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Performance and Emissions of a Tractor engine operating on biodiesel-diesel blends with EGR

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ABSTRACT

The influences of different diesel/biodiesel blends and EGR rate on brake specific fuel consumption (BSFC), exhaust gas temperature, NO, HC, CO emissions, are studied and demonstrated. In this paper a four stroke direct injection, water cooled, diesel engine was used. Biodiesel either in neat form or as a blend with diesel fuel is extensively investigated to solve the twin problem of reduction of fossil fuels and ecological degradation. Exhaust gas recirculation (EGR) is an impressive technique for decreasing NO emissions. When EGR is utilized in engine, NO emission is decreased. If the engine was fueled with biodiesel-diesel blends, the BSFC would increase due to the lower brake power produced and It was found that BSFC increased with increase in EGR rates. Engine power and torque decreases through the use of biodiesel fuel blends. The results showed that B0 stands on the top level of power and B50 is at the lowest level. Reduction in exhaust gas temperature was observed but emissions of HC and CO were found to be increased with usage of EGR.

1) Introduction

Today, air pollutants emitted by diesel vehicles such as nitrogen oxide (NO_x) and unburned hydro carbons (UHC) have created serious air pollution problems in major cities around the world. Regulations and control measures aimed at lowering exhaust emissions from truck and bus diesel engines have been adopted in an effort to improve air quality in cities. Biodiesel fuels derived from vegetable oils are alternative to diesel fuels for diesel engines. The use of biodiesel fuel in diesel engines does not require any engine modification. It is achieved by forming triglycerides through the transesterification process [1].The transesterification is the process of removing glycerides and combining oil esters of vegetable oil with alcohol. Physical and chemical processes within a diesel engine such as injection timing, fuel vaporization, and ignition delay are changed with the use of biodiesel fuel compared to petroleum diesel fuel. The differences in chemical composition and configuration between the fuels manifest such differences in engine processes, which ultimately lead to differences in engine parameters (combustion, performance and emissions). Lower heating value, lower volatility, higher viscosity and higher production costs are some of the biodiesel's negative attributes [2]. Biodiesel produces significantly lower emissions of particulate matters (PM), carbon monoxide (CO) and hydrocarbon (HC) [3, 4, 5, 6]. To obtain lower NO_x emissions, exhaust gas recirculation (EGR) can be utilized with biodiesel fuels in diesel engines. EGR is an impressive technique for decreasing NO_x emissions from diesel engine exhaust [4,7]. The reduction in NO_x emissions with the increase of EGR rate is the result of:

- Increase of inlet heat capacity due to higher specific heat capacity of recirculated CO_2 and H_2O compared to O_2 and N_2 (at constant boost pressure) resulting in lower gas temperatures during combustion [8,9].
- Reduction of inlet O_2 concentration, whose main task is slowing the mixing between O_2 and fuel resulting in the extension of flame region. Thus, the amount of gas that absorbs heat release increases, resulting in a lower flame temperature [8,9]

