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Field Monitoring of Engine Oil

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Abstract: Conditions of the elements of tribomechanical system are very complex and determinate great deal by the adequate characteristics of lubricants. Complexity of conditions is determinated by: temperature of elements in contact and temperature of lubricant, outer load (specific pressure in contact zone), dynamic character of making contact and power and motion transmission.

In regard with primary role of lubricant to reduce the negative effects of tribological processes related to friction, wear and increase of temperature in the tribomehanical systems, all types of maintenance include lubrication as a very important part of the whole procedure. On the other hand, lubricant is, as the contact element of the system, carrier of information about the state of the whole system, from the aspect of tribological and other ageing processes. Due to that, analysis of oils, based on properly defined program, represents a very effective metod for monitoring the state of tehnical systems, which ensures early warning signals of potential problems that could lead to failure and break down of the tehnical systems. In the systems structure, besides the mechanical components, the state is also changed of the lubricant itself, what leads to loss of lubricating properties.

Investigation procedure of physico-chemical and tribological characteristics of lubricant during exploitation consists of following: oil sampling from real tribomechanical system; measuring physico-chemical characteristics of oil; establishing of wear products participation in oil and measuring tribological characteristics of tribomechanical system in model conditions using sampled oil as lubricant.
Analysis of oil samples which contain particles, created as results of wear, enable evaluation of system tribology condition in different phases of system exploatation.

In this project, it will be presented results of experimental research physico-chemical and tribological characteristics oil was sampled from engines of vehicles, Mercedes O 345, that were exploited. The research was conducted through periodic sampling oil from engine vehicles listed above. Apart from the fresh oil („zero“ sample), samples are taken after 10.000 km, 20.000 km and 30.000 km. During the sampling of oil choice of the sampling were conducted carefully according to the actual oil usage, which enabled each sample as representative one.

Keywords: tribomechanical system, engine oil, tribology, maintenance, Oil Analysis.

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1. Introduction

It is not always simple to determine a type of lubricant, frequency of lubrication and the quantity of the lubricant to be used. Optimal recommendation would be to follow the specification of technical system manufacturers, experience, lab research or professional recommendation of lubricant suppliers. Rationalization of lubricants consumption represents significant task which can be obtained by on time oil replacement. That allows maximal period of use and on the same time appreciable quantity of lubrication. In regard with primary role of lubricant to reduce the negative effects of tribological processes related to friction, wear and increase of temperature in the tribomechanical systems, all types of maintenance include lubrication as a very important part of the whole procedure. On the other hand, lubricant is, as the contact element of the system, carrier of information about the state of the whole system, from the aspect of tribological and other ageing processes. Due to that, analysis of oils, based on properly defined program, represents a very effective metod for monitoring the state of technical systems, which ensures early warning signals of potential problems that could lead to failure and break down of the technical systems. In the systems structure, besides the mechanical components, the state is also changed of the lubricant itself, what leads to loss of lubricating properties.

Using Oil Analysis programs for engine oils has several benefits: reduction of unscheduled vehicle downtime, improvement of vehicle reliability, help in organizing effectiveness of maintenance schedules, extension of engine life, optimization of oil change intervals and reduction of cost of vehicle maintenance.

2. Tribomechanical System

Real systems are complex tribomechanical systems. Conditions of the elements of tribomechanical system are very complex and determinate great deal by the adequate characteristics of lubricants.

Vehicle as a technical mean is a set of complex tribomechanical systems composed of range of subsystems that are also complex tribomechanical systems.

They are composed of elements that participate in power transmission, moment of force from the motor, over transmissions (power transmitter, differential and other systems), to executive organs of a vehicle.

If the engine assemblies are considered from the aspect of tribomechanical systems (e.g. assemblies piston-piston ring-cylinder, cam-valve lifter, bearing-journal bearing) defined by tribological processes, it can be shown that the determination of the content of wear products, content of contaminants, state of lubricants and lubrication conditions have a significant influence on the implementation of maintenance of these systems.

We should emphasize the importance of monitoring oil for lubrication of tribomechanical engine assemblies, which provides that in the early stages of the functioning of the system identification of potential causes and phenomena that lead to damage and failure. Prognostication and detection of potential and/or current damage and failures in the system, checking the functionality of oil and determination of usage life are the main factors of the implementation of monitoring oil.

Therefore, because the mobile components of tribomechanical system engines necessarily wear, and that contaminants and wear products are collected in the oil for lubrication, and because of the need to monitor changes in fluid properties during exploitation, the conclusion can be drawn that of all the techniques of monitoring the key to maintain the condition and to achieve certain techno-economic effects is the monitoring of lubricants.

Analysis of the contents of different metals that are in the lubricant is very important. Metal particles are abrasive, and act as catalysts in the oxidation of oils. In engine oils, the origin of the elements may be from the additives, the wear, the fuel, air and liquid for cooling. Metals from the additives can be Zn, Ca, Ba, or Mg and that indicates the change of additives. Metals originating from wear are: Fe, Pb, Cu, Cr, Al, Mn, Ag, Sn, and they point to the increased wear in these systems. Elements originating from the liquid for cooling are Na and B, and their increased content indicates the penetration of cooling liquid in the lubricant. Increased content of Si or Ca, which originates from the air, points to a malfunction of the air filter.

