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Evaluating the effect of biodiesel and EGR system on diesel engine emissions

P. Soltani Nazarloo[1], H. Haji Agha Alizadeh[2*], H. Poorvousooghi Gargari[3] , H. Faridi[4]

[1] *Bu-Ali Sina University, Hamadan, Iran, arazsoltani@yahoo.com*
[2] *Bu-Ali Sina University, Hamadan, Iran, h-alizade@basu.ac.ir*
[3] *E. Azarbaijan Agricultural Education Center, Tabriz, Iran, vousoogh@gmail.com*
[4] *Bu-Ali Sina University, Hamadan, Iran, sima_faridi_66@yahoo.com*

[*] *Corresponding Author*

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ABSTRACT

Vehicle Emission is one of the main causes of environmental damage. Vehicle engines produce carbon dioxide (CO_2), hydrocarbon (HC), Nitrogen oxides (NO_x) and many other harmful substances. An investigation was conducted using a compression-ignition engine fuelled with different ratios of blends of diesel and biodiesel at different EGR rates. The effects of different ratios of fuel blends and EGR rate on the emission characteristics (unburned hydrocarbon (HC), nitric oxide (NO), carbon dioxide (CO_2) and oxygen (O_2) were examined. The air-fuel equivalence ratio (λ), oil temperature and intake gas temperature were also analyzed. Results show that the different ratios of blends of diesel and biodiesel decrease HC emissions compared to those of the diesel fuel. The addition of biodiesel can increase NO, CO_2 and O_2 emissions compared with that of the diesel. EGR can reduce NO emissions in a compression-ignition engine fueled with diesel and biodiesel blends. The results also indicate that fuel consumption and air-fuel equivalence ratio were decreased by 19.2% and 72.9%, respectively, for 20% biodiesel blend with 20% EGR compared to diesel fuel without EGR. Intake gas temperature and oil temperature were also observed to increase by 87.5% and 6.2%, respectively, for 20% biodiesel blend with 20% EGR compared to diesel fuel without EGR.

1) Introduction

Improved fuel efficiency and higher power with lower maintenance costs have increased popularity of diesel engine vehicles. Diesel engines are used for movement of bulk goods, powering stationary/mobile equipment, and generating electricity more economically than any other device in the same size range. In most of the global car markets, record diesel car sales have been observed in recent years [1]. The exhorting expectation of additional developments in diesel fuel and diesel vehicle sales in the future has forced diesel engine manufacturers to improve the technology in terms of power, fuel efficiency and emissions. Diesel engine emissions are classified as carcinogenic [2]. The strict emission laws are forcing engine manufacturers to improve technologies to meet exhaust emission limits. Due to their fuel efficiency, ease of maintenance and durability, diesel engines are commonly used in power-plants in rural areas all over the world as well as the farm equipment. Diesel engines are considered to be good alternative to gasoline engines because they produce lower quantity of emissions [3]. On the other hand, higher oxide emissions of nitrogen (NO_x) and particulate matters (PM) have been identified as the main drawbacks of the diesel engines. Although, the main components of diesel exhaust include carbon dioxide (CO_2), water vapor (H_2O), nitrogen (N_2), and oxygen (O_2); carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), particulate matters (PM) are present in smaller but environmentally significant quantities. NO_x comprises of nitric oxide (NO) and nitrogen dioxide (NO_2); both of which are considered to be deleterious to environmental and human health. NO_2 is considered to be more toxic than NO. It affects human health directly and is a precursor to ozone formation, which is mainly responsible for smog formation. The ratio of NO_2 and NO in diesel engine exhaust is quite small, but NO is quickly oxidized in the environment; forming NO_2 [4]. Diesel engines mainly emit NO, hence attention has been focused on reducing NO formation [5]. In order to meet the emission standards and slow the fast depletion of petroleum reserves, investigation for alternative fuels for diesel engines has been undertaken. Biodiesel from vegetable oils are viable alternative to diesel fuel for diesel engines. The use of biodiesel in diesel engines does not require any engine modification. Biodiesel results in considerably lower emissions of PM, carbon monoxide (CO) and hydrocarbon (HC) without any extra fuel consumption or engine performance drawbacks. Many researchers have found that biodiesel fueled engines produce higher NOx emissions compared to diesel [6, 7]. Therefore, several exhaust pre-treatment and post treatment methods have been incorporated in modern diesel engines. Exhaust Gas Recirculation (EGR) is a pre-treatment method, which is utilized widely to decrease and also control nitrogen oxides (NO_x) emission from diesel engines. EGR controls the NO_x, because it decreases oxygen concentration and flame temperature of the working fluid in the combustion chamber. Wagner et al. [8] attempted to obtain a lower emission of NO_x and soot using a highly diluted intake blend. At a very high EGR rate (around 44%), emission of particulate matters reduced considerably with continuous drop in NO_x emission, but this high EGR rate significantly affects the fuel efficiency/economy. Agarwal et al. [9] examined the effect of EGR on performance and emissions, carbon deposits, and wear of various parts of a diesel engine and reported that hydrocarbons, carbon monoxide, and smoke opacity were increased with EGR, but NO_x emissions were reduced drastically. Qi et al. [10] observed that the brake specific fuel combustion (BSFC) and soot emission were slightly increased, and nitrogen oxide (NO_x) emission was reduced with the increasing EGR rate. Based on the investigative work conducted by Anandavelu et al. [11] utilizing diesel and eucalyptus oil fuel (EOF) blends with and without 15% EGR, it was observed that with the increase in the ratio of eucalyptus oil in diesel, smoke, NO_x and unburned hydrocarbon emissions decreased. In this study, the combined effects of waste cooking oil biodiesel with the incorporation of exhaust gas recirculation (EGR) on the engine emission characteristics are examined and compared with the results achieved from the engine operating on commercially available diesel in the market.

