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Performance Investigation of Variable Compression Ratio Engine

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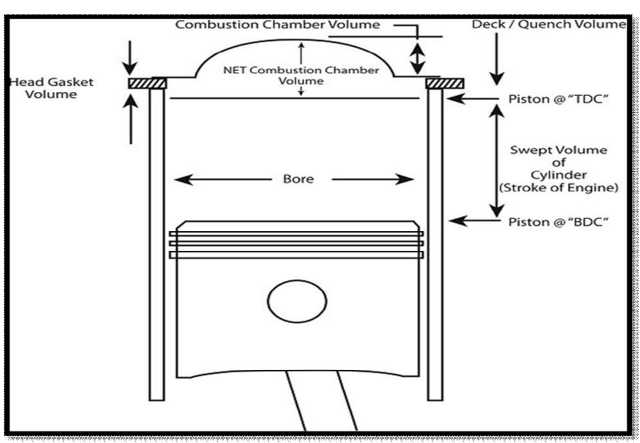
Abstract: Variable Compression Ratio (VCR) engine test can be used to determine the effect of Compression Ratio (CR) on the performance and emissions of the engine. The combustion situation, when provided with a pressure transducer. The performance frequency parameters like efficiencies, power, and specific fuel consumption are determined. The combustion phenomenon is also observed through this work, we can find the optimum compression ratio for which the best performance is possible. In order to find out the optimum compression ratio, experiments were carried out on a single-cylinder four-stroke variable compression ratio engine. Tests were carried out at compression ratios of 18, 17, and 16 at different loads the performance characteristics of the engine like Brake power (BP), Thermal Efficiency, Brake Specific Fuel Consumption (BSFC). A variable compression ratio engine is able to operate at different compression ratios, depending on particular vehicle performance needs. The VCR engine is optimized for the full range of driving conditions, as acceleration, speed, and load.
Keywords: Performance, Compression ratio, Load, Break Power, William Line's Method, Emission, Thermal Efficiency, Diesel Engine, Fuel Consumption

I. INTRODUCTION

Each year, the ultimate goal of emission legislation is to force technology to the point where practically viable zero-emission vehicles become a reality. The path to reach this target is a formidable challenge. The ever-increasing demand for petroleum-based fuels and their availability has lead to extensive research on Diesel fuelled engines. A better design of the engine can significantly improve the combustion quality and in turn, will lead to better brake thermal efficiencies and hence saves fuel. India though rich in coal abundantly and endowed with renewable energy in the form of solar, wind, hydro, and bio-energy has a very small hydrocarbon reserve. India is a net importer of energy. Nearly 25% of its energy needs are met through imports mainly in the form of crude oil and natural gas. The rising oil bill has been the focus of serious concerns due to the pressure it has placed on scarce foreign exchange resources and is also largely responsible for energy supply shortages. The sub-optimal consumption of commercial energy adversely affects the productive sectors, which in turn hampers economic growth. The present work deals with finding the better compression ratio for the Diesel fuelled C.I. engine at variable load and constant speed operation. All over the world, the reduction of automotive fuel consumption and emissions is leading to the introduction of various new technologies in engines.



Combustion Engine Compression Ratio Formula

$$CR = \frac{\left(\frac{\pi}{4} b^2 s\right) + V_c}{V_c}$$

$CR -$ compression ratio
$b -$ cylinder bore diameter in inches
$s -$ piston stroke length in inches
$V_c -$ minimum clearance volume at the end of compression stroke in in^3

Fig. 1 Compression Ratio Terminology

The static compressive ratio of the internal combustion engine or external combustion engine is a value that represents the ratio of the volume of the is a combustion chamber from its largest capacity to its smallest capacity. In a piston engine, it is the ratio between the volume of the cylinder and combustion chamber when the piston is the bottom of a stroke, and the volume of the combustion chamber, and the piston when the piston is at the top of its stroke.

A. Variable Compression Ratio

Worldwide pressure to reduce automotive fuel consumption and CO2 emissions are leading to the introduction of various new technologies for the automotive engine. The concept of variable compression ratio (VCR) promises improved engine performance, efficiency, and reduced emissions. VCR is identified as the key enabling technology of downsized engines. Variable Compression Ratio (VCR) is a system that is used to adjust the compression ratios of the internal combustion engine. In simple terms, it changes the combustion chamber size of the cylinder according to various different operating conditions such as speed, load, acceleration, and torque. Car emissions and fuel economy are two challenges for the automotive sector in which the VCR engine is a very decent technology approaching low fuel consumption and pollutant emission reduction. The car manufacturers have to look forward to more thermally efficient and less polluting engines. In the present world, the automotive sector spends millions of dollars for approaching low emission as well as low fuel consumption cars. Various different ways are been discovered such as hybrid cars, fuel cell cars, solar cars, and many more as future development. VCR engine would practically prove to be a boon for the automotive sector. The concept of the VCR engine significantly contributes its benefits to thermo-dynamic efficiency. The concept of the VCR is that it continuously operates at different compression ratios as per the need of the performance. The change in the combustion chamber volume continuously takes place with the varying compression ratio.

