A Review on Effect of Exhaust Gas Recirculation (EGR) in Diesel Engines

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ABSTRACT

Exhaust gas recirculation (EGR) system means to use the exhaust gas coming from exhaust manifold to inlet manifold in order to reduce the emission of NOₓ, which is particularly very harmful. Engine without EGR are more pollutant & uses more atmospherically air for combustion. By implementation of EGR system in engine, the partial exhaust gas is re-circulated again in engine. It is first cooled in EGR cooler & then it is mixed with atmosheric air & then passed to combustion chamber. Fresh atmospheric air required is reduced & automatically pollutant (CO, CO₂, HC, NOX etc.) is reduced. The aim of this work is to review the potential of exhaust gas recirculation (EGR) to reduce the exhaust emissions, particularly NOₓ emissions, and to delimit the application range of this technique.

Keywords—Diesel Engine, Performance, Exhaust Gas Recirculation, Combustion, Emission.

I. INTRODUCTION

The Exhaust Gas Recirculation (EGR) system is designed to reduce the amount of Oxides of Nitrogen (NOₓ) created by the engine during operating periods that usually result in high combustion temperature. NOₓ is formed in high concentrations whenever combustion temperature exceeds about 2500°F. The EGR system reduces NOₓ production by re-circulating small amounts of exhaust gases into the intake manifold where it mixes with the incoming air/fuel charge. By diluting the air/fuel mixture under these conditions, peak temperature and pressure are reduced, resulting in an overall reduction of NOₓ output. Generally speaking EGR flow should match following operating conditions:

- High EGR flow is necessary during cruising and mid-range acceleration, when combustion temperature is typically very high.
- Low EGR flow is needed during low speed and light load condition.
- No EGR flow should occur during conditions when EGR operation could adversely affect engine operating efficiency or vehicle drive ability (engine warm up, idle, wide open throttle, etc.)

EGR is an effective method for NOₓ control. The exhaust gases mainly consist of inert carbon dioxide, nitrogen and possess high specific heat. When recirculated to engine inlet, it can reduce oxygen concentration and act as a heat sink. This process reduces oxygen concentration and peak combustion temperature, which results in reduced NOₓ. EGR is one of the most effective techniques currently available for reducing NOₓ emissions in internal combustion engines. However, the application of EGR also incurs penalties. It can significantly increase smoke, fuel consumption and reduce thermal efficiency unless suitably optimized. The higher NOₓ emission can be effectively controlled by employing EGR.

1.1 Classification of EGR systems

Various EGR systems have been classified on the basis of EGR temperature, configuration and pressure.

a. Classification based on temperature

(i) Hot EGR: Exhaust gas is recirculated without being cooled, resulting in increased intake charge temperature.
(ii) Fully cooled EGR: Exhaust gas is fully cooled before mixing with fresh in take air using a water-cooled heat exchanger. In this case, the moisture present in the exhaust gas may condense and the resulting water
droplets may cause undesirable effects inside the engine cylinder.

(iii) Partly cooled EGR: To avoid water condensation, the temperature of the exhaust gas is kept just above its dew point temperature.

b. Classification based on configuration

(i) Long route system (LR): In an LR system the pressure drop across the air intake and the stagnation pressure in the exhaust gas stream make the EGR possible. The exhaust gas velocity creates a small stagnation pressure, which in combination with low pressure after the intake air, gives rise to a pressure difference to accomplish EGR across the entire torque/speed envelop of the engine.

(ii) Short route system (SR): These systems differed mainly in the method used to set up a positive pressure difference across the EGR circuit. Another way of controlling the EGR-rate is to use variable nozzle turbine (VNT). Most of the VNT systems have single entrance, which reduce the efficiency of the system by exhaust pulse separation. Cooled EGR should be supplied effectively.

c. Classification based on pressure

Two different routes for EGR, namely low-pressure and high-pressure route systems may be used.