In this study, the influences of diesel/biodiesel mixtures on emission are investigated.

2) Transesterification

Waste cooking oil is considered as feedstock for the biodiesel production. The method of biodiesel production is known as transesterification.

The process takes place by combining vegetable oil with alcohol in the presence of a catalyst. Methyl esters are preferred, as methanol is non-hygroscopic and is less expensive than other alcohols. The optimum proportions are one liter of waste cooking oil, 200 ml of methanol, and 8.0 grams of NaOH. The properties of diesel and waste cooking oil biodiesel are listed in Table 1.

3) Exhaust Gas recirculation

Exhaust Gas Recirculation is a very effective technique for NO_x control. Exhaust gases mostly consist of carbon dioxide, nitrogen and water vapor. When a portion of this exhaust gas is re-circulated to the cylinder, it acts as diluent to the combusting blend. The specific heat of the EGR is much higher than fresh air; hence EGR increases the heat capacity (specific heat) of the intake charge, thus reducing the temperature increase for the same heat release in the combustion chamber. Re-circulated exhaust gas displaces fresh air entering the combustion chamber with carbon dioxide and water vapor present in engine exhaust. As a consequence of this air displacement, the amount of oxygen in the intake mixture is reduced. Decreased oxygen available for combustion decreases the effective air–fuel ratio which affects exhaust emissions substantially. Also the mixing of exhaust gases with intake air causes a rise in specific heat of the intake blend, which consequently decreases the flame temperature. Thus mixture of lower oxygen quantity in the intake air and decreased flame temperature decreases rate of NO_x formationreactions. The EGR (%) is defined as [12],

$$\text{EGR (\%)} = \frac{Volume\ of\ EGR}{total\ intake\ charge\ ito\ the\ cylinder} * 100 \quad (1)$$

A different method of measurement of the amount of EGR is by the use of CO_2 concentration [12],

$$\text{EGR ratio} = \frac{[CO_2]_{\text{intake}} - [CO_2]_{\text{ambient}}}{[CO_2]_{\text{exhaust}} - [CO_2]_{\text{ambient}}} \quad (2)$$

