

## TRIBODIAGNOSTIC CONTROL OF MOTOR OIL (MO) PROPERTIES IN IVECO CROSSWAY BUSES

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**Abstract:** Within the Project VV1 "Design and application of tribodiagnostic methodologies for operation and maintenance of ground equipment of the Armed Forces of the Slovak Republic in the years 2018 - 2020, she was performed motor oil (MO) sampling series and property measurement series (MO) PETRONAS URANIA FE LS, SAE 5W-30, (O-1178), in IVECO CROSSWAY vehicles. The aim was to perform on the basis of the performed experimental measurements experimental verification of parameters of operating substances and materials of newly introduced ground military equipment.

**Keywords:** Motor oil; Appearance; Density; Kinematic Viscosity; TBN; TAN; Fash Point; Flow Point.

### 1 INTRODUCTION

Motor oils are technologically very complex products with lots of parameters which must be fulfilled during various loading conditions. Increasing their quality parameters affect the stability, performance as well as the relative prolongation of life norm. Ever higher requirements in terms of emission load are imposed on them. They are made from petroleum and synthetic base oils or from their mixtures, and are modified by complex of additives to the required properties. In the engine they perform a wide range of essential functions under various conditions. And their operation is exactly one of the determining factors on their degradation during the life norm. It is clear that the demands on the quality of motor oil are really high. It is therefore not desirable to underestimate the choice of motor oil as some so called "quasi-motorists" do. Its recommended characteristics for the engine are given by the vehicle manufacturer in the service and operation documentation. For the choice of motor oil from the perspective of the end-user, two parameters are particularly important and that is the viscous and performance specification. Motor oil has to provide excellent lubrication of the working surfaces, to reduce wear of contact surfaces, to serve as a sealing material between working surfaces, to provide heat dissipation, cleanness of working surfaces, to protect against corrosion - by conservation of engine parts, to mediate the transfer of energy, to act as a sound insulator, etc. To perform the required functions, motor oil must maintain the original properties as long as possible (especially stability in oxidative and thermo oxidative processes during high temperatures, pressures, humidity, light, radiation, etc., together with catalytic action of various metals). So in order to ensure reliable engine lubrication it is necessary that the engine oil meets the required properties, such as:

- optimal life.

### 2 SAMPLING OF TEST VEHICLES



**Fig. 1** IVECO Crossway vehicle tested  
Source: authors.

IVECO Crossway bus; Cylinder displacement: 7,790.0 cm<sup>3</sup>; Oxidation catalyst + AdBlue; Synthetic urea; Power: 243.00 kW / 2,500 rpm. Min-1; Fuel: NM min. 51 CC.



**Fig. 2** MO sampling from the vehicle engine  
Source: authors.



**Fig. 3** MO sampling from the vehicle engine  
Source: authors.



**Fig. 4** Engine nameplate  
Source: authors.

### 3 TESTED ENGINE OIL

#### Basic specification:

SAE 3W-30; API CF; ACEA E7, E.4.

#### Company specifications:

MACK EO-M Plus; MAN M3277; MB-Approval 228.5; SCANIA LDF; VOLVO VDS-3; MTU OIL TYPE 3; DAF HP1 / HP2; IVECO 18-1804 CLASSE TFE-contracted TECHNICAL REF. N ° I023.M01; RENAULT VI RXD Performance.

#### Typical physical data:

Density @ 15 °C, 0.855 [g / cm<sup>3</sup>], ASTM D 4052.  
Kinematic Viscosity / 100 °C 11.5[cSt]: ASTM D 445.  
Viscosity Index; 159ASTM D 2270.  
CCS Viscosity / -30 °C; 6100 [mPa.s]; ASTM D 5293.  
Pour Point; -40 [°C]; ASTM D 97.  
TBN; 13 [mg KOH / g]; ASTM D 2896.



