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Original Research Article

The Effects of E-B Diesel Fuel Blends on Engine Lubricating Oil in a Single Cylinder Diesel Engine

Fatih Aydın[1*], Hüseyin Öğüt[2,3]

[1*] Necmettin Erbakan University, Ereğli Faculty of Engineering and Natural Sciences, 42310 Konya / Turkey
[2] Selçuk University, Konya/Turkey
[3] Kyrgyz – Turkish Manas University, Kyrgyzstan

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Abstract

In this study, biodiesel was produced by turning the raw oil, obtained from safflower seed, into Safflower Oil Methyl Ester by transesterification method. Mixing the biodiesel fuel, which was obtained from the safflower, with diesel fuel by adding bioethanol at the rate of 2.5% and 5% and volumetrically in inverse proportion, test fuels were acquired in the form of D_{100}, $E_{2.5}B_{2.5}D_{95}$, $E_5B_5D_{90}$, $E_5B_{2.5}D_{92.5}$ and $E_{2.5}B_5D_{92.5}$. The tests of the diesel fuel and the obtained fuel blends were carried out related to the fuel features; kinematic viscosity, density, water content, pH, color, calorific value, flash point, cloud, pour and freezing points, copper strip corrosion test, iodine number, cold filter plugging point and cetane number. Also, the obtained blend was tried and examined on a four-cycle, single cylinder and on water cooled diesel engine with direct injection fuel system. The engine ran for 100 hours under partial load and the samples were taken from the engine oil at specific times and wear elements were searched. As a result of the analysis of the samples taken from engine lubricating oil, it was observed that as the engine run time increased, the wear elements in the samples increased, too. As a result of ICP oil analysis, the amount of wear elements such as iron, copper, aluminum, lead and chromium in engine lubricating oil were stated diagrammatically. It was determined that the use of $E_{2.5}B_5D_{92.5}$ produced better results than the other types of fuels in terms of wear elements.

Keywords: E-B Diesel (Ethanol-Biodiesel-Diesel), engine wear elements, lubricating oil.

*Corresponding author:
E-mail: fatihaydin@konya.edu.tr

1. Introduction

The primary tasks of lubricating oils used in the engines are to reduce the loss of power and the heating of the parts by preventing the direct contact of the engine parts which are moving on top of each other and also to help the heated part cool [1].

Lubricating oil is a material generally used to provide an easy movement minimizing the friction between two solid bodies. The oils perform lubrication by making the surfaces lubricious, hanging the surfaces and forming a film between the scraping surfaces. Lubrication is applied to reduce the friction between the engine parts and the corrosion, as a result of this friction, and also to provide the performing of the necessary task in less energy loss [2].

Lubricating oils have also functions such as preventing the accumulating of the carbon deposits, neutralizing the acids that occur during the burning and minimizing the corrosion emerging due to the acids [3].

There are two factors that cause the deterioration of the mineral oil in internal combustion engines;

- The appearance of physical and chemical changes due to the oxidation,
- Fouling due to the materials merging from the combustion space.

The working conditions of the engine are quite proper to oxidation. The oil mist is in touch with the air in the oil pan at high temperatures. The temperature is a lot higher at combustion space. Acidic materials and carbonyl complex compounds occur in the oil pan. The carbon pieces in combustion space and piston ring land accumulate in the oil pan. As a result of all these fouling factors, the oil with high acid concentration causes the corrosion in the engine and the engine mount [4].

The key feature for the oils is that they are protective and lubricant. However, these features of the oils that are used for a particular period go bad and corrosion occurs in engine parts, so the maintenance and revision period for the engine gets shorter. The engine characteristics also change depending upon the deformation of the parts. Oil life is determined for a period of time in all vehicles and it is recommended that it be changed at the end of this period. Actually, the parameters that affect the oil life change according to the vehicle. These contain the brand, age and working conditions of the vehicle and also climate conditions can be mentioned. Accordingly, the oil changing periods of the vehicles with different working conditions vary due to such factors [5].

Corrosion metals spectrometer can detect what parts of the engine are corroded, the amount of the corrosion and if the filter works or not, determining the concentration of the metals resulting from the corrosion [6]. The increase of the metal concentration in oil sample is the indication of an abnormal friction in the system. When this abnormal increase in metal concentration is confirmed, a bigger problem which may occur in the system will be prevented. By means of oil analysis, protective measures can be taken before the failure occurs recognizing the corroded products or it enables the oil to be used for a longer time than the oil changing period recommended by the engine manufacturer.

The benefits of oil analysis can be listed as follows;

- Extending oil changing periods,
- Being informed of the situation of the oil,
- Reducing the maintenance expense,
- Measuring the tendency for corrosion,
- Determining the proper maintenance periods,
- Reducing the spare part inventory,
- Bringing down the cost of equipment renewal,
- Arranging the repairmen programming [4].

The fuels that the countries produce by making use of their own vegetable and animal sources are called biofuel. Biofuels contain all types of fuel oils and gas fuels obtained from vegetable and animal sources. There are alternative fuels such as biogas, biomethanol, bioethanol and biodiesel under the title of biofuel but bioethanol is the most commonly used fuel of them [7].

