

Effects of Additional Oxygen Supply in Single Cylinder Diesel Fuel Using Variable Compression Ratio Engine

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Abstract - In the present study, a variable compression single cylinder diesel engine was used to study the effects of oxygen enrichment on the performance of engine at different compression ratios (C.R.) from 16.5 to 19.5 at different loads and compared to the amount of additional oxygen in four different rates from 1L/min to 4L/min. Oxygen cylinders were connected to intake manifold with throttle valve to supply additional oxygen. Enrichment of oxygen favours combustion in many performance parameters so the tests were carried out for the brake power (B.P.), Mean effective pressure, (P_{mef}), specific fuel consumption (S.F.C.), Mechanical efficiency ($\eta_{mecheff}$) and exhaust gas temperature (E.G.T.). The purpose of this study is to deal with the major technological characteristic of enriched oxygen used in variable compression ratio single cylinder diesel engine for best possible values of secure engine limits. The test results show that the combustion performances were enhanced as there was increase in B.P., P_{mef} and decrease in S.F.C. and increase in rate of oxygen in intake air increases the charge burning rates and flame combustibility resulting higher exhaust gas temperature. Overall mechanical efficiency in lower compression ratio was high but for higher compression ratios there was a drop in mechanical efficiency.

Keywords – Oxygen Enrichment, Variable Compression Ratio, Brake Power, Specific Fuel Consumption, Exhaust Gas Temperature.

I. INTRODUCTION

In diesel engine combustion, ratio of fuel varies according to load requirements, so principle of using air in diesel engines says that excess air improves mixing rates but at the time of exhaust, it also carry heat at higher rates which affect the thermal efficiency of each cycle. In the mixture of fuel and air in small diesel engines mixing rates depend on many designs and operating variables and those variables will affect the performance of any engine. According to research under the subject of oxygen enrichment, it results that a certain level of oxygenation can improve the mixing rates to increase the performance and reduce the certain amount of emissions^{[1][5]}.

The investigation and research in this field are very vast and conclusive in many respects. All results show a considerable increase in oxides of nitrogen and decrease in smoke, carbon monoxides and unburned hydrocarbons as the ratio of oxygen increases. Reduction in engine noise due to elevated oxygen level in induced air is also concluded by researchers^[4]. Higher oxygen concentrations increase the mixtures' burning rate at the same compression ratio and low quality fuel can also be used in engines without much affecting the performance. The main drawback of oxygen enrichment is higher level of oxides of nitrogen in exhaust due to increased maximum pressure in combustion chamber. The efforts of many researchers conclude a range of percentage of maximum concentration of oxygen in intake is 30% by volume in which both particulate matters and oxides of nitrogen can be reduced for a fixed geometry engine^[8]. Higher concentrations of oxygen cannot be controllable in combustion reaction. Oxygen enhancement can be done by two ways i.e. fuel oxygenation and intake air oxygenation^[2]. In fuel oxygenation the diesel blends are used which carries oxygen in their molecular structure and there are many types of blends had been used^[17]. In intake air oxygenation, pure oxygen is added in intake air by volume. Some researchers also made a membrane which is used in nitrogen separation so level of oxygen increased in induction phase^[3]. The most convenient method for research is adding raw oxygen to intake for certain percentage by volume. Oxygenation methods also improves the emission and performance for biodiesels and diesel blends^{[6][10][19]}.

For a fixed volume of combustion chamber and rated speed, a certain amount of oxygen can be added for optimum values of emission because the limitation of maximum pressure and temperature, that can be further controllable by the help of different compression ratios. Thus the purpose of the study to investigate the effect of oxygen enriched combustion at different compression ratio on a single cylinder four stroke naturally aspirated diesel engine with different level of oxygen concentration and compression ratios.

II. EXPERIMENTAL METHODS

A. Engine Specifications

Single cylinder direct injection naturally aspirated water cooled four stroke compression ignition engine having the following specifications in Table I and fuel specifications in Table II was used for conducting experiments.