(i) Low pressure route system: The passage for EGR is provided from downstream of the turbine to the upstream side of the compressor. It is found that by using the low pressure route method, EGR is possible up to a high load region, with significant reduction in NOx. However, some problems occur, which influence durability, prohibitionary high compressor outlet temperature and intercooler clogging.

(ii) High pressure route system: The EGR is passed from upstream of the turbine to downstream of the compressor. In the high pressure route EGR method, although EGR is possible in the high load regions, the excess air ratio decreases and fuel consumption increases remarkably.

II. LITERATURE REVIEW

2.1 Avinash Kumar Agrawal, Shrawan Kumar Singh, Shailendra Sinha, Mritunjay Kumar Shukla [1]

Conducted experiments on, effect of EGR on the exhaust gas temperature and exhaust opacity in compression ignition engines.

Results showed that, at fixed power conditions, as the percentage EGR increases (0–21%), the temperature of the exhaust gas continuously decreases. A decrease in the exhaust temperatures with increasing EGR. Thermal efficiency remains unaffected by EGR. At high loads and at EGR rates above 15%, thermal efficiency tends to decrease slightly. Opacity of the exhaust gas increases as the rate of EGR is increased. At low loads, the rate of increase in opacity was almost the same with increase in EGR but at higher loads and higher rates of EGR, opacity increases rapidly. Brake specific fuel consumption (BSFC) was fairly independent of EGR. As load increases, BSFC decreases rapidly. At 3kW the BSFC gets almost saturated at 0.22 kg/kW-hr.

2.2 Pooja Ghodasara, M. S. Rathore [2]

Conducted experiments on, prediction on reduction of emission of NOx in diesel engine using biodiesel fuel and EGR (exhaust gas recirculation) system.

Results showed that, the higher exhaust temperature with diesel engine without application of EGR was indicative of lower thermal efficiencies. At 10% EGR biodiesel gives lower exhaust temperature. The thermal efficiency was found increased with EGR at lower load. At higher load with increase in EGR rate brake thermal efficiency decreases. With increase in EGR rates NOx emission also decreases. 20% EGR gives lowest NOx emission but there will be reduction in brake thermal efficiency and increase in smoke. HC emission increases with EGR and load. The HC emissions were lower in partial load but increase at higher engine load. 10% EGR was optimum for lower HC emission. Higher smoke opacity was observed when engine was operated with EGR compared to without EGR. Smoke opacity for biodiesel with EGR was noticed lower than diesel but it increases with increase in EGR rates.

2.3 P. V. Walke, Dr. N. V. Deshpande, R. G. Bodkhe [3]

Conducted experiments on, impact of exhaust gas recirculation on the performances of diesel engine.

Results showed that, with increasing rates of EGR at different torque there was marginal decrease in brake thermal efficiency. The smoke emission increases with the increase in EGR rates for different torque. With increasing EGR at different torque there was marginal increases in BSFC. With increase in EGR the concentration of NOx decreases, as the exhaust gas absorbs some energy and hence lowers the peak combustion temperature.

2.4 K. Rajan, K. R. Senthilkumar [4]

Conducted experiments on, effect of exhaust gas recirculation (EGR) on the performance and emission characteristics of diesel engine with sunflower oil methyl ester.

Results showed that, the brake thermal efficiencies were increased with increase in load with EGR at lower load. B20 SFME with 15% EGR shows 4% increase in brake thermal efficiency at lower load (0-75%) compared to diesel without EGR. The brake specific fuel consumptions were lower for diesel at lower loads operated with EGR when compared to without EGR. At higher engine loads, BSFC with EGR was almost similar to that of without EGR for diesel fuel. Brake specific fuel consumptions were increased with increasing concentration of biodiesel blends when the engine was operated on biodiesel blends with EGR. The brake specific fuel consumptions were increased about 10% for B20 and 15% for B40 sunflower methyl ester blends at full load operation with EGR. With increase in load, exhaust gas temperature also increases. The exhaust gas temperature was found to be lower for
EGR-operated engine with diesel. The temperature of the exhaust gases for B20 and B40 sunflower methyl ester were observed lower than the diesel without EGR. The UBHC increases with increase in load and EGR rate. The 20% and 40% biodiesel blend with 15% EGR gives 5% and 15% lower UBHC emissions with full load compared to diesel with EGR. The CO increases with increase in load and EGR rate. CO emissions of SFME were comparatively lower. Higher values of CO were observed at full load for both diesel and biodiesel fuels with EGR. CO emissions were 10% and 20% lower for 20% and 40% biodiesel blends respectively with full load compared with diesel when the engine was operated with EGR. The degree of reduction in NOx was higher at higher loads. NOx emissions in case of biodiesel blends without EGR were higher than diesel. The 20% and 40% biodiesel blends have 25% and 14% lower NOx emissions respectively with full load when compared to diesel fuel without EGR.