Wearing of the parts is the main cause of inaccuracies in the process of exploitation of the mechanical components of vehicles. Characteristic of wear is the change in shape and dimensions of working area parts. Because of friction the spending of surfaces occurs which reflects in the increase of moving parts gap and change their mutual relations, and this resulted in violation of the prescribed relationship between components, and vehicles in general. Spending of surface assembly cylinder-piston is shown in the figure 1.

With the increase of tactile area spending, the tightness of engine working space violates which results in a decrease in the value of effective engine parameters (power and torque of the engine).

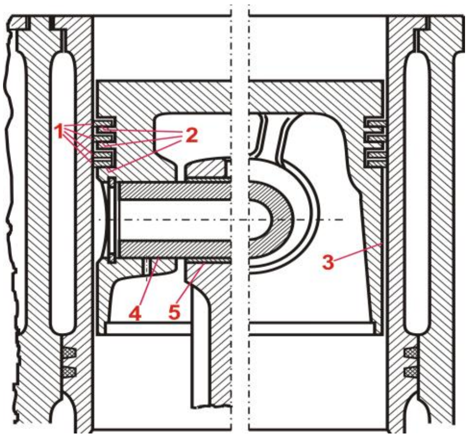

Figure 1. Tactile-wear surface assemble piston-cylinder:
1 – piston ring– cylinder, 2 – piston ring –piston, 3 – cylinder– piston, 4 – piston pin– piston and 5 – piston pin – connecting rods

More intensive than the piston and cylinder piston rings are worn, because their work conditions are extremely unfavorable. They are exposed to thermal action and effect of corrosion which causes the actions of combustion products and high pressure and at the same time insufficient lubrication of tactile area. Consequences of spending are increasing gap between the piston ring and the side surface groove piston, and also reduction of their elasticity. This causes the penetration of oil in the engine working space, and also the penetration of burnt gases in the engine crankcase.

Due to penetration of combustion products in the crankcase engine the occurrence of rinsing oil from cylinder walls, increasing the oil temperature, acceleration of the process of degradation and aging of oil, increase engine temperature and faster spending cylinder walls become evident.

Increasing gap between piston and cylinder results in intensification of wear parts of the cylinder and piston group, bearing and journal crankshaft, gear camshaft, cams camshaft and more.

Wearing of valve train parts (figure 2) affects negatively the process of making changes to the working substances. The violation of the kinematics valve train occurs which causes strokes in valve train and reducing engine power.

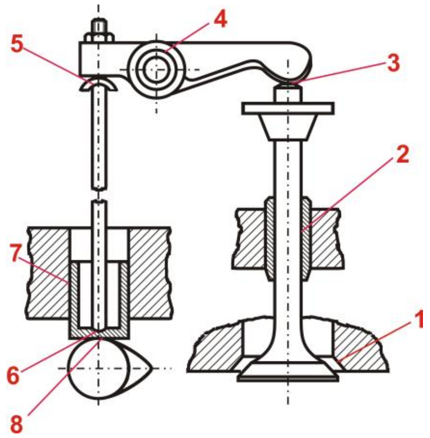

Figure 2. Areas of valve train that are exposed to wear:
1 – valve seat, 2 – valve guide, 3 – valve follower–valve stem, 4 – journal valve follower, 5 – valve seat –valve pushrod, 6 – valve lifter– valve pushrod, 7 – valve lifter – valve guide, 8 – valve lifter –cam

Areas that are particularly exposed to wear during contact are shown in the figure 2. Spending of bearings and journal crankshaft affect the deterioration of the lubrication regime, the occurrence of stroke in the bearings and engine vibration.

Spending of precision parts of pumps and injector diesel engines are manifested as:

- increased losses in fuel injection,
- deterioration of fuel atomization and
- uneven driving of fuel in the engine cylinders.

Increased smoking engine occurs because of:

- increased heating of parts as a result of difficult delivery of heat, which causes the creation of deposits in the work area;
- reducing of engine power and the increase specific consumption of fuel due to the uneven charging of cylinder with fuel as a consequence of hydrodynamic resistance, caused by the reduction of the suction pipe section due to resin type residues that deposits on the surfaces of pipes.

Increased smoking engine due to greater consumption of oil, knocking (strokes) bearings, spending of assembly cylinder-piston group and valve train are the main reasons for referral to the engine repair.

Diagnostics of tribomechanical systems in motor vehicles is part of the overall process of managing maintenance. It provides an opportunity for the user to predict the damage and/or failure, and thus prevent delay in the work and extend usage life of motor vehicles.

Dependence of the state of moving parts of the process friction and wear shows that determination of the look, shape and size of particles of wear products, lubricants and conditions of the state of lubrication are of vital importance in the process of maintenance.