Table I Engine Specifications

Engine Specifications	
Bore × Stroke	87.5 × 110 mm
Compression Ratio	16 to 22:1
Rated Power	5 kW
Rated Speed	1500 RPM
Cubic Capacity	0.662 Litre
Fuel Injection	Direct Injection
Injection Timing	21 degree BTDC
Injection Pressure	230 Bar
Type Kirloskar	TAF 1
Number of Cylinders	1

Table II Properties of Diesel Fuel Used in Test

Fuel Properties of Diesel Used in Tests	
Density at 15°C (kg/m ³)	840
HHV (MJ/kg)	44.65MJ/kg
LHV (MJ/kg)	42.15MJ/kg
Viscosity (mm ² /s)	3.647
Compression Ratio	17
Flash Point (°C)	64
Pour Point (°C)	-6
C (wt%)	85.0
H (wt%)	13.0
Sulphur Content (wt%)	0.85
Water Content (mg/kg)	97

B. Experimental Setup

A vertical variable compression ratio (VCR) engine were used which is manually adjusted by the help of one nut which is fixed at frame with the help of stud. One dial indicator was used to measure the tilt of the engine. After that it was fixed by the two lock nuts in a position for the readings for different oxygen ratios. The range of the VCR is 16.5, 17.5, 18.5 and 19.5. This test rig is brought up by Company 'K.C. Engineering, Ambala' which assembles all the sensors, accessories, dynamometer and calorimeter with taking care of calibration and errors. Intake oxygen was added by using oxygen cylinder, mounted with a flow control valve, just at the inlet of air surge tank by using flow regulating valve in order to give the adequate time for mixing. To protect the engine, low levels of intake oxygen was used in intake air. Only four levels were studied which are 1L/min, 2L/min, 3L/min & 4L/min. The naturally available oxygen is 21% by volume so the valve was completely off at first ratio. The mass balance was used to measure the fuel flow rate with an accuracy of 0.01g. The test rig is coupled with (Model) eddy current dynamometer. A kistler's piezo-electric transducer measures the combustion chamber pressure with an increment of 1 degree crank angle using data acquisition system (Company and model). Thermocouples were used to measure the temperature of inlet air, engine coolant jacket inlet, engine coolant jacket outlet, calorimeter outlet, exhaust temperature and exhaust temperature at outlet after calorie meter. A two way float type flow regulator was used to regulate the water in the engine cooling jackets and calorimeter. A crank angle sensor were used to measure the crank position is coupled with the help of pulley to the crankshaft. A four gases exhaust gas analyser is used to measure the CO, CO₂, HC and NO_x. All the specifications are given in detail in Table III.