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

Three common descriptions for the effect of EGR on the decrease of NO_x emissions are increased ignition delay, increased heat capacity, and dilution of the intake charge with inert gases. The heat capacity theory states that the addition of the inert exhaust gas into the intake increases the heat capacity (specific heat) of non-reacting matter present during the combustion. The increased heat capacity has the effect of lowering the peak combustion temperature. According to the dilution theory, the effect of EGR on NO_x is caused by increasing amounts of inert gases in the mixture, which decreases the adiabatic flame temperature [13]. It is hard to operate EGR at high loads due to drop in diffusion combustion, which may result in an immoderate increase in smoke and particulate emissions. But at low loads, un-burnt hydrocarbons included in the EGR re-burn in the blend, leading to lower un-burnt fuel in the exhaust. Apart from this, hot EGR would increase the intake charge temperature, thereby affecting combustion and exhaust emissions. Execution of EGR in diesel engines has a number of problems including (a) raised soot emission, and (b) introduction of particulate matters into the engine cylinders. When engine components come into contact with high velocity soot particulates, particulate abrasion may occur. Sulphuric acid and condensed water in EGR can also cause corrosion onset.

4) Experimental Setup

The engine used in this study was a four cylinder, four stroke, water cooled, direct injection diesel engine. The arrangement of the experimental set up is shown in figure 1 and the specifications of the test engine are given in Table 2. Figures 2-4 shows Tractor, dynamometer and EGR setup and emission analyzer at workshop. A digital FGA-4100 five gas analyzer is set up to find the emission characteristics of the engine. 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 sensor device placed in the center of the chamber to provide good contact with the smoke. Exhaust gas temperatures were calculated by applying resistance temperature detectors (RTD's) and K-type thermocouples throughout the experiments in research. During all tests, ambient conditions such as temperature and pressure were measured and recorded. The Experiments were performed at 5°C at a pressure of 0.814 atm. with conventional diesel fuel, and different ratios of blends of waste cooking oil biodiesel (WCO) with diesel.

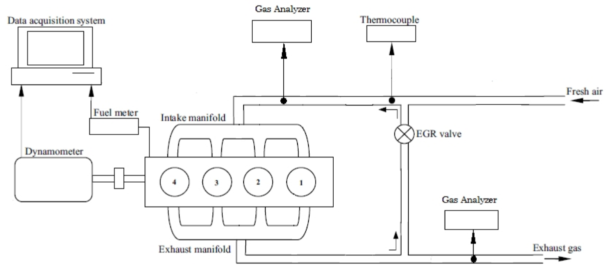

Figure 1: Experimental Setup

Table 2: Engine specifications

Model	A4-248
Number of cylinders	4
Bore × stroke	100 × 127 mm
Maximum power	75 kW@2000 rpm
Maximum torque	278 Nm@1300 rpm
Compression ratio	16.0 : 1
Cylinder volume	4.06 Lit
Number of valves per cylinder	2
Injection system	Pump-line-nozzle
Combustion chamber type	Bowl-in-piston
Number of injection holes	4
Opening pressure of nuzzles	250 bars

Table 3: Properties of gas Analyzer

Measurable	Unit	Limits	Accuracy
HC	ppm	0-9999	1
CO	Vol %	0-9.99	0.01
CO2	Vol %	0-20	0.1
O2	Vol %	0-25	0.01
NO	ppm	0-5000	1
Oil temperature	(°C)	0-150	0.1
λ	-	0.5-3.0	-

Figure 2: Tractor and Dynamometer setup

Figure 3: Emission Analyzer

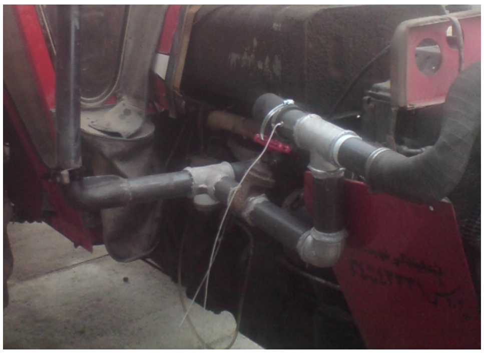

Figure 4: EGR setup

The quantity of EGR can be regulated by a control valve installed in the EGR loop. In order to comply with the aims/purposes of the study, the engine was run at different EGR rates. The percentages of recycled gases are 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 the EGR ratio by comparing the CO_2 concentrations between the exhaust and intake of the engine [14-16].

