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A COMPARISON OF EMISSIONS OF SI AND CI ENGINES IN A LOW-NITROGEN OXYCOMBUSTION ENVIRONMENT

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ABSTRACT

This paper compares the formation of various pollutants such as NO_x*, CO, Particulates in a low nitrogen oxycombustion environment in Spark-ignited (SI) and Compression-ignited (CI) engines.Various factors like heat release rate and dependence with* N_2 *concentrations in intake air were investigated to evaluate the emissions from both SI and CI engines.*

Experiments were done on SI and CI engines with similar combustion criteria and exhaust emissions were measured.No_x *emissions were found to have linear correlation with intake* N_2 *concentrations from no* N_2 *to Normal air combustion.Other emissions were plotted and compared with each case of SI and CI engines. It is compared and significance of Oxycombustion in reduction of pollutants was obtained.*

Keywords: CI engine, Exhaust Gas Recirculation, Experiment, NO_x***, Oxycombustion, SI engine***

I INTRODUCTION

In the last two decades, the researchers and manufacturers have provided major reductions in the exhaust emission levels of the automobiles due to increase global concern about the air pollution. Various regulations would likely emerge which could heavily penalize processes which release harmful emissions into the atmosphere. Regulations controlling the emissions from automobiles are becoming increasingly strict. Hence, in order to meet the strict vehicular exhaust emission norms worldwide, several exhaust treatment techniques have been employed in modern spark-ignited and compression ignited-engines. Various emissions include CO_2, NO_x,HC and particulate emissions.Oxycombustion is a potential approach in capturing CO_2 and reducing NO_x emissions.

Oxycombustion burns fuel with concentrated O_2 in a low nitrogen environment and allows the formation of NO_x emissions to be influenced by varying N_2 concentrations. It employs burning of fuel in a diluent of recycled exhaust products using Exhaust Gas Recirculation technique.

Exhaust Gas Recirculation (EGR) is a pretreatment technique, which is being used widely to reduce and control oxides of nitrogen. The exhaust gases mainly consist of carbon dioxide, nitrogen and water vapor. When recirculated it acts as a diluent to the combusting mixture. The fresh air entering the combustion chamber is displaced by recirculated exhaust gas. As a result of this,NO_xemissions are controlled as it lowers oxygen consumption and flame temperature of the working fluid in the combustion chamber. Indicated specific NO_x emissions for oxygen-enhanced EGR (O-EGR) and EGR without oxygen addition (normal or N-EGR) correlated with flame temperature but were slightly lower at a given flame temperature for O- EGR. Oxygen addition allowed the use of high levels of EGR without reducing the oxygen concentration, thereby substituting CO_2 and H_2O for a substantial portion of the N_2 as diluent.

In the case of Compression Ignition engines, Wagner et al. [1] tried to achieve lower NO_x emission and soot using highly diluted intake mixture. Continuous drop in NO_x emission and sharp decrease in particulate matters was obtained at high EGR rate (around 44%). But it significantly affects the fuel economy. Agarwal et al.[2] investigated the effect of EGR on performance and emissions, carbon deposits and engine wear reported that thermal efficiency is increased and break specific fuel consumption is decreased at lower loads with EGR compared to without EGR. Qi et al.[3] noticed that Break Specific Fuel Consumption (BSFC) and soot emissions slightly increased and NO_x emission was evidently decreased with increasing of EGR rate. Salt et al. [4] studied combined effects of enhanced oxygen and high EGR to reduce both soot and NO_x in diesel engine. Nitrogen is a natural diluent in air which lowers the flame temperature as the fuel burns in. Ladommatos et al. [5] demonstrated CO_2 and H_2O as better diluents in diesel engines. Guo and Smallwood et al. [6] reported CO_2 suppresses soot formation in laboratory diffusion flames.

Enhanced oxygen concentrations in SI engines have been considered for increased power density and thus EGR is not present in largeconcentrations. The vast majority of SI-engine NO is produced through thermal NO, also known as the extended Zeldovich mechanism. Therefore in an SI-engine,oxycombustion permits adjustment of both N_2 and/or temperature through variation of the purity of the O_2 and the EGR levels. Since oxycombustion is largely operated under stoichiometric conditions it is not expected that O concentrations can be directly influenced.

