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Research Paper

# Performance and Emission Characteristics Analysis on Direct Injection Gasoline Engine

Engineering

**KEYWORDS :** GDI, high-pressure fuel injection, Projectile, Forebody and after body, Supersonic speed, Aerodynamics.

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| **K.Kumaravel** | Assistant Professor in Mechanical Engineering, Annamalai University, Annamalainagar – 608 002, Tamilnadu, India. |
| **B.Premanand** | Assistant Professor in Mechanical Engineering, Annamalai University, Annamalainagar – 608 002, Tamilnadu, India. |
| **C.G.Saravanan** | Professor of Mechanical Engineering, Annamalai University, Annamalainagar – 608 002, Tamilnadu, India. |

## ABSTRACT

*Gasoline direct injection (GDI) engines have become popular due to their inherent potential for reduction of exhaust emissions and fuel consumption to meet increasingly stringent environmental standards. These engines require high-pressure fuel injection in order to improve the fuel atomization process and accelerate mixture preparation. The conventional diesel engine was modified to GDI engine by increasing the clearance volume. The compression ratio (CR) 17:1 of the diesel engine was modified to CR 9:1. By the use of GDI engine we can able to reduce the losses in carburetor like evaporation. Also it help to avoid fuel wall film in the manifold improved accuracy of air/fuel ratio, $CO_2$ emission also reduce, increased performance and volumetric efficiency due to cooling air charge , better cold start performance and better drive comfort . A set of test was done at different spark angles (16°,18° and 20°) and injection start angle (90°,120° and 150°) respectively keeping the particular constant like air - fuel ratio 14:67 , water flow rate (2L/min) and speed at 1500 rpm . During the test exhaust gas released like CO, HC, NOx , $CO_2$ and $O_2$ at different load and degree of spark angle advance and SOI angle has been determined The exhaust gases decreases in every gases like HC, CO, NOx except $O_2$ which increases load and brake power irrespective for all different spark angles and SOI of ATDC. According to test condition and experiment set up spark angle of 20° BTDC and 150° ATDC SOI are appropriatefor obtaining better performance and exhaust gas emission.*

## 1. INTRODUCTION

The air-fuel mixture in the gasoline engines is prepared in-cylinder and out-cylinder. While the mixture in the engine with carburetor and port fuel injection is prepared out-cylinder, mixture in the gasoline direct injection engines is prepared in-cylinder, as shown in figure 1.

In place of PFI engines where the fuel is injected through the port, in GDI engines, the fuel is injected directly into cylinders at a high pressure. During the induction stroke, only the air flows from the open intake valve and it enters into the cylinder. This ensures better control of the injection process and particularly provides the injection of fuel late during the compression stroke, when the intake valves are closed. The acting of the intake system as a pre-vaporizing chamber is an advantage in the PFI engines. As the lack of time to fuel vaporize in GDI engines, the fuel is injected into the cylinder at a very high pressure to help the atomization and vaporization process. The duration for injection timing is little; advanced injection timing causes piston wetting and retarded injection timing decrease sufficient time for fuel-air mixing . In the PFI engine, a liquid film is formed in the intake valve area of the port, which causes delayed fuel vaporization. Especially during cold start, it is necessary to increase fuel amount for the ideal stoichiometric mixture. This "over-fueling" leads to increasing HC emissions during cold start. Alternatively, injecting the fuel directly into the combustion chamber avoids the problems such as increasing HC and giving the excess fuel to engine.

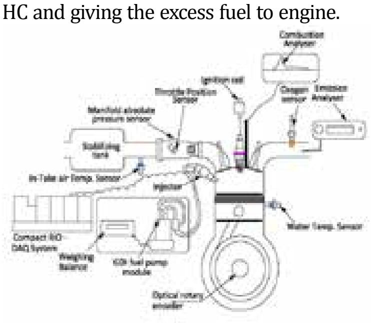

**Figure 1.Setup of GDI engine**

## 2. PERFORMANCR OF THE GDI ENGINE

The parameters that have the greatest influence on engine efficiency are compression ratio and air/fuel ratio. The effect of raising compression ratio is to increase the power output and to reduce the fuel consumption. The maximum efficiency (or minimum specific fuel consumption) occurs with a mixture that is weaker than stoichiometric. Because the port fuel injection engines work at stoichiometric air/fuel ratio, it is impossible to see more improvement in the fuel economy. In these engines, the compression ratio is about 9/1-10/1. To prevent the knock, the compression ratio cannot be increased more. For the same engine volume, the increasing volumetric efficiency also raises the engine power output.