Bioethanol is a biofuel that can be produced by the fermentation of the starchy and sugary plants or the acidic hydrolysis of cellulosic sources. The plants such as sugar beet, sugar cane, corn, wheats and potatoes; woody plants such as stalk, straw and crust; agricultural waste and molasses cane, which is by-product of sugar production, can be used as raw materials [8].

Biodiesel is a blend of oil acid-methyl ester that is produced by vegetable and animal oils, oil residue, oil waste and suitable to the TS EN 14213 and/or TS EN 14214 standards [9].

The purpose of this study is investigation of the effects of engine biodiesel, diesel and bioethanol fuel blends on engine lubrication oil.

2. Materials and Methods

Safflower oils were obtained after the safflower seeds used in this study were first peeled separately in the peeling machines, then heated and annealed through the rolling process, fried at 90^0C and later squeezed in 200 ton hydraulic press. The biodiesels of these oils were produced at -PLC supported- Pilot Production Facility that was founded within the scope of DPT 2004/7 numbered project at Selçuk University, in the unit of Agricultural Machinery Department at Faculty of Agriculture that is seen at Figure 1. In the production, methyl alcohol and NaOH were used as a catalyzer and transesterification method was used as a production method. The diesel fuel, by the way, was provided from Local market. As an engine lubricating oil, Local market 20W-50 diesel engine oil, which was recommended by the producing company in the experiment engine catalogue, was preferred.

Dynamometer, control unit and the signals from the sensors of all the parameters, expected to be measured during the engine test, are evaluated. Besides, the operator is given a warning in the event that the measured values go over the boundary conditions. On the other hand, it has functions that arrange the speed and load of the test engine and measure the fuel consumption [11].

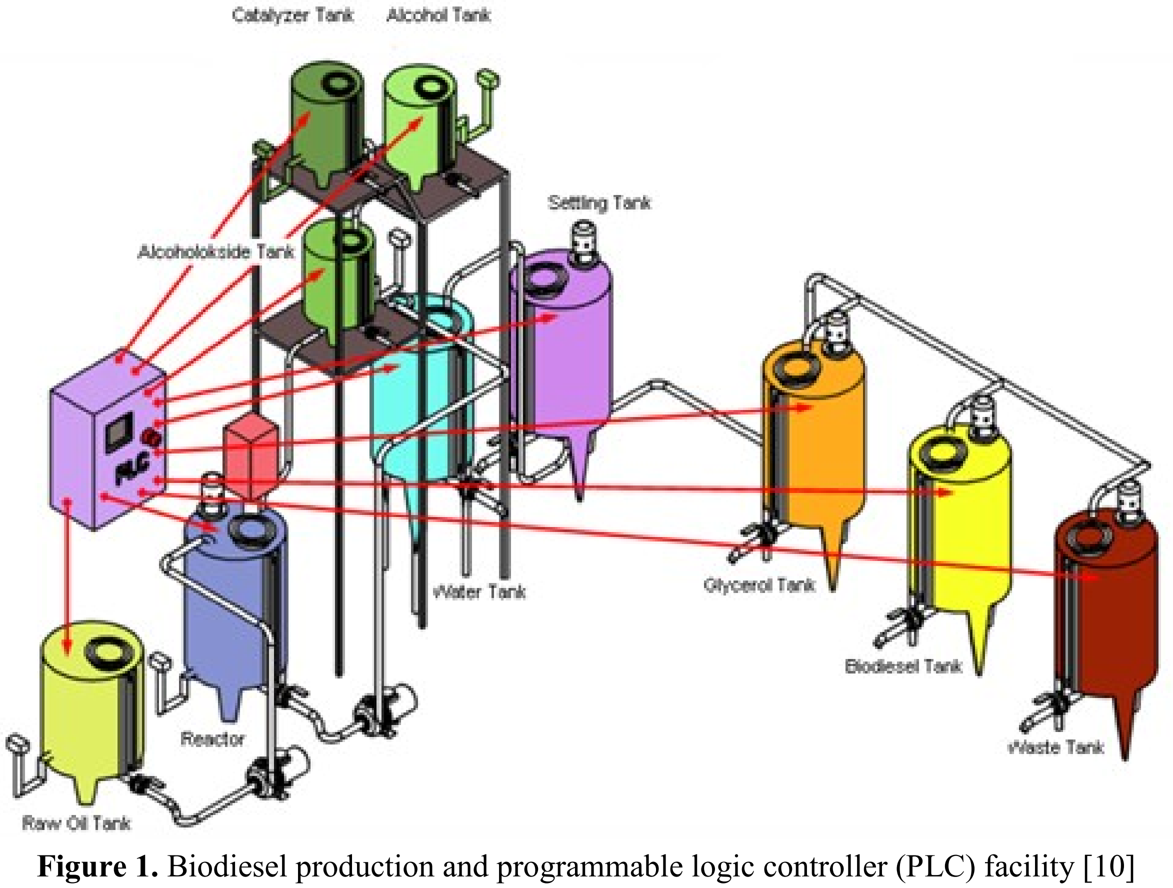

Figure 1. Biodiesel production and programmable logic controller (PLC) facility [10]

The schematic view of the testing setup is shown in Figure 2. The technical features of the Super Star brand diesel engine used in the experiments are given at Table 1.