2.5 M. Gomaa, A. J. Alimin, K. A. Kamarudin [5]

Conducted experiments on, the effect of EGR rates on NOx and smoke emissions of an IDI diesel engine fuelled with jatropha biodiesel blends.

Results showed that, the torque output was decreased and deteriorated, when EGR was operated. In fact, the torque losses were considerable with increasing EGR rates, and more visible at higher EGR rates of 20-40%. The torque loss of JBD blends was lower than that of DF, at all EGR rates. The maximum torque loss with applying EGR with JB5 and JB20 was 14.7% and 17.6% respectively, while, it found to be 26.5% with DF, as compared to the baseline value. JBD blends produced higher BTE than that of DF, at all operating conditions. The BTE improved with increasing biodiesel amount in the blends. As an example at 0% EGR, the highest improvement of BTE was achieved with JB20 by 4.6%, compared to the baseline value. At 5% EGR, the BTE of all test fuels improved. At over 5% EGR rate, the BTE started to decrease linearly with increasing EGR rates. At 40% of EGR, the higher reduction in the BTE was observed. The BTE of DF, JB5 and JB20 decreased by 22.3%, 16.4% and 7.4% respectively, compared to the baseline value. At 0% EGR, the BSEC of JBD blends was slightly higher than that of DF. At 5% EGR, the BSFC of all test fuels was lower than that of in case without EGR. At over 5% EGR, the BSFC increased linearly with increasing EGR rates. It increased rapidly, beyond 20% EGR. At 40% EGR, the BSFC of DF, JB5 and JB20 increased by 28.7%, 9.4%, and 7.6% respectively, compared to the baseline value. The BSEC of JB5 blends was lower than that of DF, at all operating conditions. The BSEC increased with increasing EGR rates. At 0% EGR, JB5 blends produced lower EGT than that of DF. In addition, the EGT decreased with increasing biodiesel percentage in the blends. The EGT increased with increasing EGR rates for all tested fuels. The CO emission of JB5 blends was lower than that of DF, at all operating conditions. At 0% EGR, JB5 and JB20 emitted similar rate of CO with 75% reduction, compared to DF. The CO emission increased with increasing EGR rates. At over 20% EGR, CO emission of all test fuels increased rapidly. The CO2 emission increased with increasing biodiesel amount in the blends. The CO2 emission of DF increased slightly, when EGR was operated. While, the CO2 emission from JB5 blends increased rapidly, especially at over 20% EGR. Beyond 20% EGR, the CO2 emission from JB20 blends was higher than that of DF. The higher increase in CO2 emission was observed, at 40% EGR. The CO2 emission of JB5 and JB20 increased by 53.7% and 62.0% respectively, while for DF increased by 21.9% compared to the baseline value. JB5 blends emitted NOX was slightly lower than that of DF, at 0% EGR. The NOX emission increases with increasing combustion temperature. At 0% EGR, the NOX emission of JB5 and JB20 was lower than the baseline value by 23% and 11%, respectively. The NOX emission of all fuels decreased linearly, when EGR was operated. The NOX emission increased with increasing biodiesel amount in the blends. In addition, the NOX emission of JB5 blends was higher than that of DF, especially at higher EGR rates over 20%. The EGT of JB20 blends was lower than that of DF, at all EGR rates. At 40% EGR, the maximum reduction in NOX emission was observed. It was 71% for both JB5 and JB20, while for DF was 79%, compared to the baseline value. The smoke opacity of JB5 and JB20 was 43.8% and 34.5% respectively, while for DF was 62.4%.

