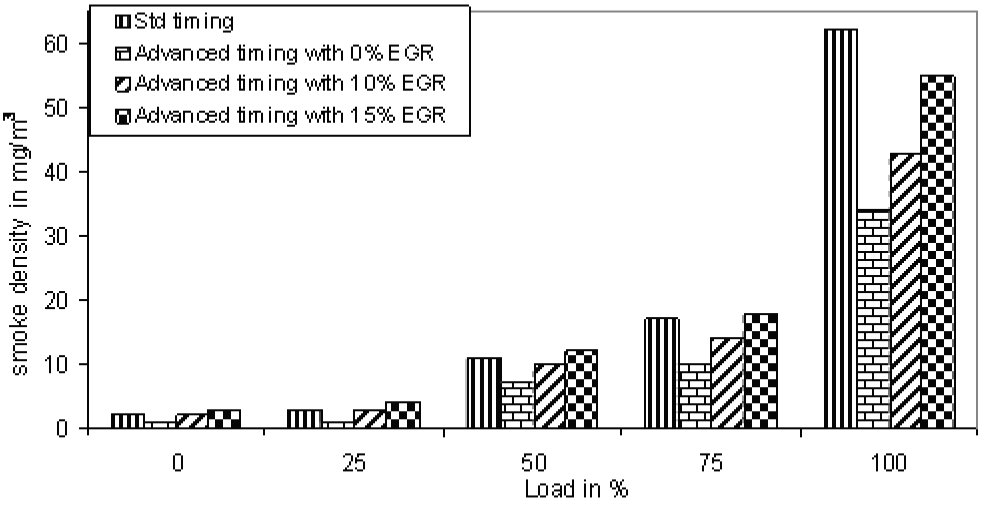


Figure 4 Effect of advanced injection timing with EGR on smoke density

3.4 UBHC emission

Variation of unburnt hydrocarbons (UBHC) emission with load at advanced injection timing and at different percentage of EGR for UCME is shown in Figure 5 by comparing them with the UBHC at standard injection timing. It was observed that the UBHC emission increases with load. A decrease in UBHC emission of about 18 % was also observed for UCME at advanced injection timing with out EGR. As a result of higher temperature exist in the combustion chamber thermal oxidation will be enhanced which leads to a reduction in UBHC emission. As a result of EGR at advanced injection timing, UBHC emission of UCME was increased by about 12 % and 31 % at 10 % and 15 % EGR respectively. It can also be seen that when compared to standard injection timing, UBHC emission at advanced injection timing and 10 % EGR is lower by about 10 % and at is higher by a marginal percentage of 5 %. at 15 % EGR.

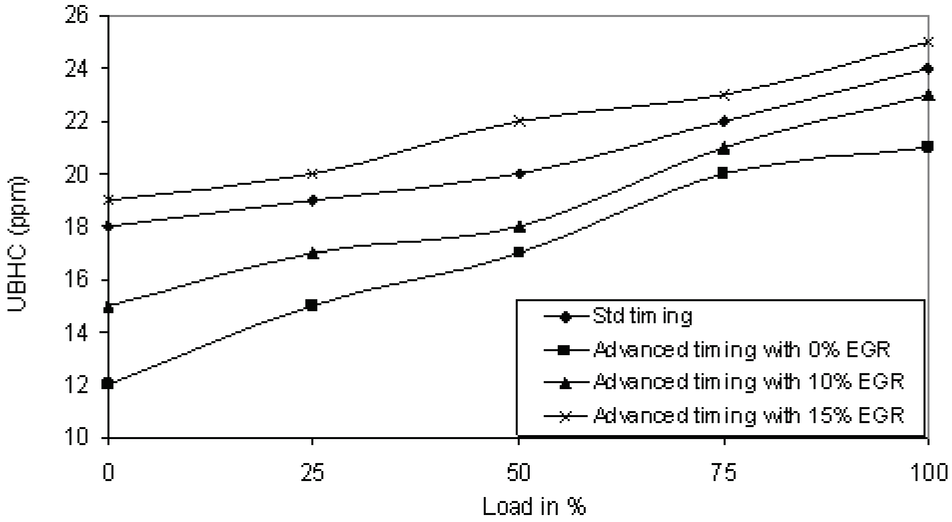


Figure 5 Effect of advanced injection timing with EGR on UBHC emission

3.5 Exhaust gas temperature

Variation of exhaust gas temperature (EGT) with load at advanced injection timing and at different percentage of EGR for UCME is shown in Figure 6 by comparing them with the EGT at standard injection timing. It was observed that as the load increases, EGT also increases. As a result of advanced injection timing EGT of UCME was increased significantly. Advancing the injection timing resulted in earlier start of combustion and hence higher combustion temperature which in turn results in higher EGT. Recycling the exhaust gases into the engine cylinder reduced the combustion temperature which resulted in decrease of EGT for UCME. The percentage decrease in EGT with respect to percentage of EGR is marginal.

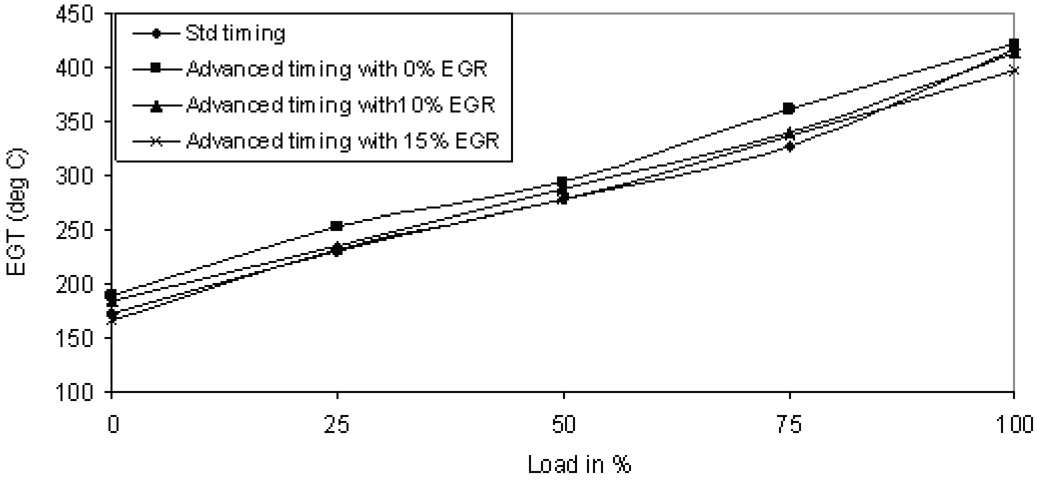


Figure 6 Effect of advanced injection timing with EGR on EGT

4. Conclusions

In the present work combined effect of advanced injection timing and EGR on the simultaneous reduction of NOx and smoke emission of a stationary CI engine fuelled with UCME was investigated. From the experimental results following conclusions were drawn.

- NOx emission of the CI engine fuelled with UCME was lower for standard injection timing when compared to advanced injection timing. At the advanced injection timing 15 % EGR produced lower NOx emission.
- As a CI engine fuel smoke density of UCME is lower at advanced injection timing. Smoke density of the CI engine was lower at advanced injection timing with 0 % EGR.
- The increase in NOx emission resulted from the combined effect of advanced injection timing and EGR was marginal when compared to the NOx emission of the engine at standard injection timing.
- Thermal efficiency of the engine was increased marginally when EGR was introduced at the advanced injection timing.
- Through combined effect advanced injection timing and EGR, NOx and smoke emission of CI engine was reduced simultaneously and this work can be extended to optimize the injection timing and percentage EGR for lower NOx and smoke emission.

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