



A SURVEY ON LOW COMPRESSION RATIO DIESEL ENGINE

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ABSTRACT

A review on the behaviour of the low compression ratio diesel engine is presented in this work. To incorporate new strategies which improve the performance of the diesel engine, the dynamic interaction between engine subsystems and their impact on combustion phenomenon has to be retrieved. Several studies have investigated the impact of compression ratio on the performance of diesel engine and its implications on the emissions. In general, diesel runs at higher compression ratios. At higher compression ratios, the NO_x emission is high even though brake thermal efficiency is high. Low compression ratio technology can be the solution to this problem. It is proposed that the reduction in compression ratio would be beneficial to reduce the NO_x emissions, thermal and mechanical stresses on the components of the engine. The main objective of this investigation was to understand the impact of lowering the compression ratio on the brake thermal efficiency and brake specific fuel consumption on the diesel engine by reducing the compression ratio from 17.5:1 to 13.7:1 in two steps by using thicker head gaskets. The test results revealed that as the compression was lowered, the NO_x emission got reduced with a little penalty in HC and CO. The brake thermal efficiency is as well reduced and brake specific fuel consumption was increased when compared with the standard compression ratio of the engine.

Keywords: low compression ratio, diesel engine, performance, brake thermal efficiency.

1. INTRODUCTION

Environment pollution issues regarding exhaust gas emissions and fuel economy has become the prime concern of the present day diesel engine [1]. To meet the emission regulations and increase the thermal efficiency of the engine, technology needs to keep upgrading. One of the most promising research ways to increase the power at full load with reduced emissions is the reduction of compression ratio [2]. The parameters that affect thermal efficiency of diesel engine are losses of heat, friction losses, quality of fuel, compression ratio, fuel injection pressure, fuel injection timing and ratio of specific heats [3]. Thermal efficiency can be increased by squeezing out the maximum possible work out of the every drop of fuel that is injected into the combustion chamber.

Carlo performed experimental analysis on the effect of the compression ratio on the performance of a single cylinder diesel engine operating with conventional combustion and low temperature combustion mode for low NO_x emissions. The compression ratio was reduced from 16.5:1 to 14.5:1 and the engine performance was evaluated in terms of thermodynamic parameters, emissions and fuel consumption. The results of compression ratio reduction evidenced a strong improvement in NO_x-particulate trade-off coupled with penalties in unburned compounds emissions and fuel consumption [4].

Cursente, in his article describes the combustion effects of the reduction of compression ratio and quantifies improvements obtained at full load and part load running conditions on a high speed diesel engine of a reduced compression ratio from 18.1:1 to 14:1. The experimental

results showed an increase of 12% of power at 4000 rpm as well as near zero NO_x and PM emissions at 1640 rpm. The brake mean effective pressure of 3, 7 bar with yet a significant increase of CO and HC emissions [5]. At full load, performance has been achieved with large bowl with reduced number for the nozzle injector and finally a lower swirl level. At low load, the reduction of emissions promoted by a thin pulverization of fuel and the best homogenization of fuel/air mixing has required an antagonist design [6].

David J. MacMillan conducted experiments to assess the effect of compression ratio on indifference to variation in injection and air fuel ratio at low and medium speeds by using different bowl sizes of the piston. It was found that at low compression ratio CO, HC and ISFC were higher with improved Soot/NO trade-off. Reducing the compression ratio from 17.9:1 to 13.7:1 marked a degradation of performance at low load, producing high CO emissions and a fall in combustion efficiency [7].

To improve the specific power while minimizing the increase in maximum cylinder pressure, a pent-roof combustion chamber and straight ports was used on a diesel engine [8]. The simulation of the engine cycle was investigated. It was found that the changes of specifications worsened combustion, however, the gross indicated mean effective pressure was found to be lower than that of the baseline engine [9]. The causes for the worsening of the combustion in experiments were analysed and the shape of combustion chamber and specifications of fuel injection system were identified for better combustion [10]. The factor contributing to reduction of the maximum pressure and exhaust temperature was increased intake air mass flow [11].