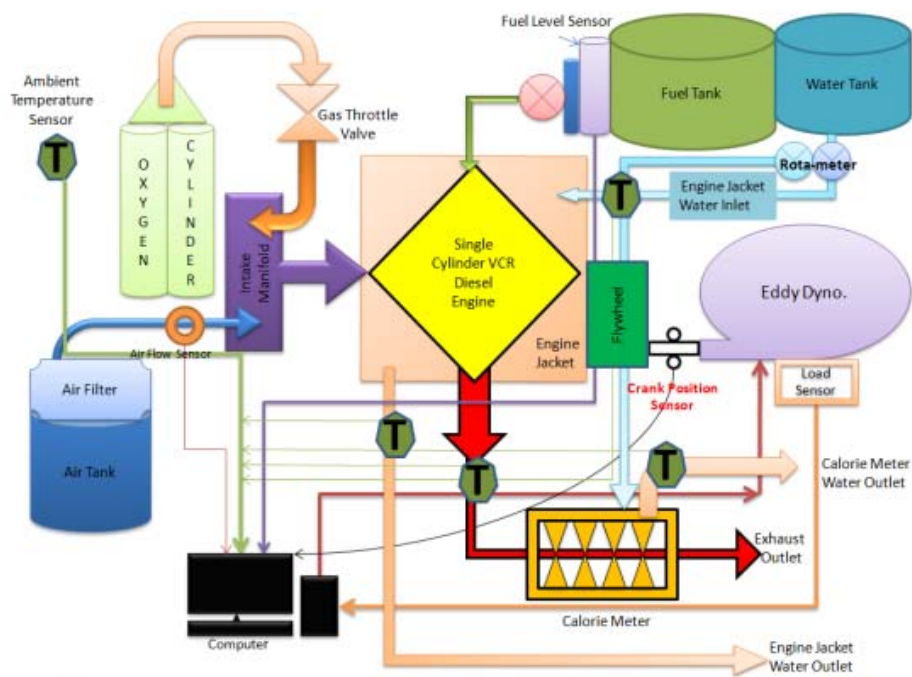


Fig. 1. Experimental Schematic of Test Rig

Table III Experimental Setup

Experimental Setup Specifications	
Calorimeter	Pipe in Pipe type
Piezo Sensor	Range 5000 PSI, with low noise cable
Crank Angle Sensor	Resolution 1 Deg, Speed 5500 RPM with TDC pulse
Temperature Sensor	RTD Type PT-100 and Thermocouple, K Type
Temperature Transmitter	2 wire, I/P RTD PT-100, 0-100 Deg C, O/P 4-20mA, Type 2 wire, Input TC, 0-1200 Deg C, Output 4-20 mA
Type of Loading	Eddy Current Dynamometer
Load Indicator	Digital, Range: 0-50 kg, Supply : 230VAC
Load Sensor	Load Cell, type strain gauge, Range : 0-50 Kg
Fuel Flow Transmitter	DP transmitter, Range : 0-500 mm WC
Air Flow Transmitter	Pressure Transmitter, Range (-) 250 mm WC
Rotameter	Engine cooling 40-400 LPH, Calorimeter 25-250 LPH
Pump	Type Mono Block
Water Supply	Continuous, clean and soft water supply @5000 LPH, at 10m. Head, Provide tap with 1" BSP size connection
Computer System	i-3 processor with DVD Drive, Windows 7 and MS Office pre-loaded.
Electric Supply	230+/- 10 V AC, 50 Hz, 1 Phase.
Manatec Eco Gas 100	Gas Analyser with NDIR technology, Measurement of CO (Range: 0-15%), CO2 (Range: 0-19.9%), HC (Range: 0-20000ppm) and NOx (Range: 0-5000ppm),

C. Experimental Procedure

The tests were operated in a cabin at the ambient temperature of 27⁰ C. Tests were carried out different compression ratio (CR), starting with 16.5 CR to an incremental CR of 1 after completing the cycle of one loading at all four fraction of oxygen concentrations. Different loading of starting from Zero load to the rated capacity of the engine to the successive loading of increment of 20% is used after every change in CR at a constant speed of 1500 RPM. Steadiness and reiterating of the conditions of operation were ensured by primarily run the test rig for 15 minutes at 50 percent load for constant 1500 rpm until the exhaust gas temperature reached 250 degree centigrade. The flow of water in engine jacket and calorimeter was fixed a 60 Litre per minute by the regulating rota-meter. It was ensured that the temperature of intake water was constant throughout in collecting data. Once these conditions were attained, the engine test rig was brought to the essential test conditions and permitted it to run for 5 minutes to ensure to stabilize reading before collecting the records. The fuel injection pressure and its injection timing was constant while experiment as per the company's standards. The diameter of exhaust pipe was increased by 15% to avoid the possibilities of backpressure.

III. RESULTS AND DISCUSSION

The prime objective of the research is to study the performance parameters affected by the varying oxygen level at different compression ratios. Basic performance parameters like B.P., S.F.C., η_{mech} , P_{mef} , and E.G.T. were used in data collection with stabilised engine conditions.

A. Brake Power

This power is usable power delivered by the engine to the load. Increase in oxygen concentration increase the mixture ratio of specific heat, this increases the conversion rate of the mixture thermal energy to work energy. The NO_x level increases as the oxygen percentage increases [6] [8] [9]. The oxygen concentration increases the brake power significantly increases [13] [14] [15]. Fig. 2. indicates that BP increases when the compression ratio increases with increment in oxygen concentrations. Up to 36% increment in power was observed at full load when oxygen concentration is increased to 4L/min when compared to 1L/min. While increasing compression ratios, maximum brake power was observed at 3L/min of oxygen enrichment.