Table 1 Technical specifications of the test engine [12]

Super Star Engine	Units	Value
Working principle	---	4 stroke, direct injection
Cylinder Bore	mm	108
Stroke	mm	100
Cylinder Number	----	1
Cylinder Volume	lt	0,92
Compression Ratio	---	17:1
Maximum Power	HP	15 (2100 min^{-1})
Maximum Torque	Nm	60 (1100 min^{-1})
Maximum Speed	min^{-1}	2600
Cooling System	---	Water Cooling
Injection Advance	kg/cm^2	175
Injection Advance	degree	28-35 ^{0} (Crank Shaft angle)

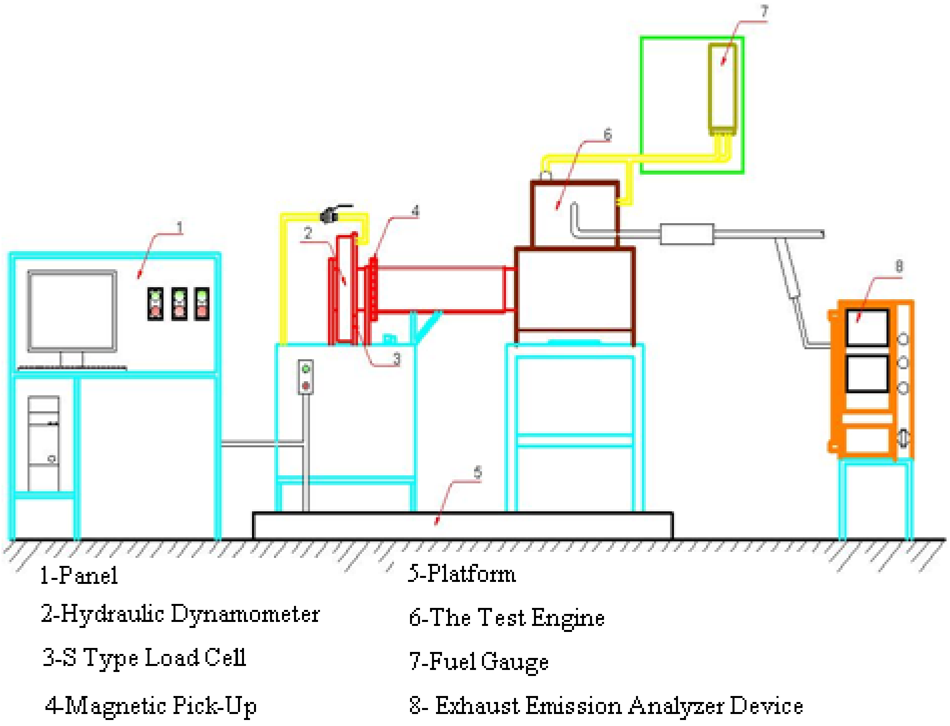

Figure. 2. Schematic view of experimental setup

The oil samples used in the tests were prepared volumetrically. The blend was tried to be homogenized within 15 minutes processing in 1500 min^{-1} by laboratory mixer and in 24000 min^{-1} by homogenizer for 7.5 min. in each. No dissolution was observed after mixing. The blends that consisted of diesel fuel, safflower biodiesel and bioethanol constituted 5 different fuels. 100% diesel fuel was called D_{100}, the fuel that was formed by adding volumetrically 2.5% bioethanol and 2.5% safflower biodiesel to the diesel fuel was called $E_{2.5}$ $B_{2.5}D_{95}$ the fuel that was formed by adding volumetrically 5% bioethanol and 5% safflower biodiesel to the diesel fuel was called $E_5B_5D_{90}$, the fuel that was formed by adding volumetrically 5% bioethanol and 2.5% safflower biodiesel to the diesel fuel was called $E_5B_{2.5}D_{92.5}$, the fuel that was formed by adding volumetrically 2.5% bioethanol and 5% safflower biodiesel to the diesel fuel was called $E_{2.5}B_5D_{92.5}$ [10].

Table 2 Names of the fuels and their volumetric constitution percentages

Fuels	Diesel	Bioethanol	Biodiesel
D_{100}	100	0	0
$E_{2.5}B_{2.5}D_{95}$	95	2.5	2.5
$E_5B_5D_{90}$	90	5	5
$E_5B_{2.5}D_{92.5}$	92.5	5	2.5
$E_{2.5}B_5D_{92.5}$	92.5	2.5	5

The names and the blend proportions of the fuels are given at Table 2. Analysis results of the oil samples used in the tests are seen at Table 3. The Standard values at the table are TS EN 590 for diesel fuel and TS EN 14214 for biodiesel.