5) Test Procedure

The engine was ran at five different speeds (1700, 1650, 1600, 1550, 1500) using different D-WCO blends along with different EGR flow rates to study the emission characteristics of the engine. Emission parameters were measured after allowing the engine to reach steady state conditions for about 20 min. The results regarding emissions obtained with B10, B20 and B50 were compared with that of diesel at the same engine operating condition. For all parameters, the average data obtained for the five-speed were considered. This study included three variable engine speed, percent biodiesel and EGR rate. Also Average values obtained at five different speeds were considered.

6) Results and Discussion

Figure 5 shows fuel consumption with diesel-biodiesel blends at different EGR rates. Results of calculating the rate of fuel consumption in different states showed that increasing the percentage of biodiesel (Up to 20%) and amount of EGR, decreased fuel consumption rate. The reduction in fuel consumption by increasing the percentage of biodiesel (Up to 20%) in the fuel blends was due to Oxygen content of biodiesel and complete combustion and improved combustion conditions. However, fuel consumption increased with a higher percentage of biodiesel (Higher than 20%). The increased rate of fuel consumption in fuel blends that have over 20% biodiesel are due to biodiesel’s lower heating value and higher density than diesel fuel [17].

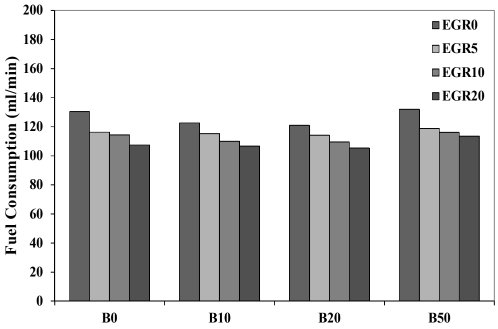

Figure 5: Effects of fuel blend composition and EGR on the Fuel Consumption. (Mean Statistic=115.82, Std. Deviation=19.86)

Today's engines are known as thermophilic engines. Engine design and the alloy used in manufacturing engine lead to toleration of temperatures of well above 100 degrees. Such designs and alloys used prevent engine cylinders from wear and fuel consumption is reduced considerably. EGR increases engine temperature due to hot gases. When an engine operates at high temperatures, the amount of fuel that burns incompletely is minimized and as a result, fuel consumption is reduced.

Air–fuel equivalence ratio, λ (lambda), is the ratio of actual AFR (Fuel–air ratio) to stoichiometry for a given mixture. If λ < 1, the fuel-air mixture is called rich, if λ > 1, the mixture is lean, and if λ= 1, the mixture is stoichiometric [18]. The effect of biodiesel and EGR percentage of the equivalence ratio are displayed in Figure 6.

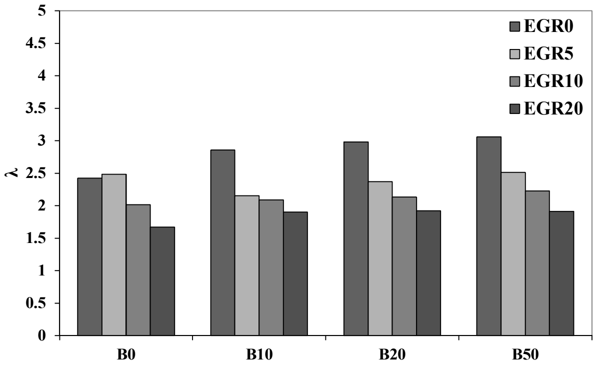

Figure 6: Effects of fuel blend composition and EGR on the air-fuel equivalence ratio (Mean Statistic=2.29, Std. Deviation=0.89)

The equivalence ratio is reduced when biodiesel is increased. This result occurs because the increase in biodiesel improves the density of the fuel blend and therefore causes the increase of fuel at the same volume and consequently decreases the actual fuel-air ratio [18]. The results obtained in this experimental study are in agreement with that observed by other authors [18]. Also, according to figure3, it was found that the air-fuel equivalence ratio reduced when the EGR percentage increased. This result occurred because increase in the EGR ratio led to reduction in O2 availability due to thermal throttling effect and therefore caused the decrease in air at the same volume, thus, decreasing the actual air-fuel ratio [19].

