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Detection of the Possible Engine Damages in Case of a Continuous Track Military Vehicles with Tribological Investigations

Detecting the engine failures of the continuous track military vehicles is challenging because their engines are always built-in narrow places covered with armored plates. In the case of the older engines, modern computer diagnostics cannot be used for failure analysis; the solution for these tasks is the visual analysis with the engine disassembly. A possible cost-effective failure analysis method can be the tribological and chemical analysis of the used oil from the engine, which can eliminate the engine disassembly work and as the results of the chemical oil analysis can also provide information about possible fuel or cooling water dilution or the increased wear of engine components.

The main goal of this article is to present the failure analysis method through the tribological investigation of the engines of two PTSZ-M type medium-tracked amphibious military transport vehicles.

Keywords: *military vehicle, internal combustion engine, tribological investigation, failure detection*

1. INTRODUCTION

In modern vehicles, computer diagnostics help the engine's operation, detection, and failure correction [1]. These methods cannot be used in the case of older engines because these engines are built with the original methods without integrating computer systems. To detect engine failures or components with increased wear, traditional detection methods must be used based on engine disassembly [2]. The disassembly of these military engines is a challenging and complex task in the case of continuous track military engines because, in the case of the tiniest maintenance, the armored cover plates must be removed to reach the engine itself. The complete engine must be removed from the vehicle chassis to reach the main structural elements, which is a very time- and cost-consuming task. To minimize the maintenance costs, the tribological and chemical analysis of the engine oil can be carried out for engine diagnostic purposes.

One of the main reasons for the engine failures is the increased wear processes on the surfaces of two rubbing components, which can cause malfunctions in the engine operation. These wear processes are strongly connected with the used lubricants and lubrication places of the engine. The currently available literature describes the following wear mechanisms, which are relevant in the case of internal combustion engines [3]:

a) Abrasion: long wear scars can be observed on the connecting surfaces in the direction of the relative movement. These wear a harder peak and can cause scars on the contacting surfaces (2-body abrasion) or by an external abrasive particle (3-body abrasion).
b) Adhesion: due to a local high temperature and load, the rubbing surfaces can be microscopically welded together, and the high local temperature will harden these welded areas. The continuous relative movement breaks these welded connections, which happen inside the materials of the connecting components.
c) Oxidation: the iron-containing materials connecting with the air can form an oxide layer on the surface, which can be fragmented by the relative movement and loads, which can cause the material detachment from the surface.
d) Fatigue or pitting: the rubbing surfaces can be fatigued by the repeated high mechanical loads, and the surface will be fragmented. Due to further loads, these fragments can be removed from the surface [4].
e) Erosion: the flowing gases or liquids always contain microscopical particles, and these fragments can harm the connecting surfaces and remove tiny wear particles from there. This wear usually occurs in case the flowing medium changes direction.
f) Cavitation: the flowing liquids contain solved gas molecules. These gas molecules can form

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higher bubbles, and high-pressure waves damage the covering surfaces when they collapse.

The amount of wear on the contacting surfaces of the engine components can usually be determined by the material content of the worn particles, which can be found in the engine oil. If there is an increased amount of lead in the oil of an older engine, it highlights the increased amount of wear on the plain bearings of the crankshaft and/or camshafts. An international standard exists [5] to measure and analyze the worn particles inside the new and used oil samples using the Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES). According to the methodology described in the standard, the contamination and wear particle content of the analyzed lubricant sample can be determined in mg/kg unit. These results must be compared with the result of the non-used lubricant sample. According to these results, it can be defined which engine components should be checked manually as possible maintenance sources.

During the engine operation, the fuel can get in touch with the oil in several origins (e.g., combustion chamber). Due to the high operating temperature, the fuel can significantly increase the oil aging mechanisms, resulting in quicker oil degradation. This oil aging usually leads to increased viscosity and to the depletion of oil additives. Several investigation methods exist to simulate the degradation of the lubricants under laboratory conditions. These artificially aging methods and equipment simulate the lubricant's high-temperature load and fuel dilution, which influences the tribological properties of the engine oil under real operating conditions. Nagy et al. [6] have designed a unique oil aging machine, and methodology and their artificially aged lubricant samples correlate with the aging properties of the engine oils taken from real vehicles according to the chemical and tribological measurements of the samples.

