Experimental Investigation of the Effect of Exhaust Gas Recirculation on Performance and Emissions Characteristics of a Diesel Engine Fueled with Biodiesel

A. Paykani, A. Akbarzadeh and M. T. Shervani Tabar

***Abstract*—An effort has been taken to study performance and emission characteristics of a diesel engine fueled with biodiesel and diesel fuel using EGR. All the experiments were conducted on a single-cylinder, four-stroke, water cooled, indirect injection (Lister 8-1) diesel engine at the engine full load operation and constant engine speed of 730 rpm. The results obtained with biodiesel (canola oil ethyl ester) were compared with the diesel fuel as reference fuel. The engine performance and efficiency obtained in biodiesel case were less, which could be attributed to lower calorific value of biodiesel. CO and UHC emissions for biodiesel were lower than that of diesel fuel. However, it was observed that NOx emissions for biodiesel were higher than that of diesel fuel. Exhaust gas recirculation (EGR) is a very effective technique to reduce NOx emissions from a diesel engine. In this study the venturi type EGR system was used. When similar percentages (%by volume) of exhaust gas recirculation (EGR) were used in the cases of diesel and canola oil ethyl ester, NOx emissions were considerably reduced to lower values.**

***Index Terms*—Canola oil ethyl ester; Biodiesel; Diesel engine performance; Exhaust emissions; Exhaust Gas Recirculation (EGR).**

I. Introduction

National interest in generating alternative fuels for internal combustion engines continues to be strong due to fulfill the energy demand of the world. The search for energy independence and concern for a cleaner environment have generated significant interest in biodiesel, despite its shortcomings. Biodiesel is an alternative diesel fuel which can be obtained from the transesterification of vegetable oils or animal fats and methyl or ethyl alcohols in the presence of a catalyst (alkali or acidic). An important property of biodiesel is its oxygen content of about 10%, which is usually not contained in diesel fuel. Biodiesel fuels have been recently stood out due to some important advantages such as requiring little or no modification for use in diesel engines. Moreover, they are non-toxic, have higher biodegradability and contain almost no sulphur [1]. Its shortcomings include increased NO_x emissions in the engine exhaust, poorer cold-flow properties, and shorter shelf life compared with petroleum diesel [2]. The combustion of biodiesel fuel in compression ignition (CI) engines in general results in lower smoke, particulate matter, carbon monoxide and hydrocarbon emissions compared to standard diesel fuel combustion while the engine efficiency is either unaffected or improved [3]. Numerous studies have been carried out to evaluate performance and emission characteristics of diesel engines fueled wit biodiesel. Strayer et al. [4] investigated the feasibility of using degummed canola oil and high erucic rapeseed oil as diesel fuel substitutes in small and large diesel engines. They reported that specific fuel consumption and particulate matter with these oils were higher and concluded that the engine performance is better with degummed canola oil when compared with crude canola oil for 25 hour of operation. Öztürk and Bilen [5] studied canola oil methyl ester and its blends with diesel fuel as a fuel in a direct injected diesel engine and they concluded that the NO_x emissions was slightly increased and smoke opacity was reduced. Soguzü et al. [6] investigated the effect of canola oil ethyl ester and diesel fuel on engine performance and exhaust emissions. Results revealed that the engine torque and power were reduced. Carbon monoxide emission was decreased with the use of biodiesel. The NO_x emissions of biodiesel were higher compared to diesel fuel. Ladommatos et al. [7] tested the effect of exhaust gas recirculation on diesel engine emissions. They noticed a large reduction in NO_x emissions at the expense of higher particulate and un-burnt hydrocarbon emissions.

Exhaust gas recirculation (EGR) is one of the most effective methods for reducing NO_x emissions of diesel engines. EGR system has already been used to mass - produced diesel engines, in which EGR is used at different loads of engine operating condition, resulting in effective NO_x reduction [8]. Introduction of EGR has combinations of some these effects [9]:

1) Depletion of oxygen in the intake charge
2) Increased intake temperature due to mixing with EGR
3) Increased specific heat of intake charge
4) Recycling of unburned hydrocarbons (opportunity for re-burn)

In order to meet future emission standards, EGR must be done over wider range of engine operation, and heavier EGR rate will be needed. Thus, using a specific device to expand EGR area is necessary. In this study, the venturi type EGR system was selected, because it is rather effective for expanding the EGR range [10]. In this study, the combined effects of canola oil ethyl ester with the incorporation of exhaust gas recirculation (EGR) on the engine performance and emission characteristics are analyzed and compared with the results obtained from the engine operating on net diesel.

