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Novo biorazgradljivo splošno traktorsko transmisijsko olje na osnovi oljne repice

A New Biodegradable Universal Tractor Transmission Oil Based on Rapeseed Oil

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V Sloveniji je trenutno okrog 160 000 traktorjev. Za delovanje prenosnega sistema posameznega traktorja je potrebno od 30 do 100 litrov mazalnega olja, zamenjava olja pa se ponavadi opravi enkrat na leto. Glede na dejstvo, da nam v Sloveniji uspe zbrati le manjšo količino odpadnih olj, lahko rečemo, da večina tega olja nekontrolirano izgine v okolje.

V sklopu raziskovalnega projekta smo izdelali novo, biološko razgradljivo in netoksično univerzalno traktorsko transmisijsko olje (UTTO) na osnovi oljne repice s stopnjo biološke razgradljivosti 99,6% (CEC-L-A-93). Lastnosti novega olja smo preskušali na standardnih napravah, rezultate pa primerjali z rezultati testiranja na tržišču dosegljivih UTTO olj.

(Ključne besede: olja biorazgradljiva, olja repična, lastnosti olj, razvoj olj)

At present, there are about 160 000 farm tractors in Slovenia. In the transmission system there is from 30 to 100 litres of lubrication oil which is normally changed once a year. Due to the fact, that in Slovenia we manage to collect just a small amount of used oils, we can conclude that the majority of these oils are being spilled to the environment.

During this project a new biodegradable, non-toxic rapeseed based universal tractor transmission oil (UTTO) has been fabricated with biodegradability of 99,6% (CEC-L-A-93). The properties of this new oil were investigated in standard test procedures in comparison with the commercially available UTTO oils.

(Keywords: biodegradable oils, rapseed oil, oil properties, oil development)

0 UVOD

Z uporabo okolju prijetnih maziv lahko v precejšnji meri preprečimo onesnaževanje vode in tal. Značilni zastopniki teh maziv so rastlinska olja. Zaradi sprejemljive cene in zadovoljivih mazalnih lastnosti ima široko uporabo olje na osnovi oljne repice. Tovrstno olje zagotovlja pomembne prednosti glede obnovljivosti naravnih virov, biorazgradljivosti in nestrupenosti, ima pa tudi zadovoljive lastnosti na drugih področjih. Uporablja se predvsem v odprtih mazalnih sistemih vse bolj pa tudi v hidravliki in gonilih ([1] do [4]).

Cilj raziskave je razviti novo biorazgradljivo hidravlično-transmisijsko traktorsko olje (UTTO) na osnovi oljne repice. Poglavitna naloga olja UTTO v traktorju je preprečiti zajedanje in jamičenje zobniških bokov ter drsno obrabo pri majhnih hitrostih in velikih obremenitvah. Olje mora hkrati imeti tudi zadovoljivo oksidacijsko stabilnost in zagotavljati pravilno delovanje sklopke in zavor, tako da je mogoče traktor zaustaviti v določenem času in na določeni razdalji. Dodani protiobrabni aditivi in dodatki za visoke obremenitve (aditivi EP/AW) ne smejo biti toliko dejavni, da bi povzročili korozijo

0 INTRODUCTION

To avoid extensive soil and water pollution, environmentally friendly lubricants such as vegetable oils should be used. Quality and reasonable price are the main reasons why rapeseed oil is the most commonly used vegetable oil for lubricants. This oil can offer significant environmental advantages with respect to resource renewability, biodegradability, nontoxicity as well as offering satisfactory performance in a variety of applications. Rapeseed oil is widely used in total-loss systems and is increasingly finding uses in hydraulic and power transmissions ([1] to [4]).

The aim of this research is to develop a new biodegradable universal tractor transmission oil (UTTO) based on rapeseed oil. The main objective of the transmission oil in a tractor is to prevent scuffing and pitting failure as well as the normal rubbing wear which occurs during low-speed and high-load conditions associated with their oxidation stability. Oils must also provide the correct frictional balance to allow squawk-free wet-brake performance and smooth transmission-clutch engagement. At the same time, they must provide enough clutch capacity for efficient power transfer and enough brake capacity to stop the tractor in a reasonable time and distance. The EP/AW system used must not be so active as to cause corrosion in the na elementih hidravličnega sistema traktorja, predvsem zlitin bakra pri črpalkah ([5] in [6]).

