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# INFLUENCE OF INJECTOR OPENING PRESSURE ON EXHAUST EMISSIONS IN DI DIESEL ENGINE WITH THREE LEVELS OF INSULATION WITH DIESEL OPERATION

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## ABSTRACT

Experiments were conducted to study exhaust emissions of direct injection (DI) diesel engine with different levels of low heat rejection (LHR) combustion chamber such as i) ceramic coated cylinder head, ii) air gap insulated piston and air gap insulated liner and iii) ceramic coated cylinder head along with air gap insulation with pure diesel operation with varied injector opening pressure. Exhaust emissions of particulate emissions and oxides of nitrogen ($NO_x$) were determined at various values of brake mean effective pressure (BMEP) of the engine. Particulate emissions were measured by AVL Smoke meter, while $NO_x$ by Netel Chromatograph $NO_x$ analyzer. Engine with different versions of the combustion chamber showed comparable particulate emissions, while they increased $NO_x$ emissions drastically at full load operation of the engine, when compared with conventional engine. Engine with air gap insulated piston and air gap insulated liner showed lower $NO_x$ levels at 80% of the full load operation. However, exhaust emissions reduced with an increase of injector opening pressure with different versions of the combustion chamber.

**Keywords:** Conventional Engine, LHR Combustion Chamber, Injector Opening Pressure Exhaust Emissions.

## 1. INTRODUCTION

In the context of i) depletion of fossil fuel, particularly use of diesel fuel in not only transport sector but also in agriculture sector, ii) increase of fuel prices in International market leading to burden on economic sector of Govt. of India the conservation of diesel fuel has become pertinent for the engine manufacturers, users and researchers involved in the combustion research. The civilization of any country is linked with number of vehicles used by its public. [1]. In this context, the nation should pay high tributes towards Dr. Diesel, for his remarkable invention of diesel engine, which is being used for mass transport and heavy duty engines. [2].

In the last one or two decades, the concept of adiabatic engine has gained importance. Various concepts of low heat rejection (LHR) combustion chambers are being developed employing the techniques like ceramic coating in the components, air gap in the piston and the other components etc. Out of the total amount of heat rejected to the various components, piston, liner and cylinder head are found to be the major contributors through which heat rejection take place to the coolant. It is also found that the coatings provided on cylinder head is simple technique with advanced coating techniques. The technique of providing air gap in the piston is less effective in achieving lower brake specific fuel consumption and reduction of pollutants. It also provides lower degree of insulation causing combustion chamber of diesel engine less hot. Hence the technique of air gap insulated piston, air gap insulated liner and insulated cylinder head is finding favor from the various researchers from the point of view of effectiveness ease of manufacturer and operation. LHR combustion chambers were classified as low degree (LHR–1) insulated engine such as ceramic coated combustion chambers, medium grade (LHR–2) insulated engine such as air gap insulated combustion chamber and high grade (LHR–3) insulated engine such as the combination of low grade and medium grade LHR insulated combustion chambers.

Investigations were carried out by various researchers on LHR–1 combustion chambers-ceramic coated engines with pure diesel operation.[3–5] It was reported from their investigations that brake specific fuel consumption (BSFC) improved in the range 5–9% and smoke levels decreased with ceramic coated combustion chamber.

The technique of providing an air gap in the piston involved the complications of joining two different metals. Investigations were carried out with LHR–2 combustion chamber with air gap insulated piston with nimonic crown threaded with the body of the piston fuelled with pure diesel with varied injection timing and reported brake specific fuel consumption improved by 5% [6].
By controlling the injector opening pressure and the injection rate, the spray cone angle is found to depend on injector opening pressure. Few investigators reported that injector opening pressure has a significance effect on the performance and formation of pollutants inside the direct injection diesel engine [7–8].

Experiments were conducted on high grade LHR combustion chamber with pure diesel operation.[9].It was reported that performance deteriorated with pure diesel operation at recommended injector opening pressure of 190 bar.

Comparative studies were made for different configurations of the insulated combustion chamber with pure diesel operation at constant injector opening pressure [10]. It was concluded from their studies that performance deteriorated with increase of degree of insulation with diesel operation.