GDI engine operate with lean mixture and unthrottled at part loads, this operation provide significantly improvements in fuel economy.

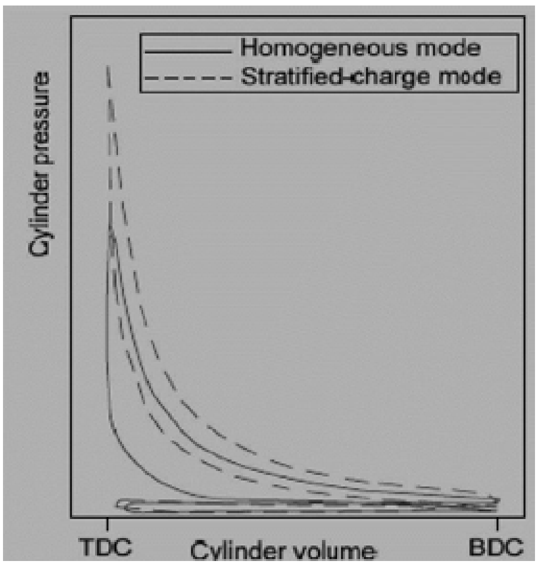


**Figure 2. GDI engine operates with homogeneous charge**

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**and stoichiometric or slightly rich mixture**

At full load, as the GDI engine operates with homogeneous charge and stoichiometric or slightly rich mixture,(as shown in figure 2) this engine gives a better power output. In GDI engine, fuel is injected into cylinder before spark plug ignites at low and medium loads. At this condition, Air/Fuel (A/F) ratio in cylinder vary, that is, mixture in front of spark plug is rich, in other places is lean. In all cylinder A/F ratio is lean and A/F ratio can access until 40/1. In homogeneous operation, fuel starts injecting into cylinder at intake stroke at full loads as shown in figure 3. The fuel, which is injected in the intake stoke, evaporates in the cylinder. The evaporation of the fuel cools the intake charge. The cooling effect permits higher compression ratios and increasing of the volumetric efficiency and thus higher torque is obtained. In the GDI engines, compression ratio can gain until 12/1. The knock does not occur because only air is compressed at low and medium loads. At full load, since fuel is injected into cylinder, the charge air cool and this, in turn, decreases knock tendency.

Since the vehicles are used usually in urban traffic, studies on improving the urban driving fuel economy have increased. Engines have run usually at part loads (low and medium loads) in urban driving. Volumetric efficiency is lower at part loads, so engine effective compression ratio decreases, engine efficiency decreases and fuel consumption increases

