Study of Combustion Characteristics of Spray for Gasoline Direct Injection (GDI) Hot Surface Ignition Heavy Duty Engine

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ABSTRACT

The objective of the present experimental work investigation has been done on the combustion characteristics of the spray, such as ignition delay (ID), duration of burn (DOB) and duration of injection (DOI) for the format of gasoline direct injection (GDI) hot surface ignition heavy duty engine at varying fuel injection pressures (100-200-300 bar) and cylinder air pressures (0 to 25 bar). For the achievement of this purpose, an experimental set-up was fabricated. The set-up employed was a small sample of GDI hot surface ignition heavy duty engine, in which a constant stainless steel cylindrical combustion chamber was used. The experiments were performed base on gasoline and diesel. The results showed that the ID, DOB and DOI strongly depend upon the fuel injection pressure, cylinder air pressure (compression ratio) and equivalence ratio for both fuels. It was found that ID, DOB and DOI for gasoline are higher than diesel. And the minimum value of ID, DOI and DOB have been obtained at the fuel injection pressure of 300 bar compared to 100 and 200 bar for both fuels. It was also found that increasing the DOI causes to increase DOB and decrease the ID for both fuels. It was observed that with increasing the ID of gasoline until 10 ms, the DOB also increased due to more time available for mixing the fuel and air. But after 10 ms delay time, the DOB decreased. For diesel, the best delay time was obtained 9 ms to achieve maximum DOB and after this time, that decreased.

Keywords: Combustion Characteristics, GDI, Heavy Duty Engine, Hot Surface Ignition.

1. INTRODUCTION

In recent years, direct injection diesel engine is used more than indirect injection engine due to its advantages. The major advantages of DI diesel engine are much more efficiency, better fuel economy and lower emissions except NOx compare to IDI engine. Also near-term regulations (Tier2 Bin 5/Bin 2 and Euro 6) for Corporate Average Fuel Economy (CAFE), CO2 emissions and regulated emissions including NOx, CO, HC, and particulate matter (PM) are demanding advanced internal combustion (IC) engines with greatly improved combustion processes [1]. Therefore a new technology is needed to reduce NOx in DI engine. In spark ignition (SI) engine NOx emission is lower than diesel engine due to gasoline properties. But its efficiency is low. So there is a need of technology to greatly increase the efficiency of gasoline engines while maintaining low emissions and low cost. Gasoline Direct Injection (GDI) with using hot surface ignition is a combustion system that overcomes many of the fundamental limitations of diesel and gasoline engines.

The hot surface assisted ignition concept is commonly applied to overcome the low temperature-starting problem in diesel engine. Introducing low cetane fuel such as alcohol and natural gas requires an extended application of the hot surface as continuous ignition assistance. The function of the hot surface is to provide favorable local ignition condition, followed by combustion propagating through the fuel air mixture to establish a stable diffusion flame [2]-[4]. A slab of insulator material, wound with a few strands of heating wire is fixed on the combustion chamber with the wire running on the face exposed to the gases. The fuel injector is located such that a part of the spray impinges head on this surface. Ignition is thus initiated. The combustion chamber, which is in the cylinder head, is made relatively narrow so that the combustion spreads quickly to the rest of the space [5]. The present work involves the study of combustion characteristics (ignition delay, duration burn and duration of injection) of spray at varying fuel injection pressures and cylinder air pressure for the format of gasoline direct injection (GDI) heavy duty engine with using hot surface ignition system. Earlier many research works were performed by using gasoline fuel in DI, HCCI, PPCI and GDCI engines. The researchers who had done the works are listed as follows: Kalghatgi [6]-[8] and [9], Manente (Lund University) [10]-[13], Weall [14], Reitz and Ra [15]-[19], Ciatti [20], [21] and Yang [22]. In addition a Group at the University of Wisconsin [23], [24] and Delphi Corporation [25], [26] have also tested gasoline fuel in diesel engines. Also a few research works were done to investigate combustion characteristics in the hot surface ignition engine with using CNG fuel. Okada [27] reported that the thermal efficiency increased with using CNG in hot surface ignition engine meanwhile emissions decreased. Aesey [28] also used natural gas in a study. In his study a hot surface assisted ignition concept was investigated in a constant volume combustion bomb and a test engine with the objective to develop a better understanding of the mechanisms involved. The experiments showed that surface temperature above
1200 °K is required to achieve acceptable ignition, strongly dependent on natural gas composition and system parameters such as injection and hot surface geometry.