In the blends and in the tests which were performed using diesel fuel; the determination of the iron, copper, aluminum, lead and chromium in the oil samples taken from the engine every 20 hours were carried out by ICP-MS-LA PELKIN ELMER ELAN DRC-e (Inductively Coupled Plasma Mass Spectrometry) brand device in the laboratory of Advanced Technology Research and Application Center at Selçuk University.

Table 3 Analyses results of the fuels

Characteristic Properties	Units	Raw Safflower Oil	Safflower Biodiesel	D_{100}	$E_{2.5}B_{2.5}$ D_{95}	E_5B_5 D_{90}	$E_5B_{2.5}$ $D_{92.5}$	$E_{2.5}B_5$ $D_{92.5}$	Bio ethanol	Limiting Values	
										Diesel Fuel	Bio diesel
Density (15^{0}C)	g/cm^3	0,92	0,88	0,83	0,83	0,83	0,83	0,83	0,79	0.82-0.84	0.86-0.90
Kinematic Viscosity (40°C)	mm^2/s	31,23	4,32	3,35	2,69	2,63	2,56	2,66	1,27	2- 4.5	3.5-5
Flash Point	^{0}C	170	121	60	——	——	——	——	——	55	101
Water Content	ppm	20,18	393	33,51	78,84	75,42	89,67	83,63	372,8	200	500
pH	——	4,8	5	5	5	5	5	5	5	——	——
Color Determination	ASTM	2,3	1,4	1,2	1,2	1,2	1,2	1,2	<0,5	——	——
Calorific Value	kJ/kg	5897	40801	47628	47389	46239	47504	46718	29594	——	——
Cloud Point	^{0}C	-1	-2	-9	-8,1	-6,4	-6	-6,2	——	——	——
Pour Point	^{0}C	-15	-7,5	-20	-12,3	-11,2	-11,1	-10,5	——	——	——
Freezing Point	^{0}C	<-20	-13,4	<-20	<-20	<-20	<-20	<-20	<-20	——	——
CFPP	^{0}C	——	-6	-19	-18	-18	-17	-18	<-50	- 20	-15
Copper Strip Corrosion	——	1a	1a	1a	1a	1a	1a	1a	1a	No:1	No:1
Iodine value	giyot/ 100g	117,9	117,9	——	——	——	——	——	——	——	——
Cetane Number	——	45,27	41,92	54,84	57,28	56,26	55,99	57,50	——	51	——

3. Results and Discussion

In this study, 5 different fuel blends that consisted of diesel fuel, safflower biodiesel and bioethanol, D_{100}, $E_{2.5}B_{2.5}D_{95}$, $E_5B_5D_{90}$, $E_5B_{2.5}D_{92.5}$ and $E_{2.5}B_5D_{92.5}$ fuels were tested in four-stroke single cylinder diesel engine and as a result of the experiments, the features of these fuel blends and their effects on engine lubricating oils were searched.

Sampling from the engine lubricating oil was performed periodically by stopping the engine after it reaches temperature regime.

The samples were put in special screw cap boxes to keep them in cool, dry and dark place and not to make them affected by the light and then their analyses were carried out.

3.1. Density values of the engine lubricating oil

In Figure 3, the density values of the engine lubricating oil are seen in the usage of diesel-biodiesel-bioethanol fuel blends. When studying the density test values performed according to ASTM 4052, it was seen that as the engine run time increased, the density increased, too. When the graphic was studied, in diesel fuel, it was seen that it increased by 0.2% in diesel fuel from the 20th hour to the 100th of the engine run time and this situation was at the ratio of 0.26%, 0.15%, 0.13% and 0.21% respectively, in the fuels of $E_{2.5}B_{2.5}D_{95}$, $E_5B_5D_{90}$, $E_5B_{2.5}D_{92.5}$ and $E_{2.5}B_5D_{92.5}$. Also, the increase in $E_5B_5D_{90}$ and $E_5B_{2.5}D_{92.5}$ fuel blends is lower than diesel fuel.

The reason is that these blends make the engine lubricating oil is thinner than the diesel fuel does. By the way, the reason of the general increase in density values is that dust, dirt, fuel and especially corroded engine parts are mixed with the engine lubricating oil.