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II. Experimental Setup and Procedure

An experimental investigation was carried out to investigate the effect of exhaust gas recirculation on performance and emission characteristics of a diesel engine fueled with biodiesel. The engine used for the investigation was a single-cylinder, four-stroke, water cooled, indirect injection (Lister 8-1) diesel engine. The technical specifications of the engine are given in Table I, and the schematic of the experimental setup is shown in Figure 1. The engine is supplied with canola oil ethyl ester and diesel fuel which some of their properties are given in Table II. The power output of the engine was measured by an electrical dynamometer. The exhaust emissions HC, CO, CO_2 and NO_x were measured by AVL 4000 exhaust gas analyzer. Table III shows the accuracy of the measurements and the uncertainty of the computed results of the various parameters. It can be seen that the uncertainty ranges from 0.7% to 5%.

Table I. General Specifications of Lister (8-1) Diesel Engine

Item	Specification
Type	Four Stroke
Number of Cylinders	1
Combustion System	IDI
Bore	114.1 mm
Stroke	139.7 mm
Swept Volume	1.43 Lit
Compression Ratio	17.5:1
Max. power hp/rpm	8/850
Injection Pressure	91.7 kg/cm^2
Injection Timing	20^0 BTDC

A. EGR System

The EGR system used with the test engine was the type that exhaust gas was recirculated back into the inlet manifold where it mixes with air and gets diluted with the intake charge which in turn acts as a diluents and reduces the peak combustion temperature inside the combustion chamber. It included a control valve, pipes and venturi as shown in Figure 2. To measure the amount of EGR, the parameter EGR ratio was considered. The EGR ratio is defined by [11]

$$\%EGR = \frac{\%CO_2(inlet)}{\%CO_2(outlet)} \times 100 \quad (1)$$

B. Test conditions examined

The engine was operated for the full load condition using different D-COEE mixtures along with various EGR flow rates to study the performance and emission characteristics of the engine at a constant speed of 730 rpm. For all engine conditions, diesel, pure biodiesel (COEE) and two D-COEE blends (B20 and B50) were examined. Table IV shows the percentages of diesel and COEE by volume and by mass in the different fuel blends. After allowing the engine to reach steady state conditions for about 20 min, performance and emission parameters were measured. The results regarding emissions and engine performance obtained with B20, B50 and B100 were compared with that of diesel at the same engine operating condition.

Table II. Fuel Specifications of Canola Oil Ethyl Ester and Diesel Fuels

Property	Method	Diesel Fuel	Canola oil ethyl ster (COEE)
Cetane number	ASTM D613	54.8	61.3
Density at 15^{o}C (kg/m^3)	ASTM D4052	852.2	877.5
Viscosity at 20^{o}C (mm^2/s)	ASTM D445	2.7	4.6
50%Distillation (^{o}C)	ASTM D86	285	355
90%Distillation (^{o}C)	ASTM D86	344	362
LCV (MJ/kg)		43.3	39.5
Sulphur (mg/kg)	ASTM D2622	59	12

III. Results and Discussion

A. Brake thermal efficiency

Figure 3 shows the variations of brake thermal efficiency for four fuels with different EGR flow rates at full load. The brake thermal efficiency decreases with substituting biodiesel. The calorific value of biodiesel was lower than that of the diesel fuel, so, there was a slight reduction in the brake thermal efficiency [1]. Moreover, the high viscous oil causes injector coking and contaminates the lubricating oil. On the other hand, the brake thermal efficiency increases at low EGR ratios for four fuels. The increase in thermal efficiency for low EGR ratios is due to the recirculation of active radicals from EGR that makes the combustion process to be enhanced, so resulting in an improvement in brake thermal efficiency. However, increasing EGR flow rates to high levels resulted in decrease in brake thermal efficiency for both net diesel fuel and COEE blends. The reduction in thermal efficiency is due to the high EGR ratios that results in deficiency in oxygen concentration in combustion process and larger replacement of air by EGR. The higher specific heat capacity of both CO_2 and H_2O and high flow rates of EGR reduces the average combustion temperature in the combustion chamber resulting in the brake thermal efficiency to reduce at high EGR flow rates.