2. EXPERIMENTAL SET-UP

The present experimental study involves the investigation of combustion characteristics of spray for gasoline direct injection (GDI) heavy duty engine with using hot surface ignition system. For the achievement of this purpose, an experimental set-up as shown in Fig.1 was fabricated. This set-up employed is a small sample of GDI hot surface ignition heavy duty engine, in which a constant stainless steel cylindrical combustion chamber (Fig.2) is used whose length is 54.2 mm, 95 mm and 7.5 mm are its diameter and thickness respectively. Specifications of combustion chamber are presented in Table 1. Two heating coils are used for increasing the temperature of air and combustion surface with maximum temperature of 1400°C. One heating coil is fitted inside of the combustion chamber (in center) as igniter and another is fitted outside for increasing the temperature of air and combustion surface. For entering compressed air (air compressor provides the compressed air) to combustion chamber, one inlet valve is fitted on the left side of the combustion chamber. And one exhaust valve is also fitted on the left side for releasing of exhaust gas. An injector with single-hole nozzle is used for injecting the fuel in the center of combustion chamber with specifications as presented in Table 2. The amount of injected fuels is presented in Table 3. For measuring the combustion characteristics such as ignition delay, duration of injection and duration of burn, a digital storage two channel Scope Meter is used (Table 4). One channel shows the start of fuel injection and the other channel shows start of combustion. When fuel is injected by means of injector, piezoelectric sensor which is fitted on the injection line sends a pulse to Scope Meter and when combustion is started, photo sensor sends a pulse to Scope Meter. The combustion characteristics can easily be measured on the screen of Scope Meter by noting the two pulses. The experiments were performed base on gasoline and diesel. These fuels were chosen due to their different properties as shown in Table 5.
Figure 2: Schematic Diagram of Combustion Chamber; a) real combustion chamber; b) 3D Model; c) Sectional View

Table 1: Specifications of Combustion Chamber

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension</td>
<td>Length = 54.2 mm, Diameter = 95 mm, Thickness = 7.5 mm</td>
</tr>
<tr>
<td>Material</td>
<td>Stainless steel</td>
</tr>
<tr>
<td>Nozzle</td>
<td>Single-hole pindle nozzle</td>
</tr>
<tr>
<td>Nozzle position</td>
<td>Center of combustion chamber</td>
</tr>
<tr>
<td>Spray angle</td>
<td>15°</td>
</tr>
<tr>
<td>Nozzle hole diameter</td>
<td>0.2 mm</td>
</tr>
<tr>
<td>Temperature controller</td>
<td>Universal temp. controller</td>
</tr>
<tr>
<td>Injection recorder</td>
<td>Piezoelectric sensor</td>
</tr>
<tr>
<td>Combustion recorder</td>
<td>Photo sensor</td>
</tr>
<tr>
<td>Testing air temperature</td>
<td>220 °C</td>
</tr>
<tr>
<td>Maximum testing cylinder air</td>
<td>26 bar</td>
</tr>
<tr>
<td>pressure</td>
<td></td>
</tr>
<tr>
<td>Maximum testing compression</td>
<td>14.45:1</td>
</tr>
<tr>
<td>ratio (calculated)</td>
<td></td>
</tr>
<tr>
<td>Testing heating coils</td>
<td>500 °C</td>
</tr>
<tr>
<td>temperature</td>
<td></td>
</tr>
<tr>
<td>Maximum heating coils</td>
<td>1400 °C</td>
</tr>
<tr>
<td>temperature</td>
<td></td>
</tr>
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</table>

Table 2: Specifications of Fuel Injection Pump

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make</td>
<td>Bosch</td>
</tr>
<tr>
<td>Type</td>
<td>Single barrel</td>
</tr>
<tr>
<td>Length of stroke</td>
<td>8 mm</td>
</tr>
<tr>
<td>Bore</td>
<td>6 mm</td>
</tr>
<tr>
<td>Injection pressure</td>
<td>Up to 500 bar</td>
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</tbody>
</table>

Table 3: Observation Table of Injected Fuel per One Stroke for Gasoline and Diesel

