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ORIGINAL ARTICLE

An Experimental Study on the Equivalence Ratio of Biodiesel and Diesel Fuel Blends in Small Diesel Engine

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ABSTRACT
The purpose of this research is to study the effect of biodiesel fuel in the mixture of pure diesel and biodiesel fuels on the equivalence ratio and the output oxygen amount in a single-cylinder diesel engine in 1800, 2000, and 2800 rpm speeds. In this experiment, biodiesel was added to pure diesel with ratios of 0, 5, 10, 15, 20 and 25%. The used biodiesel was prepared from restaurant waste oil through the esterification method. Results showed that in 1800 and 2000 rpm speeds, increasing biodiesel in mixtures decreases the equivalence ratio. However, in 2800 rpm speed, at first the equivalence ratio has gradually increased, but has decreased after that. Compared to the two previous speeds, the equivalence ratio has decreased for all blends. It's because by increasing the rotational speed of the engine, heat loss time of each cycle is shortened and fuel consumption is decreased. On the other hand, by increasing the engine speed, engine air consumption is also increased. In 1800 and 2000 rpm speeds, at first the output oxygen is high and then decreases by increasing the percent of biodiesel existing in the fuel. This indicates the improvement of the combustion process and the consumption of the major part of the oxygen existing in the fuel mixture. The same condition applies in 2000 rpm speed.
Keywords: *biodiesel, diesel fuel, blend fuels, Equivalence Ratio, output oxygen.*

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INTRODUCTION

The increase on energy demand, environmental concern of the global warming and climate change and increasing petroleum price in the worldwide has greatly increased the interests of the application study of alternative fuels to internal combustion engines. Among these alternative fuels, biodiesel and diesohol (diesel – ethanol blends) have received much attention in recent years for Compression Ignition (CI) diesel engines [4, 6]. An alternative energy resource like biodiesel from edible and non-edible oils such as soya beans, jatropha (Jatropa curcas), sunflower and karanja (Pongamia Pinnata), palm and neem has started attracting significant attention of researchers, governments and industries as renewable, biodegradable, and non-toxic energy source. Several studies conducted by researchers identify that biofuels as a potential alternative fuel for internal combustion engines [7–8]. They have acclaimed to have zero net production of CO_2 gas in global context. It has been found that engines running on biodiesel run successfully for longer durations and the performance and emission characteristics are quite comparable to that of petroleum based diesel fuel [5–2].

Utilization of pure biodiesel requires making changes in the fueling system of engines; however, if it is mixed with pure diesel, no change is needed. Nowadays in many of the developed countries of the world, biodiesel is used as a clean fuel, and it is predicted that in near future, it will be spread in all countries of the world. Different studies have been conducted on the effect of maxing biodiesel with pure diesel on the pollutants coming out of the exhaust system. These studies show that mixing biodiesel with pure diesel decreases the harmful pollutants significantly. In this research, it has been attempted to consider the effect of biodiesel and pure diesel mixture in a single-cylinder diesel engine. The experiment was done using a single-cylinder diesel engine and the results were obtained using measurement devices.The results of Najafi et al.'s [7] research about the effect of different percentages of biodiesel and pure diesel mixture on the equivalence ratio showed that increasing biodiesel amount in the mixtures increases the equivalence ratio. In another research, Agarol (2006) investigated the effect of different mixtures of biodiesel and pure diesel on engine oil temperature. His obtained results showed that by increasing biodiesel percentage in the mixture in all the tested loads, engine oil temperature decreases significantly, so that the mixture containing 20% biodiesel in full load decreases the oil temperature by 40°C. [3].

MATERIALS AND METHODS

In this study, the used biodiesel was prepared from the restaurant waste oil through trans-esterification method. In order to prepare samples of fuel mixture, biodiesel was mixed with pure diesel in six different levels of 0, 5, 10, 15, 20 and 25%. Some of the properties of the used biodiesel and pure diesel are presented in Table1. Total of six fuel mixture samples with different percentages of two types of fuel was prepared and indicated by the acronym *BxDy* where *B* denotes biodiesel, *x* is biodiesel percentage in the sample, *D* is pure diesel, and *y* is the percentage of pure diesel in the fuel blend. Physical properties of the fuel samples are presented in Table2.

Experiments were done on a direct injection single-cylinder engine manufactured by Gunt Company in Germany. Detailed technical specifications of this engine are presented in Table3. In order to record the functional parameters of the engine, an electrical dynamometer manufactured by Gunt Company of Germany was used. To measure the gases coming out of the engine exhaust system, a five-gas emission detector manufactured by Motor Scan Company was used. This device is capable of recording CO, CO_2, HC, NO, and O_2 pollutants. All sensors adjoined to the engine were connected to a central computer. Using specialized programs of CT159 experimental set, the computer was able to simultaneously record different parameters such as power, torque, engine speed, consumed air flow, engine fuel consumption, brake specific fuel consumption of the engine, etc.

