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ORIGINAL ARTICLE

Performance Evaluation of a Small Diesel Engine Using Diesel and Biodiesel Fuel Blends

Abbas Ali Taghipoor Bafghi[1], Babak Beheshti[2] , Barat Ghobadian[3] , Morteza Almassi[4], Seyed Reza Hassan-beygi[5]
1-Department of Agricultural Machinery Engineering, Faculty of Agriculture and Natural Resources, Tehran Science and Research Branch, Islamic Azad University, Tehran, Iran.
2-Department of Agricultural Machinery Engineering, Faculty of Agriculture and Natural Resources, Tehran Science and Research Branch.Islamic Azad University, Tehran, Iran.
3-Department of Agricultural Machinery Engineering, Faculty of Agriculture,Tarbiat Modarres University, Tehran, Iran.
4-Department of Agricultural Machinery Engineering, Faculty of Agriculture and Natural Resources, Tehran Science and Research Branch.Islamic Azad University, Tehran, Iran.
5-Department of Agro-Technology, College of Abouraihan, University of Tehran, Tehran, Iran.
Email: taghipoor460@yahoo.com

ABSTRACT
The increasing use of fossil fuels, increasing cost of oil products, and reduction available resources and also the increasing trend of environmental pollution by fossil fuels have encouraged the researchers to find new alternate energy sources other than petroleum sources. The most important application of fossil fuels is in internal combustion engines. Biodiesel is a kind of biological fuel which has similar properties to diesel fuel. In this research the performance evaluation of single cylinder 4-srroke engine CT159 was studied using biodiesel and diesel fuel blends without any changes in engine structure and components. The data were analyzed using SPSS software and general linear model via one-way analysis of variance. It was a factorial experiment with randomized complete block design including four dependent parameters as torque, power, fuel consumption, and brake specific fuel consumption, and the effect of different speeds of engine and different fuel blends (B0D100, B5D95, B10D90, B15D85, B20D80, B25D75) on them was examined. The ANOVA results showed that the main effect of fuel blend on power was not significant but its effect on torque and fuel consumption was significant at 5% level and its effect on brake specific fuel consumption was significant at 1% level. Moreover, the main effect of engine speed on power, torque, fuel consumption, and brake specific fuel consumption was significant at 1% level. The interactive effect of fuel blend and engine speed on power was not significant but their effect on torque, fuel consumption, and specific fuel consumption was significant at 1% level. In all blends, as the engine speed decreased and the engine performance increased, the rate of obtained power increased compared with net diesel fuel. In general, within the speed range of 1800 to 2400 rpm the power of blended fuels was more than the diesel fuel and within the speed range of 2400 to 2800 rpm the power of blended fuel decreased and was less than B0 fuel. The same behavior is true for the torque. B5D95 blend has the lowest increase of fuel consumption compared with the other blends. The highest rate of fuel consumption belongs to B10D90. B5D95 has relatively the highest rate of power and torque increase and the lowest increase of fuel consumption and brake specific fuel consumption among all blends. In higher percentages of biodiesel, B25D75 is appropriate due to having low fuel consumption and brake specific fuel consumption and relatively good power and torque.
Keywords: *Biodiesel, Diesel Engine, Power, Torque, Brake Specific Fuel Consumption*

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INTRODUCTION

Petro-diesel is the most important and the most common fuel used in diesel engines so far in many countries around the world. The use of petro-diesel in diesel engines leads to the emission of harmful pollutants with complicated chemical compositions, which cause irreparable damage to the environment.