A PTSZ-M type medium-tracked amphibious military transport vehicle was chosen for our investigations, which is still used in the Hungarian Defence Forces. In our research, oil samples from the engines of two PTSZ-M type military vehicles were taken, which were thoroughly investigated with oil diagnostic and tribological methods. Our main goal was to detect the possible failures of the engine without engine disassembly. With the results of our research, we want to support the maintenance planning of these vehicles to keep them in operational condition.

2. INVESTIGATIONS

The engines always require different liquids to increase their lifetime and safety and ensure the lowest possible energy consumption, which is engine oil in this case. The oil functions material with the main purpose of lubrication to minimize the wear on the engine components and to optimize the friction coefficient value. However, the engine oil is not only used for lubrication: they provide sealing properties between continuously moving components (e.g., between piston rings and cylinder wall surface, the oil seals the high-pressure combustion gases inside the combustion chamber). The used oil is also a cooling liquid; it plays a critical role in the thermal management of the engine and cooling liquid. Additionally, it has critical anti-corrosion and cleaning properties; the oil removes the wear particles and the combustion residues from the engine components and transfers them from the lubricated places. It also must be mentioned that the oil also acts as a vibration-decreasing component inside the engine [3,7,8].

The former Hungarian People's Army purchased several PTSZ-M type medium-tracked amphibious military transport vehicles in the 1970s, which were produced in the former Soviet Union, and some of these vehicles are still available in the current Hungarian Defence Forces. Figure 1 shows a PTSZ-M vehicle in land and water operation conditions.

Figure 1. PTSZ-M military vehicle in land operations (top) and in water operation (bottom) condition (pictures of the authors)

The military vehicles used in this article were manufactured in the 1970s, and thanks to continuous maintenance, they remained in operational condition. The engine of this vehicle is a V-54P type engine with 12 cylinders in V arrangement. This engine is a four-stroke natural aspiration diesel engine with 4 valves at each cylinder, and it operates with direct fuel injection. The performance of this engine is 262 kW (350 HP) [9]. This engine type was planned with an MT16P type special engine oil, which was also produced in the former Soviet Union. This engine oil was not purchasable in Hungary in the last two decades, so the Hungarian Defence Forces are using an ÖMV Panzer type 20W50 oil instead because it is widely used in similar types of engines.

Its manufacturer designed this type of lubricant for extremely loaded military vehicles. The 20W50 mark of the engine oil represents the viscosity classification of the oil, which is a standardized classification prepared by the SAE (Society of Automotive Engineers). The 20W50 classification means a multigrade engine oil, and it is produced by using a mineral base oil. The kinematic viscosity of the engine oil used in the V-54P engines of the PTSZ-M type military transporting vehicles at the temperature of 100°C is 17,4 $\mathrm{mm/s^2}$, and its density is 0,888 g/cm^3 measured on 15°C. This type of lubricant is called a high viscosity engine oil, which is specially designed for the lubrication needs of engines with higher performance levels and older engines. According to the SAE classification, the engine oil used in the PTSZ-M vehicle is a multigrade lubricant, which can be operated between -15 and +55°C temperature range, which correlates with the Hungarian climate circumstances. The kinematic viscosity of the lubricants with 20W50 SAE classification should be between 16,3 and 21,9 mm/s^2 measured at 100°C. It is a natural process that the viscosity of the liquids decreases with the increase of their temperature, which also decreases the internal friction of the liquids – this is called the dynamic viscosity of the material. In the case of the operation of military vehicles, applying lubricants with higher maximal pumping temperatures is better; the only exception is during the cold starts of the engine. It is especially important to use lubricant with the right viscosity classification because the tasks of the engine oils are diversified: lubrication, sealing, heating-cooling, and vibration decreasing [10].

According to the previously written facts, oils play a crucial role in an engine's normal operation. Because each engine component is somehow lubricated with the oil, the oil can also be used for diagnostical purposes because the wear particles can be stored in the lubricant, and several assumptions can be defined according to the contamination and wear particle content of the lubricants. This data can be referred to as the sources of possible failures and damages, and these issues can be detected before the fatal damage occurs and the maintenance works can be done in time.

