**Tonća Ćaleta Prolić, Miroslav Felja, Renata Petek Grahovac, Anđelko Lepušić**

ISSN 0350-350X
GOMABN 54, 3, 257-270
Professional paper

# IMPACT OF VISCOSITY MODIFIERS ON FORMULATION OF UNIVERSAL GEAR TRACTOR OIL (UTTO) SAE 10W-30

*Abstract*
*Universal tractor transmission oil (UTTO) is used for the lubrication of gear transmissions, wet brakes and hydraulic systems for agricultural and construction machinery. The trend in the development of UTTO lubricants focuses on multigrade formulations with the high viscosity index oils, which enables improved performance at various working temperatures. Lower viscosity grade SAE 10W-30 allow the better pumpability at low temperatures and improved durability at high temperatures as well as better protection against wear that, indirectly, causes the fuel savings and costs reduction. In this work different types of viscosity modifiers in UTTO lubricant were investigated. The final formulation of the UTTO lubricant is tested by implementation of field tests in tractor in order to determine the optimal life time of lubricants aiming the possibility of its extension.*

***Keywords:*** *UTTO, multigrade lubricants, viscosity modifiers, testing*

## 1. Introduction

Universal gear tractor oil (UTTO) is used to lubricate gear transmissions, wet brakes and hydraulic systems for agricultural and construction machinery. Due to their multi-purpose performance UTTO lubricants must meet complex requirement such as high power transmission loads, intrusion of water and pollutants, work at low and high temperatures and demanding conditions by braking. The trend of permanent extension of the oil change intervals, improving the life time of lubricants and demand on fuel savings lead to increasingly stringent demands regarding the lubricants. Also, modern agricultural and construction machines have smaller containers for lubricants. Therefore UTTO lubricants of lower viscosity grades 10W-X or 5W-30, similar to that of motor oil, represent a trend. By formulating these types of lubricants a significant impact has the proper selection of base oil. The tendency is to use more hydrocracked base oils (Group III), and advanced additive technology. Great attention must be paid to the proper selection of viscosity modifier (VM) because of possible damage at the injection site due to reduced pumpability of oil in the oil pump at low temperatures, i.e. the engine "cold start".

## 2. An overview of specifications and requirements for UTTO lubricants

The quality of UTTO oils, as well as their working performances are defined by specifications of designers and manufacturers of agricultural and construction machinery. These specifications define the approval procedures.

### 2.1 Specifications

Specific constructions of agricultural and construction equipment have caused differences in the specifications of original manufacturer of machinery and equipment. The specifications that UTTO lubricant must meet:

- API GL-4
- Catterpilar TO-2
- ALLISON C-4
- JOHN DEERE J20C
- CASE NEW HOLAND CNHMAT3525
- Ford ESN-M2C134-D
- Ford ESN-M2C86-C
- MASSEY FERGUSON CMS M1141 / M1143 / M1145
- ZF TE-ML 03E / 05F / 06K / 17E

### 2.2 Requirements for UTTO lubricants quality

The specifications define requirements for the working performances of UTTO lubricants. UTTO lubricant formulations due to its wide applications need to meet different requirements and quality levels by the application. A good lubrication of the transmission, differentials and final drive gears, transmissions systems for steering and braking is necessary. Also, it must ensure proper cooling and friction for wet brakes and clutches for connecting devices. Such lubricant must be compatible with all components of the system and enable reliable operation at high and low temperatures and therefore extended time of oil filling changes.

In addition to the aforementioned application properties the UTTO lubricants have the following performances:

- Good rheological properties,
- Adequate friction characteristics,
- High oxidation and thermal stability,
- Corrosion protection,
- Protection against wear and resistance to high loads,
- Compatibility with various materials,
- Good anti-foaming properties,
- Good dispersant-detergent properties.

## 3. Formulation of UTTO lubricants

In formulating three UTTO lubricants the core component is the base oil. The base oil may be of mineral or synthetic base. Recently, apart from the conventional oils of mineral base (Group I), the hydrocracked base oils (Group III) are used in formulations, in order to achieve easier the lower viscosity grade SAE 10W-XX or 5W-XX. Then, there is a functional additive with the additive technology for meeting all the characteristic performances of UTTO lubricant. Also, an additional additive can be used to lower the pour point (PPD), while for the lowering of viscosity grades it is necessary to add viscosity modifiers (VMs). VMs together with other additives and base oils enable the satisfactory performance of UTTO lubricant and thereby extending its life cycle. In this article we will illustrate the correct choice of viscosity modifier for UTTO lubricant.