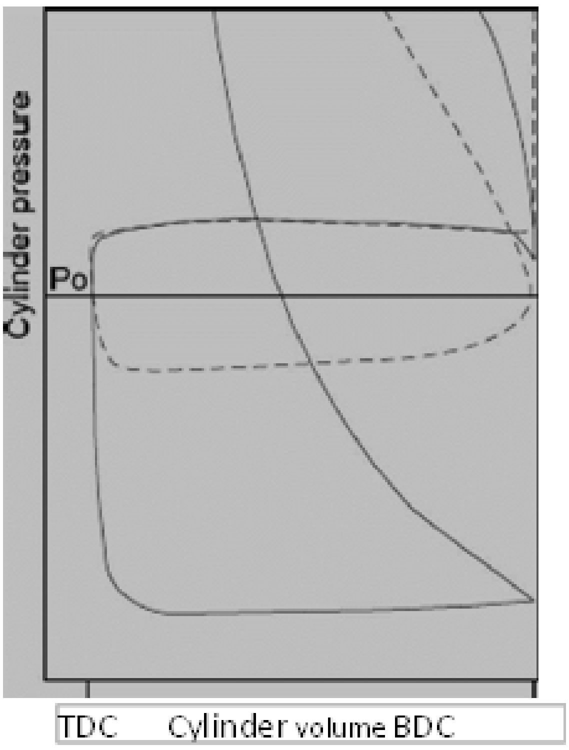


**Figure 3.Cylinder pressure VS cylindervolume**.

The urban driving fuel economy of the vehicles is very high. Distinction between the highway fuel economies of vehicles is very little. As majority of the life time of the vehicles pass in the urban driving, the owners of the vehicles prefer the vehicles of which the urban driving fuel economy is low.
At full load, as the GDI engine operate with throttle, only a small reduction of fuel consumption can be obtained to the PFI engine. There is the more fuel economy potential at part load. At compression stroke, since air is given the cylinders without throttle for stratified charge mode, pumping losses of the GDI engine is minimum at part loads. The improvements in thermal efficiency have been obtained as a result of reduced pumping losses, higher compression ratios and further extension of the lean operating limit under stratified combustion conditions at low engine loads. In the DI gasoline engines, fuel consumption can be decreased by up to 20%, and a 10% power output improvement can be achieved over traditional PFI engines.

The $CO_2$ emissions, which are one of the gases, bring about the global warming. To decrease $CO_2$ emitted from vehicles, it is required to decrease fuel consumption. Downsizing (reduction of the engine size) is seen as a major way of improving fuel consumption and reducing greenhouse emissions of spark ignited engines. In the same weight and size, significant decreases in $CO_2$ emissions, more power and higher break mean effective pressure can be obtained. GDI engines are very suitable for turbocharger applications. The use of GDI engine with turbocharger provides also high engine knock resistance especially at high load and low engine speed where PFI turbocharged engines are still limited. Turbocharged GDI engines have showed great potential to meet the contradictory targets of lower fuel consumption as well as high torque and power output. In Table 1, it is given specifications of the two different engines belonging to the 2009 model VW Passat vehicle, for example. TSI engine urban driving fuel economy is 18% lower than that of PFI engine. $CO_2$ emission is 12% lower than that of PFI engine. Although TSI engine swept volume is lower than PFI engine, power and torque is higher by 20% and 35%, respectively (Table). As engine torque is maximum at interval 1500-4000 1/min, shifting is not necessary at the acceleration and thus drive comfort increase.

**Table 1. Comparison of the GDI and PFI engines**

| Engine Type | Gasoline engine | TSI gasoline engine |
|---|---|---|
| Swept Volume | 1.6 L | 1.4L |
| Max. Power | 75 kW 5600 1/min | 90 kW 5000 – 5500 1/min |
| Max. Torque | 148 Nm 3800 1/min | 200 Nm 1500 – 4000 1/min |
| Mixture formation system | PFI (port fuel injection) | GDI (Gasoline direct injection) |
| Fuel economy (urban driving L/100 km) | 10,5 | 8,6 |
| Fuel economy (highway driving L/100 km) | 6,0 | 5,5 |
| $CO_2$ emission g/km | 179 | 157 |

**2.1.Operating Modes:**
GDI engine operates at different operating modes depending on load and engine speed for a stable and efficient engine operation. These engines have three basic operating modes, stratified with an overall lean mixture, homogeneous with lean mixtures and homogeneous with stoichiometric mixtures. The engine is operated with the stratified, homogeneous lean and homogeneous stoichiometric modes; at low load and speed, at medium load and speed and at high load and speed, respectively. Fig. 6 shows an example of the GDI operating modes depending on engine load and speed.

**2.2. Charge Modes in GDI Engine:**
**a.Stratified Charge:**
At the partial load conditions, stratified charge (late injection) is used, that is, fuel is injected during the compression stroke

to supply the stratified charge. The engine can be operated at an air-fuel ratio exceeding 100 and fully unthrottled operation is possible, but the engine is throttled slightly in this zone and the air-fuel ratio is controlled to range from 30 to 40 in order to introduce a large quantity of Exhaust Gas Recirculation (EGR) and to supply the vacuum for the brake system.

