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EXPERIMENTAL INVESTIGATIONS ON EXHAUST EMISSIONS OF SEMI- ADIABATIC DIESEL ENGINE WITH EXHAUST GAS RECIRCULATION

G. SAYANNA[1], M.V.S. MURALI KRISHNA[2], P. USHA SRI[1] AND M. RAVI CHANDRA[3]

[1]*Department of Mechanical Engineering, University College of Engineering (A), Osmania University, Hyderabad 500 007, Telangana, India*
[2]*Mechanical Engineering Department, ChaitanyaBharathi Institute of Technology, Gandipet, Hyderabad 500 075, Telangana, India*
[3]*Department of Mechanical Engineering, Gayatri Vidya Parishad College of Engineering, Madhurawada Visakhapatnam 530 048, A.P., India*

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ABSTRACT

Particulate emissions and Nitrogen oxides (NOx) levels are exhaust emissions from compression ignition (CI) engine. Once they are in-haled- in, they cause health hazards, besides environmental impact. Hence control of these emissions are important and an urgent task. In the context of depletion of fossil fuels, coupled with exponential growth rate of traction power engines in automobiles and for human luxuries, energy consumption has increased by many folds. This has triggered ever increase of fuel prices in international market and due to uneven distribution of oil resources in the world, a few oil rich countries are getting benefitted and oil lacking countries are suffering from non- affordability. Alcohols and vegetable oils are important substitutes for diesel fuel, as they are renewable. However, drawbacks associated with vegetable oils (high viscosity and low volatility) and alcohols (low cetane number and calorific value of the alcohols) call for low heat rejection (LHR) diesel engine. Exhaust gas recirculation (EGR) is one of the techniques to reduce pollution levels. Investigations were carried out to determine exhaust emissions of particulate matter and oxides of nitrogen with neat diesel operation at different values of brake mean effective pressure of the engine with varied injection timing with provision of EGR and compared the data with conventional engine with neat diesel operation. LHR engine consisted of air gap insulated piston with Stainless Steel crown, a low thermal conductivity material and air gap insulated liner with Stainless Steel insert. Particulate matter and NOx emissions will reduce with optimum EGR system.

KEY WORDS : Particulate Emissions, Nitrogen Oxides (NOx), LHR engine and Exhaust Gas Recirculation (EGR)

INTRODUCTION

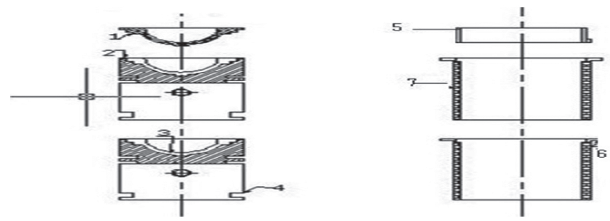
Energy demand (Lee *et al.,* 2014) is increasing due to ever increasing number of vehicles employing internal combustion engines (Haywood, 2013). World is presently confronted with the twin crisis of fossil fuel depletion and environmental degradation. Fossil fuels are limited resources; hence, search for renewable fuels is becoming more and more prominent for ensuring energy security (Murali Krishna *et al.*, 2014) and environmental protection. In the context of fast depletion of fossil fuels, ever increase of fuel prices and increase of pollution levels with fossil fuels, the search for alternative techniques has become pertinent. The concept of the engine with LHR combustion chamber (Murali Krishna *et al.*, 2014a) is to reduce heat loss to the coolant, by providing thermal resistance in the path of heat flow to the coolant. Any saving in this part of the energy distribution would either increase the energy lost through exhaust gases or increase the power output. Considerable efforts are under way to reduce heat loss to the coolant by various researchers (Murali Krishna *et al.*, 2015; Dinagar *et al.*, 1993). However, the results are a little confusing as to whether the insulation would improve or deteriorate thermal efficiency. The approach being pursued to decrease heat rejection Ceramic Coating LHR combustion chamber with low thermal conductivity materials on crown of the piston, inner portion of the liner and cylinder head with Superni-90. The major pollutants emitted from diesel engine are particulate emissions and NOx