**Fig. 5** Tested motor oil  
Source: authors.

### 4 CRITERIA FOR EVALUATING MO PROPERTIES

#### *Appearance (comparison of clarity, gloss, odor and turbidity)*

According to own methodology (practical experience and expertise) to determine the satisfactory or unsatisfactory. Do not allow turbidity - matt surface with light reflection.

#### *Kinematic viscosity (primary and essential property for the usability of the engine oil in the vehicle engine)*

Only allow engine oil to operate within the viscosity range of  $\pm 20\%$  of the reference sample and diesel engine oil manufacturer's data.

#### *Viscosity index*

Temperature dependence of oil fluidity. The degree of viscosity index determines the guarantee of sufficient lubrication under operating conditions. Allow the engine oil to be operated only within a viscosity index of  $\pm 15$  points from the reference sample.

#### *Flash point (basic parameter for lubrication of piston rings, especially in the exhaust phase)*

Do not allow engine oil operation when point for a diesel engine.

#### *TBN - alkalinity number (parameter for the dispersion of acid sludge, its state expresses the life of the oil)*

Do not allow the operation of the engine oil when the TBN value is reduced by more than 50 % of the value of the reference sample and the engine oil manufacturer's data.

*Antioxidant content (durability and foaming, ...)*

Do not allow the operation of engine oil when the antioxidant content decreases by more than 50 % the values of the reference sample and the data of the engine oil manufacturer.

*Aromatic content (effect on carbonization of engine working parts)*

Do not allow the operation of engine oil when the value of the aromatics content is increased by more than 300 % of the value of the reference sample and the data of the engine oil manufacturer.

*Wear elements (concentration of elements - assessment of the state of wear of work surfaces)*

Carry out the assessment of wear elements by statistical observation and comparison of values for the same engine types with a focus on values in accordance with ISO 14830.

*Total contamination (for assessments of particulate matter in engine oil)*

Assessment of total pollution in accordance with the ISO 14830 standard with a focus on mileage and hours worked, not to allow operation at above-limit, ie. - very high pollution according to purity class.

*Glycol content* (Ethylene Glycol-  $C_2H_6O_2$ , or Propylene Glycol-  $C_3H_8O_2$ ) is not permitted in engine oil. The glycol causes the additive to separate from the base oil in the engine oil and to cause overall viscosity and thickening of the engine oil. The presence of glycols in the engine oil is not permitted.



**Fig. 6** Demonstration of MO degradation by fuel and ethylene glycols  
Source: authors.

*Total engine oil additive*

The engine oil must be usable in the working parts of the engine in all conditions. It must have this applicability, regardless of how hot, cold, harsh or dusty the environment is in which it is used and regardless of the extent to which the engine is used. Additives are chemicals of complex composition, the addition of which to the base oil improves the performance of engine oils, slows down their aging and degradation, thus enabling the oils to safely and reliably meet all the requirements of modern engines. Do not allow the operation of engine oil when the

value of the total additive is reduced by more than 50 %.



**Fig. 7** Demonstration of MO degradation at contamination with ethylene glycols (Ethylene Glycol-  $C_2H_6O_2$ , or Propylene Glycol-  $C_3H_8O_2$ ), also at sulfation  
Source: authors.

*Carbon black content (Carbon residue (CCT))*

The increased content of soot in the exhaust gases is a manifestation of the great richness of the mixture ( $\lambda$ ) of the engine. An engine that works 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 the contact parts of the engine and also get into the engine oil, which leads to faster carbonation (clogging of low and high heat sludge) piston rings, clogging oil filter or lubrication channels through which the engine oil is passed. As a result, it is devalued motor oil and insufficient lubrication, which leads to higher wear of individual engine parts.

The maximum CCT value is up to 2 % w / w.

