Review on performance enhancement methods of diesel engine based on piston geometry, injection pressure and exhaust gas recirculation

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Abstract— ***This is the review and case studies of the effect of the piston bowl geometry, fuel injection pressure and exhaust gas recirculation on the performance and emissions of the diesel engine. Our attempt is to bring clarity to the understanding of the effects caused by the above mentioned parameters on the diesel engine. This paper discusses how the performance and emission changes occur due to change in injection pressure. Also, what is the effect of piston geometries such as tangentially grooved piston, square bowl piston on the engine due to the turbulence caused by the geometries. This paper also discusses the effect of the change in percentages of the EGR (exhaust gas recirculation) on the emission and performance of an engine.***

Index Terms—**Combustion phases, Combustion chamber geometry, EGR, Fuel injection pressure**

I. Introduction

The combustion process is a far more complex sequence of events than the simple constant volume and/or constant pressure processes used in air standard cycles. The full sequence of events in the engine cylinder, consisting of:

1) Generation of air motion during the open period; particularly in the form of organized swirl and/or controlled turbulence levels in high speed engines for transport purposes, and establishment of the air flow pattern near TDC;
2) Injection of fuel with control of timing and duration and possible modulation of injection rate near TDC;
3) Mixing of fuel and air under conditions determined by (i) and (ii) above;
4) Initiation of combustion following the delay period, and subsequent combustion first under pre-mixed and later under diffusion conditions;
5) Separation of products and reactants under the combined action of density changes in a rapidly changing velocity field—buoyancy effects—with further fuel-air mixing and combustion occurring simultaneously

Conventionally the process is treated as consisting of at least three distinct periods,

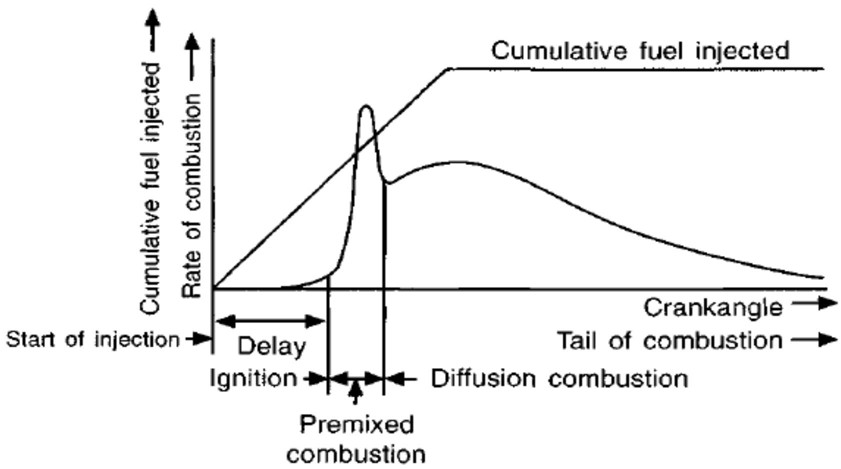

Fig. 1.1) Phases of combustion

It is well known that in DI diesel engines swirl motion is needed for proper mixing of fuel and air. Moreover, the efficiency of diesel engines can be improved by increasing the burn rate of fuel air mixture. This can be achieved in two ways; one by designing the combustion chamber in order to reduce contact between the flame and the chamber surface, and two by providing the intake system so as to impart a swirl motion to the incoming air[1].In this paper we are going to discuss about the combustion chamber geometries such as the square bowl piston geometry and he tangentially grooved hemispherical bowl piston geometry.

Another parameter that effects the combustion phenomenon is the fuel injection pressures. Major pollutants of concern emitted by compression ignition (CI) engine are oxides of nitrogen (NO_x) and particulate matter (PM). For controlling emissions, higher fuel injection pressures, split and multiple injections, exhaust gas recirculation (EGR), intake air pressure boosting etc. are being applied[3].It is seen by the research done by the researcher that the higher the injection pressure the more atomized the fuel droplets get and the more complete burning takes place, which improves both performance as well as the reduction in emissions.