In order to find the optimum compression ratio, experiments were conducted on a single cylinder variable compression ratio diesel engine at compression ratios of 13.2, 13.9, 14.8, 16.9, 18.1 and 20.2. Results showed a significant improvement in performance and emission characteristics at a compression ratio of 14.8. The compression ratios lower than 14.8 and higher than 14.8 indicated a drop in thermal efficiency, rise in fuel consumption along with the increased smoke densities [12].

The engine's effective compression ratio can be estimated with flexible intake valve actuation without the need for in-cylinder pressure data. The experimentation scheme was able to converge within 3 engine cycles after a transient event with less than 6% average steady state error compared to experimental data [13].

Reducing soot emission with engine technology is effective for reducing Particulate emission. It results in minimizing extra fuel consumption and downsizing [14]. Soot emission level mainly depends on excess air ratio and can be reduced by keeping excess air ratio high. Lean combustion under the limited amount of air and maximum in-cylinder pressure requires decrease in fuel injection quantity and yields decrease in engine power [15]. In order to achieve low soot emission without decreasing engine output, low soot combustion with minimum excess air ratio without a significant increase in soot emissions is required [16]. Low compression ratio encompasses increase in power density under the limited maximum in-cylinder pressure [17]. On a low compression ratio diesel engine and in high EGR rate operating conditions to evaluate the benefits of multiple injection strategies to

improve the trade-off between engine emissions, noise and fuel economy[18]. It was found that by decreasing the peak heat release process appears to be satisfactory for controlling the combustion noise. Multiple injections are used in the appropriate thermodynamic and auto ignition delay conditions in order to reduce the instantaneous fuel burning rate [19]. To enhance the fuel spray distribution and air use in the combustion chamber, multiple injection strategies are used. The cooling effect associated with fuel vaporization lowers locally and globally the temperature of the gases contained in the combustion chamber [20]. This phenomenon can be applied to increase the ignition delay allowing for a longer mixing period and thus a more homogeneous fuel/air mixture to modify the rate of heat release in the early stage of combustion [21].

1.1 Compression ratio

Compression is a process in which charge is confined and pressed into a smaller volume within the area of a cylinder. Compression forces all of the molecules to be pressed together under high pressure [22]. Static compression ratio is the ratio derived from the sweep volume of the cylinder using the full crank stroke from bottom dead centre to top dead centre. Dynamic compression ratio uses the position of the piston at intake valve closing rather than bottom dead centre of the crank stroke to determine the sweep volume of the cylinder [23]. Dynamic compression ratio is always less than the static compression ratio. The actual compression and expansion processes in engines depend on valve timing details and the importance of flow through the valves while they are opening and closing which depend on engine speed.

1.2 Calculation of compression ratio (r_c)

The geometry of cylinder, piston, connecting rod and crankshaft is shown in Figure-1.

The compression ratio of a reciprocating engine can be calculated using the following formulae,

$$\text{Compression ratio } r_c = \text{maximum cylinder volume} / \text{minimum cylinder volume} \\ = (V_d + V_c) / V_c$$

Where V_d = displaced or swept volume and V_c is the clearance volume.

Ratio of cylinder bore to piston stroke, $R_{bs} = B/L$

Where B = bore and L = stroke

Ratio of connecting rod length to crank radius $R = l/a$

Where l = connecting rod length and a = crank radius

Stroke and crank radius are related as, $L = 2a$

The cylinder volume V at any crank position θ is,

$$V = V_c + \Pi B^2 (l + a - s) / 4$$

Where 's' is the distance between the crank axis and the piston pin axis and is given by,

$$S = a \cos \theta + (l^2 - a^2 \sin^2 \theta)^{1/2}$$

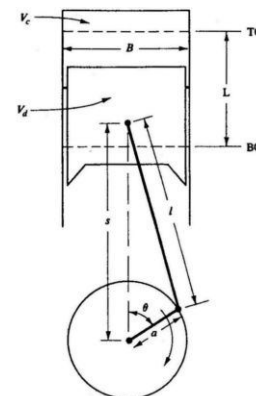


Figure-1. Geometry of piston cylinder arrangement.