II. PROPOSED METHODOLOGY

This is the experimental setup, which we are going to use for testing, As shown in the figure, the test equipment is composed of the four-stroke variable compassion ratio engine and emission tester used in the exhaust gas analyzer.

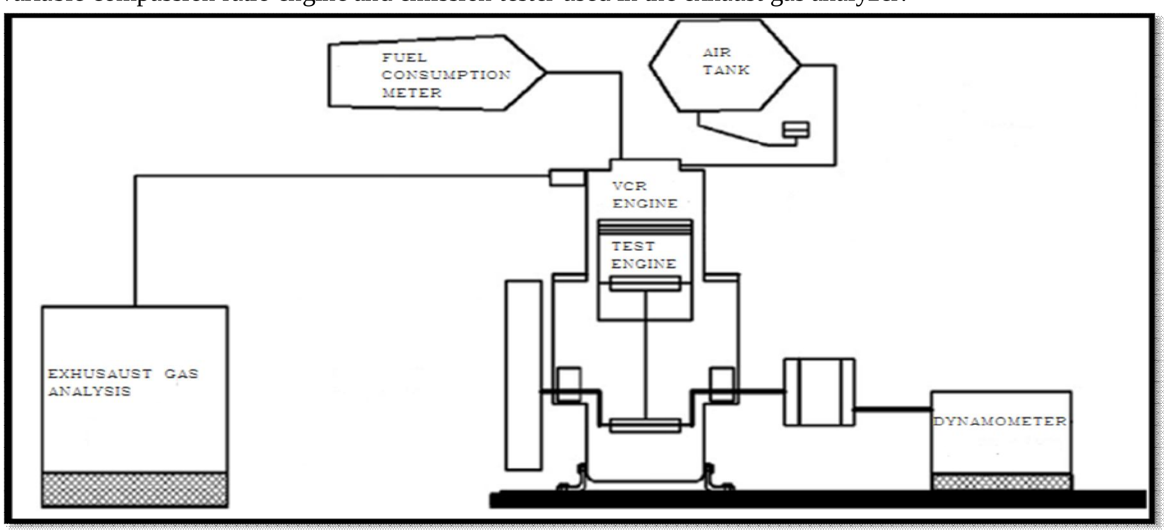


Fig. 2 Experimental Setup Line Diagram

The setup consists of single-cylinder four strokes (Kirloskar), water-cooled, Multi-fuel, research engine connected to eddy current type dynamometer for the load. The main components of the system are dynamometer, exhaust gas analyzer, fuel tank, fuel injector, load indicator. The VCR engine has to be operated on the diesel at different compression ratios, with a load range at each given value of compression ratio. The engine has an eddy current dynamometer to measure its output. It consists of stators on which are fitted with a number of electromagnets and a rotor disc made of copper or steel and coupled to the shaft of the engine. In modes, the compression can be varied without stopping the engine without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. The setup has fuel tanks for fuel tests, manometers, fuel measuring units, transmitters for air and fuel flow measurements. Rotameters are provided for cooling water and calorimeter water flows measurement. The exhaust emissions of the engine are analyzed using an exhaust gas analyzer. The constituents of the exhaust gas were measured. Lab view-based Engine Performance Analysis software package “Enginesoft” is provided for online performance evaluation.

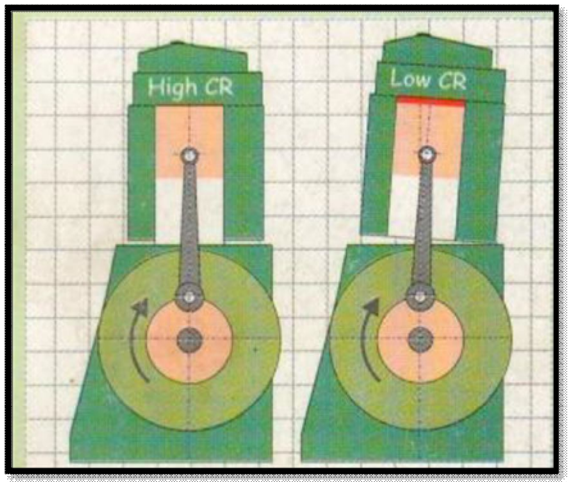


Fig. 3 Principle of Tilting Cylinder Block Assembly

A. *Engine Specification*

Sr No.	Features	Specifications
1	Make	Kirloskar oil engines ltd.
2	Type	Four stoke, water cooled diesel
3	No of cylinder	1
4	Combustion principle	Compression ignitio
5	Max. Speed	1500
6	Crank radius	55 mm
7	Connecting rod length	234 mm
8	Cylinder dia.	87.5 mm
9	Stroke length	110 mm
10	Loading	Eddy current dynamometer
11	Load (max.)	23.86 n-m
12	Max. Power	3.5 KW
13	Compression ratio	Variable from 12:1 to 18:1
14	Overall dimensions	617 l x 504 w x 877 H
15	Weight	160 KGS
16	Direcction of rotation	Clockwise (looking from flywheel side)