The oil for lubrication monitoring during exploitation is one of the most important diagnostic procedure, which includes state of tribomechanical system, based on the functions and importance of which should be satisfied in this system. The advantage of the above mentioned procedure is reflected in the fact that information about the functionality of components of the system is obtained without stopping and dismantling the vehicle.

Modern trends of diagnosis in recent years, go to the affirmation of the monitoring of oil, which has resulted in growth of interest of producers and users of oil. The reasons lie primarily in increasing the reliability, effectiveness, economy, and recently more and more present protection of the environment.

3. Results of Engine Oil Investigation during Exploitation

In this part the results of experimental testing of engine oil are presented. The physico-chemical characteristics of oil in accordance with standard methods are examined in the Laboratory for fuels and lubricants VTI Belgrade, shown in table 1. The tribological characteristics of oil are examined in the Laboratory of tribology, Faculty of mechanical engineering in Kragujevac. The analysis was done on the fresh (new) oils and oils that are used in the engine assembles of vehicles. Testing of used samples were carried out in accordance with common criteria defined by the quality of used oil.

Allowable values of deviation limits of individual physico-chemical characteristics of the oil are conditioned by the type of oil, working conditions and internal recommendations of the manufacturer of lubricants and users. Limited value characteristics of oils that condition the change of oil charging from engine are given in table 2. They represent the criteria for the change of oil charge. Deviation of only one source changes characteristics of oil charge, no matter of what characteristics are about.

Table 1. Implemented tests and methods for examining the physico-chemical characteristics of oil

Characteristic	Method
Density, gr/cm^3	JUS B.H8.015
Kinematic viscosity, mm^2/s	JUS B.H8.022
Viscosity Index	JUS B.H8.024
Flash Point (°C)	ISO 2592, ASTM D 92
Pour Point (°C)	ISO 3016
Foaming, ml/ml: 24°C; 94°C; 24° C	ASTM D892
Water Content, mas.%	ASTM D 95
Total Base Number (TBN), mgKOH/g	ASTM D 2896
Insoluble substances in pentane, %	ASTM D 893
Insoluble substances in benzene, %	ASTM D 4055
Fe Content, %	ASS
Cu Content, %	ASS

Table 2. Allowed values deviation of physico-chemical characteristics of new and used oil

Physical-chemical characteristics oil and products wear	Maximum allowed variation
	Engine oil
Viscosity at 40°C and 100°C, mm^2/s	20%
Viscosity Index, %	± 5 %
Total Base Number (TBN), mg KOH/gr	pad do 50%
Flash Point, °C	20 %
Water Content, %	0,2 %
Indissoluble substances in pentane, %	3,5
Indissoluble substances in benzene, %	2,5
Products wear – Content Fe, ppm(μg/gr)	100 ppm
Products wear – Content Cu, ppm(μg/gr)	50 ppm

The origin of several elements in the used engine oil (table 3) may be from additives (Zn, Ca, Ba and Mg), the wear products (Fe, Pb, Cu, Cr, Al, Mn, Ag and Sn) and contaminants originating from fuel, air and liquid cooling (Na, B, Si and Ca).

Table 3. The origin of certain wear elements in the engine oil

Elements	Wear Metal Source
Fe	cylinder liners, piston ring, journal bearing, valve lifter, camshaft, crankshaft
Al	piston, Al-Sn bearings, turbocharger
Ag	silvered parts, bearings, journals
Cr	hard chrome plated parts, pistons, cylinders, valve lifter, exhaust valve, connecting rods
Cu	Cu-Pb bearings, bushings, oil coolers, camshaft, valve train (valves with system for opening and closing), fuel injector, regulator
Pb	Cu-Pb bearings, gasoline, additives
Sn	bronzed parts, bearings, pistons
B	Antifreeze
Na	antifreeze
Ca	from atmosphere
Si	particles from atmosphere
Zn,Mg,Mo	from additives

The research was carried out in three vehicles (buses MERCEDES O 345) which have embedded engine Mercedes-Benz, type OM 447HLA. This is four-stroked engine with six cylinders arranged in line, turbo diesel, liquid refrigeration and with a combined lubrication, which meets Euro 2 emission standards related to exhaust gases. Technical data of engines are given in table 4.

Table 4. Technical data for Mercedes-Benz engine, type OM 447HLA

Engine Mercedes-Benz, type OM 447HLA	
Engine type	four-stroked, turbo diesel (euro 2)
Number and spacing cylinders	6, linear
Cylinder bore, mm	128
Engine capacity, litres	11,97
Compression ratio	18 : 1
Nominal output, in 2200 min^{-1}, KW	220
Maximum torque, in 1100 min^{-1}, Nm	1100
Minimal number of revolutions idle stroke, min^{-1}	600
Rated speed, min^{-1}	2500
Maximum permissive temperature coolant, °C	105
Pressure motor oil (Rated speed), bar	2,5
Pressure motor oil (idle stroke), bar	0,5
The amount of oil with filter, litres	25

Characteristics of zero samples of engine oil, VALVOLINE, SAE classification SAE 10W-40 and API classification CF and ACEA E4 are shown in table 5, and the results used oil samples in table 6.

