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THE ENGINE PERFORMANCE OF A DIESEL ENGINE AND THE RESEARCH OF THE EFFECT OF FUEL ADDITIVES ON ENGINE OIL AND ENGINE PARTS

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ABSTRACT
In this study, the development of properties of diesel fuel, and the effect of methanol fuel on engine performance and on engine parts have been researched. For this purpose, this study consists of the analyses respectively in that organometal MnO_2 synthesis, fuel analysis, engine tests involving the values of the engine performance and the effect of methanol used in this study on engine lubricating oil have been examined. Experiments have been made by adding methanol into 1 liter fuel in the rates of 5%,10% and 15% under 200 bar pressure of the injector spray in the diesel engine having 4-cylinder with direct-injection. The 1% of dodecanol has been added to each one of the fuels mixtures with methanol-diesel in order to prevent the phase separation. The effects of methanol fuel adding to diesel fuel in certain properties on engine performance, engine lubricating oil, and on engine components has been researched. In addition, the organometallic compounds of Mn have been synthesized and their solutions have been prepared in order to improve the fuel properties. The effectives on the values of engine performance of the additive, which is effective on the freezing point of fuel and cetane number, have been tried to determine by using methanol-diesel fuel with $Mn0_2$-diesel fuels.

Keywords: *MnO_2 organometal, methanol-dodecanol*

1. Introduction

Countries are turning to new sources of energy to meet their own energy needs. Energy needing along with it requires the exploration of energy resources and the evaluating of best available sources. In addition, to conserve the environmental awareness for countries to meet the energy need, to increase efficiency, and to ensure the diversity of the sources and their continuity are becoming more important. The legal restrictions have encouraged the efforts to diminish exhaust emissions emitting from engine vehicles to the environment. Both the emission control methods and the works done for alternative fuels have continued heavily in order to meet the requirements of legal restrictions [1, 2].

The main engine fuels s an alternative to petroleum are alcohols (ethanol, methanol), natural gas, biogas, hydrogen, and vegetable oils. Alcohol, alcohol-gasoline and alcohol-diesel mixtures are most widely used. Alcohols (ethanol, methanol) cause the positive effects in the exhaust emissions because of the molecular structure having smaller than diesel fuel, not carrying oxygen in their structures and not containing sulfur carcinogenic n substances and heavy metals which diesel fuel has [3,4]. Alcohol has failed to show a well-improvement until recently because of the reasons that it is more expensive than petroleum products, the amount of water in the structure of alcohol causes a corrosive effect slightly on the fuel systems of the vehicle engines, and also the phase separation becomes. However, a lot of researches on alcohols with the aim of getting fuel had been made during the energy crises and after the crises had been overcome the studies were slowed down. It is considered that methanol has the popularity to be the highest within the alternative alcohol fuels. The fact that methanol can be produced from different items in number, that it costs cheaper than alternative fuels, and that it create a cleaner burning can be considered in the most important reasons for this [2,5,6]. Methanol can be also produced by using raw materials like domestic waste, municipal solid waste, and recyclable wood [7]. Methyl alcohol is one of the most common industrial solvents. Methanol has a much more wide flammability limits when it is compared to gasoline and diesel oil. For this reason, the saturated steam in the storage or transport tank can be explosive in the environmental temperatures. Methanol burns with a clear flame and it is hard to see it. In stoichiometric mixture, a massive amount of air that is required is 6.44 kg. This feature is an advantage in terms of exhaust emissions [8]. The most important factor that prevents a direct use of methanol in diesel engines is the low cetane number. As it is well known that cetane number of methanol is 3 according to CFR [2009]. When considering, this value is 14 for normal petrol and is between 40-60 for diesel fuel, it is obvious that the pure methanol is not used as fuel for diesel engines [9].

