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Research Article

Emission and Lubrication Performance of Hazelnut Oil as A Lubricant

Arzu KEVEN[1*], Cengiz ONER[2]

[1] *Dep. of Vehicle and Transp. Technol., Golcuk Voc. High School, Kocaeli University, Kocaeli, Turkey.*
* **Corresponding Author** : **Email:** arzu.keven@kocaeli.edu.tr - **ORCID:** 0000-0003-0040-9167

[2]*Dep. of Mechanical Engineering, Bingol University, Bingol, Turkey.*
Email: coner@bingol.edu.tr - **ORCID:** 0000-0002-3278-2831

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Abstract:

The aim of this study is to search the tribological and emission performances of hazelnut oil as a lubricant in one cylinder two-stroke gasoline engine and simulation-testing machine. The tribological and emission performances of mineral oil and hazelnut oil as lubricant were compared. In the experiments, simulation-testing machine and one cylinder two-stroke gasoline engine were used to determine the tribological performance of these two lubricants. The wears on the surfaces of cylinder were analyzed to examine the lubricant performances. In addition to lubrication performance, exhaust emissions of the lubricants were also measured. To observe the effects of different kinds of cylinder surface materials, TiN, CrN and gray cast iron coated cylinder surfaces were used in simulation testing machine. The wear as well as the soot formation on the cylinder surfaces increased when hazelnut oil was used as the engine lubricant. However, hazelnut oil exhibited good lubrication properties in simulation testing machine. When hazelnut oil was used, CO and HC emissions increased while CO_2 emission decreased.

1. Introduction

Turkey is an important hazelnut producer country in the world. This makes it a popular choice as alternative fuel and lubricant. The rise in energy demand and the finite reserves have made the renewable alternative energy sources, the high efficiency of energy conversions, the minimal harmful effects to the environment and the recovery of previously unused energies very important [1, 2, 3, 4]. As can be seen in literature, investigations of harmless, alternative, low emissions fuels to use in energy producing equipment are the real problem must be solved [5, 6, 7]. The moving parts of a two-stroke engine are lubricated either by adding lubricant into the fuel of by pumping oil from a separate tank. Two-stroke internal combustion engines produce more contaminations and emission than the four-stroke ones, because of oil burning in the combustion chamber [8]. Since the ineffective lubrication caused from different lubricant system, the wear occurred in a two-stroke engine is more than that of a four-stroke one [9]. The wear and friction mechanism of a fuel engine is very important and essential topic to study on. The new methods have been improved to reduce friction and wear in the surface of the cylinder and the piston ring of the internal combustion engines therefore various lubricating oil were produced. There is an increasing interest about using of vegetable oil which can be played a very important role to substitute the petroleum lubricant, as it possesses lots of advantages over base lubricant like environmentally friendly, renewability, less toxicity, biodegradability and so on [10]. Some authors suggest the importance of the use of vegetable oils for the engine wear because of the mineral oil derived from petroleum oil is toxic and non-biodegradable [11]. Masjuki *et al* [12] used mineral oil-based lubricants and palm oil in a two-stroke single cylinder gasoline engine. In exhaust emission tests, the engine was operated at different loads while constant load was used in wear tests. The results of the experiment showed that the palm oil-based lubrication oil has a better performance in wears, and the mineral oil-based lubricating oil showed better performance about the friction. Also, showed that the palm oil-based lubricant is better effective in reducing of CO and HC emission levels. By using a universal wear and friction test machine to simulate a two-stroke internal combustion engine bench wear test is done. Igartua *et al* [8] investigated alternative eco-friendly lubes for clean two-stroke internal combustion engines. By selection of optimal synthetic esters base oil high performance lubricant with ethanol-containing fuels was improved. From this lubricant, very good wear resistance obtained, also ashless and low carbon soot deposit formation were happened. Jayadas *et al* [10] investigated tribological performance of coconut oil as lubricant. They evaluated the tribological properties of coconut oil by using a four-ball tester and a test equipment to test the wear of a two-stroke engine. The antiwear/extreme pressure additive influence on the tribological performance of coconut oil was investigated. The AW/EP addition improved the lubricity of coconut oil and decreased the wear on the surface considerably. İşler *et al* [13] investigated different oils for 10w40 motorcycle engine with four strokes. Mineral, bio mineral, synthetic, biosynthetic based oils were prepared and the lubricant properties are showed in their study. The best lubricity values for engine oils were obtained for biosynthetic lubricants at ambient temperatures. In this paper, it was concluded that 5% addition of canola methyl ester to the motor oil would give a lot of advantages to national renewable resources then importing crude oil. Tung and Gao [14] simulated the tribological characteristics using a modified friction machine with high frequency reciprocating. In a fixture holder reciprocating against the cylinder liner segment a section of piston ring installed. The ring coatings with thermal-sprayed CrN and physical vapor deposited diamond-like-carbon. The test results showed that compared to CrN coated piston ring, Diamond-like-carbon (DLC) coating decreased the wear of the cylinder surface but piston ring did not change. The micro-hardness and corrosion resistance of CrN coated cylinder is higher compared with gray cast iron cylinder, moreover the friction coefficient of CrN coated cylinder is smaller than that of gray cast iron cylinder [15, 16, 17]. In this study, to determine the tribological and emission performances of mineral oil and hazelnut oil by using in one cylinder two-stroke gasoline engine and in a simulation-testing machine as lubricant were aimed. Moreover, analyzing the wears on the TiN, CrN and gray cast iron coated cylinder surfaces and the soot formation on the cylinder surfaces were aimed.