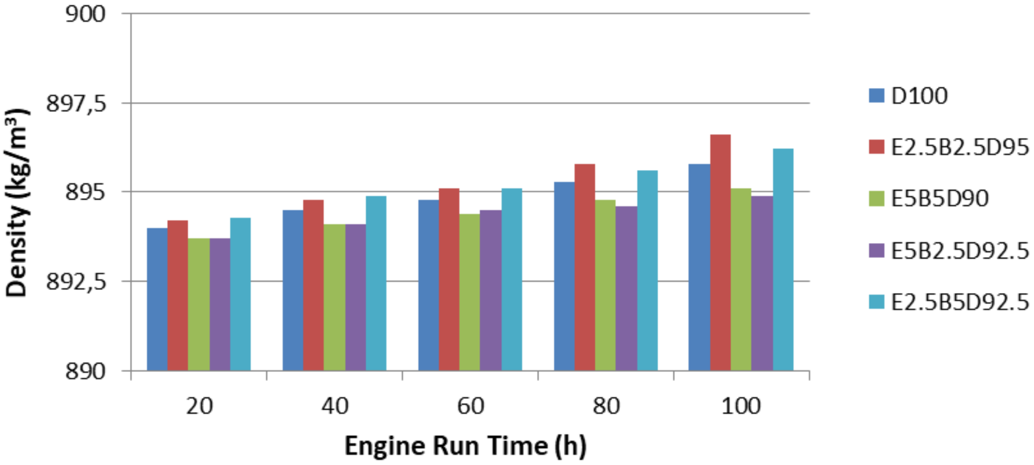

Figure. 3. Density values of the engine lubricating oil

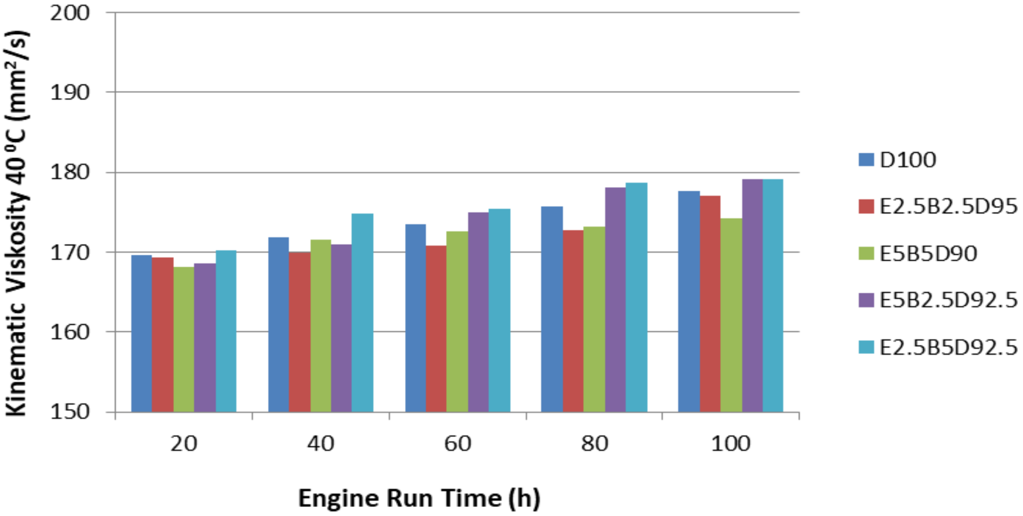

Figure. 4. The kinematic viscosity values of the engine lubricating oil at 40 °C

3.2. The kinematic viscosity values of the engine lubricating oil at 40 °C

In Figure 4, the kinematic viscosity values of the engine lubricating oil at 40°C are seen in the usage of diesel fuel-biodiesel- bioethanol fuel blends. When the graphic is searched, it is seen that as the engine run time increased, kinematic viscosity values at 40°C increased as well. In diesel fuel, it was seen that they increased by 4.67% from the 20th hour to 100th of the engine run time and in fuel blends of $E_{2.5}B_{2.5}D_{95}$, $E_5B_5D_{90}$, $E_5B_{2.5}D_{92.5}$ and $E_{2.5}B_5D_{92.5}$ it increased by 4.60%, 3.62%, 6.28% and 5.18 % respectively.

Also, the increase of $E_{2.5}B_{2.5}D_{95}$ and $E_5B_5D_{90}$ fuel blends is lower than diesel fuel. The reason is that the fuel is mixed with the engine lubricating oil less than the diesel fuel is. As is density values, the reason of the general increase in the kinematic viscosity values at 40°C is that as the engine run time increases, dust, dirt, fuel and especially corroded engine parts are mixed with the engine lubricating oil.

3.3. The kinematic viscosity values of the engine lubricating oil at 100 °C

In Figure 5, in the usage of diesel fuel-biodiesel-bioethanol fuel blends, the kinematic viscosity values of the engine lubricating oil at 100°C are seen. While the graphic was examined, it was seen that as the engine run time increased the kinematic viscosity values at 100°C increased as well. In diesel fuel, it was seen that they increased by 3.53% from the 20th hour to 100th hour of engine run time and in the fuel blends of $E_{2.5}B_{2.5}D_{95}$, $E_5B_5D_{90}$, $E_5B_{2.5}D_{92.5}$ and $E_{2.5}B_5D_{92.5}$ they increased by 4.06%, 5.49%, 4.56% and 3.27% respectively.

The reason of the general increase of kinematic viscosity values at 100°C was the density and, as is kinematic viscosity values at 40°C, dust, dirt, fuel and especially corroded engine parts which were mixed with the engine lubricating oil. Taking into account the engine run temperature, the importance of kinematic viscosity values at 100°C is seen better.