V tej raziskavi smo koeficient trenja izmerili na preskuševališču SRV. Protiobrabne in nosilne lastnosti oljnega filma (lastnosti EP/AW) smo določili na SRV, s štirimi kroglami in preskuševališču FZG, odpornost na jamičenje pa za izbrana olja določili na preskuševališču FZG. Za elementno analizo maziv smo uporabili rentgensko fluorescenčno spektrometrijo ED-XRF. V prispevku ni poudarjena samo raziskava fizikalno-kemijskih lastnosti biološko razgradljivih UTTO olj, temveč je v ospredju ocena mazalnih sposobnosti olj na podlagi laboratorijskih preskusov s praktičnega inženirskega izhodišča.

tractor''s hydraulic system where pumps containing alloys of copper can be present ([5] and [6]).

In the present study the average coefficient of friction has been measured on a SRV test rig. EP/AW performance has been established on the SRV, the Four-Ball test rig and FZG gear test equipment. Pitting resistance for selected oils was determined on the FZG test device. The elemental analysis of additives was performed by using ED-XRF spectrometry. The main objective of this paper is not the study of the physical and chemical properties of the new biodegradable UTTO oil, but to assess the lubrication properties on the laboratory field tests machine from an engineering point of view.

1 PRIPRAVA VZORCEV

Izbrali smo dva različna vzorca olja UTTO na rastlinski osnovi. Lastnosti teh olj smo primerjali z lastnostmi petih komercialno dosegljivih mineralnih olj UTTO, dveh drugih olj na rastlinski osnovi ter dvema biorazgradljivima sintetičnima oljema, kakor je predstavljeno v preglednici 1.

1 OIL SAMPLES

We have formulated two different vegetable-based UTTO oils for the investigations. The properties of these two oils were compared to five commercially available mineral-based UTTO oils, two vegetable-based hydraulic oils and two fast biodegradable synthetic oils, as shown in Table 1.

Preglednica 1. *Pregled preskušanih olj*
Table 1. *Survey of tested oils*

Bazno olje / **Basestock**	**Vrsta olja** / **Oil type**	**Viskoznost / Viscosity** *mm²/s* $\nu_{40\,°C}$	$\nu_{100\,°C}$	**Oznaka** / **Oil code**
repično olje rapeseed oil	biorazgradljivo UTTO biodegradable UTTO	48,8	10,4	R1
repično olje rapeseed oil	bioraz. hidravlično olje biodeg. hydraulic oil	39,4	8,9	R2
oleinsko sončnično olje high oleic sunflower oil	biorazgradljivo UTTO biodegradable UTTO	51,4	10,6	S1
oleinsko sončnično olje high oleic sunflower oil	bioraz. hidravlično olje biodeg. hydraulic oil	43,3	9,3	S2
sintetični ester synthetic ester	bioraz. reduktorsko olje biodegradable gear oil	101	17,8	G
sintetični ester synthetic ester	biorazgradljivo UTTO biodegradable UTTO	51,3	10,9	H
mineralno olje mineral oil	UTTO	81,6	10,9	M3
mineralno olje mineral oil	UTTO	87,9	11,0	M4
mineralno olje mineral oil	UTTO	63,4	9,2	M5
mineralno olje mineral oil	UTTO	55,1	9,2	M6
mineralno olje mineral oil	UTTO	56,0	9,3	M7
repično olje rapeseed oil	bazno olje base oil	35,0	8,0	baz-R
oleinsko sončnično olje high oleic sunflower oil	bazno olje base oil	38,5	8,4	baz-S
dodatki additive	paket aditivov 1 additive package 1	100,3	17,6	adit-1
dodatki additive	paket aditivov 2 additive package 2	880,0	80,0	adit-2

Za raziskovanje vpliva onesnaženja biorazgradljivega olja z vodo in mineralnim oljem UTTO na proces obrabe smo pripravili dodatnih osem vzorcev. Znano je, da pri zamenjavi olja v traktorju najmanj 2 odstotka starega olja ostane v sistemu, delež vode v olju pa je tudi večja kakor pri industrijskih hidravličnih sistemih. Kontaminacija olja z vodo in starim mineralnim oljem je torej pri obratovanju traktorja pričakovan pojav. Sestava kontaminiranih vzorcev olj je predstavljena v preglednici 2.

