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Effect of Oxygen Enrichment on Emission Characteristics of a Variable Compression Ratio Diesel Engine

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Abstract:* The objective of this research is to explore the effect of oxygen enrichment on emission characteristics for a single cylinder variable compression ratio diesel engine. In this study, a computerised test rig with data acquisition system for a variable compression ratio engine connected with eddy current dynamometer and additional oxygen cylinders to supply the constant oxygen supply by gas regulator in intake air near to intake manifold were used to explore the emission changes by varying compression ratios and oxygen concentrations. Tests were carried out to study the magnitudes of Carbon Dioxides (CO_2), Carbon Mono-oxides (CO), Oxides of Nitrogen (NO_x) and Hydrocarbons (HC) at two rated Compression Ratios (CR) 16:1 and 17:1 to compare the results with or without oxygen enrichments at the constant rate of 1 litre and 2 litres per minute. However both the techniques increases the NO_x emission levels because the enriched air increases the burn and mixing rates of mixture so the temperature increases but also decreases the amount of HC and CO emissions. CO emission decreases because of increase in complete combustion reaction in presence of higher oxygen concentration so the level of CO_2 emission increases.
Keywords: Oxygen Enrichment, Variable Compression Ratio Engine, Diesel Engine, Emission Characteristics

I. INTRODUCTION

Today, in diesel engine combustion, reducing the emission content is prime concern. NO_x Emission, Hydrocarbon (HC), Carbon mono-oxide (CO) and Particulate Matter (PM) emitted by engine which are prime study concern for the researcher community. To reduce the amount of pollutants and its emissions levels many researchers are working frequently to find out solutions for decreasing these levels in the steady as well as transient operations. Formation of NO_x is usually increased by increase the temperature of burned gas so these high temperatures due to stoichiometric air–fuel mixtures are likely to increase NO_x emissions [3][8][9]. In experimental steady conditions, the NO_x emissions can be decreased by lowering the peak cylinder temperature by using diluents like exhaust gas recirculation (EGR) and it can be further decreased by retarded injection timing [3][13]. Increasing the heat transfer from cylinder wall can also reduce the NO_x formation. The injection pressure and exhaust pressure also play here an important role [2] [3].

HC in diesel engines is made up by decomposed fuel molecules or recombined intermediate compounds. During the ignition delay period, results of under mixing the fuel–air ratios increases that cannot ignite rapidly enough to sustain as a flame [5]. Incomplete combustion and unburned HC increases with slow mixing of fuel in air, resulting in over rich mixture or quenching of the flame. HC mainly produces around the perimeter of the reaction zone, where the mixture is too lean to burn, in the fuel reserved in the nozzle sac in the spray cores and tail [9]. HC emissions are greatly affected by load, ambient conditions, boosting and fuel feeding system [10]. There is a strong correlation exists between smoke and HC emissions during load. In naturally aspirated engines, HC emission is enhanced with fuels of higher viscosity, lower cetane number, small cavity design on piston head, higher crevices volume and adsorption capacity of lubricating film and with low grade coolant. Carbon monoxide forms as an intermediate combustion product. Magnitudes of CO and CO_2 depend on the fuel–air equivalence ratio. Usually at a steady state operation it does not vary drastically in diesel engine operation [9]-[13].

Unburned fuel is primary reason of formation of PM which is formed from unburned fuel that nucleates from the vapour phase to a solid phase in rich fuel zone at higher temperatures. Production of PM or soot is prominently dependent on engine load, as the load increases, more fuel is injected into the cylinders, increasing the temperatures in the rich zones. It also depends on higher temperature, duration of diffusion combustion and lower oxygen availability. Increase in combustion effectiveness and decrease in soot emission can be done if the available oxygen is more than the stoichiometric ratio in combustion chamber. This can be done by increasing the oxygen content of fuel or by increasing the intake oxygen concentration. Increase in peak pressure in cylinder, decrease in ignition delay, CO, UBHC, PM and smoke emission by increasing the oxygen concentration in combustion.