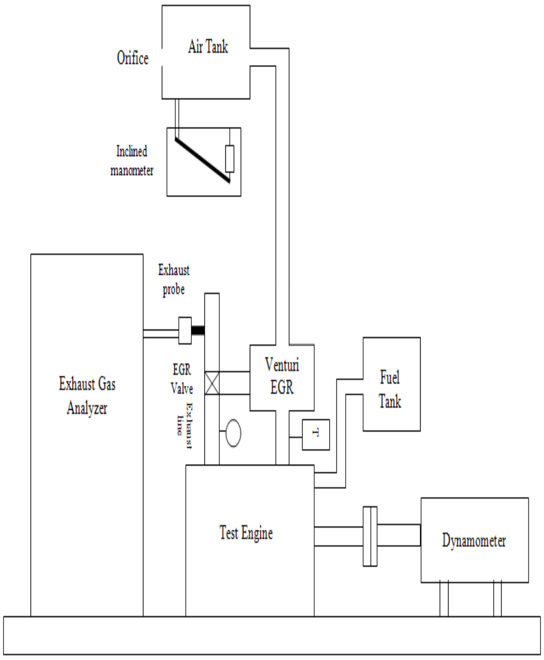

Fig. 1. Schematic diagram of experimental setup

TABLE III. AVERAGE UNCERTAINTIES OF SOME MEASURED AND CALCULATED PARAMETERS

S. no	Parameters	Uncertainty (%)
1	Speed	1.1
2	Time	0.8
3	Mass flow rate of air	1.6
4	Mass flow rate of fuel	3.9
5	Load	0.7
6	Oxides of nitrogen	2.2
7	Unburned hydrocarbons	2.8
8	Carbon monoxide	3.4
9	EGR rate	5

Fig. 2. Photographic view of the venturi EGR system on the intake manifold

TABLE IV. DIESEL AND COEE VOLUME AND MASS PERCENTAGES OF THE TESTED FUEL MIXTURES

Fuel	Diesel volume (%)	Diesel mass (%)	COEE volume (%)	COEE mass (%)
Diesel	100	100	0	0
B20	80	78.6	20	21.4
B50	50	48.2	50	51.8
COEE	0	0	100	100

B. Oxides of nitrogen

Figure 4 depicts the variation of NO_x emissions for four fuels with different EGR flow rates at full load. Generally, biodiesel produces higher NO_x emissions than diesel fuel.

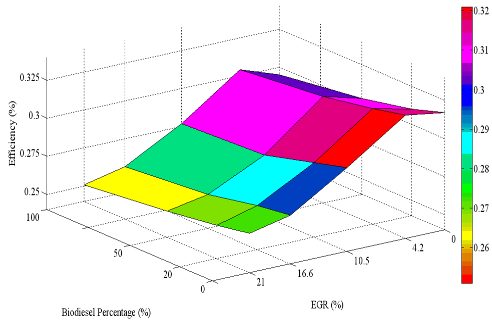

Fig. 3. Variation of brake thermal efficiency for net diesel, COEE and diesel-COEE blends with different EGR flow rates.

The oxygen content of biodiesel is an important factor in the high NO_x formation levels, because oxygen content of biodiesel provides high local peak temperatures and a corresponding excess of air [12]. Therefore, the higher NO_x emissions can be attributed to the more complete combustion of the biodiesel with presence of more oxygen in the combustion chamber [13]. On the other hand, the NO_x emissions tend to decrease significantly with increase in EGR ratio for all load condition due to the rise in total heat capacity of combustion chamber charge by EGR, which lowers the peak combustion temperatures. As shown in Figure 4, NO_x emissions reduce with increase in EGR flow percentage for both net diesel fuel and COEE blends, this is due to the fact that presence of inert gases such as CO_2 and H_2O in the combustion chamber reduces the peak combustion temperature, and also it replaces the oxygen in the combustion chamber. As a result of reduction in both parameters the NO_x decrease with EGR.