At present, the most common alternatives to fossil fuels are befouls [1]. A lot of countries have begun to produce befouls in different ways in order to deal with environmental pollution and depletion of fossil fuel sources. Each country can produce befoul from domestic resources such as plants with regard to the abundance of plant products in that country, agricultural waste and food residuals and thus meets its fuel needed [3]. The most suitable alternative fuel for diesel engine is known as biodiesel due to their vital source [10]. Biodiesel is generally composed of methyl ester or ethyl ester and contains several alkyl groups with hydrocarbon chains of C15 to C17 which are known as fatty acids. Biodiesel refers to a wide range of fuels that are produced by plant oils and animal fats when used in internal combustion engines and heat machines make less pollution than fossil fuels. Biodiesel is very similar to diesel fuel except that it did not contain undesirable substances like sulfur, nitrogen, and polycyclic aromatics. This fuel can replace diesel fuel without making any changes in boilers and internal combustion engines [5]. The major difference in chemical structure of biodiesel and diesel engines is their oxygen content. Oxygen content in diesel fuel is zero while biodiesel contains 10-12 % oxygen by weight. Biodiesel oxygen content reduces energy density and emission of particulates in it [6].

Many studies have been conducted concerning about the effects of using befouls such as biodiesel, bioethanol on performance parameters of diesel engine. In a research, methyl and ethyl ester of soybean oil were compared as an alternative to diesel fuel. The results of the tests showed that the engine power has decreased by 7.8% for ethyl ester of soybean and by 6.6% for methyl ester of soybean. Moreover, brake specific fuel consumption has increased 12% for ethyl ester and 10% for methyl ester of soybean compared with diesel fuel [7].

Investigation of Carraretto et al. [12] on a six cylinders direct injection diesel engine revealed that with increasing biodiesel percentage in the blend the power and torque of the engine decreased slightly over entire speed range. Moreover, with pure biodiesel, the maximum torque was found to have reached at higher engine speed.

Qi et al. [2] conducted an experimental investigation on the performance of a single cylinder DI diesel engine using crude soybean biodiesel/diesel blends (diesel, SB30, SB50, SB80 and SB100) at different loading conditions. They reported about 7–12% increase in bsfc for different blends compared with diesel fuel at 90% of rated load condition.

In an investigation performed on a DI diesel engine fuelled canola oil methyl ester and waste palm oil methyl ester revealed that the engine brake power decreased 4–5% as well as the engine bsfc increased 9–10% when compared with those of diesel fuel [5].

Rahimi et al. [9] studied the performance of a Ruggerini RD 270 (two cylinders, direct injection) diesel engine using the biodiesel–diesel–bioethanol fuel blends with different volumetric percentages. The results showed that with adding 12% bioethanol and 8% biodiesel to diesel fuel, the maximum power and torque of the engine reduced by 8.1% and 6.5%, respectively. The engine specific fuel consumption increased 12.1% as well. The researchers named the blends ''Diesterol'' and stated that the Diesterol fuel could appropriately replace diesel fuel without any modification in the engine structure and engine parts.

Hassan-Beygi et al. [11] investigated the performance of a Perkins A63544 diesel engine fuelled diesel-biodiesel-bioethanol fuel blends. They reported that adding biodiesel and bioethanol to diesel fuel did not change the engine power and torque significantly except for the D65B25E10 fuel blend that decreased the engine power and torque. The engine specific fuel consumption increased in the range of 3.47–11.03% compare with pure diesel fuel when the biodiesel and bioethanol were added to the diesel fuel.

The literature survey showed that there are many studies concerning the performance parameters of medium to large diesel engine using diesel-biodiesel blends. However, information concerning the performance evaluation of small diesel engines fueled by diesel-biodiesel blends is limited. Therefore, in this study the power, torque and specific fuel consumption of a small direct injection air-cooled diesel engine was evaluated using diesel-biodiesel fuel blends without any change in engine components and systems.

MATERIALS AND METHODS

Biodiesel used in this investigation was supplied from National Bioenergy Research Center (NBERC) of Tarbiat Modaress University, Tehran, Iran. The biodiesel was produced by transesterification method from fried oil. The biodiesel would meet the requirements of international standard of ASTM D6751-09. Table 1 gives the different diesel-biodiesel fuel blends used in this study. In this table, letter B represents biodiesel and letter D represents diesel fuel and the numbers next to each letter specify the volume percentage share of each fuel in the blends.