### 3.1 Viscosity modifiers

Viscosity modifiers are polymeric compounds soluble in oil, which are added instead of heavy oil components that ensure thickening and good shear stability under mechanical load. In addition, the VMs increase the viscosity index, whereupon lubricant becomes less prone to the viscosity change with the temperature change. At high temperatures, the polymer molecules uncoil whereat their hydrodynamic volume increases resulting with a greater thickening effect. At lower temperatures the same polymer chain coils leading to the smaller thickening effect. A pure lubricant (without VMs) is very viscous at low temperatures, while viscosity at high temperatures falls. A total or partial abandonment of the high viscosity base oils (heavier oil components) in the formulation reduces the occurance of crystals and waxes at low temperatures. Such multigrade oils meet the low-temperature requirements likewise the low viscosity oil at low temperature or in "cold start" engine. Due to lower internal friction the engine efficiency is higher whilst fuel consumption is lower. At high temperatures, the lubricant has a corresponding viscosity and forms a thicker oil film providing better lubricity, oil durability as well as wear protection. Increasing awareness on the environment protection requires from the lubricants for new agricultural and construction machines the control of sludge formation, securing cleanliness of the application site, reduction of the viscosity increase due to the appearance of oxidation and maintaining of the durability of seals and friction materials [7]. Therefore, the VMs play a significant role in formulating multigrade UTTO lubricants of lower viscosity.

#### 3.1.1 The selection of viscosity modifiers

The choice of the right VM in order to achieve optimal properties for specific application depends on the following properties of VM [1,2]:

• The thickening effect, expressed by shear stability index (SSI). The lower SSI the greater thickening effect. SSI = ($kv_{initial}$ - $kv_{later}$) / ($kv_{initial}$ - $kv_{base\ oil}$). The higher molecular weight VM achieve higher thickening effect.

• Shear stability, i.e. resistance to viscosity loss. It is expressed as a percentage of viscosity loss = ($kv_{initial}$ - $kv_{later}$) / $kv_{initial}$ ×100. The VMs of lower molecular weight exhibit improved shear stability.

Lubricant must remain within its viscosity grade and provide an adequate lubricity. A temporary viscosity loss of fluid due to a non-Newtonian behavior can be measured by the Cold Craking Simulator - CCS method (ASTM D 5293) at low temperatures. A constant drop of viscosity that occurs because of the degradation of the polymer molecules is measured by the methods: Bosh injector (ASTM D 6278) and KRL shear test (DIN 51350-6) four balls. The duration of the test was increased from 20 h to 100 h. Branched molecules in VM are sensitive to shear and show worse shear stability. Therefore the VM of lower molecular weight are recommended.

• The increase of the viscosity index, smaller change of the viscosity with temperature change, i.e. it is necessary to maintain elastohydrodynamic (EHD) film of lubricant trough a whole range of operating temperature.

• Improvement of the dispersant properties by the copolymerization of polar monomers containing a hetero atom (amino compounds).

**3.1.2 Types of viscosity modifier** [3]

• Polyisobutylene (PIB) is the first known viscosity modifier. It has good oxidation and thermal stability as well as a good thickening effect but worse low temperature properties. Application of the lower molecular weight PIB is recommended.

• Maleic anhydride-styrene copolymer (MSC) is formed by reaction of styrene and maleic anhydride. It has a great effect of thickening, good low temperature properties, but inferior to the PMA type. Addition of polar molecules (amines) enhances their dispersive properties.

• The olefin copolymer (OCP) is formed by polymerization of ethylene and propylene. It has a good thickening effect and thermal stability therefore it is added in small quantities. However, it has worse low temperature properties. Due to the low cost it is used in motor oil formulations.

• Styrene isoprene copolymer (SIP); excellent thermal and oxidative stability and dispersity. It is necessary to add larger quantities (poor thickening performance).

• Polyalkylmethacrylates (PMA) are formed by esterification of methacrylic acid. They are used as a viscosity modifiers and low temperature viscosity improvers. They have extremely good solubility in various types of base oils. By increasing the side chain length the solubility and thickening effect increase, the appearance of crystals adversely reduces. They have good thermal and oxidation stability. Because of their good working properties they are widely applied in various lubricants (hydraulic transmission). It is necessary to add larger quantities due to their poor thickening performance. Introduction of amine compounds increases the dispersive characteristics (DPMA).

• Styrene-butadiene copolymer (SBR) has excellent thermal and oxidation stability, as well as low temperature properties. It is used in modern motor oil formulations and contributes to fuel savings. The disadvantage is the high price.