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

*Fuel content* has the effect of triggering chemical reactions, such as sulfation and nitration, in which additives fall out of the base oil. The limit value for the fuel content in engine oil is 5 % w / w / 50,000 ppm (some engine manufacturers already state value of 4 % w / w / 4,000ppm). The percentage weight of fuel in the engine oil also affects the flash point of the engine oil. For diesel-diesel engine oils, the limit value is 180 °C (The risk factor is already 190 °C). The limit value for petrol-ignition engine motor oils is 160 °C (the risk factor is already 170 °C). By this is meant engines with a directly normal reciprocating movement of the piston.

*Nitration products.* Nitration is the introduction of one or more NO<sub>2</sub> groups into organic compounds.

Nitration is the conversion of ammonium salts into nitrites by the action of bacteria. These processes in engine oil cause the breakdown of the base oil components and additives. It is a negative parameter in engine oil.

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

*Ferroparticle Content (26Fe55,845; 27Co58,933; 28Ni58,693) - Measured by 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 assessment of motor oils, the following limitation was set for Ferroparticles:

- 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> Hazardous amount of Ferroparticles.
- Amount <101 ppm and more> Intolerable amount of Ferroparticles.

*Note:* 1 ppm = 0.0001 %

## 5 MEANS OF TRIBODIAGNOSTICS

Means of measuring MO O-1178, SAE 5W-30 in the Laboratory of Tribodiagnosics, Armed Forces Academy of General M. R. Štefánik, Liptovský Mikuláš are shown in the following photo.



**Fig. 8** Laboratory of Tribodiagnosics-SpectroVisc 3050-blue, Spectro Q 1000 Fluidscan-yellow, Ferro Check 2000-blue with screen  
Source: authors.



**Fig. 10** In-vehicle COPMBO measurement kit  
Source: authors.



**Fig. 11** SpectroVisc Tribovisc measuring cell 3050  
Source: authors.



**Fig. 12** Spectro Q 1000 Fluidscan  
Source: authors.

## OVERALL EVALUATION

**Tab. 1** Change of individual properties during the course of measurements at Iveco Crossway; EVČ 687-55-02 and EVČ 687-55-40 for R 2019 and 2020