Table (1): Diesel and biodiesel fuel blends used in this study

B0D100	B5D95	B10D90	B15D85	B20D80	B25D75

The experiments were carried out in thermodynamic laboratory, technical faculty, Islamic Azad University, Dezful Branch, Dezful, Iran. In order to study the effect of different diesel and biodiesel fuel blends on small diesel engine performance parameters a test set up unit (Gunt model CT 159, Germany) was used in this study (Fig. 1). The set up stand consists of three main components including a CT 159 for mounting of the engine and as a control unit, a universal drive and brake unit or dynamometer, (HM 365) as a load unit, and a four-stroke diesel engine (CT 151). The main function of CT 159 is to mount the engine, supply it with fuel and air and record and display relevant measurement data. The engine is mounted on a vibration-insulated base plate and connected by way of a belt drive to HM 365 dynamometer. After the engine warmed up the dynamometer acts as a brake for applying resistant load to the engine. The lower section of the mobile frame contains fuel tanks and a vessel for the intake air. A measuring tube for fuel consumption is also included in the test unit. The speed and torque are adjusted and displayed on the dynamometer. The measured values are transmitted directly to a personal computer via USB and the data acquisition software.

The diesel engine power, torque and fuel consumption were measured at six engine speed levels (1800, 2000, 2200, 2400, 2600, and 2800 rpm) for the diesel-biodiesel fuel blends. The specifications of the direct injection diesel engine to carry out the tests are given in Table 2.

Brake specific fuel consumption is defined as the fuel mass consumed to produce 1 kWh actual work in engine and designated by BSFC (g/kWh). The amount of brake specific fuel consumption is calculated by Equation (1).

$$BSFC = \frac{M}{P} \qquad (1)$$

Where: M is the rate of fuel consumption (g/h) and P is the engine power (kW).

Figure (1): The desired set including engine and dynamometer

Table (2): 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

All the experiments were replicated three times and the mean values were reported.

The obtained data were analyzed using factorial method as randomized complete block design. In this research, the effect of engine speed and different fuel blends (independent variables) on power, torque, fuel consumption, and brake specific fuel consumption of engine (dependent variables) was studied. After ensuring the significant effect of engine speed and the effect of fuel blends on power, torque, fuel consumption, and brake specific fuel consumption, and also the interactive effect of engine speed × fuel blends, the means of fuel blends × engine speed were compared through Duncan's test and the obtained results were analyzed by SAS software.

RESULTS AND DISCUSSION

In this research, physical specifications of biodiesel and diesel fuel blends including density, kinematic viscosity, freeze point, pour point, and cloud point at different levels were determined and examined. The results are given in Table (3).

Table3: The fuel blends specifications based on ASTM D-6751-09 standard.

Fuel specifications	B0D100	B5D95	B10D90	B15D85	B20D80	B25D75	Accuracy
Specific gravity (kg/m^3)	0.7694	0.7694	0.7694	0.7694	0.7694	0.7694	±1 kg/m^3
Kinematics viscosity at 40 ˚C (cSt)	2.6921	3.11256	3.1497	3.1984	3.4910	3.6327	±0.1 cSt
Pour point (˚C)	-3	-3.5	-4	-4.8	-5	-6.5	±1 ˚C
Cloud point (˚C)	-2	-2.5	-3	-3.5	-4	-4.8	±1 ˚C
Freeze Point(˚C)	-20.5	-19	-17	-15	-16	-19	±1 ˚C

The results showed that the increase of density and viscosity of fuel blends is directly related to biodiesel share in the blend and decreases the efficiency of fuels which is due to heavy compounds with complicated molecules. High viscosity affects fuel powdering quality during injector spraying so that the injector is not able to change fuel into small particles for appropriate evaporation and combustion. Moreover, the results indicated that the increase of biodiesel share in blended fuel and the decrease of diesel fuel share would lead to the increase of cloud point temperature and loss. The reason is that free glycerin molecules are placed between fuel molecules and inhibit the formation of waxy compounds which result in lowering the cloud point and loss and play an important role in improving performance and maintenance conditions.