Engine oil, a multi-purpose composition, plays a major role in the reliable operation of motor vehicles. Without oil, it is actually impossible to run motor vehicles. Figure 7 shows the variations of oil temperature with different EGR flow rates for different ratios of diesel-biodiesel fuel blends. By observing the figure it can be concluded that with increasing EGR levels and biodiesel percentages, oil temperature increased for all fuel blends. Hot gases from the EGR and oxygenated biodiesel caused an increase in engine pieces temperature due to high temperature of exhaust gas and oxygen content of biodiesel that caused flame temperature increased. Thus, the oil temperature increase can be attributed to higher temperature of engine pieces and the circulation of engine oil between these pieces for cooling.

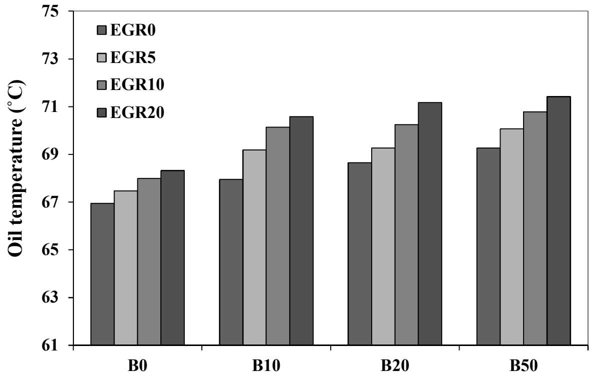

Figure 7: Effects of fuel blend composition and EGR on the Oil temperature (Mean Statistic=19.71 Std. Deviation=5.26)

Figure 8 represents the fluctuations of the exhaust gas temperature at the entry to the inlet manifold with different EGR flow rates for different ratios of diesel-biodiesel fuel blends. When EGR rates are increased, the exhaust temperature at the entry to the inlet manifold becomes higher than atmospheric temperature. High temperature of the exhaust gases are mixed with incoming fresh air to raise the temperature of incoming air mixture into the cylinder. Thus, the inlet gas temperature increase can be attributed to high temperature of the exhaust gases. Increasing the amount of biodiesel in the fuel blend had no significant impact on the temperature of the incoming gases and inlet temperature for all fuel blends were relatively close to each other.

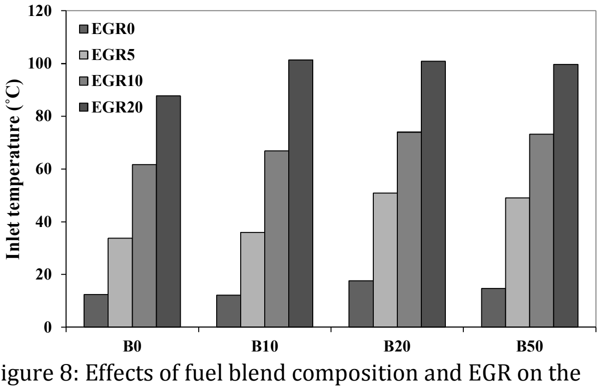

Figure 8: Effects of fuel blend composition and EGR on the Inlet temperature (Mean Statistic=204.1, Std. Deviation=48.13)

The variations of CO2 emissions for commercial diesel and different ratios of biodiesel blends are shown in Figure9. CO2 emission for B50 (50% diesel, 50% biodiesel) biodiesel, without EGR, was 11.2%, by volume, whereas the same for commercial diesel was 6.4%, by volume. CO2 emissions increased with the increasing biodiesel percentages. CO2 formation is affected by the carbon–hydrogen ratio in the fuel. Stoichiometrically, combustion of a hydrocarbon fuel should produce only CO2 and water (H2O) which depends on the carbon–hydrogen ratio in the fuel [20]. Thus, CO2 emission can be reduced by reducing fuel's carbon content per unit of energy. CO2 emissions for B50, B20, and B10 increased by 4.7%, 3%, and 2.1% respectively, compared to those of B0. Gumus [21] showed that higher CO2 emission of biodiesel indicates effective combustion due to the oxygen content of biodiesel, which improves the combustion of fuel. Due to the use of EGR, CO2 emission increased with the increase in EGR percentage. CO2 emission for 5% EGR was 7% by volume and that of 20% EGR was 9.5% by volume for commercial diesel fuel. Also, the difference between the amount of CO2 with EGR5 and EGR20 for all fuel blends was approximately 3% by volume. The reason for this increase in CO2 emissions was the presence of CO2 in the exhaust gas.