We have prepared eight biodegradable oil samples to investigate the influence of water and mineral UTTO oil as a contaminant in the wear process. It is well known that during an oil change at least 2% of the old oil remains in the lubrication system and that the tractor's hydraulic oil may operate at higher levels of water contamination than the industrial hydraulic oils. The contamination with water and mineral oil is therefore expected to occur during normal field service. The composition of the contaminated biodegradable oil samples is presented in Table 2.

Preglednica 2. *Olja na rastlinski osnovi onesnažena z vodo in mineralnim oljem*
Table 2. *Vegetable-based oil samples contaminated with water and mineral UTTO oil*

Sestava **Composition**	**Oznaka** **Oil code**
R1 + 1% vode / R1 + 1% of water	R1+v
R2 + 1% vode / R2 + 1% of water	R2+v
S1 + 1% vode / S1 + 1% of water	S1+v
S2 + 1% vode / S2 + 1% of water	S2+v
R1 + 10% mineralnega UTTO olja, M5 / R1 + 10% of mineral UTTO oil, M5	R1+M5
R1 + 10% mineralnega UTTO olja, M5 / R2 + 10% of mineral UTTO oil, M5	R2+M5
S1 + 10% mineralnega UTTO olja, M5 / S1 + 10% of mineral UTTO oil, M5	S1+M5
S2 + 10% mineralnega UTTO olja, M5 / S2 + 10% of mineral UTTO oil, M5	S2+M5

2 REZULTATI PRESKUSOV

2.1 Elementna analiza dodatkov

Elementna analiza dodatkov je prikazana na sliki 1.

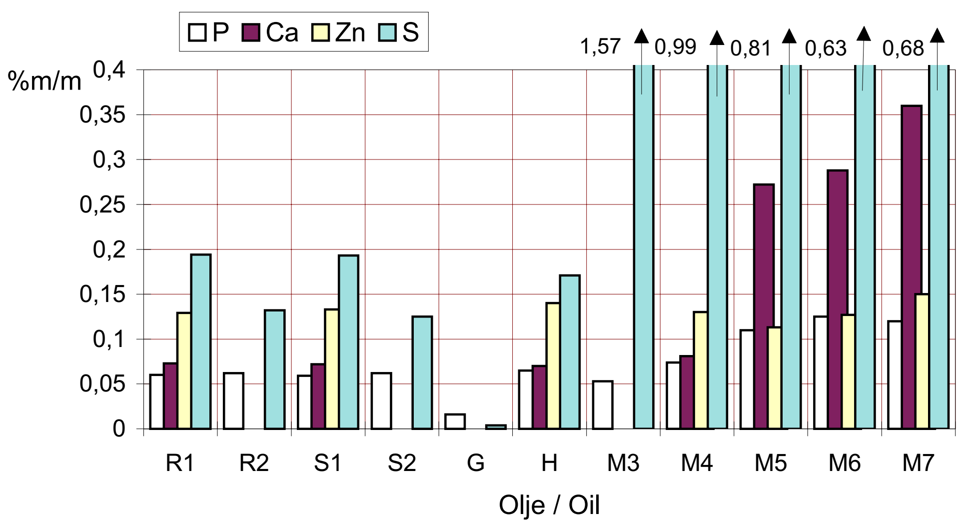
Elementna sestava dodatkov je podobna za biorazgradljiva olja, označena z R1, S1 in H (sl.1). Nadaljnja podobnost je opazna pri sestavi mineralnih olj UTTO, označenih z M5, M6 in M7, ki imajo večji delež kalcija kakor ostala analizirana olja. Vzorci olja

2 RESULTS OF INVESTIGATIONS

2.1 Elemental analysis of additives

The elemental analysis of additives for selected oils is shown in Fig.1.