• The hydrogenated star polyisopene (STAR) is formed by a controlled radical polymerization. Demonstrate a good shear stability even at lower loads, but somewhat worse low temperature properties. Also, it increases the viscosity index, and may be used in the high viscosity base oils [7].

## 4. Experimental part

The paper investigates different types of VM in the formulation of 10W-30 UTTO oil. The same type of functional additive was used for all test formulations, as well as for Group I base oil. The following table presents the main characteristics of the tested viscosity modifiers.

Table 1: Physico-chemical properties of viscosity modifiers

| VISCOSITY MODIFIERS (VM) FORMULATIONS | Type | KV @ 100 °C, mm²/s (ISO 3104) | SSI | | |
|---|---|---|---|---|---|
| | | | 30 cycles (DIN 51 382) | 250 cycles (DIN 51 382) | KRL 20 h (DIN 51350-6) |
| **A** | PMA | 1520 | | 21 | 62 |
| **B** | MSC-D | 600 | 55 | | 80 |
| **C** | OCP | 970 | 20 | | 15 |
| **D** | PMA-D | 500 | 1 | 0 | 25 |
| **E** | PO/PIB | 790 | | 0 | 8 |
| **F** | PMA | 1100 | 4 | 10 | 47 |
| **G** | PMA-D | 750 | | | 42 |

The key requirements set before formulating according to the specification for UTTO lubricants: ZF TE-ML 03E/05F, John Deere J20C, M Massey Ferguson 1143, Case New Holland CNH MAT3525 and Allison C-4 (Table 2).

Table 2: Key requirements of UTTO specifications

| PROPERTIES | METHOD | REQUIREMENTS OF UTTO SPECIFICATIONS |
|---|---|---|
| Kin. viscosity at 100 °C, mm²/s | ISO 3104 | 9.3 – 12.5 |
| Viscosity index | ISO 2909 | min 140 |
| Pour point, °C | ISO 3104 | max -36 |
| Din. viscosity CCS at -25 °C, mPa s | ASTM D 5293 | max 7000 |
| Shear stability, KRL,100 h kv at 100 °C after test, mm²/s | DIN 51350-6 | min 6.5 |

Seven test formulations with seven types of viscosity modifiers (Table 3) are prepared. All seven formulations were within the limits of the SAE 10W-30 viscosity grade (Figures 1-3). The formulation E had too low viscosity index and dynamic viscosity at -25 °C (CCS), while the C formulation had too low pour point (Figure 4).

Table 3: Tested lubricant formulations

| | TESTED FORMULATION | | | | | | |
|---|---|---|---|---|---|---|---|
| **VISCOSITY MODIFIER, %** | **FA** | **FB** | **FC** | **FD** | **FE** | **FF** | **FG** |
| MA | 5.80 | | | | | | |
| MB | | 5.00 | | | | | |
| MC | | | 10.00 | | | | |
| MD | | | | 8.70 | | | |
| ME | | | | | 8.00 | | |
| MF | | | | | | 5.00 | |
| MG | | | | | | | 10.00 |
| Additive Package | + | + | + | + | + | + | + |
| PPD | + | + | + | + | + | + | + |
| Base oil Group I | + | + | + | + | + | + | + |
| **PHYSICAL AND CHEMICAL PROPERTIES** | | | | | | | |
| Kinematic viscosity at 100 °C, mm ²/s | 10.75 | 10.32 | 10.58 | 10.17 | 10.68 | 10.31 | 10.08 |
| Kinematic viscosity at 40 °C, mm ²/s | 57.91 | 59.81 | 61.36 | 60.86 | 80.47 | 59.59 | 56.05 |
| VI | 179 | 162 | 163 | 155 | 118 | 163 | 167 |
| Pour Point, °C | -45 | -39 | -33 | -51 | -39 | -45 | -51 |
| Dynamic Viscosity at -25 °C, mPa s (CCS) | 5530 | 5420 | 4180 | 7240 | 17700 | 8040 | 5290 |
| Dynamic Viscosity at -18 °C, mPa s (Brookfield) | 2100 | 2964 | 3199 | 2999 | 3799 | 3199 | 1900 |
| HSHTV | 3.56 | 3.24 | 3.33 | 3.37 | 3.52 | 3.45 | 3.64 |
| Shear stability, KV at 100 °C, after 100 h of shear (KRL), mm²/s | 5.90 | 6.70 | | 7.20 | | 5.85 | 6.75 |