<table>
<thead>
<tr>
<th>Fuel Injection Pressure (bar)</th>
<th>Gasoline (ml)</th>
<th>Diesel (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.181</td>
<td>0.171</td>
</tr>
<tr>
<td>200</td>
<td>0.127</td>
<td>0.12</td>
</tr>
<tr>
<td>300</td>
<td>0.11</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Table 4: Specifications of Scope Meter

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make</td>
<td>Fluke</td>
</tr>
<tr>
<td>Type</td>
<td>190-062 Digital Storage Scope Meter</td>
</tr>
<tr>
<td>Model</td>
<td>60 MHz</td>
</tr>
<tr>
<td>No. of channel</td>
<td>2</td>
</tr>
<tr>
<td>Real-time sampling rates</td>
<td>Up to 625 MS/s</td>
</tr>
<tr>
<td>Resolution</td>
<td>Up to 400 pico second (ps)</td>
</tr>
</tbody>
</table>

Table 5: Comparison of Properties of Gasoline and Diesel

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Diesel</th>
<th>Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Made from</td>
<td>Petroleum/ Crude Oil</td>
<td>Petroleum/ Crude Oil</td>
</tr>
<tr>
<td>Energy content</td>
<td>38.6 MJ/litter</td>
<td>34.6 MJ/litter</td>
</tr>
<tr>
<td>Auto-ignition temp.</td>
<td>210°C</td>
<td>246°C</td>
</tr>
</tbody>
</table>
2.1 METHODOLOGY OF EXPERIMENT

1. Temperature of the combustion chamber is increased by means of heating coils and then compressed air is sent to the combustion chamber by air compressor.

2. Fuel injection pump is used to inject the fuel into the combustion chamber through injector (with a single-hole pintle nozzle).

3. 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.

4. The event of injection is recorded by using piezoelectric sensor and the event of combustion is recorded by using of photo sensor which is placed in front of optical window.

5. Ignition delay is measured in ms by noting the difference between event of injection and that of combustion.

6. Duration of injection is measured in ms by noting the difference between the start and the end of injection.

7. Duration of burn is measured in ms by noting the difference between the start and the end of combustion.

The ignition characteristics can be observed in the Scope Meter screen. The signal sequences are shown in Fig. 3.

3. RESULTS AND DISCUSSION

The ignition delay period is also called the preparatory phase during which some fuel has already been admitted but has not yet ignited. 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 [5]. In present work this period is counted from the start of injection to the start of combustion in ms.

Fig. 4 shows the ignition delay versus varying cylinder air pressure from 0 to 25 bar for gasoline and diesel respectively. The pressures are gauge pressure. It is clearly observed from Fig. 4 that with increase in cylinder air pressure the ignition delay decreases. When the air pressure inside the cylinder increases, the amount of oxygen which enters to the cylinder also increases and better mixing of air and fuel occurs, consequently more complete and fast combustion takes place. 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 (air impingement) of air molecules. 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 results shown in Fig. 4, it can be seen that with increasing fuel injection pressure from 100 bar to 300 bar, the ignition delay decreases due to the reduction in the physical delay. 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.

<table>
<thead>
<tr>
<th>Boiling temp.</th>
<th>200°C</th>
<th>40°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octane No.</td>
<td>-</td>
<td>85</td>
</tr>
<tr>
<td>Cetane No.</td>
<td>50</td>
<td>-</td>
</tr>
<tr>
<td>Flash point</td>
<td>72°C</td>
<td>43°C</td>
</tr>
<tr>
<td>Density</td>
<td>0.832 kg/l</td>
<td>0.77 kg/l</td>
</tr>
</tbody>
</table>

**Figure 3:** signal sequences on Scope Meter in Present Experiment
In this study, the volume of the combustion chamber was constant and it was not changeable to achieve varying compression ratio. But with changing the cylinder air pressure, compression ratio can be changed by using below formulas.

\[
P_1 V_1^\gamma = P_2 V_2^\gamma, \quad \frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^\gamma
\]

\[
\left(\frac{P_2}{P_1}\right)^{1/\gamma} = \frac{V_1}{V_2} \quad \text{and} \quad \left(\frac{P_2}{P_1}\right)^{1/\gamma} = CR
\]

Where CR is compression ratio and \(\gamma = \frac{c_P}{c_V}\) (in this work \(\gamma = 1.22\)), \(P_{\text{min}} = 1\) bar and \(P_{\text{max}} = 26\) bar (the pressures are absolute pressure). For minimum and maximum air pressure, with simple calculation the compression ratio will be 1:1 and 14.45:1, respectively. It is known that, the compression ratio has strong influence on this ignition delay [29]. As expected, increasing the cylinder air pressure increases the compression ratio which in turn reduces the ignition delay in both gasoline and diesel as shown in Fig. 4. Because, a higher compression ratio increases the temperature and pressure of the air at the beginning of injection. Self-ignition temperature is another reason for reduction of ignition delay with the increase in compression ratio. The self-ignition temperature reduces with the increase in compression ratio. This is apparently 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.