The objective of the current survey is to investigate and compare the potential benefits and emission characteristics of SI and CI engines operating under normal andoxygen enhanced environments. Normal EGR adds CO_2 and H_2O to the mixture, which limits the amount of CO_2 that can be added because the O_2 becomes too dilute to sustain the stable combustion. In case of Oxycombustion, a source of pure O_2 has supplemented the oxygen supplied by air in order to sustain a constant O_2 concentration when EGR was increased, which allowed O_2 and EGR to replace N_2 rather than adding to it. In CI engines oxy-combustion is essentially a modification to EGR (EGR with oxygen addition) and will be referred to herein as oxygen-enhanced EGR (O-EGR). EGR without oxygen addition will be referred to as normal EGR (N-EGR). N-EGR consists of fuel air and EGR where O-EGR involves additional O_2 volume.

II EXPERIMENTAL SETUP

Experimental for SI and CI engines has similar setup and methods. Seperate loops for dry and wet EGR schemes were used in Spark Ignited engine, while the Compression Ignition engine involve liquified O_2 source.

2.1 Spark Ignited Engine – Material and Methods

The engine used was a Waukesha Cooperative Fuel Research(CFR) F4 engine, which was a four-stroke, single cylinder, port injected, spark-ignited engine with variable compression ratio.Engine speed was controlled by an induction generator and variable-frequency drive, set to 600 rotations-per-minute (RPM). The engine intake was unthrottled and all tests were performed using a stoichiometric mixture. Main parameters of the engine and conditions are listed in Table 2.1. Fig. 2.1shows a layout of the experimental setup. In-cylinder pressure data were obtained using a piezoelectric KISTLER 7061B water-cooled pressure transducer, recorded with a resolution of 0.1 crank-angle-degrees (CAD).

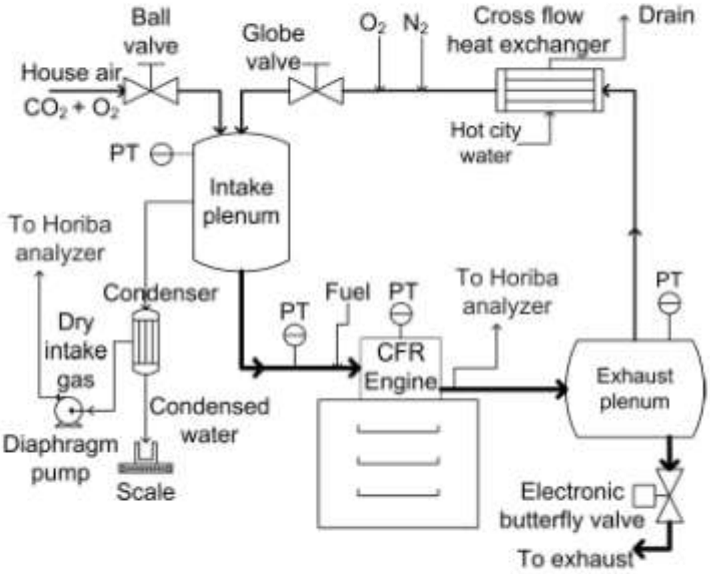
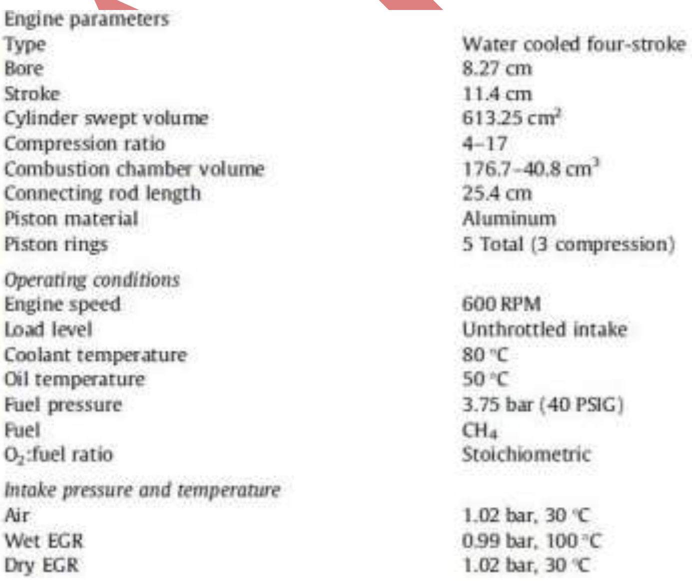


Fig. 2.1 Layout of experimental setup

Fuel injection was controlled by a MOTEC M4 ECU, and measured using a Hastings mass-flow meter. Exhaust and intake composition were measured using a Horiba emissions analyzer with sensors for CO_2, CO, O_2, unburned hydrocarbons, and NO_x. In addition, the exhaustmole fraction of NO_x in parts-per-million (ppm) was directlymeasured with a Siemens VDO/NGK Smart NO_x-Sensor. For detailed description of Experimental setup, refer to Ref [8].