The elemental composition of additives is quite similar for the biodegradable oils labelled R1, S1, and H. The mineral UTTO oils labelled M5, M6 and M7 are also similar and contain a significantly higher level of calcium than any other tested oil. The



Sl. 1. *Elementna sestava preskušanih olj*
Fig. 1. *Elemental composition of tested oils*

R2, S2 in G med dodatki ne vsebujejo kalcija in cinka. Pomemben je podatek, da mineralna olja UTTO vsebujejo veliko koncentracijo žvepla kot dodanega elementa EP.

oils labelled R2, S2, G and M3 do not contain calcium and zinc as an additive component. It is clear from Fig. 1 that the mineral UTTO oils contain a large concentration of sulphur as an EP additive component.

2.2 Rezultati na napravi SRV

2.2 Results obtained on SRV test device

Koeficiente trenja, obrabo in nosilnost oljne plasti smo določili na visokofrekvenčni napravi SRV, ki povzroča linearno izmenično gibanje kroglice po ploščici v pogojih mejnega mazanja. Tanko plast testiranega maziva nanesemo na ploščico pred vsakim preskusom. Naprava in postopek preskušanja sta podrobno opisana v standardu DIN 51 834 T2 [7].

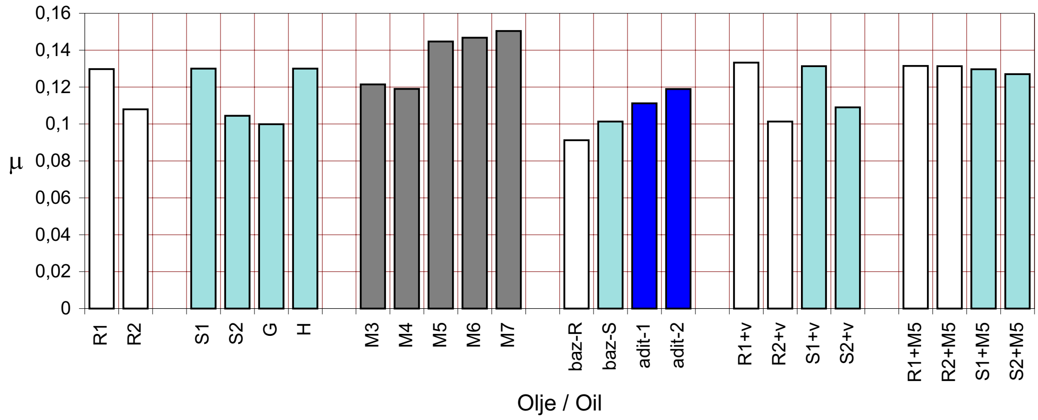
The coefficient of friction measurements, wear and load bearing, were performed on a SRV high-frequency test device which produces a linear oscillating motion of a ball on a flat, under boundary lubricating conditions. A thin layer of lubricant is spread over the flat specimen before each test. The test rig configuration and the test specimens are described more precisely in DIN standard 51 834 T2 [7].

2.2.1 Meritev koeficienta trenja

2.2.1 Friction coefficient measurement

Spremembe strižnih sil, pretvorjene v koeficient trenja, merimo neposredno v odvisnosti od časa. Rezultate zbiramo prek računalniškega sistema. Pri preskusu smo merili koeficient trenja pri čistem drsenju [7].

The variations in tangential force, transformed to the coefficient of friction, are recorded simultaneously as a function of time using a computer-based data acquisition system. On this test rig, just the friction coefficient during sliding motion was measured [7].



Sl. 2. *Srednja vrednost koeficienta trenja*
Fig. 2. *Friction coefficient mean values*
obremenitev/load, 300N; hertzov tlak/Hertz pressure, 3,17 GPa;
frekvenca/frequency, 50 Hz; ampiltuda/amplitude, 1000 μm; hitrost/speed, 0,05m/s;
temperatura/temperature, 50 °C; čas preskusa/duration, 120 mi.

Slika 2 prikazuje rezultate meritev koeficienta trenja. Srednja vrednost koeficienta trenja zavzema pri pogojih mejnega mazanja podobno vrednost za biorazgradljiva olja, označena z R1, S1 in H. Elementna sestava dodatkov za omenjena olja je podobna. Najvišjo vrednost koeficienta trenja kažejo mineralna olja M5, M6 in M7.

