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TRIBOTECHNICAL DIAGNOSTICS - DEGRADATION OF ENGINE OIL PROPERTIES SAE 10W-40 IN IVECO CROSSWAY DURING LONG JOURNEYS

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Abstract: This paper addresses tribotechnical diagnostics, specifically by examining the properties of the engine oil (MO) type i-Sigma top MS; SAE 10W-40 used in the IVECO CROSSWAY bus with a higher number of total mileage from the inter-vehicle standard. In the abstract of the paper, the characteristics of the measured technique, tribodiagnostic instruments of measurement and a more detailed specification of the oil properties and the monitoring of its gradual degradation during long-term operation are presented. Long-term operation in the sense of the article means a continuous mileage run of more than 200 km (one race without stop) and a MO temperature in the range of 80 ºC to 130 ºC. All measurements were carried out in the tribodiagnostic laboratory of the Department of Mechanical Engineering of the Armed Forces Academy of General M. R. Štefánik (hereinafter referred to as „AOS") in Liptovský Mikuláš.

Keywords: Motor oil; ACEA; API; SAE; VW 501 01; 505 00; 504.00; 507.00/MB-Approval 229.31/229.51; Kinematic viscosity; Motor oil condition; Motor oil degradation.

1 INTRODUCTION

Oils are technologically very complex products with many parameters that must meet performance requirements under different load conditions. Despite the manufacturer's declaration of service life and mileage, there may be cases where accelerated degradation occurs and the associated risk of premature wear or engine failure. In this work, we focused on the measurement of engine oil quality indicators during operation and the detection of the degree of degradation. The sampling was carried out by IVECO CROSSWAY EVADIS Fig. 1a, b.

Fig. 1a IVECO CROSSWAY EVADIS
Source: author.

Fig. 1b IVECO CROSSWAY EVADIS
Source: author.

We carried out measurements of a reference sample and 2 measurements of the oil charge. The sampling was carried out in the workshop area of the Department of Mechanical Engineering and the measurements were carried out in the tribodiagnostic laboratory also belonging to the Department of Mechanical Engineering. The thesis consists of a theoretical and a practical part.

2 VEHICLE IVECO CROSSWAY EVADIS

The IVECO CROSSWAY EVADIS is a vehicle equipped with an in-line 6-cylinder diesel engine, which has a power output of 331 kW at 2100 rpm and an engine capacity of 10 308 cm^3. At the beginning of the measurements the vehicle had covered 320,574 kilometres and at the last measurement 336,588 kilometres. ENGINE CURSOR 10. In-line turbocharged diesel 6-cylinder, VGT turbocharger with controlled geometry, 4 valves per cylinder, OHC timing with electronically controlled cylinder head injection units, ITB decompression engine brake with power controlled turbocharger. Electromagnetic fan clutch. Emission standard EURO 5 or EEV 5 (SCR method - use of AdBlue).

3 i-Sigma top MS SAE 10W-40 ENGINE OIL

Eni i-Sigma top MS 10W-40 is a modern high-performance engine oil with synthetic technology capable of saving fuel for the highest load, extended drain intervals for commercial vehicles, especially for vehicles with the new generation of diesel engines equipped with exhaust aftertreatment system (EURO 5) *i-Sigma top MS 10W-40.*

Tab. 1 Selected features MO Eni i-Sigma top MS 10W-40

Grade SAE		10W-40
Density at 15 °C	$kg.m^{-3}$	860
ACEA	-	E6, E9, E7
ACI	-	CI-4
Kinematic viscosity at 100 °C	$mm^2.s^{-1}$	13.1
Kinematic viscosity at 40 °C	$mm^2.s^{-1}$	86
Viscosity index	-	150
Dynamic viscosity at –25 °C	mPa.s	6500
Flash point (o.k.)	°C	230
Freezing point	°C	-36

Source: author.

4 MEASUREMENT RESULTS

4.1 Kinematics

Kinematic viscosity (measured on SpectroVisc Q 3050). The main and essential characteristic for the usability of engine oils in a vehicle.

For the assessment of the quality parameter kinematic viscosity MO, an interval of maximum +20 % and minimum -20 % from the reference sample of engine oil of the prescribed specification SAE; API; ACEA; or company specification (e.g. VW; MB ...) has been established.

- Kinematic viscosity/40 °C: 90.90 [cSt], the decrease compared to the reference sample is by 7.68 [cSt] - MO glass transition by 8.44 [%]. Degradation in terms of kinematic viscosity decreased first (glass transition by 12.02 [cSt]/-9.71 [%]). In the second measurement, the MO compared to the reference sample stacked us by +7.68 [cSt]/-8.44 [%] at that the tendency of kinematic viscosity compared to the reference sample was a tendency of decreasing (more fluid). The trend between the first and the second sample was upward (slightly more viscous). The allowable tolerance derived from the reference sample is 90.09 [cSt], ±20 % (+20 %=118.29.00 [cSt], -20 %=78.86 [cSt]) - the sample value of the MO used is satisfactory**.**

Tab. 2 Kinematic viscosity values of crankcase oil at 40 °C a 100 °C

	Unit of meas.	Ref.s.	i-S/1	i-S/2	i-S/3
Date of collection	d.m.y.	4.4.2023	21.6.2023	5.10.2023	10.1.2024
Date of measurement	d.m.y	12.4.2023	26.6.2023	6.11.2023	18.1.2024
Bus tachometer status	[km]	320,574	325,703	336,588	341,881
Running in MO	[km]	0	5,129	10,885	5,293
Viscosity index	Dimensionless	159	159	159	159
K. viscosity at 40 °C	cSt	118,29 +20% 98,58 78,86 -20%	86,8 12,02 -13,68%	90,90 7,68 -8,44%	97,23 1,34 -1,38%
K. viscosity at 100 °C	cSt	18,04 +20% 15,03 12,02 -20%	13,57 1,46 -9,71%	14,13 0,89 -6,31%	14,87 0,16 -1,07%

Source: author.