Table 2.1 CFR Engine Parameters and Run Conditions



Engine parameters	
Type	Water cooled four-stroke
Bore	8.27 cm
Stroke	11.4 cm
Cylinder swept volume	613.25 cm^2
Compression ratio	4–17
Combustion chamber volume	176.7–40.8 cm^3
Connecting rod length	25.4 cm
Piston material	Aluminum
Piston rings	5 Total (3 compression)
Operating conditions	
Engine speed	600 RPM
Load level	Unthrottled intake
Coolant temperature	80 °C
Oil temperature	50 °C
Fuel pressure	3.75 bar (40 PSIG)
Fuel	CH_4
O_2:fuel ratio	Stoichiometric
Intake pressure and temperature	
Air	1.02 bar, 30 °C
Wet EGR	0.99 bar, 100 °C
Dry EGR	1.02 bar, 30 °C

EGR experiments were performed with true recirculated exhaust and intake temperature was maintained at 100^0C to prevent condensation.Additional tests were performed under constant N_2 concentrations to evaluate the influence of EGR compositions and EGR dilution on emissions and engine performance parameters.

2.2 Compression Ignited Engine - Material and Methods

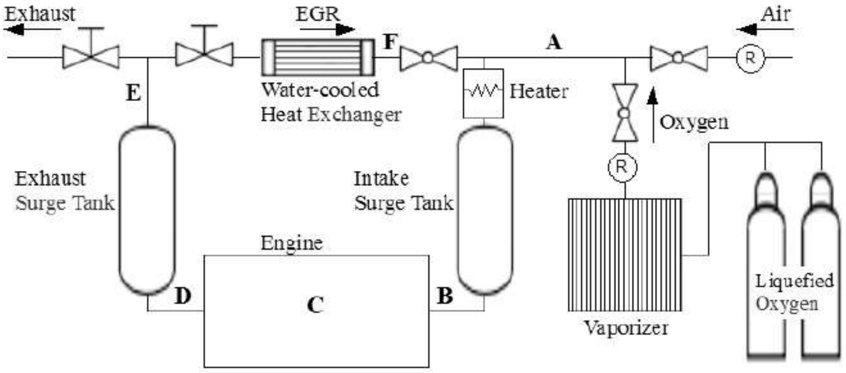


Fig. 2.2 Layout of Experimental Setup

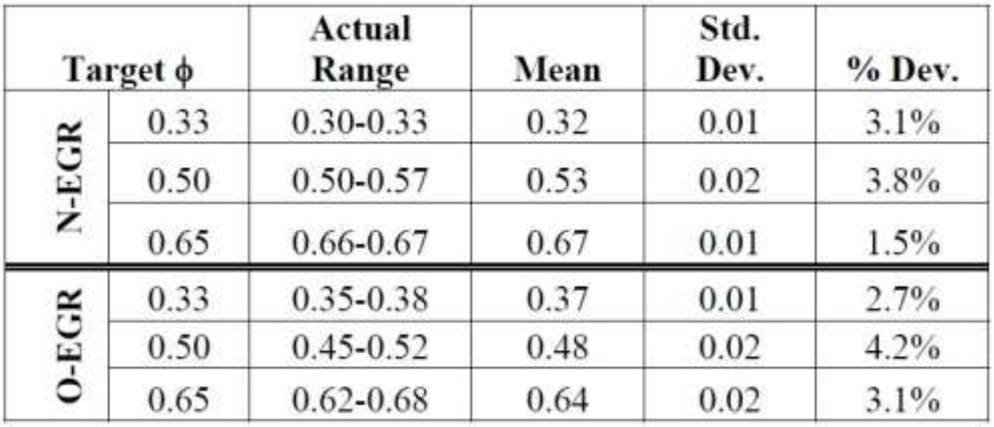
Experiments were conducted on a 1994 Cummins 5.9 L six-cylinder diesel engine. This engine had previously been modified to operate on a single cylinder by deactivating five of the six. With these modifications, all measurements and calculations were done on a single cylinder, thereby removing the concern of cylinder-to-cylinder variability. A more detailed description of the engine modifications can be found in Cooley (2000). Air was supplied to the engine from a compressed air source, which allowed the charge air pressure to be varied. A pressure regulator on the air inlet provided pressure control from approximately 0-25 psig. Oxygen stored in liquid cylinder tanks was used to supplement the intake air such that the oxygen concentration could be maintained constant while the amount of EGR was increased. A surge tank on the inlet side of the engine helped smooth air pressure fluctuations due to valve operation and a similar surge tank on the exhaust side helped to smooth pressure fluctuations in the exhaust line. Figure 2.2 provides a flow diagram for the engine setup and also depicts the air, EGR, and O_2 flow paths. Sweeps of gradually increasing levels of EGR were completed with and without oxygen addition (O-EGR and N-EGR) for three different loads (overall equivalence ratios). The engine speed was maintained at 1500 rpm for all loads. At each operating condition exhaust the following measurements were taken at the lettered locations indicated in Figure 2.2:

