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## APPLICATIVE MONITORING OF VEHICLES ENGINE OIL

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**Apstrakt:** *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. Determination of tribomechanical systems condition has very important role in development of friction theory and practice, wear and lubrication. There are used today different physical and chemical methods and tribology methods for tribomechanical system diagnosis. Experience in technical systems exploitation showed that the most effective failure prognosis is according to parameters, particles created as result of wear, which are reliable indicators of wear. Analysis of oil samples which contain particles, created as results of wear, enable evaluation of system tribology condition in different phases of system exploitation. The paper presents the physical chemical tests in the analysis of oils that are used for the assessment of his condition. Furthermore the results of experimental research of physical chemical characteristics engines oil was sampled from engines of vehicles, which were in use. The research results are originating from the research of the paper authors.*

**Keywords:** *Monitoring, lubrication systems, analysis oils, proactive maintenance, diagnosis.*

### 1. INTRODUCTION

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.

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.

In application, oils change their properties through [1]: contamination by combustion products and metal wear particles, consumption of additives which is chemical and bears impact on important oil functions and base oil oxidation.

The primary role of engine oil is the lubrication of moving engine parts and reducing friction and

wear of metal surfaces which provides the good engine performance and its long life. In order to provide a defined quality of engine oils during production and for final products to meet the product specifications we need to know the physical chemical characteristics of engine oils.

Certain physical-chemical characteristics which are significant for the quality of engine oils are achieved by adding additives to base oils. The most frequent additives are for: improving of viscosity index-improvers, reducing pour point-depressants, maintaining engine cleanness-detergents and dispersants, preventing oxidation-antioxidants, preventing corrosion-corrosion inhibitors.

### 2. LUBRICANT SERVICE LIFE AND ANALYSIS

To know analytical properties of lubricants is the base to make a decision in development, production and application of lubricants. The lubricant classifications and approved system specify many performance characteristics and

analytical tests. The analytical tests are classical and instrumental. Instrumental technical have the advantages in small quantity of the sample and rapid analyze. As a part of the common proactive strategy of the hydraulic systems maintenance, concept of on-line monitoring is introduced in practice, recently [2], [3], [4], [5], [6]. It is a combination of the measurement procedures, by which sample of fluid is to be analyzed is taken directly from the system and the results of the measurements are continuously. On-line monitoring considering, first of all, control of cleanliness classes (according to ISO, NAS, SAE), control of humidity, viscosity, permittivity (acid), temperature...

The following tests are the most used in condition monitoring: Spectrometric analysis, Analytical Ferrography, Rotrode Filter Spectroscopy (RFS), Infrared Analysis (FT-IR), Viscosity, Total Acid Number (TAN), Total Base Number, Water and Particle Count.

Spectrometric analysis is a technique for detecting and quantifying metallic particulates in used oil arising from wear, contamination and additive packages. The oil sample is energized to make each element emit or absorb a quantifiable amount of energy, which indicates the element's concentration in the oil. The results represent the concentration of all dissolved metals and particles. The equipment for spectrometric analysis is the standard equipment for oil analysis laboratories today. It provides information on technical system, contamination and wears condition relatively quickly and accurately. Spectroscopy is more-or-less blind to the larger particles in an oil sample, more precisely, to particles greater than 10  $\mu\text{m}$  in diameter, which are more indicative of an abnormal wear mode [7].

Analytical ferrography is a technique which separates magnetic wear particles from oil. Those particles settle on a glass slide known as a ferrogram. Microscopic examination enables to determine the wear mode and probable sources of wear in the technical system. Analytical ferrography is an exceptional indicator of abnormal ferrous wear and it is inadequate for nonferrous wear.

Rotrode Filter Spectroscopy (RFS) was first introduced in 1992. This spectrometric technique detects coarse wear metals and contaminants in a used oil sample. Diameter of those particles is up to 25  $\mu\text{m}$ , but it excludes all additives. The coarse particles are especially important. They are the first indicators of abnormal wear situations.

