

# Monitoring Physical and Chemical Characteristics Oil for Lubrication

*Different technical systems require for the appropriate lubricant to be used at the appropriate place, at the appropriate time and in an appropriate quantity. Determination of technical systems condition has very important role in development of friction theory and practice, wear and lubrication. Lubricant is, as the contact element of the tribomechanical 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 method 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. 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.*

**Keywords:** monitoring, maintenance, oil analysis, physical and chemical characteristics

## 1. INTRODUCTION

Rationalization of lubricants consumption represents significant task with can be obtained by on time oil replacement. 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 changes characteristics oils, represents a very effective method 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.

Analyzing great number of failures of complex tribomechanical systems we can conclude that there have been certain changes as in system that failed as in lubricant. Namely, failure of tribomechanical system can appear due to changes in lubricant characteristics, or changes in lubricant characteristics can appear due to failure of other elements of

tribomechanical system.

Numerous tests and instruments have been developed to help monitor and diagnose machinery lubrication problems. A great deal has been written about the development of new techniques for lubrication analysis and enhancing the ability to determine technical system, lubricant, and contaminant condition from oil.

## 2. DIAGNOSIS OF TRIBOMECHANICAL ENGINE ASSEMBLIES

The essence of diagnosis is based on the prognostication (recognition) of damage and/or failure through the characteristic diagnostic parameters. This allows prevention of the occurrence of delays, and increase reliability, economy, and usage life. Diagnosis of tribomechanical system can provide validation, working capacity and the functionality of the system, and to point out the place, form and cause of failure.

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.

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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.

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.

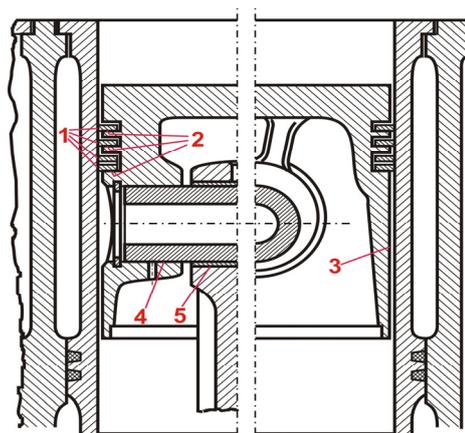
Analysis of the contents of different metals that are in the lubricant is very important. Metal particles are abrasive, and act as catalysts in the oxidation of oils. In motor oils, the origin of the elements may be from the additives, the wear, the fuel, air and liquid for cooling. Metals from the additives 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 originate 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.

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).

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 crank case.



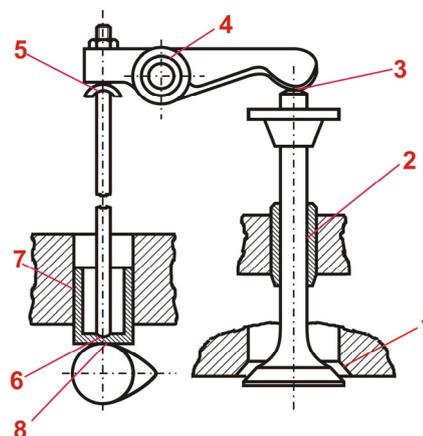
**Figure 1.** Tribomechanical systems and wear surface assemble piston-cylinder:

- 1 – piston ring– cylinder, 2 – piston ring –piston,
- 3 – cylinder– piston, 4 – piston pin–piston and
- 5 – piston pin – connecting rods

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.** Tribomechanical system 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.

Wear 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.

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 MOTOR OIL INVESTIGATION DURING EXPLOITATION

The physical and chemical characteristics of oil in accordance with standard methods are examined, are practice in Laboratory of fuel and lubricant of VTI Belgrade, table 1. The analysis was done on the fresh (new) oils and oils that are used in the motor assembles of vehicles.

Allowable values of deviation limits of individual 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 1.