Engine tests were done according to ECE R-96 Standard in full load and in 1800, 2000, and 2800 rpm speeds. Before beginning the experiment, the engine started to work for 5 minutes with regular gasoline under full load until the engine was fully warmed up and ready for experiment. Tests were conducted with all fuel blends in different speeds. It should be noted that after each experiment of each fuel blend, the engine was turned off and the existing fuel was sent out the system using drain plug. Also, fuel filters placed in the path were cleaned up.

RESULTS AND DISCUSSION

Equivalence ratio

Equivalence ratio is calculated by dividing the fuel to real air ratio by the fuel to theoretical air ratio or by dividing the air to stoichiometric fuel ratio by air to real fuel ratio. Air to real fuel ratio is easily obtained by dividing the engine input air flow by the fuel flow used in different cycles through the experiments conducted on the engine. However, in order to obtain air to theoretical fuel ratio, combustion stoichiometric equations should be used and the amounts of this ratio for different blends of fuel should be determined. In this experiment, biodiesel ($C_{20}H_{39}O_2$) with 0, 5, 10, 15, 20 and 25% ratios is mixed with pure diesel ($C_{16}H_{34}$) volumetrically. Considering the mole percent of biodiesel (D_B)and pure diesel (D_D), the general formula of biodiesel and pure diesel mixture is obtained by the following chemical formula:

$$C_{20DB+16DD}H_{39DB+34DD}O_{2DB}$$

Also, the mole percent of biodiesel and pure diesel is obtained by Equs.(1) and (2) respectively:

$$D_B = \frac{\%V_B \times \rho_B \times WM_B}{\%V_B \times \rho_B \times WM_B + \%V_D \times \rho_D \times WM_D} \quad (1)$$

$$D_D = \frac{\%V_D \times \rho_D \times WM_D}{\%V_B \times \rho_B \times WM_B + \%V_D \times \rho_D \times WM_D} \quad (2)$$

where:

D_B is biodiesel mole percent; D_D is pure diesel mole percent; V_B is biodiesel fuel volume percent; V_D is pure diesel fuel volume percent; ρ_B is biodiesel fuel density; ρ_D is pure diesel fuel density; WM_B is biodiesel molar mass (gr); and WM_D is pure diesel molar mass (gr).

The chemical equation of the intended fuel can be easily obtained by the above equations. For example, for a 10% biodiesel mixture we have:

$$C_{1652}H_{3465}O_{26} + 2505.25\ (O_2+3.76\ N_2) \rightarrow 1652\ CO_2 + 1732.5\ H_2O + 9416.75\ N_2$$

In the above chemical equation, by obtaining the air mass and dividing it by fuel mass, we can calculate air to theoretical fuel ratio. The equivalence ratio is achieved by dividing the theoretical ratios to practical ratios using Equ.(3):

$$\emptyset = \frac{(F/A)_{act}}{(F/A)_{st}} \quad (3)$$

where:

$(F/A)_{act}$ is fuel to real air ratio and $(F/A)_{st}$ is fuel to theoretical air ratio.
According to its design conditions, each engine has the highest performance and produces the least pollutants in a particular equivalence ratio. The effect of increasing biodiesel in mixtures on the equivalence ratio of 1800, 2000, and 2800 rpm speeds is shown in Fig.1.
Considering the obtained diagram, it is observed that in 1800 and 2000 rpm speeds, increasing biodiesel in mixtures decreases the equivalence ratio. The reason for this can be the increase of fuel density resulting from the increase of biodiesel amount in the composition of fuels. Increasing the density of mixtures leads to more consumption of fuel in the same volume unit and consequently, the real ratio of air to fuel decreases.
In 2800 rpm speed, at first the equivalence ratio has gradually increased, but has decreased after that. Compared to the two previous speeds, the equivalence ratio has decreased for all compounds. It's because by increasing the rotational speed of the engine, heat loss time of each cycle is shortened and fuel consumption is decreased. On the other hand, by increasing the engine speed, engine air consumption is also increased.

Table1: Properties of biodiesel and diesel used in this study.

properties	**biodiesel**	**Pure diesel**
Density(kg/m^3)	878	821
Cetan Number	66	57
Octan Number	-	-
Boiling Temperature(°C)	330	دمای جوش280
Molecular formula	$C_{20}H_{39}O_2$	$C_{16}H_{34}$
Molar Mass(gram)	311	226
% oxygen	10.5	0
% Carbon	77	85
% Hydrogen	12.5	15
Ratio of hydrogen to carbon	16	18
Viscosity(mm^2/s)	6.482	2.45
Heating value(kj/kg)	41300	44500

Table 2: Some Properties measured for the fuel blends.