.Automobile exhausts reaches oceans in the form of acid rain, there by polluting water. Hence control of these emissions is an immediate task and important. Hence globally, stringent regulations are made for permissible pollutants in the exhaust of the engines. In diesel engines, it is rather difficult to lower NOx and PM emissions simultaneously due to soot-NOx trade off. High NOx and PM emissions are still the main obstacle in the development of next generation conventional diesel engines. There are many methods like employing improved exhaust gas after–treatment technologies, higher fuel injection pressures (Cole *et al.*, 1985), split and multiple injections (Celikten, 2003), exhaust gas recirculation (EGR), intake air pressure boosting etc. are being applied to reduce particulate matter emissions and NOx levels in the exhaust of the compression ignition engine. LHR engine reduces particulate emission due to improved combustion. However, the major problem with any type of LHR engine is it increases drastically NOx levels in comparison with CE with neat diesel operation. There are many methods to reduce NOx levels like varying engine parameters, Selective Catalytic Reduction Technique (Janardhan *et al.*, 2012) SCRT and EGR. The method of SCRT is tedious where zeolites are used. EGR offers simple solution where exhaust gas is re circulated (Krishnan *et al.*, 2018) to inlet manifold of the engine levels. Inhaling of these pollutants causes health hazards like severe headache, tuberculosis, lung cancer, dizziness, nausea, respiratory problems, skin cancer and Head hemorrhage.

MATERIALS AND METHODS

Fabrication of engine with LHR combustion chamber

Fig.1 shows assembly details of air gap insulated piston, air gap insulated liner and LHR combustion chamber. The top portion of the piston, crown made of low thermal conductivity material, stainless steel was screwed to aluminum body of the piston, providing optimum thickness of 2.8 mm air gap in between the crown and the body of the piston. A Stainless Steel (SS) insert was screwed to the top portion of the liner in such a manner that optimum thickness of an air gap of 2.8 mm was maint ained between the insertand the liner body. The combination of low thermal conductivity materials of air and SS provide sufficient insulation for heat flow to the coolant thus resulted in LHR combustion chamber.



1. Stainless Steel with threads, 2.SS gasket, 3. Air gap in piston, 4. Body of piston, 5.SS insert with threads, 6. Air gap in liner, 7.Liner

Fig. 1. Assembly details of air gap insulated piston and air gap insulated liner

The photographic views of air gap insulated piston and air gap insulated liner are shown in Fig.2.

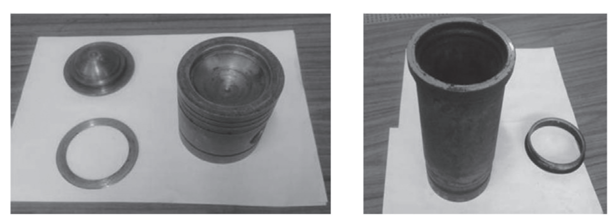


Fig. 2. The photographs of air gap insulated piston and air gap insulated liner

Experimental set–up

Fig.3 shows schematic diagram of the experimental setup used for the investigations on the engine with LHR combustion chamber with diesel. Accuracy of the instruments is shown in Table 1. Specifications of the test engine are given in Table 2. The engine tests are carried out with a single–cylinder, four–stroke, naturally aspirated, water cooled, direct–injection compression ignition engine of brake power 3.68 kW operated at a constant speed of 1500 rev/min. The compression ratio of the engine is

16:1. The engine is connected to an electric dynamometer for measuring its brake power. Dynamometer is loaded by a loading rheostat. The fuel consumption is registered with an aid of fuel measuring device (Burette and stop watch). Diesel is injected into the engine through conventional injection system. Air consumption of the engine was obtained with an aid of air-box, orifice flow meter andU–tube water manometer assembly.

Air box with diaphragm is used to damp out the pulsations produced by the engine, for ensuring a steady flow of air through the intake manifold. Sensor method is provided to vary injection timing. Coolant water jacket inlet temperature, outlet jacket temperature and exhaust gas temperature are measured by employing iron and iron- constantan thermocouples connected to analogue temperature indicators.

The naturally aspirated engine was provided with water–cooling system in which outlet temperature of water is maintained at 80 ^{o}C by adjusting the water flow rate. The water flow rate is measured by means of analogue water flow meter. Engine oil is provided with a pressure feed system. No temperature control was incorporated, for measuring the lube oil temperature. EGR system is designed based upon mass flow rate of hot fluid, cold fluid and their temperatures so as to find out the length of heat exchanger.