2. LOW COMPRESSION TECHNOLOGY

Low compression technology diesel engines have become recognized as viable solution. The slower ignition that results will allow time for better mixing of air and fuel and, therefore, more complete combustion occurs to reduce soot and NO_x. The reduction in compression ratio lowers the cylinder pressure which gives rise to a virtuous cycle of beneficial effects that were previously available. The lower cylinder pressure reduces the thermal and mechanical stresses in the engine. So that, the heavy cast iron block traditionally needed to stop a diesel ripping itself apart can be replaced with lighter materials, which increase the fuel economy. The vibrations caused by the conventional diesel engine substantially get reduced due to low cylinder pressures. As lighter moving parts can be used on the engine, internal friction and inertia is reduced and the engine spins faster and more freely. The low compression ratio engine reduces the combustion chamber temperature and therefore NO_x emissions get reduced. The low compression ratio helps to extend the engine load range [24].

3. PARAMETERS CONSIDERED FOR REDUCING THE COMPRESSION RATIO

3.1 Thicker head gaskets: This is by far the suitable method and has dramatic effect in lowering the compression ratio in an engine.

3.2 Low compression pistons: The pistons are much shorter than conventional ones. The advantage is that they are also often lighter so the engine will run a little more freely. It is recommended that combining low compression pistons with a shorter stroke to get advantage. The shape of the piston crown will also have a bearing on the amount of compression that takes place in the engine.

3.3 Shorter rods and reducing the stroke: A shorter stroke will have a dramatic effect on the compression ratio. By combining this method with low compression pistons, high boost pressures can be attained when adding a turbocharger. The crank will also have some impact on the throw of the engine and the crank, piston crowns and rods should ideally all be matched up.

3.4 Head work: head work increases the volume of the cylinder but the effectiveness depends a lot on how the intake and exhaust valves are seated, and how much space there is to work with. Removing the head is relatively simple and does not require as much effort as other compression lowering methods.

3.5 Decompression plates: They are essentially an extension to the head and can be very effective at reducing the compression ratio. The block side needs a conventional gasket seal but the head side generally only

requires a non setting high temperature sealant (in the case of aluminium decompression plates). Plates can be made of a variety of metals. The decompression plates may fail prematurely in high boost applications where high temperatures are involved. It is viewed that this is a good thing as replacing a decompression plate is a lot easier to do than replacing pistons and heads should they go, and in these extreme conditions this can be quite likely and the plate failure will have flagged up the potential problem.

3.6 Long duration cams: Long duration cams delay the closing of the intake valve and substantially reduce the compression ratio. The cam specification to determine the compression ratio is the intake valve closing time angle. Changing the intake center line changes the compression ratio. Retarding the cam delays intake closing and decrease the compression ratio. It is necessary to determine the position of the piston at intake valve closing to calculate the compression ratio.

4. EXPERIMENTAL METHODS

The engine used is a four stroke single cylinder, vertical, water cooled, natural aspirated, direct injection diesel engine. The specifications of the engine are given in Table-1.

Table-1. Specifications of engine test rig.

Component	Specification
Make	Kirloskar Engines Ltd, Pune
Type of engine	Four Stroke Single Cylinder Water Cooled Engine
Bore and Stroke	87.5 mm & 110 mm
Compression ratio	17.5 : 1
BHP and rpm	4.4kW & 1500 rpm
Fuel injection pressure	200 N/mm ²
Fuel injection timing	23° BTDC
Dynamometer	Eddy Current Dynamometer

A pressure transducer is used to monitor the injection pressure. The engine apparatus was interfaced with an emission measurement device AVL Digas 444 a five gas analyser, and also the setup is provided with necessary instruments for measuring combustion pressure and crank angle. These signals are interfaced to the computer through engine indicator for P-V and P-θ diagrams with AVL INDIMICRA 602 -T10602A software version V2.5. Atmospheric air enters the intake manifold of the engine through an air filter and an air box. An air flow sensor fitted with the air box gave the input for the air consumption to the data acquisition system. All the inputs such as air and fuel consumption, engine brake



power, cylinder pressure and crank angle were recorded by the data acquisition system, which is stored in the computer and displayed in the monitor. A thermocouple in conjunction with a temperature indicator was connected at the exhaust pipe to measure the temperature of the exhaust gas. The smoke density of the exhaust was measured by

the help of an AVL415 diesel smoke meter. A crank position sensor was connected to the output shaft to record the crank angle. The engine test rig is shown in Figure-2 and the schematic diagram of experimental setup is given in Figure-3.