Increase in NO_x by increasing oxygen intake in air is prime concern in oxygen enriched combustion but it can be reduced up to 50% by retarding the ignition timings [3]. Intake air oxygen concentration in IDI decreases ignition delay drastically and reduces noise of combustion, smoke level, HC and CO emission whereas increase in NO_x emission by increasing the oxygen levels. Oxygen enrichment resulting increase in indicated power of the engine for some extent. Many researchers addressed that burning of low quality fuel can be done by increasing the oxygen enrichment [14] [22] [23]. They concluded more energy is released in near the beginning phase of combustion with oxygen rich air intake. As the NO_x-PM trade off, studies addressed that smoke emission was reduced by factor of 4 but NO_x emission increased by factor of 5 by increasing the intake air with 30% of higher oxygen concentrations [16]. So it is clear that heating value and ignition ability can be increased by using more oxygen in combustion by some extent.

II. EXPERIMENTAL SETUP

In this experiment, a single cylinder diesel engine water cooled variable compression ration engine was used. Loading was done by eddy current dynamometer & computerized data acquisition system was used. Further details are shown in Table I. Diesel fuel was tested before using in experiment. The properties of fuel are given in Table II. Gas regulator was used to deliver the additional just before the intake manifold by inserting the pipe in intake manifold without any leakage in filtered intake air. Gas flow regulator delivered constant feeding of oxygen in air which can be regulated by a valve for different volume from 1L to 4L per minute[4]. Volumetric type of fuel gauge and mass air flow sensor was used to measure the amount of fuel and air. A cylindrical tank was used for air reservoir which was fitted with sharp edged orifice. The volume of the tank was large enough to feed sufficient air to the engine. Intake air reservoir is very big so this was assumed that the flashing suction formed by engine will not change the air pressure inside the air tank.

TABLE I
Engine Specifications

Make	Kirloskar TAF 1	Bore	87.5mm
Rated Power	5HP	Stroke	110mm
Speed	1500-2000 rpm	Type of ignition	Compression
No. of cycle	One	Method of loading	Eddy dynamometer
Compression ratio	Variable	Start	Manual Crank

TABLE III
Fuel Properties of Diesel Used in Tests

Density at 15^oC (kg/m^3)	835
HHV (MJ/kg)	44.245MJ/kg
LHV (MJ/kg)	42.005MJ/kg
Viscosity (mm^2/s)	3.523
Compression Ratio	17
Flash Point (^oC)	62.6
Pour Point (^oC)	-6.2
C (wt%)	86.0
H (wt%)	12.0
Sulphur Content (wt%)	0.85
Water Content (mg/kg)	94

III.EXPERIMENTAL PROCEDURE

Tests were conducted at the ambient temperature of 25^{0}C. Readings were carried out only on two different compression ratios (CR) i.e. 16 and 17 CR at only on two concentrations of additional oxygen i.e. 1l/min and 2l/min. Load started from zero load to the rated capacity of the engine to the successive loading of increment of 20% is used at a constant speed of 1500 RPM. Stability and repeating of the conditions of procedure were ensured by primarily run the test rig for 12 minutes at 50% load for constant 1250 rpm until the exhaust gas temperature reached 170^0C. The flow of water in engine jacket and calorimeter was fixed 60 litres per minute by the regulating rota-meter. The temperature of cooling jackets and calorimeter was constant 25^0C throughout in collecting data. After these stable conditions were attained, the engine test rig was brought to the critical test conditions after cooling whole system and permitted it to run for 5 minutes to ensure to stabilize reading before collecting the records. There was no change in fuel injection timing and injection pressure during experiment.

IV. RESULTS & DISCUSSION

The objectives of the study are to determine suitable value for an engine's compression ratio in which additional oxygen is used to lean the combustion for minimum possible emission levels. We took only two compression ratios and only two oxygen concentrations 16 to 17 and 1L/min to 2L/min respectively. Data were collected under the stabilized engine conditions for the basic emission parameters like CO_2, NO_x, HC and CO.

