STUDY ON PERFORMANCE AND EMISSION CHARACTERISTICS OF A SINGLE CYLINDER DIESEL ENGINE USING EXHAUST GAS RECIRCULATION

by

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Exhaust gas re-circulation is a method used in compression ignition engines to control and reduce NO_x emission. These emissions are controlled by reducing the oxygen concentration inside the cylinder and thereby reducing the flame temperature of the charge mixture inside the combustion chamber. In the present investigation, experiments were performed to study the effect of exhaust gas re-circulation on performance and emission characteristics in a four stroke single cylinder, water cooled and constant speed diesel engine. The experiments were performed to study the performance and emissions for different exhaust gas re-circulation ratios of the engine. Performance parameters such as brake thermal efficiency, indicated thermal efficiency, specific fuel consumption, total fuel consumption and emission parameters such as oxides of nitrogen, unburned hydrocarbons, carbon monoxide, carbon dioxide and smoke opacity were measured. Reductions in NO_x and CO_2 were observed but other emissions like HC, CO, and smoke opacity were found to have increased with the usage of exhaust gas re-circulation. The 15% exhaust gas re-circulation was found optimum for the engine in the aspects of performance and emission.

Key words: *Diesel engine, oxides of nitrogen, exhaust gas re-circulation*

Introduction

Diesel (compression ignition) engines are commonly used in transportation, industrial, and agricultural machinery. But emissions from this type of engines have substantial effects on the environmental system. Therefore there is an increasing demand on tightening the emissions standards of diesel vehicles, as well as demand on developing techniques for reducing emissions from in-service diesel engine vehicles [1, 2]. Engine manufacturers globally succeeded to develop diesel engines with high specific power output and high thermal efficiency, always trying to keep inside the limits of the enforced emission regulations that becomes more and more rigorous every day. Over the last decades, several achievements were

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made for the development of cleaner diesel engines, by adopting many engine-related techniques, *e. g.* the use of common-rail systems (common rail direct injection – CRDI, turbocharged direct injection – TDI), exhaust gas after-treatment, exhaust gas re-circulation, fuel injection control strategies, *etc.* [3, 4].

Exhaust gas re-circulation (EGR) is one among the important techniques, which is used to lessen the NO_x emission from compression ignition engine. Diesel engines are usually categorized by low consumption of fuel and very low emissions of HC and CO. But, when talking about the NO_x emissions, they are very high for diesel engines. Therefore, in order to cope with the environmental regulations, the NO_x emissions should be reduced in the exhaust gas. Many countries have already imposed emission legislation on NO_x in diesel engines and generator set engines [5, 6].

The EGR is a method where a particular portion of exhaust gas is re-circulated by mixing it back with the fresh air entering into the cylinder. The re-circulated exhaust mainly consists of CO_2, N_2, and water vapor. Since these gases do not burn again they can be re-circulated back into the cylinder. During this re-circulation, the actual fluid is diluted by reducing the oxygen concentration entering the combustion chamber. Also when the specific heat of exhaust gas is considered, it is much higher than that of the fresh air, which in turn increases the specific heat of the intake charge. This will ultimately decrease the overall temperature rise for the same heat release in the combustion chamber [5, 7].

It was found by many researchers focused on EGR technique in a diesel engine that, it could reduce NO_x emission. Venkateswarulu *et al.* [8] investigated the diesel engine using hot EGR along with cetane improver. From their results, they reported that the brake thermal efficiency (BTE) of the engine increases with the increase in the EGR percentage along with a reduction in brake specific fuel consumption (BSFE) and exhaust gas temperatures (EGT). Also, there was a reduction in oxides of nitrogen by 33% during the EGR operation. Rajan *et al.* [9] studied the effect of sunflower methyl ester on a four stroke direct injection diesel engine employed with exhaust gas re-circulation technique. They reported that there is a 25% reduction in NO_x and smoke emissions with 15% EGR rate compared with a conventional engine. Hussain *et al.* [10] studied the effect of exhaust gas re-circulation on emission and performance characteristics of a three cylinder, air cooled diesel engine. From their experiments, they concluded that NO_x emission decreased with EGR because of a decrease in exhaust gas temperature. They observed that 15% EGR rate is effective to reduce NO_x emission substantially without deteriorating engine performance in terms of BTE and BSFE. Wagner *et al.* [11] experimented to achieve low oxides of emission and soot emission by using diluted intake charge mixture. At very high exhaust gas re-circulation rate of about 44%, the particulate matter emission decreased harshly along with an unceasing drop in NO_x emission. Also, this high EGR rate reduced the fuel economy of the engine.