Regulating the NO_x emissions, mainly, involves decreasing the in-cylinder temperatures [10, 11].The application of EGR increases HC, CO, and particulate matter (PM) emissions along with slightly higher specific fuel consumption [6]. An examination was managed on a single cylinder DI diesel engine and performance and emission characteristics with rice bran methyl ester (RBME) and its blends as fuel with EGR systems were observed [10]. They reported that a 20% biodiesel blend with 15% EGR produced less NO_x, CO and HC emissions and also enhanced thermal efficiency while decreasing BSFC. The performance of a single cylinder DI diesel engine was investigated with Jatropha oil methyl ester biodiesel (JBD) with hot EGR [25]. They found that an optimized EGR of 15% resulted in sufficient reduction of NO_x emissions with minimum probability of smoke, CO, UBHC emissions. Increased EGR rates produced more NO_x emissions. A test was executed on a DI diesel engine with hydrogen utilized as a dual fuel mode with EGR technique, in which results showed an increase in brake thermal efficiency and lower smoke levels, particulates and NO_x emissions due to the absence of carbon in hydrogen fuel [12]. Another study examined a naturally aspirated, single cylinder DI diesel engine with several rates of EGR, fuel injection pressures, injection timing and intake gas temperatures, finding that the NO_x reduction ratio has a strong positive correlation with oxygen concentration. This means that the increased oxygen concentration is increased NO_x. They proposed that for a given level of oxygen concentration, the cooled EGR reduces more NO_x with low EGR rates than hot [7]. A 3D-multi dimensional pattern was used to study the effect of EGR temperature on a turbocharged DI diesel engine with three different engine speeds [11]. They reported that high EGR temperature caused reducing the engine brake thermal efficiency, increasing peak combustion pressure, reducing air fuel ratio and increasing soot emissions. In this study the integrated effects of utilization of waste cooking oil (WCO) biodiesel fuel combustion with the exhaust gas recirculation (EGR) to decrease NO_x emissions and engine performance and emissions of a tractor diesel engine are examined and compared with the results achieved from the engine operating on petroleum-based diesel fuel [12].

In this study the influences of diesel/biodiesel mixtures and EGR rate on performance and emission is studied.

2) Fuel preparation

Fuels used in this investigation were pure conventional diesel fuel available in Iran and the main material of biodiesel was restaurant waste frying oil which was converted to methyl ester (biodiesel) with the transesterification method in accordance with the international standards. The biodiesel fuel blends are prepared based on volume percentage (B0D100, B10D90, B20D80, and B50D50). The letter "D" stands for "diesel fuel" and the letter "B" stands for biodiesel. For example B20D80 means that the blend contains 80% diesel fuel and 20% biodiesel. A number of important properties of diesel fuel and biodiesel were also measured. The basic properties of the fuels are shown in Table1.

3) Experimental setup and measurements

Figure 1 exhibits a schematic set up of the diesel engine testing device used for investigating engine performance and emissions. Figures 2-4 shows Tractor, dynamometer and EGR setup and emission analyzer at workshop. The research was performed on a naturally aspirated, water-cooled, 4-cylinder, direct-injection diesel engine. The characteristics of the engine are shown in Table 2.

Table 1: Properties of diesel fuel and biodiesel

Fuel analysis	Method	WCO biodiesel	Diesel fuel
Density@15°C (g/cm3)	ASTM D4052	0.880	0.845
Kinematic viscosity 40°C (CST)	ASTM D445	5.48	2.8
Cetane number	ASTM D613	60	57
Lower calorific value (KJ/kg)	-	38730	42570
Flash point (°C)	ASTM D92	176	64
Cloud point (°C)	ASTM D2500	-1	2
Pour point (°C)	ASTM D97	-4	0
Free glycerin (%mass)	ASTM D6584	0.016	0.01