Fourier-Transform Infra-Red Spectroscopy is a spectrometric technique for detecting organic contaminants, water and oil degradation products in

a used oil sample. It monitors lubricant degradation (oxidation, nitration, sulfation, additive depletion) and liquid contaminants (water, glycol, fuel dilution).

Viscosity is the resistance of a fluid to flow and the most important lubricant physical property. The fluid is placed in a "viscometer" (a calibrated capillary tube for precise flow measurement between two pre-marked points on the tube) and pre-heated to a given temperature in a "viscosity bath" (which is usually oil-filled). After the oil reaches the desired viscosity temperature, gravity-influenced flow of the oil is initiated in the viscometer and timed between two calibrated points. This time becomes the determinant for the result.

Total Acid Number (TAN) is a neutralization number intended for measuring all acidic and acid-acting materials in the lubricant, including strong and weak acids. It is a titration method designed to indicate the relative acidity in a lubricant. The TAN is calculated from the amount of KOH consumed. The acid number is used as a guide to follow the oxidative degeneration of oil in service.

Total Base Number (TBN) is a neutralization number intended for measuring all basic (alkaline) materials in the lube (acid-neutralizing components in the lubricant additive package). The converse of the TAN, this titration is used to determine the reserve alkalinity of a lubricant. The TBN is highest when oil is new and decreases with its use. Low TBN normally indicates that the oil has reached the end of its useful life.

Water can be detected visually if gross contamination is present. Excessive water in a system destroys a lubricant's ability to separate opposing moving parts, allowing severe wear to occur with resulting high frictional heat. There are several methods used for testing the moisture contamination (crackle, FT-IR water, centrifuge, Karl Fischer) each with a different level of detection (1000 ppm or 0.1 % for first three methods and 10 ppm or 0.001 % for Karl Fischer method).

Particle Count is a method used to count and classify particulate in a fluid according to accepted size ranges, usually to ISO 4406 and NAS 1638 [8]. There are several different types of instrumentation on the market, utilizing a variety of measurement mechanisms, from optical laser counters to pore blockage monitors.

### **3. THE RESULTS OF OIL ANALYSIS AND DISCUSSION**

In this part are presented the results of oil analysis examination during application in four-

stroke engines by physic-chemical methods in order to evaluate possibilities of engine condition monitoring by oil analysis. This part presents the results of experimental research of physic-chemical characteristics of engines oil which was sampled from engines of PUCH 300GD, Pinzgauer 710 and IKARBUS IK 104P vehicles [9], [10].

The research was carried out in two vehicles PUCH 300GD (PUCH-1, PUCH-2), two vehicles PINZGAUER 710M (PINZ-1, PINZ-2) and two vehicles IKARBUS IK 104P (IK104P-1, IK104P-2).

The research was conducted through periodic sampling oil from engine vehicles listed above.

Apart from the fresh oil ("zero" sample), samples are taken after 1.000 km, 2.000 km, 3.000 km, 4.000 km and 5.000 km for vehicles.

The physical-chemical characteristics of oil in accordance with standard methods are examined, shown in table 1.

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

Characteristic	Method
Kinematic viscosity, mm <sup>2</sup> /s	SRPS B.H8.022
Viscosity Index	SRPS B.H8.024
Flash Point (°C)	ISO 2592, ASTM D 92
Pour Point (°C)	ISO 3016
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

The analysis was done on the fresh (new) oils and oils that are used in the engines of 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.

The wear mechanism of a tribological lubrication system consists in the wear of contact surfaces, and lubricant consumption. If there is wear of the contact surfaces, there are wear particles present.

Regardless of the availability of numerous methods for diagnosing the physico-chemical changes of lubricants, in order to create a true picture of the condition of lubricants from the user system, it is of importance to satisfy the precondition of the possibility to obtain a representative sample. That is why it is extremely important to take the sample in a proper way.

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 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 a characteristic is about.

