Effect of Variable Compression Ratio on Performance and Emissions Characteristics of IC Engine

S.V.Umamaheswara Rao¹, Amrut raj, K. Satyanarayana², T.V.Hanumantha Rao²
R.Tirumaleswara Naik³

¹Dept of Marine Engineering, Andhra University, Visakhapatnam India - 531006
²ANITS, Mechanical Engineering, Sangivalasa, Visakhapatnam, India, 531162
³Dept of Mechanical Engineering, Indian Institute of science, Bangalore, India, 560012

Abstract:-Variable Compression Ratio (V.C.R) engine test rig can be used to determine the effect of compression Ratio on the performance and emissions of the engine. The performance measuring parameters like efficiencies, power produced and specific fuel consumption are determined. Further, the smoke intensity and emissions are also observed. The objective is to determine the optimum compression ratio for which the best performance is possible. In order to determine the optimum compression ratio, experiments were carried out on a single cylinder four stroke variable compression ratio diesel engine. Tests were carried out at compression ratios of 16.5, 17.0, 17.5, 18.0 and 19.0 at different loads. The performance characteristics of engine like Brake power (BP), Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC) are extracted. Results showed a significant improved performance at a compression ratio of 17.5. The compression ratio lesser than 19.0 showed a drop in brake thermal efficiency and rise in fuel consumption. I.C engine should meet the accepted emission norms before coming on to the road. The main pollutants are CO, CO₂, SOₓ, HC, NOₓ, Soot etc from which NOx is one of the most harmful components. A study has also been conducted to check the effect of compression ratio on the emissions and smoke intensity. The emission levels were found to peak at compression ratio of 19.0 and lowest at 17.5.

Key words: Performance, Emissions, variable compression ratio, Diesel engine.

I. INTRODUCTION

Each year, the ultimate goal of emission legislation is to force technology to the point where a practically viable zero emission vehicle become a reality. The path to reach this target is a formidable challenge. The ever increasing demand for the petroleum based fuels and their scare 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 hydro carbon reserves (0.4% of the world’s 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. An engine is a machine designed to convert one form of energy into mechanical energy.

II. COMPRESSION RATIO (CR):

The compression ratio of an internal-combustion engine or external combustion engine is a value that represents the ratio of the volume of its combustion chamber from its largest capacity to its smallest capacity. It is a fundamental specification for many common combustion engines. The ratio is calculated by the following formula:

\[ CR = \frac{\pi b^2 s + V_c}{V_c} \]

Where:
- \( b \) = effective stroke of the engine
- \( s \) = clearance volume. It is the volume of the combustion chamber (including head gasket).

III. VARIABLE COMPRESSION RATIO

Variable compression ratio is technology to adjust the compression ratio of an internal combustion
engine while the engine is in operation. This is done to increase fuel efficiency while under varying loads. Higher loads require lower ratios to be more efficient and vice versa. Variable compression engines allow for the volume above the piston at 'Top dead center' to be changed. For automotive use this needs to be done dynamically in response to the load and driving demands.

A. Advantages of Variable Compression Ratio:
Petrol engines have a limit on the maximum pressure during the compression stroke, after which the fuel/air mixture detonates rather than burns. To achieve higher power outputs at the same speed, more fuel must be burned and therefore more air is needed. To achieve this, turbochargers or superchargers are used to increase the inlet pressure. This would result in detonation of the fuel/air mixture unless the compression ratio was decreased, i.e. the volume above the piston made greater. This can be done to greater or lesser extent with massive increases in power being possible. The down side of this is that under light loading, the engine can lack power and torque. The solution is to be able to vary the inlet pressure and adjust the compression ratio to suit. This gives the best of both worlds, a small efficient engine that behaves exactly like a modern family car engine but turns into a highly tuned one on demand. Variable Compression Ratio (VCR) is becoming increasingly desirable as oil prices increase and car buyers have an increased interest in fuel economy. In addition to this, Global Climate Warming requires measures from international community. To Automobile industry it means stricter limits to car emissions, especially CO2. Variable compression ratio is one cost effective way achieving these targets. In addition VCR allows free use of different fuels besides petrol e.g. LPG or ethanol. The cylinder head can be altered by using a hydraulic system which is connected to the crank shaft and responds according to the load and acceleration required.