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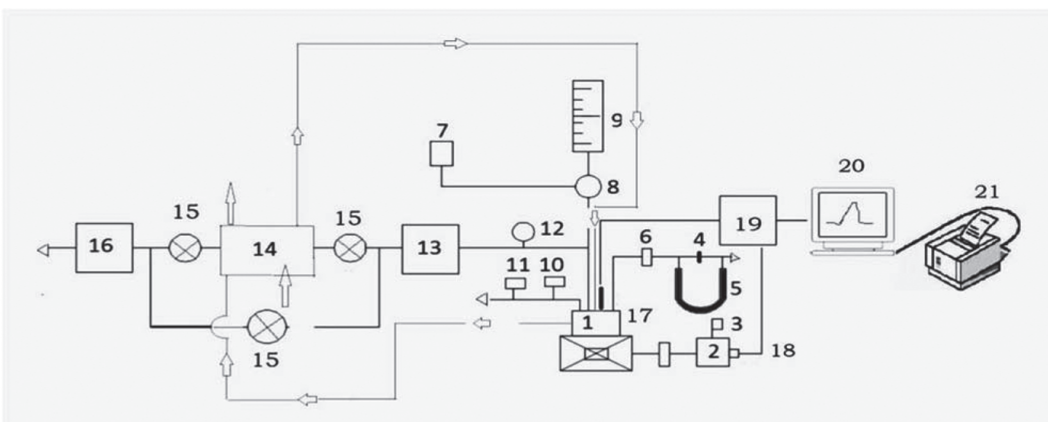
Exhaust Emissions

The major pollutants emitted from diesel engine are particulate emissions and NOx levels. Inhaling of these pollutants causes health hazards like severe headache, tuberculosis, lung cancer, dizziness, nausea, respiratory problems, skin cancer, hemorrhage. The contaminated air containing



1.Engine, 2.Electical Dynamometer, 3.Load Box, 4.Orifice meter, 5.U–tube water manometer, 6.Air–box, 7.Fuel tank, 9.Burette, 10.Outlet jacket water temperature indicator,11. Outlet jacket water flow meter,12. Exhaust gas temperature indicator, 13. AVL Smoke meter.14. Heat exchanger (HE), 15.Control valve.16. Netel Chromatograph NOx analyzer 17.Piezoelectric pressure transducer, 18.TDC encoder, 19.Console, 20.Personal computer 21.Printer.

Fig. 3. Schematic diagram of experimental set-up

Table 1. Accuracy of the Instruments

Instrument	Purpose	Accuracy
EGT indicator	For measuring EGT	5o C
Tachometer	For measuring speed of the engine	5 rpm
Burette	For measuring flow rate of fuel to the engine	0.5 cc/s
Stop watch	For noting down time taken for 10 cc of fuel	0.5 Sec
Hydrometer	For measuring density of fuel	0.1 gm/cc
Dynamometer	For measuring brake power of the engine	1 watt
Water flow meter	For measuring water flow rate to the engine	5 gm/s
Particulate Analyzer	For measuring particulate emissions	1 HSU
NOx Analyzer	For measuring nitrogen oxide levels	5 ppm

carbon dioxide released from automobiles reaches ocean in the form of acid rain, there by polluting water. Hence control of these emissions is an immediate task and important. Hence globally, stringent regulations are made for permissible pollutants in the exhaust of the engines.

Exhaust emissions of particulate matter and nitrogen oxide (NOx) levels were recorded by AVL(Acompany tradename) Particulate matter analyzer and Netel Chromatograph (Acompany trade name) NOx analyzer at different values of brake mean effective pressure of the engine. The accuracy of Measurement of particulate emissions is ±1 HSU (Hartridge Smoke Unit), while it is ±5 ppm with NOx analyzer. The specifications and operating principle of the analyzers are given in Table 4.

RESULTS AND DISCUSSION

Double Pipe Heat Exchanger

Heat exchanger transfers the energy from a hot fluid to a cold fluid, with maximum rate and minimum investment and running costs. Aconcentric–pipe heat-transfer apparatus is employed. The principle of heat exchanger was employed that is heat lost by hot fluid (exhaust gas) is heat gained by cold fluid (ambient air). The length of the heat exchanger was calculated by knowing mass flow rate of fluid and temperatures of hot and cold fluid (Kern, 1963). The optimum EGR was found to be 10% of the total mass flow rate.