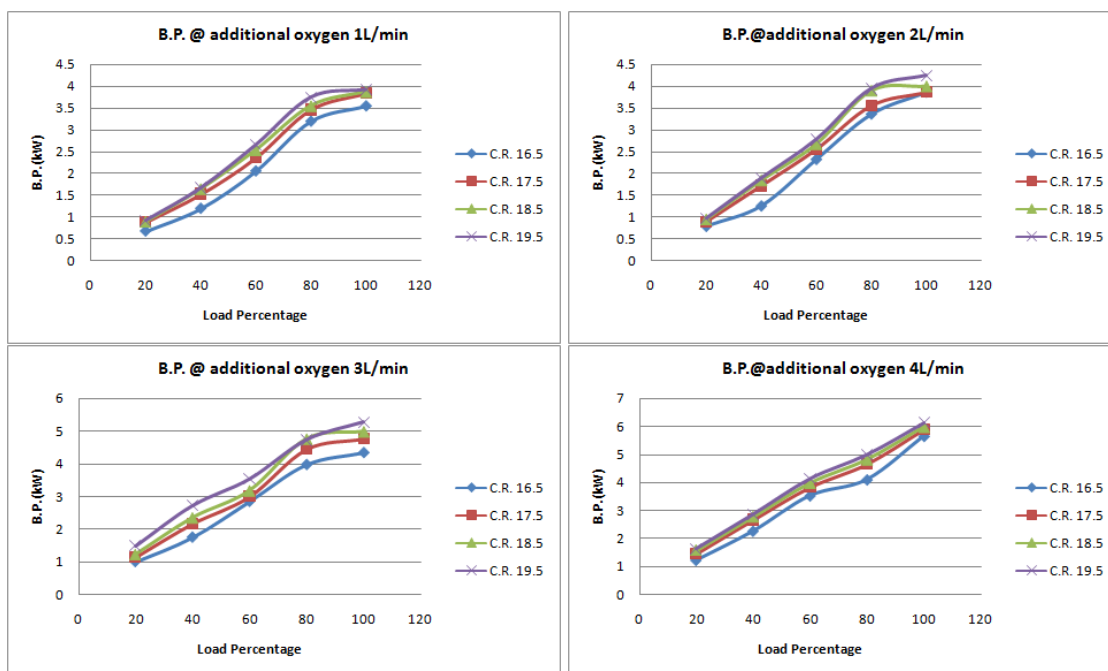


Fig. 2. Brake power with different oxygen concentrations at different compression ratios

B. Mechanical Efficiency

Mechanical efficiency is the ratio of the brake power delivered by the engine to the indicated power. So when the brake power increases the mechanical efficiency increases [8] [16]. A set of data is collected for mechanical efficiency at different loads, oxygen concentrations and compression ratios. It can be seen in Fig. 3. that average of 6% increase in mechanical efficiency is obtained for an enrichment of 2L/min when compared with 1L/min at compression ratio at 16.5 and 17.5 and the maximum of 14% can be obtained for enrichment of 4L/min oxygen when compared to 1L/min of oxygen enrichment. At compression ratio 16.5 and 17.5 mechanical efficiency goes up at all the oxygen enrichment levels from 1L/min to 4L/min but its average of 7% decreases as compression ratio increases to 18.5 to 19.5 at the 3/4th load and full load conditions.