2. Material and Methods

In the experiments, one cylinder two-stroke air cooled gasoline engine and simulation testing machine were used to determine the tribological performance of hazelnut oil. The two-stroke gasoline engine is an engine with displacement of 98.2 cc, maximum power of 3.5 hp and fuel/oil ratio of 20/1. The gasoline engine was loaded by pumping water from the water reservoir. In the two-stroke gasoline engine, lubrication was occurred by using mixture of oil and gasoline. The mixture of oil and gasoline burnt in combustion chamber. The gasoline engine is tested for 100 hours by using mineral oil and hazelnut oil as lubricant. After the experiments, the surfaces of cylinder were examined by using scanning electron microscopy to investigate the wear. In this study, the simulation testing machine was designed to obtain the wear mechanism similar to two-stroke gasoline engine. The simulation testing machine is shown in Fig.1.

Figure 1. *Simulation testing machine.*

In the simulation testing machine, the pressure applied by the piston ring to cylinder surface was 3.436 MPa. This testing machine was operated at constant load of 10 N and constant speed of 147 rpm. The gray cast iron, TiN and CrN coated cylinder samples were used as cylinder sample in testing machine. The cylinder samples were coated with 2 μm thickness using PVD (physical vapor deposition) technique. Stroke length of the cylinder sample is 120 mm. The simulation testing machine was run 40 hours for each cylinder material including gray cast iron, TiN and CrN coatings. To simulate the engine operating conditions, the temperatures of the lubricants and surface materials were increased to 200 °C by using a heater. The contact area between piston rings and cylinder surface was lubricated by pumping hazelnut oil and mineral oil. After the experiments in the testing machine completed, the wear losses in the cylinder samples were measured by using a sensitive balance.

3. Results and Discussions

3.1. Experimental studies in the two-stroke gasoline engine

Two-stroke gasoline engine was operated with mineral oil and hazelnut oil as lubricant at constant speed of 2800 rpm and constant load for wear tests. Fuel-oil ratio of engine was 20:1. After the experiments for both oils, the cylinder surfaces were examined. When mineral oil and hazelnut oil were used as lubricant, the situations of cylinders from two-stroke engine are given in Fig. 2 and Fig. 3, respectively. When hazelnut oil was used, wear and soot amount on the cylinder surface increased compared to mineral oil as seen in the Fig. 2 and Fig. 3. If the cylinder surfaces are examined carefully, cracks on these surfaces will clearly be seen in the Fig. 2 and Fig. 3. The wear and soot on the cylinder surfaces may be an indicator of abnormal combustion caused from hazelnut oil.

Figure 2. *The surface of cylinder when mineral oil when was used as lubricant.*

The cetane number of hazelnut oil was measured as 52. The higher cetane number (the lower octane number) of hazelnut oil may cause autoignition of fuel-air mixture. In a gasoline engine, autoignition causes abnormal combustion. In addition to cetane number, the carbon number of hazelnut oil was determined. The carbon number measured of hazelnut oil was 56. This carbon content of hazelnut oil may be caused soot formation. Properties of hazelnut oil and mineral oil were given Table 1. In the experiments, scanning electron microscopy (SEM) was used to understand the tribological performance of hazelnut oil and mineral oil.