To improve the properties of diesel fuel and in order to eliminate problems that may arise, the fuel additives together with fuel is used in the engines. At the beginning of the factors that determine the quality of fuel, additives are used. These additives are chemical substances that have been produced to give a variety of features to the fuel, adding to the fuel in the proportions of certain. In these properties of the fuel, cetane number is of a great importance in terms of engine performance and exhaust emissions. These additives increase the cetane number from 45 to 55 values [10]. Another method used to improve the properties of the fuel is that organometal compounds can be added into the fuel. These are compounds, in which carbon-hydrogen atoms are attached to a metal. It is indicated that organometallic additive prevents the reactions which make up branching in hydrocarbons when manganese-base additives are used and it has made them flat by breaking the bonds of carbon in the branched structure. It prevents the deposition of the bottom by creating hydrocarbons that are lighter structure, and provides the homogeneous dispersion of fuel within the tank.

Table 1. The structures used in the synthesis of organometal and their amounts

Spindle oil	250 g
MnO_2	45 g
Resin acid	100 g
Total	395 g

Table 2. The identification of the test fuels

Naming of the fuel	
D+20Mn	Organometallic manganese fuel additive in diesel fuel is 20ppm
D+40Mn	Organometallic manganese fuel additive in diesel fuel is 40ppm
D+60Mn	Organometallic manganese fuel additive in diesel fuel is 60ppm
D+80Mn	Organometallic manganese fuel additive in diesel fuel is 80ppm

In addition, the formation of the high-temperature corrosion that is called vanadium corrosion has been prevented [11,12].

2. Materials and methods

Experiments have been formed in 4 phases. These are; the synthesis of MnO_2 that is organometal compound to be used as an additive in the experiments, engine performance tests, fuel analysis, and the analyses made to demonstrate the impact of the types of fuel used on the engine oil and the parts. The same type of diesel fuel were used in all experimental studies and the diesel fuel used, that is sold in a commercial fuel station in Elazığ City, is a type of commercial oil. A good combustion in diesel engines is closely related to fuel specifications. These features are the physical and chemical properties of fuels. Organometal Mn is the first one of the additives to be added to diesel fuel that is used in these experiments to improve the properties of the fuel. With this aim, at first, by using MnO2 as a reactive, the compound was obtained. For the synthesis of the organometal compound, a reactor of 1000 ml was used. Spindle oil, which is in the organic structure, MnO_2 salt and abiyetik acids, which are in the structure of resinik acids, have got a reaction in the reactor.

Reaction has been realized in 180 ^{0}C during 2 hours in total. The obtained organometal compound contains 11,3% MnO_2 in the mass. At the end of the reaction, in order to solve the parts of the residue, 2% ethanol were added. The prepared organometal MnO_2 compound has been added into the diesel fuel in the amounts of 20, 40, 60 and 80 ppm. 8 hours previously the engine tests were begun; the mentioned fuel mixtures with the additives were prepared and incubated. The samples prepared in ppm have been prepared by applying the dilution process. After 1000 mg additive was added into the fuel of 1 lt, the intended amounts were taken out and the rest of it was completed in the amount of 1 liter.

The diesel fuel, to which organometal additive was added in different amounts, was called in table 2, and its ideal fall in its freezing point as a result of experiments made with the help of Tanaka MPC-102 device is 40 ppm organometal MnO2. In the second stage of the experiments, the fuel analyses made brought out the properties of the fuel as a result of the fact that the synthesized organometal Mn02 additive was added into diesel fuel at different rates.

The cetane number and the cetane index of the fuel was measured by the device of Zeltex ZX440 type which operates under the principle of infrared spectrometer. Samples have been calibrated in accordance with ASTM standards. For the viscosity determination according to ASTM D88 standards, in the device produced from the Ubbelohde measuring tube, Saybolt Universal Viscosity measurements were made. The measurements made were recorded in seconds. According to TS EN 14214 standards, measurements were made a 40 0C. Flash point determination was made with the help of a device of APM-7 model capable of measuring in accordance with Pensky-Martens closed cup method.