A - Volumetric flow rate, pressure, temperature
B - Pressure, temperature, xO_2, xCO_2, xNO_x
C - Engine speed (RPM), engine position (crank angle), in-cylinder pressure
D - Temperature, opacity
E - Pressure, xO_2, xCO_2, xNO_x
F – Temperature

Detailed descriptions of engine modifications can be found in Cooley [9].

Table 2.2 shows the intake gas compositions for Normal EGR and Oxygen enhanced EGR.

Table 2.2 Intake Gas Compositions



	Target ϕ	Actual Range	Mean	Std. Dev.	% Dev.
N-EGR	0.33	0.30-0.33	0.32	0.01	3.1%
	0.50	0.50-0.57	0.53	0.02	3.8%
	0.65	0.66-0.67	0.67	0.01	1.5%
O-EGR	0.33	0.35-0.38	0.37	0.01	2.7%
	0.50	0.45-0.52	0.48	0.02	4.2%
	0.65	0.62-0.68	0.64	0.02	3.1%

III RESULTS AND DISCUSSIONS

3.1 Effect of N_2 concentration on NO_x emissions

A parametric study was done on experiment using EGR with varying quantity of N_2 and keeping all other possible parameters to be constant. The results were plotted for 5 different N_2 concentrations. For both engines, Fig. 3.1 shows that the NO_x emission shows a linear correlation between N_2 in the Oxidizer.

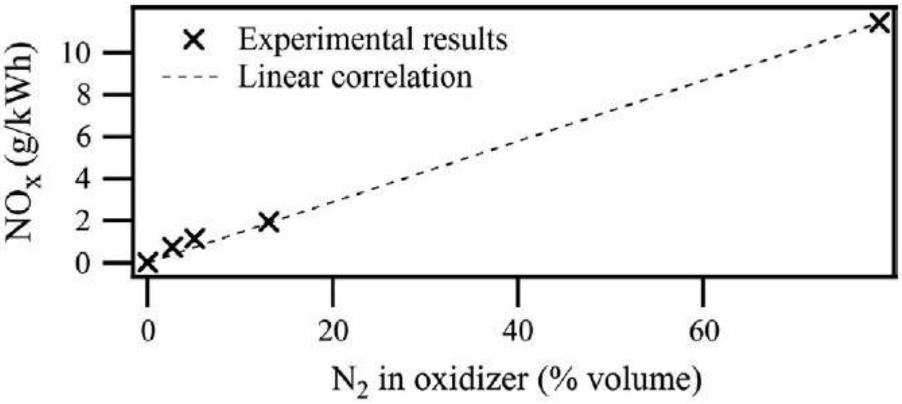
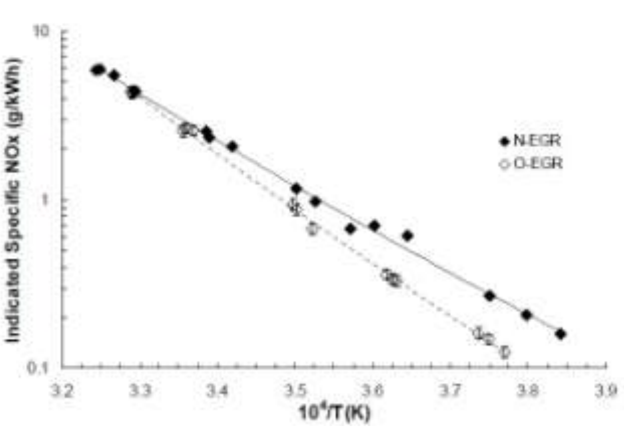


Fig. 3.1

For CI engines, as the EGR level was increased during each sweep, the composition of the intake gases changed. In N-EGR cases, the N_2 concentration remained relatively constant with increasing EGR, while the CO_2 concentration increased and the O_2 concentration decreased. The H_2O concentration in the intake remained essentially zero because the EGR was cooled sufficiently to condense out virtually all of the water. For the O-EGR cases, the N_2 concentration decreased significantly with increasing EGR because CO_2 and H_2O replaced N_2 rather than adding to it. Additionally, the CO_2 concentrations for O-EGR were significantly higher than for N-EGR.