**b.Homogenous Charge:**
A homogeneous charge (early injection) is (shown in figure 4) preferred for the higher load conditions, that is, fuel is injected during the intake stroke so as to provide a homogeneous mixture. In most of this mode, the engine is operated under stoichiometric or a slightly rich condition at full load. In the lowest load conditions in this mode, the engine is operated at homogeneous lean conditions with air-fuel ratio of from 20 to 25 for further improvement of fuel economy. During operation with homogeneous charge the adjustment of engine load is done by throttling while during operation with stratified charge the engine runs with unthrottled conditions and engine load is adjusted by fuel/air-equivalence ratio.

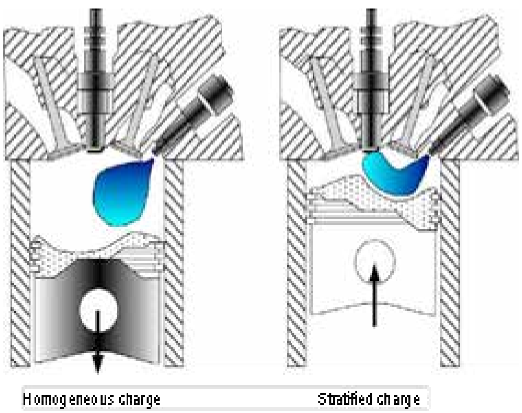


**Figure 4. Homogeneous charge vs Stratified Charge**

**2.3. Combustion Process:**
In the stratified operation, three combustion systems are used to form an ignitable mixture near spark plug at the instant ignition. These are the wall-guided, air-guided and spray-guided combustion systems.

**a) Wall-Guided combustion system:**
The fuel is transported to the spark plug by using a specially shaped piston surface. As the fuel is injected on the piston surface, it cannot completely evaporate and, in turn, HC and CO emissions, and fuel consumption increase. To use this system alone is not efficient.

**b) Air-Guided combustion system:**
The fuel is injected into air flow, which moves the fuel spray near the spark plug. The air flow is obtained by inlet ports with special shape and air speed is controlled with air baffles in the manifold. In this technique, fuel does not wet the piston and cylinder. Most of stratified-charge GDI engines use a large-scale air motion (swirl or tumble) as well as specially shaped piston a surface in order to keep the fuel spray compact and to move it to the spark plug. In the air-guided and wall guided combustion systems the injector is placed remote to the spark plug.

VW direct injection combustion system is a combination of two systems– wall guided and air guided –by tumble flow. This system is less sensitive against the cyclic variations of airflow. This combustion system shows advantages as well in the stratified and in the homogenous mode. Injector is intake-side placed. The fuel is injected to the piston under given angle. The piston has two bowls. The fuel bowl is on the intake-side; the air bowl is on exhaust-side. Tumble flow is obtained by special shaped intake port. The fuel is guided simultaneously via air and fuel bowl to the spark plug

**c) Spray-Guided combustion system:**
In the spray-guided technique fuel is injected near spark plug where it also evaporates. The spray-guided technique theoretically has the highest efficiency. The spray guided combustion process requires advanced injector systems such as piezo injection. This technique has some advantages: reduced wall wetting, increased stratified operation region, less sensitive to in-cylinder air flow, less sensitive to cylinder to cylinder variation and reduced raw HC emissions. Reported disadvantages are spark plug reliability (fouling) and poor robustness (high sensitivity to variation in ignition &injection timing). Mercedes-Benz developed a new spray guided combustion system. This system has the Stratified-Charged Gasoline Injection (CGI) engine with Piezo injection technology. The spray-guided injection achieves better fuel efficiency than conventional wall-guided direct injection systems. The main advantage of the CGI engine is obtained at the stratified operating mode. During this mode the engine is run with high excess air and thus excellent fuel efficiency is provided. Multiple injections extend this lean-burn operating mode to higher rpm and load ranges, too. During each compression stroke, a series of injections is made spaced just fractions of a second apart. This allows the better mixture formation and combustion, and lower fuel consumption.