Table 3. The analysis results of compounds containing Mn

Fuels	Index	Cetane number	Viscosity (SSU)	Flash point (^{0}C)	Decrease in freezing point (^{0}C)
D	46.3	47	36	73	0
D+20 Mn	46.2	47,5	35	71.5	4,2
D+40 Mn	46	48,6	34.1	70	7,5
D+60 Mn	46.3	48,63	34.	69.8	8.2
D+80 Mn	46.2	49	33	69.3	8,5

Table 4. The engine's features used in the experiments

4-Cylinder Diesel Engine	
Number of cylinders	4
Injection type	direct
Stroke (mm)	105
Cooling liquid	Water cooled
Maximum torque (1500-1600 rev/min) (Nm)	320
Maximum engine power (1800 rev/min) (kW)	80
Max. speed (Min^{-1})	3000

The test set is composed of 4-cylinder diesel engine (Mitsubishi Canter), hydraulic dynamometer, the test panel (computer screen). Experiments were realized in the 4-cylinder diesel engine of Mitsubishi Canter model. For this engine with a maximum torque of 320 Nm at 1500 rpm (revs per minute), the specifications in Table 4 are explained.

Table 5. Dynamometer specifications

Torque range	0–1700 Nm ± 1
Speed range	0- 7500 rpm
Weight	45 kgf
Total weight	110 kgf
Body diameter	350 mm
Torque lever length	350 mm

Data received from the engine by the device connected to the computer unit were recorded in digital setting.

After the preparation of fuel additives, in the experiments made, firstly by running the engine idle for 15 minutes without load, it is projected that the engine comes to its operating temperature. After running the engine at low rpm speed, measures were taken in the specific ranges. In the engine's injection pressure and its advance, any changes have not been made according to the differences of the fuel. In this way, without being any modifications, it has been intended to approach the results, that may be occur in the use of fuel additives. During measurements, the values taken from the engine have been collected and recorded by the computer. After the first experiments made with the standard diesel fuel, the tests with methanol + dodecanol + diesel fuel were started. 1% dodecanol fuel adding separately into each one of test fuels, the experiments of methanol+diesel fuel in the rates of 5%, 10% and 15% have been completed. In the molecular level, dodecanol, which is an alcohol heavier than methanol, has been added into the mixture and so its stabilization has been provided and the phase mixture has been prevented, too [13]. Second, in the fuel experiments, with the contribution of the organometal Mn02 of 40 ppm, which gives the fall of the best freezing point, by adding the additive of 80 ppm, in which the cetane number was measured the highest, into 1 liter of fuel, the tests were conducted. Comparing the data obtained, it is aimed that this mixture can be developed by the addition of organometal Mn02 additive, which gives the best results, into the 10% methanol + diesel fuel.

3. Results and discussion

Specific fuel consumption is defined as the amount of fuel consumed per unit power. In order to provide the same performance, methanol with diesel fuel needs more fuel in the cylinder. In this way, it is thought that it causes the rising of the specific fuel consumption. When considering the results of the experiment made, it was seen that with the increase in the number of cycles, the specific fuel consumption decreases for all test fuels, and at 1500 rpm, at which the engine produces maximum torque, the specific fuel consumption reaches down to the minimum value. The reduction of the volumetric efficiency with the increasing of the engine cycle has led to increase the specific fuel consumption. Considering all the engine cycles, with the increasing of the methanol rate in the diesel fuel, an increasing was determined in the consumption of specific fuel. Because of the low energy content of methanol, its specific fuel consumption is higher than diesel fuel. Compared to diesel fuel, an increase in the rate of 4,5% in the % 5M + D fuel, 8,8% in the 10% M+D fuel and 13% in the 15% M+D fuel was determined. The first cause of the increasing of specific fuel consumption for the test fuels containing methanol is that the heat value of methanol is low [14].

When Figure 2 is examined, the organometal additives together with the amount of Mn added fuel, specific fuel consumption has decreased. It is thought that due to the fact that organometal Mn additive, which causes the viscosity and flash points of fuels to fall, affects the combustion in a positive way.