The present paper attempted to study pollution levels with different configurations of LHR combustion chamber, with pure diesel operation with varied injector opening pressure. Comparative performance studies were made with different versions of LHR combustion chamber with conventional engine (CE) with diesel operation.

## 2. MATERIAL AND METHOD

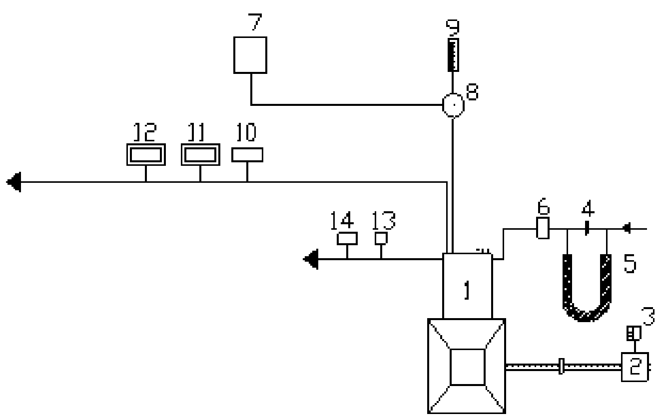
The physical-chemical properties of the diesel fuel are presented in Table-1. Fuels with flash point above $52^{o}$ C are considered as safe. Thus diesel is extremely safe fuel to handle. Diesel has high cetnane number, which shows efficient combustion in compression ignition engine. Diesel fuel has moderate viscosity. Hence there are no problems with the process of injection.

**Table.1:** Properties of diesel fuel

| Fuel | Density (gm/cc) | Bulk modulus @ 20Mpa | Kinematic viscosity @ 40°C (cSt) | Flash point (Open cup) (° C) | Low calorific value (kJ/kg) |
|---|---|---|---|---|---|
| Diesel | 0.84 | 1475 | 2.25 | 66 | 42000 |

Engine with high grade LHR combustion chamber contained a two–part piston; the top crown made of low thermal conductivity material, superni–90 ( an alloy of nickel) screwed to aluminum body of the piston, providing a 3mm air gap in between the crown and the body of the piston. The optimum thickness of air gap in the air gap piston was found to be 3 mm for improved performance of the engine with diesel as fuel [6]. The height of the piston was maintained such that compression ratio was not altered. A superni-90 insert was screwed to the top portion of the liner in such a manner that an air gap of 3 mm was maintained between the insert and the liner body. At 500°C the thermal conductivity of superni–90 and air are 20.92 and 0.057 W/m–K. Partially stabilized zirconium (PSZ) of thickness 500 microns was coated on inside portion of cylinder head.

Schematic diagram of experimental setup used for the investigations on compression ignition diesel engine with diesel operation is shown in Fig 2. The test fuel used in the experimentation was pure diesel. Experimental engine was vertical, single–cylinder, four–stroke, water–cooled,3.68 kW brake power at a speed of 1500 rpm with compression ratio of 16:1, bore 80 mm, stroke length of 110 mm and Kirloskar make engine. The combustion chamber consisted of a direct injection type with no special arrangement for swirling motion of air. The engine was connected to an electric dynamometer for measuring its brake power. Burette method was used for finding fuel consumption of the engine. Air consumption of the engine was measured by an air–box method (Air box was provided with an orifice flow meter and U–tube water manometer). Air box was provided with damper to minimize the pressure pulsations of the engine.




1. Engine, 2. Electical Dynamo meter, 3. Load Box, 4. Orifice meter, 5. U-tube water manometer, 6. Air box, 7. Fuel tank, 8. Three way valve, 9. Burette, 10. Exhaust gas temperature indicator, 11. AVL Smoke meter, 12. Netel Chromatograph NOx Analyzer, 13. Outlet jacket water temperature indicator and 14. Outlet-jacket water flow meter

**Fig.1:** Schematic diagram of experimental set–up

The naturally aspirated engine was provided with water–cooling system in which outlet temperature of water was maintained at 80° C by adjusting the water flow rate. Engine oil was provided with a pressure feed system. No temperature control was incorporated, for measuring the lube oil temperature. Injector opening pressure was changed from 190 bar to 270 bar (in steps of 40 bar) using nozzle testing device. The maximum injector opening pressure was restricted to 270 bar due to practical difficulties involved. Exhaust emissions of particulate matter and $NO_x$ were recorded by AVL particulate Matter Analyzer and Netel Chromatograph $NO_x$ analyzer at various values of BMEP of the engine. The accuracy of analyzers is ±1%.