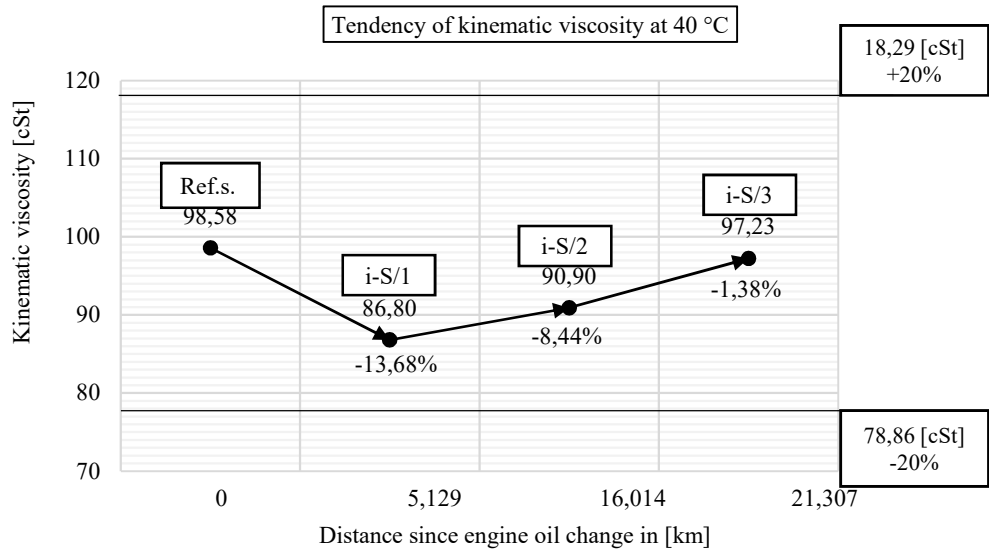


Fig. 2a The course of kinematic viscosities of MO at 40 °C
Source: author.

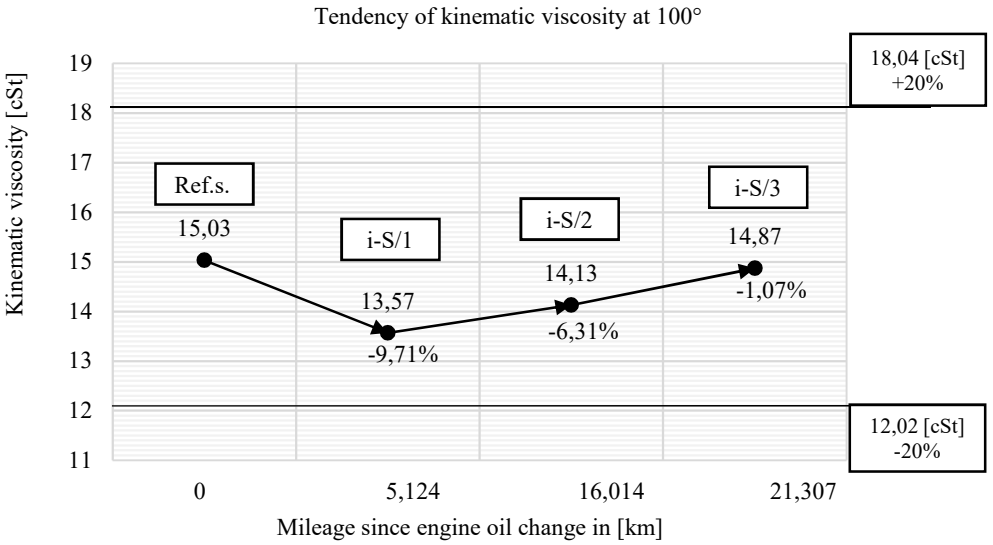


Fig. 2b The course of kinematic viscosities of MO at 100°C
Source: author.

- Kinematic viscosity/100 °C: 14.13 [cSt], the decrease compared to the reference sample is 0.89 [cSt], the MO glass transition is 6.31 [%]. Degradation in terms of kinematic viscosity decreased first (glass transition by 1.46 [cSt]/-13.68 [%]). In the second measurement, the MO stacked by 0.89 [cSt]/-6.31 [%] when compared to the reference sample, the tendency of kinematic viscosity compared to the reference sample was decreasing (more fluid). The trend between the first and the second sample was upward (slightly more viscous). The allowable tolerance is derived from the reference sample of 15.03 [cSt], ±20 % (+20 %=18.03 [cSt], -20 %=12.02 [cSt]) - the sample value of the MO used is satisfactory [4].

4.2 Criterion for Assessing the Performance of Engine Oils *(measured on FluidScan Q-1000)*

TBN - alkalinity number (parameter for acid sludge dispersion)
Do not allow operation of the engine oil if the TBN value changes by more than 50 % of the value of the reference sample.

TAN - acid number (parameter for dispersion of alkaline sludge)
Do not allow operation of the engine oil if the TAN value changes by more than 50 % of the value of the reference sample.

Antioxidant content (resistance and strength of MO structure...)
Do not allow operation of the engine oil when the antioxidant content drops by more than 50 % of the value of the reference sample.
Wear elements (concentration - density of elements - assessment of the state of wear of working surfaces).
Assessment of wear elements by statistical observation and comparison of values for the same engine types, focusing on ISO 14830 values.

Total contamination (to assess particulate matter in engine oil).
Assessment of total contamination according to ISO 14830 focusing on distance and hours worked, not to allow operation at above limit, i.e. - very high contamination according to cleanliness class.

Glycol content (ethylene glycol-$C_2H_6O_2$ or propylene glycol-$C_3H_8O_2$) is not allowed in motor oil.
Glycol causes some of the additive to separate from the base oil in the MO and causes a change in the overall viscosity and thickening of the engine oil. The presence of glycols in engine oil is not permitted.

The total amount of additive in the engine oil.
The engine oil must be usable in the working parts of the engine under all conditions. It must have this serviceability no matter how hot, cold, harsh or dusty the environment in which it is used and regardless of the extent of engine use. Additives are chemicals of complex composition, the addition of which to the base oil improves the performance of engine oils, slowing their ageing and degradation, enabling the oils to safely and reliably meet all the demands of modern engines. Not allowing the engine oil to operate when the total additive value is reduced by more than 50 %. [1]

Soot content (carbon residue (CCT)).
Increased soot content in the exhaust gases is a manifestation of the high mixture richness (λ) of the engine. An engine that operates with a rich mixture not only produces black smoke from the exhaust, but also produces more soot and unburned hydrocarbons (HC). These soot and unburned HC are trapped on engine contact parts and also enter the engine oil, leading to faster carbonization (low and high temperature sludge build-up). piston rings, oil filter plugs or lubrication passages through which the engine oil flows. As a result, engine oil deterioration and inadequate lubrication occur, leading to increased wear on individual engine parts. The specified value for the maximum concentration of CCT is up to 2 % w/t [5].

Water content
Has the effect of triggering chemical reactions, such as sulphation, in which additives fall out of the base oil.
Water is a strong activator of corrosion (rusting) of engine parts. The limit value for the water content in engine oil is 0.5 % w/w/5 000 ppm (concentrations as low as 0.1-0.3 % w/w/1 000-3 000 ppm are already a risk factor) [5].