The origin of several elements in the used motor oil (table 2) 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 1.** Implemented tests and methods for examining the physical and chemical characteristics of oil and allowed values deviation

Characteristic	Method	Maximum allowed variation motor oil
Density, gr/cm <sup>3</sup>	JUS B.H8.015	
Kinematic viscosity, mm <sup>2</sup> /s	JUS B.H8.022	- 20%
Viscosity at 40°C and 100°C, mm <sup>2</sup> /s		
Viscosity Index	JUS B.H8.024	± 5 %
Flash Point (°C)	ISO 2592, ASTM D 92	20 %
Pour Point (°C)	ISO 3016	
Foaming, ml/ml: 24°C; 94°C; 24°C	ASTM D892	
Water Content, mas. %	ASTM D 95	max 0,2 %
Total Base Number (TBN), mgKOH/g	ASTM D 2896	degradation to 50%
Insoluble substances in pentane, %	ASTM D 893	max 3,5
Insoluble substances in benzene, %	ASTM D 4055	max 2,5
Fe Content, %	ASS	100 ppm
Cu Content, %	ASS	50 ppm

**Table 2.** The origin of certain wear elements in the motor 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.

**Table 3.** Technical data for Mercedes-Benz engine, type OM 447HL

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, litre	11,97
Compression ratio	18 : 1
Nominal output, in 2200 min <sup>-1</sup> , KW	220
Maximum torque, in 1100 min <sup>-1</sup> , Nm	1100
Minimal number of revolutions idle stroke, min <sup>-1</sup>	600
Rated speed, min <sup>-1</sup>	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, litre	25

Characteristics of zero samples of motor oil, VALVOLINE, SAE classification SAE 10W-40 and API classification CF and ACEA E4 are shown in table 4, and the results used oil samples in table 5.

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.

Each sample was taken from the 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.

Engine used motor 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 motor oil were expected and within the allowable limits.

**Table 4.** 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 5.** The results of testing samples of used oil from engines examined vehicles

Characteristic \ Sample	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	black	black	3,0	black	black	black	3,0	black	black	black
Viscosity 40°C, mm <sup>2</sup> /s	94,96	85,87	84,16	84	94,96	83,61	83,59	83,04	94,96	84,81	82,35	81,76
Viscosity 100°C, mm <sup>2</sup> /s	14,37	12,67	12,64	12,61	14,37	13,15	12,99	12,55	14,37	12,78	12,64	12,38
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	0,09	0,22	0,31	0	0,08	0,18	0,27	0	0,05	0,15	0,25
INSOLUBLE SUBSTANCES IN BENZENE, %	0	0,13	0,19	0,37	0	0,11	0,16	0,32	0	0,10	0,15	0,30
Content Fe, (ppm)	0	13,5	13,7	37,4	0	11,8	13,6	19,8	0	9,6	12,5	14,8
Content Cu, (ppm)	0	1,3	1,5	1,9	0	1,3	2,3	2,5	0	1,3	3,3	3,9

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 motor 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.

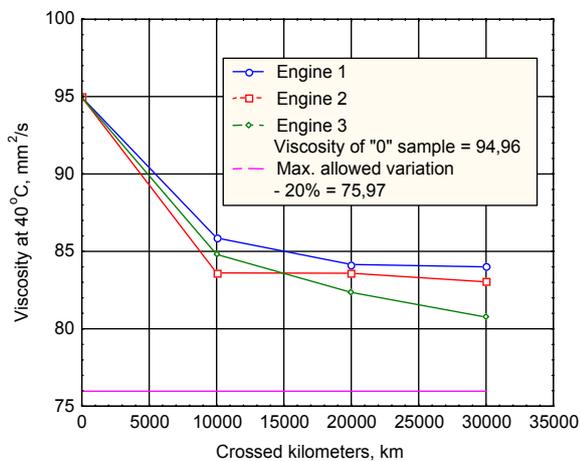


Figure 3. The change of viscosity at 40° C

Figure 3. shows the changes viscosity at 40 °C motor oil during generation. 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 peak for the vehicle 13,9 %. This is far below the allowed limit of 20 % (table 1).

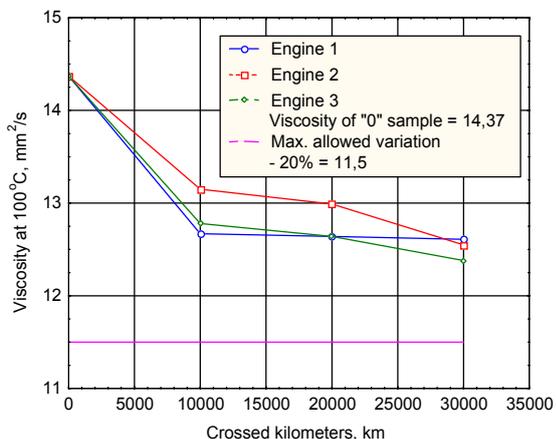


Figure 4. The change of viscosity at 100° C

Figure 4. shows the changes viscosity at 100°C motor 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).