To understand the negative processes happening inside an operating engine without significant disassembly, the lubricant itself must be thoroughly analyzed. This analysis means the oil diagnostic in our case because the oil can contain information to deduct the processes and mechanisms inside the engine. For our investigations, the samples were taken from the engines of two PTSZ-M type military vehicles without disassembly. From the engine of the 1st vehicle a 2-hour, and of the 2nd vehicle, a 50-hour oil sample was taken. During the sampling process, the engines had to be warmed to ensure a good, homogenized engine oil. For the reference of our measurements, a neat, not used oil sample was taken from the bottle of the engine oil. To ensure the precise results and their good comparison, the chemical and tribological analysis of the oil samples was carried out under laboratory conditions. For the tribological investigations, an Optimol SRV®5 type, universal tribological measuring equipment was used (see Figure 2.). This tribometer is acknowledged worldwide and used for several tribological investigations [11], [12] because of its reliability and precision, and it has numerous international standards, too [13]. This equipment can be used for specimen application, which allows to carry out measurements with relatively low specimen costs. In the case of a ball-on-disc tribosystem (see in Figure 3.), the tribological properties of the used lubricants or the surface coatings can be analyzed with the realized oscillation movement.

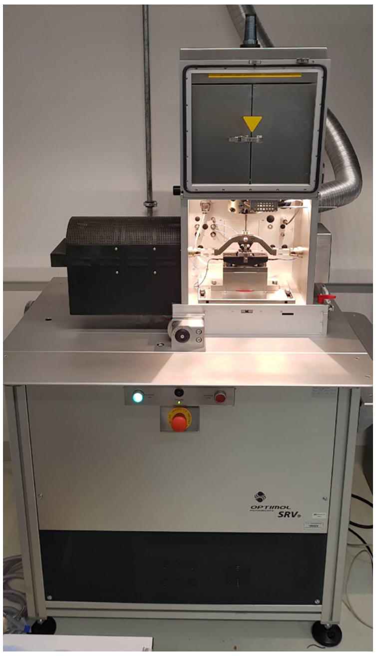


Figure 2. Optimol SRV®5 tribometer, which was used for the tribological investigation of the lubricant samples (picture of the authors)

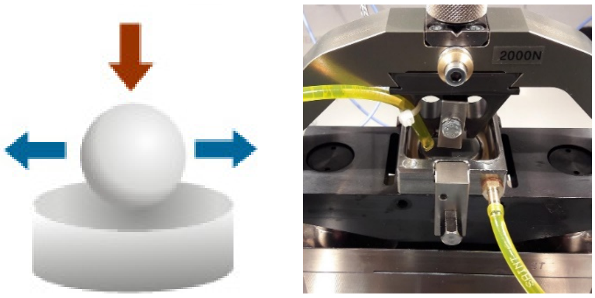


Figure 3. The tribosystem (left) and the specimens assembled into the tribometer (right) were used for the investigations (picture of the authors)

The oil samples from the two investigated military vehicle engines were sent to the LubCheck laboratory of the MOL-LUB Ltd. in Almásfüzitő, Hungary, together with the reference sample. All the important parameters of the oil samples can be measured in this laboratory, and the results can be compared with the values of the neat, non-used sample. The results can be categorized into three main groups: oil status parameters (e.g., kinematic viscosity, density, dispersants or oil additives elements like calcium, phosphorus, or zinc), contamination values (e.g., fuel content, water content, or soot content) and wear metal content (aluminum, iron, copper, or lead). The employees of the LubCheck laboratory of the MOL-LUB Ltd. also use color marks in their LubCheck reports: the yellow color represents the warning message, and the red color represents the critical values. In contrast, the unmarked values are the normal values of their vast experience. Furthermore, a scientific report is produced on the case of each investigated oil sample, including a professional opinion.

The investigations were carried out with the standardized Ø 10 mm ball and Ø 24 mm x 7.9 mm disc specimens made from 100Cr6 material, which also correlates with the previously mentioned standard. The hardness of the ball specimens was 60 ± 2 HRC, and their average surface roughness was 0,025 ± 0,005 µm, while the hardness of the disc specimens was 62 ± 1 HRC, and their average surface roughness was between 0,035 and 0,05 µm.