II. Effect of PISTON GEOMETRY on engine performance

A. Square bowl piston geometry

The geometry of combustion chamber used in [2] reference was chosen to study the effect of turbulence on rate of heat release (ROHR) in HCCI(homogeneous charge compression ignition)engine. HCCI combustion is limited in load due to high peak pressures and too fast combustion. If the speed of combustion can be decreased the load range can be extended. Therefore two different combustion chamber geometries were investigated, one with a disc shape and one with a square bowl in piston. The later one provokes squish-generated gas flow into the bowl causing turbulence. The disc shaped combustion chamber was used as a reference case. Combustion duration and ROHR were studied using heat release analysis [2]. Chemiluminescence imaging was used to visualise the combustion inside the combustion chamber.

Experimental Apparatus:

The engine used in this study was a six cylinder diesel engine which was converted for HCCI operation by using port fuel injection (PFI). The engine was operating on only single cylinder .A piezoelectric water-cooled pressure transducer was used to monitor the in-cylinder pressure and this information was used to control the phasing of combustion by changing the inlet air temperature with an electrical heater. Some vital engine data can be found in table 2.1. The fuel was a mixture of acetone and ethanol with volume ratio of 1:9.

Table 2.1) Engine Specifications

Displaced volume	1951 cc
Stroke	154 mm
Bore	127 mm
Connecting rod	255 mm
Exhaust valve open	82° BBDC (@ 0.15 mm lift)
Exhaust valve close	38° ATDC (@ 0.15 mm lift)
Inlet valve open	39° BTDC (@ 0.15 mm lift)
Inlet valve close	63° ABDC (@ 0.15 mm lift)
Valve lift inlet	14 mm
Valve lift exhaust	14 mm
Fuel system	PFI
Fuel	Ethanol/Acetone: 90%/10%
Engine speed	1200 rpm
intake pressure	1 Bar Absolute
intake temperature	75-125 °C
Compression ratio	17.2:1

Results

1) It was seen that rate of heat release rate decreased significantly and the combustion duration increased in square bowl piston as compared to normal disc shaped piston geometry.
2) Pressure rise rate in the square bowl piston was less thus higher load can be applied to the engine.
3) Chemiluminescence imaging showed that the combustion starts in the bowl and propagates into the squish volume.
4) Chemiluminescence imaging also showed that the combustion started in the same corner of the bowl in all cycles.

B. Tangentially grooved piston geometry

The case study for tangentially grooved piston is taken from the research paper "effect of tangential grooves on piston crown of D.I. diesel engine with blends of cotton seed oil methyl easter" by C.V. Subba Reddy et. al.

The figure 2.1 below shows the tangentially grooved piston which is compared to a normal hemispherical bowl piston. The engine used for testing is a Kirloskar make 5hp direct injection diesel engine. The operating condition for both the cases are kept constant and the performance of the engine was evaluated based on the thermal efficiency, specific fuel consumption and the emission parameters such as CO and smoke opacity.

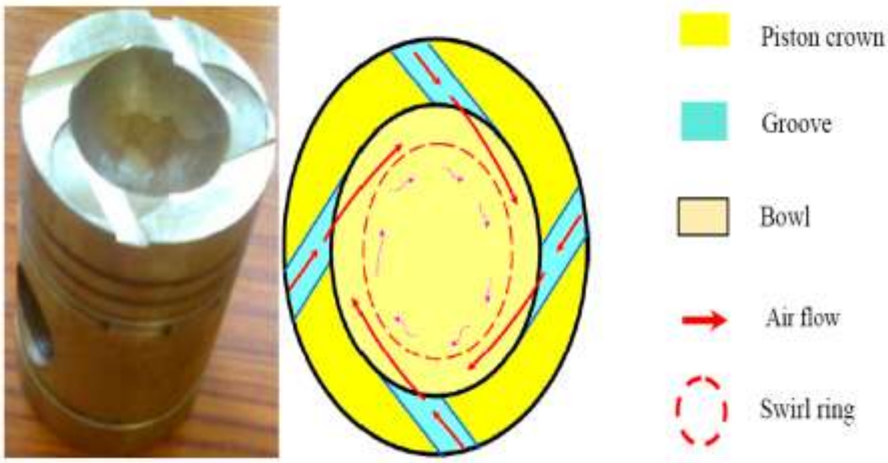

Fig. 2.1) Tangentially grooved piston geometry

Results:

1) Brake thermal efficiency was seen to improve with the use of tangentially grooved piston as compared to the base piston. This has happened due to the better mixing of the air fuel mixture inside the combustion chamber which leads to better combustion efficiency.