In practice, the higher the compression ratio, the higher will be the engine friction, the leakage, and the torque required for starting. Thus, the diesel engine designers use the lowest compression ratio. It also makes the cold starting of the engine easier. The design practice is just the opposite of that adopted in SI engine design, where the highest possible compression ratio is used which is limited only by knocking [30].

Fig. 5 represents the difference of the ignition delay between gasoline and diesel with cylinder air pressure at varying injection pressure. As shown in Fig. 5, the ignition delay of gasoline is longer than diesel. This is due different ignition qualities of both fuels. The auto ignition temperature of a fuel is a very important ignition quality. If the auto ignition temperature of a fuel is low, the delay period is reduced [30]. Thus, due to the higher resistance of gasoline to auto ignition, this fuel has greater ignition delays than diesel mid-distillate fuel [31]. It is notable that the ignition quality of the fuels may be affected by volatility, latent heat, viscosity and surface tension. Volatility and latent heat affect the time taken to form an envelope of the vapor. And the viscosity and surface tension influence the fineness of atomization of fuel.

![Figure 4: Difference of ID between Gasoline and Diesel with CAP at Different IP](image)

![Figure 5: Difference of ID between Gasoline and Diesel with CAP](image)
Determination of burn duration of diesel engine is a difficult task because the total combustion process consists of phases such as rapid premixed combustion, mixing controlled combustion and the late combustion (period of after burning) of fuel present in the fuel rich combustion products. It can be defined as the time interval from the start of heat release to the end of heat release [32]. Another definition of duration of burn is the difference between the start of combustion (SOC) and the end of combustion (EOC) which was measured by using a light sensor in this study. Fig. 6 represents the duration of burn versus the cylinder air pressure at varying injection pressure for gasoline and diesel. The Fig. Shows that increasing the cylinder air pressure results in increasing the compression ratio, more mass of air implies a higher equivalence ratio. The duration of burn increases gradually until the injection air pressure of 15 bar for gasoline and 10 bar for diesel due to more possibility of complete combustion at the high compression and equivalence ratios. After the point of 15 bar for gasoline and the point of 10 bar for diesel, the duration of burn slips back. The 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. This creates a favorable condition for the reduction of ignition lag and increase in the flame speed [33]. Another reason is may be due to reduction in equivalence ratio from stoichiometric to lean. (The amount of fuel injected throughout (0, 5, 10, 15, 20, 25 bar) was constant, therefore at the point of 0 bar the mixture was rich and at the point of 25 bar, the mixture was lean because of excess air inside the cylinder). In present experiment, at the point of 0 bar for gasoline and diesel incomplete combustion took place due to oxygen deficiency meanwhile, at the point of 25 bar for both fuels the combustion is lean because at this point the amount of fuel is less than air. It can also be observed from Fig. 6 that the fuel injection pressure has influence on the duration of burn as expected. The fuel penetration distance becomes longer and the mixture formation of the fuel and air was improved when the combustion duration became shorter as the fuel injection pressure became higher [34].