Table 5. Results of zero samples of oil from the engine

Motor oil VALVOLINE, SAE classification: SAE 10W-40; API classification: CF ACEA E4						
Viscosity at 100°C(cSt)	Viscosity at 40°C (cSt)	Viscosity Index	Pour Point (°C)	Flash Point (°C)	TBN	Foaming
14,37	94,96	156	- 36	210	10,7	passage

Table 6. The results of testing samples of used oil from engines examined vehicles

Characteristic	Engine O 345-1				Engine O 345-2				Engine O 345-3			
	0	1	2	3	0	1	2	3	0	1	2	3
Color	3,0	black			3,0	black			3,0	black		
Viscosity 40°C, mm^2/s	94,9	85,8	84,1	84	94,9	83,6	83,5	83,0	94,9	84,8	82,3	81,7
Viscosity 100°C, mm^2/s	14,3	12,6	12,6	12,6	14,3	13,1	12,9	12,5	14,3	12,7	12,6	12,3
Viscosity index	156	156	149	145	156	155	149	147	156	153	148	146
Flash point, °C	210	206	202	200	210	204	201	199	210	205	202	201
TBN,mg KOH/g	10,7	10,1	9,42	8,6	10,7	10,3	9,65	8,7	10,7	10	9,87	7,1
Insoluble substances in pentane, %	–	0,09	0,22	0,31	–	0,08	0,18	0,27	–	0,05	0,15	0,25
Insoluble substances in benzene, %	–	0,13	0,19	0,37	–	0,11	0,16	0,32	–	0,10	0,15	0,30
Content Fe, (ppm)	–	13,5	13,7	37,4	–	11,8	13,6	19,8	–	9,6	12,5	14,8
Content Cu, (ppm)	–	1,3	1,5	1,9	–	1,3	2,3	2,5	–	1,3	3,3	3,9

The research was conducted through periodic sampling oil from engine vehicles listed above. Apart from the fresh oil („zero“ sample), samples are taken after 10.000 km, 20.000 km and 30.000 km. After 30.000 km the replacement oil charging engines in all three vehicles.

During the sampling of oil choice of the sampling were conducted carefully according to the actual oil usage, which enabled each sample as representative one. Each sample was taken from the living zone, i.e. zone closer to the elements in contact. In that way we avoided the sampling of oil from the bottom of the motor housing (outlet for discharge), as is at the bottom of the largest concentration of contaminants. This is achieved simply by modifying the outlet for oil extending toward the active zone of oil within the housing with the appropriate length of tubule.

Also, special attention is paid to the preservation of samples from contamination, as in the phase of identifying the sample and phase of manipulation, which is fully met by applying the prescribed procedures. In accordance with the time provided a very high level of purity of all elements in the chain of systems for sampling, as well as the separation of samples in a way that is not perturb the integrity of data that it carries on the state of components of vehicles from which sampling was done.

Engine used engine oil, VALVOLINE quality API CF and ACEA E4, gradation SAE 10W-40. For testing buses are exploited in the conditions of city driving. The task was to check the interval to replace motor oil after 30.000 km. It is found that the changes characteristic for engine oil were expected and within the allowable limits.

During exploitation increase viscosity lubricants is expected to. Viscosity reduction is considered to be dangerous from the increase.

Reasons for the increase of viscosity lubricants are as follows: oxidation of lubricants, cavitation due to foaming lubricants, dissolution of lubricants with water, pouring and charging system viscosity fat greater than recommended and contamination of solid particles and products wear lubricants.

On the other hand, the reasons for the reduction of lubricants viscosity are: lubricants contamination of fuel (for engine oil), shearing additive for reclamation viscosity, drop point of flash, grinding molecules, lubricants contamination without solubility with water, pouring and charging system viscosity less fat than recommended, and the impact of liquid cooling. Also, the causes may be high temperature, load, uncontrolled long interval use, insufficient amount of oil in the oil system, inefficient cooling systems and the like.