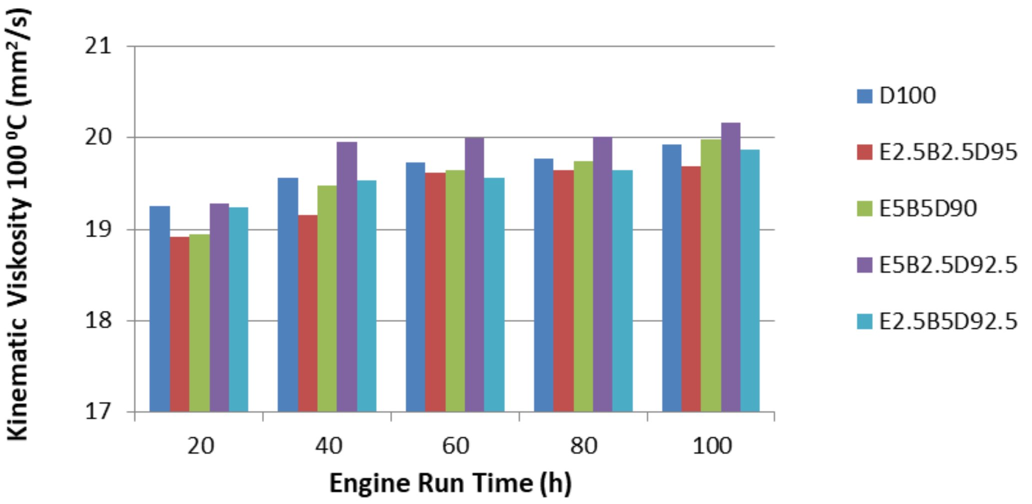

Figure. 5. The kinematic viscosity values of the engine lubricating oil at 100 °C

3.4. Water content values of the engine lubricating oil

In Figure 6, in the usage of diesel-biodiesel-bioethanol fuel blends, water content values of engine lubricating oil are seen. When studying the graphic, in diesel fuel, it was seen that the water content decreased by 6.90% from the 20th hour to 100th hour of the engine run time and in the usage of $E_{2.5}B_{2.5}D_{95}$, $E_5B_5D_{90}$, $E_5B_{2.5}D_{92.5}$ and $E_{2.5}B_5D_{92.5}$ fuel blends, it decreased by 0.03%, 7.60%, 9.57% and 9.40% respectively. The reason is that when the engine run time increased it became more stable in the temperature regime.

3.5. Iron (Fe) element

It is the most common metallic particle determined in the oil samples. Many parts of the machine contribute to the formation of this metal. The primary places are cylinder sleeves, cam shaft, crank shaft and valve disks. When the results of the analysis are examined, it is the most important metallic particle to determine the changing period of lubricating oil. The redundancy of this metallic formation is likely to cause excessive oil consumption, abnormal engine sound, performance problems, oil pressure and abnormal running temperature, broken piston rings, rusting in the system [13].

In Figure 7, the values of iron (Fe) element which is one of the corrosion products in the lubricating oil are seen in the usage of diesel fuel - biodiesel - bioethanol fuel blends.

When the graphic is studied, it is seen that as the engine run time increased, the amount of iron in the engine lubricating oil increased as well. According to D_{100} fuel, it was determined that the amount of iron (Fe) element decreased by 33.24% and 76.03% respectively in the fuel blends of $E_{2.5}B_{2.5}D_{95}$ and $E_{2.5}B5D_{92.5}$ from the 20th hour to 100th hour of engine run time and it increased by 13.40% and 37.16% in $E_5B_5D_{90}$ and $E_5B_{2.5}D_{92.5}$ fuel blends.

Accordingly, the period of oil change will be longer in the usage of $E_{2.5}B_{2.5}D_{95}$ and $E_{2.5}B_5D_{92.5}$ fuel blends.