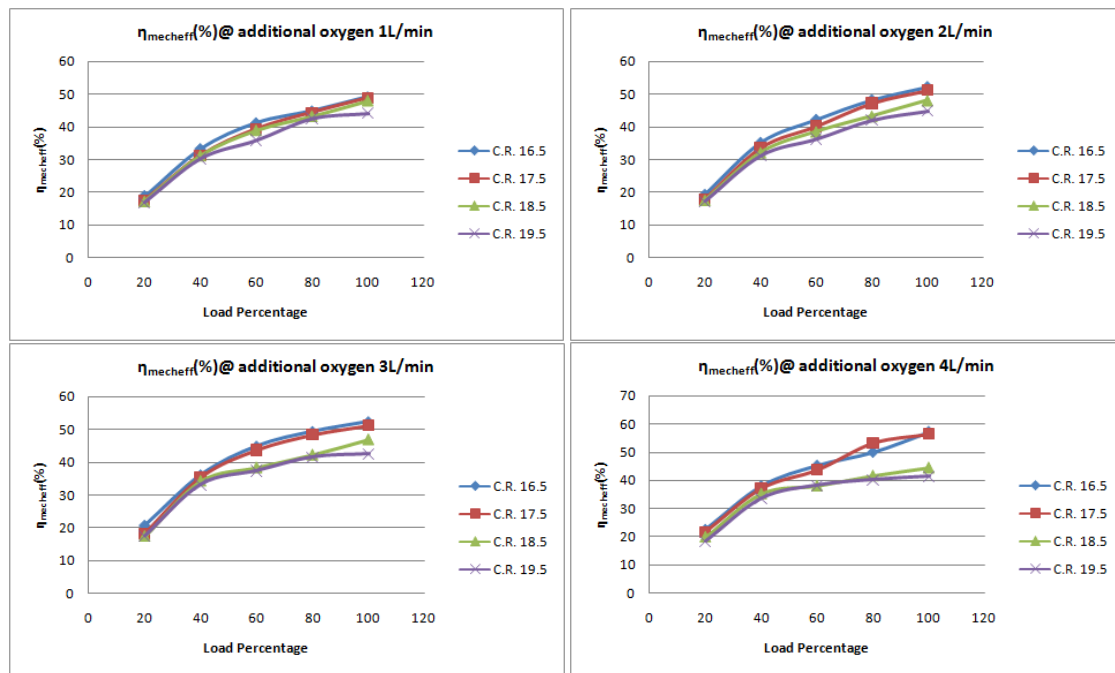


Fig. 3. Mechanical Efficiency with different oxygen concentrations at different compression ratios

C. Specific Fuel Consumption

The fuel flow rate per unit power output is called S.F.C. It measures how efficiently an engine is using the fuel supplied to produce the work [4]. With reference to Fig. 4, as the level of oxygen increases from 1L to 4L/min the specific fuel consumption decreases average by 37% at full load condition but subsequently as the compression ratio increases from 16.5 to 19.5, average 41.25% increment was observed during full load conditions. This means as the compression ratio goes up the S.F.C. goes up but as the pure oxygen increases in intake the level of S.F.C. decreased. So the higher compression ratios can help in decrease in S.F.C. by utilizing the fuel properly for better engine outputs even at higher oxygen levels.

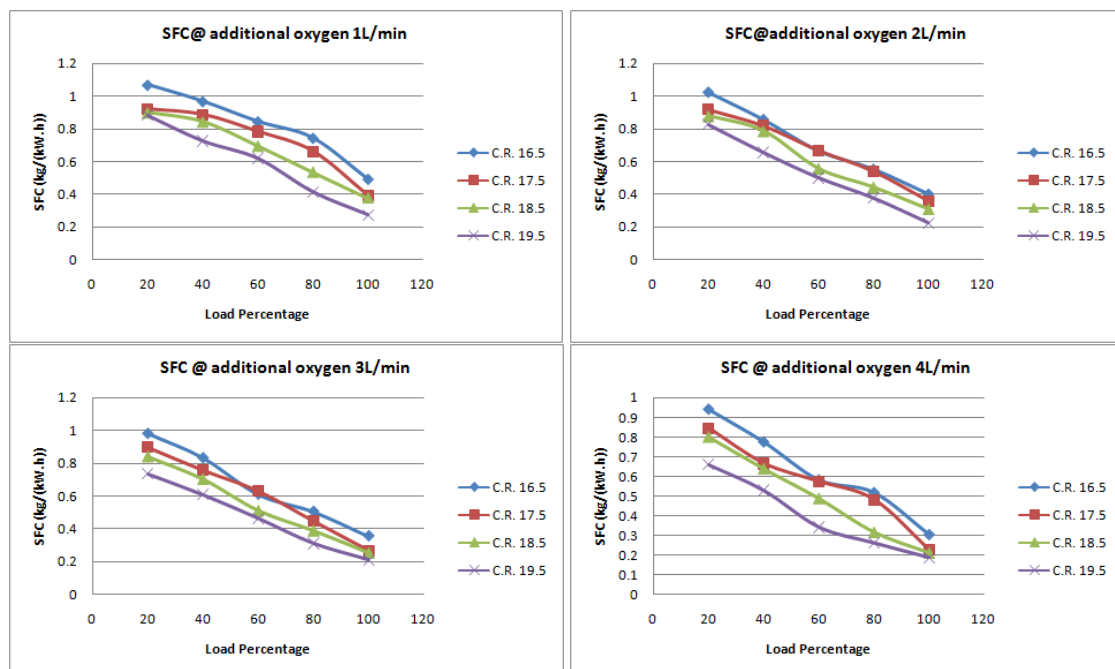


Fig. 4. Specific fuel consumption with different oxygen concentrations at different compression ratios