A. CO_2 Emission

It has already been discussed in the introduction that the addition of oxygen in intake air to diesel improves the quality of combustion. This eventually reduces CO emission and increases CO2 emission [6]. The variations of CO2 emission for the diesel combustion with and without oxygen enrichment are shown in Fig. 1 for the rated compression ratio of 16:1 and 17:1. The figure clearly shows the increase in CO2 emission with the increase in oxygen percentage at different compression ratios. The additional oxygen concentration in intake air enhances the combustion, and thus, the emission of CO2 is decreased. CO2 emission higher oxygen content in intake is about 6 to 8% lower than that with neat diesel at full load condition. It can be mentioned that CO2 is a greenhouse gas and its discharge into the environment is harmful to the environment. But the oxygen enrichment in combustion will reduces its magnitude up to some extent with increasing the oxygen in exhaust.

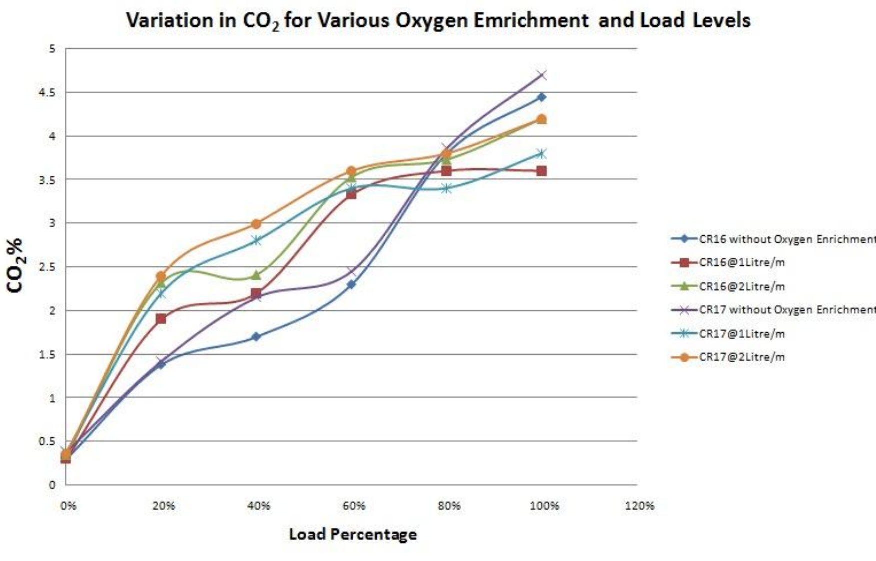

Fig. 1 Variation in % CO_2 for Various Oxygen Enrichment and Load Levels at Two Compression RatiosCO$_2$ Emission

B. NO_x Emission

All the oxides of nitrogen formed during combustion due to the oxidation of nitrogen are collectively known as NOx. The amount of NO_x formed and its emission depend mainly on the combustion temperature, oxygen concentration and the residence time of the combustion products within the combustion zone [19-21]. The variations of NOx emission with intake air enrichment for the diesel and their different compression ratios are shown in Fig. 2 for the rated compression ratio range from 16: to 17:1. The highest NO_x emission is found with compression ratio 17 and with 2litre/m oxygen enrichment level. As shown in figure, NOx level increase up to 23% by increasing both compression ratios and oxygen volume in intake air.

The higher temperature inside the cylinder creates the suitable environment for NO_x emission. It has also been reported by many researchers that at lower compression ratio, the premixed combustion phase is lengthened due to the longer ignition delay [7] and eventually decreases the NO_x emission. NO_x emission at full load condition is found to be 384 and 392 ppm for combustion with atmospheric air and 455 and 484 ppm for combustion with enriched oxygen at 2litre/m respectively, at compression ratios of 16:1 and 17:1.

