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Effect of fuel injection pressure and air cylinder pressure on ignition lag of direct injection (DI) diesel engine

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Abstract

The effect of fuel injection pressure and cylinder air pressure on ignition lag of direct injection (DI) diesel engine is studied. The combustion characteristic ignition delay at varying cylinder air pressure (15-20 and 25 bar) and fuel injection pressure (100-200 and 300 bar) based on diesel and gasoline. The tests have been performed in a constant combustion chamber with single-hole pintle nozzle which the conditions were similar to real DI engine conditions. The results showed that with increase in cylinder air pressure from 15 to 25 the ignition delay decrease for diesel and gasoline. Also a minimum value of ignition delay was observed at the fuel injection pressure of 300 bar for both fuel at varying cylinder air pressure. It was also found that the combustion duration increases with increase in ignition delay for both fuels, due to more time to mix the fuel and air.
Key words: Ignition Delay, Cylinder Air Pressure, Fuel Injection Pressure, Direct Injection, Pintle Nozzle.

1. Introduction

It is well known that NO_X emission of indirect injection (IDI) engine is lower than direct injection (DI) engine. But the IDI engine is less efficient than the DI engine. This is because the high velocity air motion in the combustion chamber causes high heat transfer rates resulting in greater loss of fuel energy. The lower efficiency of the IDI engine has resulted in it being out-of-favour and although there are a large number of these engines currently being produced, virtually all new engine designs use direct injection technology [1]. The performance and emission characteristics of diesel engines depends on various factors like fuel quantity injected, fuel injection timing, fuel injection pressure, shape of combustion chamber, position and size of injection nozzle hole, fuel spray pattern, air swirl, ambient air temperature, compression ratio, cylinder air pressure and etc. The fuel injection system in a direct injection diesel engine is to achieve a high degree of atomization for better penetration of fuel in order to utilize the full air charge and to promote the evaporation in a very short time and to achieve higher combustion efficiency. The fuel injection pressure in a standard diesel engine is in the range of 200 to 1700 atm depending on the engine size and type of combustion system employed [2]. The objective of present experimental work is an aim to investigate the effect of cylinder air pressure and fuel injection pressure on ignition Lag of DI diesel. The experiments performed at different fuel injection pressures (100-200-300 bar) and cylinder air pressures (15-20 and 25 bar) fueled with diesel and gasoline. Earlier several experimental studies have been investigated the effect of fuel injection pressure on performance, emission and combustion characteristics for the format of DI diesel engine[3].from those study it was found that high injection pressures decreases the injection duration thus maximizing the time available for fuel/air mixing prior to ignition. It was also reported that the implementation of injection pressure has a great effect on the mixture formation, ignition delay, flame pattern, turbulence, then affects to the flame development, combustion characteristics and emissions elements. Low ignition delay and combustion duration were observed at high fuel injection pressure. In a research [4], the effects of mixture formation on ignition and combustion of a multi-hole diesel spray were investigated. The results of testing showed that increasing injection pressures makes spray tip penetration longer and promotes a greater amount of fuel-air mixing occurs during ignition delay as compared at lowest injection pressure (P_{inj}=100 MPa). In another work [5], the combustion duration was decreases by 2-3^0 with increase in compression ratio due to less ignition delay and maximum amount of charge was burnt in the first 20^0 of crank angle rotation during combustion

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stage. In addition a few studies have been investigated the effect of cylinder air pressure and boost pressure on performance of diesel engine [6-7].

2. Experimental Set-Up

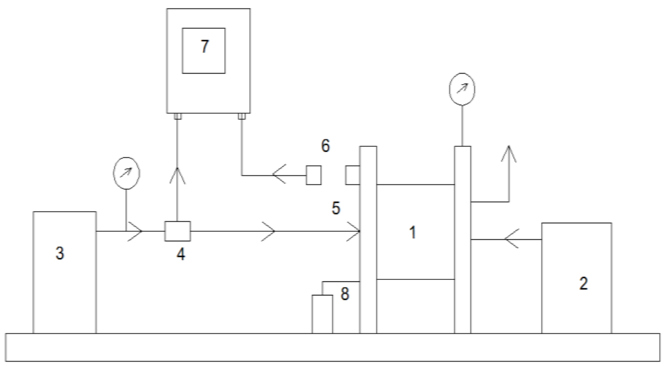

Figure 1: Experimental Set-Up Block diagram.