D. Mean Effective Pressure

This is useful engine performance parameter measure which is obtained by dividing the work per cycle by the cylinder volume displaced per cycle. The higher oxygen fraction in mixture can decrease the tendency of low peak pressure at constant load [12]. From the sets of data collected, it was observed according to the Fig. 5. that cylinder peak pressure was increased in the range of 14 to 23% as the oxygen level increased at full load condition from 1L to 4L/min and as the compression ratio is increased resulting increased in the mean effective pressure by 10 to 18% at full load with different oxygen concentration levels.

E. Exhaust Gas Temperature

Higher combustion efficiency can be observed with the higher exhaust gas temperatures. So the higher output of exhaust gas is the simplest form to study the combustion efficiency [14]. Higher oxygen levels in mixture can increase the combustion rate and high compression ratios also increase the temperature by increasing the pressure resulting higher temperatures of exhaust gas due to more complete combustion [15]. The conclusion was drawn from the sets of data as shown in Fig. 6. that the temperature of exhaust is increased average by 35°C when oxygen level was increased from 1L to 4L/min at full load conditions. The second observation was that when the compression ratio is increased from 16.5 to 19.5, the peak pressure is further increased and resulting in average increment of exhaust gas temperature 51°C.

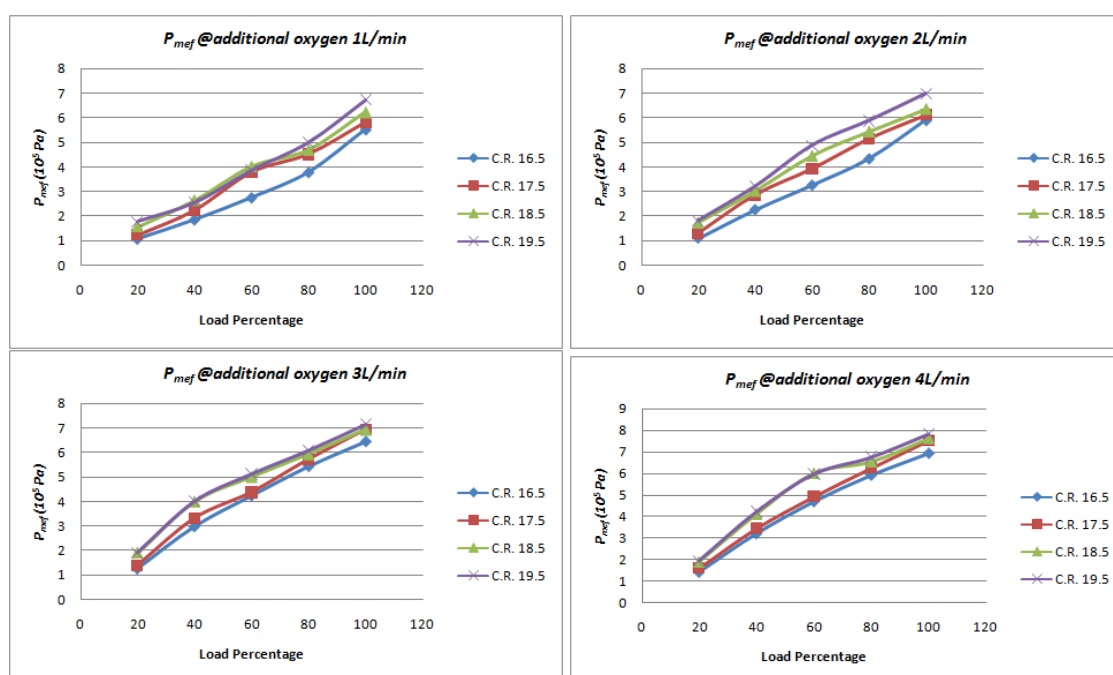


Fig. 5. Mean effective pressure with different oxygen concentrations at different compression ratios