B. Disadvantages of Fixed Compression Ratio
Power output is reduced, Fuel efficiency is not optimized, and pollution from combustion is not minimized.

C. Ways to Modify Variable Compression Ratio
Moving the cylinder head, Variation of combustion chamber volume, Variation of piston deck height, Modification of connecting rod geometry, Moving the crank pin within the crankshaft (effectively varying the stroke), Moving the crankshaft axis.

IV. LITERATURE REVIEW
Worldwide pressure to reduce automotive fuel consumption and CO2 emissions is leading to the introduction of various new technologies for the C.I engine as it fights for market share with the petrol. So far, variable compression ratio (VCR) engines have not reached the market, despite patents and experiments dating back over decades. VCR technology could provide the key to enable exceptional efficiency at light loads without loss of full load performance. This paper will review the many embodiments of VCR, the implications for volume manufacture and the strategy for VCR implementation in order to produce the maximum benefit. To find out the Optimum Compression Ratio of the Computerized Variable Compression Ratio (VCR) Single Cylinder Four Stroke Diesel Engine using Experimentation analysis. Various parameters defining the performance of V.C.R diesel engine are calculated and they are used as means for obtaining optimum compression ratio. By plotting performance and emission graphs of different loads and different compression ratios from that optimum compression ratio obtained.

V. EXPERIMENTAL SETUP:
The layout of the experimental setup is shown in Fig 1. The main components of the system are (1) The engine,(2) Fuel injection pum,(3) Dynamometer,(4) Device for changing starting of fuel ,(5) Supercharging system,(6) Dynamic injection indicator, (7) Data acquisition system (8) Smoke meter, (9) Exhaust gas analyzer (10) Pressure transducer
Table-1: Engine specifications:-

<table>
<thead>
<tr>
<th>Features</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make</td>
<td>Kirloskar oil Engine</td>
</tr>
<tr>
<td>Type</td>
<td>Four stroke, Water cooled Diesel</td>
</tr>
<tr>
<td>No of cylinders</td>
<td>One</td>
</tr>
<tr>
<td>Combustion Principle</td>
<td>Compression ignition</td>
</tr>
<tr>
<td>Max speed</td>
<td>1500</td>
</tr>
<tr>
<td>Crank Radius</td>
<td>55mm</td>
</tr>
<tr>
<td>Connecting Rod length</td>
<td>300mm</td>
</tr>
<tr>
<td>Cylinder diameter</td>
<td>80mm</td>
</tr>
<tr>
<td>Stroke length</td>
<td>110mm</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>Variable</td>
</tr>
<tr>
<td>Loading</td>
<td>Eddy current dynamometer</td>
</tr>
</tbody>
</table>

Reasons for Selecting the Engine: This engine can with stand higher pressures encountered and also used extensively in agricultural and industrial sectors. Therefore this engine is selected for conducting experiments. Moreover necessary modifications on the piston and the cylinder head can easily be made.

Dynamometer: The engine has a eddy current dynamometer to measure its output. it consists of stator on which are fitted with a number of electromagnets and a rotor disc made of a copper or steel and coupled to shaft of engine . When the rotor rotates eddy currents are produced in the stator due to magnetic flux set up by the passage of field current in the electro magnets. This eddy current opposes the rotor motion thus loading the engine.

Device for Changing Start of Injection: This device can change fuel injection timing from 55 degrees before top dead center (b TDC) to top dead center (TDC).