Figure 1: Kinematic viscosity at 100 °C

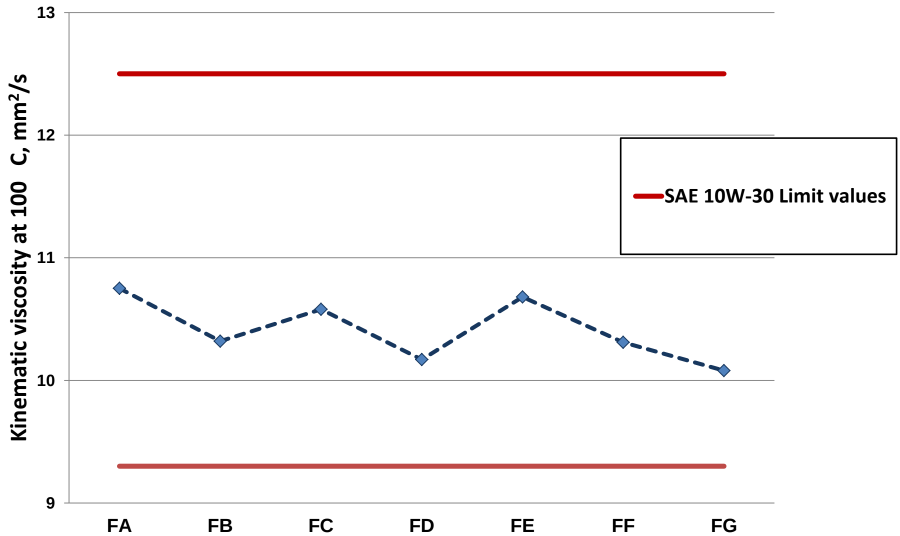



Figure 2: Viscosity index of tested formulations

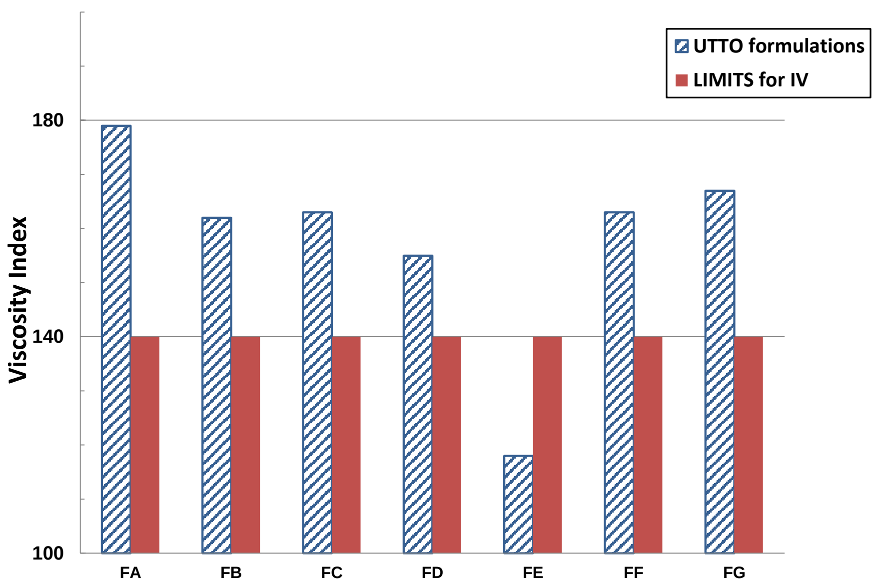


Figure 3: Dynamic viscosity at -25 °C (CCS) of tested formulations

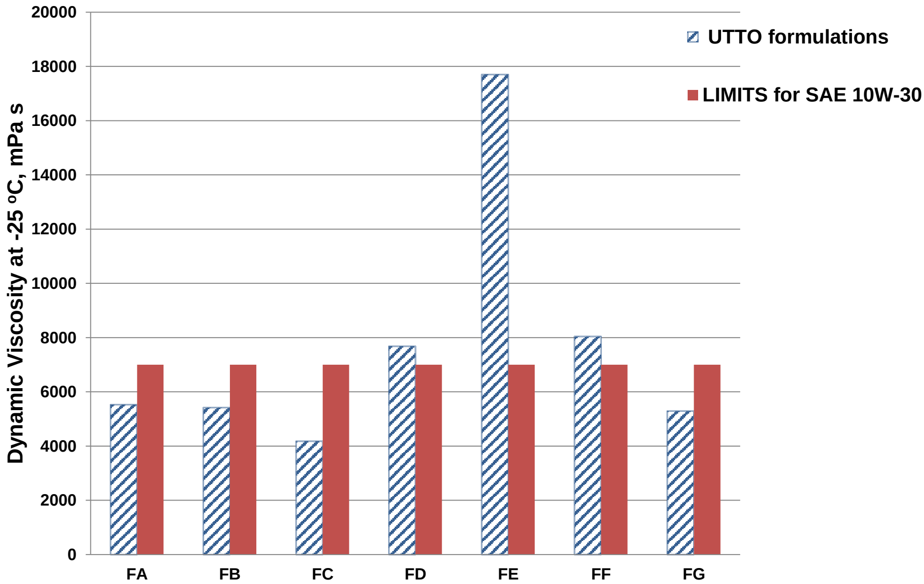
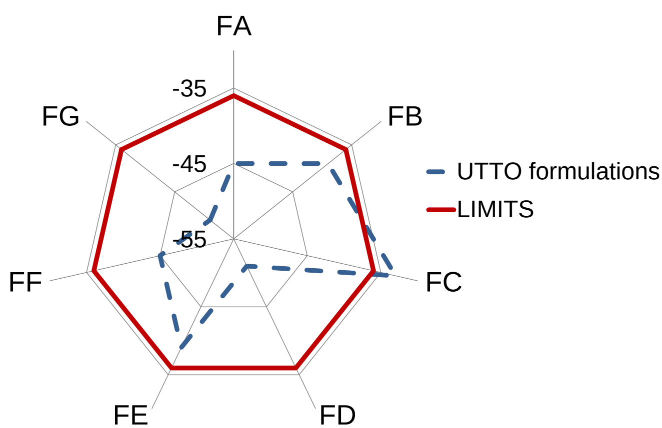



Figure 4: Pour point of tested formulations