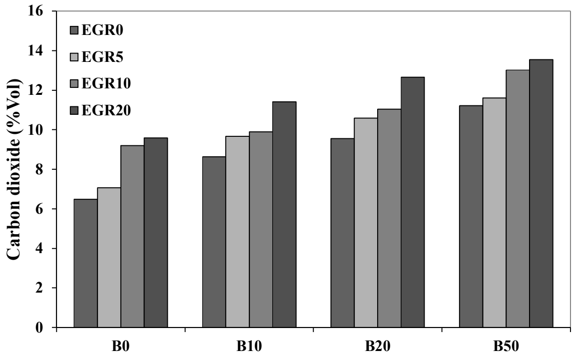

Figure 9: Effects of fuel blend composition and EGR on the Carbon dioxide emission (Mean Statistic=7.7 Std. Deviation=3.13)

Oxygen in the exhaust is the result of excessive air (leaning out) in the air–fuel ratio. As the air–fuel mixture becomes higher in air and lower in fuel, it may be referred to as going out of stoichiometric [22]. O2 emissions results are demonstrated in Figure6 for different fuel blends and EGR ratios. As pointed out in Figure10, O2 emissions increased with the increased biodiesel percentage. Heywood [23] noted that diesel engines are frequently operated under fuel-lean burning conditions. In the current study, excess air was naturally aspirated into the combustion chamber to mix with the atomized biodiesel. Chemically bound oxygen in the biodiesel provided another extra source of the oxygen component, which added to the excess inlet air in the reactant mixture. Hence, burning biodiesel produced more residual oxygen emissions than burning diesel fuel alone, as shown in Figure 14 [24]. Ilkilic [25] stated that biodiesel contains more oxygen than diesel fuel which leads to rising O2 in the exhaust. O2 emissions for B50, B20, and B10 increased by 2.4%, 1.4%, and 0.7%, respectively compared to those of B0 without EGR. Also, by consulting figure6, it can be stated that that oxygen reduced with an increase in the EGR percentage. Re-circulated exhaust gas displaces fresh air entering the combustion chamber with carbon dioxide and water vapor present in engine exhaust. As a consequence of this air displacement, a lower amount of oxygen in the intake mixture is available for combustion. Reduced oxygen is available for combustion which lowers the effective air–fuel ratio. This effective reduction in air–fuel ratio affects exhaust emissions substantially [9].

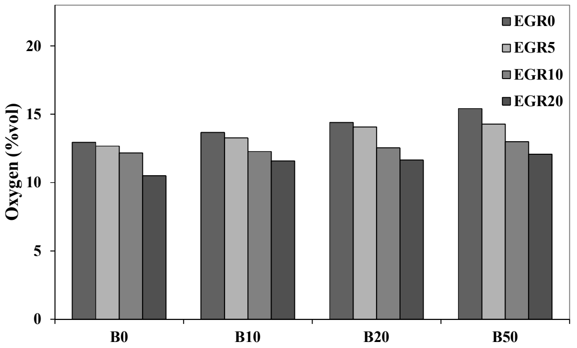

Figure 10: Effects of fuel blend composition and EGR on the oxygen emission (Mean Statistic=13.67 Std. Deviation=2.75)

The variation of UHC emissions for four fuels with different ratios along with different EGR flow rates is shown in Figure 11. It is obvious that the UHC emissions decreased as the diesel-WCO mixtures were utilized. The oxygen content in the biodiesel molecule causes a more complete combustion [10]; the higher cetane number of biodiesel decreases the ignition delay and the combustion timing when higher biodiesel is utilized. All of these could lead to decrease in HC emissions of the engine. Some researchers found alike consequences of HC emissions with diesel-biodiesel blends [27].