P.č.	Property / Unit	06/18/2019	06/18/2019	10/27/2019	09/10/2020	09/18/2019	10/27/2019	09/10/2020
		Reference Not used	EVČ 687 30 02 For comparison 04.11.2020 as Sample No. 1 AOS-1	EVČ 687 30 02 For comparison 04.11.2020 as Sample No. 1 AOS-1	EVČ 687 30 02 For comparison 04.11.2020 as Sample No. 1 AOS-1	EVČ 687 55 40 For comparison 04.11.2020 as Sample No.2 AOS-2	EVČ 687 55 40 For comparison 04.11.2020 as Sample No.2 AOS-2	EVČ 687 55 40 For comparison 04.11.2020 as Sample No.2 AOS-2
		REFERENCE no. R AOS 06/18/2019 SAE 5W-30	Sample No.1 AOS-1 taken 14.05.2019 SAE 5W-30 IVECO Crossway / 68 73 002	* Sample No.2 AOS-2 taken from 26.09.2019 SAE 5W-30 IVECO Crossway / 68 73 002	Sample No.1 AOS-1 taken from 07.09.2020 SAE 5W-30 IVECO Crossway / 687 30 02	*** Sample No.1 AOS-3 taken 14.05.2019 SAE 5W-30 IVECO Crossway / 68 75 540	*** Sample No.2 AOS-4 taken from 26.09.2019 SAE 5W-30 IVECO Crossway / 68 75 540	Sample No.2 AOS-2 taken from 07.09.2020 SAE 5W-30 IVECO Crossway / 687 55 40
COMBO-AOS 06/18/2019	COMBO-AOS Measured 06/18/2019	Laboratory-AOS Measured 27.10.2019	Lab.Tribo.Diag.- AOWITH Measured 10.09.2020	AOS LM Measured 06/18/2019	AOS LM Measured 27.10.2019	Lab.Tribo.Diag.- AOWITH Measured 10.09.2020		
x.1.	Number of works km / Mh from production-vehicle [km / Mh]	xx	<b>7,733 from production</b>	<b>20,761 from production</b>	<b>39,738 from production Mixed operation</b>	<b>9,839 from production</b>	<b>22,224 from production</b>	<b>48,209 from production 95% - Long rides</b>
x.2.	Number of works km / Mh from exchanges-MO [km / Mh]	xx	<b>7,733 th most common</b>	<b>20,761 th most common</b>	<b>39,738 th most common</b>	<b>9,839 th most common</b>	<b>22,224 th most common</b>	<b>48,209 th most common 17.07.2019, oil pan resealing</b>
x.3.	Life standard-MO [km / Mh]	xx	<b>80,000 / 2 years</b>	<b>80,000 / 2 years</b>	<b>80,000 / 2 years</b>	<b>80,000 / 2 years</b>	<b>80,000 / 2 years</b>	<b>80,000 / 2 years</b>
1.	Appearance [visual]	Clear with reflection yellow-orange	<b>Slightly dark with reflection</b>	<b>Slightly dark with reflection</b>	<b>Dark with reflection</b>	<b>Slightly dark with reflection</b>	<b>Slightly dark with reflection</b>	<b>Dark with reflection</b>
2.	xx	xx	xx	xx	xx	xx	xx	xx
3.	Ferroparticles-Fe, Ni, Co [ppm]	0.0	xx	<b>9.8928 +9.8928</b>	<b>1.2500 +1.2500</b>	<b>1.33867 +1.33867</b>	<b>4.55454 +4.55454</b>	<b>3,2000 th most common +3.2000</b>
4.	Kinematic viscosity 40 °C [cSt]	+20% 88.09 73.41 -20% 58.73	<b>76.59</b> +3.18 / + 4.33%	<b>77.68</b> +4.27 / + 5.81%	<b>80.40</b> +6.99 / + 9.52%	<b>74.09</b> + 0.68 / + 0.93%	<b>76.80</b> +3.39 / + 4.61%	<b>80.50</b> +7.09 / + 9.65%
	Kinematic viscosity 100 °C [cSt]	+20% 14.49 12.08 -20% 9.67	<b>12.47</b> + 0.39 / + 3.22%	<b>12.60</b> + 0.52 / + 4.30%	<b>12.93</b> +0.85 / + 7.03%	<b>12.31</b> + 0.23 / + 1.90%	<b>12.46</b> + 0.38 / + 3.14%	<b>12.93</b> +0.85 / + 7.03%
5.	xx	xx	xx	xx	xx	xx	xx	xx
6.	xx	xx	xx	xx	xx	xx	xx	xx
7.	TBN [mg KOH / g]	8.15	<b>8.55 +0.4</b>	<b>7.60 -0.55</b>	<b>6.50 -1.65</b>	<b>8.50 +0.35</b>	<b>7.60 +0.55</b>	<b>6.30 -1.85</b>
8.	Soot [% w / t]	0.0	<b>0.055 +0.05</b>	<b>0.115 +0.115</b>	<b>0.190 +0.190</b>	<b>0.040 +0.04</b>	<b>0.120 +0.120</b>	<b>0.220 +0.220</b>
9.	xx	xx	xx	xx	xx	xx	xx	xx
10.	Oxidation [abs / 01]	16.15	<b>15.25 -1.0</b>	<b>16.25 +0.10</b>	<b>17.10 +0.95</b>	<b>15.60 -0.55</b>	<b>16.50 +0.35</b>	<b>18.1 +1.95</b>
	Nitration [abs / cm]	xx	xx	xx	xx	xx	xx	xx
	Sulfation [abs / 01]	25.15	<b>22.12 -3.03</b>	<b>22.05 -0.10</b>	<b>22.50 -2.65</b>	<b>22.12 -3.03</b>	<b>22.55 -2.60</b>	<b>23.50 -1.65</b>
	Glycols [%]	0.0	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
11.	Water content [ppm]	366 ?!	<b>290.5 +290.5</b>	<b>312.0 +312.0</b>	<b>349.0 -17</b>	<b>408.0 +408</b>	<b>294.0 +294</b>	<b>368.0 +2</b>
12.	Additive [%]	100	<b>94.25 -5.75</b>	<b>91.00 -9.00</b>	<b>68.00 - 32.00</b>	<b>95.00 -5.00</b>	<b>92.00 -8.00</b>	<b>74.00 -26.00</b>