For the tribological investigations, a self-developed measurement method was used. The measurement method was based on the international ISO 19291:2016 standard [14], and during the scientific research of the Department of Internal Combustion Engines and Propulsion Technology, have defined some modifications [15,16,17]. The used tribometer produces oscillation movement with 1 mm stroke and 50 Hz frequency, which moves the upper ball specimen on the plain surface of the disc specimen. The whole tribosystem is heated up to the usual lubricant temperature ranges inside an internal combustion engine, in this case, up to 80 and 110 °C, according to the ISO standard. A peristaltic pump with silicone pipes was used to realize a continuous oil circuit simulating the oil flow inside an operating engine. The oil circuit is supplemented with an external secondary oil heating device to heat up the oil sample separated from the used testing specimens to the same temperature as the specimens. Approximately 15 ml of lubricant is needed to fill up the whole oil circuit, and 225 ml/h oil flow speed was set up for our measurements. The investigation method contains two main steps: a 30-second-long run-in step with 50 N load to secure the proper lubrication status of the specimens and a longer, two-hour-long step with 200 N load to measure the friction and wear properties of the investigated lubricant.

The Optimol SRV®5 tribometer can measure two friction coefficient values: the COF value (coefficient of friction) representing the maximal friction coefficient value in each stroke and the FAI value (friction absolute integral) representing the integral average value of the friction coefficient in each stroke. According to the movement pattern of the oscillation, the COF value is always taken from the dead ends of the movement because higher energy is required to begin a movement than to keep it in moving status. That's why the COF value represents the frictional properties of the lubricant from the dry and boundary layer lubrication regime (in this regime, a molecular boundary layer is formed by the lubricant and the additive molecules [7]). The FAI value is a calculated integral average value of the measured friction coefficient values with 25 kHz recording frequency, which represents mainly the boundary and mixed lubrication regimes (the liquid starts to fill up the space between the two contacting surfaces, so the impact of the viscosity of the lubricant is higher [7]).

According to the investigations of Paulovics et al. [18], a good correlation can be established between the wear scar diameters and the wear volume measurement, which require a more complex confocal microscope and more time for the microscopical measurements and their evaluation. For our research, a Keyence VHX-1000 type digital microscope (see Figure 4.) was used to measure the dimensions of the wear scars on the contacting surfaces. After the tribological measurements, the wear scars were analyzed to document the wear scar images and the measures and their dimensions (e.g., wear scar diameter – WSD).

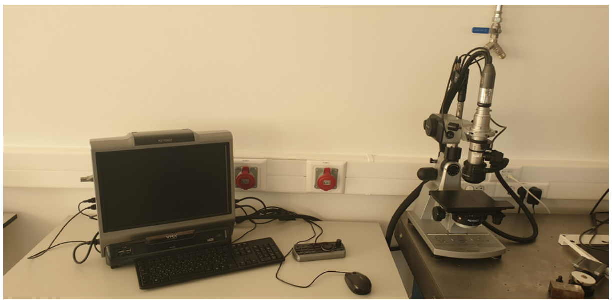


Figure 4. Keyence VHX-1000 digital microscope, which was used for measuring the wear scar dimensions on the testing specimens after the tribometer measurements (picture of the authors)

For the tribological investigations, the two used and the neat non-used oil samples were tested independently 3 times to avoid any uncertain effects on the tribometer. The average and standard deviation values were calculated from each comparison value (COF, FAI, WSD), and these were evaluated and graphically presented in this article.

3. RESULTS

According to the LubCheck measurements with the reference oil sample (ÖMV Panzer 20W50), it can be mentioned that this oil meets the relevant standards. The kinematic viscosity of this engine oil should be between 16.3 and 21.9 mm/s^2 on 100°C, and the measured value is 17.8 mm/s^2. Furthermore, each measured value showed a corresponding value. According to the expectations, the oil sample contains no fuel, no water, and the measured amount of all wear particle elements is equal to or under the 1 mg/kg value. The tribological results made with the ÖMV 20W50 lubricants can be observed in Figure 5.

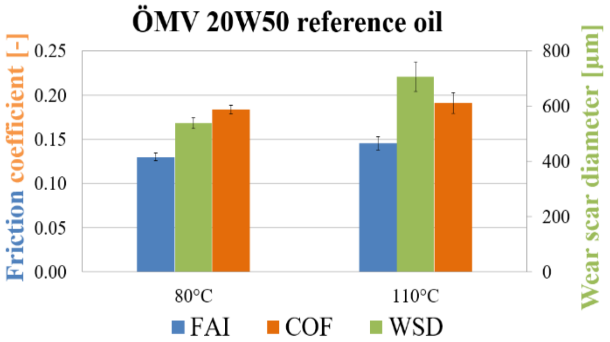
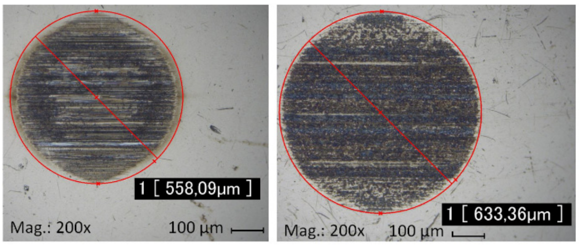