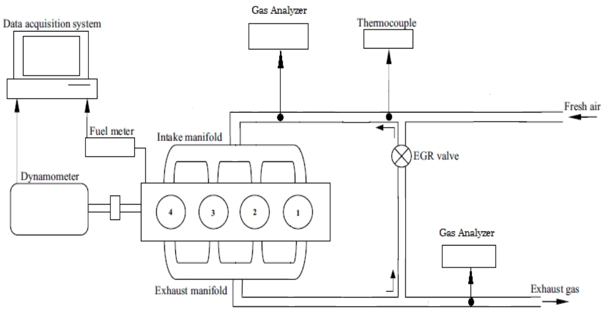

Figure 1: Experimental Setup

Figure 2: Tractor and Dynamometer setup

Figure 3: Emission Analyzer

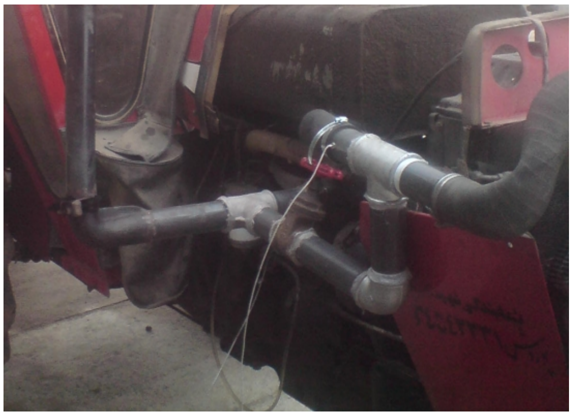

Figure 4: EGR setup

Exhaust gas temperatures were calculated by applying resistance temperature detectors (RTD's) and K-type thermocouples throughout the experiments. To measure power and torque, a NJ-Froment XT-200 dynamometer was used. The power and torque of the dynamometer were measured automatically by applying a magnetic field. During all tests, ambient conditions such as temperature and pressure were measured and recorded. Experiments were performed at 5°C and pressure of 0.814 atm. FOFEN FGA-4100-4G automotive emission analyzer was used to measure emissions. The measurement capabilities, units and precision of this system are presented in Table 3. The gas analyzer consisted of a sensor that was placed in the exhaust as well as a sensing device placed in the center of the chamber to provide good contact with the smoke. The quantity of EGR could be regulated by a control valve installed in the EGR loop. The data for HC, NO, CO, CO2 exhaust gas temperatures, and fuel consumption was recorded. The engine performance and emission patterns were then analyzed. The optimum EGR rate was found on the basis of performance and emissions of the engine. Then the engine was run with and without EGR. The percentage of recycled gases is usually described by an EGR ratio, i.e. the mass ratio of recycled gases to the whole engine intake. The fresh air intake includes insignificant amounts of CO_2 while the recycled portion carries a substantial amount of CO_2 that increases with the EGR flow rate and engine loads. CO_2 is just a combustion product hence, it is intuitive and feasible to measure EGR ratio by comparing the CO_2 concentrations between the exhaust and intake of the engine [8, 25, and 24].

Table 2: Engine specifications

Model	A4-248
Number of cylinders	4
Cylinder stroke	127ml
cylinder diameter	101mm
Maximum power	75 kW/2000 rev/min
Maximum torque	278 Nm/1300 rev/min
Compression ratio	16.0 : 1
Cylinder volume	4.06 lit

4) Test method

The results of diesel-biodiesel fuel blends on engine performance and emissions were compared whit diesel fuel. The engine was run at several speeds (1500-1700 rpm). Torque, power, specific Fuel Consumption and emissions were measured for the performance analysis. Each test was repeated three times to ensure the reliability of the data. The engine was gradually loaded. And the speed was automatically reduced as the load increased. This study included three variable engine speed, percent biodiesel and EGR rate. Also Average values obtained at five different speeds were considered.

Table 3: Properties of gas Analyzer.

Measurable	Unit	Limits	Accuracy
Hydrocarbons (HC)	ppm	0-9999	1
Carbon monoxide (CO)	Vol %	0-9.99	0.01
Carbon dioxide (CO2)	Vol %	0-20	0.1
Oxygen (O2)	Vol %	0-25	0.01
Nitrogen monoxide (NO)	ppm	0-5000	1

5) Results and discussion

After the engine reached the stable working condition for each test, power, torque, specific Fuel Consumption and exhaust emissions were measured and analyzed.

Experimental results of the engine power, using conventional diesel and biodiesel fuel blends and average changes for the engine power at all engine speeds is presented in Figure 5. It can be seen from figure 2 that engine power decreases through the use of biodiesel fuel blends. The results showed that B0 stands on the top level of power and B50 is at the lowest level. Some researchers have reported that engine power is increased when using biodiesel-diesel blends. They reported that due to the improved combustion of biodiesel due to high oxygen content the power increases.