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

Physical-chemical characteristics oil and products wear	Maximum allowed variation
	Motor oil
Viscosity at 40°C and 100°C, mm <sup>2</sup> /s	20%
Viscosity Index, %	± 5 %
Total Base Number (TBN), mg KOH/gr	The fall to 50%
Flash Point, °C	20 %
Water Content, %	0,2 %
Products wear – Content Fe, ppm(µg/gr)	100 ppm
Products wear – Content Cu, ppm(µg/gr)	50 ppm

Used engine oil in examined vehicles are shown in table 3. Characteristics of zero samples of motor oil are shown in table 4, and the results used oil samples in table 5.

**Table 3.** Used engine oil in examined vehicles [9]

Engine oil from engine of PUCH 300 GD vehicles		
SAE classification	API classification	Manufacturer
SAE 15W-40	API SG/CE	FAM Krusevac
Engine oil from engine of PINZGAUER 710 M vehicles		
SAE classification	API classification	Manufacturer
SAE 30/S3	-	GALAX Beograd
Engine oil from engine of IKARBUS 104 P vehicles		
SAE classification	API classification	Manufacturer
SAE 15W-40	API SG/CE	FAM Krusevac

The viscosity index is an empirical number which shows how the viscosity of some oils changes by increasing or reducing the temperature. High viscosity index shows relatively small tendency of viscosity to change upon influence of certain temperature, as oppose of low viscosity index which shows greater viscosity change with temperature.

**Table 4.** Results of zero samples of oil from the engine [9]

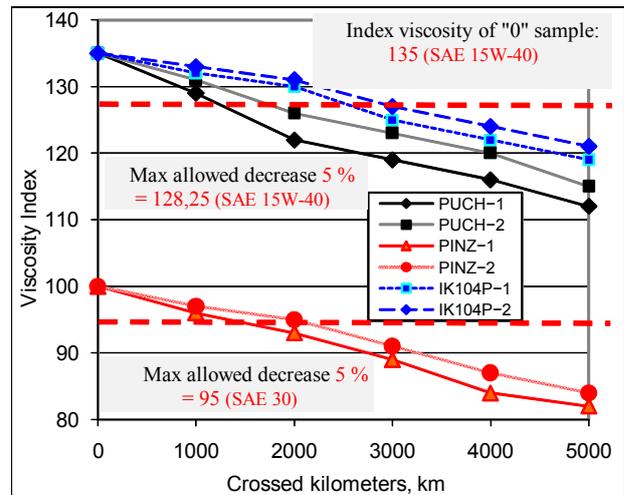
Characteristic	Type of motor oil	
	FAM SAE 15W-40	Galax SAE 30/S3
Color	3,0	3,0
Density, gr/cm <sup>3</sup>	0,881	0,902
Viscosity at 40°C, mm <sup>2</sup> /s	104,81	104,63
Viscosity at 100°C, mm <sup>2</sup> /s	14,12	11,67
Viscosity Index	—	—
Flash Point, °C	230	240
TBN, mg KOH/g	10,5	9,8