Engine Power

Figure (2) displays the changes of studied engine power to the engine speed using diesel and biodiesel fuel blends. According to the results of Table (4) the main effect of fuel blend on the power is not significant and thus it is not necessary to compare the means. On the other hand, the main effect of engine speed on the power is significant at 1% level so the means are compared. However, the interactive effect of fuel blend × engine speed on the power is not significant.

Table 4: The ANOVA results of power and torque

Sources of variation	Degree of freedom	Means square	
		Power (kw)	Torque (N.m)
Fuel blend	5	ns 0.005	*0.125
Engine speed	5	**0.271	**27.719
Interactive effect of engine speed and fuel	25	ns 0.007	**0.114
Error	72	0.005	0.043

**: significant at 1% level
*: significant at 5% level
Ns: non-significant

Comparison of the means showed that B20D80 blend at 2400 rpm had the highest rate of maximum power and then B10D90, B5D95, B25D75, B15D85, and B0D100 blends had the highest rate of maximum power, respectively. It was observed that B0D100 blend had the lowest rate of maximum power. Diagrams related to power changes to engine speed indicate that all fuel blends at 2300 rpm have maximum power. Among the blends, B20 had the highest maximum power and B0 had the lowest maximum power. Generally, within the speed range of 1800 to 2400 rpm the power of blended fuel is more than diesel fuel and within the speed range of 2400 to 2800 rpm the power of blends decreases and is less than B0 fuel. As mentioned before, the power of pure diesel fuel is lower than the power of biodiesel and diesel blends within the speed range of 2400 rpm while in some references it has been mentioned that engine power in biodiesel fuel blends must be lower than pure diesel fuel due to lower thermal value of biodiesel fuel [7]. Therefore, it seems like that the lower power of pure diesel fuel is the low quality of consumed diesel fuel. On the other hand, since biodiesel fuel contains oxygen, complete combustion increases the power of diesel and biodiesel fuel blends. The results of the effect of engine speed on engine power in different fuel blends are given in Table (5).

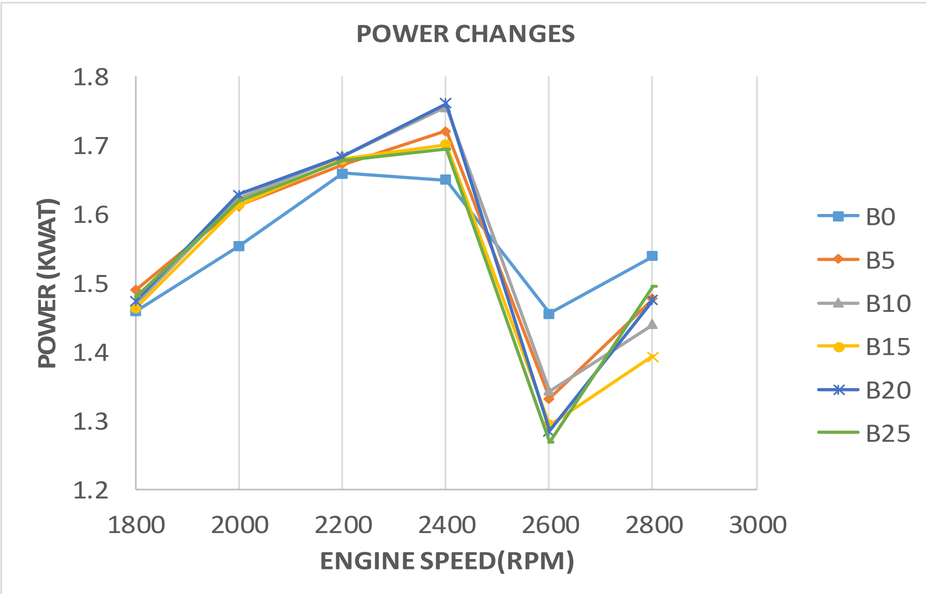

Figure (2): The relationship between engine power-speed in different diesel-biodiesel fuel blends