Fuel content
It has the effect of triggering chemical reactions such as nitration, in which additives are dropped out of the base oil. The limit value for fuel content in engine oil is 5 % w/w/50,000 ppm (some engine manufacturers already quote a value of 4 % w/w/4,000 ppm). The percentage of fuel in the engine oil also affects the flash point of the engine oil. For diesel engine oils, the limit value is 180 °C (the risk factor is already 190 °C). The limit value for spark-ignition engine oils is 160 °C (the risk factor is already 170 °C). This refers to engines with a directly normal reciprocating piston movement [5].

Nitration products.
Nitration is the introduction of one or more NO2 groups into organic compounds. Nitration is the conversion of ammonium salts to nitrite by bacterial action. These processes in engine oil cause the breakdown of the components and additives of the base oil. It is a negative parameter in engine oil [5].

Sulphation products.
Sulfation is the process of sulfate formation. Sulfates are salts of sulfuric acid, sulfates. These processes in engine oil cause the breakdown of the components and additives of the base oil. It is a negative parameter in engine oil [5].

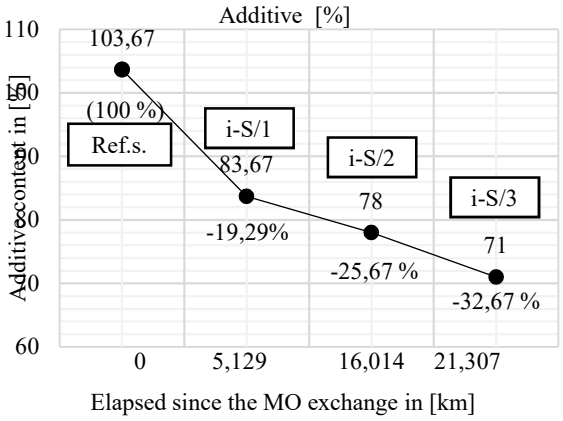
Ferroparticle content (26Fe55,845; 27Co58,933; 28Ni58,693)
- measured with a laboratory tribodiagnostic instrument - FerroCheck 2000 series: ferromagnetic metals are metals with magnetic properties. Their presence in engine oils indicates wear of the respective engine contact surfaces. For the evaluation of engine oils, the following limitation has been set for ferro particles:
- FerroCheck 2000 is set to an interface of 1 000 ppm.
- Amount <0 ppm - 30 ppm> Occurrence of ferroparticles.
- Amount <30 ppm - 70 ppm> Increased occurrence of ferroparticles.
- Amount <70 ppm - 100 ppm> Dangerous amount of ferroparticles.
- Amount <101 ppm and above> Intolerable amount of ferroparticles.

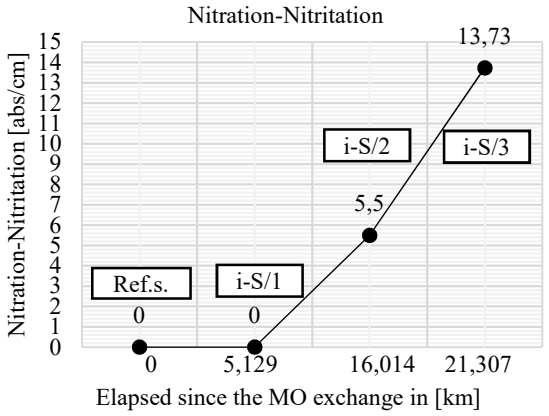
Note: 1 ppm = 0,0001 %
Test methods and procedures used

Tab. 3 Measured values of selected MO properties

	Unit of meas.	Ref.s.	i-S/1		i-S/2		i-S/3	
Unit of meas.	d.m.y.	4.4.2023	21.6.2023		5.10.2023		10.1.2024	
Date of measurement	d.m.y.	12.4.2023	26.6.2023		6.11.2023		18.1.2024	
Number of kilometres	[km]	320,574	325,703		336,588		341,881	
Driven distance since replacement MO	[km]		5.129		16.014		21.307	
Additives	[%]	103,67	83,67	-19,29	36,00	-65,27	71,00	-32,67
Glycols	[%]	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Nitritation/Nitration	[abs/cm]	0,00	0,00	0,00	5,50	5,50	13,73	13,73
Oxidation [abs/0,1]	[abs/0,1]	20,10	20,23	0,13	20,83	0,72	23,98	3,88
Soot	[% wt]	0,00	0,10	0,00	0,18	0,18	0,08	0,08
Sulfation	[abs/0,1]	20,50	19,23	-1,27	16,18	-4,33	20,90	0,40
TBN	[mg KOH]	4,73	5,43	0,70	2,43	-2,31	3,18	-1,56
Water content	[ppm]	773,33	348,00	-425,33	615,50	-157,8	850,75	77,42
Pherochastics	[ppm]	0,00	27,33	+27,33	33,18	+33,18	10,50	-90,50

Source: author.

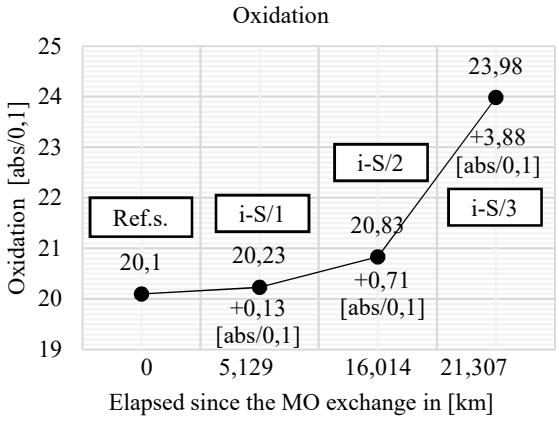




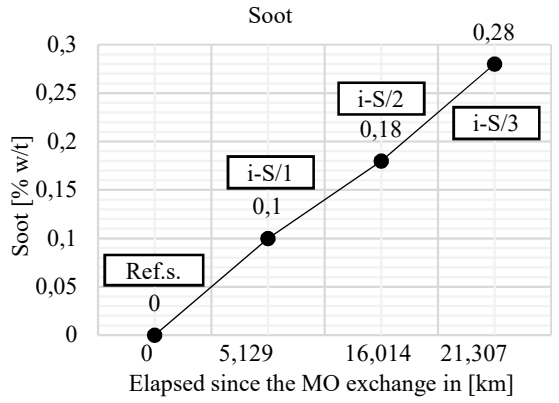
- **Additivity [%] -** Decrease in total additivity vs. (~103.67 %) was as follows for individual measurements:
  After 5,129 km/26.6.2023 - decrease by 19.29 % (to a value of 83.67 %), after 16,014 km since MO replacement/06.11.2023 - decrease by 25.67 % (to a value of 78.00 %), further after 21,307 km since MO replacement/18.1.2023 - decrease by 32.67 % (to a value of 71.00 %). In the course of the 21.307 km travelled, 4.8 lit. MO.
  - The sample value of the MO **used is satisfactory.**