The duration of burn for gasoline as shown in Fig. 7 is almost longer than diesel. As previously mentioned in Fig. 5, gasoline has greater ignition delay relative to diesel, which gives more time to fuel and air for mixing, resulting in more time for mixing, thus, producing the homogeneous charge and complete combustion. This leads to increase in duration of burn. Meanwhile, the volatility of gasoline is more than diesel which helps mix in the fuel and air quickly after injection. Also the viscosity and density of gasoline are less than diesel which cause to increase the amount of injected fuel (in milliliter) per stroke inside the combustion chamber at different injection pressure. Consequently, these properties of gasoline aim to increase the duration of burn compared to diesel.
Fig. 8 represents the duration of injection versus the cylinder air pressure for gasoline and diesel. Injection duration and the intake air temperature, play a vital role in the improved better vaporization of the fuel [35]. It can be observed that increasing the cylinder air pressure causes to increase the duration of injection at varying injection pressure. The results show that increasing the injection pressure from 100 to 300 bar resulting in decreasing the duration of injection far gasoline and diesel. But the cylinder air pressure and compression ratio have inverse effect on duration of injection for diesel compared to gasoline. Fig. 9 shows that the difference of the duration of injection between gasoline and diesel with varying cylinder air pressure at different injection pressure. The results show that the injection duration of gasoline is more than diesel due to property differences of these fuels such as viscosity, density and bulk modulus. Due to these properties, the amount of injected gasoline (in milliliter) per stroke inside the combustion chamber was more than diesel in present study. It can be seen from Fig. 9 that the duration of injection (average of injection pressure, 100-200-300 bar) increased for gasoline, but gradually decreased for diesel.

It can clearly be observed from Fig. 10 that the duration of burn first increases until 9 and 10 ms delay time for diesel and gasoline respectively and then decreases. The duration of burn increases due to more time to mix the fuel and air. But, when the ignition delay is too high, the time of burning decreases due to other factors such as compression ratio, in-cylinder pressure, temperature and air/fuel ratio. In general the maximum duration of burn was achieved after 9 ms delay for diesel and 10 ms for gasoline (the conditions were same for both fuels).
In Figs. 11 and 12, the effect of ignition delay, cylinder air pressure (compression ratio) and equivalence ratio on duration of burn at different fuel injection pressure for gasoline and diesel are investigated simultaneously. It can be seen that before the cylinder air pressure of 15 bar for gasoline and 10 bar for diesel, the effect of long ignition delay (more time to mix the fuel and air) and mixture structure are not stronger than effect of compression ratio (with increasing the compression ratio more complete combustion occurs). But after the point of 15 bar, the ignition delay has an effect over the duration of burn. Because with a decrease in the ignition delay, the time for mixing of fuel and air will be less and property of charge will not be sufficient to achieve a good combustion. On the other hand, after the point of 15 bar for the gasoline and 10 bar for diesel, the impacts of high compression ratio and ignition delay cause to decrease the burn duration.

Figs. 13 and 12 show the effect of ignition delay and duration of injection on duration of burn for gasoline and diesel fuels. It is found that increasing the duration of injection causes to increase duration of burn and decrease the ignition delay for both fuels. It can be seen from Figs. that the maximum value of burn duration and minimum value of ignition delay are in the injection duration range of 30 to 35 ms for gasoline and 25 to 30 ms for diesel.
Figs. 15 and 16 represent the ignition delay against the varying injection pressure (100-200-300 bar) at different cylinder air pressure (0 to 25 bar) for gasoline and diesel fuels respectively. The data in Figs. 15 and 16 show that the ignition delay decreases with increasing the injection pressure for both fuels. The reason behind this reduction is that fact that increases in injection pressure enhances the fuel atomization and also increases the turbulence in the combustion chamber [36]. It is also observed that ignition delay decreases for both fuels with increase the cylinder air pressure in the order of 0 to 25 bar, except the point of CAP=0 and IP=300 bar for diesel.

It is known that the auto ignition temperature of gasoline is more than diesel. Due to this property, the ignition delay of gasoline is greater than diesel in same condition as shown in Fig. 17.
It can be seen from Figs. 18 and 19 that the duration of burn decreased at the cylinder air pressure of 5, 10 and 25 bar for both fuels as injection pressure increased. And that increased at the cylinder air pressure of 0, 15 and 20 bar for both fuels. Increasing the injection pressure aims to decrease the fuel particle diameters to enhance faster and more effective vaporization and penetration of the fuel particles. Therefore, higher injection pressure initially generates a faster combustion rate [37]. So duration of burn decreases due to faster combustion rate with increase in injection pressure from 100 to 300 bar as shown in Fig. 20. Another reason for reduction of the duration of burn can be attributed to the improved atomization of fuel, turbulence and mixing with the increase in injection pressure. Also it can be observed from result that duration of gasoline fuel is more than diesel fuel due to fuel properties of these fuels. Gasoline is more volatile than diesel, which causes better vaporization of gasoline; as a result air/fuel mixing process is better and complete relative to diesel. Another factor that has an influence is boiling temperature. The boiling temperature of gasoline is less than diesel. This means the low boiling temperature of gasoline helps to easy change into a vapor at low ambient temperature and burning duration increased.
It was found that as the injection pressure was increased, the SOI was retarded from -1.75 CAD to -0.75 CAD bTDC for B-20. Also the duration of fuel injection was decreased from 480 to 315 psec in order to limit the peak burn rate of B-20 [36]. In present study also duration of injection decreased with increasing the injection pressure at different cylinder air pressure for both fuels as shown in Figs. 21, 22 and 23. The injection duration of gasoline was observed more than diesel in a study [38]. Similarly the amount of injected gasoline (in milliliter) per stroke inside the combustion chamber was more than diesel in present study due to differences of viscosity, density and bulk modulus.