Data Acquisition System: For studying the processes inside the cylinder data acquisition system are used. These are used for analyzing the measured cylinder pressure data and to quantify the combustion parameters. The components of the system are the pressure pick up, charge amplifier, TDC position sensor, A/D card and a personal computer. Various parameters such as peak cylinder pressure, occurrence of peak pressure, start of combustion and ignition delay are analyzed with the system.

Exhaust Gas Analyzer: A Non-dispersive infrared gas analyzer (FUJI, Japan) is used to measure HC and CO emissions. Cold traps are provided to prevent moisture from entering the exhaust gas analyzer. The emission measurements are carried out on dry basis.

VI. Performance Calculations:

Friction Power (FP): The link between the brake power output and indicated power output of an engine is its friction. Friction has a dominating effect on the performance of an engine. Almost invariably, the frictional losses are ultimately dissipated to cooling system (and exhaust) as they appear in the form of frictional heat and this influences the cooling capacity required. Moreover lower friction means availability of more brake power. Hence brake specific fuel consumption is lower. This fuel economy is important because it

About the test engine: The engine chosen to carryout experimentation is a single cylinder, water cooled, vertical, direct injection, constant speed, CI engine.
decides the speed at which an engine can be run economically. Thus the level of friction decides the maximum output of the engine which can be obtained economically.

In design and testing of an engine measurement of friction power is important for getting an insight into the methods by which the output of an engine can be increased. In the evaluation of IP and mechanical efficiency measured friction power is also used. By following methods: William’s line method, Morse test, Motoring test, Difference between IP and BP.

**William’s line method**

Gross fuel consumption Vs B.P at a constant Speed is plotted and the graph is extrapolated back to zero fuel consumption as shown in graph 1, the point where this graph cuts the BP axis in an indication of the friction power of the engine at that speed. This negative work represents the combined loss due to mechanical friction, pumping and blowing.

**Indicated Power (IP):** However while calculating the Mechanical efficiency another factor called Indicated Power (IP) is considered. It is defined as the power developed by combustion of fuel in the combustion chamber (IP). It is always more than brake power. It is the sum of Friction Power and brake power.

**Indicated Mean effective pressure:** When quoted as an indicated mean effective pressure or IMEP (defined below), it may be thought of as the average pressure acting on a piston during a power stroke of its cycle. It is obtained by using the formula:

\[ IP = \frac{\text{Imep} \times \text{LAN}}{60} \]

So, \[ \text{Imep} = \frac{60IP}{\text{LAN}} \]

**Brake Specific fuel Consumption (BSFC):** Brake Specific fuel consumption (BSFC) or sometimes simply Brake specific fuel consumption, BSFC, is an engineering term that is used to describe the fuel efficiency of an engine design with respect to thrust output. Brake Specific Fuel Consumption may also be thought of as fuel consumption (grams/second) per unit of thrust (Kilo Newton, or KN). It is obtained by using the formulae.

\[ \text{BSFC} = \frac{\text{FC}}{\text{BP}} \]

**Indicated Specific fuel Consumption (ISFC):** Indicated Specific fuel consumption (ISFC) or sometimes simply Indicated specific fuel consumption, ISFC, is an engineering term that is used to describe the fuel efficiency of an engine design with respect to thrust output. Indicated Specific Fuel Consumption may also be thought of as fuel consumption (grams/second) per unit of thrust (Kilo Newton, or KN). It is obtained by using the formulae.

\[ \text{ISFC} = \frac{\text{FC}}{\text{IP}} \]

**Brake Thermal Efficiency:** Brake Thermal Efficiency is defined as brake power of a heat engine as a function of the thermal input from the fuel. It is used to evaluate how well an engine converts the heat from a fuel to mechanical energy. It is obtained by using the formulae

\[ \text{BTE} = \frac{\text{BP} \times 3600}{\text{FC} \times \text{CV}} \]