- **Glycols [%] 0,00** - Value the same as Ref.ref - The presence of glycols in the engine oil has not been detected. During the operation from the change of MO/4.4.2023, until the measurement on 18.1.20024 a positive value was measured - 0,00%
  - The sample value of the MO **used is satisfactory.**

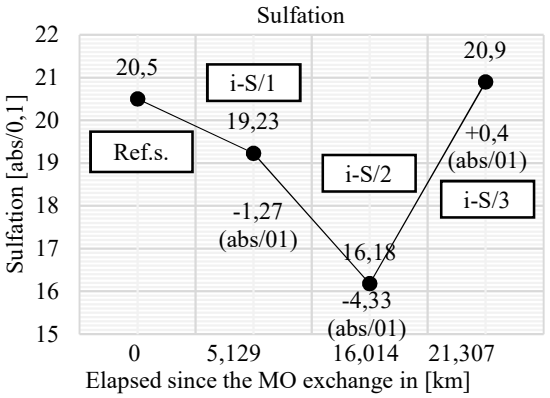
- **Nitration-Nitritation** [abs/cm] After 5,129 km/26.6.2023 - a value of 0.00 abs/cm was measured, after 16,014 km from MO replacement/06.11.2023 - a value of 5.50 was measured (to a value of 5.50 abs/cm), then after 21,307 km from MO replacement/18.1.2023 - a value of 13.73 was measured (to a value of 13.73 abs/cm). The measured values of Nitration-Nitritation tell us about the fuel absorption in MO. In the course of 21,307 km travelled, 4.8 litres were replenished. MO. Nitration is the conversion of ammonium salts to nitrites, these processes in the engine oil cause the decomposition of the components and additives of the base oil. It is a negative parameter in engine oil.
  - The sample value of the MO **used is satisfactory.**



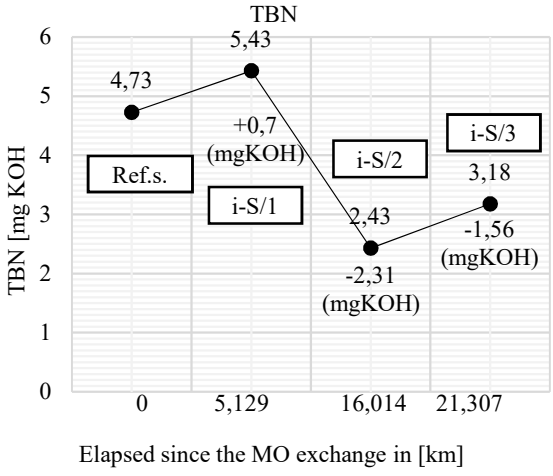
- **Oxidation** [abs/01] When measuring Ref.vz. MO oxidation was found to be 20,1 abs/01 (4.4.2023 - MO replacement in vehicle). This oxidation was due to the fact that the MO was topped up from 200 litres. barrel to several types of equipment. MO was stored in this way for more than 1 year, i.e. there was constant oxidation of MO - the oil was not secured against oxidation by a hermetic seal. After 5,129 km/26.6.2023 - a value of 20,23 abs/01 was measured (increased by 0,13 abs/01), after 16,014 km from the MO replacement/06.11.2023 - a value of 20,83 abs/01 was measured (increased by 0,72 abs/01), then after 21,307 km from the MO replacement/18.1.2023 - a value of 23,98 was measured (increased by 3,88 abs/01). In the course of the 21,307 km driven, 4.8 litres of fuel was added. MO.
  - The sample value of the MO **used is satisfactory.**



- **Soot** [% w/t] After 5,129 km/26.6.2023 - a value of 0.10 % w/t was measured (increase of 0.10 %w/t), after 16,014 km from MO replacement/06.11.2023 - a value of 0.18 %w/t was measured (increase of 0.18 %w/t), then after 21,307 km from MO replacement/18.1.2023 - a value of 0.28 was measured (increase of 0.28 %w/t). The measured soot values are within the standard given that the soot limit is 0.00 %w/t MO. During the 21,307 km travelled, 4.8 litres of MO were replenished.
  - The sample value of the MO **used is satisfactory.**



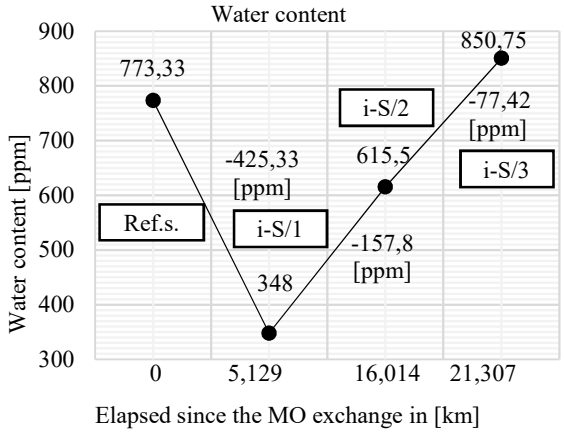
- **Sulfation** [abs/01] When measuring Ref.vz. MO sulphation 20,50 abs/01 was detected (4.4.2023 - replacement of MO in the vehicle). This sulphation was caused by the hydrophilicity of the MO and the humid environment. Thus MO was stored for more than 1. year, that means that there was a constant dissolution of moisture – water in MO from the air. The MO was not secured against moisture ingress by a hermetic seal. After 5,129 km/26.6.2023 - a value of 19,23 abs/01 was measured (decrease by 1,27 abs/01), after 16,014 km from the MO replacement/06.11.2023 - a value of 16,18 abs/01 was measured (decrease by 4,33 abs/01), then after 21,307 km from the MO replacement/18.1.2023 - a value of 20,90 (decrease by 0,40 abs/01) was measured. The decrease in sulphation values and subsequent increase was due to the change in water quantity during operation. During the 21,307 km travelled, 4.8 litres were replenished. MO.
  - The sample value of the MO **used is satisfactory.**



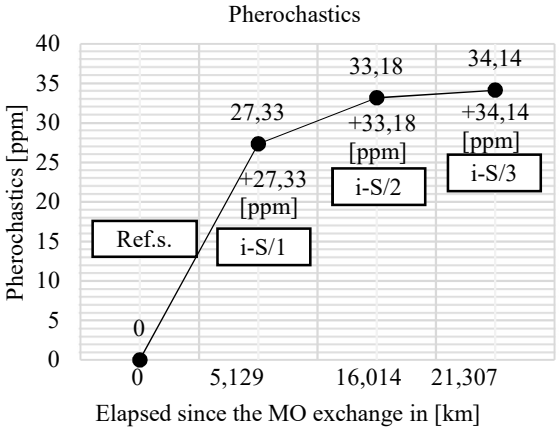
- **Alkalinity (TBN) [**mg KOH/g] When measuring Ref.vz. MO alkalinity was found to be 4.73 mg KOH/g (4.4.2023 - MO replacement in vehicle).