The present study focuses on implementation of hot exhaust gas re-circulation in a single cylinder direction injection diesel engine with various EGR proportions and to evaluate the performance and emission characteristics with and without EGR.

Experimental set-up

The experimental investigation was carried out on a single-cylinder, four stroke naturally aspirated water cooled diesel engine coupled with eddy current dynamometer for loading purpose. Three set of tests were conducted first one being cold start and the second and third tests in running conditions. The reading of second and third tests are found closer to each other and the same has been used for analysis purpose. The specification of the test engine and dynamometer used are given in tabs. 1 and 2, respectively. The schematic view experimental set-up is shown in fig. 1. The EGR was done by ducting some of the exhaust flow back into the intake system of the test engine.

Table 1. Specification of test engine

Make	Kirloskar
Type	Single cylinder, 4 stroke, vertical, direct injection, compression ignition engine
Power	5.95 kW
Rated speed	1500 rpm
Bore × stroke	95 × 110 mm
Cooling type	Water cooling

Table 2. Specification of the dynamometer

Make	Laurence Scott and electromotor Ltd.
Maximum power	10 kW
Volts	220/230 V
Rated current	43.5 A
Rated speed	1500 rpm
Windings	Shunt

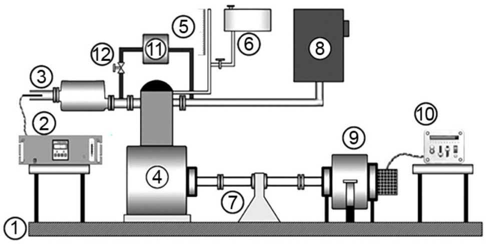

Figure 1. Schematic view of experimental set-up; *1 – test bed, 2 – exhaust gas analyzer, 3 – analyzer probe, 4 – single cylinder direct injection diesel engine, 5 – burette, 6 – fuel tank, 7 – power output shaft, 8 – air induction box, 9 – dynamometer, 10 – electrical loading panel, 11 – steel wool filter, 12 – EGR control valve*

The composition of exhaust gas emitted was measured by a gas analyzer, which measures HC, CO, and CO_2 by non-dispersive infra-red (NDIR) and NO_x by electrochemical method. Smoke emission was measured by the smoke meter. The specification of the gas analyzer and smoke meter are given in tabs. 3 and 4, respectively. All the measurement devices had been calibrated accurately before the start of engine experiment. The efficiency of the generator is high and same for all set of experiments and hence efficiency is not taken into account for calculation purpose.

Table 3. Specification of the exhaust gas analyzer

Make	NETEL	
Measuring item	Measuring range	Measuring method
CO [%]	0.00-0.99	NDIR
HC [ppm]	0-20000	NDIR
CO_2 [%]	0.0-20.0	NDIR
NO_x [ppm]	0-5000	Electrochemical

Table 4. Specification of the smoke meter

Make	NETEL
Display indication	Light absorption coefficient and percentage opacity
Display range	0 to 9.99 m
Response time	0.3 seconds
Warm up time	3 minutes

Results and discussion

The BTE is defined as the actual brake work per cycle divided by the amount of fuel chemical energy [12]. Figure 2 shows the variation of BTE of the engine for different brake power under different EGR ratios. The BTE of the engine increases with the increase of EGR ratio. For diesel operation, the BTE at maximum load is 27.2%, whereas for 20% EGR, the BTE at maximum load is 31.19%. From the figure, it can be seen that at minimum brake power, the variation of efficiency for diesel is very less compared with EGR engine. At maximum brake power (full load), the BTE of 20% EGR ratio increased about 12.8% than the diesel fueled engine operated without EGR. This happened because the lean mixture is allowed to enter into the engine cylinder during the suction stroke and but increasing the EGR quantity the air-fuel ratio reduced towards stoichiometric ratio which resulted in the increased brake power [13].