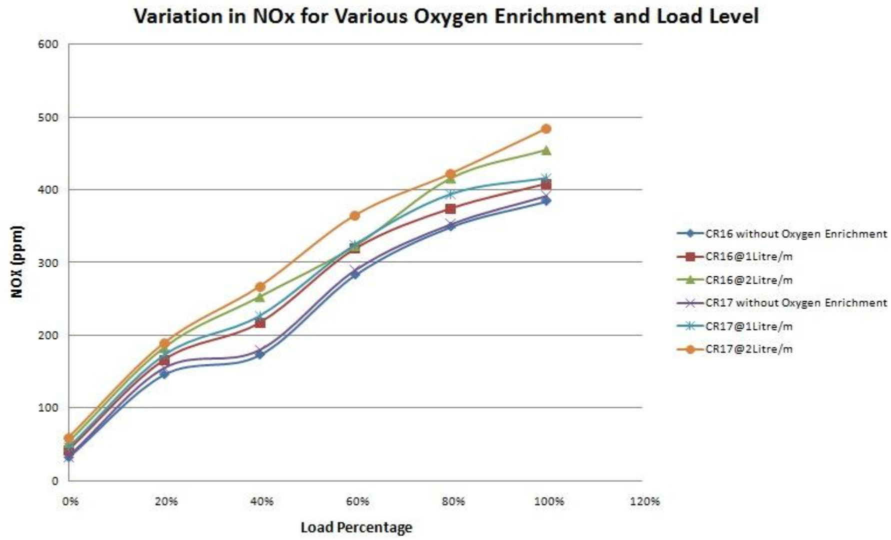

Fig. 2 Variation in NO_x (ppm) for Various Oxygen Enrichment and Load Levels at Two Compression Ratios

C. HC Emission

The amount of unburned hydrocarbon (HC) from any engine depends on the composition and also the combustion characteristics of the fuel used [18]. It has already been observed that the combustion is improved with oxygenation of intake air with diesel. This clearly indicates the possibility of lower HC emissions with oxygen enrichment [15] [17].

It can be seen from the Fig. 3 that the HC emission decreases with the increase in oxygen concentration and increasing compression ratios. The highest HC emission is observed with compression ratio 16:1 without oxygen enrichment, and the lowest one is noted at highest compression ratio 17:1 with oxygen enrichment at 2litre/m. This is due to the presence of oxygen in intake air which results in smooth and more complete combustion. HC is a product of incomplete combustion, and hence, its formation and emission are reduced with the addition of oxygen to diesel fuel. HC emission from the engine is found to be around 27% less with higher oxygen concentration and with higher rated compression ratio compared to that with diesel at full load condition.

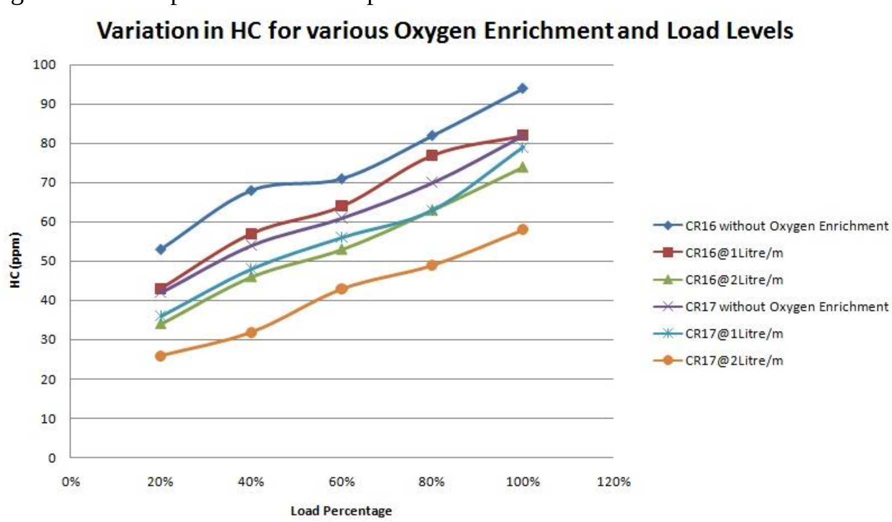

Fig. 3 Variation in HC (ppm) for Various Oxygen Enrichment and Load Levels at Two Compression Ratios