Table 1. *Properties of hazelnut oil and mineral oil*

Property	Hazelnut oil	Mineral oil
Viscosity (cst) at 40 ºC	35	40
Viscosity (cst) at 100ºC	6.5	7.1
Carbon number	56	35

Figure 3. *The surface of cylinder hazelnut oil was used as lubricant.*

SEM analyses of the cylinder parts obtained the middle of the stroke when mineral oil and hazelnut oil were used as lubricant, are given in Fig. 4 and Fig. 5, respectively. These SEM analyses showed that wear on the surface of cylinder increased when hazelnut oil was used as lubricant as can be seen in Fig. 5. In addition to wear, Fig. 5 showed that hazelnut oil caused surface cracks on cylinder walls. SEM analyses of the surfaces obtained from near TDC (top dead center) of the cylinder when mineral oil and hazelnut oil were used, are given in Fig. 6 and Fig. 7, respectively. When SEM photomicrographs were compared, it was seen that wear of surface in TDC was more than that of surface in middle of stroke as can be seen in Fig. 6 and Fig. 7. From Fig. 7, it is understood that hazelnut oil caused more wear on cylinder surface than mineral oil as can be seen clearly. The wear and cracks on the surface of cylinder may be caused from worse lubrication properties of hazelnut oil compared to mineral oil. One of the most important factors which are effective lubricity performance of a lubricant is its sulfur content [16]. Sulfur content of lubricants and gasoline is given in Table 2. From Table 2, hazelnut oil has less sulfur content than mineral oil as can be seen. In this case, lubricant property of hazelnut oil was decreased. In Table 3, surface roughness values of the cylinder are presented. Table 3 showed that the surface roughness increased when hazelnut oil was used as lubricant. In addition, there was more surface roughness in TDC.

Table 2. *Sulfur content of lubricants and fuel*

Lubricants and fuel	Sulfur content (ppm)
Mineral oil	>990 ppm
Gasoline	9,1 ppm
Hazelnut oil	4,3 ppm

Table 3. *The surface roughness of the cylinder when mineral oil and hazelnut oil were used as lubricant.*

Cylinder surface	In used mineral oil surface roughness (Ra)	In used hazelnut oil surface roughness (Ra)
TDC	0,51 µm	0,67 µm
Mid-stroke	0,45 µm	0,50 µm
BDC	**0,41 µm**	**0,43 µm**

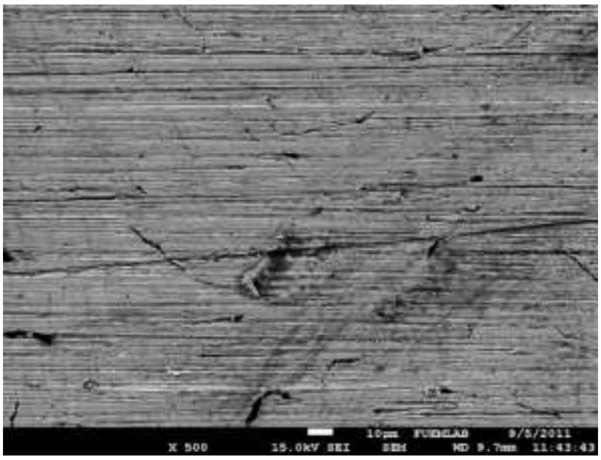

Figure 4. *SEM analyses of the middle part of the cylinder when mineral oil was used as lubricant.*

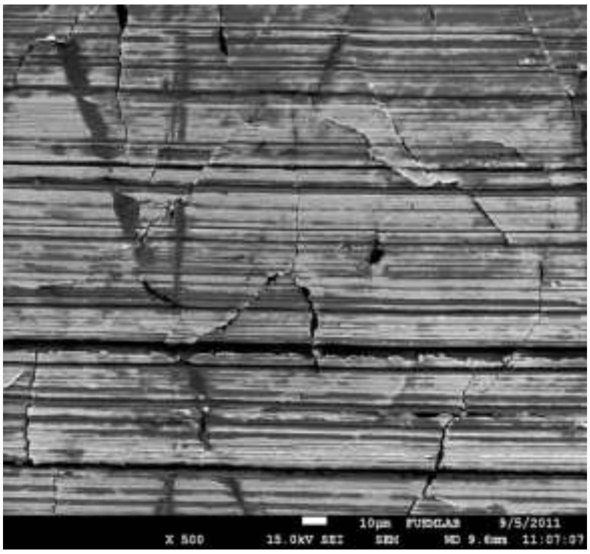

Figure 5. *SEM analyses of the middle part of cylinder when hazelnut oil was used as lubricant.*

3.2. Experimental studies in the simulation testing machine

Simulation testing machine was designed to simulate wear mechanism in internal combustion engine.

