Cold EGR 장착 디젤엔진에서의 NOx 저감에 관한 실험적 연구

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An Experimental Study on NO_X Reduction in a Diesel Engine with Cold EGR

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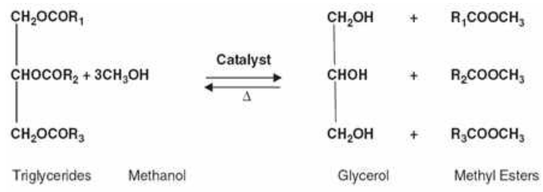
요 약

The objective of the current research work is to investigate the usage of biodiesel combined with the use of EGR in order to reduce the emission of all regulated pollutants from diesel engines. A single cylinder, air cooled, constant speed direct injection diesel engine was used for the experimental work and a cold EGR system was developed and fitted to the engine. Concentrations of HCs, NOx, and CO from the exhaust gas along with the smoke opacity were measured. Engine performance parameters such as the brake thermal efficiency (BTE) and the brake specific energy consumption (BSEC) were also calculated from the measured data. The results from the present investigation suggest that 25-30% EGR rate could give excellent NOx reduction without any significance penalty on smoke opacity or BSEC under the engine load of up to 40%. Under the full load condition, 15% EGR rate was found to be an option while higher EGR rate resulted in inferior performance and heavy smoke.

1. Introduction

Inefficient use of energy led to green house effect, global warming, acid rain, smog, shift in climatic conditions etc. Pollution by the transport in industrial and domestic sectors is increasing by increased consumption of fossil fuel. Environmental concerns and emission norms have led to the development of advanced engine technologies to reduce NOx. Among the green house emissions, NOx is one component and causes smog, acid rain, particles, water quality deterioration, toxic chemicals [1]. Renewable fuels of bio-origin, which are environment friendly, provide improved performance, while being used as diesel substitute and are not harmful to human health. The vegetable oils have comparable energy density, cetane number, heat of vaporization, and stoichiometric air fuel ratio with those of mineral diesel fuel [2]. The flash point of vegetable oils is also very high (above 200ºC). Their heating value is at the range of 39-40 MJ/kg, comparatively lower than that of diesel fuels (about 45 MJ/kg). The cloud and pour point of vegetable oils is higher than that of diesel fuel [3]. Among these potential plant alternatives, Jatropha curcas has the highest potential for use as diesel fuel. The present study was undertaken to evaluate the potential suitability of Jatropha oil in a diesel engine. Biodiesel has similar physical and thermal properties compared to conventional diesel fuel; the detail is shown in Table 1. Biodiesel is compatible with conventional diesel and can be blended in any proportion with petroleum diesel to produce a stable blend. Transestrification is a reversible reaction of fat or oil (triglyceride) with a primary alcohol to form esters and glycerol. R1, R2, and R3 are the alkyl groups of different carbon chain lengths (varying between 12 and 18) and -COO- is a carboxyl group [4]. Alcohol combines with the triglycerides to form glycerol and esters. The reaction is shown in Fig.1.

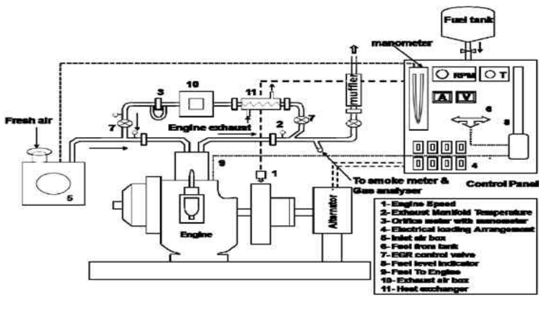


[Fig. 1] Typical transestrification reaction.

EGR is an effective method for NOx control, The exhaust gases mainly consist of inert carbon dioxide and nitrogen, and they 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. The higher NOx emission can be effectively controlled by employing EGR [5]. Considering the fact the following objectives were envisaged for the present research work. Comprehensive literature survey and development of experimental diesel engine test rig also development of exhaust gas recirculation system for cooled EGR.

[Table 1] Selected fuel proprties for petro diesel & biodiesel

Fuel Property	Petro diesel	Biodiesel
Fuel Standard	ASTM D975	ASTM PS121
Fuel Composition	C10-C21 HC	C12-C22 FAME
Lower Heating Value, Btu/gal	131,295	117,093
Kin. Viscosity, @40 °C	1.3-4.1	1.9-6.0
Specific Gravity, kg/l @ 60 F	0.85	0.88
Density, lb/gal @ 15 °C	7.079	7.328
Water, ppm by wt.	161	0.05% max.
Carbon, wt%	87	77
Hydrogen, wt%	13	12
Oxygen by dif. wt%	0	11
Sulphur, wt%	0.05 max	0.00-0.0024
Boiling Point, °C	188-343	182-338
Flash Point, 0 °C	60-80	100-170
Cloud Point, 0 °C	-15 to 5	-3 to 12
Pour Point, 0 °C	-35 to -15	-15 to 10
Cetane Number	40-55	48-65
Stoichometric air/fuel ratio	15	13.8



[Fig. 2] Schematic Line Diagram of Test Rig

Determination of EGR rates was done for conducting exhaustive experiments on the test rig to evaluate performance and emission characteristics of biodiesel and diesel with and without EGR and compare with base line data of diesel.