2.6 A. Paykani, A. Akbarzadeh, M. T. Shervani Tabar [6]

Conducted experiments on, effect of exhaust gas recirculation on performance and emissions characteristics of a diesel engine fueled with biodiesel.

Results showed that, the brake thermal efficiency decreases with substituting biodiesel. The brake thermal efficiency increases at low EGR ratios for four fuels. Increasing EGR flow rates to high levels resulted in decrease in brake thermal efficiency for both net diesel fuel and COEE blends. The NOx emissions tend to decrease significantly with increase in EGR ratio for all load condition. NOX emissions reduce with increase in EGR flow percentage for both net diesel fuel and COEE blends. UHC emissions decrease as the diesel-COEE blends were used. Increasing EGR flow rate to low level resulted in a slight decrease in UHC emissions. The CO variation follows a close trend with increase in COEE substitution percentage resulting in slight decrease in CO emission. Increasing EGR flow rates to high levels resulted in considerable rise in CO emission for both net diesel fuel and COEE blends.

2.7 S. Ghosh, D. Dutta [7]

Conducted experiments on, the effects of EGR on the performance and exhaust emissions of a diesel engine operated on diesel oil and soybean oil methyl ester (SOME).
Results showed that, the brake thermal efficiencies were increased with increase in load with or without EGR at lower load. Brake thermal efficiency of diesel fuel was higher than SOME at all loading conditions with and without EGR operations. At full load operation the brake thermal efficiency marginally decreases in both cases with the increase of the EGR rate. The specific fuel consumptions were lower for diesel at all loading conditions when operated with EGR and without EGR when compared to SOME. At higher loads of the engine, SOME with 10% EGR was almost same to that of without EGR for diesel fuel but 7.4% higher at full load operation for SOME with 10% EGR.

The biodiesel emits higher NOx than diesel fuel at all loading conditions. The emission of NOx tends to decrease significantly with the increase of EGR rate for all loading conditions for both the fuels. At full load condition NOx emission for diesel and SOME were respectively 796ppm and 880ppm at constant speed of the engine without EGR. Maximum NOx reduction occurs with 10% EGR. At full load condition reduction of NOx for SOME and diesel was respectively 160ppm and 130ppm with 10% EGR. Higher amount of smoke emission was observed in the exhaust when the engine was operated with EGR compared to without EGR in both cases. Smoke emissions increases with increasing engine load and EGR rates. Soybean oil methyl ester (SOME) showed 5.5% lower smoke compared to diesel oil at full load condition when operated without EGR. At full load condition almost same smoke emission was observed for both the fuels with EGR. Hydrocarbon emission increases with the increase in load in the engine. At full load condition SOME emits 12% and 7.5% lower HC than diesel when operated without EGR and with 10% EGR.

2.8 N. Ravi Kumar, Y. M. C. Sekhar, S. Adinarayana [8]

Conducted experiments on, effects of compression ratio and EGR on performance, combustion and emissions of DI injection diesel engine.

Results showed that, at 1/4 load condition with 5% EGR the combustion duration was only 37° of crank angle rotation. With increase in load the combustion duration also increased gradually 39° at 1/2 load 42° at 3/4 load and 46° at full load. At no load the combustion was started at crank angle of 361° and completed at 393° with total combustion duration of 32°. With increase in load the combustion duration was slightly increased. Around 70% of the total charge was burnt in the first 20° of the crank angle rotation and remaining 30% charge was burnt for further rotation of the crank angle. With increase in percentage of EGR the NOx emissions were reduced. At compression ratio 15 and 10% EGR the percentage reduction of NOx was 26.5% and at full load it was 62.5%.

2.9 Kavati Venkateswarlu, Bhagavathula Sree Rama Chandra Murthy, Vissakodeti Venkata Subbarao [9]

Conducted experiments on, effect of exhaust gas recirculation and di-tertiary butyl peroxide on diesel-biodiesel blends for performance and emission studies.