Figure 5. The results of the tribological investigations with the ÖMV 20W50 engine oil used as a reference oil sample (figure of the authors)

The results show a relatively low standard deviation in the case of each measured value (this indicates an excellent reproducibility), and the protection of the contacting surfaces against wear met the expectations.

Figure 6 represents the wear scar images, including measured wear scar diameters from the two measured temperatures. The images indicate that the wear process was consistent, and the dominant wear mechanism is abrasive wear.



T=80°C T=110°C

Figure 6. The wear scar images in case of the ÖMV 20W50 engine oil were used as reference oil samples (pictures of the authors)

The chemical analysis of sample number 1 (presented in Table 1.) revealed an interesting result. The kinematic viscosity of this oil sample was significantly decreased; these values were 89% and 74% lower on 40 and 100°C, respectively, compared to the reference sample results. Furthermore, the color marking of the fuel content value was also set to serious red. According to these values, it can be stated that a significant amount of fuel was placed inside the engine oil during this 2-hour operation, which was the reason for the significant viscosity decrease. Because of the high fuel percentage inside the engine oil, the viscosity index of the sample was also decreased by 63%. The concentration of several chemical elements, like calcium (dispersant additive), phosphorous, zinc, and sulfur (friction and wear modifying additive), were also significantly reduced, which refers to the additive content of the lubricant. The fuel dilution of the sample can also explain the reduction of these elements because these results are measured in mg/kg value. There are fewer lubricant additives in each kg oil sample and more fuel molecules. The wear metal particles in the oil sample have resulted in a slight increase compared to the reference sample, and the highest concentration was measured in the case of the lead (Pb) element, which is mainly in the plain bearings of the engine. The sample's relatively low amount of wear metal content correlates with the expectations because an engine oil with 2 hours running time should not contain such a high amount of worn particles. In the summary of the chemical report, the LubCheck representative suggests analyzing the engine's fuel system manually to find the source of the high amount of fuel in the engine oil.

Table 1. Comparison of the LubCheck results of the 0h reference and 2h engine oil sample

Parameter	0h sample	2h sample
Kinematic viscosity 40°C [mm^2/s]	178	19
Kinematic viscosity 100°C [mm^2/s]	17,8	4,7
Dispersant [-]	109	178
Ca content [mg/kg]	4221	1359
P content [mg/kg]	1047	488
Zn content [mg/kg]	1206	589
S content [mg/kg]	5658	3509
Fuel content	Negative	Serious
Cooling water content	Negative	Negative
Na content [mg/kg]	5	17
Cr content [mg/kg]	<1	<1
Cu content [mg/kg]	<1	4
Fe content [mg/kg]	1	4
Pb content [mg/kg]	<1	14

The tribological results of oil sample number 1 revealed an interesting tendency (see Figure 7.). A small amount of friction decreasing and slight wear increasing can be observed at the lower operating temperature (80°C), while at the higher temperature value (110°C), significant friction and wear reduction were measured.

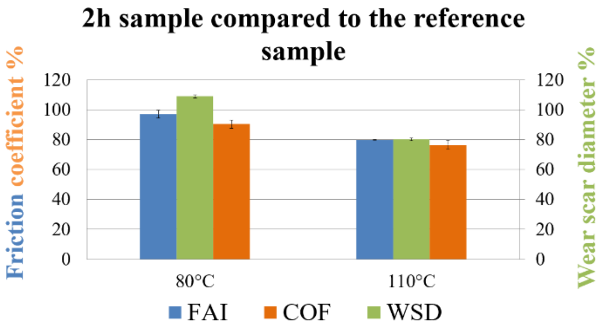
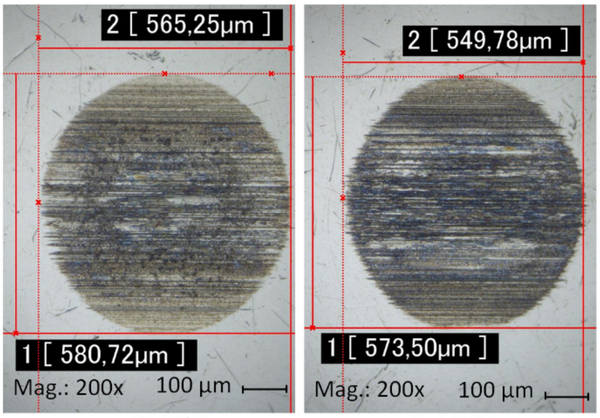