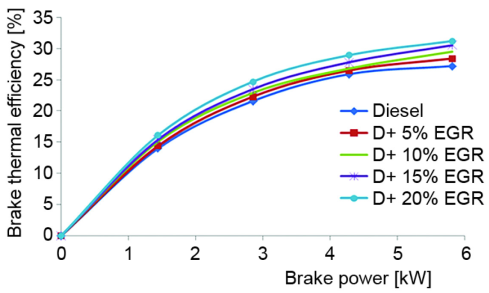

Figure 2. Variation of BTE for different EGR ratios

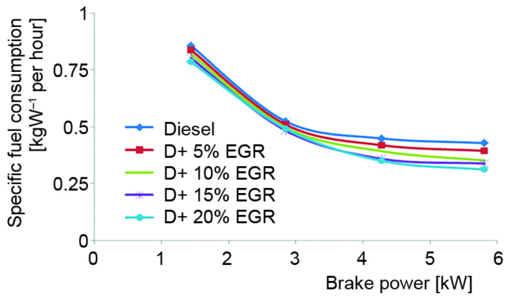

Figure 3. Variation of SFC for different EGR ratios

Specific fuel consumption (SFC) of the engine is the measure of the efficiency of the engine by the ratio of the fuel supplied to produce work. In general, lower value of SFC is desirable which explains that the engine produces the same amount of work from lower fuel consumption. Figure 3 shows the deviation of SFC under various EGR ratios. The specific fuel consumption of the engine decreases with increase in EGR ratio. From the figure, it can be seen that at minimum brake power, the variation of SFC for diesel and EGR engine and the variation gradually increases with increase in brake power. At medium brake power (40% load) of the engine with 20% EGR, the SFC of the engine decreases 5.76% compared with the conventional engine (without EGR). At maximum brake power of the engine, the specific fuel consumption of 20% EGR ratio decreased about 25.92% than the diesel fueled engine operated without EGR. The decrease in SFC with EGR is due to increase in intake charge temperature which increases the rate of combustion of the fuel. Hawi *et al.* [14] also found a similar type of results while operating the single cylinder, four stroke diesel engine with EGR.

Figure 4 shows the deviation of oxides of nitrogen (NO_x) emission with respect to brake power under various EGR ratios. It is observed that NO_x emission decreases with increase in EGR ratio at lower and higher loads of the engine. The NO_x emission has decreased about 6.17% for 20% of EGR ratio at maximum load. For 5, 10, and 15% EGR ratio, the NO_x emission decreased of about 3.38, 3.39 and 4.18%, respectively, compared with a conventional engine. The reduction of NO_x emission is due to the intensification of a three-atom molecule inert gas such as CO_2, H_2O, *etc.*, present in the intake charge. Also, the combustion temperature decreased with increase in EGR ratio due to the increase in inert mass inside the combustion chamber.

Figures 5 and 6 show the variation of unburned hydrocarbon and carbon monoxides emissions with respect to brake power under various EGR ratios. From these figures, it is clearly understood that HC and CO emissions increase with increasing EGR. At minimum (no load)

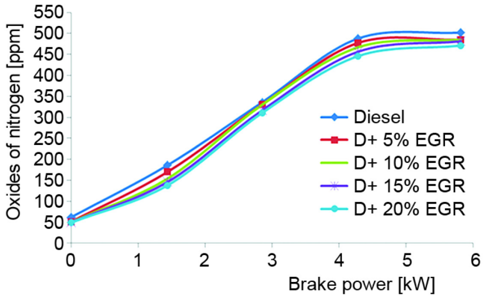

Figure 4. Variation of oxides of nitrogen for different EGR ratios

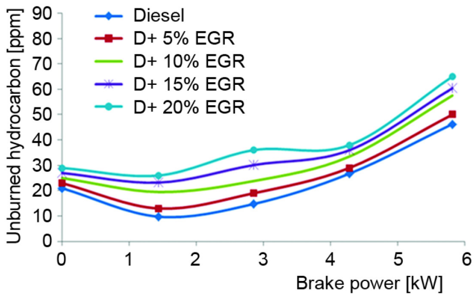

Figure 5. Variation of unburned hydrocarbons for different EGR ratios

and maximum brake power (full load), the HC emission of 20% EGR engine increased about 27.51% and 28.84% than the diesel fueled engine operated without EGR. Similarly, CO emission increased 8.75% and 14.28% during EGR operation at a minimum and maximum load, respectively. The reduction in excess oxygen concentration results in rich air-fuel mixtures at various locations inside the combustion chamber. The combustion process of this mixture approached stoichiometric ratio, which resulted in elevated HC, and CO emissions due to the reduction in presence of excess air inside the cylinder. At part loads, the lean mixtures are tougher to ignite because of the presence of heterogeneous mixture which resulted in the higher amount of HC and CO emissions [15, 16].