Fuel Blends	Density(gr/cm^3)	Viscosity(mm^2/s)
B0D100	0.7694	2.6921
B5D95	0.7698	3.11256
B10D90	0.7711	3.1497
B15D85	0.7751	3.1984
B20D80	0.7763	3.4910
B25D75	0.784	3.6327

Table 3: Technical specifications of diesel engine CT151

Model	Hatz B20-6
Manufacturer	Gunt Company, Germany
Number of cylinders	1
Cylinder stroke	62 mm
Cylinder bore	69 mm
Rated power	1.5 kW at 3000 rpm
Compression ratio	21:1
Cooling system	Air cooled
Fuel injection system	Direct

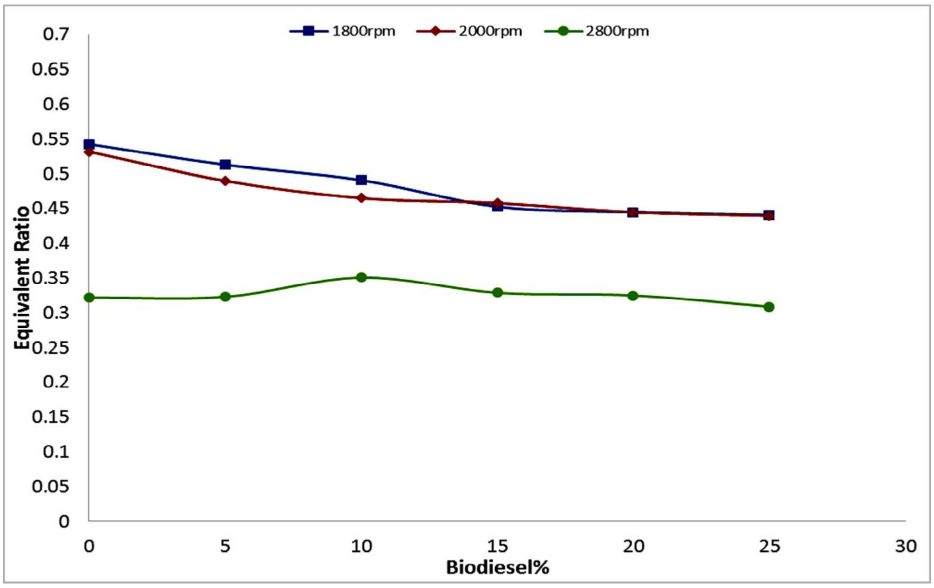

Fig1. Equivalence ratio changes fuel blends Due to the amount of biodiesel in each fuel blend at speeds of 1800,2000, 2800rpm

The effect of biodiesel on the amount of oxygen coming out of the exhaust system

As a biofuel, biodiesel has high amounts of oxygen. When this fuel is mixed with pure diesel, the existence of extra oxygen will improve the combustion properties of pure diesel as well as the combustion quality of the engine in the power phase. However, extra oxygen is desirable only to a specified amount; when it is increased, some of the thermophysical properties such as heating value, octane number, density, and viscosity are negatively affected. These factors not only increase fuel consumption, but also worsen the combustion quality [3]. The effect of increasing biodiesel amount in mixtures on the output oxygen amount is shown in Fig.2.

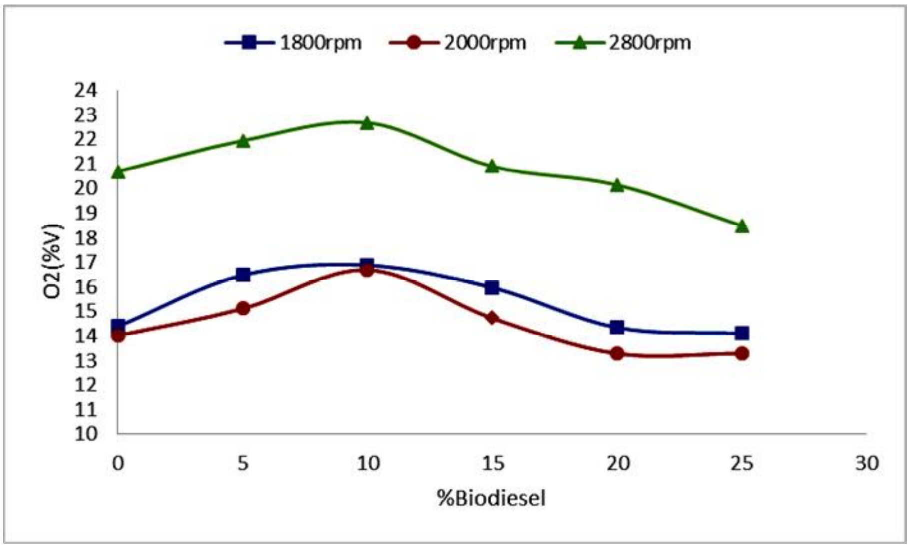

Figure 2: The effect of biodiesel on the amount of oxygen coming out of the exhaust system.

As shown in Fig.2, in 1800 and 2000 rpm speeds, at first the output oxygen is high and then it decreases by increasing the percentage of biodiesel existing in the fuel. This is indicative of the improvement of combustion process and the consumption of the major part of the oxygen existing in the fuel mixture. The same conditions apply in 2800 rpm speed. The interesting point is the high percentage of the oxygen which has not been consumed in exhaust system output in 2800 rpm speed compared to 1800 and 2000 rpm speeds. It can be justified in this way that since in slower rotations there is enough time for a good ignition, the fuel is relatively fully combusted in this time interval.

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