2) Brake specific fuel consumption was seen to have decreased as the fuel required for maintaining the engine speed constant has decreased as compared to the base engine piston geometry.

3) CO percentages are seen to be decreased with the use of tangential grooves to the hemispherical bowl of the base piston.

4) Smoke opacity reading seems to have decreased with the use of tangentially grooved piston geometry.

III. EFFECT OF FUEL INJECTION PRESSURES ON THE PERFORMANCE OF THE ENGINE

The fuel injection pressure seems to have huge impact on the combustion of the engine. Nowadays the injectors used in the modern cars are piezo and solenoid injectors which are controlled by the electronic control unit. The pressures of the fuel discharged from the injector is formed inside the fuel rail or known as the common rail in the diesel engines. This injection pressure is decided by the electronic circuit according to the state of the vehicle such as the speed and the load.

. The case study we have selected is from the research paper "Effect of fuel injection pressure and injection timing on spray characteristics and particulate size–number distribution in a biodiesel fuelled common rail direct injection diesel engine" by Avinash Kumar Agarwal et. al.for the CRDI (common rail direct injection) engine with a programmable injector parameter facility. It also has the optical window which can be used to visualise the combustion inside the cylinder. The engine used is a single cylinder engine (AVL List GmbH, 5402) with a transient AC dynamometer. The fuel injection pressures were changed from 500 bar to 1000 bars to evaluate the performance of the engine.

The figure below shows the setup used in this case where the injector driver is responsible to change the fuel injection pressure. High speed camera is used to grab the image inside the combustion chamber with the help of optical window.

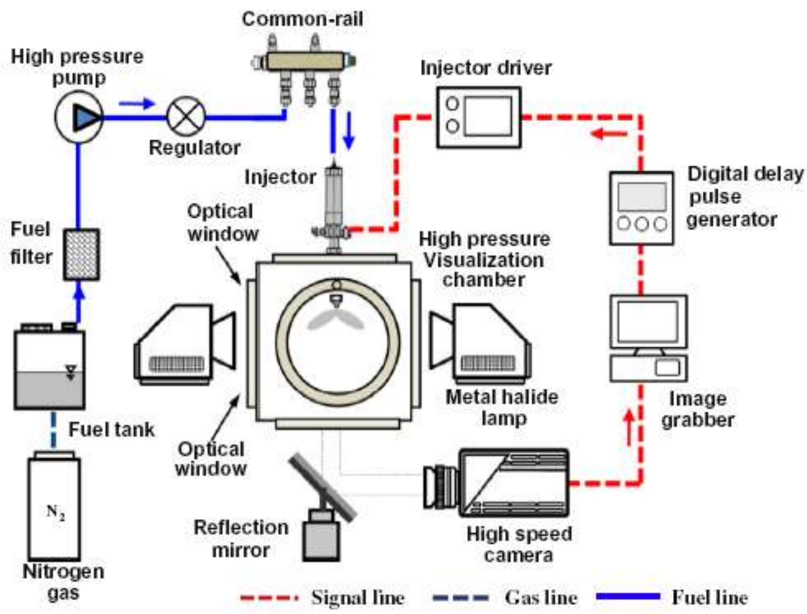

Fig. 3.1) Engine setup for testing

Results:

1) The results show that as the injection pressure increases the spray tip penetration increases with the same start of injection timing.

2) It can be seen that as the injection pressure increases the spray area from the injector inside the cylinder also increases.