D. CO Emission

CO emission decreases at steady state operation but in the long run the level of CO_2 emission will increases due to complete oxidation of the reactants [19][21]. But the level of CO emission will also decrease with increase in oxygen concentration and rated compression ratio in diesel combustion. As shown in Fig. 4 that by increasing the compression ratio, CO level decrease up to 5% with oxygen enrichment. As oxygen level increases in intake air, the level of CO decreased up to 10% and 19% respectively for rated compression 16:1 and 17:1.

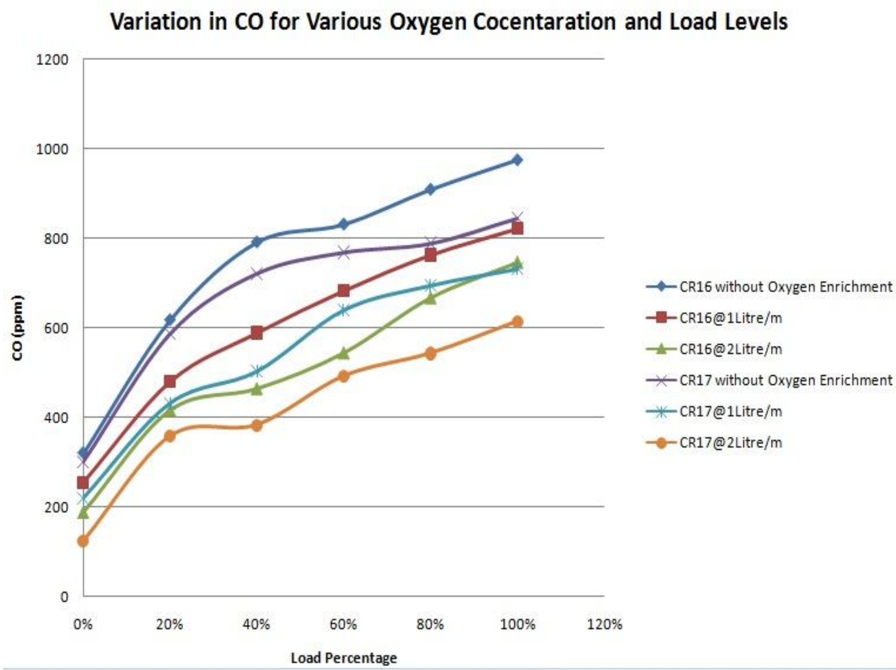

Fig. 4 Variation in CO (ppm) for Various Oxygen Enrichment and Load Levels at Two Compression Ratios

V. CONCLUSIONS

The following conclusions can be drawn from this experimental study using different oxygen concentration with two different compression ratios with diesel fuel in a variable compression ratio engine.

CO_2, CO and HC emissions are significantly reduced when level of pure oxygen increased in intake air to increase the oxygen content of air with diesel. The emissions of CO_2, CO and HC with oxygen enrichment and higher compression ratios are found to be less by 11%, 27% and 10%, respectively, compared to diesel at normal operating condition with air only. CO_2, CO and HC emissions increase with the decrease in compression ratio.

However, NOx emissions increase with oxygen concentration at higher compression ratios. The NOx increment is 23% and 2%, respectively, with compared to oxygen enrichment and without oxygen enrichment. Also NOx emissions increase with the increase in compression ratio.

At higher compression ratios, the performance and combustion characteristics are improved as well as the emissions of CO, HC and CO are reduced, which can be beneficial for CI engines running with oxygen enrichment. The higher NOx emission with higher compression ratios can be reduced by retardation in ignition timings or effective cooling rates or by diluting the charge by less specific heat fluid or implementing some after treatment method such as exhaust gas recirculation (EGR) technique. The future research work may be carried out with more parametric variations such as the effect of injection timing, injection pressure and exhaust gas recirculation and preheating of intake air [1].

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