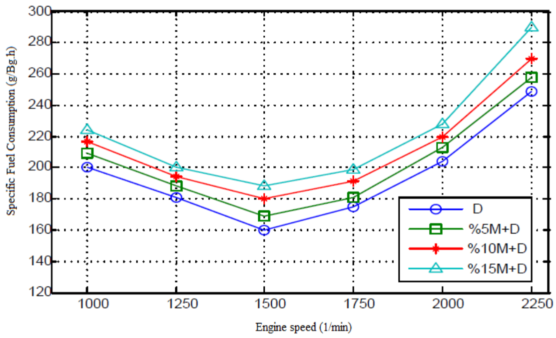

Fig. 1 – The effect of the mixtures of methanol-diesel in the changing proportions and of the cycle number on specific fuel consumption

When the exhaust emission values are analyzed, it is determined that the acting of the organometal Mn as a catalyst during combustion has created better results. Considering the specific fuel consumption, engine power and moment values, it is clear that the additive does not constitute a change very much. For all speeds, when the reference is compared with the diesel fuel, the 40Mn additive in the rate of 2,4% and the 80Mn additive in the rate of 3,9% have provided a reduction. This decrease in the specific fuel consumption can be explained by the increase of cetane number of the fuel, and the decrease of the viscosity of the fuel and the fall of flash point.

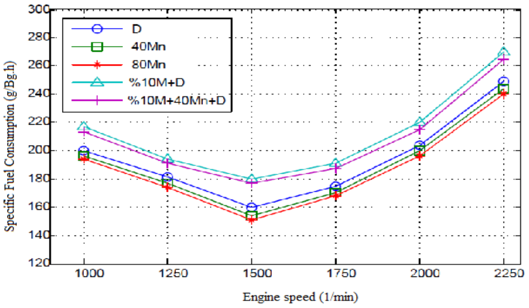

Fig. 2 – The effect of changing fuel types and of the cycle number on the specific fuel consumption

The power obtained within a cycle in the cylinders of the engines is called as indicate power. Indicate power does not include mechanical losses occurred in the engines. High viscosity and density causes the fuel not to be sprayed from the injector in an atomized way. This state extends the time of combustion delay and it causes the deterioration of combustion. Calculating the power of the engine, the maximum pressure occurred as a result of combustion is ignored, because this pressure in the work time declines rapidly as a result of the volume growth. For this reason, in the calculating of the engine power, the average indicative pressure is used [15]. The addition of methanol into the diesel fuel has led to a decrease of engine power with the increase of the rate of methanol in the mixture. This decrease is more than the previous one. For all the engine cycles, the reductions have been determined at the rate of 9% for the fuel of 5%M+D, of 12% for the fuel of 10%M+D and of 17,1% for the fuel of 15%M+D.

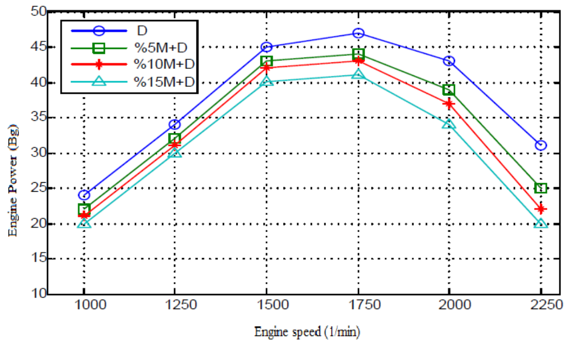

Fig. 3 – The effect of the mixture of methanol-diesel and of the cycle number in the changing proportions on the engine power