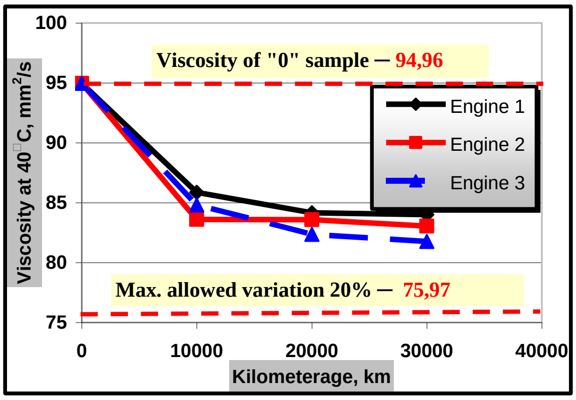

Figure 3. The change of viscosity at 40°C

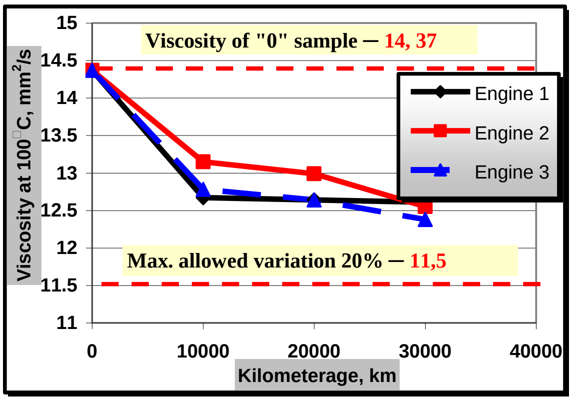

Figure 4. The change of viscosity at 100°C

Figure 3. shows the changes viscosity at 40°□C engine oil during exploitation. It is during the fall viscosity after the first 10.000 km of oil from all three engines, and after this period, viscosity remains approximately constant until the end of the interval changes oil charge. Fall viscosity for the entire period of exploitation of oil is 11,54 % for the first vehicle, 12,55 % for the second and 13,9 % for the third vehicle. This is far below the allowed limit of 20 % (table 2).

Figure 4. shows the changes viscosity at 100°C engine oil. Fall viscosity for the entire period of exploitation of oil is 12,24 % for the first vehicle, 12,66 % for the second and 13,84 % for the third vehicle, which is also below the allowed limit of 20 % (table 2).

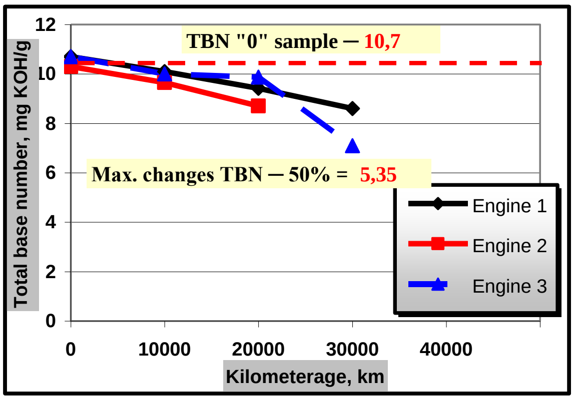

Figure 5. The change of TBN

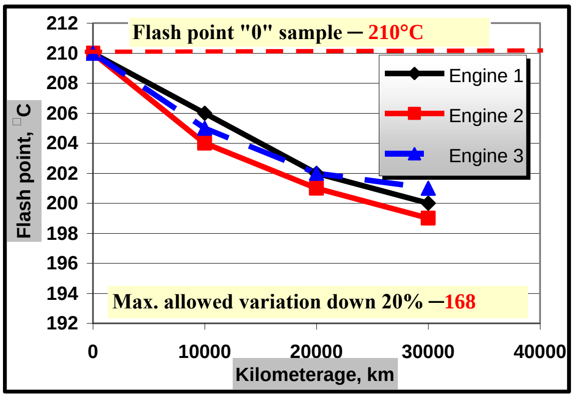

Figure 6. The change of flash point

Figure 5. shows the changes of total base number (TBN). TBN value is the largest in the new (fresh) oil, and reduces during the time spent in the work. Low TBN value indicates that working life of oil is near the end. TBN is usually used in engine lubricants, a sudden drop points to the poor quality of fuel (high sulfur content). The importance of TBN is the possibility of evaluating the degree of additive quality, which is performed on the basis of differences in alkalinity between used and fresh oil. Until 30.000 km TBN value does not exceed the allowed limit. The fall of TBN for the entire period of exploitation of oil is 19,61 % for the first vehicle, for the second 18,69 % and 33,64 % for the third vehicle, which is below the allowed limit of 50 % (table 2).

Flash point represents data that shows what temperature leads to open fire ignition by the steam created by oil heating. In engine oil analysis the flash point determines the presence of fuel oil, which is a consequence of poor motor (bad work injectors). The reduction of flash point is due to the penetration of fuel.

Figure 6 shows the change of flash point for engine oil from the bus Mercedes O 345. The decrease in the flash point is noticeable, and by the end of exploitation testing does not exceed the allowed limits (20 %, table 2) for none of the observed vehicles. The fall flash point is: for the first vehicle 4,76 %, for the second vehicle 5,23 %, and for the third vehicle 4,28 %. This indicates that there was no significant penetration of fuel in the engine lubrication system for the above mentioned vehicles.

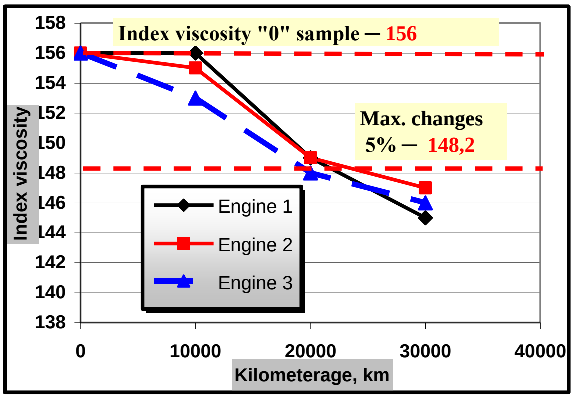

Figure 7. The change of Viscosity Index

Viscosity Index, as it is mentioned, is the tendency of viscosity changes with the temperature and is expressed empirical, using non-dimensional number. During the exploitation it is desired that the viscosity changes as lesser as possible with the change of temperature. If during work temperature modes are changeable and cause major changes of viscosity that may cause disruptions in the functioning of the system, which is a manifestation of increased friction, wear and damage.