1. Constant Volume Combustion Chamber
2. Centrifugal Air compressor
3. Fuel injection pump
4. Piezoelectric sensor
5. Single-hole Pintle Nozzle type Fuel Injector
6. Photo sensor
7. Scope Meter
8. Temperature Indicator

The experiments were carried out in a constant combustion chamber whose length is 30 mm, 95 mm and 7.5 mm are its diameter and thickness respectively which is small sample of DI diesel engine. A heating coil was used for increasing the temperature of air with maximum temperature of 1400°C. For entering compressed air (air compressor provides the compressed air) to combustion chamber, one inlet valve is fitted in the combustion chamber. And one exhaust valve is fitted for releasing of exhaust gas. An injector with single-hole nozzle is used for injecting the fuel into the combustion chamber. For measuring the ignition delay a digital storage two channel Scope Meter is used. The Fig. 1 shows the block diagram of present experimental set-up.

2.1 Methodology of Experiment

- Temperature of the combustion chamber is increased by means of heating coil and then compressed air is sent to the combustion chamber by air compressor.
- Fuel injection pump is used to inject the fuel into the combustion chamber through injector (with a single-hole pintle nozzle).
- The injection timing is varied and controlled by handle of fuel injection pump through pintle nozzle and vaporized fuel is injected into the cylinder and after completion of ignition delay, combustion is started. The event is recorded on the digital Scope Meter.
- The event of injection is recorded by using piezoelectric sensor which is fitted on the line of injection system and the event of combustion is recorded by using of photo sensor which is placed in front of optical window.
- Ignition delay is measured in ms by noting the difference between event of injection and that of combustion.
- The ignition characteristics can be observed in the Scope Meter screen by noting the two pulses of photo and piezoelectric sensors.

3. Validation of Analytical Test Results

3.1 Results and Discussion

Ignition delay is very important parameter in combustion phenomenon [7]. The delay period in the compression ignition engine exerts a very great influence on both engine design and performance. It is of extreme importance because of its effect on both combustion rate and knocking and also its influence on engine starting ability and the presence of smoke in the exhaust. The fuel does not ignite immediately upon injection into the combustion chamber. There is a definite period of inactivity between the time when the first droplet of fuel hits the hot air in the combustion chamber and the time it starts through the actual burning phase. This period is known as the ignition delay period [8]. In the present study this period is counted from the start of injection to the start of combustion in ms. Figs. 2 and 3 show the ignition delay with cylinder air pressure from 15 to 25 bar for diesel and gasoline respectively. The pressures are gauge pressure. It is clearly observed from Figs. 2 and 3 that with increase in cylinder air pressure the ignition delay decreases due to the reduction in the physical delay.