Figure 7. The tribological results of oil sample number 1, compared to the ÖMV 20W50 reference engine oil (figure of the authors)

Figure 8 illustrates the wear scar images on the ball specimen surfaces in the case of the 2-hour oil sample. The signs of higher loads can be observed on the wear images compared to the reference sample results because both the abrasion and adhesion wear can be defined on the images. However, the wear scar diameters are not showing the increased load: the slight increase of WSD on the 80°C measurements is not significant, and on the 110°C measurements, the WSD was reduced by 20%.



T=80°C T=110°C

Figure 8. Wear scar images on the ball specimen surfaces with the oil sample number 1 (2-hour running time) on 80 (left) and 110°C (right) (pictures of the authors)

As the summary of oil sample number 1 it can be defined that the fuel dilution influences the tribological performance of the oil. The diesel fuel used in the investigated PTSZ-M type military vehicle provides better lubrication properties compared with the petrol fuel, but the diesel fuel is not as good lubricating material as the used engine oil, which was designed for tribological purposes. The high amount of fuel content in the lubricants mainly decreases the lubrication of the connecting metal engine components. It also accelerates the degradation of the oil (known as oil aging), which leads to oxidation and viscosity increase [19]. The fuel content of the lubricants cannot be observed in the tribological results, especially at higher temperatures, because the fuel evaporates in the heating phase of the measurement, so the tribological performance of the oil did not change significantly.

Furthermore, the investigated oil sample is operated only for two hours, so the degradation caused by the fuel and time was not so crucial. According to the research results, the engine's failure analysis is necessary. Firstly, the fuel system should be checked (fuel pump, fuel injectors of each cylinder) because, in case of slight malfunctions of these engine components, the fuel can be mixed up directly with the engine oil. If no damage can be defined in the engine's fuel system, it is also possible that the fuel was poured into the oil during the multiple cold starts next to the piston rings in this high concentration.

Oil sample number 2 with 50 hours of a lifetime has provided completely different properties. The LubCheck analysis results of this sample are presented in Table 2, compared with the reference sample results. Only a slight modification was observed in the kinematic viscosity values (8% decrease at 40°C and 5% decrease in 100°C measuring temperature), and similar changes (less than ± 10%) could be defined in the measured values of additive-related values too (Ca, P, Zn, and S). However, a significant 28% decrease was defined in the dispersant (to keep the metallic particle in floating status [20]) property of the sample, which was marked as a yellow warning by the colleagues of the LubCheck laboratory. With the decrease of the dispersant reservoir, the concentration of the wear particles was also increased (aluminum up to 8, iron up to 60, copper up to 113, and lead up to 53 mg/kg value) because the dispersant additives of the lubricant should separate the wear particles from the oil molecules to keep them in floating status, which indicates a strong correlation between dispersant property and the wear particle content of the lubricant. The lack of dispersant additives in the lubricant accelerates the formation of the agglomerates from wear particles which will increase the 3-body abrasion wear mechanism on the connecting surfaces of the engine components. The chemical analysis revealed a significant sodium increase in the investigated oil sample, and the cooling water content was also positive. The sodium can be found in the cooling water as an additive (sodium nitrite – $NaNO_2$), which is responsible for the corrosion protection of the metallic parts of the cooling circuit [21].