Table 1 Engine Specification

III. EXPERIMENTAL SET-UP

A. Experimental Test Rig

Fig. 4 Experimental Test Rig

This is the experimental setup, which we are going to use for our testing. As shown in figure 4, the test component is composed of The setup consists of single-cylinder, four-stroke, water-cooled, Multi-fuel, research engine connected to an eddy current type dynamometer for the load. The main components of the system are Dynamometer, Exhaust gas analyzer, fuel tank, fuel injector, and load indicator. The VCR engine has to be operated on the diesel at different compression ratios, with a load range at each given value of compression ratio. The engine has an eddy current dynamometer to measure its output. it consists of stators on which are fitted with a number of electromagnets and a rotor disc made of copper or steel and coupled to the shaft of the engine. In modes, the compression can be varied without stopping the engine without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. The setup has fuel tanks for fuel tests, manometers, fuel measuring units, transmitters for air and fuel flow measurements. Rota meters are provided for cooling water and calorimeter water flows measurement. The exhaust emissions of the engine are analyzed using an exhaust gas analyzer. The constituents of the exhaust gas were measured. Labview-based Engine Performance Analysis software package “Enginesoft” is provided for online performance evaluation.

B. Experimental Procedure

In this experiment, the diesel engine is used with an eddy current dynamometer. Load is varied by a dynamometer. we are taken 21 readings on pure diesel. Varying parameters are compression ratio and Load. First of all the water flow for the cooling of the engine is turned on and then the engine is cranked with the handle and started. Then the fuel line is filled with the diesel and allowed to stable. The knob for the load is set at load 1 and the compression ratio is set by Compression ratio adjustment. Then the “Enginesoft” software is attached to the engine setup and the start of reading is done. The software takes 60 seconds for taking the reading of any specific reading. Then the load and compression ratio is adjusted as per the table and 21 readings were taken as per table and individual software files are saved. Then the engine is stopped and the Compression ratio is changed (i.e. 18-17-16). The same procedure is followed again.

C. Compression Ratio Adjustment and Compression Ratio Adjustment Arrangement

Fig. 5 Experimental Test Rig Fig. 6 Experimental Test Rig

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Slightly loosen 6 Allen bolts provided for clamping the tilting block. Loosen the lock nut on the adjuster and rotate the adjuster so that the compression ratio is set to "maximum". Refer to the marking on the CR indicator. Lock the adjuster by the lock nut and tighten all the 6 Allen bolts gently. You may measure and note the center distance between two pivot pins of the CR indicator. After changing the compression ratio, the difference can be used to know the new CR. The compression ratio adjustment arrangement is as shown in figure 5. An exhaust Gas Analyzer is used to measure the level of pollutants in the exhaust of the car. Gas Analyzer is used in various government authorized test centers. The setup of the exhaust gas analyzer is shown in figure 6.

IV. EXPERIMENT MEASUREMENT

Using all parameters and reading will to graphically represent and will be analysed Engine performance parameters like Brake power (BP), Specific fuel consumptions, Brake thermal efficiency, and Mechanical efficiency. Similarly, We will find HC, CO, and NOX which are emission parameters. We will consider the load and speed of the engine during the test.

Ex. No.	Compression ratio	Load	Speed (rpm)	FC (cc/min)	Air (mmwc)	O_2 (%)	CO_2 (%)	HC (ppm)	CO (%)	No_x (ppm)
1	18	1	1500	8	59.17	19.28	0.9	10	0.07	88
2	18	3	1500	10	58.49	19.23	1.1	25	0.05	184
3	18	5	1500	12	55.81	18.66	1.3	27	0.03	321
4	18	7	1500	14	53.74	18.13	1.7	34	0.03	535
5	18	9	1500	16	53.17	17.98	1.8	45	0.03	769
6	18	11	1500	18	51.89	17.52	2	29	0.02	837
7	18	13	1500	21	51.22	17.33	2.1	54	0.03	992
8	17	1	1500	8	59.94	18.87	1	25	0.06	119
9	17	3	1500	10	58.5	18.91	1.1	27	0.04	201
10	17	5	1500	12	57.65	18.66	1.3	32	0.03	339
11	17	7	1500	13	53.39	18.14	1.6	41	0.03	531
12	17	9	1500	16	53.16	18	1.8	49	0.02	795
13	17	11	1500	18	52.06	17.48	2	36	0.02	874
14	17	13	1500	20	51.57	17.31	2.1	65	0.03	1050
15	16	1	1500	8	60.54	19.27	1	26	0.05	137
16	16	3	1500	10	59.92	18.87	1.1	29	0.04	222
17	16	5	1500	11	55.79	18.56	1.4	20	0.04	333
18	16	7	1500	14	55.99	18.44	1.5	34	0.03	539
19	16	9	1500	16	54.94	17.98	1.8	48	0.02	830
20	16	11	1500	18	52.67	17.57	1.9	45	0.02	904
21	16	13	1500	21	50.85	17.27	2.1	73	0.03	1066