Results showed that, brake thermal efficiency increases up to an optimum value of EGR and then decreases. BTE was also found to be increasing with increase in biodiesel at a given EGR percentage. The combined effect of optimum EGR and DTBP can increase the BTE by 6-7%. Brake specific fuel consumption decreases with increase in EGR and reaches a minimum value at about 10% EGR and then increases slightly up to 20% EGR. Further with increase in biodiesel percentage also BSFC increases. With increase in percentage of EGR as well as biodiesel, the exhaust gas temperatures reduced. The maximum cylinder pressure decreases slightly with the EGR. With the increase in the percentage of EGR, CO increases however the effect of CO emission was found less at higher percentages of biodiesel. Further, the emissions were found rapidly increasing with EGR up to 10% and beyond which there was only an insignificant rise. The combined effect of EGR and DTBP could reduce the NOx emissions significantly. The HC emissions increased slightly from 0% to 10% EGR for all fuels and beyond which there was a reduction. However with the increase in biodiesel percentage, the HC emissions found decreasing. The increase in the smoke opacity was insignificant initially and increases with further increase in EGR which also increases with the increase in percentage of biodiesel.

2.10 Mr. Harshraj Dungar, Prof. Gaurav P. Rathod [10]

Conducted experiments on, combine effect of exhaust gas recirculation (EGR) and varying inlet air pressure on performance and emission of diesel engine.

Results showed that, brake thermal efficiency was found to have decreased with increasing rates of EGR but with increasing inlet air pressure the brake thermal efficiency was increased. BSFC was increased with increasing in EGR rate. But by increasing inlet air pressure with EGR system, BSFC was decreased. The exhaust gas temperature decreases more by increasing inlet air pressure with EGR rate. Emission of HC, CO and CO2 increased with increasing inlet air pressure and EGR rate. NOx was reduced more by combining EGR rate with increasing inlet air pressure.


Conducted experiments on, performance of exhaust gas recirculation (EGR) system on diesel engine.

Results showed that, when brake power of the engine increases, exhaust gas temperature of the engine also increases. The brake power of the engine varies from 1.232 kW to 2.464 kW and exhaust gas temperature varies from 105°C to 129°C with EGR system. The value of exhaust gas temperature of the diesel engine with EGR was less than that of without EGR system at same brake power. When brake power of the engine increases, fuel consumption of the engine also increases. The brake power of the engine varies from 1.232 kW to 2.464 kW and fuel consumption varies from 0.7288 kg/hr to 1.1808 kg/hr with EGR system. The value of fuel consumption of the diesel engine with
EGR was more than that of without EGR system at same brake power. When brake power of the engine increases, brake thermal efficiency of the engine also increases. The brake power of the engine varies from 1.232 kW to 2.464 kW and brake thermal efficiency varies from 14.15% to 17.47% with EGR system. When brake power of the engine increases, emission of carbon monoxide (CO) of the engine also increases. The brake power of the engine varies from 1.232 kW to 2.464 kW and emission of carbon monoxide (CO) varies from 0.03% to 0.04% with EGR system. The value of emission of CO of the diesel engine with EGR was less than that of without EGR system at same brake power. When brake power of the engine increases, emission of carbon dioxide (CO₂) of the engine also increases. The brake power of the engine varies from 1.232 kW to 2.464 kW and emission of carbon dioxide (CO₂) varies from 0.8% to 1% with EGR system. The value of emission of CO₂ of the diesel engine with EGR was less than that of without EGR system at same brake power. When brake power of the engine increases, emission of nitrogen oxide (NOx) of the engine also increases. The brake power of the engine varies from 1.232 kW to 2.464 kW and emission of nitrogen oxide (NOx) varies from 731 ppm to 764 ppm with EGR system. The value of emission of NOx of the diesel engine with EGR was less than that of without EGR system at same brake power. When brake power of the engine increases, the emission of hydro carbon (HC) of the engine decreases. The brake power of the engine varies from 1.232 kW to 2.464 kW and emission of hydro carbon (HC) varies from 19.5 ppm to 17 ppm with EGR system. The value of emission of HC of the diesel engine with EGR was more than that of without EGR system at same brake power.