The engine power has increased up to a certain cycle number and in the average 1800 r/min, the engine speed has began to decline. The effect of the changing types of fuel and of the cycle number on the engine power is given in the figure 3. This reduction can be explained by the fact that the time allocated for combustion is short and the volumetric efficiency decreases. When figure 3 is examined, it has been determined that the engine power is low due to the fact that the combustion efficiency is poor at the low revs. In the middle revs, due to the improvement of the combustion, the engine power has been increasing for all the test fuels. However, for the revs coming after the middle revs, the engine power has shown a decrease for all the test fuels. This state can be explained by the fact that the time allocated for the combustion has reduced together with the increased rev, that the volumetric efficiency has fallen and that the frictions have increased. This increase has become until the engine cycle in which the maximum power has been obtained. In the engine power values in the diesel fuel, into which organometal Mn has been added, a very little increase has been provided. It can be thought that even if it is at a low rate, this increase in the engine power, it can be stemmed from the increasing of the fuel cetane number and from the low viscosity. The fact that there is the sufficient period of time in order for the combustion act of the fuel with the help of the additive, and that it effects the combustion in a positive way due to the atomizing better in the cylinder, as provided a contribution with the engine power.

In case of the full loading of the engine, and in all the engine speed, the effect of the mixture of the methanol-diesel in the different proportions on the engine moment can be seen in the figures. That the sub-heat value of the methanol and the cetane number are low has resulted in a low engine torque in all the methanol-diesel mixtures in comparison with the reference diesel fuel.

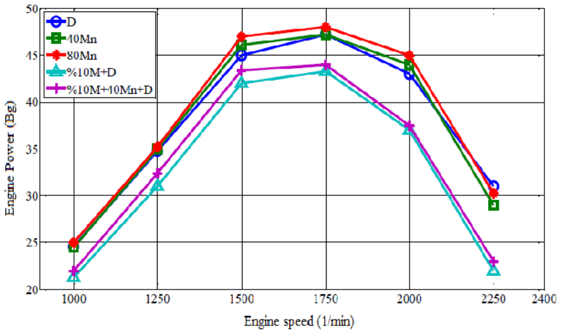

Fig. 4 – The effect of the changing types of fuel and of the cycle number on the engine power

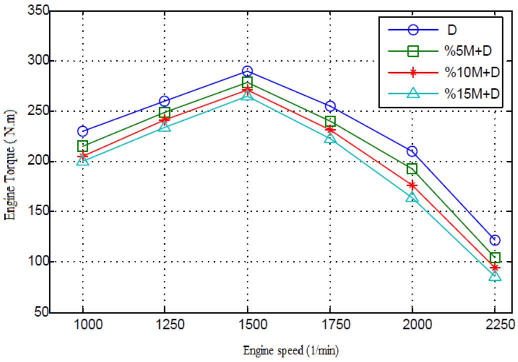

Fig. 5 – The effect of the changing proportions of methanol-diesel mixtures and of the cycle number on the engine moment

Reduction in the number of cetane has caused both the increase of the ignition delay period and the sufficient time for the combustion not to be formed. It has been seen that as long as the methanol ratio increases by volume in the mixture, the engine torque decreases. In the measurement made in the range of 1000-2250 r / min, the lowest engine moment has been obtained in the fuel of 15 %M + D. In the engine torque values, a reduction has been recorded in the rates of 6,3 % for the fuel of 5%M+D, of 10% for the fuel of 10%M+D, and of 14,3% for the fuel of 15%M+D. That methanol reduces the temperature of the cylinder extends the duration of ignition delay and due to the low cetane number, the engine knock increases. Accordingly, the combustion quality of the fuel decreases and the thermal efficiency reduced. Due to the excessively cooling effect of methanol, the event of the flame extinguishing is effective on the reduction of the torque [16].

When the test results are analyzed as a result of an addition of organometal Mn, the insignificant changes have not been observed. The adding of the additive of 40Mn into the mixture of the methanol-diesel fuel, the values of the engine performance has increased at the rate of 3% in comparison with the fuel of 10%M+D. The increase of amount of air in the cylinder causes the temperature to rise inside the cylinder.