The change in alkalinity is related to changes in oxidation, and fuel and water content of MO. Based on the alkalinity values we can estimate the ageing. After 5,129 km/26.6.2023 - a value of 5,43 mg KOH/g was measured (decrease by 0,70 mg KOH/g), after 16,014 km from MO replacement/06.11.2023 - a value of 2,43 mg KOH/g was measured (decrease by 2,31 mg KOH/g), then after 21,307 km from MO replacement/18.1.2023 - a value of 3,18 mg KOH/g was measured (decrease by 1,56 mg KOH/g). This oscillation of values is due to oxidation, fuel saturation to MO, hydrophilization of water to MO and oil upgrading by adding it to the lubrication system. During the 21,307 km travelled, 4.8 litres of MO were replenished.

- The sample value of the MO **used is satisfactory.**



- **Water content** [ppm] When measuring Ref.vz. the amount of H_2O in the MO was measured to be 773,33 ppm (4.4.2023 - replacement of MO in the vehicle). This presence of water was due to hydrophilization of MO from the humid environment. Thus MO was stored for more than 1 year, i.e. there was a constant dissolution of moisture - water in MO from the air. The MO was not secured against moisture penetration by a hermetic seal. After 5,129 km/26.6.2023 - a value of 348,00 ppm was measured (decrease by 425,33 ppm), after 16,014 km after MO replacement/06.11.2023 - a value of 615,50 ppm was measured (decrease by 157,8 ppm), further after 21.307 km after MO replacement/18.1.2023 - a value of 850,75 ppm was measured (increase by 77,42 ppm). The change in measured values is related to the type of operation and is evaporation from the crankcase into the intake manifold. During the 21,307 km travelled, 4.8 litres of MO were replenished. Considering that the limit value for the amount of water in the engine oil of 5,000 ppm the MO **used is satisfactory.**



Other parameters of the monitored properties, measured in the Laboratory of tribodiagnostics of AOS on device FERROCHECK 2000, are within the tolerances of usability of MO (Table 3. Measured values of selected properties of MO), valid for the used MO Samples i-S/2 MO i-Sigma top MS SAE 10W40, IVECO CROSSWAY Evadis, EVČ LM780CT:

- Pherochastics-Fe, Ni, Co [ppm](1 ppm=0.0001 % of the whole) /33.18/ - Increased occurrence - the ranges of applicability are given above in Table 2.1. Do not allow operation when greater than 101 ppm of Ferroparticles are found in the MO - The sample value of the MO used is satisfactory [2].

4.3 Performance Evaluation Criterion for Spectrocube Engine Oils

(measured on SPECTROCUBE)

Content of measured elements:

- Measured with a laboratory tribodiagnostic device - Spectrocube:

Elements are detected by X-ray lamp irradiation (radiation - evaluation of the frequency characteristics of individual elements)

- Measured parameters reference sample MO i-Sigma top MS SAE 10W40, IVECO CROSSWAY Evadis, EVČ LM780CT.
- The selection of the parameters of the individual elements was chosen according to the possible contamination from the engine, and dropped elements from the additive and impurities from the external environment (air intake into the engine) [3].

Tab. 4 Resulting assembly from SpectroCube and reference sample (Ref.) MO i-Sigma top MS SAE 10W40, IVECO CROSSWAY Evadis, 12.4.2023

No.	ET	Element	Concentration	Error	Unit	No.	ET	Element	Concentration	Error	Unit
16	**S**	Sulphur	2625	1	ppm	51	**Sb**	Antinoma	< 1,7	-	ppm
20	**Ca**	Calcium	1255	2	ppm	27	**Co**	Coblat	< 1,0	-	ppm
30	**Zn**	Zincum	849,5	0,8	ppn	47	**Ag**	Silver	< 0,4	-	ppm
15	**P**	Phosphorus	696,8	1,1	ppm	25	**Mn**	Manganese	< 0,4	-	ppm
12	**Mg**	Magnesium	610	12	ppm	24	**Cr**	Chromium	< 0,3	-	ppm
17	**Cl**	Chlorine	93,9	0,2	ppm	28	**Ni**	Nickel	< 0,3	-	ppm
14	**Si**	Silicon	79,5	0,7	ppm	56	**Ba**	Barium	< 0,3	-	ppm
13	**Al**	Aluminium	18,7	0,4	ppm	40	**Zr**	Zirconiun	< 0,2	-	ppm
42	**Mo**	Molybdenum	7,6	0,2	ppm	29	**Cu**	Copper	< 0,2	-	ppm
19	**K**	Potassium	6,9	0,2	ppm	80	**Hg**	Mercury	< 0,2	-	ppm
53	**I**	Iodine	3,3	1,9	ppm	22	**Ti**	Titanium	< 0,2	-	ppm
26	**Fe**	Irone	1,94	0,05	ppm	48	**Cd**	Cadmium	< 0,2	-	ppm
38	**Sr**	Strontium	0,40	0,04	ppm	50	**Sn**	Tin	< 0,2	-	ppm
83	**Bi**	Bismuth	0,16	0,05	ppm	34	**Se**	Selenium	< 0,1	-	ppm
35	**Br**	Bomine	0,11	0,02	ppm	82	**Pb**	Lead	< 0,1	-	ppm
81	**Tl**	Thallium	0,09	0,05	ppm	74	**W**	Tungsten	< 0,1	-	ppm
33	**As**	Arsenic	0,5	0,03	ppm	23	**V**	Vanadium	< 0,0	-	ppm

Source: author.