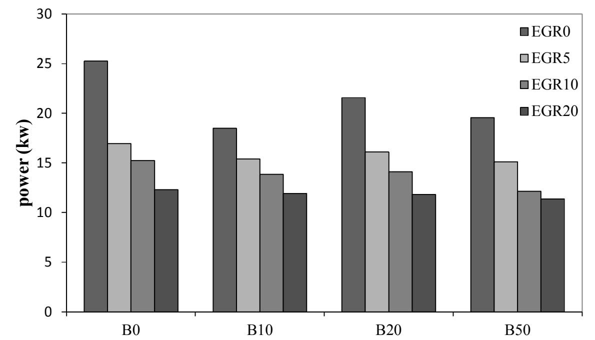

Figure 5: Variation of power for diesel and diesel-waste cooking oil blends with different EGR flow rates (Mean Statistic=15.6, Std. Deviation=7.29)

In this study, reduce in engine power could be due to the lower hating value of the fuel blends [3, 9]. The power and torque output was reduced when EGR was activated. The reason lead to reduce the power and torque output is the decrease in combustion work. The decrease in combustion work could be due to the lower combustion temperatures and reduction in air-fuel ratio (AFR) as a result of EGR use.

As shown in figure 6 engine torques of biodiesel blends is lower than the net diesel fuel. As can be seen, the engine torque reduces when using biodiesel blends. Similar to engine power, the reduction in engine torque could be due to the lower hating value of the fuel blends [3, 9].

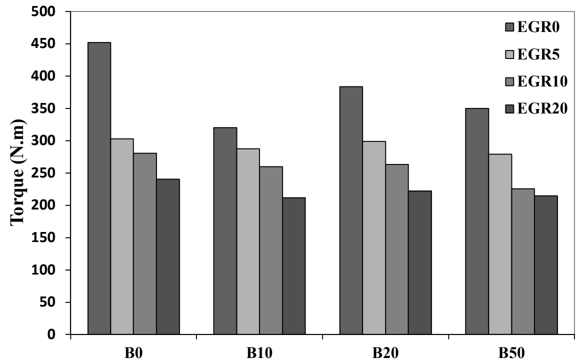

Figure 6: Variation of torque for diesel and diesel-waste cooking oil blends with different EGR flow rates (Mean Statistic=287.04 Std. Deviation=133.23)

The influences of the diesel–biodiesel fuel blends on BSFC are showed in Figure 7.

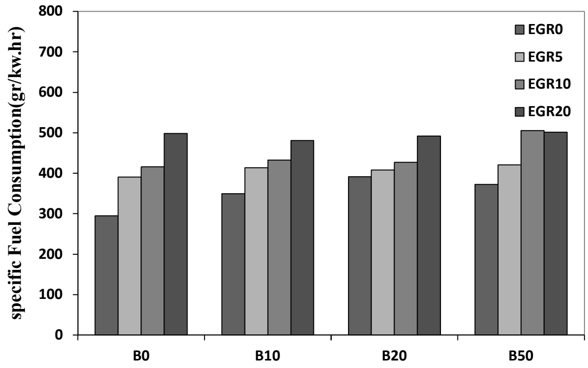

Figure 7: Variation of Specific Fuel Consumption for diesel and diesel-waste cooking oil blends with different EGR flow rates (Mean Statistic=434.7 Std. Deviation=168.61)

The increase of BSFC is generally due to the lower calorific values of biodiesel compared with that of the diesel fuel [26]. If the engine was fueled with biodiesel-diesel blends, the BSFC would increase due to the lower brake power produced, caused by the lower energy content of the biodiesel [27, 28]. At the same time due to its higher density for the same volume, more biodiesel fuel based on the mass flow was injected into the combustion chamber than diesel fuel [29, 30]. It was found that BSFC increased with increase in EGR rates as available oxygen for combustion was reduced for the amount of fuel supplied and density of air decreased; thus less available oxygen for combustion. Therefore, air fuel ratio is changed and this increased the BSFC [31].The results obtained are in agreement with that observed by other researchers [30, 32].