\* Note: In 2019 it was referred to as Sample No.2 AOS-2 - In this evaluation it is compared only from the point of view of EVČ 68 73 002 - Ing. Miroslav MARKO, PhD., AOS LM

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Source: author.

## 6 CONCLUSION

2 samples of MO type O-1178, SAE 5W-30, were measured in the Tribodiagnosics Laboratories, in 3 series, from Iveco Crossway buses.

**Reference sample no. R** - AOS showed the state: Kinematic viscosity at 40 °C: COMPLIES [73.41 cSt.  $\pm 20\%$  <58.73 cSt; 88.09 cSt>]. Kinematic viscosity at 100 °C: COMPLIES [12.08 cSt.  $\pm 20\%$  9.67 cSt; 14.49 cSt>]. water contamination 366 [ppm], slight degradation by sulphation 25.15 [abs / 01], probably by the action of water + air O<sub>2</sub> present; oxidation 16.15 [abs / 01], measured alkalinity number TBN 8.15 [mg KOH / g]).

**Sample No. 1 - AOS-1** used MO O-1178, Taken on 07.09.2020 / measured 10.09.2020, (MO inspection at tachometer 39.738 km), Iveco Crossway bus, EVČ 687-30-02: SUITABLE for further use in operation. - Satisfactory kinematic viscosity / 40 °C: 80.40 [cSt], increase in MO viscosity is +6.99 [cSt] - increase in MO viscosity by +9.52 [%]. The allowable tolerance is derived from a reference sample of 73.41 [cSt],  $\pm 20\%$  (-20 % = 58.73 [cSt], + 20 % = 88.09 [cSt]), cf. table no. II / 6.4.3.

- Satisfactory kinematic viscosity / 100 °C: 12.93 [cSt], increase in MO viscosity is +0.85 [cSt] - increase in MO viscosity by +7.03 [%]. The allowable tolerance is derived from a reference sample of 12.08 [cSt],  $\pm 20\%$  (-20 % = 9.67 [cSt], + 20 % = 12.08 [cSt]), cf. table no. II / 6.4.3.

Other parameters of the monitored properties, measured in the Laboratory of Tribodiagnosics of AOS, are within the tolerances of the usability of MO (see Table No. II / 6.4.3), applies to the used MO No. 1, AOS-1:

- Ferroparticles-Fe, Ni, Co [ppm] (1 ppm = 0.0001 % of the total) / 1.2500 / Occurrence of ferroparticles the range of applicability is given above in point II / 5, last 17 sub-point. Do not allow operation when more than 101 ppm of Ferroparticles appear in the MO. Satisfies.

- Alkalinity number (TBN) [mg KOH / g] / 6.50 / decrease compared to R-AOS by 1.65 [mg KOH] do not allow the operation of engine oil when the TBN value decreases by more than 50 % of the value of the reference sample / Complies . -Setting [% w / t] / 0.19 / increase over R-AOS by 0.19 [% w / t] / maximum value is up to 2 % w / t / Satisfactory. -Oxidation [abs / 01] / 17.10 / increase over R-AOS by 0.95 [abs / 01] / do not allow MO operation when the value of antioxidant content decreases by more than 50% of the value of the reference sample / Satisfies.

