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Influence of injector opening pressures on the performance, emission and combustion characteristics of DI diesel engine running on calophyllum inophyllum linn oil (honne oil)

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Abstract

The present work examines the use of a non-edible vegetable oil namely honne oil, a new possible alternative fuel for diesel engine. The use of neat honne oil (H100) in diesel engine has not been reported in the literature. A direct injection (DI) diesel engine typically used in agricultural sector was operated on neat diesel (ND) and H100. Injector opening pressure (IOP) was changed to study the performance, emission and combustion characteristics. It was observed that increasing the IOP with H100 from the rated injector opening pressure (200 bars) increased the brake thermal efficiency and reduced CO, HC and smoke opacity emissions. However, NO_x emission was increased. With H100, ignition delay decreased as injector opening pressure increased. Improved premixed heat release rate was observed with H100 when the injector opening pressure is advanced. The best IOP is 240 bars with H100 based on brake thermal efficiency.

Key Words: *Neat honne oil, diesel engine, injector opening pressure, performance, emissions, combustion*

1. Introduction

The continuous rise in global prices of crude oil, the increasing threat to environment due to exhaust emissions, the problem of global warming and the supply fuel oil instabilities have adversely impacted the developing countries, to the petroleum importing countries like India. From the point of view of long term energy security, it is necessary to develop new alternative fuels with properties comparable to petroleum based fuels. Vegetable oils are important alternative fuels. The major limitation of vegetable oil is its viscosity, the magnitude of which is higher than that of diesel fuel. High viscosity of the vegetable oil leads to poor fuel atomisation, which in turn may lead to poor combustion, ring sticking, injector cocking, injector deposits, injector pump failure, high nozzle valve opening pressures and lubricating oil dilution by crank case polymerisation [1]. Several investigators [2-9] have reported experimental works on different neat vegetable oil in DI diesel engine without varying injector opening pressure.

1.1 Previous works on use of neat vegetable oils in diesel engine

Performance and emission characteristics of karanja oil and its blends have been found to be comparable to that of mineral diesel [2]. It is observed that for neat orange oil emissions of HC, CO, smoke opacity get reduced whereas NO_x emissions decrease as compared to ND [3]. Herchel et al., [4] used neat vegetable oil and concluded that smoke opacity and NO_x lowered while CO and HC increased.

Silvio et al., [5] demonstrated that use of 100% vegetable oil was possible in DI diesel engine and CO, HC, CO_2, specific fuel consumption were increased and NO_x decreased over a range of operation. With vegetable oil, emissions of CO, HC and SO_x were found to be higher, whereas NO_x and PM emissions were lower compared to ND [6,7]. Wang et al., [8] conducted experiment on vegetable oil. They have reported that at maximum load higher exhaust gas temperature and HC, lower CO and NO_x as compared to ND. The use of 100% vegetable oil at maximum load results in increased brake specific fuel consumption, CO, HC, and CO_2[9].

1.2 Present work

As per the present authors' knowledge use of neat honne oil in diesel engine is not reported in the literature. The objective of the present work is to study, through experiments, the influence of IOP on the performance, emission and combustion characteristics of H100 fed direct injection (DI) diesel engine. A description of honne tree is reported in our previous work [10].

2 MATERIALS AND METHODS

2.1 Fuel characterisation

The properties of H100 and ND were determined as per the methods approved by the Bureau of Indian Standards and the results are tabulated in Table 1. .

2.2 Experimental set up and plan

Experimental tests were conducted on a DI diesel engine, typically used in agricultural sector. The specifications of the engine are given in Table 2. Two fuel tanks were used in the present investigation with switch over arrangement, so that supply of fuel can be changed without stopping the engine operation.

The engine tests were conducted for the entire load range (0 to 100% i.e., 0 to 5 hp in steps of 25%) at constant speed of 1500 rpm. The cooling water temperature was maintained constant (70 to $75^{O}C$). The engine parameters, such as fuel consumption, air consumption, exhaust gas temperature (EGT) and exhaust gas emissions were measured for both fuel samples (ND and H50) thrice and averaged**.** The engine was started with diesel fuel and the data was collected after attaining steady state. Then the experiment was switched over to H100.

The manufacturer specified IOP is 200 bars. Tests were carried out with H100 to optimize the IOP. These experiments were carried out at different IOPs of 200, 220, 240 and 260 bars. The injection timing of 23^{o} bTDC was kept the same through the experimental work. The exhaust gas composition was analysed by using exhaust gas analyzer (make: MRU, Germany, model: DELTA 1600 S) and smoke opacity was measured using smoke opacity meter (make: MRU, Germany, model: Optrans 1600).