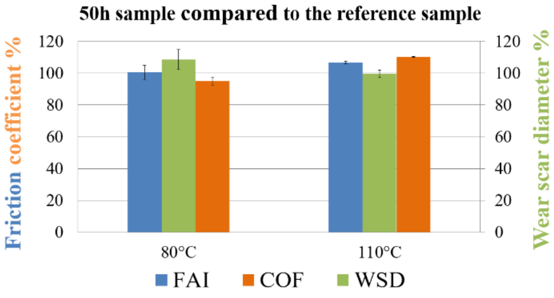


Figure 9. The tribological results of oil sample number 2, compared to the ÖMV 20W50 reference engine oil (figure of the authors)

Figure 9 presents the tribological results of oil sample number 2 (50-hour operation time). The tendency of this oil sample is completely different from the previous one: the measured tribological parameters have slightly increased, and only the COF value has slightly decreased with the research temperature of 80°C, which refers to the frictional losses measured at the dead centers of the oscillation movement.

Table 2. Comparison of the LubCheck results of the 0h reference and 50h engine oil sample

Parameter	0h sample	50h sample
Kinematic viscosity 40°C [mm^2/s]	178	163
Kinematic viscosity 100°C [mm^2/s]	17,8	16,9
Dispersant [-]	109	69
Ca content [mg/kg]	4221	4195
P content [mg/kg]	1047	1116
Zn content [mg/kg]	1206	1241
S content [mg/kg]	5658	6057
Fuel content	Negative	Negative
Cooling water content	Negative	Positive
Na content [mg/kg]	5	70
Cr content [mg/kg]	<1	<1
Cu content [mg/kg]	<1	113
Fe content [mg/kg]	1	60
Pb content [mg/kg]	<1	53

The wear scar images on the ball specimens can be observed in Figure 10, which were prepared with a digital microscope. According to the digital microscope images, a significant difference can be established between the results of the two research temperature values. The 80°C temperature measurement shows a relatively small wear scar diameter with the dominant abrasion wear mechanism. In contrast, the WSD value on 110°C measurements is significantly larger, and tiny fatigue holes can also be observed on the worn surface next to the abrasion. The increased amount of abrasion and fatigue wear can be explained by the increased wear particle content and the depleting of the dispersant reservoir of the oil sample: the wear particles could increase the 3-body abrasion between two connecting surfaces, and they can also act like nano ball bearings which increase the fatigue load of the surfaces too.

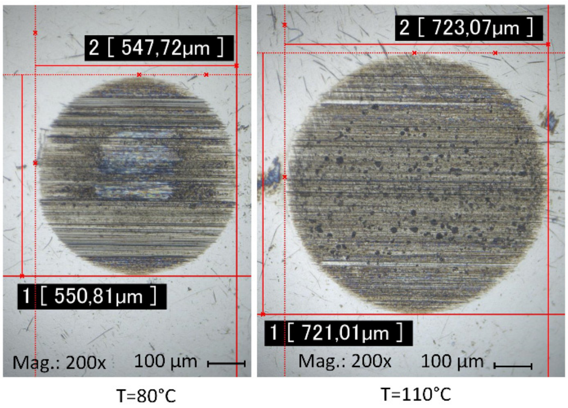


Figure 10. Wear scar images on the ball specimen surfaces with oil sample number 2 (50-hour running time) on 80 (left) and 110°C (right) (pictures of the authors)

The investigation results with the 50-hour oil sample can be summarized as follows. The lubricant can still protect the connecting surfaces against fatal wear and its damages even with wear particle content (Cu and Pb) and cooling water dilution. The LubCheck results have revealed that the sealings of the cooling water and oil channels should be manually checked. Furthermore, the failure analysis of the plain bearings should be carried out to check their status and replace them if necessary. It is recommended to carry out the pressurized analysis of the cooling water channels to define the possible water leakage sources, and the necessary maintenance works can be performed. Because of the presence of bearing materials in the lubricant, the plain bearings of the crankshaft and camshaft should be controlled with the engine disassembly process because these bearings are built in the main structural systems of the engine.

4. DISCUSSION

The results of the chemical analysis and the tribological measurements are correlating. According to the gained results, it can be stated that the described method provides excellent results. This method can be used widely to control the wear status of the engine without disassembling it. This method is very useful in the case of engines that are difficult to reach and disassemble.

The method presented in this article can be adapted into several failure analyses and maintenance works because the lubricant inside a machine acts like a fingerprint, as it contains lots of tiny fragmented particles, and the material of these particles can be measured. For example, Rasuo et al. have presented articles about developing a maintenance method for aircraft and jet engines [22, 23]. They have formulated a 15-step method to maintain the jet engines. One of these steps contains the spectrometrical analysis of the oil, including Fe, Cu, Ni, Zn, Cr, and Mg content analysis. The measurement method of the authors of this article can extend that spectrometrical oil analysis with several extra crucial oil parameters like viscosity or reservoir of different oil additives. The presented lubricant analysis can support not just the maintenance works but the development of these machines as well. According to this information, the machines can be further developed to be more wear-resistant and provide a longer lifetime.