**Figure 20:** Difference of DOB between Gasoline and Diesel with IP

**Figure 21:** DOI versus IP at Different CAP for Gasoline

**Figure 22:** DOI versus IP at Different CAP for Diesel
4. CONCLUSIONS

The purpose of present experimental work was to study the combustion characteristics of spray, such as ignition delay, duration of burn and duration of injection for the format of gasoline direct injection (GDI) hot surface ignition heavy duty engine at the varying fuel injection pressure (100-200-300 bar) and cylinder air pressure (0 to 25 bar). For the achievement of this purpose, an experimental set-up was fabricated. The set-up employed was a small sample of GDI heavy duty engine, in which a constant stainless steel cylindrical combustion chamber was used. The experiments were performed base on gasoline and diesel. These fuels were chosen due to their different properties. The conclusions drawn from the present study are the following points:

- Ignition delay strongly depends upon the injection pressure, cylinder air pressure (compression ratio), duration of injection and equivalence ratio for both fuels.
- Ignition delay decreases with increase in injection pressure from 100 to 300 bar and cylinder air pressure from 0 to 25 bar for both fuels due to the reduction in the physical delay.
- Ignition delay of gasoline is higher than diesel at the varying injection pressure and cylinder air pressure.
- Ignition delay has strong effects on duration of burn for both fuels.
- Duration of burn depends upon injection pressure, cylinder air pressure, ignition delay, equivalence ratio and duration of injection for both fuels.
- Duration of burn gradually increases until the injection air pressure of 15 bar for gasoline and 10 bar for diesel due to more possibility of complete combustion at the high compression at these points.
- Burn duration and Injection duration of gasoline are more than diesel due to property of these fuels such as such as viscosity, density and bulk modulus.
- Duration of burn first increases until 9 and 10 ms delay time for diesel and gasoline respectively and then decreases.
- Increasing the duration of injection causes to increase duration of burn and decrease the ignition delay for both fuels.
- Minimum value of ignition delay, duration of injection and duration of burn have been obtained at injection pressure of 300 bar compared to 100 and 200 bar for both fuels.
- Maximum value of ignition delay, duration of injection and duration of burn have been obtained at injection pressure of 100 bar.
- Increasing the injection pressure from 100 to 300 bar resulting in decreasing the duration of injection for gasoline and diesel.
- Duration of injection (in average of injection pressures) increased for gasoline, but almost constant for diesel with increase in cylinder air pressure.
- Duration of injection decreased with increasing the injection pressure at different cylinder air pressure for both fuels.
NOMENCLATURES

CAD  degrees  Crank angle degrees
CAFÉ  Corporate Average Fuel Economy
CAP  bar  Cylinder Air Pressure
CI  Compression Ignition
CR  Compression Ratios
DI  Direct Injection
DOB  crank deg (or ms)  Duration of Burn
DOI  crank deg (or ms)  Duration of Injection
EOC  crank deg (or ms)  End of Combustion
GDI  Gasoline Direct Injection
GDCI  Gasoline Direct Compression Ignition
HCCI  Homogeneous Charge Compression Ignition
HSDI  High Speed Compression Ignition
ID  crank deg (or ms)  Ignition Delay
IDI  Indirect Injection
IP  bar  Injection Pressure
PPCI  Partially Premixed Compression Ignition
CR  Compression Ratio
SI  Spark Ignition
SOC  crank deg (or ms)  Start of Combustion
SOI  crank deg (or ms)  Start of Injection
TDC  Top Dead Center

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REFERENCES


BIOGRAPHIES

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