**3. Engine Modification:**
- Conventional diesel engine was modified to GDI engine by increasing the clearance volume.
- A single cylinder four stroke 5 HP diesel engine was modified to operate a spark ignited direct injection (GDI) engine.
- The compression ratio (CR) 17:1 of the diesel engine was modified to CR 9:1 by increasing the clearance volume in the engine head.
- Diesel injector is replaced by spark plug and diesel pump is replaced by a dummy flange.
- The engine head was drilled with two holes of size M14 for mounting gasoline injector and M10 size for combustion pressure sensor.
- High energy ignition on the cylinder body for spark timing and ignition of the engine.
- The injected fuel spout, with the proper angle of the crankshaft revolution during the compression stroke rebounces from the piston head and is directed towards the spark plug electrodes

**4.Control Factors and Experimental Array:**
- A Vertical water cooled, single cylinder, four strokes, kirloskar 5 HP was used for the study. The engine was coupled to a dynamometer for load measurement. By using an analyzer Oxides of Nitrogen (NOx), Hydrocarbons, Carbon monoxide and Carbon dioxide were measured.
- Conventional diesel engine was modified to GDI engine by increasing the clearance volume.
- A Single Cylinder four stroke 5 HP diesel engine was modified to operate a spark ignited injection (GDI) engine.
- The compression ratio (CR) 17:1 of the diesel engine was modified to CR 9:1 by increasing the clearance volume in the engine head.
- Diesel injector is replaced by spark plug and diesel pump is replaced by a dummy flange.
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- The injected fuel spout, with the proper angle of the crankshaft revolution during the compression stroke rebounces from the piston head and is directed towards the spark plug electrodes.

**5. Results and Discussion**

**a. Hydrocarbon**

In load Vs HC graph(shown in figure 5) , HC emission is maximum when 16° spark angle BTDC and 90° ATDC of SOI followed by 20° spark angle BTDC and 150° ATDC SOI and 18° spark angle BTDC and 120° ATDC SOI release minimum HC . Similarly case of brake power Vs HC 160° spark angle BTDC and 90° ATDC SOI release maximum amount of HC followed by 20°, 16°spark angle of BTDC respectively. But, as the brake power increase irrespective of spark angle and ATDC SOI emission is almost same. Table 2 gives the Observation table for different load conditions. Figure 6shows the hydrocarbon against brake power.

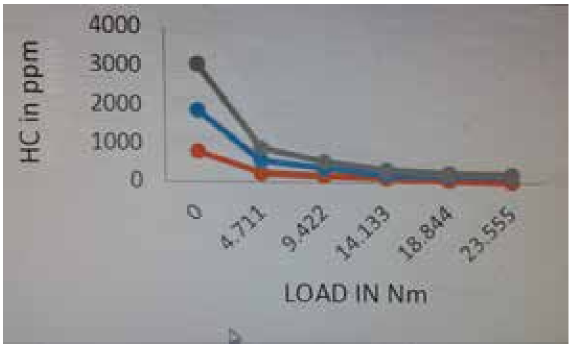


**Figure 5. Hydrocarbon against load**

**TABLE 2.OBSERVATION TABLE FOR DIFFERENT LOAD CONDITIONS**

| Load | Load | Fuel Consumption | Fuel | Brake Power |
|---|---|---|---|---|
| (%) | (Nm) | Kg/min | Consumption Kg/hr | kW = WN/c c =9549.305 |
| 20 | 4.711 | 0.015 | 0.9 | 0.74 |
| 40 | 9.422 | 0.016 | 0.96 | 1.48 |
| 60 | 14.133 | 0.018 | 1.08 | 2.22 |
| 80 | 18.844 | 0.021 | 1.26 | 2.96 |
| 100 | 23.555 | 0.024 | 1.44 | 3.70 |
| 0 | 0 | 0.016 | 0.96 | 0 |