Figure 8 displays the variations of the exhaust gas temperature with diesel and different blends of waste cooking oil biodiesel along with different EGR rates. In general, due to increase in EGR quantity inside the engine cylinder, there is a reduction in peak combustion temperature and hence a reduction in exhaust gas temperature. The reasons for temperature reduction include: relatively lower availability of oxygen for combustion and higher specific heat of intake air mixture as explained earlier. This reflects an effective utilization procedure of heat energy [15, 16, and 33] and is in agreement with that observed by other researchers [26, 34]. However other references have been obtained, which represent inconsistencies with the results of the present study [10]. These references report that the addition of EGR increased exhaust gas recirculation. This is caused by shifting of the combustion process to a later stage into the expansion stroke and also the longer combustion duration for all fuels leading to prolonged combustion process.

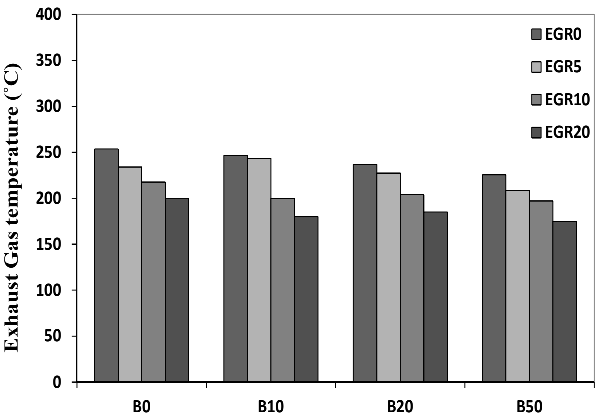

Figure 8: Variation of Exhaust gas Temperature for diesel and different ratios of diesel-waste cooking oil blends with different EGR flow rates (Mean Statistic=204.1 Std. Deviation=48.13)

The temperatures of the exhaust gases for B10, B20 and B50 waste cooking oil biodiesel fuel were observed to be lower than the temperatures of the exhaust gases for diesel fuel without EGR. This result for WCO biodiesel and its different blend ratio is attributed to shorter ignition delays and therefore advanced combustion proportionate compared to diesel fuel.

The variation of UHC emissions for the four different fuels with different EGR flow rates is displayed in Figure 9. It is obvious that the UHC emissions were reduced as the diesel-WCO blends were used. Several causes have been suggested to describe the reduction in HC emissions when ordinary diesel is replaced with biodiesel. The oxygen content in the biodiesel molecule causes a more complete combustion [35]; the higher cetane number of biodiesel decreases the combustion delay, and also the combustion timing when biodiesel utilization rate and amount is increased. All of these causes could reduce the HC emissions of the engine. Some researchers came to the same conclusion regarding HC emissions with diesel-biodiesel blends [26].

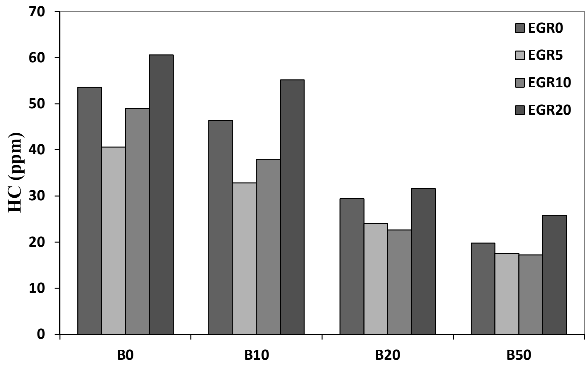

Figure 9. Variation of unburned hydrocarbons for diesel and diesel-WCO biodiesel blends with different EGR flow rates (Mean Statistic=24.1 Std. Deviation=21.06)