3) It was also seen that mean diameter of the fuel droplet reduces as the fuel injection pressure increases.

4) The particulate size of the emissions decreases with the increase in the fuel injection pressure because of better air-fuel mixing.

The figures below show the variation in the spray tip penetration and the spray area with change in fuel injection pressure.

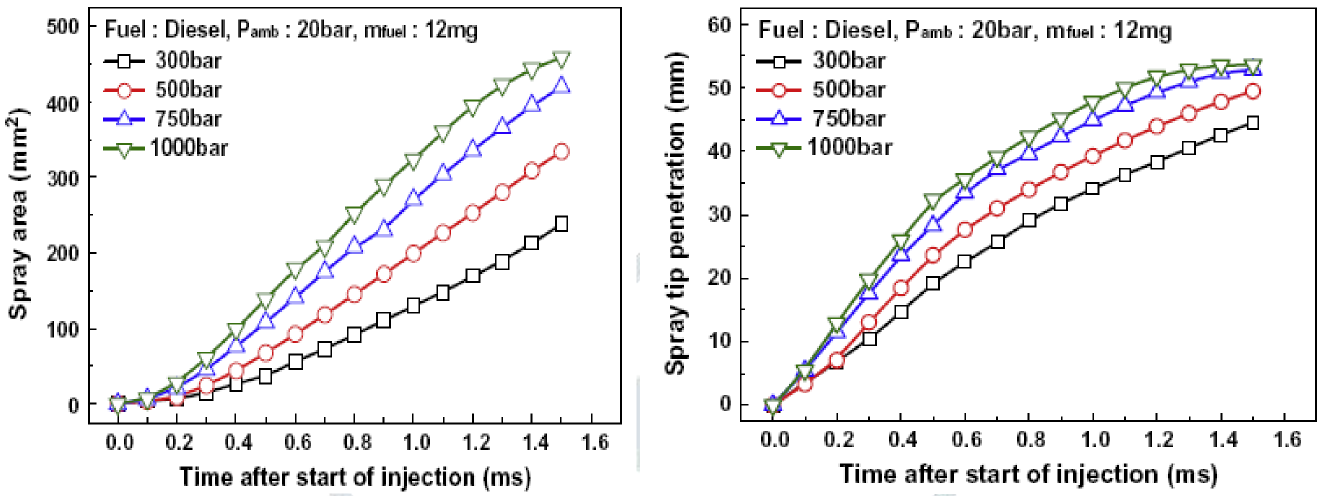

Fig. 3.2) Variation in spray area and spray tip penetration with varying fuel injection pressure

IV. Effect of EGR (Exhaust Gas Recirculation) on Performance of the Engine

The case study for the effects of EGR is taken from the research paper "Effect of Exhaust Gas Recirculation (EGR) on Performance and Emission characteristics of a Three Cylinder Direct Injection Compression Ignition Engine" by Jaffar Hussain et. al.

The EGR in the diesel engine is used mainly to reduce the NO_x emissions from the exhaust of the engine. The NO_x can be controlled as the EGR reduces the peak temperature and pressure inside the combustion chamber by reducing the oxygen content in the cylinder. This is done by admitting the exhaust gas from the exhaust manifold into the intake manifold where it mixes with the fresh charge replacing the fresh air.

The test was performed on a three cylinder constant speed direct injection diesel engine for different rate of EGR. The engine is naturally aspirated air cooled engine with a compression ratio of 17:1 and speed of 1500 rpm. The engine test setup is as shown in the figure below.