Engine Torque

Experimented engine torque changes to engine speed are shown in Figure (3) using diesel-biodiesel fuel blends. According to the results of Table (4), the main effect of fuel blend on torque is significant at 5% level and the main effect of engine speed on torque is significant at 1% level. Moreover, the interactive effect of fuel blend × engine speed on the torque is significant at 1% level. Therefore the means were compared for the torque. Comparison of the means of the effect of fuel blend × engine speed on the torque via Duncan method showed that B5D95 blend at 1800 rpm had the highest rate of maximum torque and was higher than other blends within the experiment. Then, B10D90, B20D80, B15D85, B25D75, and B0D100 blends had the highest rate of maximum torque, respectively. Among the blends, pure diesel blend had the lowest rate of maximum torque.

As observed in Figure (3), nearly all fuel blends have similar torques within the speed range of 2400 rpm. In this speed range, B20 fuel blend has the highest rate and B0 fuel blend has the lowest rate. As the speed increases in nearly all blends, the torque decreases and then is fixed. The engine torque changes result from the fact that cylinder is well filled during the breathing process [8]. In very high speeds breathing time is less and consequently the cylinder does not get full well. As a result, compression pressure and combustion pressure will decrease and inertia forces of moving parts of engine will increase and ultimately, the real torque of the engine will reduce.

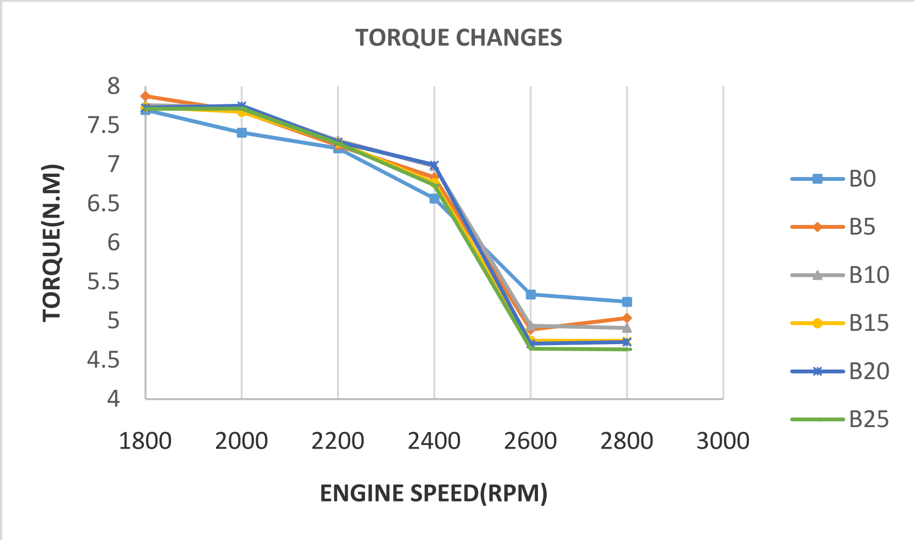

Figure (3): The relationship between engine torque-speed in different diesel- biodiesel fuel blends

Engine Brake Specific Fuel Consumption

According to the results of Table (5), the main effect of fuel blend on s fuel consumption and brake specific fuel consumption is significant at 5% and 1% levels respectively. On the other hand, the main effect of engine speed on fuel consumption and brake specific fuel consumption is significant at 1% level. Moreover, the interactive effect of fuel blend × engine speed on fuel consumption and brake specific fuel consumption is significant at 1% level and thus the means are compared.