Among the remaining formulations five were used for shear stability tests (KRL) at 100 h while two were below the limits of ZF lists (Figure 5). Among the remaining three formulations that have passed all limiting requirements of specifications for UTTO lubricants, the FB formulation was chosen because of the lowest load.

Figure 5: Shear stability (KRL) of tested formulations

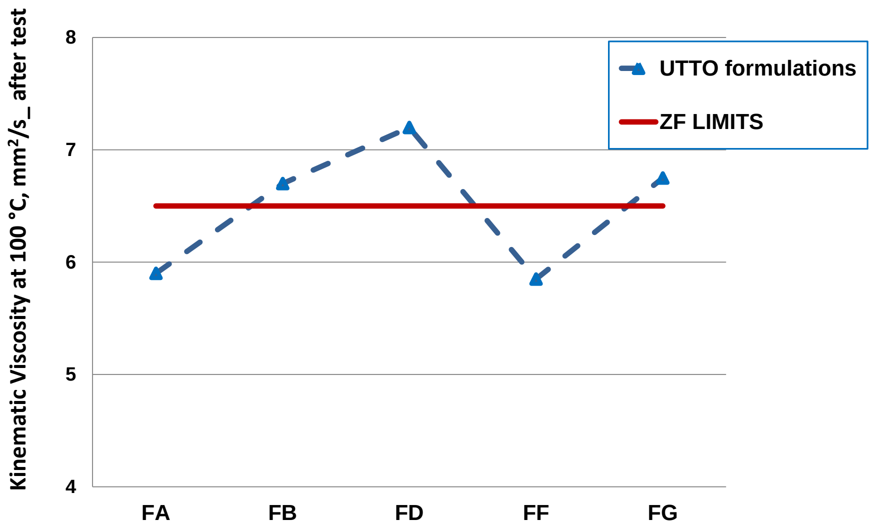
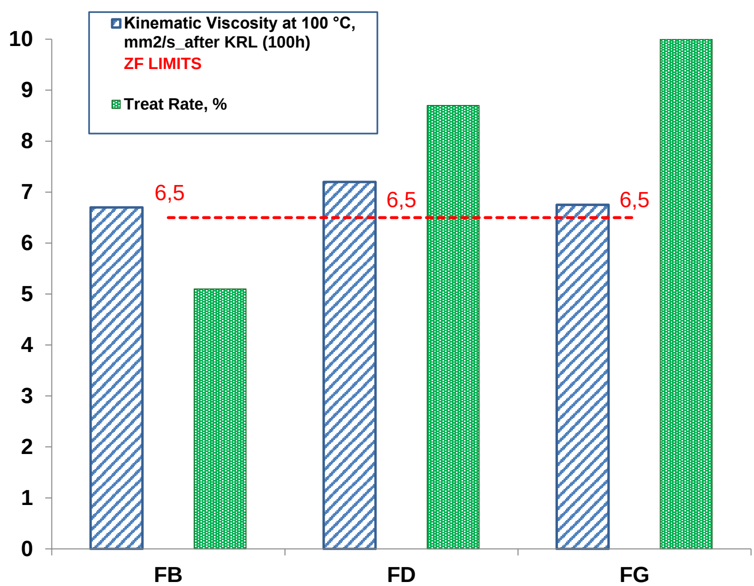