In cylinder pressure and top dead centre (TDC) signals were acquired and stored on a high speed computer based digital data acquisition system. The data from 100 consecutive cycles were recorded (hard ware is designed to take the data up to 300 consecutive cycles). These were processed with specially developed software to obtain combustion parameters like, rate of pressure rise, maximum rate of pressure rise, occurrence of maximum rate of pressure rise, net heat release rate, maximum net heat release rate, occurrence of maximum net heat release rate, second derivative of rate of pressure rise, start of combustion, estimated end of combustion, delay period and combustion duration.

3. Results and discussion

3.1 Fuel properties and characteristics

The composition of H100 oil is reported in our previous work [10]. The viscosity of honne oil is 32.47 cSt at 40^{O}C whereas at 100 ^{O}C the viscosity is 9.09 cSt. At high temperatures the viscosity falls to below 10 cSt which reduces the atomisation problem. Density of honne oil is slightly higher than ND. The flash point of H100 is better than ND. Presence of oxygen in oil improves combustion and reduces emissions but decreases the heating value of the oil. The heating value of honne oil is approximately 90% of the value of ND but is comparable with other vegetable oils as reported by Rakopoulos et al., [11].

3.2 Effect on performance parameters

In this section the experiments conducted using ND and H100 are reported and discussed.

Fig. 1 shows the brake thermal efficiency of ND and H100 at different loads at different IOP. There is a steady increase in brake thermal efficiency for all the IOPs as load increases in ND and H100 operation. With H100, maximum brake thermal efficiency is corresponding to IOP of 240 bars, however less than ND. High IOP means the injection always takes place at high pressure and hence atomisation is better and mixing with air is good leads to better combustion and in turn improves brake thermal efficiency. It is also to be noted that the oxygen present in the H100 molecules take part in combustion which in turn enhances the combustion process.

With H100 and IOP of 260 bars, brake thermal efficiency decreased compared to IOP of 240 bars. As IOP increased drop let size decreased. A smaller droplet will have lesser momentum and its relative velocity decrease in air resulting in its partial suffocation by its own products of combustion.

Variation in EGT with loads at different IOPs is shown in Fig. 2. EGT of H100 is highest at 200 bar where the thermal efficiency is lowest. This is due to sluggish combustion at lower IOP will lead to increased EGT. During premixed combustion phase low heat release rate was observed (Fig. 8). Major portion of the heat is released during the diffusion combustion phase which could not be converted into work

3.3 Effect on emission parameters

The HC and CO emissions of both fuels were lower in partial engine load, however, increased at higher engine load as shown in Fig. 3 and 4 respectively. This is due to relatively less oxygen available for the reaction when more fuel is injected in to the engine cylinder at higher engine load. It is observed that CO and HC emissions of H100 drop as IOP increased and reached to a least at 240 bars. This is due to increased atomisation lead to better spray and combustion also due to a lower ignition delay (Fig. 8). High IOP improves spray characteristics will lead to a lower physical delay period. This will enhance the performance with vegetable oils, which normally have a high ignition delay on account of their high viscosity. The improved spray also leads to better combustion and brake thermal efficiency. CO and HC emissions of H100 at IOP 240 bars are still higher than ND at all loads. The highest IOP i.e., 260 bars leads to an increase in the CO and HC level. The reason is already explained under the section 3.2.

. Figure 5 shows that smoke opacity of H100 steadily drop with increase in the IOP. This is due to improvement in spray leads to improved mixture formation. Smoke opacity at 260 bars over the entire load range is less than ND. As explained in section 3.2, at IOP of 260 bars, smoke opacity should increase due to partial suffocation of its own products of combustion. This requires further investigation.

Figure 6 shows the oxides of nitrogen emission at different IOP at different loads. For both the fuels, NO_x emission increased with load as expected due to increase in cylinder temperature. With H100, NO_x emission increases with increasing IOP. This is due to faster combustion and higher temperatures reached in the cycle. Even though EGT of H100 at 200 bars is high, NO_x is least. Higher EGT is due to sluggish combustion i.e., major portion of heat is released during later part of diffusion phase combustion (Fig. 6). This heat is insufficient to produce NO_x.