Change of engine oil Viscosity Index from the bus Mercedes O 345 is shown in the figure 7. The decrease in the Viscosity Index oil is evident: for the first vehicle 7,5 %, for the second vehicle 5,76 % and for the third vehicle 6,41 %, which exceeds the limit of 5 % (table 2).

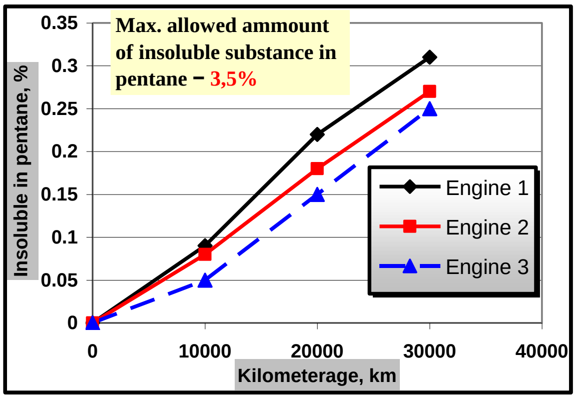

Figure 8. The change of amount of insoluble substances in pentane

Insoluble residues after treatment in pentane are oxidant products and mechanical impurities, while insoluble residues after treatment in benzene are insoluble materials such as coke, scale, dust, soot, particles originated from wear contact area of tribomechanical systems of engines and other mechanical impurities.

Graphical display of changes in the value of insoluble substances in pentane and benzene is given in the figure 8. and 9. The content of insoluble substances in the oil is negligible compared to the allowed deviation values (maximum insoluble in pentane 0,31 %, and it is allowed up to 3,5 %, maximum insoluble in 0,37 % benzene, and it is allowed up to 2,5 %).

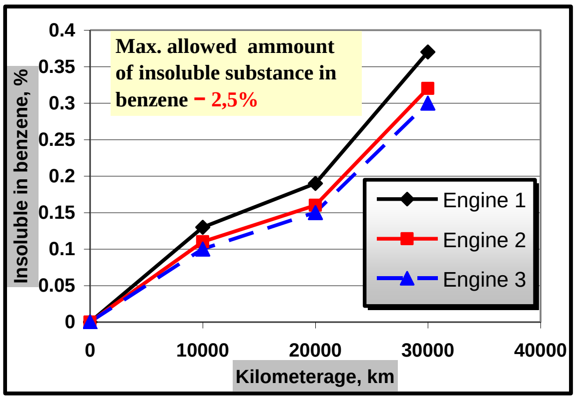

Figure 9. The change of amount of insoluble substances in benzene

In order to view the degree of wear of elements in tribomechanical system engines the atomic absorption spectrophotometry (AAS) is applied for oil sampled from examined engines. This method is determined by the type and concentration of metals (Fe and Cu) in the oil charge.
Atomic absorption spectrophotometry is a very sensitive, simple, fast and reproductive method, used for the detection of most elements. It is based on measurement of light absorption by the atoms that are in the non-excited state. Reduction of missed light intensity increases proportionally with the increasing of number of atoms that are in the non-excited state.

Absorption is determined by measuring changes in intensity before and after the leakage of light through the atomic gas and it is proportional to the concentration of measured element. If the concentrations of elements are small, light absorption is linearly dependent on concentration. Metals like iron (Fe) and copper (Cu) were selected for identification because they are typical elements contained in the examined engines. On the basis of changes in their concentration in the oil charge it can be determined their origin from engine elements and the degree of wear.