Figure 6: Selected formulations of UTTO lubricants



## 5. Field tests

The selected formulation FB was used in field test performed at the tractor SAME DEUTZ 90. The field test lasted 17 months and the tractor was running 1260 operating hours.

### 5.1 The aim of the field tests

The aim of the field tests was to:

- determine optimal drain intervals for UTTO lubricants aiming at extending it over 1000 operating hours,
- monitor the lubricants quality during field testing in accordance with the acceptance criteria,
- determine the behavior of commercial multigrade UTTO lubricant in severe working conditions (carrying cargo and hilly terrain)
- decrease the costs of lubricants and vehicle maintenance, storage costs, and consequently the reduction of disposal costs of used lubricant and packaging.

### 5.2 The dynamics of sampling

Samples were taken after 20, 300, 450, 650, 900 and 1260 operating hours. The field test took 17 months due to an uneven use of the tractor due to the weather conditions.

### 5.3 Acceptance criteria for multigrade UTTO lubricant viscosity grade SAE 10W-30

As acceptance criteria for lubricant are chosen on the limits defined by equipment manufacturers, as well as from previous experience of experts from the national oil company in the field of lubricants testing (Table 4). The final acceptance criteria will be given at the end of the trial tests.

Table 4: Acceptance criteria for lubricant

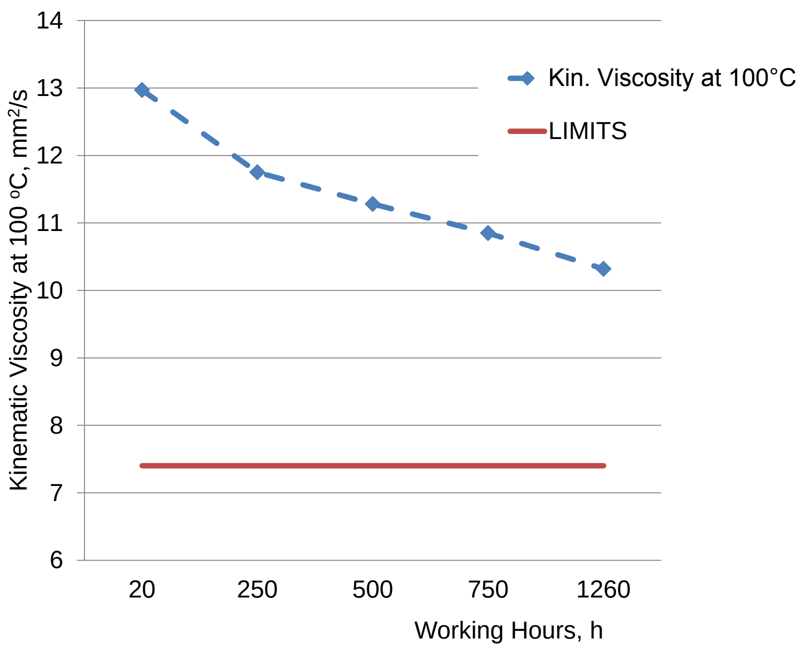
| PROPERTY | TEST METHOD | ACCEPTANCE CRITERIA |
|---|---|---|
| Kinematic viscosity at 100 °C, $mm^2/s$ | ISO 3104 | min 6.5 $mm^2/s$ |
| Corrosivity to Cu, 3h/120 °C | ISO 2160 | max 2 |
| Acidity nummber, mg KOH/g | ISO 6618 | ± 50 % initial value |
| Iron (Fe), mg/kg | INTERNAL METHOD EDX | max 200 |
| Lead (Pb), mg/kg | INTERNAL METHOD EDX | min 200 |

### 5.4 The field tests results

During the field tests all UTTO lubricant samples were subjected to the complete physicochemical and mechanical-dynamic testing. The test results are collected in Table 5 and analyzed graphically.