3.4 Combustion characteristics

Cylinder pressure crank angle variation at maximum load with ND and H100 at different IOPs is given in Fig. 7. H100 at different IOPs follows the trend similar to the ND pressure diagram at rated IOP. The cylinder peak pressure is highest with ND followed by H100 at IOP of 240, 260, 220, 200 bars. At maximum load, peak cylinder pressure occurred at 360^o with ND, whereas it occurred at 368^o, 366^o, 364^o and 369^o with H100 at IOP of 200, 220, 240 and 260 bars respectively. With H100, as peak pressure moved away from top dead centre, brake thermal efficiency decreased (except for IOP of 260 bars) (Fig. 1) however CO, HC and smoke opacity increased (Fig. 3-5).

Variation of net heat release rate crank angle with ND and H100 at different IOPs at maximum load are shown in Fig. 8. With H100, it indicates improved premixed heat release rates when the IOP is enhanced. Improvement in combustion can be seen as IOP increases from 220 bar and above. This is due to better fuel atomisation. This was seen in the case of performance and emissions also. Reduced smoke levels (less than ND) and increased brake thermal efficiency and NO_x emissions were observed when the IOP is increased. As the IOP increased from 200 bars combustion starts earlier indicating that there is a good reduction in the ignition delay.

4. Conclusions

Based on the experimental work on a DI diesel engine fuelled with ND and H100 the following conclusions are drawn.

With H100, increasing the IOP from the rated value (200 bars) to 240 bars resulted in improvement in performance and emissions due to better spray formation in turn combustion. The following changes were noticed at maximum load.

- Brake thermal efficiency increases from 26.26% to 28.28%.
- CO reduced from 0.28 % to 0.2 % by volume.
- HC reduced from 75 ppm to 65 ppm.
- Smoke opacity reduced from 89% to 82.1%.
- NO_x increased from 648 ppm to 699 ppm.
- A least smoke opacity and maximum NO_x is observed at IOP 260 bars
- An improvement in the heat release rate and reduction in ignition delay were also noticed with increase in the IOP.

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Table 1 Properties of the fuel

Properties	Units	Methods IS 1448	D100	H100	H50
Density at 30^0C,	kg/m^3	P:16	830	910	872
Flash point,	^{0}C	P:69	56	224	72
Kinematic viscosity at 40^0C,	cSt	P:25	3.12	32.47	9.75
Kinematic viscosity at 100^0C,	cSt	P:25		9.09	4.39
Calorific value,	kJ/kg	P:6	43000	39100	41104

Table 2 Engine specifications

Manufacturer	Kirloskar Oil Engines Ltd., India,
Model	TV_SR II, naturally aspirated
Engine	Single cylinder, direct injection diesel engine
Bore / stroke / compression ratio	80 mm / 110 mm / 16.5:1
Speed	1500 rpm, constant
Injection pressure / advance	200 bar / 23^o bTDC
Cylinder pressure (Cp) / line pressure (Fp)	0-200 bar / 0-2000 bar (fixed 45 mm before the injector)
Resolution	0.1 bar for Cp / 1 bar for Fp
Type of sensor	Piezo electric (5000 PSI for Cp and 10000 PSI for Fp)
Response time	4 micro seconds
Sampling resolution	1 degree crank angle
Crank angle sensor	360 degree encoder with a resolution of 1 degree

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Fig. 1 Variation of brake thermal efficiency

Fig. 2 Variation of exhaust gas temperature

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Fig. 4 Variation of HC emissions