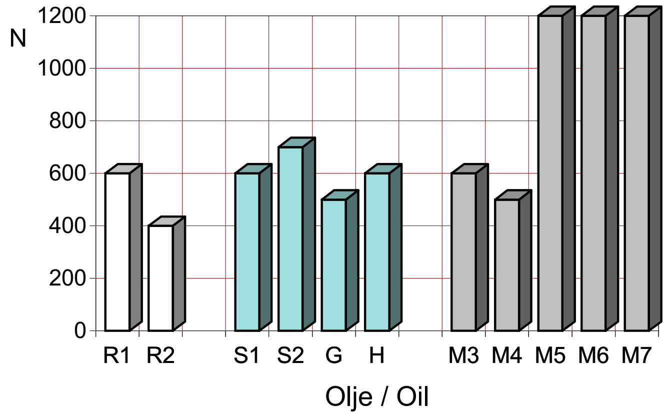
Figure 2 shows the results of the friction coefficient measurement. The mineral-based UTTO oils M5, M6, and M7 show the highest value of friction coefficient. Oil samples, contaminated with water and mineral oil labelled M5, do not show a significant difference in the friction coefficient with respect to the uncontaminated samples.

2.2.2 Nosilnost, izmerjena na napravi SRV

2.2.2 Load-bearing test results

Preverjanje nosilnih lastnosti oljne plasti na napravi SRV ni predpisano z nobenim standardom. Postopek preskusa je opisan v literaturi [8]. Obremenitev se povečuje stopenjsko v enominutnih korakih, do

Checking the load-bearing capacity of oils on the SRV test rig is not a standard test. The procedure is described in reference [8]. The load was applied progressively in one minute intervals until the



Sl. 3. *Rezultati nosilnosti izmerjeni na napravi SRV*
Fig. 3. *Load-bearing test results measured on the SRV test device*
stopnjevanje obremenitve/load, increased in stages per 100 N;
trajanje ene stopnje/duration per stage, 1 min; hitrost/speed, 0,05m/s;
frekvenca/frequency, 50 Hz; amplituda/amplitude, 1000 µm

pretrga oljne plasti. Obremenitev, pri kateri pride do pretrga oljne plasti in se pojavi neposreden stik obeh kovinskih površin, se poda kot rezultat.

Največjo nosilnost oljnega filma smo dosegli pri preskušanju mineralnih olj UTTO, označenih z M5, M6 in M7, ki imajo največjo koncentracijo kalcija in veliko koncentracijo žvepla. Znova opazimo, da dosežejo biorazgradljiva olja R1, S2 in H enakovreden rezultat (sl. 3).

2.3 Rezultati preskušanja na napravi s štirimi kroglicami

Tri jeklene kroglice, premera 12,7 mm, so vpete s prižemo in prekrite s testnim mazivom. Četrta, zgornja kroglica iste velikosti in kakovosti, je obremenjena in se vrti. Preskuševališče je podrobno opisano s standardom DN 51350 [9].

2.3.1 Protiobrabne lastnosti

Test uporabljamo za določanje protiobrabnih lastnosti maziv, ki obratujejo v razmerah mejnega mazanja. Kakovost olj se med sabo primerja z merjenjem povprečnega premera obrabne kotanje spodnjih treh krogel.

Znova je izražena podobnost med rezultati za olja M5, M6 in M7. Nekaj večja obraba je nastala pri preskušanju olj R1, S1 in H (sl. 4).

2.3.2 Indeks nosilnosti

Preskus je sestavljen iz serije 10 sekundnih testov, pri katerih obremenitev povečujemo stopenjsko do zavaritve testnih kroglic. Po vsakem intervalu izmerimo velikost poškodbe na spodnjih treh kroglicah. Indeks nosilnosti se izračuna v skladu s standardom ASTM D-2783 [10].

oil film breaks. The load at which the lubrication film breaks and the metal-to-metal contact occurs is reported as a result.

The load-bearing test results on the SRV test rig are presented in Fig. 3. The best results were obtained with the mineral UTTO oils labelled M5, M6 and M7, which contain the highest concentration ratio of calcium and zinc. The other tested oils exhibit significantly lower load-bearing properties.

2.3 Results obtained on the four-ball test device

The three 12.7 mm diameter steel balls are clamped together and covered with the lubricant to be evaluated, a fourth ball of the same size and quality, referred to as a top ball, is pressed with a force into the cavity formed by the clamped balls. The test rig is precisely described in the DIN 51 350 standard [9].