**Kinematic viscosity** - as one of the most important properties of lubricants is a measure of internal friction, which acts as a resistance to the change of position of the lubricant molecules under the influence of shear stress. It is dependent on temperature and pressure. The ratio of the viscosity and density is called the kinematic viscosity. Threshold value for the kinematic viscosity is 6.5 mm$^2$/s. During field testing the kinematic viscosity did not change significantly. After an initial decline, it stabilized within the acceptance criteria (Figure 7).

Figure 7: Kinematic viscosity at 100 °C during field testing



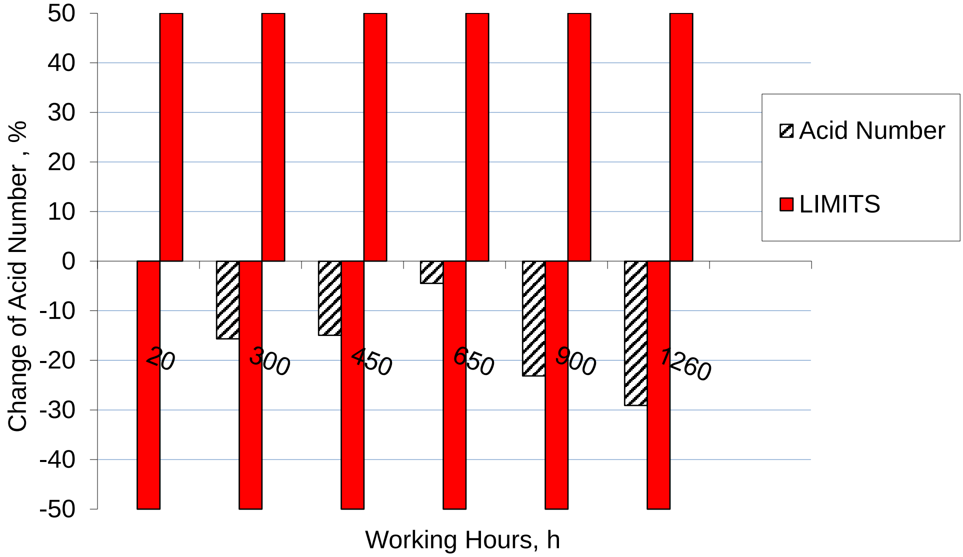

**The acid number** - as an indicator of oil additivity has not significantly changed during field testing. It changed less than 50 % of the initial value. Initially, there was a slight decline due to wear of functional additive, followed by an increase due to oxidation of the lubricant (Figure 8).

**Metal content** - the increase of iron and lead contents in the test oil was monitored because of the wear during the field tests. Their concentration was below 200 mg / kg, which shows that the grease provides good protection properties against the wear (Table 5).

**Content of heavy metals** (Cr, Ni, Cd) is determined by an energy dispersive X-ray fluorescence spectrometry (EDX), which shown to be low.

**The content of calcium and zinc** – was monitored in order to follow the additive content in lubricants during application. Even after 1260 operating hours the corresponding additivation was notified without a significant decline.

Figure 8: Change of Acid Number during field testing




**Scar diameter** – samples of lubricant were subjected to the mechanical testing of the lubricating layer. In the test apparatus with four balls placed in the form of a tetrahedron, one rotating and three stationary balls of the same material and dimensions. The balls are placed in the handle, which can be loaded and filled with the test oil. By testing the scar diameter the wear load is standardized (1200 $min^{-1}$, 392 N, 75 °C, 1 h). After the examinations, the diameter of wear beads is measured. For more solid lubricating film, at a higher load the welding of beads occurs while the wear is smaller. During field examinations, there was no significant increase in medium wear diameter compared to the fresh sample [4,5].

Also the content of water and mechanical impurities were determined, which were present in trace amounts. The lubricant prevents formation of deposits and preserves the cleanliness of gears. Samples are examined regarding corrosion to copper, which was maximal up to 1b. For each reducer, in parallel with a fresh sample, IR spectrum of lubricant was recorded. Small or no changes in the spectrum were noticed.