**Indicated Thermal Efficiency:** The ratio between the indicated power output of an engine and the rate of supply of energy in the steam or fuel. It is obtained by the relation

\[ \text{ITE} = \frac{\text{IP} \times 3600}{\text{FC} \times \text{CV}} \]

**Mechanical Efficiency:**

Mechanical efficiency measures the effectiveness of a machine in transforming the energy and power that is input to the device into an output force and movement. Efficiency is measured as a ratio of the measured performance to the performance of an ideal machine. It is given by the relation.

\[ \text{ME} = \frac{\text{BP}}{\text{IP}} \]

**VII. GAS ANALYSER**

**A. Six Gas Exhaust Analysis Theory**

Use of a four or five Gas Exhaust Analyser can be helpful in troubleshooting both emissions and driveability concerns. Presently, shop grade analysers are capable of measuring from as few as two exhaust gasses, HC and CO, to as many as six. The six gasses measured (for diesel emissions) by the latest technology exhaust analysers are: HC, CO, CO2, O2, SOx and NOx. All six of these gasses, especially O2 and CO2, are excellent
troubleshooting tools. Use of an exhaust gas analyser will allow you to narrow down the potential cause of driveability and emissions concerns, focus your troubleshooting tests in the area(s) most likely to be causing the concern, and save diagnostic time. In addition to helping you focus your troubleshooting, an exhaust gas analyser also gives you the ability to measure the effectiveness of repairs by comparing before and after exhaust readings. In troubleshooting, always remember the combustion chemistry equation: Fuel (hydrogen, carbon, sulphur) + Air (nitrogen, oxygen) = Carbon dioxide + water vapour + oxygen + carbon monoxide + hydrocarbon + oxides of nitrogen + sulphur oxides.

When we do exhaust analysis, we are being detectives. We look at what came out of the exhaust and figure out what could have happened before to create those emissions. What happened in the combustion chamber, or before the combustion chamber, to create these result. We can use clues and patterns of exhaust readings to figure out if we have a problem in one of the following areas: Air/Fuel Ratio, Combustion, Ignition, and Emission Control Devices. Then we know where to start our diagnosis with visual and functional tests.

VIII. SMOKE TEST

The smoke emitted from diesel (compression ignition) engine vehicles is assessed for its density. It is carried out by the use of an approved and calibrated smoke meter. The engine will be accelerated up to governed speed and the density of the smoke measured. After the third acceleration the average reading is recorded. If the reading is below 2.5m-1 for non-turbocharged engines or 3.0m-1 for turbocharged engines the vehicle will pass. However if the average is higher, a further acceleration is carried out and the average of the last three readings is used, this will continue until a maximum of six accelerations have been carried out. If the average of the fourth, fifth and sixth acceleration is higher than the appropriate level the vehicle will not pass the test. In addition to the smoke meter readings, any of the following will result in the vehicle being refused a certificate: exhaust emits excessive smoke or vapour of any colour, to an extent likely to obscure vision, emissions cannot be measured because a tail pipe is damaged or an accessory is fitted which prevents the insertion of the smoke meter probe insufficient oil in the engine or low oil pressure which could cause engine damage if engine is accelerated, obvious signs of an engine defect such as an unusual noise or emission of smoke, obvious signs that the governors have been tampered with or are not operating. It is important that vehicles are properly maintained (including changing of timing belts) in accordance with the manufacturers' recommendation and presented for test at normal working temperature.