Fig. 5 Variation of smoke opacity emissions

Fig. 6 Variation of NO_x emissions

Fig. 7 Variation of cylinder pressure

Fig. 8 Variation of net heat release rate

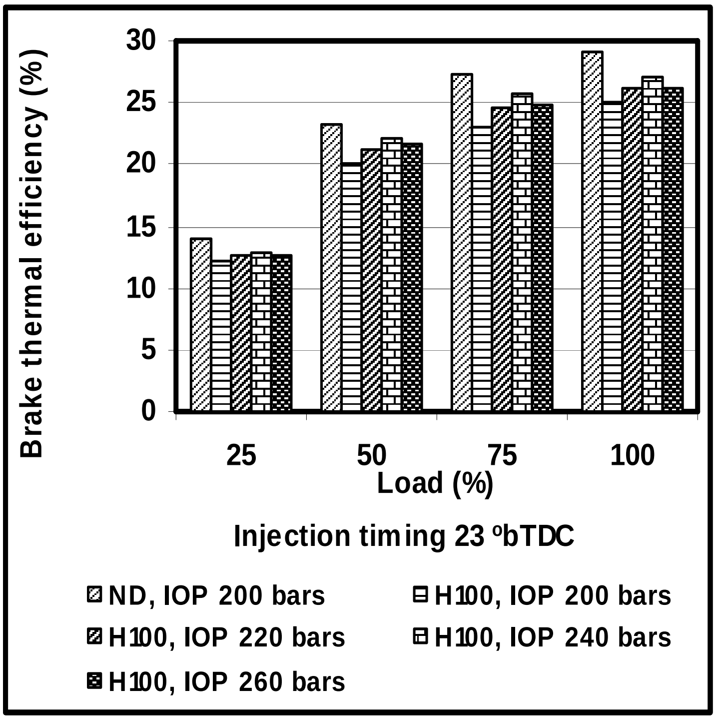

Fig. 1 Variation of brake thermal efficiency

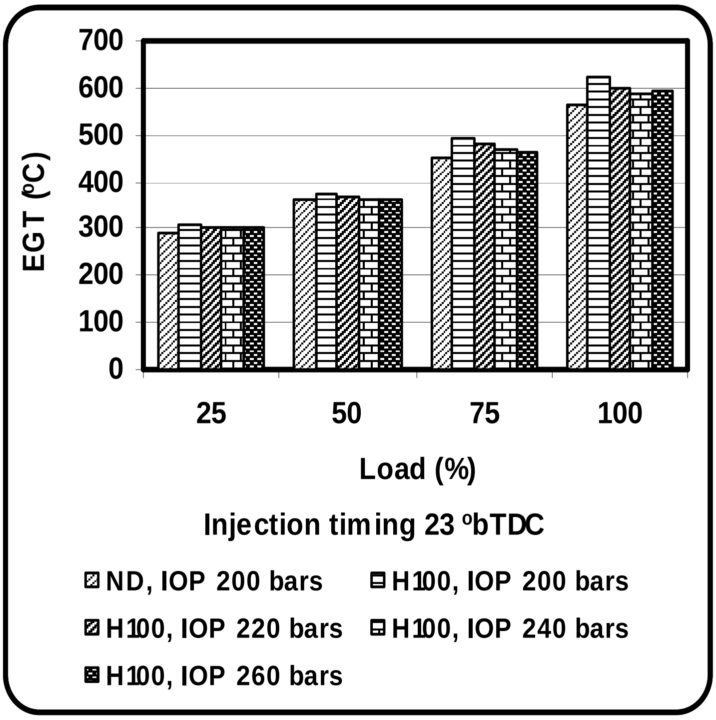