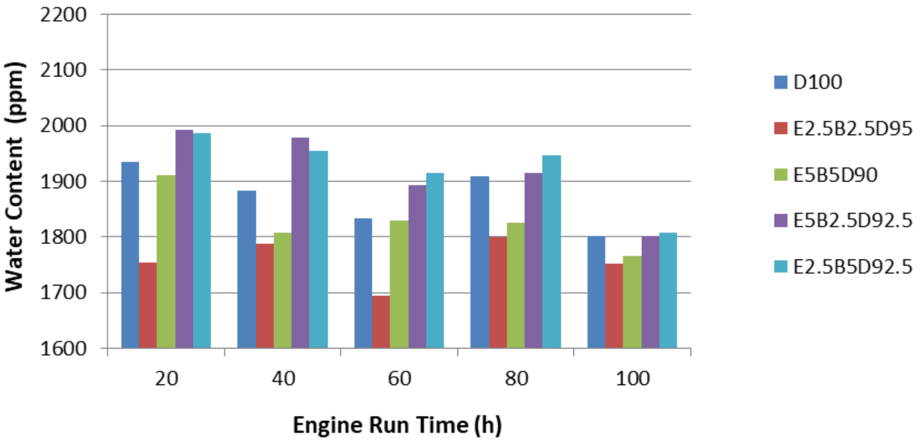

Figure. 6. Water content values of the engine lubricating oil

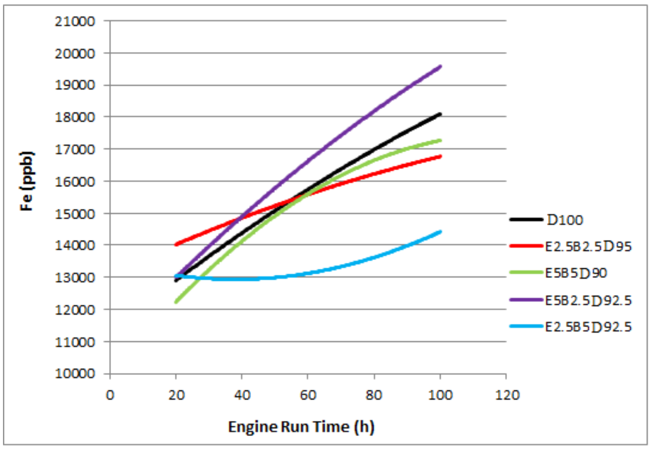

Figure. 7. The amount of iron in the engine lubricating oil

3.6. Copper (Cu) element

It exists in bronze and brass alloys. This metallic formation is in gear and valve disks, some types of gear, turbocharger bearings, cam bearings and piston pin bearings; many gear systems with high copper content and break plates that contain sintered bronze. In case of a high copper level, corrosion formation in oil cooling system must be paid attention [14].

In Figure 8, in the usage of diesel fuel-biodiesel-bioethanol fuel blends, the values of copper element (Cu), one of the corrosion products in the engine lubricating oil, are seen. When the graphic is examined, it is seen that as the engine run time increased, the amount of copper in the engine lubricating oil increased, too. According to $D_{100\ \mathrm{fuel}}$, it was determined that the amount of copper element (Cu) decreased by 46.43%, 20.44%

and 27.93% respectively in $E_{2.5}B_{2.5}D_{95}$, $E_5B_5D_{90}$ and $E_{2.5}B_5D_{92.5}$ fuel blends from the 20th hour to the 100th hour of engine run time but it increased by 53.27% in $E_5B_{2.5}D_{92.5}$ fuel blend.

3.7. Aluminum (Al) element

It arises from pistons, piston head and piston rings, shaft bearings. It can be detected in high proportions in the samples taken at the end of the first start hours, especially after the machine production and the revision. When this metallic formation is in high ratio in the analysis, it can be thought that there is dirt in air induction system and in oil filter, and there is a problem in valve covers and oil pan. In the progressive aspects, some problems occur like excessive oil consumption, the loss of performance and abnormal machine sound [2, 14].

In Figure 9, the values of aluminum (Al), one of the corrosion products in the engine lubricating oil in the usage of diesel fuel-biodiesel-bioethanol fuel blends, are seen. When the graphic is studied, it is seen that as the engine run time increased the amount of aluminum in the engine lubricating oil increased, too. According to D_{100} fuel, it was determined that the amount of aluminum (Al) element increased by 23.80% and 53.72% respectively in $E_{2.5}B_{2.5}D_{95}$ and $E_5B_{2.5}D_{92}$ fuel blends from the 20th to 100th hour of engine run time but there was no remarkable change in the fuel blends of $E_5B_5D_{90}$ and $E_{2.5}B_5D_{92.5}$.

3.8. Lead (Pb) element

It is generally used for covering. It can come from the corrosion of journal bearings or lead tin solder and some sealing components. It can exist in gear and clutch system and brake friction plates. Also it can occur due to the fuel [5].

In the Figure 10, the values of lead (Pb) element, one of the corrosion products in the engine lubricating oil in the usage of diesel fuel- biodiesel- bioethanol fuel blends, are seen. When the graphic is examined, it is seen that as the engine run time increased, the amount of lead in the engine lubricating oil increased as well. According to D_{100} fuel, it was determined that the amount of lead (Pb) decreased by 63.95%, 68.36% and 90.81% respectively in $E_{2.5}B_{2.5}D_{95}$, $E_5B_5D_{90}$ and $E_{2.5}B_5D_{92.5}$ fuel blends from the 20th hour to the 100th hour of the engine run time but it increased by 2.40% in $E_5B_{2.5}D_{92.5}$ fuel blend.