Table 2 Observations Table

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Torque (N.m)	B.P (KW)	FC (Kg/hr)	SFC (kg/kwh)	BTE (%)	FP (KW)	IP (KW)	ITE (%)	ME (%)
1.81485	0.284931	0.39984	1.403284895	5.986953	1.83	2.114931	44.43874	13.47237
5.44455	0.854794	0.4998	0.58470204	14.36869	1.83	2.684794	45.13012	31.83835
9.07425	1.424657	0.59976	0.420985469	19.95651	1.83	3.254657	45.59103	43.77288
12.70395	1.99452	0.69972	0.350821224	23.94781	1.83	3.82452	45.92026	52.15086
16.33365	2.564383	0.79968	0.311841088	26.94129	1.83	4.394383	46.16718	58.35593
19.96335	3.134246	0.89964	0.287035547	29.26955	1.83	4.964246	46.35923	63.1364
23.59305	3.704109	1.04958	0.283355604	29.64967	1.83	5.534109	44.29797	66.93235
1.81485	0.284931	0.39984	1.403284895	5.986953	1.95	2.234931	46.96017	12.749
5.44455	0.854794	0.4998	0.58470204	14.36869	1.95	2.804794	47.14726	30.47619
9.07425	1.424657	0.59976	0.420985469	19.95651	1.95	3.374657	47.27199	42.21635
12.70395	1.99452	0.64974	0.325762565	25.78995	1.95	3.94452	51.00424	50.56433
16.33365	2.564383	0.79968	0.311841088	26.94129	1.95	4.514383	47.42789	56.80473
19.96335	3.134246	0.89964	0.287035547	29.26955	1.95	5.084246	47.47986	61.64623
23.59305	3.704109	0.9996	0.26986248	31.13215	1.95	5.654109	47.52144	65.51181
1.81485	0.284931	0.39984	1.403284895	5.986953	1.73	2.014931	42.33755	14.141
5.44455	0.854794	0.4998	0.58470204	14.36869	1.73	2.584794	43.44916	33.07011
9.07425	1.424657	0.54978	0.385903346	21.77074	1.73	3.154657	48.20753	45.16044
12.70395	1.99452	0.69972	0.350821224	23.94781	1.73	3.72452	44.71958	53.55106
16.33365	2.564383	0.79968	0.311841088	26.94129	1.73	4.294383	45.11659	59.71482
19.96335	3.134246	0.89964	0.287035547	29.26955	1.73	4.864246	45.42537	64.43436
23.59305	3.704109	1.04958	0.283355604	29.64967	1.73	5.434109	43.49752	68.16405

Table 3 Performance Table

A. *Simple Calculations*

Sample calculations for 1 kg load at Constant speed 1500 rpm of Diesel engine when working on Diesel **.**
Calorific Value of the fuel = 42850 kJ/kg
Dynamometer Length = 0.185 m
Density = 0.833 kg/lit
Fuel consumption = 8 cc/min

- *Brake Power (BP)*

$$BP = \frac{2\times\pi\times N\times T}{60\times1000} \text{ kW}$$

Where, N = Brake Speed, RPM =1500

$$= \frac{2\times3.14\times1500\times1.81485}{60{,}000} = 0.284931 \text{ kW}$$

T = Torque, N-m

$$= (\text{LOAD} \times 9.81) \times \textit{DYNAMOMETER ARM LENGTH, N.M}$$

$$= (1 \times 9.81) \times 0.185$$

$$= 1.81485 \text{ Nm}$$

- *Fuel Consumption (FC)*

$$FC = \frac{\text{fc (cc/min)} \times 60 \text{ (min)} \times \text{Density (kg/lit.)}}{1000} \text{ kJ/hr}$$

$$= \frac{8 \times 60 \times 0.833}{1000}$$

=0.39984 kJ/hr

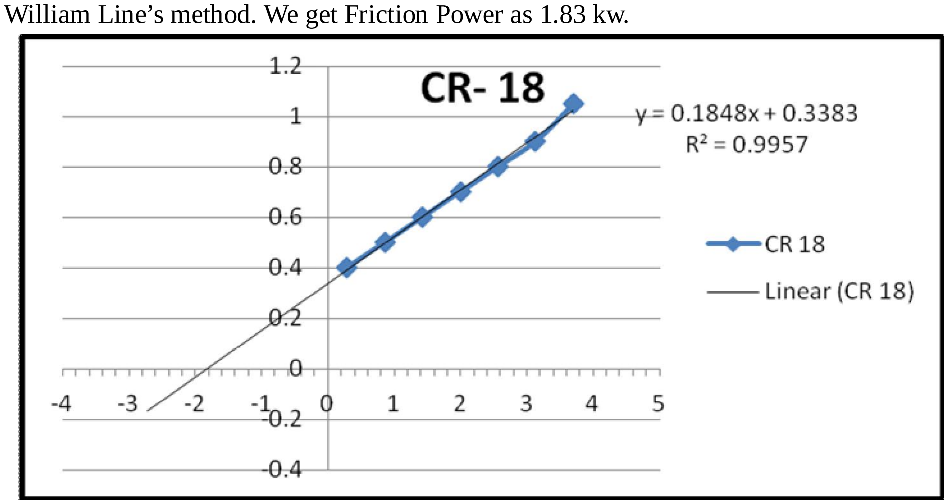
- *Specific Fuel Consumption (SFC)*

$$\text{SFC} = \frac{\text{FC}}{\text{BP}} \text{ kg/kWh}$$

$$= \frac{0.39984}{0.283931}$$

$$= 1.403287112 \text{ kg/kWh}$$

1) *Friction power (FP):* Is calculated with the help of William Line's method by plotting graph Break Power Vs. Fuel Consumption by William Line's method. We get Friction Power as 1.83 kw.