Figure-2. Engine test rig.

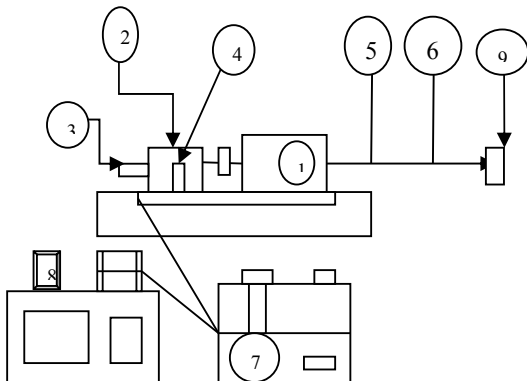


Figure-3. Schematic diagram of experimental setup.

1. Engine 2. Dynamometer 3. Crank angle encoder 4. Load cell 5. Exhaust gas analyzer 6. Smoke meter 7. Control panel 8. Computer 9. Silencer

5. EXPERIMENTAL PROCEDURE

The engine used in this study was a direct injection single cylinder engine manufactured by Kirloskar. The engine was run at different compression ratios to evaluate the performance with emission characteristics. Initially the engine was run on no load condition and its speed was maintained at a constant speed of 1500 rpm. The engine was tested at varying loads of 4.5 A, 9A, 13.5A and 18 A by means of an electrical dynamometer. For each loading conditions, the engine was run for at least 2 min after the data was collected. By

changing the thickness of the cylinder head gasket the compression ratio can be changed to a certain limit. In order to vary the compression ratio of the engine in the present study, a thin copper spacer of 1 mm thick was inserted between the engine cylinder head and the cylinder block. With this various compression ratios of 15.37:1 and 13.7:1 are obtained by using 2 spacers apart from the standard compression ratio of 17.5:1.

6. RESULTS AND DISCUSSIONS

Brake thermal efficiency: Brake thermal efficiency gives the idea of the output generated by the engine w.r.t the heat supplied in the form of fuel. In general, increasing the compression ratio improves the efficiency of the engine due to the reduced ignition delay. Figure-4 shows the variation of brake thermal efficiency with load. The brake thermal efficiency with standard compression ratio of 17.5:1 was found to be 27.03% at full load of 18A and brake thermal efficiency decreases as the compression ratio was reduced. This can be attributed that the fuel added to the cylinder which vaporizes and mixes with air to produce a fuel/air ratio distribution which is non uniform and varies with time. This lead to the inferior combustion at reduced compression ratio of 13.7:1. This can be overcome by premixed compression ignition combustion by controlling ignition timing based on model-based prediction of ignition delay. Not only changing the profile of the combustion chamber or piston bowl but also the fuel spray pattern enhances the brake thermal efficiency in low compression ratio diesel engine.

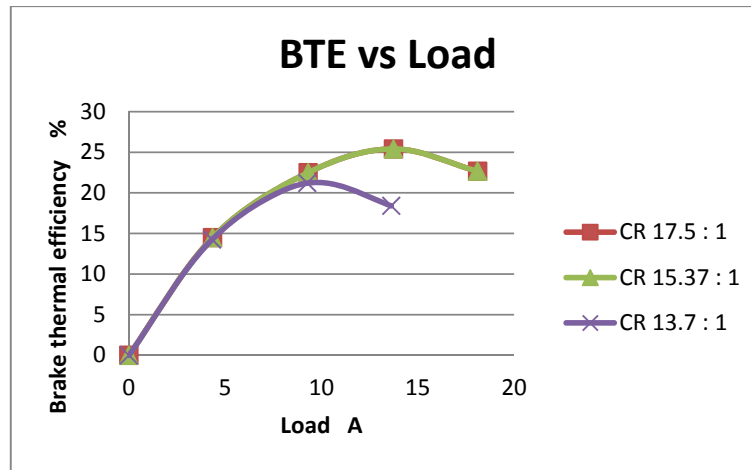


Figure-4. Variation of brake thermal efficiency w.r.t load.