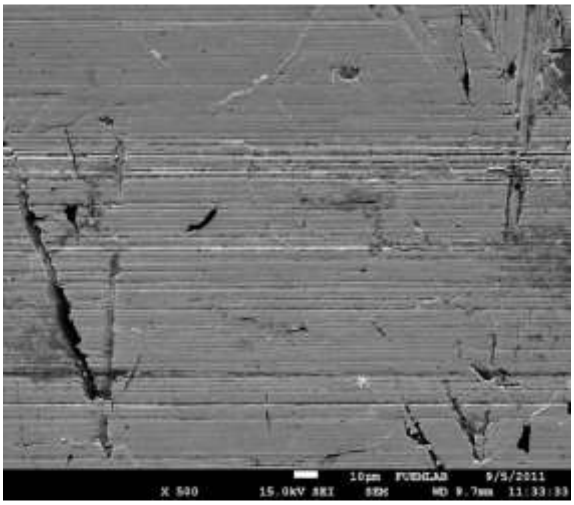

Figure 6. *SEM analyses of TDC (top dead center) of cylinder when mineral oil was used as lubricant.*

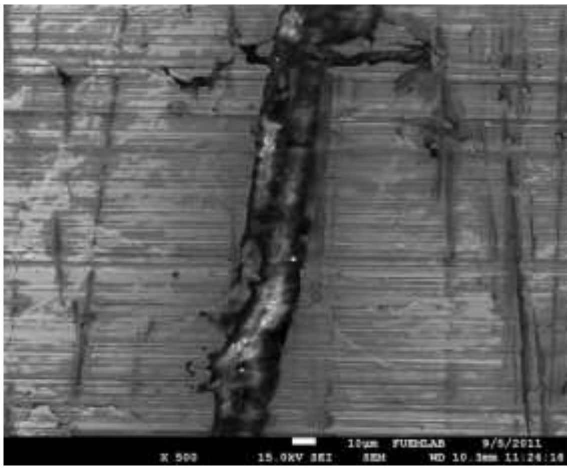

Figure 7. *SEM analyses of TDC (top dead center) of cylinder when hazelnut oil was used as lubricant.*

This testing machine was operated at regular interval (10 h). TiN and CrN coating in cylinder samples were used for reducing wear. At first, testing machine was operated by using gray cast iron cylinder sample. Then, testing machine was operated by using cylinder samples coated with CrN and TiN, respectively. The contact area between piston rings and cylinder surface was lubricated by pumping hazelnut oil and mineral oil. After the experiments, tested cylinder samples were cleaned using acetone and dried. These cylinder samples were weighted by using a sensitive balance to determine the wear loss. The weight losses of cylinder samples are given in Fig. 8 and Fig. 9 as can be seen. These figures showed that weight loss of cast iron cylinder sample was more than those of samples coated with CrN and TiN. In addition, the weight loss of cylinder sample coated with TiN was slightly more than that of sample coated with CrN. The properties of CrN and TiN are given in Table 4 as can be seen. From Table 4, friction coefficient of TiN was more than CrN as its seen clearly.

Table 4. *Properties of CrN and TiN*

Chemical composition	CrN	TiN
Coating range (µm)	2	2
Hardness, kg/mm^2	2200±400	2900±200
Friction coefficient	0,5	0,66
Surface roughness, Ra	0,2	0,2

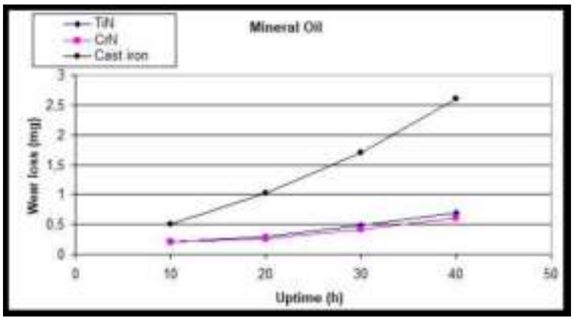

Figure 8. *Weight loss of cylinder samples when mineral oil was used.*

The more surface friction coefficient, the more wear. The wear resistance of cylinder samples coated CrN and TiN was more than that of cast iron cylinder sample. When Fig. 8 and Fig. 9 were compared with each other it was seen that hazelnut oil exhibited wear loss similar to mineral oil. The experimental results exhibited that hazelnut oil was not a good lubricant in two-stroke gasoline engine, but hazelnut oil was as a good lubricant as mineral oil in simulation testing machine. From table 1, viscosity change with temperature of hazelnut oil is similar to mineral oil as can be seen. Due to this viscosity property of hazelnut oil, it may be occurred as good a lubricant film as mineral oil between the piston ring and cylinder sample.