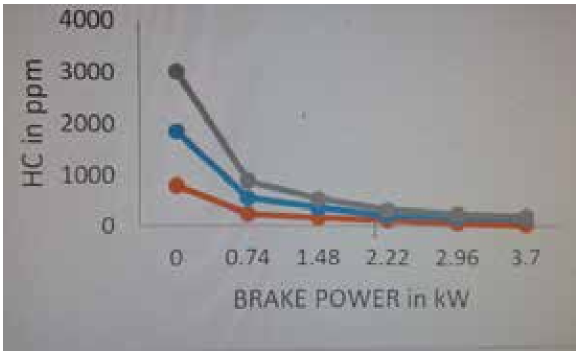


**Figure 6 Hydrocarbon against brake power**

**b.Carbon monoxide**

CO emission is maximum when spark 16° spark angle BTDC , compare to 20° spark angle BTDC and 150° ATDC SOI and 18° spark angle BTDC and 120° ATDC SOI . Brake power Vs CO graph (shown in figure 7) also give emission more when brake power is less but it reduces as brake power increases. Lastly reach similar point baring spark angle and SOI.

**Figure 8 shows the Carbon monoxide against brake power.**

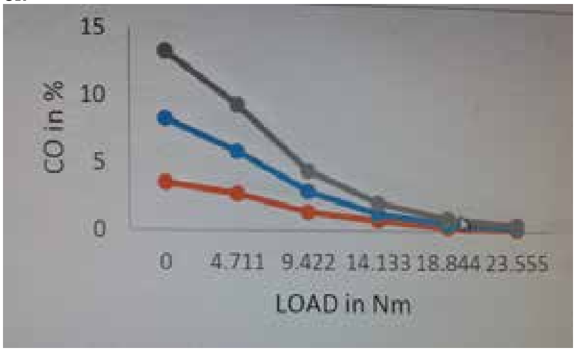


**Figure 7 Carbon monoxide against load**

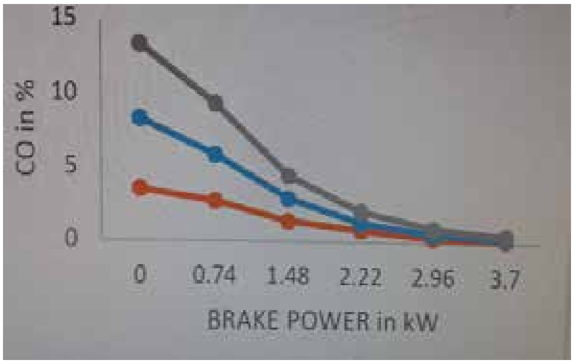


**Figure 8 Carbon monoxide against brake power**

**c.Oxides of Nitrogen**

Load Vs NOx graph (shown in figure 9) shows that at zero load maximum exhaust emission of NOx but steeply decreases and gradually increases and nearly constant as load increases irrespectively of spark angle BTDC and ATDC of SOI. Also, brake power Vs NOx graph goes as similar to the load Vs NOx .

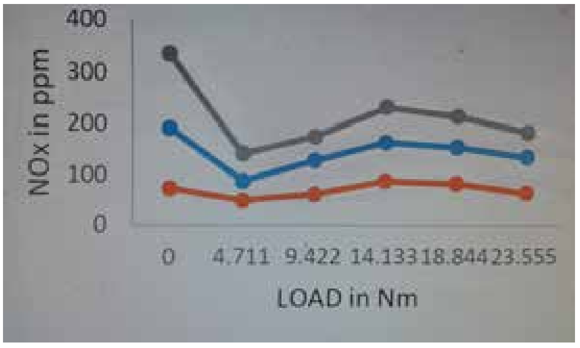


**Figure 9 Oxides of nitrogen against load**

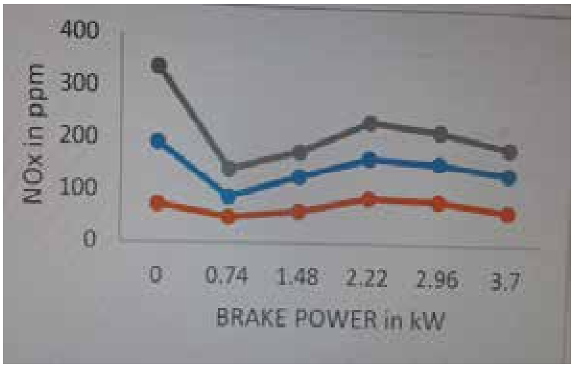


**Figure 10 Oxides of nitrogen against brake power**

**d.carbon di oxide**

From the load Vs $CO_2$, (as shown in figure 11) $CO_2$ exhaust emission gradually decreases as load increases. Similarly, brake power Vs $CO_2$ decreases as load increases but they does not meet at a specific point. Figure 12shows the Carbon dioxide against brake power.