3.2 NO_x Emissions



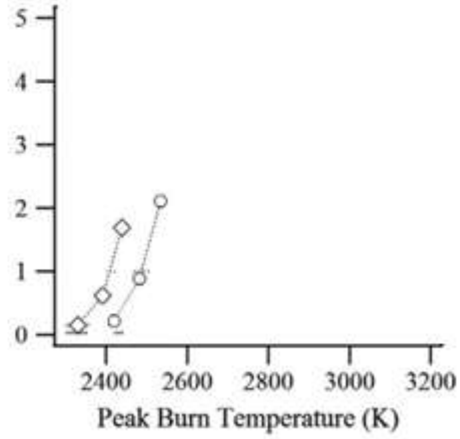


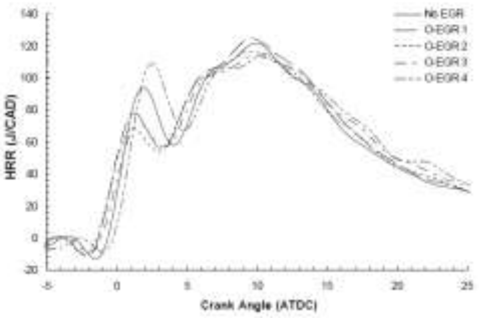
Fig. 3.2.1

Fig. 3.2.2

Fig. 3.2.1 shows the Indicated specific NO_x as a function of peak temperature for a CI engine and fig. 3.2.2 shows specific NO_x as a function of flame temperature for a SI engine.

Dilutions performed using Normal EGR and Oxygen enhanced EGR for same temperatues reports the diluion with O-EGR gives a decreased combustion temperature and resulting in reduction of NO_x emissions for a CI engine.But with Spark ignited engine the peak burned-gas temperature does not correspond perfectly with the NO_x emissions, which is expected since it is a point-value and does not account for the volume of gas at that temperature or the duration, but overall a clear trend exists between increasing temperature and higher NO_x emissions.Regulations were satisfied only at the lower O_2 volume fractions.

3.3 Heat Release Rate



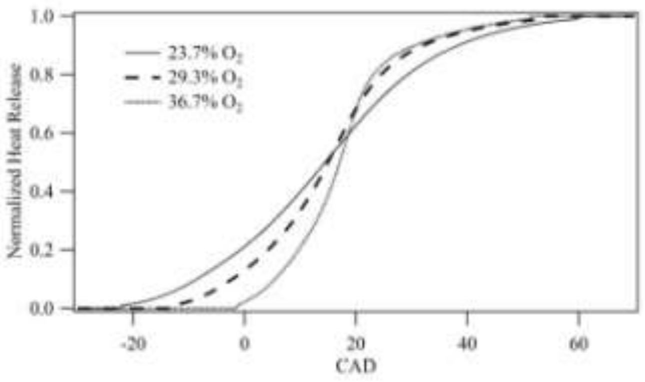


Fig.3.2.1

Fig.3.2.2

Fig. 3.2.1 shows Heat release rates for various O-EGR cases for CI engine. Fig 3.2.2 shows the heat release rate for various O_2 concentrations for SI engine.

Both case studies were investigated in same conditions and results indicated that the O-EGR cases involved less heat release for a CI engine.For an SI engine results showed that ideal oxycombustion case produced high heat release rate with low O_2 concentrations.Increasing HRR for each O_2 concentration could give maximum thermal efficiency at lower O_2 concentration.