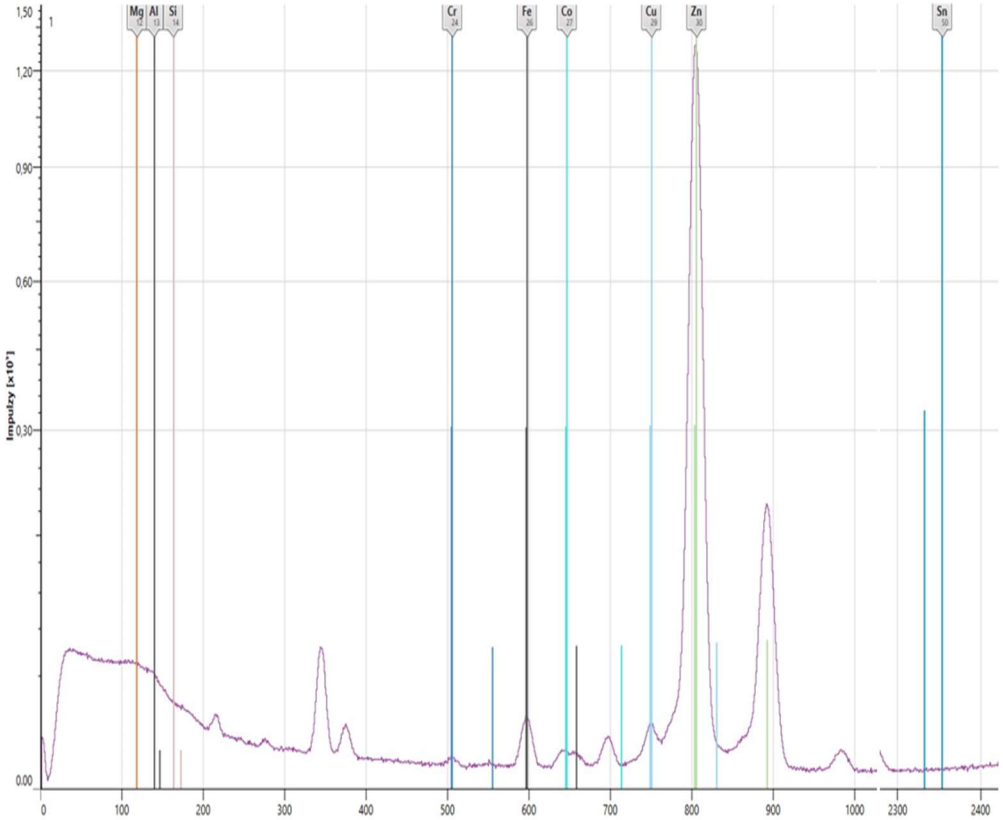


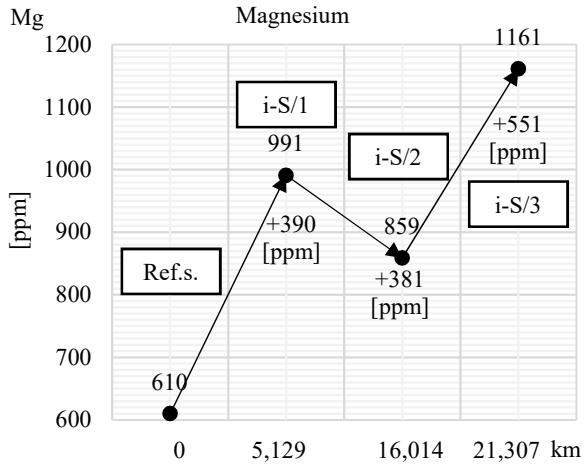
Fig. 3 Frequency response graph: reference sample (Ref.sample) MO Samples i-S/2 MO i-Sigma top MS SAE 10W40, IVECO CROSSWAY Evadis, EVČ LM780CT, v Impulse / eV [mA]
Source: author.

Tab. 5 Comparison of the elements of the reference sample and the used samples i-S/1, i-S/3. These are the underlined elements from the above resulting assembly from SpectroCube

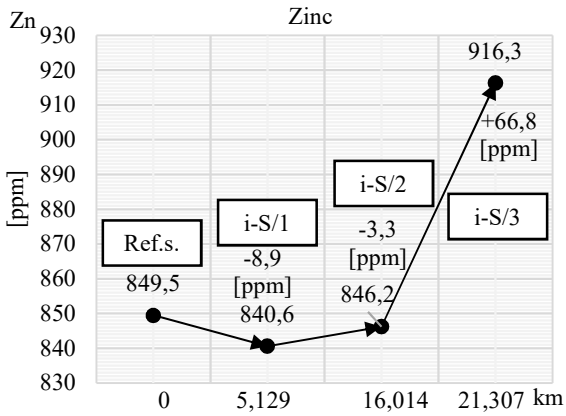
Number in Mendelian table sign	Element tag	Title	Measured value						Unit
			Ref.	i-S/1		i-S/2		i-S/3	
12	Mg	Magnesium	610	991	+390	859	+381,0	1161	+551	Ppm
30	Zn	Zinc	849,5	840,6	-8,9	846,2	-3,3	916,3	+66,8	Ppm
14	Si	Silicon	79,8	41,8	- 38,0	34,6	-45,2	124,6	+44,8	Ppm
13	Al	Aluminum	18,7	17,8	+0,9	4,6	-14,1	1,5	-17,2	Ppm
26	Fe	Iron	1,94	11,1	+9,16	15,1	+13,16	20,6	+18,66	Ppm
82	Pb	Lead	0,1	2,2	+2,1	2,2	+2,1	2,7	+2,6	Ppm
29	Cu	Copper	0,2	1,8	+1,6	3,2	+3,0	4,7	+4,5	Ppm
24	Cr	Chrome	0,3	1,4	+1,1	2,1	+1,8	2,8	+2,5	Ppm
50	Sn	Tin	0,2	1,1	+0,9	1,1	+0,9	1,2	+1	Ppm
27	Co	Cobalt	1	1	0	1	0	0,3	-0,7	Ppm

Source: author.