Conducted experiments on, the effect of EGR rates on performance and emissions of a DI diesel engine fuelled with biodiesel blends. Conducted experiments on, the effect of EGR rates on performance and emissions of a DI diesel engine fuelled with biodiesel blends.

Results showed that, the brake thermal efficiency has been found to decrease by recirculating exhaust gas. The maximum brake thermal efficiency has been found to be 13.34% at 4931.04 W for without EGR condition. Exhaust gas temperature reduces with the application of EGR which in turn reduces the NOx pollutant in the engine emission. The minimum value of exhaust gas temperature was found to be 148°C for a brake power of 4931.04 with 1/4 valve opening for EGR. The brake thermal efficiency has found to increase by injecting the di-ethyl ether. The maximum brake thermal efficiency for a brake power 4931.04 W was found to be 16.52% at 3/4 EGR valve opening. EGT reduces with the application of EGR which in turn reduces the NOx pollutants in the engine emission. The minimum value of exhaust gas temperature was found to be 144ºC for a brake power of 4931.04 W with 1/4 EGR valve opening. The brake thermal efficiency was found to increase by injecting the di-ethyl ether. The maximum brake thermal efficiency at 4931.04 W was found to be 16.74% with 3/4 EGR valve opening. Exhaust gas temperature reduces with the application of EGR. The minimum value of EGT for a brake power of 4931.04 W was found to be 140ºC with 1/4 EGR valve opening. The brake thermal efficiency increases by increasing the EGR valve opening except for neat diesel fuel. The maximum brake thermal efficiency was found to be 16.74% for 20% C₃H₇OH blends at 3/4 EGR valve opening. The least brake thermal efficiency was 11.31 % at 3/4 EGR valve opening which was obtained for neat diesel fuel. The exhaust gas temperature has decreased by recirculating the exhaust gases for all the fuel blends at different EGR valve openings. The minimum exhaust
gas temperature was found to be 140°C for 20% DEE blend at 1/4 EGR valve opening. With the usage of DPF, the PM emission has been decreased at larger rate. The PM emission has been increased with the EGR for neat diesel fuel whereas in the case of 20% di-ethyl ether, it has diminished. The lowest PM emission was found with DPF and DOC for neat diesel fuel at without EGR condition. Overall there has been about 95% reduction in PM emission with the usage of DPF. The NOx emission was dropped to a minimum with the usage of DPF for 3/4 EGR valve opening. There was a significant decrease in NOx emission with the usage of after treatment devices.


Conducted experiments on effect of exhaust gas recirculation on the performance and emission characteristics of CI engine fuelled with diesel – compressed biogas and ROME – compressed biogas. In this work, an experimental work had been carried out to analyze the performance and emission characteristics of diesel engine by varying the EGR of 5% and 10% when fuelled with diesel – CBG and ROME – CBG at 80% and 100% load.

Results showed that, BTE increases with increase in EGR rate. HC emissions were increases with increase in load and EGR rate. The CO emissions were increases with increase in load and EGR rate. NOX decreases with increase in EGR rate. The smoke increases slightly as the EGR rates increases.

III. CONCLUSION

EGR is a very useful technique for reducing the NOx emission. EGR displaces oxygen in the intake air and dilute the intake charge by exhaust gas recirculated to the combustion chamber. Recirculated exhaust gas lowers the oxygen concentration in combustion chamber and increase the specific heat of the intake air mixture, which results in lower flame temperatures. Thus, it can be concluded that higher rate of EGR can be applied at lower loads and lower rate of EGR can be applied at higher load. EGR can be applied to diesel engine fueled with diesel oil, biodiesel, LPG, hydrogen, etc. without sacrificing its efficiency and fuel economy and NOx reduction can thus be achieved.

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