2. Testing procedure

A single cylinder, air cooled, direct injection diesel engine made by Kirloskar was selected for the present research work. AVL 437 smoke meter and AVL Di gas analyzer were used for emission measurement. The schematic diagram of the experimental setup with EGR along with all instrumentations is shown in Fig. 2

3. Results and Discussions

3.1 Thermal Efficiency

From Fig. 3 it was observed that initially with increasing brake power, the brake thermal efficiencies of all the fuels were increased and then tended to decrease with further increase in brake power. Thermal efficiency is found to be slightly increased with EGR at lower engine

[Table 2] Specifications of the Diesel Engine

Maker	Kirloskar
Model	DAF 8
Rated Brake Power(bhp/kW)	9.6/7
Rated Speed (rpm)	1500
Number of Cylinder	One
Number of Cylinder	102 x 110
Rated Speed (rpm)	17.5:1
Cooling System	Air Cooled(Radial cooled)
Lubrication System	Forced Feed
Cubic Capacity	0.948 Lit
SFC at rated hp/1500rpm	251 g/kwh(185 g/bhp-hr)
Inlet Valve Open (Degree)	4.5 BTDC
Inlet Valve Closed (Degree)	35.5 ABDC
Inlet Valve Closed (Degree)	35.5 BBDC
Exhaust Valve Closed (Degree)	4.5 ATDC
Fuel Injection Timing (Degree)	26 BTDC

loads. The possible reason may be attributed to the re-burning of HCs that enters the combustion chamber with the recirculated exhaust gases. At higher engine loads thermal efficiency remains unaffected by EGR. When the engine was operated on biodiesel blends with EGR, the thermal efficiency improved with increasing concentration of biodiesel in the blend. This may be possibly due to the improved thermal efficiency observed with oxygenated fuels. An important observation is that all biodiesel blends have higher thermal efficiency than the baseline data.

3.2 Brake Specific Energy Consumption

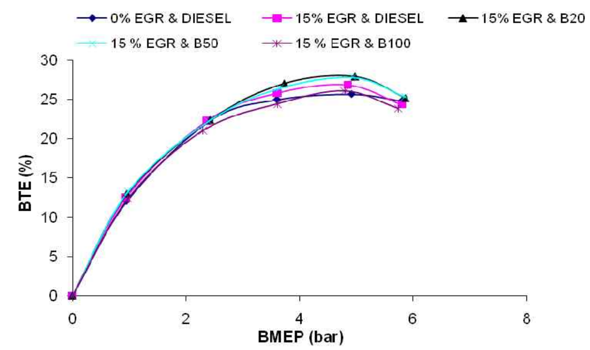
From Fig. 4 it can be observed that BSEC was lower for diesel with EGR compared to the baseline data at lower loads. But at higher loads the BSEC with and without EGR follows the same trend. When the engine was operated on biodiesel blends, the BSEC reduced with increasing concentration of biodiesel. A possible reason for lower BSEC may be better thermal efficiency. The 50% biodiesel blend gave the lowest BSEC with EGR. For neat Biodiesel with and without EGR, the BSEC was higher than the baseline data at lower loads. At higher loads, the engine followed an almost similar BSEC trend for all data sets, in which the BSEC continue increasing with increasing EGR rates.

3.3 NOx Emissions

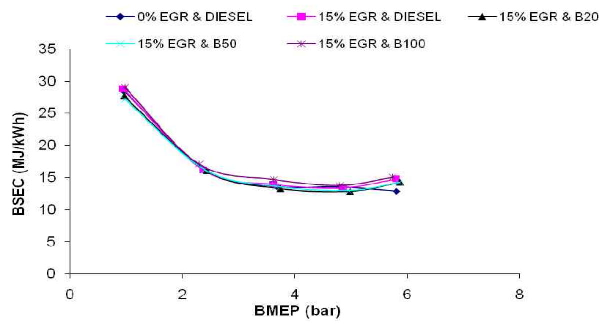
From Fig. 5, the NOx emissions increased with the increasing engine load, due to higher combustion temperature. This proves that the most important factor for the emission of NOx is the combustion temperature in the engine cylinder and the local stoichiometric of the mixture. Here it was observed that diesel with 15% EGR rate gave the lowest NOx emission as compared to the other test fuel samples. This is due to the presence of inert gases in combustion chamber and the unavailability of molecular oxygen.