Exhaust Emissions

Fig. 4 shows the variation of particulate emissions with brake mean effective pressure (BMEP) with different versions of the engine with neat diesel, at various injection timings at an injector opening pressure of 190bar. A rich fuel–air mixture resulted in higher particulate emissions because of the availability of oxygen was less. The value of particulate emissions increased from no load to full load in both versions of the engine. 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

Table 2. Specifications of the test engine

Description	Specification
Engine make and model	Kirloskar (India) AV1
Maximum power output at a speed of 1500 rpm	3.68 kW
Number of cylinders × cylinder position× stroke	One × Vertical position × four-stroke
Bore × stroke	80 mm × 110 mm
Method of cooling	Water cooled
Rated speed (constant)	1500 rpm
Fuel injection system	In-line and direct injection
Compression ratio	16:1
BMEP @ 1500 rpm	5.31 bar
Manufacturer's recommended injection timing and pressure	27obTDC × 190 bar
Dynamometer	Electrical dynamometer
Number of holes of injector and size	Three × 0.25 mm
Type of combustion chamber	Direct injection type
Fuel injection nozzle	Make: MICO-BOSCH No- 0431-202-120/HB
Fuel injection pump	Make: BOSCH: NO- 8085587/1

Table 4. Specifications of gas analyzers

Name of the analyzer	Measuring Range	Precision	Resolution	Accuracy of Measurement
AVL Particulate Matter Analyzer	0-100 HSU	1 HSU	1 HSU	±1 HSU
Netel Chromatograph NOx analyzer	0-5000ppm	5 ppm	1 ppm	±5 ppm

abrupt rise in particulate emissions due to less available oxygen, causing the decrease of oxygen-fuel ratio, leading to incomplete combustion, producing more sootdensity. The variation Up to 80% of full load, drastic reduction of particulate emissions was observed in the both versions of the engine. Increased oxidation rate of soot in relation to soot formation might have reduced particulate emissions. Higher surface temperatures of engine with LHR combustion chamber aided this process. Beyond 80% of full load, marginal and slight increase of particulate emissions was observed in the LHR engine, when compared to CE. Fuel cracking at higher temperature might have increased. Higher temperature of engine with LHR combustion chamber produced increased rates of both soot formation and burn up. The reduction in volumetric efficiency and oxygen-fuel ratio were responsible factors for increasing particulate emissions in the LHR engine near the fulllo adoperation of the engine. Ase xpected, particulate emissions increased in the LHR engine because of higher temperatures and improper utilization of the fuel consequent upon predominant diffusion combustion. Particulate emissions were observed to be less at all loads in both versions of the engine, with advanced injection timings. Increase of oxygen-fuel fuel ratios and atomization of fuel might have caused effective combustion in both versions of the engine at their respective optimum injection timings.

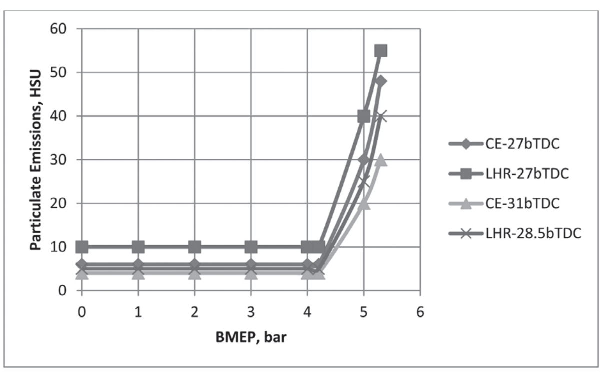


Fig. 4. Variation of particulate emissions with brake mean effective pressure (BMEP) of the engine.

Fig. 5 presents bar charts showing the variation of particulate emissions with provision of EGR and without EGR for both versions of the engine at different injection timings with neat diesel operation.

Particulate emissions decreased with the

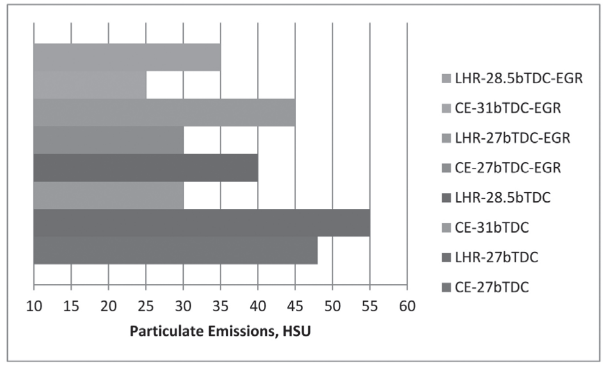


Fig. 5. Bar charts showing the variation of particulate emissions with provision of EGR

provision of EGR. Combustion improved with increase of mass flow rate of EGR up to 10% leading to reduce particulate emissions with both versions of the engine at different injection timings. CE at its advanced injection timing with EGR reduced particulate emissions considerably in comparison with LHR engine. Increase of fuel cracking increased particulate emissions with LHR engine.