Graph 1 William Line's Method

2) *Indicated Power (IP)*

IP = FP+BP

=1.83+0.284931

=2.114931 kw

3) *Efficiency*

- Mechanical Efficiency (ME)

$$\eta_m = \frac{BP}{IP} \times 100\%$$

$$= \frac{0.284931}{2.114931} \times 100$$

$$= 13.47\ \%$$

- Brake Thermal Efficiency (BTE)

$$\eta_{BT} = \frac{BP*3600}{\text{HEAT SUPPLIED BY FUEL } (mf \times CV)} \times 100\ \%$$

$$\eta_{BT} = \frac{0.284931*3600}{(0.39984 \times 42850)} \times 100\ \%$$

$$= 5.98\%$$

- Indicated Thermal Efficiency (ITE)

$$\eta_{IT} = \frac{IP*3600}{\text{HEAT SUPPLIED BY FUEL } (mf \times CV)} \times 100\ \%$$

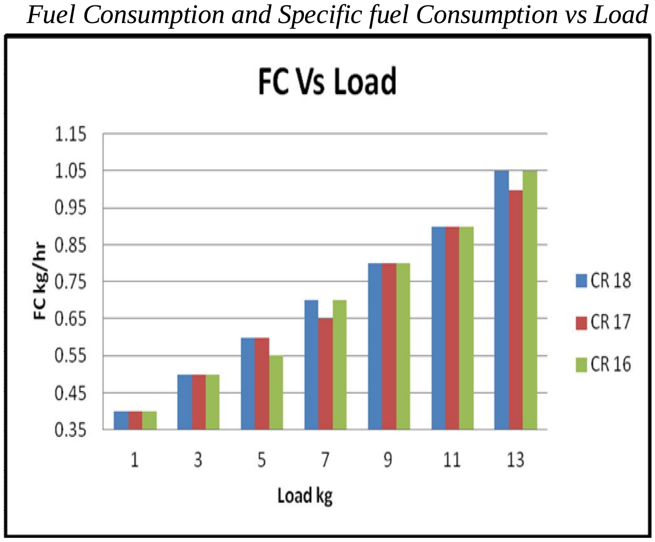
$$\eta_{IT} = \frac{2.114931*3600}{(0.39984 \times 42850)} \times 100\ \%$$

$$= 44.43\%$$

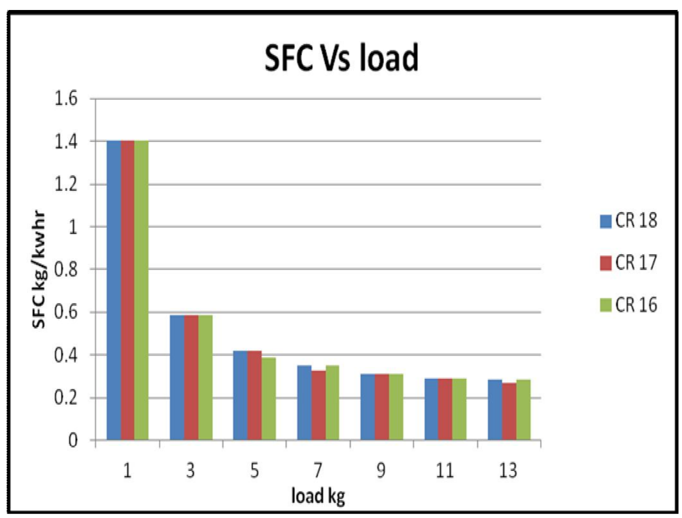
V. RESULT

Experiment were performed at 1 kg, 3kg, 5kg, 7kg, 9kg and 13kg engine load and break power, SFC, BTE, are measured with different compression ratio. In each test, the compression ratio was changed to 18, 17 and 16. Based on the mass consumption rate of the fuel and break power, SFC, and BTE can be calculated.

A. *Fuel Consumption and Specific fuel Consumption vs Load*



Graph 2 FC Vs Load



Graph 3 SFC VS Load

From t graph 1 and 2, we can see that compassion ratio 17 has better result than other one.