Comparison of the means of the effect of fuel blend × engine speed on the engine fuel consumption via Duncan method showed that diesel fuel has the lowest rate of fuel consumption compared to other blends. B5D95 and B25D75 blends have nearly similar fuel consumption to diesel fuel and B10D90, B20D80, and B15D85 have the highest rate of fuel consumption, respectively. The results also showed that diesel fuel has the lowest rate of brake specific fuel consumption compared with the other blends.

Table (5): The ANOVA results of fuel consumption and specific fuel consumption

Sources of variation	Degree of freedom	Mean of Squares	
		Fuel consumption (kg/h)	Specific fuel consumption (g/kwh)
Fuel blend	5	0.004*	9916.143**
Engine speed	5	0.007**	31953.746**
Interactive effect of engine speed and fuel	25	0.005**	5890.606**
Error	72	0.001	388.113

** : significant at 1% level

*: significant at 5% level

It is observed in figure (4) that the rate of pure diesel fuel consumption is less than other fuel blends and on the contrary B20D80 has the highest fuel consumption. After net diesel fuel, B5D95 had the lowest rate of fuel consumption. It is observed that as the rate of biodiesel increases in fuel blends more amount of fuel is consumed for producing the same amount of power since the heating value of biodiesel is lower than diesel fuel. According to table (5) engine brake specific fuel consumption is less than the other blends during the application of pure diesel fuel and B20D80 blend has the highest rate of brake specific fuel consumption to diesel fuel.

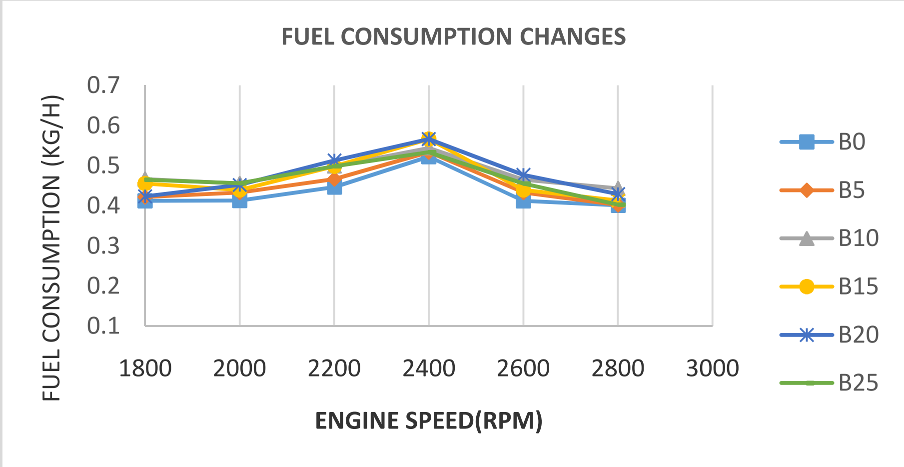

Figure (4): The relationship between fuel consumption-engine speed in different diesel-biodiesel fuel blends

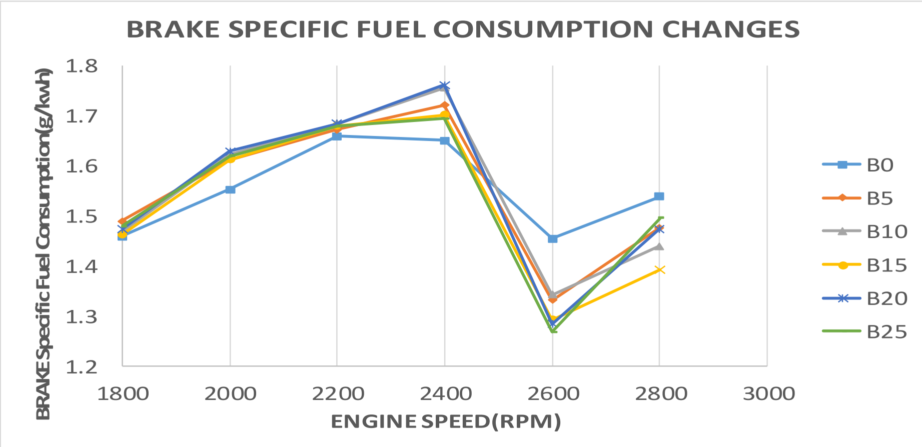

Figure (5): The relationship between brake specific fuel consumption- engine speed in different diesel-biodiesel fuel blends