Brake specific fuel consumption: An important parameter to measure the engine performance is the brake specific fuel consumption. Figure-5 shows the variation of BSFC with load at different compression ratios. In general, the BSFC decreases with the increase in load on engine. It was found from the figure that the BSFC was

increased as the compression ratio was reduced. At higher compression ratio lesser value of BSFC is apparent because of better atomization which is associated with a marginal delay in admission of fuel due to high needle lift pressure during injection.

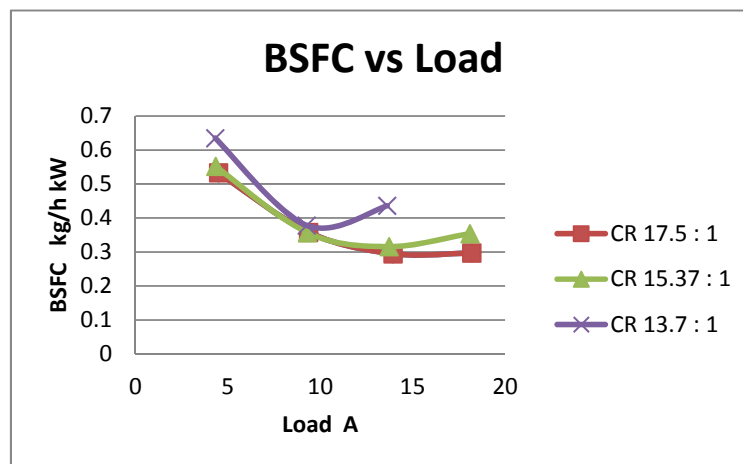


Figure-5. Variation of brake specific fuel consumption w.r.t Load.

7. CONCLUSIONS

Tuning a conventional diesel engine into a low compression ratio diesel engine is demonstrated in this work. Unlike conventional diesel engines, low compression ratio diesel engines operate at relatively low peak temperatures and pressures. Low compression ratio reduces the pre mixed part of the combustion, which reduces the cylinder pressure and therefore the temperature, which reduces NO_x production and also allows the fuel to mix better avoiding locally rich areas that produce soot. The downside to lowering the compression ratio of a diesel engine is that, during warm-

up, the engine temperature can be too low to support proper combustion.

REFERENCES

- [1] Abou Al-Sood.M.M., Ibrahim.A.M. and Abdel Latif.A.A. 1999. Optimum compression ratio variation of a 4-stroke, direct-injection diesel engine for minimum BSFC. SAE Paper 1999-01-2519.