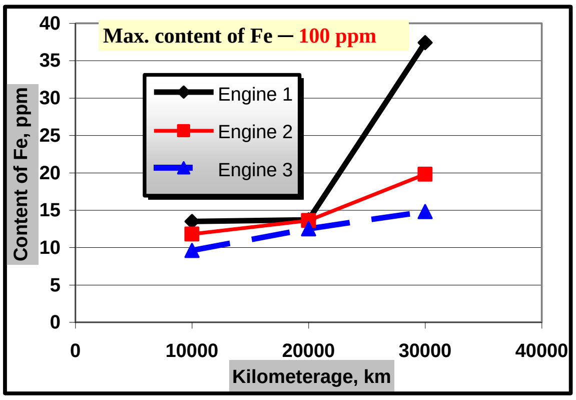

Figure 10.The change of content Fe

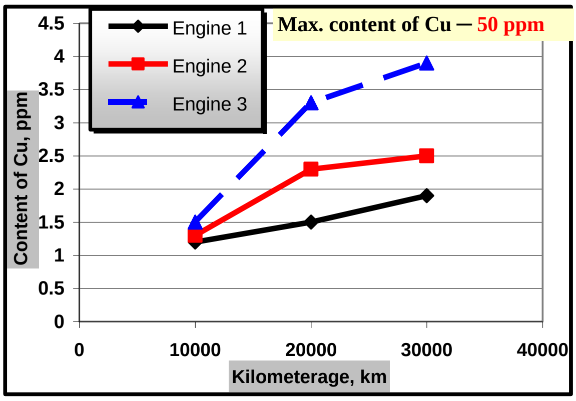

Figure 11.The change of content Cu

Iron content (figure 10), as a product of wear, in the oil charge to the end of exploitation testing have a growing trend and in the last sampling, after 30.000 km, was 37,4 ppm (37,4 %) of the maximum allowed value for the first vehicle, 19,8 ppm (19,8 %) for second vehicle and 14,8 ppm (14,8 %) for the third vehicle. Operational criteria for a replacement of engine oil charge to the end of exploitation investigation of iron is significantly below the allowed limits for all three vehicles. Iron content indicates that the wear in the engine tribomechanical systems of all three vehicles are within the allowable limits. Established iron content (figure

10) indicates that the wear in the engine tribomechanical systems from which sampling was done in the oil is permitted limits.

Copper content (figure 11), as a product of wear in the oil charge to the end of exploitation testing have a growing trend and in the last sampling, after 30.000 km, was 1,9 ppm (3,8 %) of the maximum allowed value for the first vehicle; 2,5 ppm (5 %) for the second vehicle, and 3,9 ppm (7,8 %) for the third vehicle. It can be concluded that the copper content is far below the allowed limit of 50 ppm.

Measuring system, applied on determination of tribological characteristics of tribomechanical system elements is composed of:

- tribometer TPD-93 for measuring normal force, frictional force and frictional coefficient;
- termometer for measuring temperature of oil and elements in contact;
- PQ-2000 particles quantification;
- microscope for measuring wear parameters (length h, width b, and depth of worn zone);
- Talysurf 6, computerized measuring device for measuring surface topography and wear parameters.

These investigations purport previous determination of contact conditions:

- contact geometry;
- intensity and character of outer load;
- motion type (continual, cyclic, etc.) and velocity;
- temperature of elements in contact;
- lubrication method.

Detail analysis of real tribomechanical system establish previously determinate parameters form elements of contact pair. Elements in contact pair needs to have strictly defined characteristics (material, hardness, surface condition, etc.).
On the basis of the tests using the corresponding histograms, the change of contact friction coefficients on time using a tribometre was obtained. The dependences on the sample oil and the vehicle mileage, as well as block's wear width were considered also.

The test results were used to identify certain tribological phenomena, which occurred in the engines of considered vehicles. The friction related to tribological phenomena were identified using the friction coefficient. The damage wear was determined using the width and depth of the wear.

Table 7 shows the average values of the friction coefficient of sample engine oils, width and depth of the track wear.

Table 7. The results of experimental research of the engine oils tribological characteristics [3]

Engine oil	Friction coefficient μ	Boundary lubrication	
		width of the block track wear (mm)	depth of the block track wear (μm)
Sample 0 (Mercedes O 345)	0,101	0,378	0,595
Sample 1 (Mercedes O 345)	0,0985	0,4	0,666
Sample 2 (Mercedes O 345)	0,0983	0,415	0,717
Sample 3 (Mercedes O 345)	0,0968	0,494	1,016

Figure 12 shows the changes of the friction coefficient of engine oil samples on vehicle kilometeterage.

A large value of friction coefficient (μ = 0,101) in fresh engine oil SAE 10W-40, API CF (zero sample), used in Mercedes O345, is higher than friction coefficient of used engine oil because of ZnDDP (zincdialkylditiophosphate) content. The ZnDDP content of engine oil is different from transmission oil, due to the engine conditions. The ZnDDP additive has three important functions: it serves as an antioxidant, anti-corrosion and anti-wear additive. At low temperatures (below 100 °C) the ZnDDP has antioxidant function. If applied at higher temperatures, which is the case for engine oils, it thermally decomposes, where the resulting products have antioxidant function.

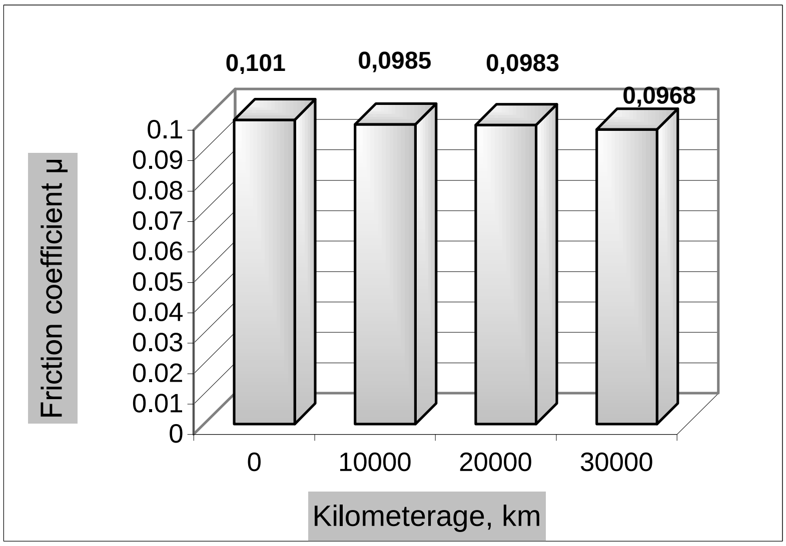

Figure 12. A change of the friction coefficient of the engine oil used in Mercedes O 345

Figures 13 shows changes of the width wear of sampled engine oil on the vehicle's kilometerage.