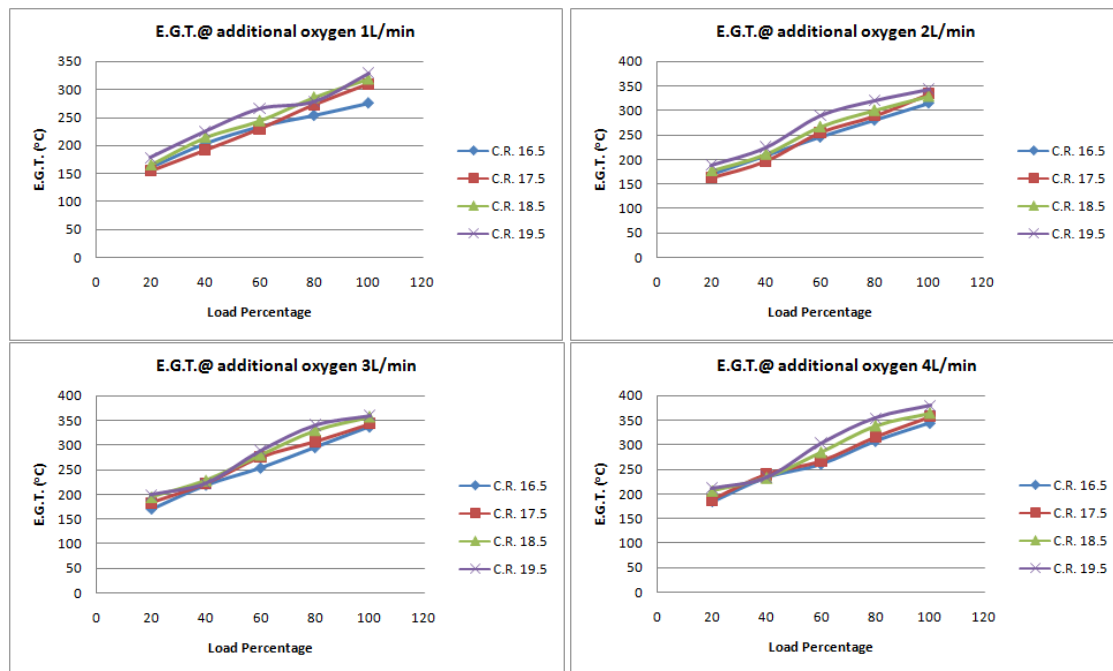


Fig. 6. Exhaust gas temperature with different oxygen concentrations at different compression ratios

IV. CONCLUSION

A variable compression ratio single cylinder diesel engine was used to study about the change in performance parameters by using enriched oxygen level at different compression ratios. The following point can be concluded from the research:

- 1) When compared to 1L/min to 4L/min of oxygen enrichment, the increment in B.P. was calculated 36% at full load condition and maximum B.P. output was recorded at 3L/min.
- 2) Increase in mechanical efficiency was recorded 14% for compression ratio 16.5 and 17.5 at all load conditions from 1L to 4L/min but decrease of 7% in compression ratio 18.5 and 19.5 for full load conditions at 3L and 4L/min.
- 3) A decrease in specific fuel consumption was average 37% but due to increase in compression ratio it was increased slightly up when compression ratio was increased.
- 4) Due to increase in oxygen level, the mean effective pressure can be increase up to 14 to 23%. The compression ratio can further increase the mean effective pressure by 10 to 18%.
- 5) Combustion efficiency was recorded effective at higher level of intake oxygen due to exhaust gas temperature increased by 35°C. Due to increase in compression up to 19.5, the temperature difference can go up to 53°C.
- 6) Since the required modifications in the existing intake system are not complex, an additional mixing chamber is required for mixing the atmospheric air with the oxygen. As the compression ratio increases, it helps in additional boost with the oxygen enrichment for complete combustion and better efficiency.

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