- [2] Adnan Parlak, HalitYasar and BahriSahin. 2003. Performance and exhaust emission characteristics of a lower compression ratio LHR diesel engine. *Energy Conversion and Management*. (44): 163-175.
- [3] Amjad Sheik, ShenbagaVinayagaMoorthi.N, and Rudramoorthy.R. 2007. Variable compression ratio engine: a future power plant for automobiles – an overview”, *Proc. IMechE* (221), pp. 1159-1168.
- [4] Carlo Beatrice, Giovanni Avolio, Nicola Del Giacomo, and Chiara Guido. 2008. Compression Ratio Influence on the Performance of an Advanced Single-Cylinder Diesel Engine Operating in Conventional and Low Temperature Combustion Mode.SAE Technical Paper, 2008-01-1678, DOI:10.4271/2008-01-1678.
- [5] CenkSayin, and MetinGumus. 2011. Impact of compression ratio and injection parameters on the performance and emissions of a DI diesel engine fueled with biodiesel-blended diesel fuel. *Journal of Applied Thermal Engineering*. 31 pp. 3182-3188.
- [6] CursenteV, PacaudP, Gatellier. B. 2008. Reduction of the Compression Ratio on a HSDI Diesel Engine: Combustion Design Evolution for Compliance the Future Emission Standards.0839 *SAE International Journal of Fuels and Lubricants*. 1(1): 420-439,doi: 10.4271/2008-01-0839.
- [7] David.J., MacMillan, Theo Law, Paul.J., Shayler, and Ian Pegg. 2012.The Influence of Compression Ratio on Indicated Emissions and Fuel Economy Responses to Input Variables for a D.I Diesel Engine Combustion System.SAE Technical Paper, doi:10.4271/2012-01-0697.
- [8] Helmantel.A.,Gustavsson.J., and Denbratt.I. 2005. Operation of DI diesel engine with variable effective compression ratio in HCCI and conventional diesel mode. *SAE* 2005-01-0177.
- [9] Heywood.J. 1988.*Internal Combustion Engine Fundamentals*. New York, NY USA: McGraw-Hill.
- [10] Hiroshi Sono, Mitsuhiro Shibata, Yutaka Tajima, KenichiroIkeya, and YukihisaYamaya. 2010. A Study of High Power Output Diesel Engine with Low Peak Cylinder Pressure. *SAE Technical Paper* 2010-01-1107, doi: 10.4271/2010-01-1107.
- [11] Hountalas.D.T., Zannis.T.C. andMavropoulos.G.C., Potential benefits in heavy duty diesel engine performance and emissions from the use of variable compression ratio. *SAE Paper* 2006-01-0081.
- [12] Hyun kyusuh, 2011. Investigations of multiple injection strategies for the improvement of combustion and exhaust emission characteristics in a low compression ratio engines. *Journal of Applied Energy*. 88: 5013-5019.
- [13] Karla Stricker, Lyle Kocher, Ed Koeberlein, Dan Van Alstine, and Gregory M. 2012. Effective Compression Ratio Estimation in Engines with Flexible Intake Valve Actuation.American Control Conference Fairmont Queen Elizabeth, Montréal, Canada, June 27-June 29.
- [14] Klein.M.,Eriksson.L., and Aslund.J. 2006. “Compression ratio estimation based on cylinder pressure data. *Control Engineering Practice*.3(14): 197-211.
- [15] Laguitton.O., Crua.C.,Cowell.T., Heikal.M.R., Gold.M.R. 2007. The effect of compression ratio on exhaust emissions from a PCCI diesel engine. *Energy Conservation and Management*. 48, pp. 2918-2924.
- [16] Mathur.Y.B., Poonia.M.P.,Jethoo.A.S., Singh.R., 2012. Optimization of Compression Ratio of Diesel Fueled Variable Compression Ratio Engine.IJEE, pp. 99-101.
- [17] Nilesh.K.,Gajarlawar, and Dr.Amba Prasad Rao.G, 2012.An Investigation of Combustion and Emission characteristics for reduced compression ratio in Common rail diesel engine. *IJMEAR*. 03(04).
- [18] RatnakaraRao.G.V.N.S.R., RamachandraRaju.V, and MuralidharaRao.M. 2008. Optimising the compression ratio of diesel fuelled C.I engine. *ARNP Journal of Engineering and Applied Sciences*, 3(2).
- [19] RyoutaMinamino, Takao Kawabe, Hiroshi Omote, Shusuke Okada. 2013.The Effect of Compression Ratio on Low Soot Emission from Small Non-Road Diesel Engines. *SAE Technical Paper* 2013-24-0060, 2013, doi: 10.4271/2013-24-0060.
- [20] Souvik Bhattacharyya. 2000. Optimizing an irreversible diesel cycle - fine tuning of compression



ratio and cut-off ratio. Energy Con-version and Management. (41): 847-854.

- [21] Stricker.K., Kocher.L., Koeberlein. E., Van Alstine.D.G.andShaver.G.M.2012. Estimation of effective compression ratio for engines utilizing flexible intake valve actuation.Proc. IMechE Part D: Journal of Automobile Engineering.
- [22] Sylvain Mendez, BenoistThirouard. 2009. Using Multiple Injection Strategies in Diesel Combustion: Potential to Improve Emissions, Noise and Fuel Economy Trade-Off in Low CR Engines.SAE Int. J. Fuels Lubr. 1(1): 662-674, doi: 10.4271/2008-01-1329.
- [23] UsmanAsad, Prasad Divekar,Ming Zheng, and Jimi Tjong. 2013. Low Temperature Combustion Strategies for Compression Ignition Engines: Operability limits and Challenges. SAE Technical Paper 2013-01-0283, doi:10.4271/2013-01-0283.
- [24] YokotaKudo.H., Nakajima. Y., Kakegawa.H., Suzuki T. 1997. A New Concept for Low Emission Diesel Combustion. SAE Paper 970891.