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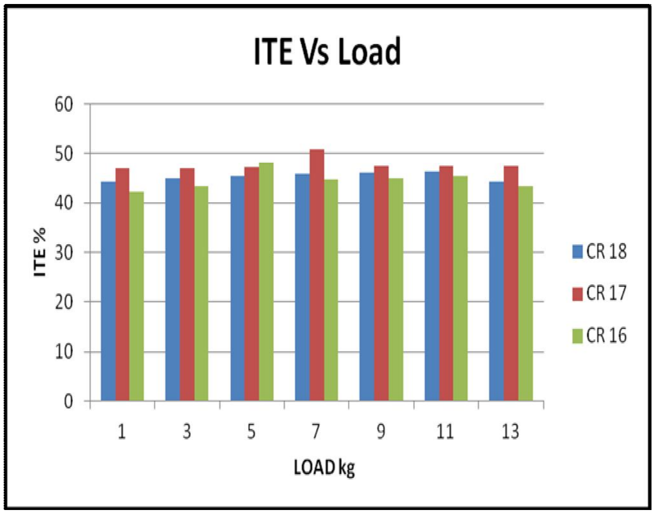
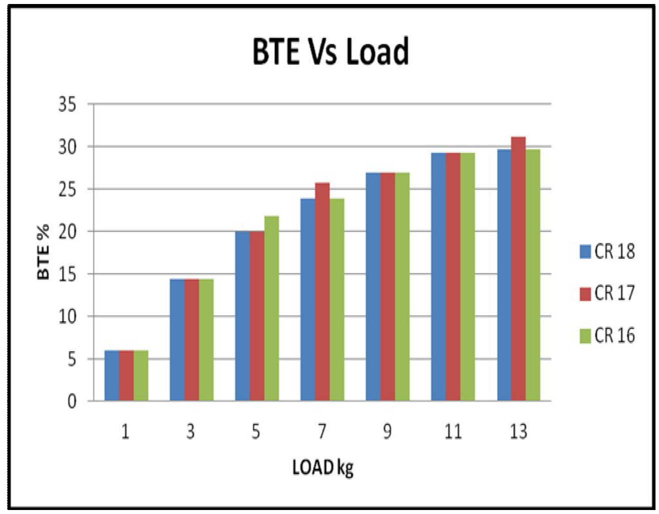
B. Indicated Thermal Efficiency And Break Thermal Efficiency Vs Load



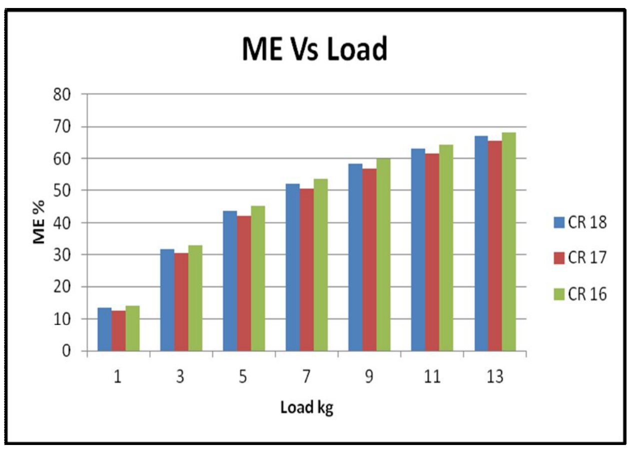
Graph 4 ITE Vs Load



Graph 5 BTE Vs Load

From t graph 4 and 5, we can see that compassion ratio 17 has better result than other compression ratios.