Table 5: Results of lubricant field testing

| **Sample** | 149/13 6.3. 2013. | 173/13 27.6. 2013. | 234/13 19.8. 2013. | 279/13 09.10. 2013. | 42/14 22.1. 2014. | 210/14 16.7. 2014. | 310/14 13.11. 2014. |
|---|---|---|---|---|---|---|---|
| **Working hours, h** | | 20 | 300 | 450 | 650 | 900 | 1260 |
| Kinematic viscosity (*v*) at 40 °C , mm²/s | 59.81 | 52.67 | 50.02 | 49.68 | 48.57 | | 49.56 |
| *v* at 100 °C , mm²/s | 10.32 | 8.50 | 8.04 | 7.92 | 7.65 | 7.33 | 7.68 |
| Δ*v* at 100 °C, % | | | 5.41 | 6.82 | 10.00 | 13.76 | 9.65 |
| Viscosity index | 162 | 137 | 131 | 128 | 123 | | 121 |
| Flash point, °C | 216 | 210 | | | | | |
| Pour point, °C | < -38 | < -38 | -36 | -42 | -39 | | -36 |
| Dinamic viscosity (η) at -18 °C, mPa s | 2964 | | | | | | |
| η at -20 °C, mPa s | 3539 | | | | | | |
| η at -35 °C, mPa s | 28594 | | | | | | |
| η at -25 °C, mPa s (CCS) | 6720 | | | | | | |
| TAN, mg KOH/g | 1.41 | 1.34 | 1.55 | 1.54 | 1.40 | 1.65 | 1.73 |
| Change of TAN, % | | | -15.67 | -14.93 | -4.48 | -23.13 | -29.10 |
| TBN, mg KOH/g | | 9.5 | 9.2 | 9.5 | 9.00 | 9.3 | 8.7 |
| Corrosion at 100 °C /3h/Cu | 1b | 1b+ | 1a | 1a | 1b | | 1a |
| Appearance and colour | CLB [1] | | CDB [2] | CDB [2] | CDB [2] | CDB [2] | CDB [2] |
| Content of water and mechanical polutants, % | 0 | 0 | VST[3] | VST[3] | VST[3] | VST[3] | 0.3 |
| Scar diameter, mm | 0.43 | 0.43 | 0.52 | 0.44 | 0.63 | 0.64 | 0.60 |
| Ca content, % | 0.38 | 0.34 | 0.32 | 0.34 | 0.31 | 0.34 | 0.29 |
| Zn content, % | 0.15 | 0.14 | 0.13 | 0.14 | 0.12 | 0.14 | 0.19 |
| Fe content, mg/kg | 0 | 3 | 3 | 59 | 32 | 43 | 84 |
| Pb content, mg/kg | 0 | 0 | 0 | <3 | <3 | 4 | 8 |
| Cu content, % | 0 | 0.0003 | 0.0117 | 0.0152 | 0.0178 | 0.0327 | 0.0313 |
| Insoluble in u n-pentane, % | | 0.008 | 0.001 | 0.029 | 0.014 | 0.008 | 0.014 |
| IR spectrum | typical | typical | VSC [4] | VSC [4] | VSC [4] | VSC [4] | VSC [4] |

[1] CLB = clear light brown, [2] CDB = clear dark brown, [3] VMT = very small traces,
[4] VMP = very small change

## 6. Conclusion

Based on the study of different types of viscosity modifiers and selected formulations in field tests and based on the information from the end users the following conclusions can be made:

- trends of development of UTTO lubricants are in the direction of broader application of multigrade oils and oils of lower viscosity grades,
- by UTTO oils formulations a great attention should be paid to key parameters of viscosity modifiers,
- best results are obtained by applying the MSC and dispersant PAMA type of viscosity modifiers,
- a right choice of viscosity modifier contributes significantly to improvement of UTTO lubricants performances,
- satisfactory course of the field test,
- interval of change extended by 25 % , i.e . 1250 instead of 1000 hours.

**References**

1. I. ZAMBERLIN: *Aditivi za maziva*, *Maziva i podmazivanje,* Jugoma, Zagreb, 1986 (p. 220-226).
2. N, CANTER: *Viscosity Index Improvers,* 2011, (p. 10-22).
3. J. Cerny, I. Vaclavickova: *Shear stability of motor oil*, Goriva i maziva, 45, 2006, (p. 315-330).
4. V. IVUŠIĆ: *Tribologija*, Hrvatsko društvo za materijale i tribologiju, Zagreb, 2002.
5. *Glosary of terms and definitions in the field of friction, wear, lubrication and tribology*, OECD Publications, Paris, 1969.
6. D. OESTERLE: *Tribology and Lubrication Tehnolology*, Lubrizol, 2006.
7. Technical documentation, Lubrizol.
8. Technical documentation, Evonik.
9. Technical documentation, INA Maziva d.o.o.

**Authors**

Tonća Ćaleta Prolić, Miroslav Felja, Renata Petek Grahovac, Anđelko Lepušić
INA MAZIVA d.o.o., Radnička cesta 175, 10000 Zagreb, Croatia
e-mail: tonca.caleta-prolic@ina.hr

**Received**
7.5.2015.

**Accepted**
16.5.2015.