Fig. 2 Variation of exhaust gas temperature

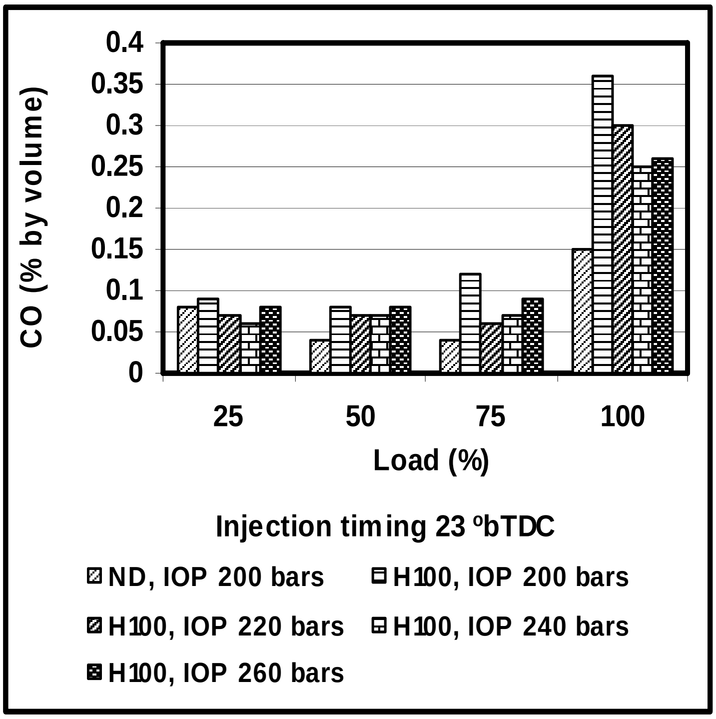

Fig. 3 Variation of CO emissions

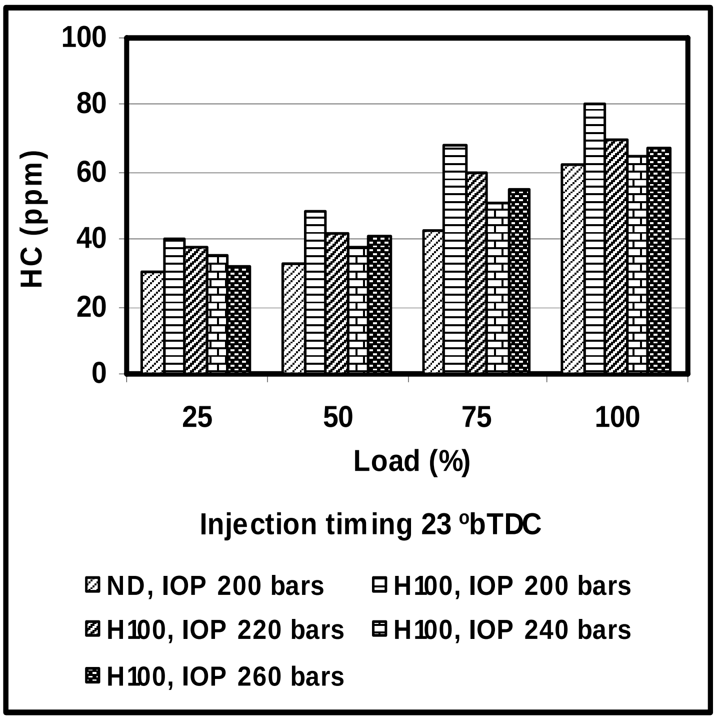

Fig. 4 Variation of HC emissions

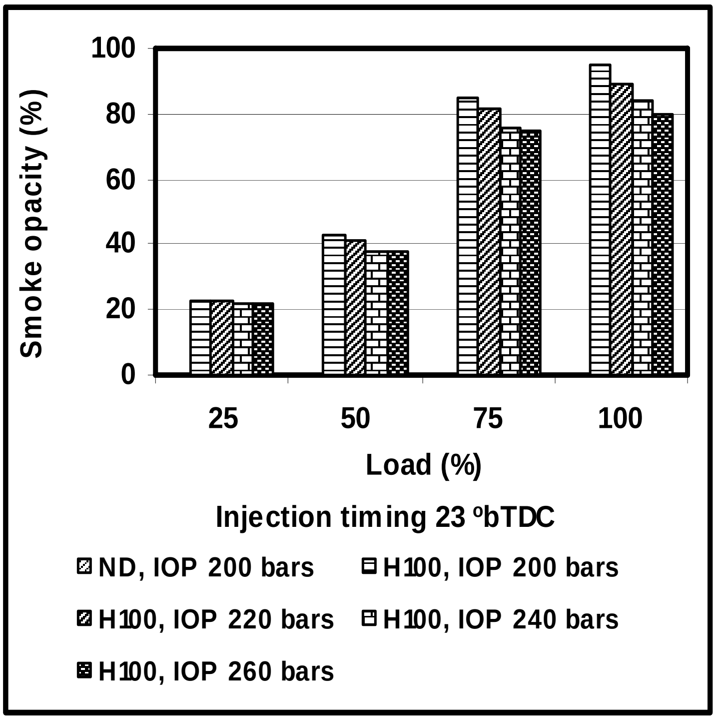