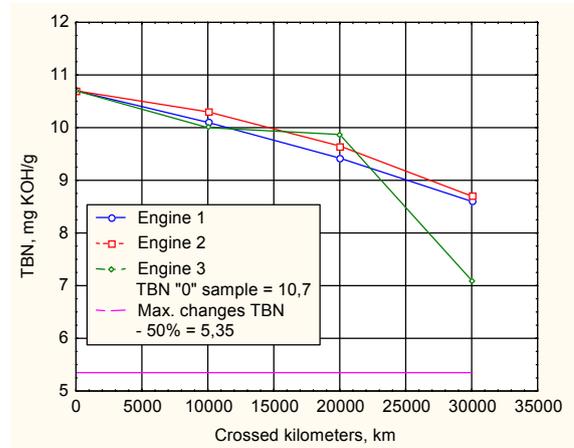


Figure 5. The change of TBN

Figure 5. shows the changes of total base number (TBN). TBN value is the largest in the new (fresh) oil, and reduces during the time service. 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.

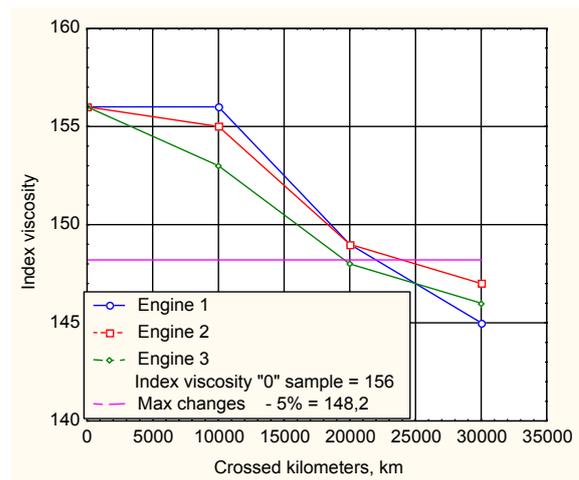
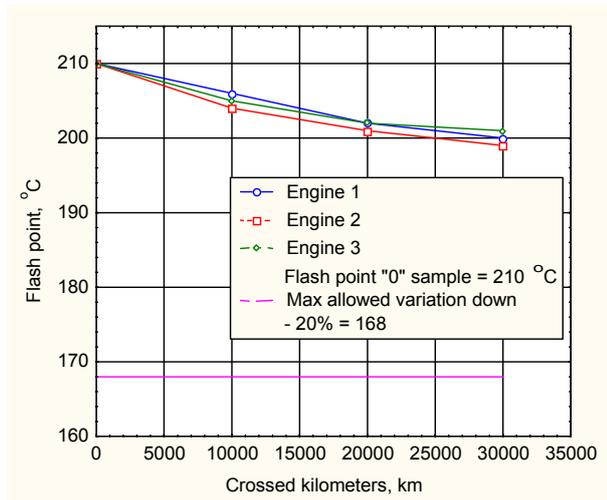


Figure 6. The change of Viscosity Index

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.

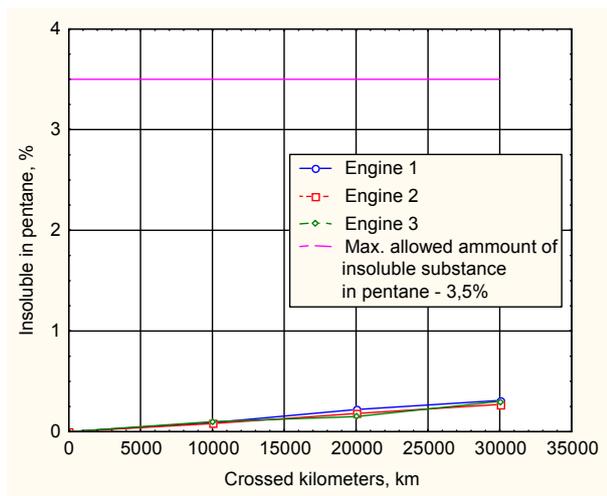
Flash point represents data that shows what temperature leads to open fire ignition by the steam created by oil heating. In motor oil analysis the flash point determines the presence of fuel oil, which is a consequence of poor motor (bad work injectors). The reduction of flash point is due to the penetration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



**Figure 7.** The change of flash point

Figure 7 shows the change of flash point for motor oil. 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.

This indicates that there was no significant penetration of fuel in the engine lubrication system for the above mentioned vehicles.