C. Unburned hydrocarbons

The variation of UHC emissions for four fuels with different EGR flow rates at full load is shown in Figure 5. It is obvious that UHC emissions decrease as the diesel-COEE blends were used. Several reasons have been proposed to explain the decrease in HC emission when substituting conventional diesel by biodiesel. Rakopoulos et al. [14] have concluded in their review work that UHC emissions decrease as the oxygen in the combustion chamber increases, either with oxygenated fuels such as biodiesel or oxygen-enriched air. On the other hand, increasing EGR flow rate to low level resulted in a slight decrease in UHC emissions. One reason for this is that a portion of the unburned gases in the exhaust from the previous cycle is recirculated and burned in the succeeding cycle. Furthermore, the presence of radicals can help to initiate the combustion process, especially with increase of intake charge temperature due to mixing with exhaust gases. Also, UHC variation follows a close trend with increase in EGR ratio resulting in increase in UHC emissions. The increase in UHC emissions is due to the reduction in oxygen concentration in the inlet charge by the EGR introduced into the cylinder which makes the UHC emissions to increase.

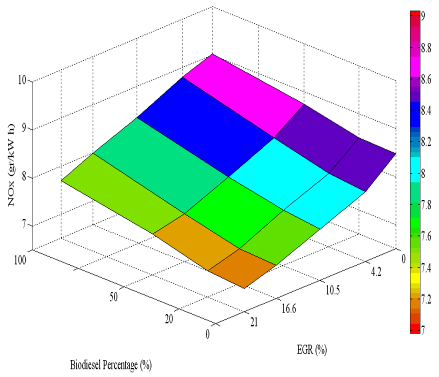

Fig. 4. Variation of oxides of nitrogen for net diesel, COEE and diesel-COEE blends with different EGR flow rates.

D. Carbon monoxide

Figure 6 portrays the variation of CO emission for four fuels with different EGR flow rates at full load. The CO variation follows a close trend with increase in COEE substitution percentage resulting in slight decrease in CO emission. This may be due to the more complete combustion of biodiesel according to the presence of more oxygen in the combustion chamber. Increasing EGR flow rates to high levels resulted in considerable rise in CO emission for both net diesel fuel and COEE blends.

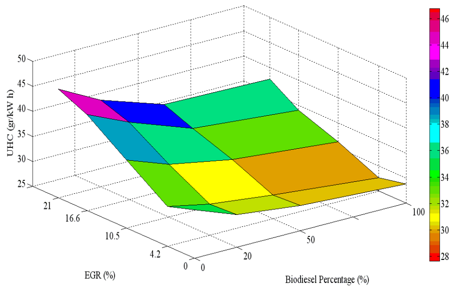

Fig. 5. Variation of unburned hydrocarbons for net diesel, COEE and diesel-COEE blends with different EGR flow rates.

This is due to the fact that high EGR flow rates results in deficiency in oxygen concentration in combustion process and incomplete combustion which tend to increase CO emission.

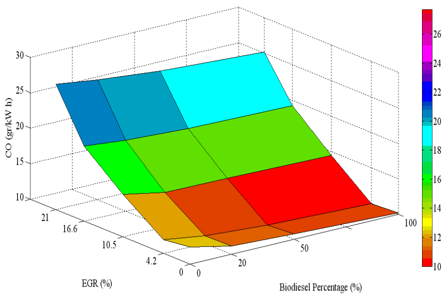

Fig. 6. Variation of carbon monoxide for net diesel, COEE and diesel-COEE blends with different EGR flow rates.

IV. Conclusions

In this paper, an experimental investigation was carried out on Lister (8-1) diesel engine using diesel fuel, B20, B50 and B100 with exhaust gas recirculation. The effect of blending biodiesel (canola oil ethyl ester) on emissions and efficiency were analyzed. The results of this study may be summarized as follows:

1. When the engine uses biodiesel, the brake thermal efficiency decreases due to the lower calorific value of biodiesel compared to net diesel fuel. It is also stated that he engine performance was inferior when using diesel-COEE blend. The brake thermal efficiency increases at low EGR ratios for four fuels. However, increasing EGR flow rates to high levels resulted in decrease in brake thermal efficiency for both net diesel fuel and COEE blends.
2. It is observed that the NO_X emissions increase directly with increasing biodiesel percentage. Using EGR was an effective technique to reduce the NO_X emissions. The NO_X emissions were decreased with increase in EGR flow percentage for both net diesel fuel and COEE blends.
3. The emissions of CO and UHC were found to be lower with increasing biodiesel percentage. Using slight amount of EGR resulted in a trivial decrease in HC and CO emissions. However, Increasing EGR flow rates to high levels resulted in considerable rise in CO and HC emissions for both net diesel fuel and COEE blends.

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