![Figure-3: SMOKE METER](image)

IX. OBSERVATION TABLES

<table>
<thead>
<tr>
<th>TABLE-2: AT 16.5 COMPRESSION RATIO:</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.No</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

![Graph-1: Friction Power](image)
Calculations at Compression Ratio 16.5:

A. Friction Power:
We plot a graph between Brake Power and Fuel flow rate. We get a straight line. If we extend this line towards south-west then it will touch the X-axis at -2.42KW. So, the Friction Power is 2.42KW. From graph 1

B. Indicated Power
Sum of 0.94 KW & 2.42 KW. So, the Indicated power will be 3.36 KW at a load of 6.0Nm
Indicated Mean Effective Pressure(Imep):
\[
\text{Imep} = \frac{60(IP)}{\text{LAN}}
\]
\[
= \frac{60(3.36*1000)/(.11*3.14*0.8*0.8*750/4)}{}
\]
= 486.47N/mm²

C. Brake Specific Fuel Consumption (BSFC):
\[
\text{BSFC} = \frac{FC}{BP}
\]
= 0.76/0.94
= 0.806 Kg/KW.hr

D. Indicated Specific Fuel Consumption (ISFC):
\[
\text{ISFC} = \frac{FC}{IP}
\]
= 0.76/3.6
= 0.71 Kg/KW.hr.

E. Brake Thermal Efficiency (BTE):
\[
\text{B.Th.E} = \frac{BP*3600}{FC*CV}
\]
= 94*100*3600/2.42*44800
= 10.42%

F. Indicated Thermal Efficiency (ITE):
\[
\text{I.Th.E} = \frac{IP*3600}{FC*CV}
\]
= 3.6*3600*100/0.76*44800
= 37.21%

G. Mechanical Efficiency (ME):
\[
\text{M.E} = \frac{BP}{IP}
\]
= 0.94/3.36
= 10.42%

<table>
<thead>
<tr>
<th>Specif ic fuel Cons umption (Kg/KW-Hr)</th>
<th>Brake Thermal Efficicieny (%)</th>
<th>Indicated Thermal Efficiency (%)</th>
<th>Mechanical Efficiency (%)</th>
<th>Air Fuel Ratio</th>
<th>Relativ e air Fuel Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.365</td>
<td>1.92</td>
<td>44.33</td>
<td>4.346</td>
<td>42.10</td>
<td>2.124</td>
</tr>
<tr>
<td>1.432</td>
<td>5.87</td>
<td>34.11</td>
<td>17.21</td>
<td>28.072</td>
<td>1.416</td>
</tr>
<tr>
<td>0.806</td>
<td>10.42</td>
<td>37.21</td>
<td>28.02</td>
<td>26.595</td>
<td>1.34</td>
</tr>
<tr>
<td>0.562</td>
<td>14.94</td>
<td>39.17</td>
<td>38.14</td>
<td>24.0625</td>
<td>1.214</td>
</tr>
<tr>
<td>0.515</td>
<td>16.33</td>
<td>36.27</td>
<td>44.98</td>
<td>19.816</td>
<td>1</td>
</tr>
<tr>
<td>0.419</td>
<td>20.07</td>
<td>40.02</td>
<td>50.144</td>
<td>19.816</td>
<td>1</td>
</tr>
</tbody>
</table>

X. PERFORMANCE ANALYSIS

Graph-2:Brake Power (Kw) Vs. Mechanical Efficiency

The variation in mechanical efficiency at different loads for different compression ratios is shown in graph 2. It is observed that mechanical efficiency increases with the increase in the load due to increase in the BP and IP. It is observed that mechanical efficiency is low for compression ratio.
16.5 and it is almost equal for 18 and 19 for a given load, it is maximum for compression ratio 17.5.

Graph-3: Brake power vs. Brake Thermal Efficiency

The variation in brake thermal efficiency at different loads for different compression ratios is shown in the above graph. It is observed that brake thermal efficiency is lowest for compression ratio 16.5, it is almost equal for all other compression.

Graph-4: Brake Power vs. Specific Fuel Consumption

The variation in Specific fuel consumption at different loads for different compression ratios is shown in the above graph. It is observed that at higher loads the SFC of all the cr are almost equal but at lower loads sfc is highest for cr 17 and lowest for cr 17.0

Graph-5: Compression Ratio vs. Break Thermal Efficiency

The variation between compression ratio and break thermal efficiency is shown in the above graph. It is observed that for a given compression ratio break thermal efficiency is higher for max load and lower for min load.