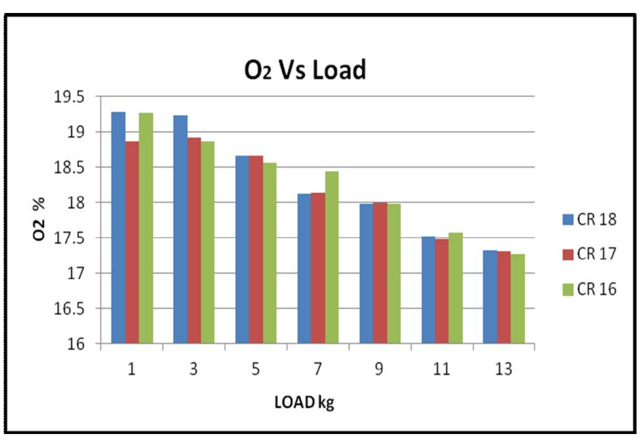
C. Mechanical Efficiency



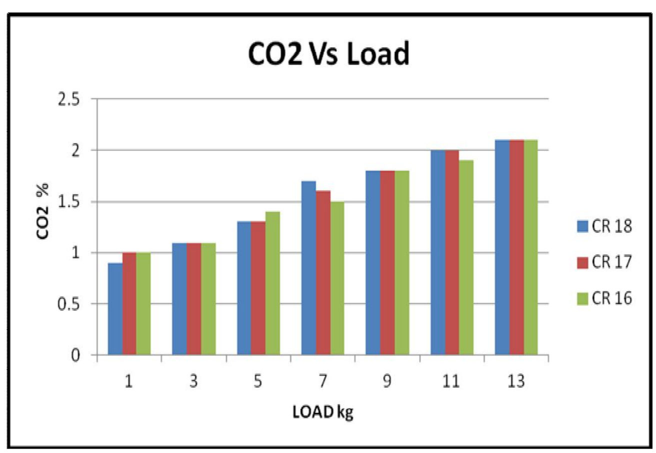
Graph 6 ME Vs Load

D. Exhaust Emission

1) O_2



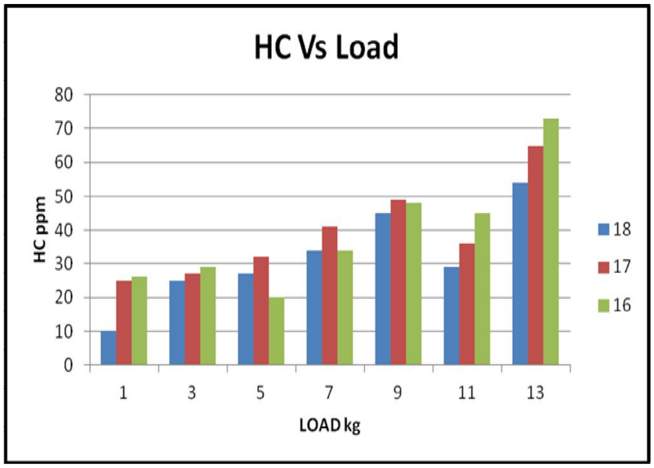
Graph 7 O_2 Vs Load

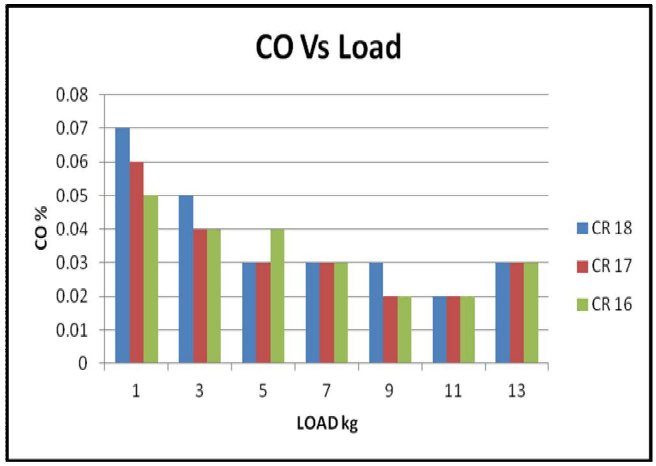


Graph 8 CO_2 Vs Load

The formation of O2 is mainly due to the incomplete fuel oxidation phenomena. O2 % volume at different compression ratios for the different loads. The formation of CO2 is mainly due to the incomplete fuel oxidation phenomena. CO2 % volume at different compression ratios for the different loads.

2) *HC and CO:* HC can affect the human mucous membranes like the throat and eyes and the environment due to the smog formation reaction that produces ozone. HC emission is completely unburned or partially burned molecules that come from heterogeneous combustion in the combustion chamber. HC ppm at different compression ratios for the different loads.

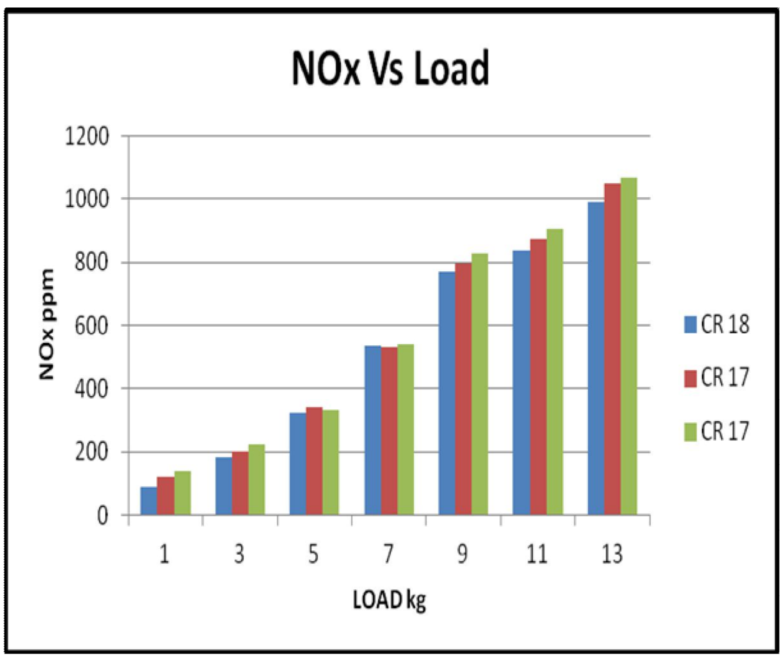




Graph 9 HC Vs Load   Graph 10 CO Vs Load

The formation of CO is mainly due to the incomplete fuel oxidation phenomena. CO % volume at different compression ratios for the different loads.

3) *NO_X:* The formation of NOX is mainly due to the incomplete fuel oxidation phenomena. NOX % volume at different compression ratios for the different loads.