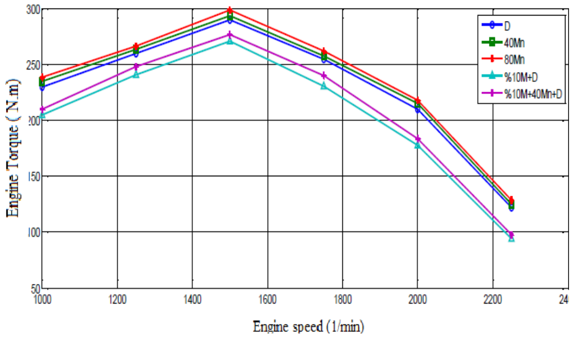

Fig. 6 – The effect of the changing types of fuels and of the rev number on the engine torque

When the test results are analyzed, the added methanol amounts enhances the temperature of the exhaust gas. The increase rate of the temperature increasing has been found approximately as 4% for the fuel of 5%M+D, 6,8% for the fuel of % 10M+D, 9,6% for the fuel of 15%M+D.

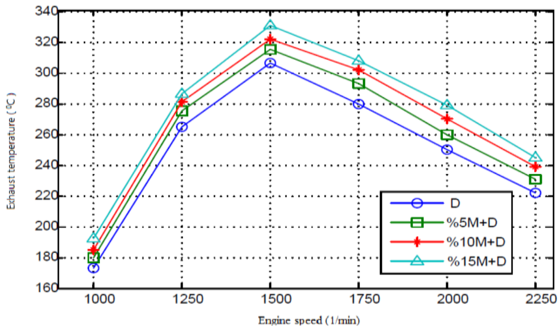

Fig. 7 – The effect of the methanol in the changing rates and of the cycle number on the exhaust temperatures

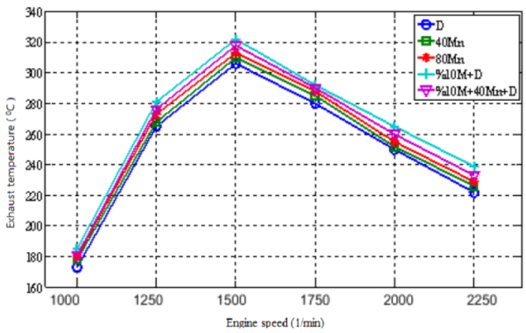

Fig. 8 – The effect of the changing types of fuel, and of the cycle number on the exhaust temperatures

In the range of cycle in which the maximum moment is obtained, the recovery of combustion leads to the increase of temperature. The shortening of the time allocated for combustion causes the fuel not to burn fully. In the calculating of all the data obtained in all the cycles, when the temperature values containing Mn additive are compared to the fuel D, these values shows a slight increase, even if they are low. It is thought that the increasing of the cetane number of the fuel causes both the decreasing of the ignition delay period formed by methanol and the reduction of the temperature of the combustion ending [7]. The increase of the proportion of methanol in the mixture causes the prolongation of the ignition delay period. Relating to the exhaust temperatures formed as a result of combustion in the cylinder, two different views are common. According to the first of these, for the cetane number of methanol is low, the ignition delay period in the cylinder extends. Therefore, the rate of the sudden pressure in the cylinder increases and this leads to a maximum temperature. Another view is that compared with diesel fuel, due to the fact that the secret heat of evaporation is high, the flame heat during the combustion and exhaust temperatures reduces. The main reason of the increase of the ignition delay period is that there is the the excess of oxygen in the structure of methanol and it pulls the cetane number of the fuel that is 47 down to the average level 40. The fact that methanol fuel enhances the combustion heat shows the parallelism with the increase of the temperature in the engine oil. [14, 17].