Fig. 5 Variation of smoke opacity emissions

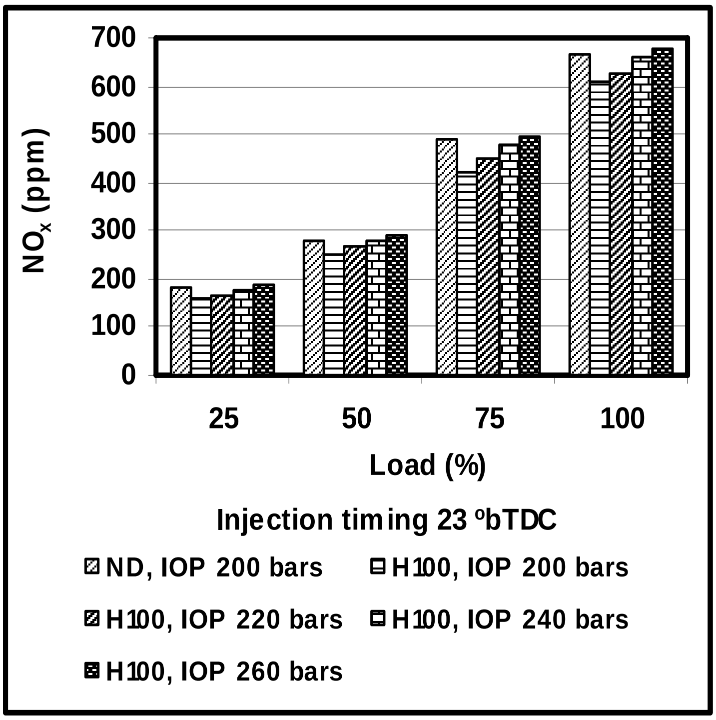

Fig. 6 Variation of NO_x emissions

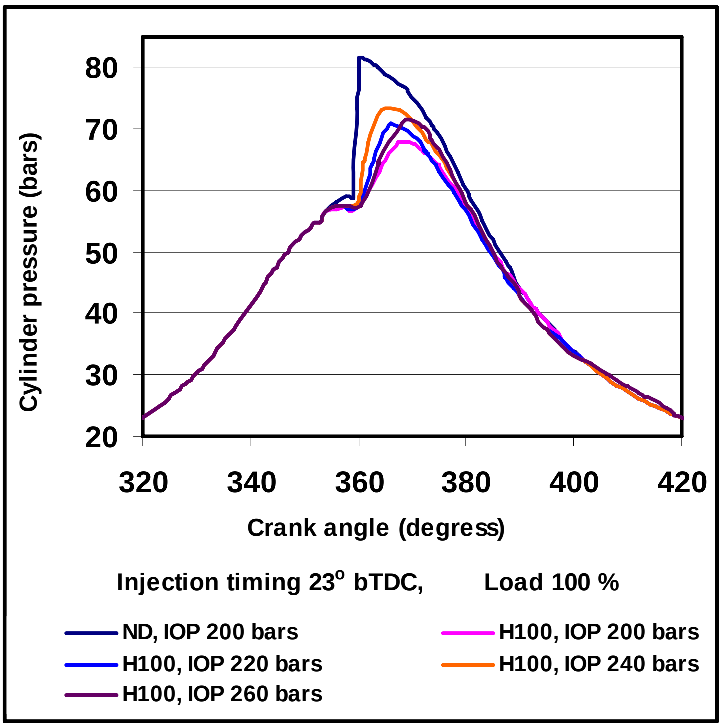

Fig. 7 Variation of cylinder pressure

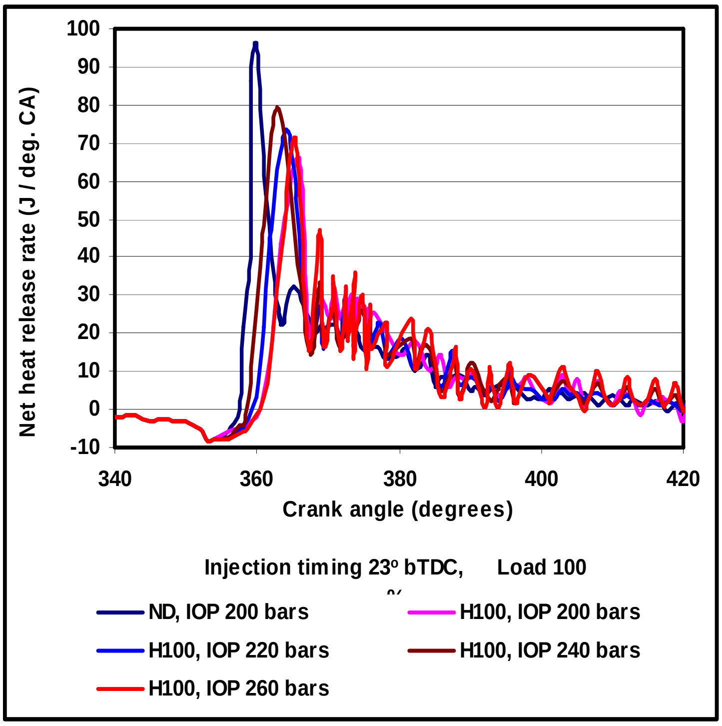

Fig. 8 Variation of net heat release rate