On the other hand, the EGR flow rate dropped to the lowest level (EGR 5%, EGR 10%) caused by a small reduction in UHC emissions. One cause for this is that part of the unburned gases in the exhaust of the previous cycle is recirculated and burned in the next cycle. Also, the presence of radicals can aid the initiation of the combustion process, particularly with the rise of intake charge temperature due to mixing with exhaust gases. In addition, change in UHC follows a trend with an expansion in EGR ratio resulting in an expansion in UHC emissions [36]. The expansion in UHC emissions is due to decrease in oxygen concentration in the inlet charge by the EGR presented into the cylinder which leads to the increase in UHC emissions. The results obtained in this regard are in agreement with that observed by other authors [15, 32].

Figure 10 displays the variation of CO emissions of diesel and WCO biodiesel blends with different EGR rates. Through the experiment it was found that emissions of CO increased with increasing EGR rate. However, CO emissions of WCO were relatively low. Higher values of CO were seen for diesel fuel with 20% EGR. For biodiesel, the extra oxygen content is believed to have partly recompensed for the oxygen lacking operation under EGR. Oxygen compounds of biodiesel have an important role in reducing CO emissions. Oxygen helps complete oxidation of carbon species during the combustion process [37]. Increasing EGR flow rates caused increase in CO emissions for both diesel fuel and WCO blends, as high EGR flow rates cause a lack in oxygen concentration in combustion processes and unfinished combustion. Some researchers found alike results for CO emissions [34, 37].

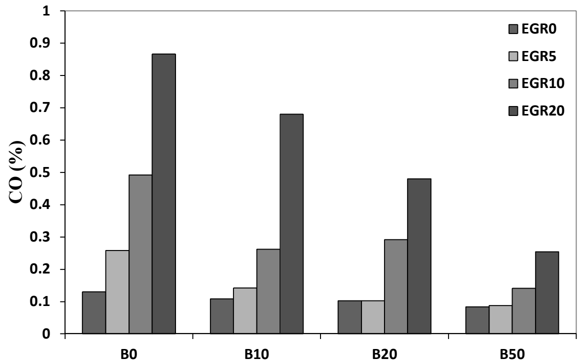

Figure 10: Variation of carbon monoxide for diesel and diesel-WCO blends with different EGR flow rates (Mean Statistic=0.36 Std. Deviation=0.54)

Figure 11 depicts the NO emissions, acquired by Diesel, B10, B20 and B50 fuels with different EGR rates. Commonly, biodiesel causes higher NO emissions than diesel fuel. The oxygen content of biodiesel is a significant parameter in high NO formation levels, because the oxygen content of biodiesel provides high local peak temperatures and a corresponding excess of air [31]. Therefore, the higher NO emissions can be ascribed to more complete combustion of the biodiesel with the existence of more oxygen in the combustion chamber [38, 39].

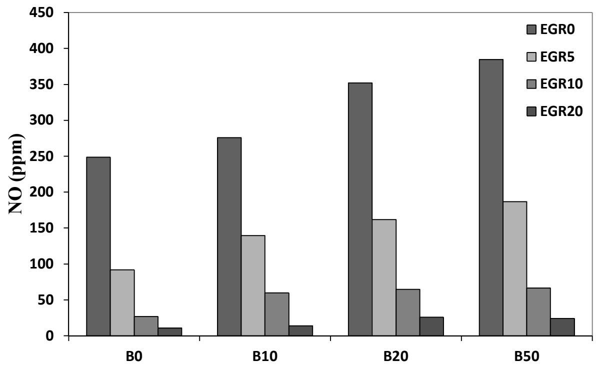

Figure 11: Variation of Nitric oxide for diesel and diesel-WCO blends with different EGR flow rates (Mean Statistic=89.05 Std. Deviation=126.46)

On the other hand, the NO emissions were reduced significantly with a rise in EGR ratio due to the increase in total heat capacity of combustion chamber charge by EGR, which reduces the peak combustion temperatures. As displayed in Figure 6, NO emissions decrease with the rise in the EGR flow percentage for both diesel fuel and WCO blends. This is due to the fact that presence of inert gases such as CO2 and also H2O in the combustion chamber decreases the peak combustion temperature. These inert gases substitute the oxygen in the combustion chamber causing a NO emission reduction with EGR. The results obtained are in agreement with that observed by other authors [16, 40].