**Table 5.** The results of testing samples of used oil from engines examined vehicles [9]

Sample	PUCH -1	PUCH -2	IK104 -1	IK104 -2	PINZ -1	PINZ -2
Viscosity at 100°C, mm <sup>2</sup> /s	0	14,1	14,1	14,1	11,6	11,6
	1	14,6	14,2	13,7	13,6	10,9
	2	15,4	15,0	12,8	13,5	10,3
	3	16,0	15,6	12,4	13,2	9,96
	4	16,6	16,1	12,3	12,9	9,3
	5	17,5	17,0	12,2	12,6	8,7
Viscosity at 40°C, mm <sup>2</sup> /s	0	104,8	104,8	104,8	104,6	104,6
	1	111,0	110,4	96,9	104,4	100,9
	2	113,5	111,8	96,2	101,9	94,4
	3	119,4	113,8	92,3	97,1	86,3
	4	126,4	115,9	90,8	94,8	79,1
	5	132,7	127,5	90,2	93,1	75,9
Viscosity Index	0	135	135	135	100	100
	1	129	131	132	133	96
	2	122	126	130	131	93
	3	119	123	125	127	89
	4	116	120	122	124	84
	5	112	115	119	121	82
Flash Point, °C	0	230	230	230	240	240
	1	220	215	217	212	196
	2	208	210	214	210	186
	3	205	204	213	202	168
	4	197	202	210	193	154
	5	192	188	189	184	136
TBN, mgKOH/g	0	10,5	10,5	10,5	9,8	9,8
	1	9,1	9,4	8,8	8,1	9,6
	2	7,2	8,9	8,7	7,7	9,1
	3	6,5	8,7	8,4	7,2	8,3
	4	6,1	8,1	7,9	6,8	7,6
	5	5,2	7,6	7,3	6,4	7,1
Fe Content (ppm)	1	98,4	27,4	30,1	20,5	19
	2	123	59,8	32,5	46,3	19,8
	3	137,1	71,2	35,6	57,6	38,3
	4	149,4	71,4	37,5	62,8	54,3
	5	165,3	86,8	38,5	69,6	105,4
	261					
Cu Content (ppm)	1	4,9	2	1,5	3,2	3,3
	2	5,9	3,4	1,9	5,1	4,1
	3	6,7	3,7	3,2	6,3	5,3
	4	7,3	3,9	4,4	7,7	6,9
	5	7,9	5,4	4,9	9,1	8,7
	9,7					

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 is shown in the figure 1. The decrease in the Viscosity Index oil is evident for all vehicles, exceeding the limit of 5 % (table 2).



**Figure 1.** The change of Viscosity Index [9]

The most important engine oils characteristic is the viscosity defined as a measure of inner friction which works as a resistance to the change of molecule positions in fluid flows when they are under the impact of shear force, or in other words, it is the resistance of fluid particles to shear.

The viscosity is a changeable category and it depends on the change of temperature and pressure.

A higher temperature reduces the viscosity and makes a fluid thinner.

Multigrade engine oils among numerous additives always contain also viscosity index improvers. These additives are special types of polymers, which in small concentration significantly improve engine oils rheological properties, especially viscosity and viscosity index.

However, during engine oils utilization, degradation of viscosity index improvers i.e. Break down of polymeric molecules occurs. It results in reduction of their molecular weight what leads to viscosity loss and oil film thickness decrease, which causes undesirable phenomena of friction and wear.

Reasons for the increase of viscosity lubricants are as follows: oxidation of lubricants, cavitations 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.

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.

As expected, kinematic viscosity usually decreases in time due to fuel penetration, or - in well maintained engines, there occurs a slight increase as a result of the increase of the oil insoluble, without fuel penetration.

Figure 2. shows the changes viscosity at 40°C engine oils during exploitation.

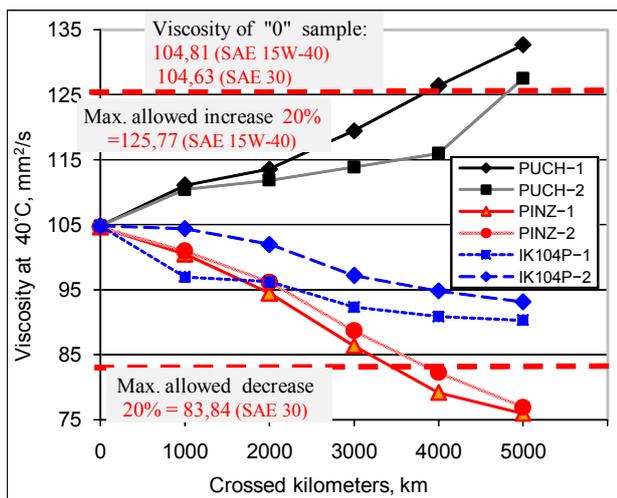


Figure 2. The change of viscosity at 40°C [9]

The increase viscosity at 40°C engine oil is evident for PUCH-1 and PUCH-2 vehicles, exceeding the limit of 20%. The decrease viscosity at 40°C engine oil is evident for PINZ (exceeding the limit of 20%) and IK104P vehicles.