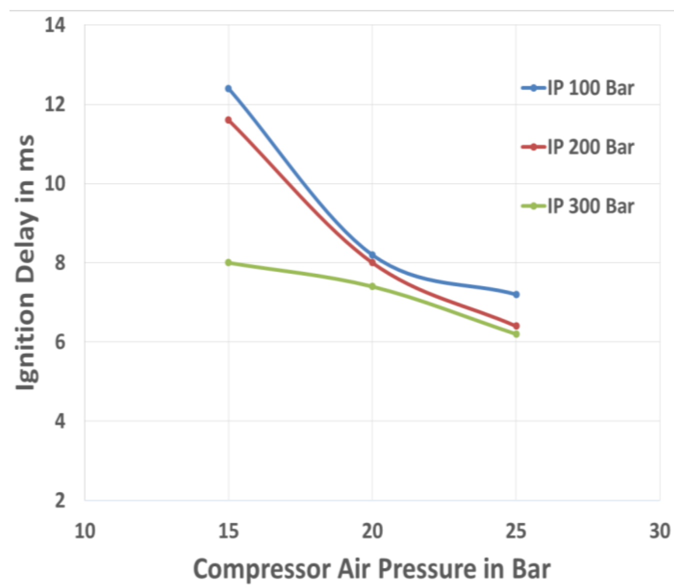

Figure 2: Effect of cylinder air pressure on ignition delay for gasoline engine

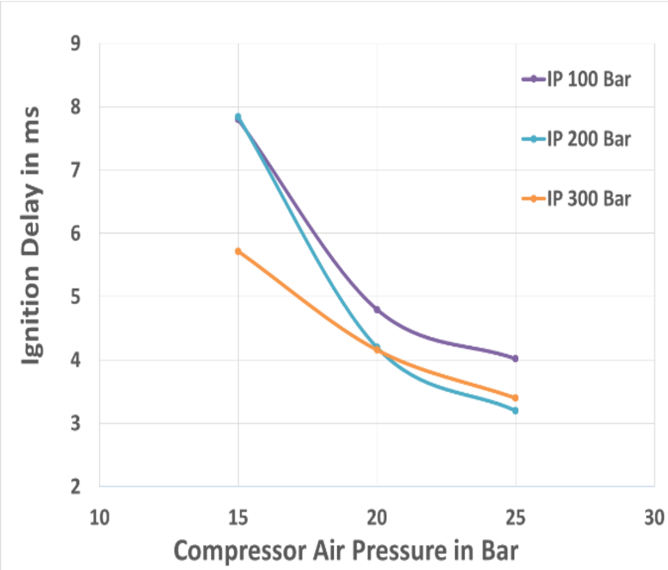

Figure 3: Effect of cylinder air pressure on ignition delay for Diesel engine

When the air pressure inside the combustion chamber increases the mixing of fuel and air improves due to increase in turbulence and oxygen concentration. Another reason for the reduction in the ignition delay is the temperature of compressed air inside the combustion chamber. It is known that with increasing the air pressure, air temperature increases due to increasing the kinetic energy of air molecules. Self-ignition temperature is another reason for reduction of ignition delay with the increase in cylinder air pressure. The self-ignition temperature of a fuel is a very important ignition quality. If the self-ignition temperature of a fuel is low, the delay period is reduced [8]. The self-ignition temperature reduces with the increase in cylinder air pressure. This is due to the increased density of the compressed air, resulting in closer contact of the molecules which thereby reduces the time of reaction when the fuel is injected. As shown in Figs. 2 and 3, the ignition delay of gasoline is longer than diesel. Because the self-ignition temperature of gasoline is more than diesel. Due to the higher resistance of gasoline to auto ignition, this fuel has greater ignition delays than diesel mid-distillate fuel [9].Injection duration and the intake air temperature, play a vital role in the improved better vaporization of the fuel [10]. In the present study, the influence of different fuel injection pressure is also investigated. The fuel injection pressure was changed by adjusting the fuel injector spring tension. From the data it can be seen that with increasing fuel injection pressure from 100 bar to 300 bar, the ignition delay decreases for diesel. But reduction of ignition delay for gasoline is in the order of 300-100 and 200 bar. The reason of reduction of ignition delay is the reduction in the physical delay. The physical delay is the time between the beginning of injection and the attainment of chemical reaction conditions. During this period, the fuel is atomized, vaporized, mixed with air and raised to its self-ignition temperature. This physical delay depends on the type of fuel, i.e., for light fuel the physical delay is small while for heavy viscous fuels the physical delay is high. The physical delay is greatly reduced by using high injection pressures, higher combustion chamber temperatures and high turbulence to facilitate breakup of the jet and improving evaporation [8]. Fuel droplet diameter is another reason of ignition delay period reduction. When the fuel injection pressure increases as a result the fuel droplet diameter decreases and longer penetration of fuel helps in better mixing which results in more complete combustion. It is observed that the minimum values of ignition delay approximately observed at the fuel injection pressure of 300 bar for both fuel at varying cylinder air pressure in the present experimental work. Fig. 4 and Fig. 5 shows the variation of ignition delay with fuel injection pressure at different compressor air pressures for gasoline and diesel fuel respectively. As it is clear from Fig. 4 and Fig. 5 that the fuel injection pressure directly impact the delay period in both cases.