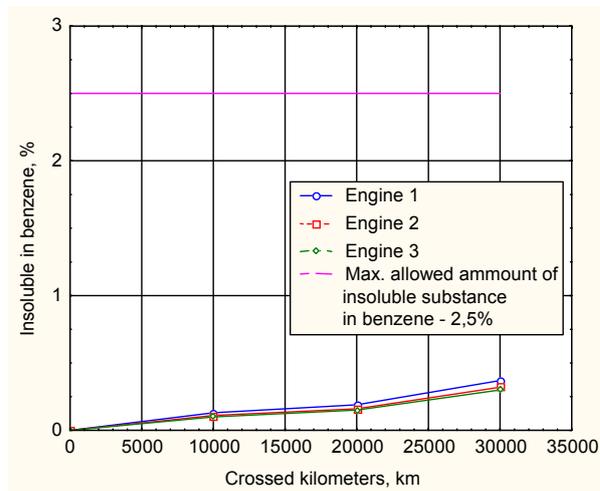


**Figure 8.** The change of amount of insoluble substances in pentane

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.



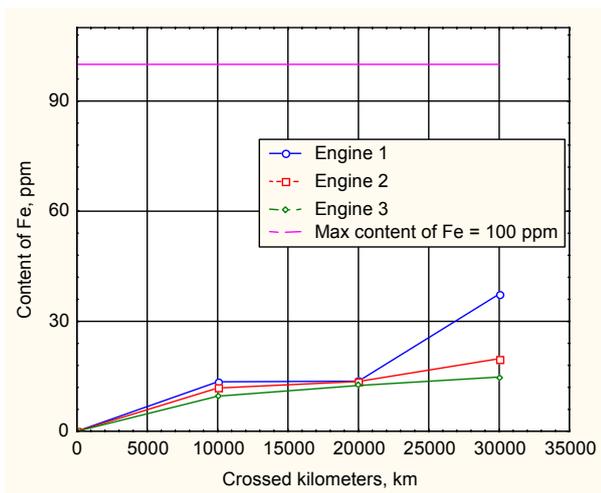
**Figure 9.** The change of amount of insoluble substances in benzene

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.

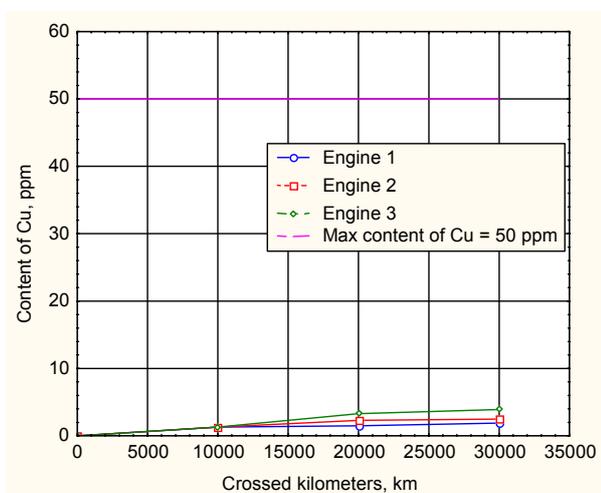
Atomic absorption spectrophotometry is a very sensitive, simple, fast and reproductive method, used for the detection of most elements. It is based on measurement of light absorption by the atoms that are in the non-excited state. Reduction of missed light intensity increases proportionally with the 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.

Iron and copper content (figure 10 and 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. Iron content indicates that the wear in the engine tribomechanical systems of all three vehicles are within the allowable limits.



**Figure 10.** The change of content Fe in motor oil



**Figure 11.** The change of content Cu in motor oil

#### 4. CONCLUSION

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

- motor 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 physical and 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.

The main focus of experimental research, realized in this paper, was put on the grease, as the information on the system as a whole. Tests conducted on the vehicle engines, which have been identified as tribomechanical systems, showed that in most cases the change of the elements functionality and the entire system is expressed through changes in lubricant characteristics. This confirms that the change of physical and chemical characteristics of oil charge can be adopted for the assessment of the system state.

During realized investigations it was concluded that changes appear in physical and chemical characteristics of lubricant in engine. These changes directly depend on condition of all elements of tribomechanical system, from their functional characteristics.

Extension of the interval using motor 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.

Metal particles, physical and chemical processes and contaminants, detected through laboratory analysis and „in-situ” methods, is the appropriate base to identify possible disfunctionalities in tribomechanical systems, as well as to determine the life of usage of oil and its functionality in oil systems.

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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