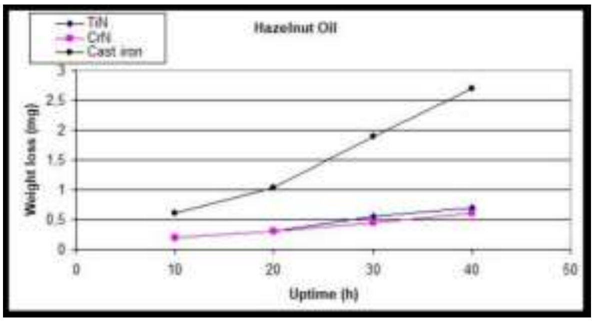

Figure 9. *Weight loss of cylinder samples when hazelnut oil was used.*

3.3. Exhaust emissions

In two-stroke gasoline engine, exhaust emission values were measured at constant speed of 2800 rpm. CO and CO_2 emissions are given in Fig. 10 and Fig. 11, respectively. It is known that CO emissions are formed because of incomplete combustion and dissociation of CO_2. When using hazelnut oil, CO emission increased while CO_2 emission decreased as can be seen clearly in Fig. 10 and Fig. 11. In addition to CO and CO_2, as can be seen in Fig. 12, hazelnut oil caused more HC formation than mineral oil. CO and HC emissions are the indicators of incomplete combustion. This incomplete combustion may be caused from knock resulting from low octane number of hazelnut oil compared to mineral oil.

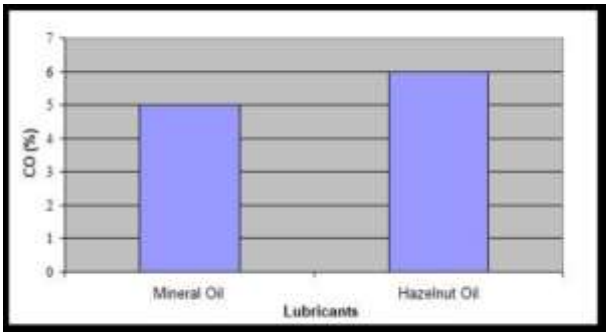

Figure 10. *CO emissions measured at 2800 rpm.*

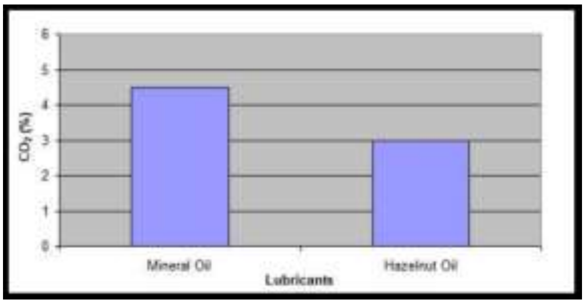

Figure 11. *CO_2 emissions measured at 2800 rpm.*

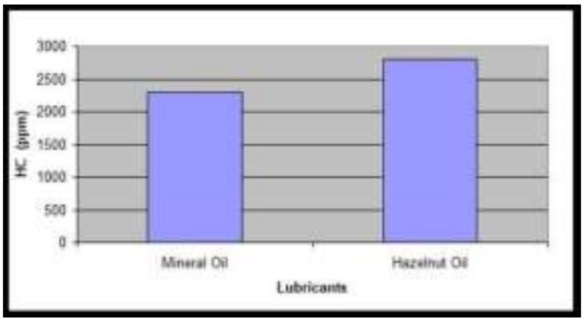

Figure 12. *HC emissions measured at 2800 rpm.*

4. Conclusions

In one cylinder-two-stroke gasoline engine, the analysis of SEM and surface roughness value exhibited that hazelnut oil caused more wear than mineral oil. The sulfur content, which one of most important parameters in terms of lubricity, of a mineral oil was much higher than that of hazelnut oil. As the result of low sulfur content, the lubricity performance of hazelnut oil was worse than that of mineral oil. In addition to wear, soot amount increased and cracks occurred in the surface of cylinder when hazelnut oil was used as lubricant The exhaust emission performance of hazelnut oil is not as good as mineral oil. When using hazelnut oil, CO and HC emission increased while CO_2 emission decreased. Mineral oil caused more good combustion within cylinder than hazelnut oil. The most sulfur content was found in mineral oil. This case exhibited that lubricant property of mineral oil was better than hazelnut oil. The experimental results demonstrated that are not useful hazelnut oil as lubricant in two-stroke gasoline engine. In the simulation testing machine, the best tribological properties were found in CrN coating. The weight loss of the TiN sample was slightly more than that of CrN sample. Hazelnut oil occurred as nearly good a lubricant film as mineral oil between two metal surfaces in testing machine. This study showed that hazelnut oil was not a good lubricant in two-stroke gasoline engine due to increasing wear and cracks on the cylinder surfaces while it was as a good lubricant in simulation testing machine.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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