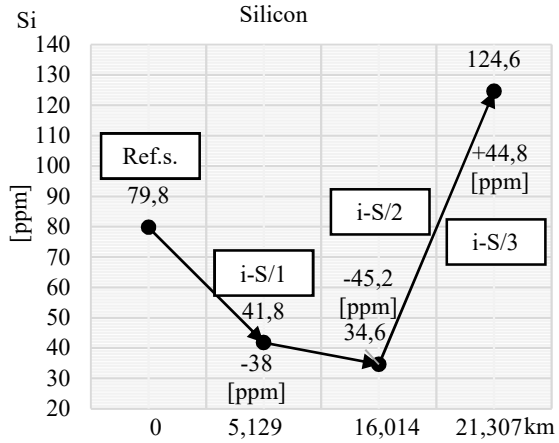
4.4 Evaluation of non-radiation of the monitored elements on the SpectroCube



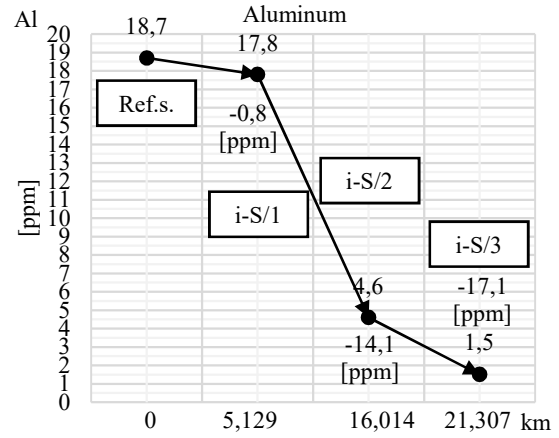
Mg:
There was an increase in the measured value of Mg = +381ppm; - abrasive particles are part of the metal alloys / admixtures of the engine interactive surfaces and MO additive residues (Mg is part of the metals of the interactive surfaces but also of the additive viz. occurrence in the reference sample). From this point of view, I consider this value in MO to be acceptable.



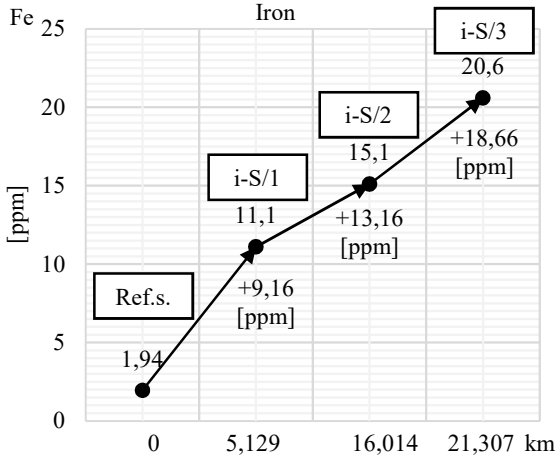
Zn:
There was a decrease in the measured value of Zn= -3.3 ppm; - abrasive particles are part of metal alloys / impurities of the engine interactive surfaces and MO additive residues (Zn is part of the metals of the interactive surfaces but also of the additive viz. occurrence in the reference sample). From this point of view I consider this value in MO as negligible - tolerable.



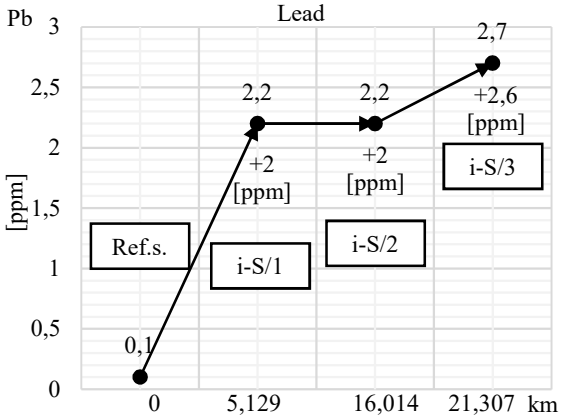
Si:
There was a decrease in the measured value of Si= -45.2 ppm; - Dust particles present in both the reference sample and the used sample are in the minimum values for normal occurrence in the MO. I consider this value to be acceptable.



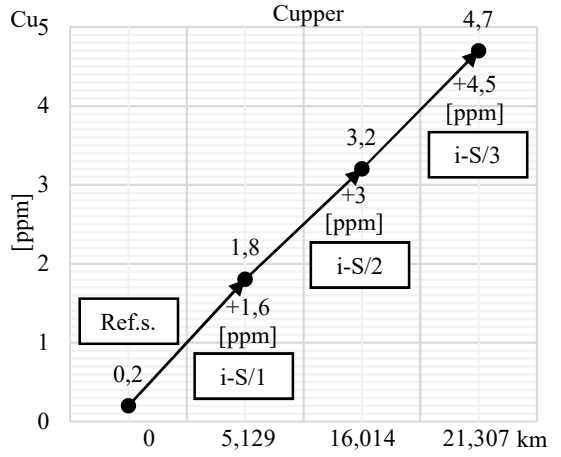
Al:
There was a decrease in the measured value of Al= -14.1 ppm; which is a negligible value in MO, aluminium is found in the engine parts (block, head, piston) there was an atomic dropout from the surface of those parts. I consider this value to be acceptable.



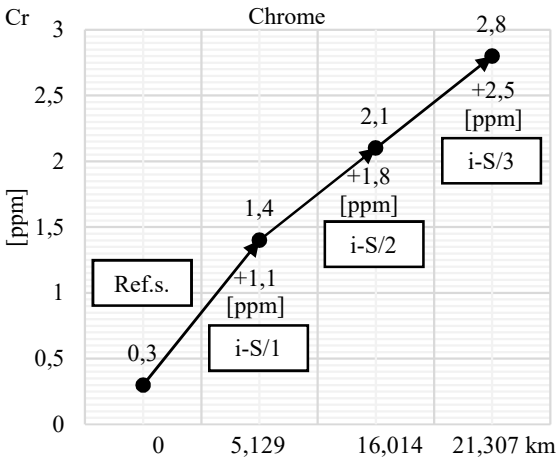
Fe:
There was an increase in the measured value of Fe=+ 13.16 ppm; I consider this value to be a usable occurrence for contact processes in MO. I consider this value to be acceptable.



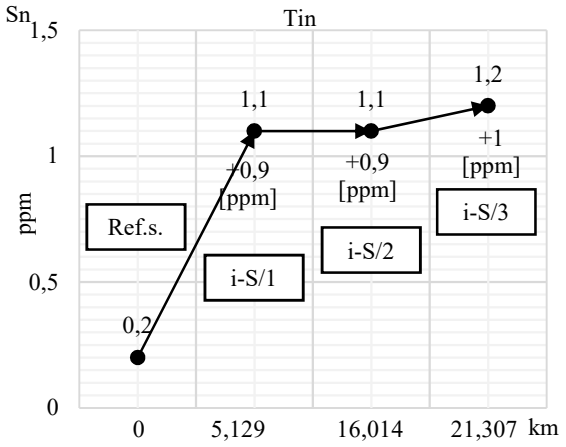
Pb:
There was an increase in the measured value of Pb= + 2.1 ppm; I consider this value to be a usable occurrence for contact processes in MO. Lead is part of the composite alloys in the engine. I consider this value to be acceptable.