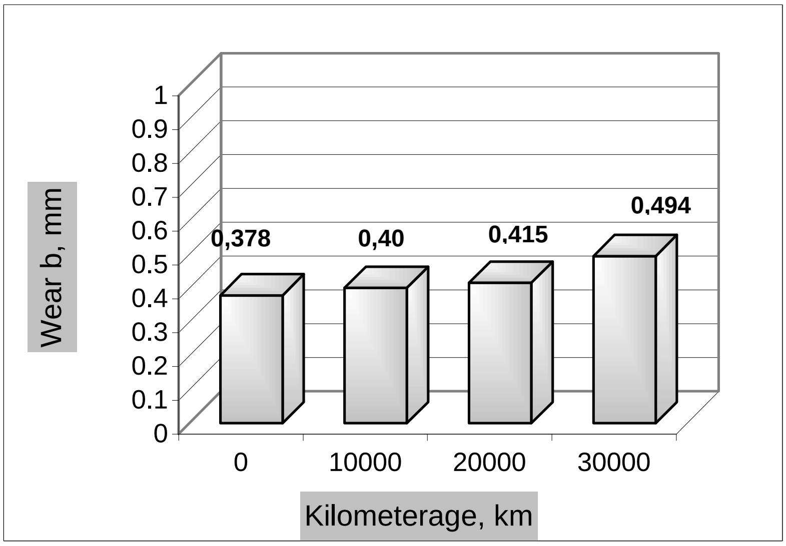

Figure 13. Changes of the width wear of Mercedes O 345 engine sampled oil on kilometerage

Increase of a wear width in the initial period can be explained by the well-known diagram of running-in period of disk and block, which corresponds to the initial use of engine with fresh oil.

An approximate constant growth of the disk wear width as a function of the kilometerage is caused by wear products increase in lubricant and gradual degradation of the lubricant's characteristics during the test. Surface roughness of the disks and blocks were measured, prior the experiments, using the Talysurf 6.

4. Conclusion

On the basis of all mentioned above next conclusions can be drawn:

- engine oil VALVOLINE, API CF and ACEA E4, gradation SAE 10W-40 is analyzed during the exploitation, and it achieves its primary function and meet the prescribed replacement interval of 30.000 km engine EURO 2 categories, which is found the characteristic analysis of physico-chemical properties of oil products and wear (Fe and Cu) during the exploitation;
- the fall of viscosity is evident during the first 10.000 km, and after this period, viscosity remains approximately constant until the end of the interval changes of oil charge. Maximum fall viscosity during the exploitation of oil from all three engines is significantly below the allowed limit of 20 %;
- after 30.000 km TBN value has not exceeded the allowable limit for oil samples from all three engines;
- the content of insoluble substances in the oil is negligible in comparison to the limit value, because there is no significant presence of oxidation products and mechanical impurities, insoluble substances such as coke, scale, dust, soot, particles originated from wear contact area of tribomechanical system in engines and other mechanical impurities;
- small decrease of flash point values shows that there was no significant penetration of fuel into the system for lubrication;
- content of iron and copper is significantly below the allowable limits for all three vehicles;
- the appearance of water in the samples is not found,
- after 30.000 km oil is replaced, only by the recommendation of the manufacturer about how to change the oil charge.

Using highly developed methods of investigation and described equipment it was shown that investigations in laboratory conditions can be used for identification of characteristics and condition of elements of tribomechanical system, and the diagnosis of engine elements. This approach to studding tribological processes gives us great advantages over investigations in real conditions. However, it can be applied when sampling doesn't disturb the functioning of real system. In this case it's oil lubricant sampling.

Realized investigations and adequate tribological measuring confirmed the possibility of identification of changes of characteristics of engine elements as complex tribomechanical systems.

Results obtained during the tests provide information on the friction coefficient, friction force, width and depth of the track wear, shape of block's contact surface wear, change of the friction coefficient and temperature during the time of contact, block's and disk's surface topography parameters before and after the testing, trace of block's and disk's wear etc.

Extension of the interval using engine oil without the monitoring of the state is very risky and can have the following consequences: mutual attachment of piston rings, burnt and mild covered pistons, quick spending of beds, burnt valves and finally jam engines.
Confirming the basic causes of failures and their elimination, control of certain phenomena, is defining proactive maintenance, as a new method that reduces maintenance costs and prolongs the life of assets.

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