3.4 Carbon Monoxide Emission

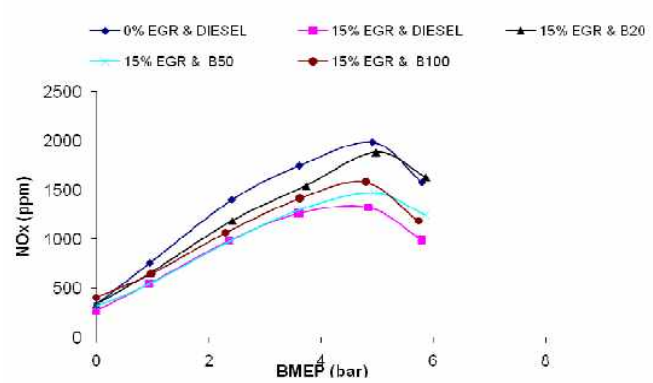
In this experiment CO and HC emissions are measured to check the completeness of combustion inside the cylinder (Fig.6). The steep rise in CO emission at full load is probably due to the dilution effect of exhaust gases and lower air fuel ratio. It was observed that diesel and B20 at 15% EGR rate gave maximum CO emission, which is probably due to the oxygen deficient operation. Here it is important to note that with 15% EGR rate the combustion quality deteriorates faster.



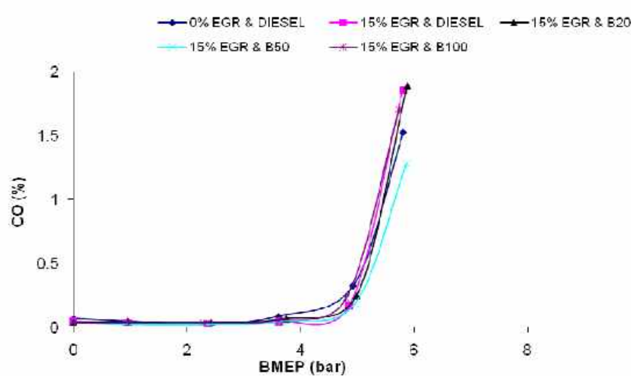
[Fig. 3] Variation of BTE Vs BMEP for different fuels with 15% EGR rate.



[Fig. 4] Variation of BSEC Vs BMEP for different fuels with 15% EGR rate.



[Fig. 5] Variation of NOx Vs BMEP for different fuels with 15% EGR rate



[Fig. 6] Variation of CO Vs BMEP for different fuels at 15% EGR rate

3.5 Un-burnt Hydro Carbon Emissions

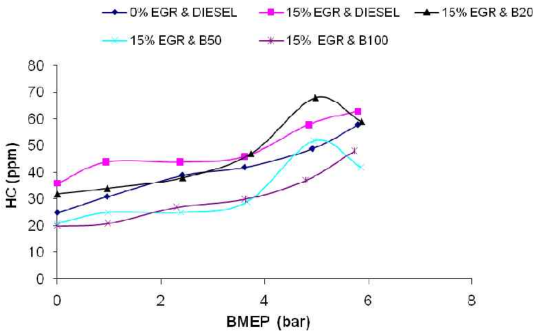
From Fig. 7 graphs show that HC emissions increase with the EGR rate and the load. The HC emissions of all the fuels are lower in partial engine loads, but increases at higher engine loads. The possible reason may be lower excess oxygen available for combustion. Lower excess oxygen concentration results in poor air-fuel mixtures at different locations inside the combustion chamber. This heterogeneous mixture does not combust properly and results in higher HC emissions. Application of EGR shows slight reduction in HC emission than without EGR. This trend followed up to 15% EGR rate. This is due to reburning of HCs in combustion chamber.

4. CONCLUSIONS

The main objective of the present investigation was to evaluate suitability of EGR system for reduction of oxides of nitrogen (NOx) of biodiesel fueled diesel engine and to evaluate the performance and emission characteristics of the engine with emission at different EGR rates.

With the application of EGR, the overall engine performance and emission characteristics with biodiesel and its blends are slightly better than the diesel fuel. Although the BTE was lower and BSEC was higher without EGR, however, in the case of EGR these parameters became superior to diesel fuel. Without EGR, NOx emission of biodiesel was higher than diesel. With increasing EGR rates, the degree of reduction in NOx at higher loads was higher. With and without application of EGR, CO, HC and smoke opacity from the biodiesel and its blends was found lower than diesel fuel during the whole experimental range.

From the present experimental study it can be suggested that at low loads more than 15% EGR rates can be employed but at higher loads maximum EGR rate should be limited to 15% to obtain better results from EGR system.



[Fig. 7] Variation of HC Vs BMEP for different fuels at 15% EGR rate.

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