- Nitration-Nitritation [abs / cm] / xx / was not measured. -Sulphation [abs / 01] / 22,50 / these processes in motor oil cause the decomposition of the base oil components and the additive, the trigger is the presence of water in the MO-it is monitored in

proportion to the presence of water / Boundary compliant.

-Water content [ppm] / 349 / reference sample was contaminated with water-366 ppm / sample no. 1 / AOS-1/349 ppm / monitored and limit values of water content in motor oil are: 0.5 % w / w / 5,000 ppm (risk factors are already concentrations 0.1 - 0.3% w / w / 1,000- 3,000 ppm) / Complies. -Glycols [%] / 0,0 / same value as for R-AOS / the presence of glycols in the engine oil is not permissible / Satisfactory. - Addivation [%] / 68.00 / decrease compared to R-AOS by 32.00 [%] / do not allow operation of engine oil when the value of total additive decreases by more than 50 % / Satisfies.

**Sample No. 2** - AOS-2 used MO O-1178, Taken on 07.09.2020 / measured 10.09.2020, (MO inspection at tachometer 48.209 km), Iveco Crossway bus, EVČ 687-55-40: SUITABLE for further use in operation. - Satisfactory kinematic viscosity / 40 °C: 80.50 [cSt], increase in MO viscosity is +7.09 [cSt] - increase in MO viscosity by +9.65 [%]. The allowable tolerance is derived from a reference sample of 73.41 [cSt],  $\pm 20\%$  (-20 % = 58.73 [cSt], + 20 % = 88.09 [cSt]), cf. table no. II / 6.4.3.

- Satisfactory kinematic viscosity / 100 °C: 12.93 [cSt], increase in MO viscosity is +0.85 [cSt] - increase in MO viscosity by +7.03 [%]. The allowable tolerance is derived from a reference sample of 12.08 [cSt],  $\pm 20\%$  (-20 % = 9.67 [cSt], + 20 % = 12.08 [cSt]), cf. table no. II / 6.4.3.

Other parameters of the monitored properties, measured in the Laboratory of Tribodiagnosics of AOS, are within the tolerances of the usability of MO (see Table No. II / 6.4.3), applies to the used MO No. 2, AOS-2:

- Ferroparticles-Fe, Ni, Co [ppm] (1 ppm = 0,0001 % of the total) / 3,2000 / Occurrence of ferroparticles the range of applicability is given above in point II / 5, last 17 sub-paragraph. Do not allow operation when more than 101 ppm of Ferroparticles appear in the MO. Satisfies.

- Alkalinity number (TBN) [mg KOH / g] / 6.30 / decrease compared to R-AOS by 1.85 [mg KOH] do not allow the operation of engine oil when the TBN value decreases by more than 50% of the value of the reference sample / Complies . -Setting [% w / t] / 0.22 / increase over R-AOS by 0.22 [% w / t] / maximum value is up to 2% w / t / Satisfactory. -Oxidation [abs / 01] / 18.10 / increase compared to R-AOS by 1.95 [abs / 01] / do not allow MO operation when the value of antioxidant content decreases by more than 50 % of the value of the reference sample / Satisfies.

- Nitration-Nitritation [abs / cm] / xx / was not measured.

- Sulphation [abs / 01] / 23,50 / these processes in motor oil cause the decomposition of the base oil components and the additive, the trigger is the presence of water in the MO-it is monitored in proportion to the presence of water.

- Water content [ppm] / 368 / reference sample was contaminated with water-366 ppm / sample no. 1 / AOS-1/349 ppm / monitored and limit values of water content in motor oil are: 0.5 % w / w / 5.000 ppm (concentrations of 0.1 - 0.3 % w / w / 1.000- 3,000 ppm) / Complies.

- Glycols [%] / 0,0 / value same as for R-AOS / the presence of glycols in the engine oil is inadmissible / Satisfactory.

- Additivation [%] / 74.00 / decrease compared to R-AOS by 26.00 [%] / do not allow operation of engine oil when the value of total additive decreases by more than 50 % / Satisfies.

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