In order to research the effect of methanol on the engine oil and on engine parts, diesel engine oil 20/50 of Petrol Office has been used as the lubricating oil in the experiments. In Lombardini 6 LD 400 single -cylinder diesel engine without load, and in the room conditions, the engine oil has been subjected to a work of 100 hours. After the test ended, in order to see the changes occurred on the engine oil, the oil in the engine was taken into a suitable container for analyses. The first one of the two engines, whose specifications are the same, has been operated using the 100 % diesel fuel in the same experimental conditions and the other engine has been operated using the fuel of 10% M+D for 100 hours, too. Two different engine oils at the certain rates by their weights being waited for 2 hours in drying-oven has been put into dried crucibles and according to ASTM standards, these engine oils being waited in 1200°C in the oven and the crucibles have been weighed on the delicate scale. As a result of the engine tests of 100 hours together with this operation, the ash ratio of the diesel oil worked by the fuel of 10% methanol-diesel is 2.08%, and the ash ratio of the lubricating oil has been detected 1,3% by weight. In the end of work, considering the amount of the ash of the measured test oil, the amount of the ash of the lubricating oil working with the fuel of 10% diesel+methanol is 60% more than the lubricating oil of the diesel fuel. According to this increasing rate, it can be said that due to the above-mentioned reasons, methanol breaking the property of the lubricating oil enhances the amount of deposit in the lubricating oil [18,19]. Alcohol that is added into engine oil brings about some problems in vehicle. It is possible that some problems occur as follows: the build-up in the combustion chamber, the setting distortions in the fuel system, the dilution of lubricating oil, the piston ring jam, the corrosion on the cylinder surface, and the spoiling of the lubricating oil in the engine. Due to a high temperature generated by methanol during combustion, a partial oxidation occurs and can cause the Piston ring to jam in the slots. As a result of this jam, the wear between the Piston ring and cylinder wall increases. High ignition temperature extends the ignition delay period and the pressure increasing rate occurred in the phase of a sudden combustion, which rises above normal, causes the increasing of the diesel knocking. Depending on the severity of the knocking occurred in the combustion chamber, it creates the deformations on the piston and in the combustion chamber [17, 20].

Table 6. The mass ash ratio of the diesel oil in the end of the work of diesel and methanol-diesel engine of 100 hours

Fuel	Ash ratio of engine oil (%)
For Diesel fuel	1.3
For %10 M+D fuel	2.08

The results showed that, after 100-hour engine tests, the lubricating oil from the engine using 10% methanol-diesel fuel contained 2.08% ash, whereas the ash content of lubricating oil from the engine using diesel fuel was 1.3%. Looking at the amount of ash at the end of the study measured the test oils, the ash content lubricating oil in the engine using 10% methanol + diesel fuel was reduced by 60, compared with the oil lubricating the engine using diesel fuel. In the experiments made, both the addition of methanol into the fuel and the increase of the combustion temperature, which methanol causes, have reduced the viscosity of the lubrication oil. According to the analyses made in Engler viscometer as a result of the measurement made in 32°C, when the methanol at the rate of 10% is used, the viscosity of the oil reduces at the rate of 6,3%.

Table 7. The viscosity value of engine oil as a result of the working of the diesel and methanol-diesel engine of 100 hours

Fuel	Viscosity value of engine oil (32 °C) SSU(Saybolt Universal)
For diesel fuel	116
For %10 M+D	109

In order to show the effect of the lubricating oil in the engine, the first compression piston ring disassembling has been made ready for SEM analyses. Another engine, whose engine specifications are the same, has been operated for 100 hours by using the fuel of 10%M+D in the same experimental conditions, and the first compression piston ring taking out from this engine has been cleaned and made ready for SEM analyses. Especially at the low temperatures, the strained oil from the cylinder has reached to the crankcase and the oil film has been washed by the fuel addition that has been accumulated towards down. When the engine is firstly operated, the oil pump pulls the oil from the crankcase, and this will take a certain time to transport it through the channels to the cylinder, piston and piston ring. This is called the lubrication delay. Because the engine has been running until this time, the cylinder-Piston ring and the piston surface have been lubricated inadequate. This case causes piston ring -piston and the cylinder to wear more than its normal wearing. In the figure 7, SEM photographs have been given taken from over the surfaces of the piston ring run with the fuel of the diesel and methanol. [21].