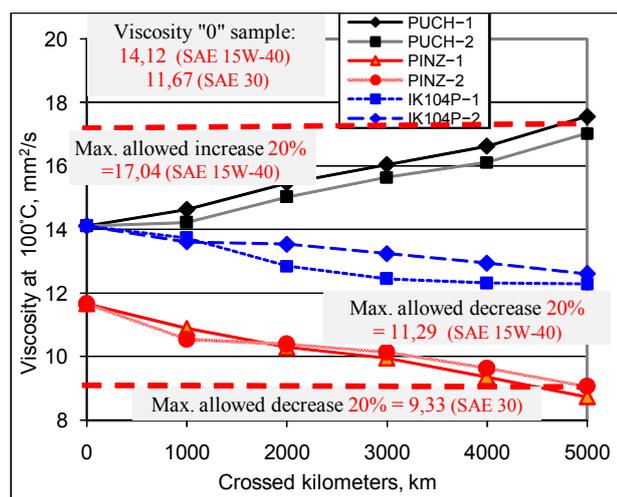


Figure 3. The change of viscosity at 100°C [9]

TBN is a neutralization number intended for measuring all basic (alkaline) materials in the lube (acid-neutralizing components in the lubricant additive package). The TBN is generally accepted as an indicator of the ability of the oil to neutralize harmful acidic byproducts of engine combustion. The TBN is highest when oil is new and decreases

with its use. Low TBN normally indicates that the oil has reached the end of its useful life. TBN is a measure of the lubricant's alkaline reserve, and mostly applies to motor lubricants. If a lube contains no alkaline additives, there is little use to determine a TBN, as there will likely be none. Combustion acids attack TBN, e.g., sulfuric acid, decreasing as it consumes.

Figure 4. shows the changes of total base number (TBN) engine oils.

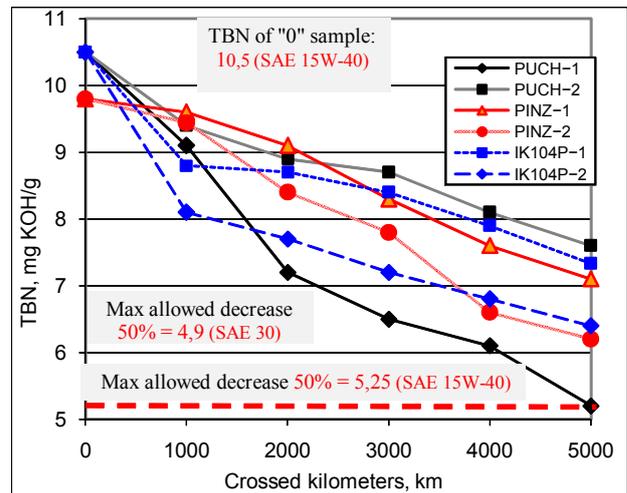


Figure 4. The change of TBN [9]

The decrease TBN engine oil is evident for all vehicles. Until 5.000 km TBN value does not exceed the allowed limit, except for PUCH-1 vehicle.

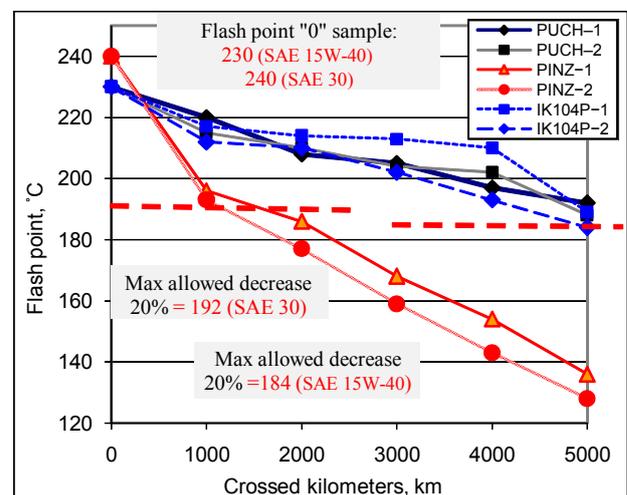


Figure 5. The change of flash point [9]

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 5 shows the change of flash point for engine oils. The decrease in the flash point is

noticeable, and by the end of exploitation testing exceeds the allowed limits (20%, table 2) for PINZ vehicles.