Conclusion

In this research, the performance evaluation of single cylinder 4-stroke engine was studied using biodiesel and diesel fuel blends. The following conclusions can be drawn from the present study:

1) The interactive effect of fuel blend × engine speed on the power is not significant, but its effect on torque, fuel consumption, and brake specific fuel consumption is significant at 1% level.
2) Generated power and torque by one-cylinder diesel engine CT159 have similar maximum power using B0D100 and B25D75 blends within the range of 2300 rpm. Among the blends, B20 has the highest maximum power and B0 has the lowest maximum power. In general within the speed range of 1800 to 2400 rpm the power of blends is more than the diesel fuel. It seems that the low power of pure diesel fuel is due to low quality of the consumed diesel fuel. On the other hand, as biodiesel fuel contains oxygen, through complete combustion the power generated by diesel and biodiesel fuel blends will increase.
3) Torque changes of experimented engine to the engine speed nearly fuel have similar torques within the speed range of 2400 rpm using diesel-biodiesel fuel blends. In this speed range, B20 fuel blend has the highest rate and B0 fuel blend has the lowest rate. As the speed increases in nearly all blends, the torque decreases and then is fixed. The engine torque changes result from the fact that cylinder is well filled during the breathing process. In very high speeds breathing time is less and consequently the cylinder does not get full well. As a result, compression pressure and combustion pressure will decrease and inertia forces of moving parts of engine will increase and ultimately, the real torque of the engine will reduce.
4) The consumption rate of pure diesel fuel is less than other blends and on the contrary, B20D80 has the highest rate of fuel consumption. After pure diesel fuel, B5D95 has the lowest rate of fuel consumption.

5) The engine specific fuel consumption is less than other blends when pure diesel fuel is used and B20D80 has the highest rate of specific fuel consumption compared with the diesel fuel.
6) In B5d95, brake specific fuel consumption within the range of 1800 to 2200 rpm shows the economic conditions. Comparison of pure diesel fuel and this blend shows that as biodiesel increases in lower engine speed and engine performance increases, the engine power somewhat increases.
7) In B0D100, i.e. pure diesel fuel within 2800 rpm the lowest rate of brake specific fuel consumption was obtained, but as the rate of power and torque is very low in this point, it has no economic value. Within the range of 2000 to 2200 rpm the rate of brake specific fuel consumption is low and considering the power and torque curves in this range it is observed that this interval indicates economic fuel consumption because in spite of maximum rates of power and torque, the brake specific fuel consumption has decreased.
8) In B10D90, the economic domain of fuel consumption is within the range of 1800 to 2200 rpm. In this range, fuel consumption is minimized and the rate of power and torque is relatively high.
9) In B15D85 within the speed of 2200 rpm the lowest rate of fuel consumption is achieved. The power is high in this point.
10) In B20D80, the economic domain of fuel consumption is within the range of 1800 to 2200 rpm. In this range, fuel consumption is minimized and the rate of power and torque is relatively high. As the engine speed increases over 2200 rpm, the fuel consumption increases gradually and power decreases. B20D80 has the highest rate of fuel consumption in comparison to other blends.
11) The rate of brake specific fuel consumption in B25D75 is less than B20D80. On the other hand, the range of 1800 to 2200 rpm is the economical range of this blend.
12) In all blends, as the engine speed decreases and the engine performance increases, the rate of power increases in comparison to pure diesel fuel. In general, within the speed range of 1800 to 2400 rpm the power of the blends is more than the diesel fuel and within the range of 2400 to 2800 rpm, the power of the blends decreases and is less than B0 fuel. The same behavior is true for the torque.

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