**Operating Conditions**

Test fuel used in the experimentation were diesel. Different injector opening pressures attempted in this experiment were 190, 230 and 270 bar. The various combustion chambers used in experiment were conventional combustion chamber, low grade insulated combustion chamber with ceramic coated cylinder head (LHR–1), medium grade insulated combustion chamber (LHR–2) with air gap insulated piston and air gap insulated liner and high grade insulated combustion chamber (LHR–3) with ceramic coated cylinder head, air gap insulated piston and air gap insulated liner. The engine was started with diesel fuel and allowed to have a warm up for about 15 minutes. Each test was repeated twelve times to ensure the reproducibility of data according to the procedure adopted in error analysis. (Minimum number of trials must be not less than ten). The results were tabulated and comparative studies of exhaust emissions were reported at different operating conditions of the compression ignition engine.

**Nomenclature**

BP=brake power of the engine, kW
*D*=bore of the cylinder, 80 mm
DI=diesel injection
HSU=Hartridge smoke unit
*I*=ammeter reading, ampere
*K*=number of cylinders, 01
*L*=stroke of the engine, 110 mm
LHR-1= Insulated combustion chamber with ceramic coated cylinder head
LHR-2= Insulated combustion chamber with air gap insulated piston and air gap insulated liner
LHR-3= Combination of LHR-1 & LHR-2 combustion chambers
*n*=power cycles per minute, N/2,
*N*=speed of the engine, 1500 rpm
V=voltmeter reading, volt
$V_s$=stroke volume, $m^3$

**Definitions of used values**

$BP=\frac{V\times I}{\eta_d\times 1000}$ equation (1)

$BP=\frac{BMEP\times 10^5\times L\times A\times n\times k}{60000}$ ---equation (2)

## 3. RESULTS AND DISCUSSION

**A. Pollution Levels**

Brake power was calculated from equation (1), while BMEP was determined from equation (2).Fig.2 indicates that particulate emissions increased from no load to full load in both versions of the combustion chamber. During the first part, the particulate emissions were more or less constant, as there was always excess air present. However, in the higher load range there was an abrupt rise in particulate emissions due to less available oxygen, causing the decrease of oxygen–fuel ratio, leading to incomplete combustion, producing higher particulate emissions. The variation of particulate emissions with BMEP typically showed an inverted L behavior due to the pre-dominance of hydrocarbons in their composition at light load and of carbon at high load. Up to 80% of full load, marginal reduction of particulate emissions was observed in the engine with LHR–2 combustion chamber, when compared to the conventional engine. This was due to the increased oxidation rate of particulate matter in relation to formation of particulate emissions. Higher surface temperatures of the engine with LHR–2 combustion chamber aided this process. Particulate emissions are formed during combustion in low oxygen regions of the flames. Engine with LHR–2 combustion chamber shorten the delay period, which curbs thermal cracking, responsible for particulate emissions. Beyond 80% of full load, marginal and slight increase of particulate emissions was observed in the engine with LHR–2 combustion chamber, when compared to conventional engine. This was due to fuel cracking at higher temperature, leading to increase in particulate emissions.

Particulate emissions were observed to be higher with engine with LHR–1 combustion chamber and LHR–3 combustion chamber at all loads when compared with conventional engine. Higher temperature of engine with LHR combustion chamber produced increased rates of both particulate emissions and burn up. The reduction in volumetric efficiency and oxygen–fuel ratios were responsible factors for increasing particulate emissions in the engine with LHR combustion chamber at near full load operation of the engine. As expected, particulate emissions increased in the engine with LHR combustion chamber, because of higher temperatures and improper utilization of the fuel consequent upon predominant diffusion combustion.