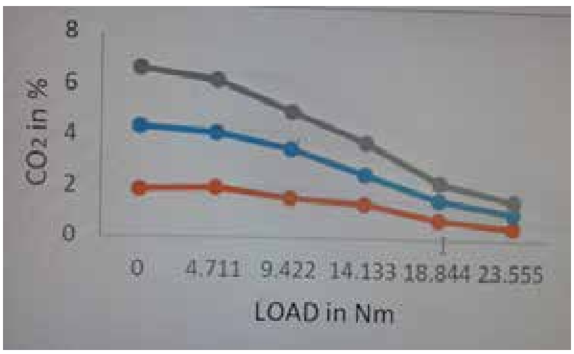


**Figure 11. Carbon dioxide against load**

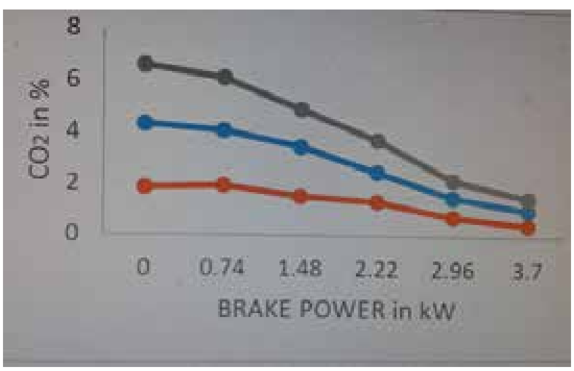


**Figure 12. Carbon dioxide against brake power**

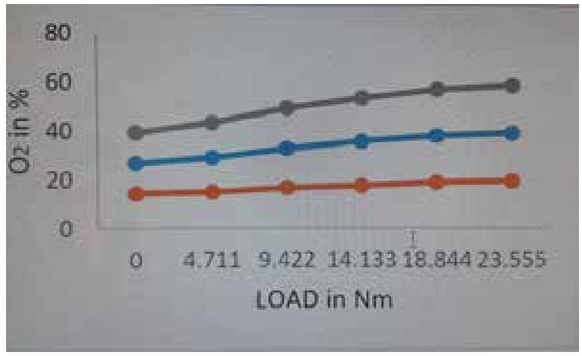


**Figure 13. Carbon dioxide against load**

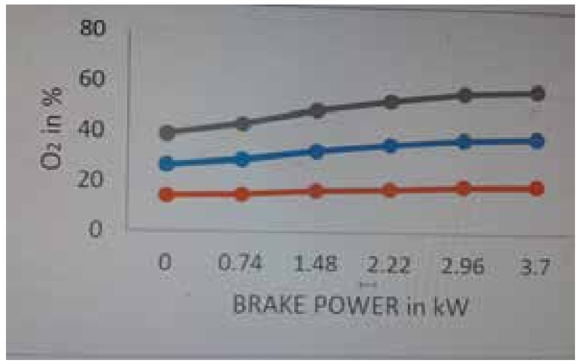


**Figure 14. Carbon dioxide against brake power**


**6. Conclusions:**

- By considering the effect of air fuel ratio and the injections timing, was concluded that the spark ignited at 18° BTDC and 120° ATDC start of injection gives better performance for GDI Engine.
- HC decreases as increasing the load but remain same at load 23.55Nm for all spark angles BTDC and ATDC SOI.
- CO also decreases gradually as increasing load and brake power but remain constant at particular load and brake power of spark angle and SOI.
- NOx, $CO_2$ reduce spontaneously although it increases gradually but do not remain same at a particular load and brake power for all spark angle reading.
- $O_2$ amount increases spontaneously for all of spark angles and start of ignition.
- From the graph it is clear that the overall emission is good in a GDI Engine.
- Engine reduce carburetor lose as compare to port fuel engine.
- Better cold start performance and better drive comfort.

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