XI. EMISSION ANALYSIS

Table-4: For the Compression Ratio 16.5:

<table>
<thead>
<tr>
<th>A/F RATIO</th>
<th>% CO₂</th>
<th>% CO</th>
<th>% O₂</th>
<th>HC ppm</th>
<th>NOx ppm</th>
<th>HSU</th>
</tr>
</thead>
<tbody>
<tr>
<td>42.1</td>
<td>2.27</td>
<td>0.267</td>
<td>17.43</td>
<td>31</td>
<td>118</td>
<td>69.48</td>
</tr>
<tr>
<td>37.4</td>
<td>3.58</td>
<td>0.367</td>
<td>16.39</td>
<td>51</td>
<td>109</td>
<td>73.29</td>
</tr>
<tr>
<td>31.09</td>
<td>2.91</td>
<td>0.269</td>
<td>16.62</td>
<td>48</td>
<td>90</td>
<td>81.31</td>
</tr>
<tr>
<td>28.8</td>
<td>3.10</td>
<td>0.247</td>
<td>16.52</td>
<td>55</td>
<td>117</td>
<td>87.20</td>
</tr>
<tr>
<td>25.2</td>
<td>6.62</td>
<td>0.392</td>
<td>11.10</td>
<td>101</td>
<td>403</td>
<td>93.94</td>
</tr>
<tr>
<td>22.45</td>
<td>5.29</td>
<td>0.499</td>
<td>11.20</td>
<td>130</td>
<td>403</td>
<td>97.03</td>
</tr>
</tbody>
</table>
Graph-6: % of Carbon Monoxide (CO) Vs. Air Fuel Ratio

The variation of % of CO with the variation of air fuel ratio is drawn in the above graph 6. CO emissions are reduced by lowering the compression ratio and trade-off with other emissions has been observed. ie. At higher loads % of CO is higher for compression ratio 19 and at compression ratio 17.5 % of CO is low for lower loads.

Graph-7: % of Carbon Dioxide (CO₂) Vs. Air Fuel Ratio

The variation of % of CO₂ with the variation of air fuel ratio is drawn in the graph 7. It is observed that at lower loads, higher compression ratio-19 have good combustion characteristics and at higher loads lower compression ratios-17.5 have good combustion characteristics.

Graph-8: Quantity of NOx vs. Air Fuel Ratio

The variation of NOx with variation of air fuel ratio is shown in graph 8. It is observed that at higher loads almost all Cr s emits higher volume of NOx, whereas at lower loads, CR of 19 & 16.5 have higher volume of NOx. For all compression ratios the value of NOx is between 200 to 500 ppm only.

Graph-9: Intensity Of Smoke Vs Air Fuel Ratio

The variation of intensity of smoke with the variation of air fuel ratio is shown in the above graph 9. In general intensity of smoke increases with increase of compression ratio. From graph it is observed that at higher loads HSU is almost uniform for all cr. For lower loads HSU is higher for Cr 19. Engine gives lesser smoke at lower loads for lower CRs.

In Table 5. the values evaluated from the observations taken from the computerised variable compression ratio engine. The performance analysis like specific fuel consumption, brake, thermal & mechanical efficiencies are observed at different compression ratios 16.5, 17.0, 17.5, 18.0, 19.0 for different loads.
Table-5: Performance table At full load:

<table>
<thead>
<tr>
<th>CRs</th>
<th>Air Fuel Ratio</th>
<th>SFC (Kg/KW-Hr)</th>
<th>B Th. Efficiency(%)</th>
<th>I Th Efficiency(%)</th>
<th>Mechanical Efficiency(%)</th>
<th>Efficiency Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.5</td>
<td>19.81</td>
<td>0.419</td>
<td>20.07</td>
<td>40.02</td>
<td>50.14</td>
<td>0.61</td>
</tr>
<tr>
<td>17.0</td>
<td>19.81</td>
<td>0.4340</td>
<td>19.38</td>
<td>50.46</td>
<td>38.39</td>
<td>0.76</td>
</tr>
<tr>
<td>17.5</td>
<td>22.45</td>
<td>0.377</td>
<td>22.21</td>
<td>45.8</td>
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<td>0.68</td>
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<tr>
<td>18.0</td>
<td>22.45</td>
<td>0.37</td>
<td>22.12</td>
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<td>41.2</td>
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<td>19.0</td>
<td>20.62</td>
<td>0.39</td>
<td>21</td>
<td>49.9</td>
<td>20.62</td>
<td>0.74</td>
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</table>

Table-6: Exhaust Gas Analysis with varying Compression Ratios: At full load.

<table>
<thead>
<tr>
<th>CR</th>
<th>Air Fuel Ratio</th>
<th>%CO₂</th>
<th>%CO</th>
<th>%O₂</th>
<th>HC (PPM)</th>
<th>NOₓ (PPM)</th>
<th>SOₓ (PPM)</th>
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</thead>
<tbody>
<tr>
<td>16.5</td>
<td>19.186</td>
<td>5.88</td>
<td>0.446</td>
<td>12.79</td>
<td>119</td>
<td>405</td>
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<td>17.0</td>
<td>19.81</td>
<td>5.80</td>
<td>0.642</td>
<td>14.22</td>
<td>115</td>
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<td>17.5</td>
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<td>18.0</td>
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<td>19.0</td>
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<td>0.656</td>
<td>11.15</td>
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<td>397</td>
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Table-7: Smoke Analysis with varying Compression Ratios:

<table>
<thead>
<tr>
<th>CR</th>
<th>HSU At no load</th>
<th>HSU At full load:</th>
</tr>
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<tbody>
<tr>
<td>16.5</td>
<td>25.44</td>
<td>88.9</td>
</tr>
<tr>
<td>17</td>
<td>59.43</td>
<td>90.96</td>
</tr>
<tr>
<td>17.5</td>
<td>69.48</td>
<td>97.03</td>
</tr>
<tr>
<td>18.0</td>
<td>59.45</td>
<td>93.05</td>
</tr>
<tr>
<td>19.0</td>
<td>68</td>
<td>98.64</td>
</tr>
</tbody>
</table>
In Table 6 and 7. The emission analysis of the gases CO, CO₂, O₂, NOx, &SOx are taken from the gas analyser and the intensity of the smoke is also measured by using smoke meter at different compression ratios 16.5, 17.0, 17.5, 18.0, 19.0 for different loads.

X. CONCLUSIONS

Compression ratio is indeed an important factor affecting the engine performance. It is therefore worthwhile to study the extent of its domination on the engine parameters.

A. Effect of compression ratio on performances characteristics:

The specific fuel consumption for lower loads is almost equal for all compression ratios and it is found to be optimum at CR of 17.5 for higher loads. It is observed from the plots that there is increase of brake thermal efficiency with CR. Mechanical efficiency is found to be optimum at compression ratio of 17.5.

B. Effect of compression ratio on emission characteristics:

The emission of carbon monoxide (CO) indicates incomplete combustion. The emissions contained lower levels of its constituent at a CR of 17.5; this is also reflected with respect to lesser unused oxygen (O₂) in the exhaust at this CR. The average emission of NOx over a range of loads is least at CR of 18.0. Hydrocarbon emissions are reduced at compression ratio of 18.0 for higher loads. Intensity of smoke (HSU) diminishes with compression ratio; this may be due to better combustion phenomenon at higher compression ratios.

By considering all the experimental result, the compression ratio of 17.5 is the optimum compression ratio for the operation of the given engine.

XI. ACKNOWLEDGEMENT

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XII REFERENCES