Descriptive statistical information of measured parameters includes the mean, standard error and standard deviation shows in Table 4.

Table 4: Descriptive statistical information

Parameter	Mean		Std. Deviation
	Statistic	Std. Error	Statistic
power	15.6	.47	7.29
Torque	287.04	8.6	133.23
Exhaust gas temperature	204.1	3.10	48.13
BSFC	434.7	10.8	168.61
HC	24.1	1.35	21.06
CO	.36	.035	.54
NO	89.05	8.16	126.46

6) Conclusion

EGR is a very useful technique for reducing the NOx emissions. In this article, an experimental study was undertaken on a tractor engine utilizing diesel fuel, B10, B20 and B50 with exhaust gas recirculation. The influence of blending biodiesel (waste cooking oil) on emissions and performance were analyzed. EGR replaces oxygen in the intake air with the exhaust gas re-circulated to the combustion chamber. Exhaust gases lower the oxygen concentration in combustion chamber and increase the specific heat of the intake air mixture, which results in lower flame temperatures. Reduced oxygen and lower flame temperatures affect performance and emissions of diesel engine in different ways. The findings of this study may be summarized as follows:

1. When biodiesel fuel blend is utilized in a diesel engine, power reduces and BSFC increases due to the lower calorific value of biodiesel compared to diesel fuel. However, increasing EGR flow rates causes reduction in power and increase in BSFC for both diesel fuel and biodiesel fuel blends.
2. It is determined that the NO emissions rise with increasing biodiesel ratio. Applying EGR was an effective technique to reduce NO emissions. NO emissions were reduced with a rise in the EGR flow percentage for both diesel fuel and biodiesel fuel blends.
3. The emission of CO and UHC were established to be lower with increasing biodiesel ratio. Applying small EGR rates caused slight reductions in HC emissions, however, increasing EGR rates to higher levels caused increase in CO and HC emissions for both diesel fuel and biodiesel fuel blends.

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چکیده

در این مطالعه تاثیر مخلوط های سوختی مختلف دیزل- بیودیزل و نرخ بازخورانی گازهای اگزوز بر روی مصرف سوخت ویژه ، درجه حرارت گاز خروجی و انتشار NO، HC، CO، مورد مطالعه قرار گرفت. موتور مورد استفاده چهار سیلندر، پاشش مستقیم و خنک شونده با آب بود. بیودیزل برای حل دو مسئله اساسی کاهش سوخت های فسیلی و تخریب محیط زیست به صورت گسترده ای مورد مطالعه قرار گرفته است. بازخورانی گازهای اگزوز به هنگام استفاده از مخلوط‌های سوختی دیزل-بیودیزل یک راه کار مناسب برای کاهش NO به شمار می‌آید. اگر موتور با مخلوط سوخت بیودیزل-دیزل راه اندازی شود، به علت توان تولیدی کمتر BSFC افزایش می یابد و همچنین BSFC با افزایش نرخ EGR افزایش داشته است. توان و گشتاور موتور با استفاده از سوخت بیودیزل کاهش می یابد. نتایج نشان داد که B0 دارای بیشترین مقدار توان و B50 دارای کمترین مقدار توان بوده است. با استفاده از بازخورانی گازهای اگزوز، کاهش NO و دمای گازهای خروجی اگزوز مشاهده شد ولی مشخص شد که آلاینده های HC و CO افزایش پیدا کرده‌اند.