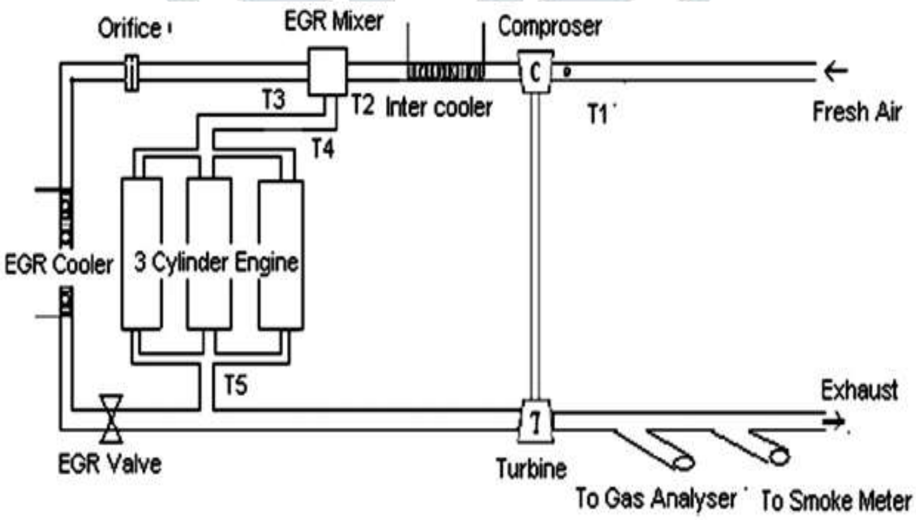

Fig 4.1) Engine test setup

Results :

1) Thermal efficiency

The figure below shows the variation in thermal efficiency with change in EGR rate for different load conditions. The results from the paper show that the thermal efficiency is unaffected by the change in the EGR rates.

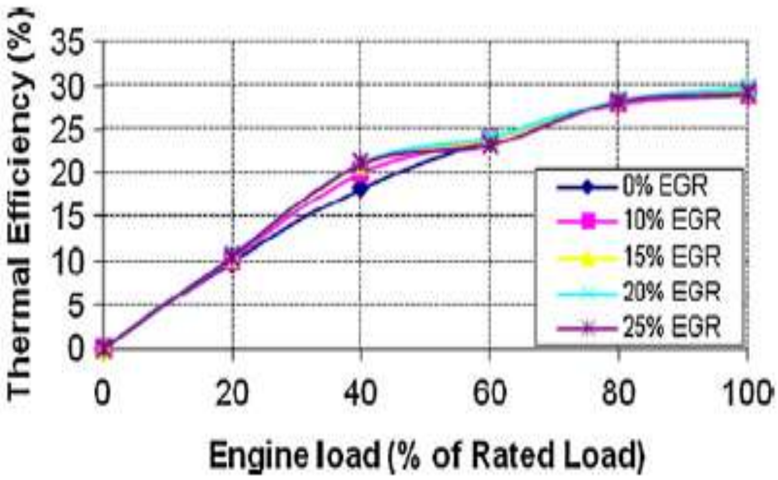

Fig. 4.2) Graph showing effect of EGR on thermal efficiency of engine

2) Brake specific fuel consumption :

The figure below shows the change in specific fuel consumption with change in EGR rate at different load conditions. It can be seen that the BSFC is same for condition of EGR and without EGR.

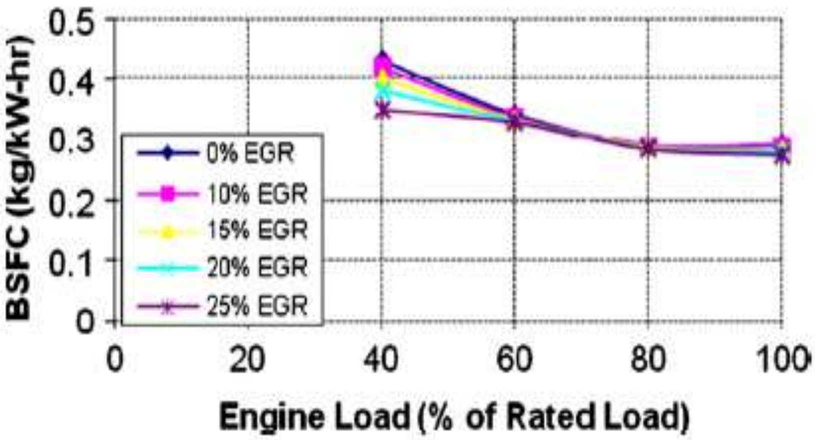

Fig. 4.3) Graph showing effect of EGR on the BSFC on the engine

3) Carbon monoxide

The figure below shows the change in carbon monoxide in exhaust gas for different EGR rates at different load conditions. It can be seen from the graph that as the EGR rate increases the carbon monoxide content goes on increasing .This happens as the EGR increase the oxygen content decrease and results in rich air-fuel composition causing higher carbon content due to incomplete combustion.