Cu:
There was an increase in the measured value of Cu= +1.8 ppm; I consider this value to be a usable occurrence for contact processes in MO. Copper is part of the composite alloys in the engine. I consider this value to be acceptable.



Cr:
There was an increase in the measured value of Cr= +1.1 ppm; I consider this value to be a usable occurrence for contact processes in MO. Chromium is a component of the surface finishes of piston rings and bearings in the engine. I consider this value to be acceptable.



Sn:
There was an increase in the measured value of Sn= + 0.9 ppm; I consider this value to be a usable occurrence for contact processes in MO. Tin is a component of composite alloys in the engine. I consider this value to be acceptable.

Co:
There was no change in the Co = 0.0 ppm value; cobalt is part of the ferrocarbons in the engine.

The overall conclusion of the measurements on the SpectroCube is that the MO sample is suitable for further use.

4.5 Separation filter, separation membrane for detecting the density of solid particles in the MO

The criterion is:

Assessment of the degree of soiling; Detergent-dispersion properties.

Drop test on chromatographic paper and separation filter is a simple test to quickly (informative only) about the quantity of MO. It provides information on the quality and extent of lubricant contamination. This test gives an indication of the content of dispersible particles (substances insoluble in n-Hexane; n-Heptane). N-Hexane insoluble substances include oil insoluble substances formed as a result of the degradation of MOs and additives as products of thermo-oxidation reactions. Excessive content of these substances deteriorates engine lubrication conditions (thickening of MO, formation of hard varnish or low and high temperature sludge). Continued operation with excessive levels of these substances in the MO can cause engine overheating or deterioration of the function of the lubrication system cleaners - the so-called sticking of the filter cartridge surface.

The lines indicate the individual spectra of deposits or yellowing on the chromatographic membrane [6].

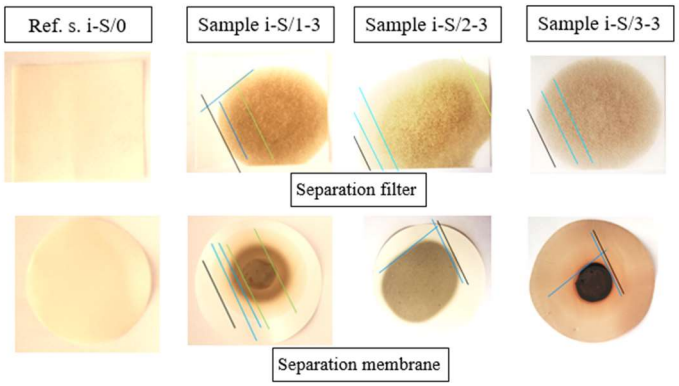


Fig. 4 Visualization of separation filters (square sample and separation membranes (circular sample)
Source: author.

Tab. 6 Degree of contamination (drop test-separation filter)

Motor oil	Degree of pollution **i-Sigma top MS**	Pattern number
The reference sample was clean, clear with no signs of densities		
1. i S/1 after 4 days	2	Litght pollution
2. i S/2 after 4 days	3	Medium pollution
3. i S/3 after 2 days	4	Medium pollution

Source: author.

Separation filter, separation membrane for detecting the density of solid particles in MO

Degree of contamination (drop test-separation filter):

Sample i-S/2-2 - (after running 10,885 km from measurement i-S/1 - total after running 16,009 km), after 3 hours after liquefaction; density of non-transparent material is in the range 0.30-0.50 [D] - density of impurities in the sample 0.0008-0.0016 [g] - **moderate fouling - evaluated from the separation filter**

Sample i-S/2-3 - (after running 10,885 km from measurement i-S/1- total after running 16,009 km), 4 days after liquefaction; density of non-transparent material 0.030-0.050 [D] - density of impurities in the sample 0.0008-0.0016 [g] **- medium fouling - yellow edges indicate good detergent dispersion properties of the MO - evaluation of the separation membranes.**

Sample i-S/3-3 - sample after two 2 day.

Measured MO after running 21.307 km 2 days after liquefaction; density of non-transparent material 0,050-0,070 [D] - density of impurities in the sample 0,0016-0,0024 [g] - medium fouling - yellow edges indicate good detergent dispersion properties of MO - evaluation of separation membranes.

After running 10,885 km since the i-S/1 measurement-a total of 16,009 km-there was no significant change in the density of non-transparent material-dispersible particles (substances not degradable in n-Hexane; n-Heptane) and there was no measured change in the detergent-dispersive properties of the MO.

The lines indicate the individual spectra of deposits or yellowing on the chromatographic membrane.

The degree of separation filter fouling and detergent-dispersion properties were compared with a comparison sample and classified by grade:

- Sample **i-S/3** (after 21,307 km) - rated grade number 4 mild to 4 moderate pollution, MO EXEMPT for further use with restriction to soot monitoring.

Note: the above samples are compared in terms of grain size - density. The separation membrane is darker, because the photochromic layer does not transmit the liquid component of the MO, which dries on the membrane at the separation filter the liquid component is absorbed into the filter, and therefore appears to us as paler and solid particles stand out in the foreground.

5 OVERALL CONCLUSION

Kinematic viscosity
Initially, the kinematic viscosity decreased. It increased with further operation due to refilling of new oil and due to long-distance trips. The engine oil is complaint.

Motor oil properties
None of the measured samples (additives, glycols, nitration, oxidation, soot, sulphation, TBN, water content, pheromone) show significant and borderline values of MO properties. The motor oil is complaint.

Evaluation of motor oil properties by Spectrocube
Selected parameters (magnesium, zinc, silicon, aluminium, iron, lead, copper, chromium, tin, cobalt) increased and decreased variously within the specified tolerances during the measurement. The engine oil is **complaint**.

Evaluation of separation filters and membranes
Density of non-transparent material - The density of impurities in the sample during the measurement was - Mild and moderate fouling. Motor oil is **compliant**.

The aim of the research was to determine the degradation of MO with atypical viscosity in the commonrail engine with oil viscosity - 10W-40. This vehicle was in the operation during long routes over 100 km. Typical oil viscosity used in common rail engine is 5W-30. The aim of the research was to determine the degradation of MO with atypical viscosity in the commonrail engine with oil viscosity - 10W-40. This vehicle was in the operation during long routes over 100 km. Typical oil viscosity used in common rail engine is 5W-30. Life of measured MO is 15,000 km or 2 year (guaranteed by producer). Our purpose was to measure maximum life of MO

including his parameters to find out, if we can exceed the above stated parameters of measured MO.

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