Graph 11 NO_X Vs Load

E. Effect Of Compression Ratio On Emission Characteristics

From the above all the emission graphs we can see that compression ratio 17 has a better result than another one.

VI. CONCLUSION AND FUTURE SCOPE

A. Conclusion

From this experimental work, we conclude the following results,

1) The Break thermal efficiency, Mechanical efficiency and Indicated Thermal efficiency are higher for the compression ratio of 17 compared to other compression ratios.
2) Break Specific fuel consumption is lower and Break Power is almost similar with minor variations for the compression ratio of 17 compared to other compression ratios.
3) The various emissions namely CO, HC, NOx and decreasing for the compression ratio 17 compared to other compression ratios.
4) The NOx emission increasing for all the compression ratios due to the increase in cylinder temperature. However, still NOx is lower in the case of 17, compression ratio due to proper combustion.
5) The Smoke emission is also lower for all the compression ratios at higher loads due to enhanced combustion.

B. Future Scope

Researchers can future work on different compression ratios with fuel blending in the diesel engines. Someone can extend the work for different compression ratios with a varying injection pressure of diesel engines.

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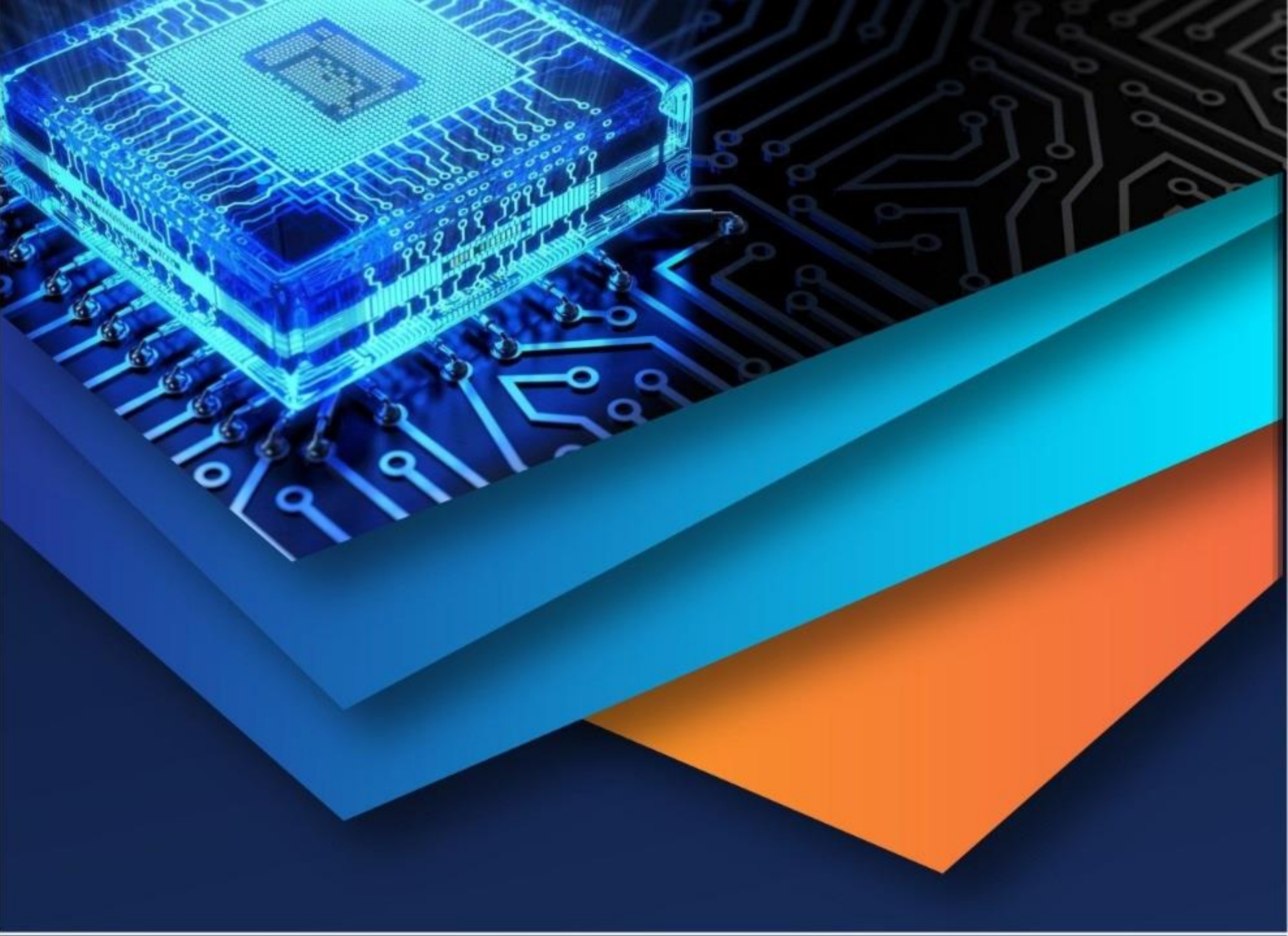

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