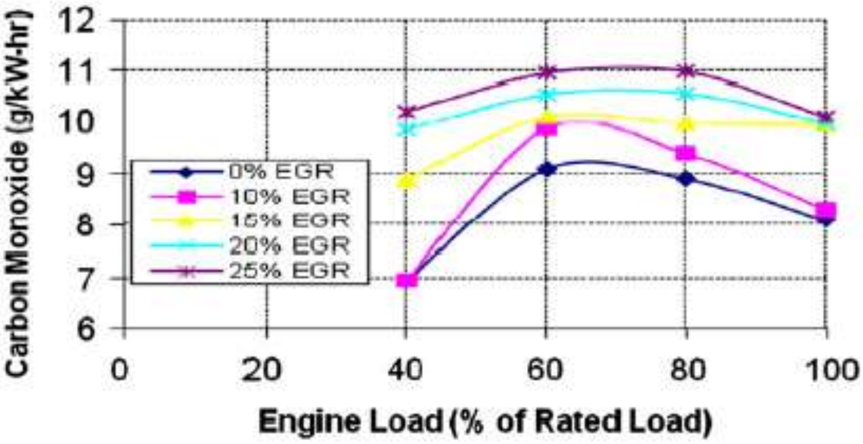

Fig. 4.4) Graph shows the effect of EGR on the CO content in the exhaust

4) NO_x

The figure below shows that variation in the NO_x emissions with change in EGR rate at different load conditions. It can be seen that the NO_x emission goes on decreasing as the increase in EGR takes place. This happens as the burnt gases replace the fresh charge of air inside the cylinder the peak pressure is reduced resulting in the less NO_x formation.

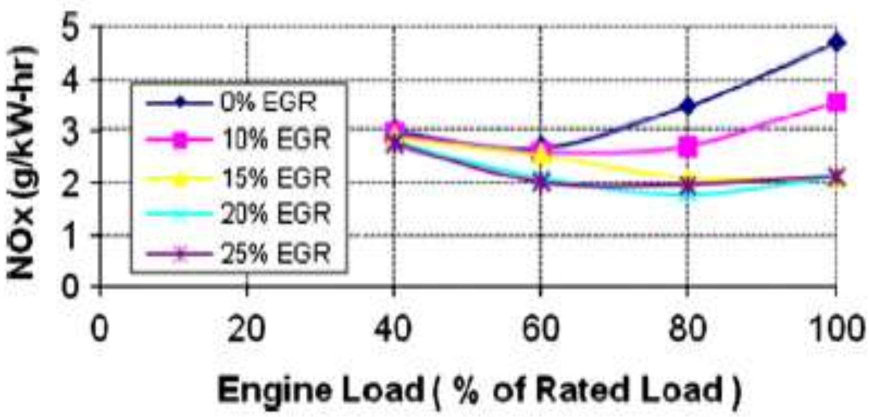

Fig. 4.5) Graph shows the effect of EGR on the NO_x content in the exhaust

V. Conclusions

i) The higher fuel injection pressure results into better thermal efficiency and better specific fuel consumption due to better mixing of air and fuel.

ii) Higher injection pressure also results in better combustion efficiency due to decreases in the mean diameter of the fuel droplet.

iii)Also the particulate size of the emission also decreases with the increase in the fuel injection pressures.

iv) The piston geometry affects the performance and the emissions of the diesel engine. The square bowl piston and the tangentially grooved piston showed the better thermal efficiency and lower BSFC as compared to the base piston geometry.

v) The increase in the EGR rate does not affect the thermal efficiency and BSFC of the engine but it decreases the NO_x content in the exhaust.

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