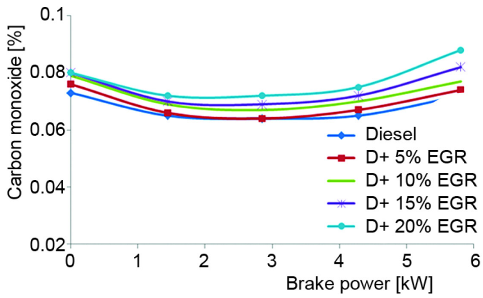

Figure 6. Variation of carbon monoxide for different EGR ratios

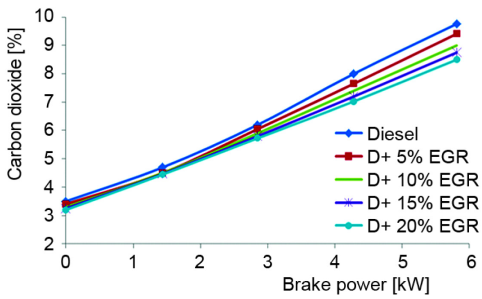

Figure 7. Variation of carbon dioxide emission for different EGR ratios

Figure 7 shows the variation of carbon dioxide (CO_2) emission with respect to brake power under various EGR ratios. Since CO_2 has higher specific heat capacity it acts as a heat-absorbing agent during the combustion process, which will reflect in the reduction of the peak temperature inside the engine cylinder. It can be observed that the CO_2 emissions from diesel operation range from 3.5% at minimum load to 10% at maximum load but in the case 20% EGR it ranges from 3.2% at minimum load to 8.5% at maximum load. At a minimum and maximum brake power, the CO_2 emission of 20% EGR engine decreased about 8.57 to 12.90% than the diesel fueled engine operated without EGR. This happened because the circulation of high amount of EGR reduces the peak combustion temperature inside the cylinder and the lack of oxygen present in combustion chamber has resulted in poor combustion and lesser CO_2 emissions.

The particulate matter present in the exhaust gas is quantified by measuring the smoke opacity of the exhaust gas. Figure 8 shows the variation of smoke opacity with respect

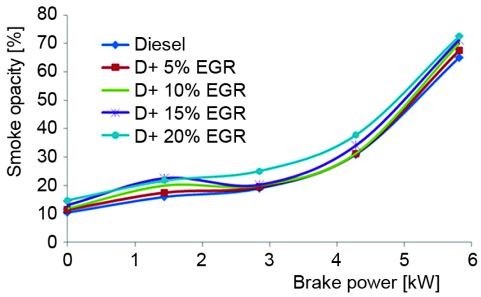

Figure 8. Variation of smoke opacity for different EGR ratios

to brake power under various EGR ratios. The smoke opacity composition of the exhaust gas increases with increase in EGR ratio. At maximum brake power (full load), the CO_2 emission of 20% EGR engine decreased about 10.34% than the diesel fueled engine operated without EGR. This is because EGR decreases the oxygen availability required for the combustion of fuel, which results in fairly incomplete combustion and also increases the particulate matter formulation.

Conclusions

In this study, the performance and emission characteristics of a four stroke, single cylinder direct injection diesel engine were evaluated with EGR. The effect of EGR on diesel engine fueled with neat diesel was studied and the results are given below.

- The experiments showed that increase in EGR percentage increases the brake thermal efficiency and indicated thermal efficiencies of the engine during all the load conditions. The variation of increase is more at higher loads compared with lower loads.
- The specific fuel and total fuel consumption of the engine fueled with diesel decrease with increase in EGR percentage during all the loads. The variation of decrease in fuel consumption is more at higher loads compared with lower loads. The brake power of the engine was not affected and remains same for all the EGR ratios.
- It was seen that the oxides of nitrogen emission reduced drastically by employing EGR. The increase of EGR percentage reduces the NO_x emission more because of reduction in exhaust gas temperature of the engine during EGR.
- The CO and HC emissions of the engine increased slightly during exhaust gas recirculation. Increasing EGR decreased the oxygen intake and resulted in stoichiometric combustion which in turn increased CO and HC emission which is mainly because of reduction in excess air and lower combustion temperature.

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