The further development of the lubricant chemical analyses can open new doors: quantifying the amount of fuel inside the lubricants can be important with warning and serious marking limits. Furthermore, the measurement of the oil aging parameters (e.g., nitration and oxidation level) with Fourier-transform infrared spectroscopy (FT-IR) [24] can also provide important information about the status of the lubricants. In the case of the element analysis of the lubricant additives (e.g., Ca, Zn, P, and S), it is also possible that these elements are not present in their original molecular structure but as their degradation by-products, and so the protection function of the engine oils can also be reduced.

In conclusion, it can be declared that the presented chemical analysis of the engine oil samples can be beneficial in case of hardly reachable engines like military vehicles because, according to these results, the status of the internal combustion engines can be continuously monitored, and the necessary maintenance works including component replacement and oil changing intervals can also be planned in time. This type of monitoring can also be beneficial in the case of newer vehicles with exhaust gas post-treatment systems [25] or other types of machines (e.g., deep drawing machines or transmission). The in-time maintenance works can also decrease the early performed engine disassembly tasks, saving time and money and providing environmental protection advantages [26].

5. CONCLUSION

It is a time-consuming process to check the status of the drivetrain components in the case of military vehicles because the heavy engine covering plates must be removed to reach the engine itself. The engine disassembly is much more complicated because the whole engine must be taken out of the vehicle to start the maintenance work. An alternative engine status analysis method was presented in this article because it eliminates the engine disassembly tasks and it saves valuable time and cost. The chemical and oil dilution properties, including wear particle elements, can be analyzed in the LubCheck laboratory of the MOL-LUB Ltd. in Almásfüzitő, Hungary, which indicates when and where the maintenance works should be carried out.

During our research, oil samples from the engines of two PTSZ-M type medium-tracked amphibious military transport vehicles were analyzed via chemical and tribological methods. The results of the investigations can be summarized as follows:

- A significant amount of fuel was defined in oil sample number 1 with 2 hours of lifetime, which significantly reduced the kinematic viscosity of the lubricant. This viscosity decrease influences the lubrication and protection function of the engine oil too.
- Increased cooling water and bearing metal materials were observed in oil sample number 2 with 50 hours of operating time. The cooling water ruins the viscosity and the lubrication property of the engine oil. The increased amount of bearing particles inside the engine oil slightly increased the wear on the connecting surfaces and amplified the fatigue wear mechanism of the engine components, mainly under higher operating temperature conditions.

According to the research results, it can be defined that the check of the investigated engines is justified: in the case of the 1st engine, the control should concentrate on the sources where the fuel and engine oil can meet (e.g., fuel supplying system), while in case of the 2nd engine, the sealings of the cooling water channels and the plain bearings of the crankshaft and camshaft should be thoroughly analyzed.

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ОТКРИВАЊЕ МОГУЋИХ ОШТЕЋЕЊА МОТОРА У СЛУЧАЈУ ВОЈНИХ ВОЗИЛА СА КОНТИНУАЛНИМ КОЛОСЕКОМ СА ТРИБОЛОШКИМ ИСТРАЖИВАЊИМА

Р. Кути, Ф. Кенцел, Л. Чапо, Л. Фелди, А.Д. Тот

Откривање кварова на моторима војних возила континуалног колосека је изазовно јер су њихови мотори увек уграђени у уска места покривена оклопним плочама. У случају старијих мотора, савремена компјутерска дијагностика се не може користити за анализу кварова; решење за ове задатке је визуелна анализа са демонтажом мотора. Могућа исплатива метода анализе кварова може бити триболошка и хемијска анализа коришћеног уља из мотора, која може елиминисати рад на демонтажи мотора, а будући да резултати хемијске анализе уља такође могу пружити информације о могућем разблажењу горива или расхладне воде или повећано хабање компоненти мотора.
Основни циљ овог рада је да се кроз триболошко испитивање мотора два амфибијска војно транспортна возила средње гусеничара типа ПТСЗ-М представи метод анализе квара.