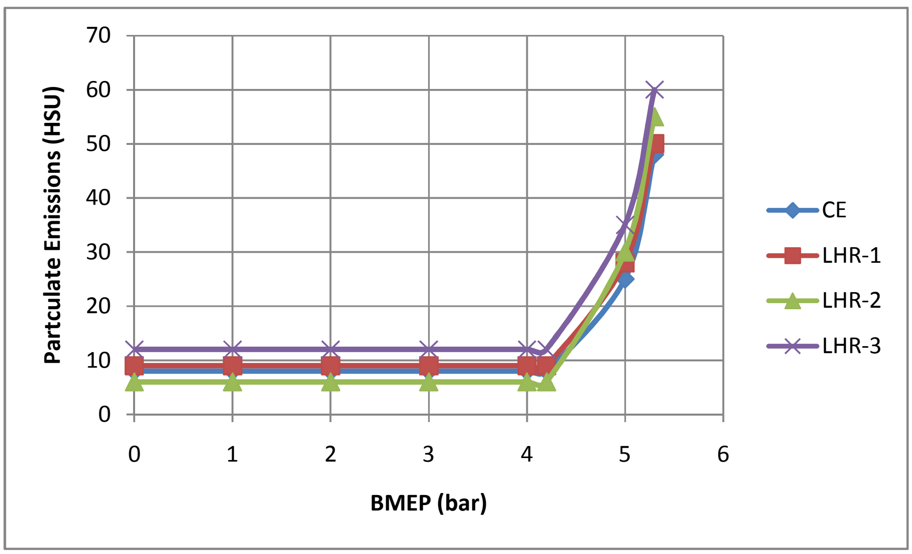



**Fig.2:** Variation of particulate emissions with brake mean effective pressure(BMEP) with pure diesel operation in conventional engine and engine with air gap insulated piston and air gap insulated liner (LHR) at an injection timing of $27^o$ bTDC and injector opening pressure of 190 bar

The temperature and availability of oxygen are the reasons for the formation of $NO_x$. For both versions of the combustion chamber, $NO_x$ concentrations raised steadily as the fuel/air ratio increased (Fig.3) with increasing BP/BMEP, at constant injection timing. At part load, $NO_x$ concentrations were less in engine with different versions combustion chamber. This was due to the availability of excess oxygen. At remaining loads, $NO_x$ concentrations steadily increased with the load in both versions of the combustion chamber.

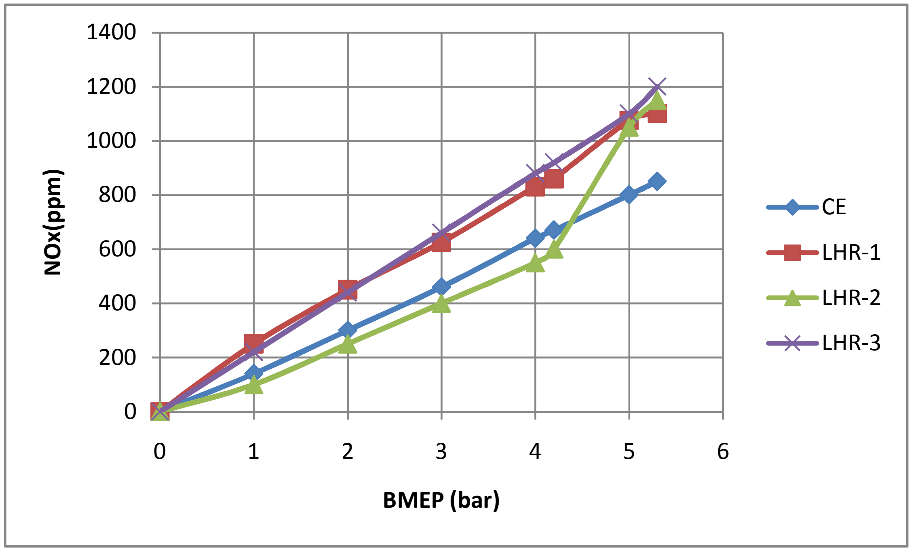



**Fig.3:** Variation of nitrogen oxide ($NO_x$) levels with brake mean effective pressure(BMEP) with pure diesel operation in conventional engine and engine with different versions of the LHR combustion chamber at an injection timing of 27$^o$ bTDC and injector opening pressure of 190 bar