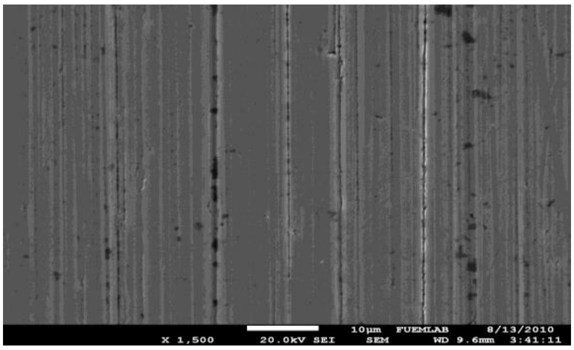

Fig. 9 – SEM photographs with the x 1500 magnification taken from over the cross-section of the engine piston ring run by diesel fuel

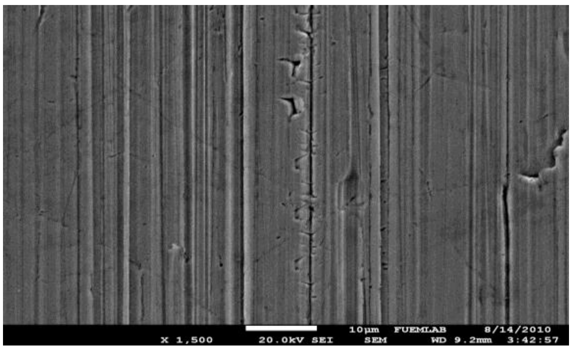

Fig. 10 – SEM photographs with the x 1500 magnification taken from over the cross-section of the engine piston ring run by the fuel of 10% M+D

The corrosions that occur too much in the engines are the corrosions of piston ring, piston and cylinder. However, the compression and oil piston ring s have been continuously scratching the lubricating oil over the surface of the cylinder wall. In the wear mechanism, this case causing a partial tear of the oil film starts an abrasive corrosion. In general, when we look at the SEM photographs of the engine piston ring s in which the diesel and methanol fuel are used, it is seen that there are the deeper wearing lines on the surface of the Piston ring run by methanol fuel. This case can be explained by the fact that the solvents in the chemical structure of methanol decrease the viscosity of the lubricating the wear increases.

4. Conclusions

The fact that methanol forms atom C less than diesel fuel, that it keeps oxygen in its structure, and that it has a molecular structure smaller than diesel fuel, has affected the combustion in a positive way. The excess of the oxygen in the structure of methanol enhances the temperature of combustion. Compared with the diesel fuel, the sub-heat value of methanol is lower than it, and this case enhances the specific fuel consumption and reduces engine performance. If methanol is added into the diesel fuel, it reduces the engine power. For all the engine cycles, the reduction in the engine power has been detected in the rate of 9% for the fuel of 5%M+D, of 12% for the fuel of 10% M+D, and of 17,1% for the fuel of 15% M+D.

In order to improve the properties of the fuel, organometal additive Mn02 has reduced the freezing point of the fuel in the amount of the most appropriate dosing. In addition, adding of the additive into the diesel fuel has reduced the flaming point and the value of viscosity. The reduction in the viscosity shows that the diesel fuel has been exposed to the catalytic cracking with the additive and the substances like paraffin have been resolved. Organometal MnO2 has a positive effect on the cetane number of the fuel. Methanol that is added into the fuel refines the lubricating oil of the engine. As a result of a 100 hours' operation, when compared the engine oil, in which diesel fuel has been used, with the lubricating oil, in which the methanol fuel has been used, the engine oil has reduced at the rate of 6,3. Methanol that thins engine oil enhances engine wearing. It is thought that the partial oxidation, which is formed by the high temperature created by methanol, causes the jams in the slots of the Piston ring. Looking at the results of SEM photographs of the engine Piston ring s in which the diesel and methanol fuel are used, it is seen that there are the deeper wearing lines on the surface of the Piston ring run by methanol fuel.

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