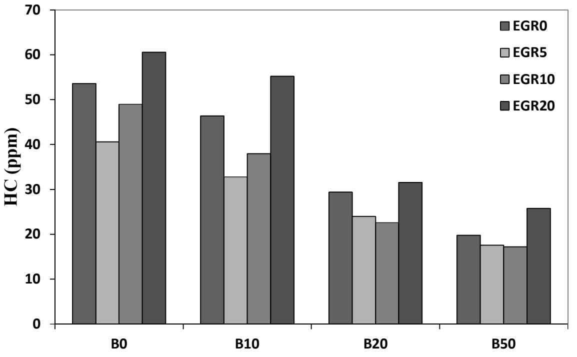

Figure 11: Variation of unburned hydrocarbons for net diesel and diesel-WCO biodiesel blends with different EGR flow rates (Mean Statistic=24.1 Std. Deviation=21.06)

On the other hand, increasing EGR flow rate to the lower levels (EGR 5%, EGR 10%) caused a small reduction in UHC emissions. One cause for such a reduction is that a part of the unburned gases in the exhaust of the previous cycle is recirculated and burned in the later cycle. Also, the presence of radicals can aid to initiate 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 the EGR ratio resulting in an expansion in UHC emissions [28]. The increase in UHC emissions is due to the increasing in the oxygen concentration in the inlet charge presented into the cylinder [29, 30].

Figure 12 shows NO emissions for commercial diesel, B10, B20 and B50 biodiesel 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 formation levels of NO, because the oxygen content of biodiesel provides high local peak temperatures and a corresponding excess 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 [32, 33]. On the other hand, NO emissions reduced significantly with an increase in the EGR ratio due to the increase in total heat capacity of the combustion chamber charge by EGR, which reduces the peak combustion temperatures. As displayed in Figure9, NO emissions decrease with the rise in the EGR flow percentage for both commercial diesel fuel and WCO blends of biodiesel. This is due to the fact that presence of inert gases such as CO2 and H2O in the combustion chamber decreases the peak combustion temperature, and also substitutes oxygen in the combustion chamber causing reduction in NO with EGR. The results achieved are in agreement with that observed by other authors [9, 11].

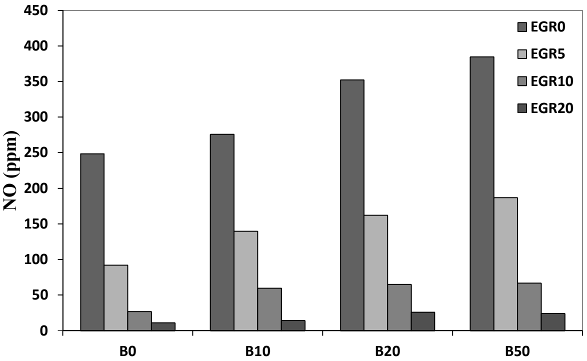

Figure 12: Variation of Nitric oxide for commercial diesel and diesel-WCO blends with different EGR flow rates (Mean Statistic=89.05 Std. Deviation=126.46)

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

Table 4: Descriptive statistical information

Parameter	Mean		Std. Deviation
	Statistic	Std. Error	Statistic
FC	115.82	1.28	19.86
λ	2.29	0.06	0.89
Inlet gas Temp.	204.1	3.10	48.13
Oil Temp.	19.71	0.34	5.26
HC	24.1	1.35	21.06
CO2	7.7	0.2	3.13
NO	89.05	8.16	126.46
O2	13.67	0.18	2.75

7) Conclusion

In this study, the effect of biodiesel and its blends on emissions were experimentally investigated on a tractor diesel engine whereas EGR was used to reduce NO emissions. The following results were achieved:

1. The advanced biodiesel blends combustion resulted in the reduction of HC while both NO, CO_2 emissions were increased. The increased amount of oxygen in the biodiesel molecule is believed to be an additional reason for reduction of HC and increase of NO emissions. The increase in fuel consumption for B50 biodiesel fuel is mainly due to the lower heating value of biodiesel fuel compared to diesel fuel.
2. The use of EGR was more effective in combustion of biodiesel blends compared to diesel combustion. This is because NO emissions were reduced more while HC emission was kept relatively low. The increased CO_2 concentration in recirculated exhaust gas and the retardation of the already advanced combustion from utilization of biodiesel are the main reasons for higher NO reduction with the use of EGR for biodiesel fuels. Thus, biodiesel fuel along with EGR can be used to reduce NO emissions simultaneously.
3. The lower air/fuel ratio with biodiesel fuel compared to operation with diesel (for the same EGR level).
4. Compared with conventional diesel fuel, the exhaust NO was reduced significantly with biodiesel blends and 20% EGR due to less oxygen available in the recirculated exhaust gases which lowers the flame temperature in the combustion chamber.
5. The total un-burnt HC emissions were decreased by 35% for 20% biodiesel blends compared to diesel fuel with 5% and 10% EGR and CO_2 and O_2 were observed as increases.

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بررسی تاثیر بیودیزل و سامانه بازخورانی گازهای خروجی بر آلاینده های خروجی از موتور دیزل

پرویز سلطانی نظرلو[1]، حسین حاجی آقا علیزاده[2*]، حسن پوروثوقی گرگری[3]، حمیده فریدی[4]

[1] *دانشگاه بوعلی سینا، همدان، ایران،* arazsoltani@yahoo.com
[2] *دانشگاه بوعلی سینا، همدان، ایران،* h-alizade@basu.ac.ir
[3] *مرکز آموزش کشاورزی آذربایجان شرقی، تبریز، ایران،* vousoogh@gmail.com
[4] *دانشگاه بوعلی سینا، همدان، ایران،* sima_faridi_66@yahoo.com
**نویسندۀ مسئول*

چکیده

آلاینده های خودرو یکی از عوامل اصلی آسیب های زیست محیطی است. موتورهای خودرو تولید کننده ی دی اکسید کربن ، هیدروکربن نسوخته، اکسیدهای نیتروژن و بسیاری دیگر از مواد مضر هستند. یک بررسی با استفاده از موتور اشتعال تراکمی راه اندازی شده با نسبت های مختلف دیزل و بیودیزل به همراه نرخ مختلف بازخورانی گازهای خروجی انجام شد. تاثیر نسبت های مختلف مخلوط سوختی و نرخ بازخورانی گازهای خروجی بر مشخصات آلاینده هایی مثل هیدروکربن های نسوخته ، اکسید نیتریک ، دی اکسید کربن و اکسیژن مورد بررسی قرار گرفتند. نسبت هم ارزی هوا و سوخت ، دمای روغن و دمای گاز ورودی نیز مورد بررسی قرار گرفت. نتایج نشان می دهد که نسبت های مختلف مخلوط دیزل و بیودیزل انتشار هیدروکربن را نسبت به سوخت دیزل کاهش می دهد. افزودن بیودیزل می تواند در مقایسه با سوخت دیزل تولید اکسید نیتروژن، دی اکسید کربن و اکسیژن بیشتری کند. بازخورانی گازهای خروجی به همراه مخلوط سوخت دیزل و بیودیزل می تواند انتشار NO را در یک موتور اشتعال تراکمی کاهش دهد. همچنین نتایج نشان می دهد که مصرف سوخت و نسبت هم ارزی سوخت و هوا برای ۲۰٪ بیودیزل با ۲۰٪ بازخورانی گازهای خروجی به ترتیب به اندازه ی ۱۹,۲ ٪ و ۷۲,۹٪ در مقایسه با سوخت دیزل بدون بازخورانی گازهای خروجی ، کاهش یافته است. همچنین مشاهده شد که دمای گاز ورودی و درجه حرارت روغن نیز برای ۲۰ ٪ بیودیزل با ۲۰ ٪ بازخورانی گازهای خروجی به ترتیب ۸۷,۵ ٪ و ۶,۲ ٪، در مقایسه با سوخت دیزل بدون بازخورانی گازهای خروجی افزایش داشت.

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