3.4 CO Emissions

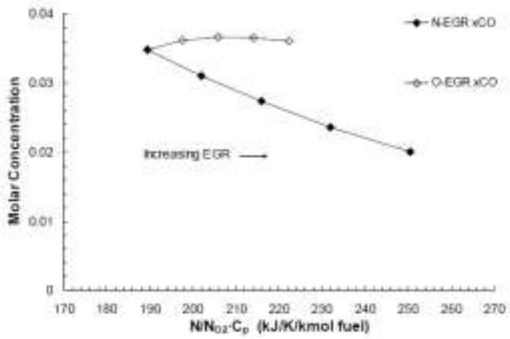


Fig.3.4.1

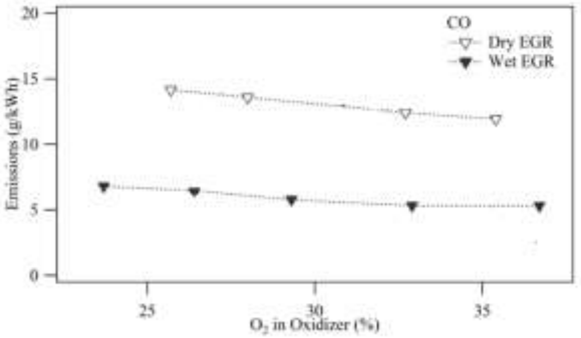


Fig.3.4.2

Fig 3.4.1 shows the equilibrium concentration of CO emissions plotted against N/No2.Cp for 2 test cases of N-EGR and O-EGR in CI engine. Fig 3.4.2 shows the CO emissions in g/kWh for different O_2 volumes for dry and wet EGR cases.

Equilibrium concentrations when plotted,the concentration of CO is found to be higher for O-EGR cases as expected. O-EGR may therefore produce lower flame temperatures than N-EGR due to dissociation of CO_2 to CO in CI engines. But in the case of SI engine, measured engine out emissions of CO shows for all oxygen concentrations, wet EGR produced lower engine emisions than dry EGR. It is noted that CO emissions remain relatively constant for various O_2 concentrations.

3.5 Relation between NO_x and Particulate emission in CI engine

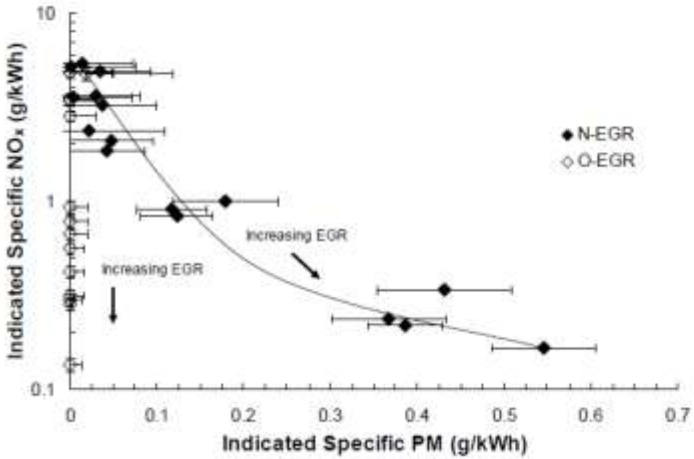


Fig 3.5 Indicated specific NO_x emission vs Indicated specific Particulate matter

It is essential while discussing the emissions of a Compression Ignition engine to correlate the NO_x emissions and major particulate emissions. As indicated in the graph, normal EGR results in a curve which shows that the increasing EGR causes reduction in NO_x but increase in Particulate emission. But O-EGR case is found to be effective in decresing the NO_x emissions without particulate emissions.

IV CONCLUSIONS

The different emissions and influence of various parameters in an SI and CI engine operating under oxycombustion conditins have been analyzed and compared. The most significant results are given below.

1. NO_x emissions were found to have linear dependence on intake N_2 concentrations.
2. NO_x reduction in N-EGR and O-EGR cases was primarily due to flame temperature reduction in CI engine where the NO_x reduction in SI engine was dependent of on combustion temperature and N_2 concentration.
3. In CI engine, O-EGR produced somewhat lower NO_x emission than N-EGR due to reduced intake concentrations. In SI engine the NO_x emissions were found to be somwhat dependent on working fluid concentrations.
4. Indicated specific particulate emissions increased with increase in EGR for N-EGR but remain constant for O-EGR cases in CI engine.
5. CO emissions were found more in O-EGR cases for CI engine whike for SI engine it remains constant for various O_2 volumes.
6. It was predicted that emssion standards for NO_x and particulate emission from CI engine could be achieved with 8% of total intake flow provided by added O_2. While in SI engines, NO_x regulations could be satisfied with reduction of N_2 volume fraction to approximately 1.9% for wet EGR and 1% for dry EGR.

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