Fig. 6 shows the variation of nitrogen oxide levels (NOx) with brake power with different versions of the engine with neat diesel, at various injection timings at an injector opening pressure of 190 bar. The temperature and availability of oxygen are the reasons forthe formation of NOx. For both versions of the engine, NOx concentrations raised steadily as the fuel/air ratio increased with increasing BP/ BMEP, at constant injection timing. At part load, NOx concentrations were less in both versions of the engine. This was due to the availability of excess oxygen. At remaining loads, NOx concentrations steadily increased with the load in both versions of the engine. At peak load, with higher peak pressures, and hence temperatures, and larger regions of close-to-stoichiometric burned gas, NOx

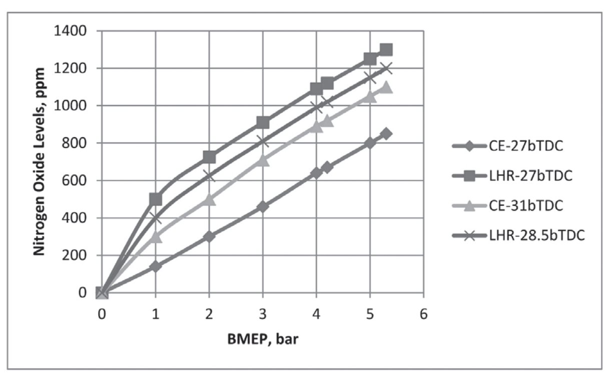


Fig. 6. Variation of nitrogen oxide levels with brake mean effective pressure (BMEP) of the engine

levels increased in both versions of the engine. Increasing the injection advance resulted in higher combustion temperatures and increase of resident timeleading to produce more NOx concentration in the exhaust of CE at its optimum injection timing. At the optimum injection timing, the LHR engine produced lower NOx emissions, at all loads compared to the same version of the engine at the recommended injection timing. Decrease of combustion temperatures might have lowered NOx emissions withadvanced injection timing with LHR engine. However, NOx emissions were marginally lower in the LHR engine when compared to the CE at their respective optimum injection timings, due to increase of residence time in the CE.

Fig. 7 presents bar charts showing the variation of particulate emissions with provision of EGR and without EGR for both versions of the engine at different injection timings with neat diesel operation.

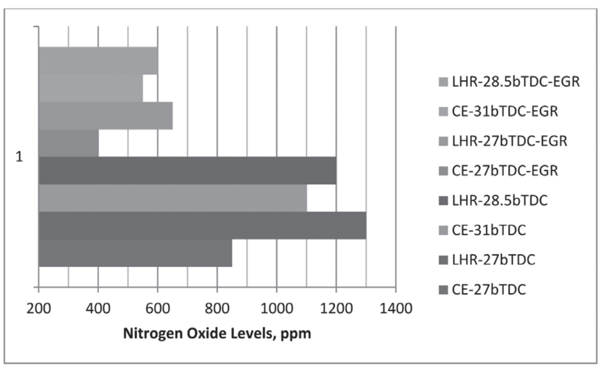


Fig. 5. Bar charts showing the variation of nitrogen oxide levels with provision of EGR

Nitrogen oxide levels decreased with provision of EGR with both versions of the engine at different injection timings with neat diesel operation. Reduction of supply of oxygen might have reduced NO_x emissions with EGR up to 10% mass flow rate.

CONCLUSION

On the basis of version of the engine:

1. LHR engine marginally increased particulate emissions in comparison with conventional engine
2. LHR engine drastically increased nitrogen oxide levels in comparison with conventional engine

On the basis of advanced injection timings

1. At advanced injection timing, LHR engine reduced particulate emissions and nitrogen oxide levels
2. At advanced injection timing, Conventional engine reduced particulate emissions and increased nitrogen levels

On the basis of EGR

1. With provision of EGR, thermal efficiency improved up 10% of mass flow rate, particulate emissions and nitrogen oxide levels considerably decreased

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