This was because, local $NO_x$ concentrations raised from the residual gas value following the start of combustion, to a peak at the point where the local burned gas equivalence ratio changed from lean to rich. At full load, with higher peak pressures, and hence temperatures, and larger regions of close–to–stoichiometric burned gas, $NO_x$ levels increased in engine with different versions of the combustion chamber. Though amount of fuel injected decreased proportionally as the overall equivalence ratio was decreased, much of the fuel still burns close to stoichiometric. Thus $NO_x$ emissions should be roughly proportional to the mass of fuel injected (provided burned gas pressures and temperature do not change greatly). Engine with LHR–1 combustion chamber and LHR–2 combustion chamber showed higher NOx emissions than pure diesel operation on conventional engine. This was due to increase of combustion temperatures. The engine with LHR–2 combustion chamber recorded lower $NO_x$ levels up to 80% of the full load, and beyond that load it produced higher $NO_x$ levels compared to conventional engine. As the air-fuel ratios were higher in the LHR combustion chamber, causing more dilution, due to mixing with the excess air, leading to produce less NOx concentrations, up to 80% of the full load, when compared to conventional engine. Beyond 80% of full load, due to the reduction of fuel-air equivalence ratio with LHR–2 combustion chamber, which was approaching to the stoichiometric ratio, causing higher value of $NO_x$ levels.

**C. Effect of Injector Opening Pressure & Comparative Studies on Different Combustion Chambers**

Table.2 shows variation of pollution levels with injector opening pressure for conventional engine and engine with different configurations of the LHR combustion chamber with pure diesel operation. Particulate emissions decreased marginally with increase of injector opening pressure in both versions of the combustion chamber at full load operation. This was due to improved spray characteristics of the fuel. Particulate emissions were higher with engine with LHR–3 combustion chamber due to cracking of fuel at elevated temperatures. NOx emissions increased with the increase of injector opening pressure in the CE due to increase of fuel-air mixing rate, heat release rate during the premixed- combustion and mixing–controlled combustion phases. However, $NO_x$ emissions decreased with different versions of the LHR combustion chamber. This was because of decrease of gas temperatures in the LHR combustion chamber and increase of the same in the CE with the increase of injector opening pressure. NOx emissions were higher in engine with LHR–3 combustion chamber due to existing of high temperatures because of provision of high degree of insulation.

**Table.2:** Variation of pollution levels with injector opening pressure with diesel operation

| Parameter/Unit | Conventional Engine | | | Engine with LHR combustion chamber | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LHR–1 | | | LHR–2 | | | LHR–3 | | |
| | | | | Injector Opening Pressure (bar)) | | | Injector Opening Pressure (bar) | | | Injector Opening Pressure (bar) | | |
| | 190 | 230 | 270 | 190 | 230 | 270 | 190 | 230 | 270 | 190 | 230 | 270 |
| Particulate Emissions (HSU) | 48 | 38 | 34 | 50 | 45 | 40 | 55 | 50 | 45 | 60 | 55 | 50 |
| NOx emissions (ppm) | 850 | 900 | 950 | 1100 | 1050 | 1000 | 1150 | 1100 | 1050 | 1200 | 1150 | 1100 |

## 4. CONCLUSIONS

1. In comparison with conventional engine, engine with LHR–1 combustion chamber with ceramic coated cylinder head with diesel operation particulate emissions comparable and increased $NO_x$ levels by 18% at an injector opening pressure of 190 bar.
2. In comparison with conventional engine, engine with LHR–2 combustion chamber with air gap insulated piston and air gap insulated liner with diesel operation increased particulate emissions by 14% and $NO_x$ levels by 29% at an injector opening pressure of 190 bar.
3. In comparison with conventional engine, engine with LHR–3 combustion chamber with air gap insulated piston, air gap insulated liner and ceramic coated cylinder head with diesel operation increased particulate emissions by 25% and NOx levels by 41% at an injector opening pressure of 190 bar.
4. However, pollution levels improved with engine with various configurations of LHR combustion chamber at an injector opening pressure of 270 bar in comparison with 190 bar.

### 4.1 Research Findings.

Comparative studies were made on pollution levels with different configurations of the combustion chamber with pure diesel operation with varied injector opening pressure.

### 4.2 Future Scope of Work

Injection timing can also be varied along with change of injector opening pressure. Investigations can be extended to alternate fuels for diesel fuel like vegetable oils, biodiesel and alcohols. Alcohol (methanol or ethanol) can be inducted during suction stroke and diesel can be injected during end of compression stroke to reduce pollution levels of particulate emissions and $NO_x$ emissions.

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