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.

Iron and copper content (figure 6 and 7), as a product of wear, in the oil charge to the end of exploitation testing has a growing trend.

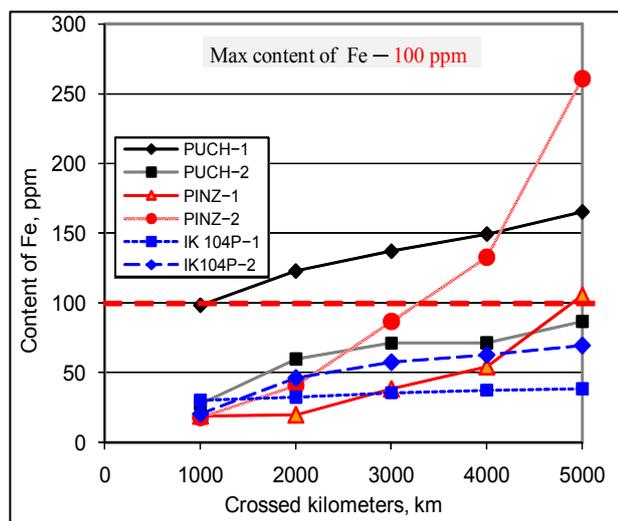


Figure 6. The change of content Fe [9]

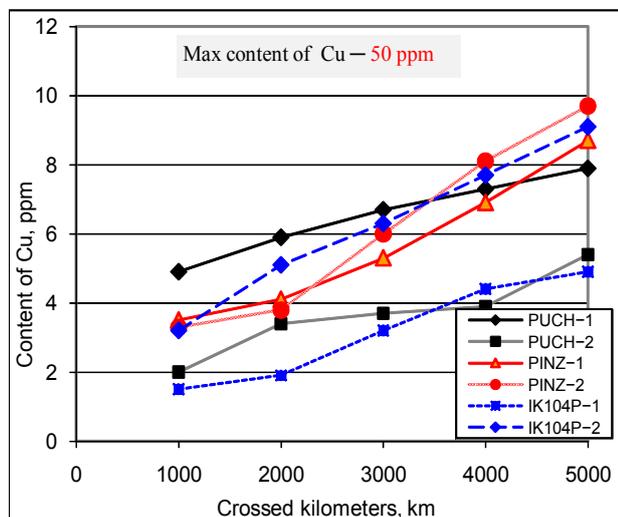


Figure 7. The change of content Cu [9]

Content of iron is significantly above the allowable limits (100 ppm, table 2) for PUCH-1 and PINZ-2 vehicles.

Content of cooper is significantly below the allowable limits (50 ppm, table 2) for all vehicles.

#### 4. CONCLUSION

The interpretation of used oils analysis is very complex, because the individual analyses are interdependent. That is the reason why it is necessary to know the entire oil analysis, and not bring conclusions based on individual analysis results. It is also necessary to establish both normal and critical quality levels for specific oils in given engines and under specific application conditions. The lubricant, being an inevitable factor in the tribomechanical system of engine has – apart from the usual lubricating role, also an important role in detecting the engine operation efficiency and condition. This is achieved through a systematic monitoring of oil in application and a permanent contact between the motor oil manufacturer and user.

Analyses from used oil sample should always be compared with previous samples and final conclusions should be based on “trend analysis” and has two closely related objectives: to obtain information on the lubricant drain intervals and preventive maintenance of the machine.

Investigations it was realized that there is a change of physical-chemical characteristics of oil for lubrication in the engines vehicle. These changes are in direct dependence on the state of all elements tribomechanical engines system, and depending on their functional characteristics.

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