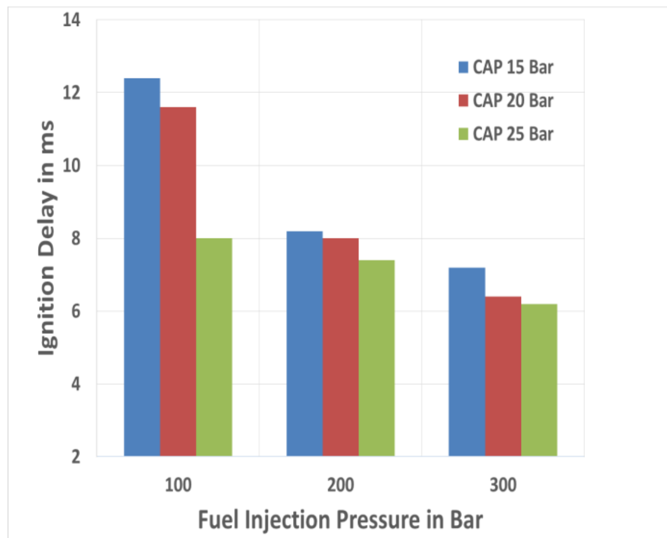

Figure 4: Effect of fuel injection pressure on ignition delay for gasoline engine

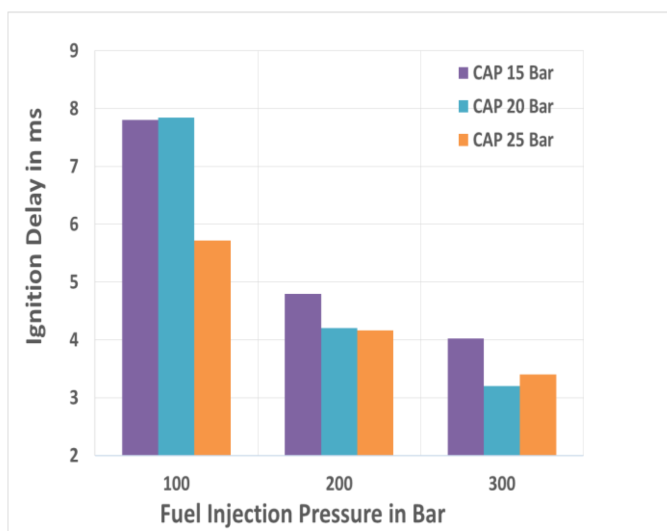

Figure 5: Effect of fuel injection pressure on ignition delay for diesel engine

4. Conclusion

The purpose of present experimental work was to study the effect of cylinder air pressure and fuel injection pressure on combustion characteristics of DI diesel engine. The range of injection pressure was from 100 to 300 bar and cylinder air pressure from 10 to 25 bar. The experimental set-up which was fabricated for this study was a constant combustion chamber. The set-up employed was a small sample of DI diesel engine. The results lead to the following conclusions:

- With increase in cylinder air pressure the ignition delay decreases due to the reduction in the physical delay for diesel and gasoline. Ignition delay and fuel injection duration of gasoline are longer than diesel. Combustion duration decreases as the cylinder air pressure increases. This is because of the increase in the end-of-compression temperature and pressure and decrease in the fraction residual gases.
- With increasing fuel injection pressure from 100 bar to 300 bar, the ignition delay decreases for diesel. But reduction of ignition delay for gasoline is in the order of 300-100 and 200 bar. The reason of reduction of ignition delay is the reduction in the physical delay.
- Minimum values of ignition delay was observed at the fuel injection pressure of 300 bar for both fuel at varying cylinder air pressure.

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