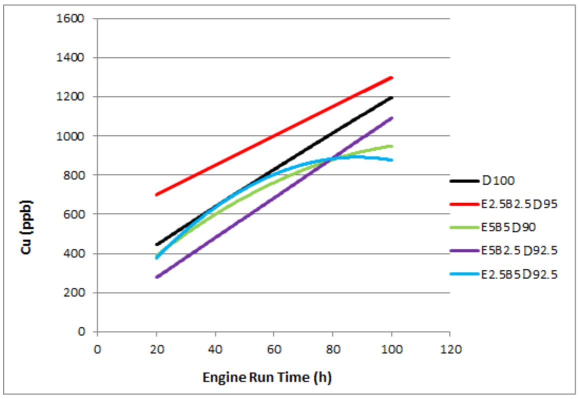

Figure. 8. The amount of copper in the engine lubricating oil

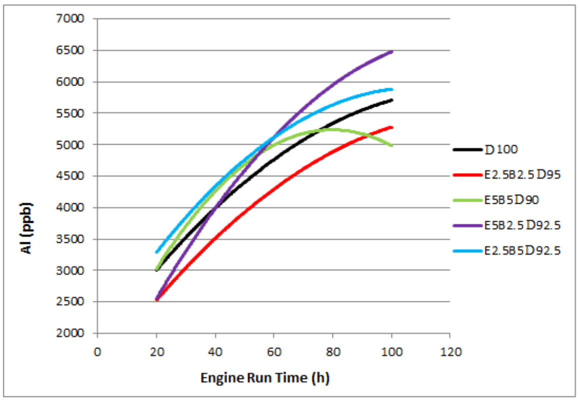

Figure. 9. The amount of aluminum in the engine lubricating oil

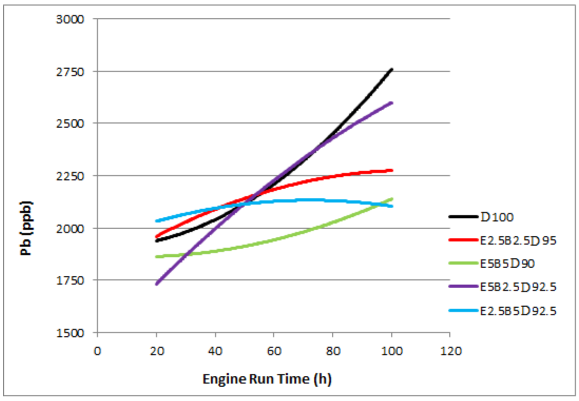

Figure. 10. The amount of lead in the engine lubricating oil

3.9. Chromium (Cr) element

Chromium is generally used as the coating material of the machine elements. Chromium coated piston rings and chromium and chromium alloy machine parts constitute the sources of this metal. Also, it can come from gasket, cylinder and some insert bearings. The increase of the air pollution in the cylinder and in the broken rings enhances the proportion of this metal. The detection of the increase of this metal shows that there is excessive oil consumption or oil leakage and deterioration in the oil quality [2].

In the Figure 11, the values of chromium (Cr) element, one of the corrosion products in the engine lubricating oil in the usage of diesel fuel- biodiesel- bioethanol fuel blends, are seen. When the graphic is examined, it is seen that as the engine run time increased, the amount of chromium in the engine lubricating oil increased as well. According to D_{100} fuel, it was determined that the amount of chromium (Cr) element increased by 4.77% and 59.07% respectively in the fuel blends of $E_{2.5}B_{2.5}D_{95}$ and $E_5B_5D_{90}$ from the 20th hour to the 100th hour of the engine run time but it decreased by 66.86% and 85.63% in $E_5B_{2.5}D_{92.5}$ and $E_{2.5}B_5D_{92.5}$ fuel blends.

In the oil analysis, when the graphic of corrosion elements was studied it was seen that the usage of some blend types showed a decrease after the 50th hour of engine run time. When these blend fuels are used in internal combustion engines, the changing period of the engine oil extends.

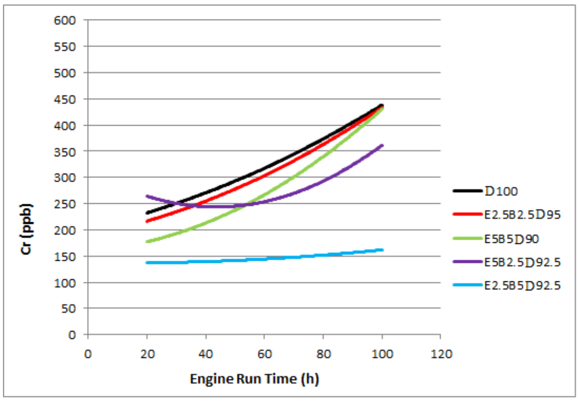

Figure. 11. The amount of chromium in the engine lubricating oil

As a result of the engine tests, the results, which were obtained when analysis values of corrosion elements in the lubricating oil were studied, showed similarities with the results of the studies performed by Kılıç [5]; Avcı [2] and Müjdeci [14] in terms of engine oil of diesel fuel and they showed similarities with the results of the studies by Kara [15] and Özçelik [16] in terms of the fuel blends of biodiesel-diesel fuels.

In the literature studies, no researches were found about the corrosion element analysis of bioethanol-biodiesel-diesel fuel blends in the engine lubricating oil.

4. Conclusions

When the ICP analysis results of the engine lubricating oil were studied it was seen that as the engine run time increased, the amount of iron, copper, aluminum, lead and chromium, which were the corrosion products in the oil and the most important signs of the corrosion in the engine, increased as well.

As a result of the tests, when it was evaluated in terms of lubricating oil, it was detected that the most suitable engine-fuel blend was $E_{2.5}B_5D_{92.5}$ fuel in the usage of diesel fuel - biodiesel - bioethanol fuel blends.

The reason is that cetane number of $E_{2.5}B_5D_{92.5}$ was higher than the other blends as seen in Table 3. The high cetane number makes the engine run silently, affects the increase of combustion efficiency and makes the first movement of the engine easier.

Acknowledgement

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