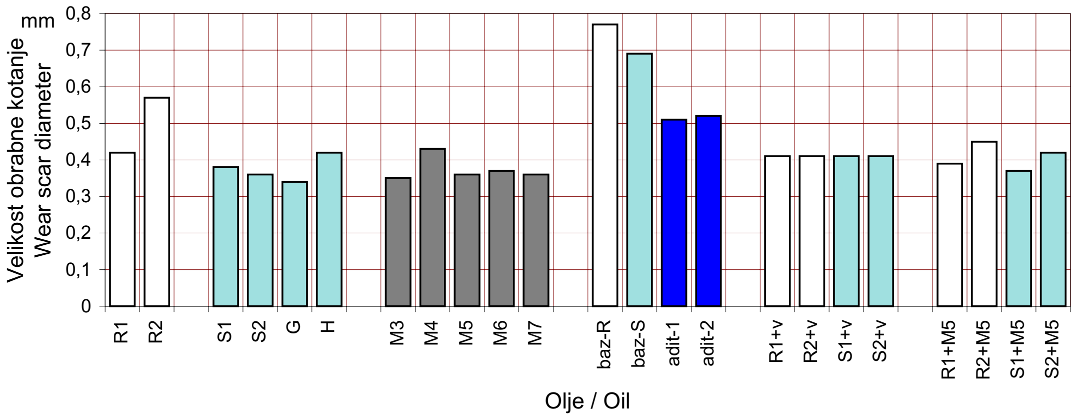
2.3.1 Wear test results

The test is used to determine the relative wear-preventing properties of lubricants operating under boundary lubrication conditions. The oils are compared by using the average size of the scar diameters worn on the three lower clamped balls.

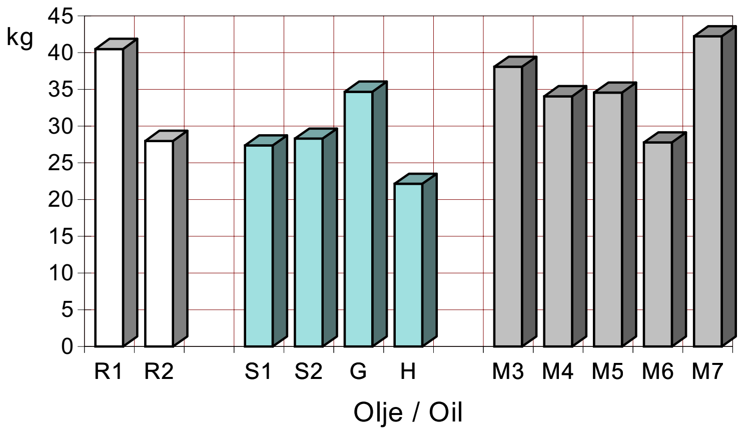
Similar results were obtained for oils M5, M6 and M7 in this experiment. The results for oils R1, S1 and were observed to be a little higher.

2.3.2 Load wear index

The weld load test is a series of 10 second runs where the loading is increased at specified intervals until the rotating ball seizes and welds to the other balls. At the end of each interval the average scar diameter is measured. The Load Wear Index is calculated according to the standard ASTM D-2783 [10].



Sl. 4. *Premeri obrabnih kotanj*
Fig. 4. *Wear scar diameters*
obremenitev/load, 392 N (40 kg); vrtilna frekvenca/rotating speed, 1500 min^{-1}/1500 rpm; hitrost/speed, 0,8 m/s; temperatura/temperature, 65 °C; čas preskusa/duration, 60 min



Sl. 5. *Indeks obrabe*
Fig. 5. *Load Wear Index*
vrtilna frekvenca/rotating speed, 1760 ± 40 min^{-1}/1760 ± 40 rpm; hitrost/speed, 0,9 m/s; trajanje ene stopnje/duration, 10 s; temperatura/temperature, 18,33 to 35 °C

Podobni med rezultati za posamezna olja, ki smo jih spremljali pri poprejšnjih preskusih, pri tem preskusu ni več opaziti (sl 5). Najboljši rezultati so doseženi s testiranjem olj M7 in R1, medtem ko najnižji indeks nosilnosti kaže olje z oznako H.

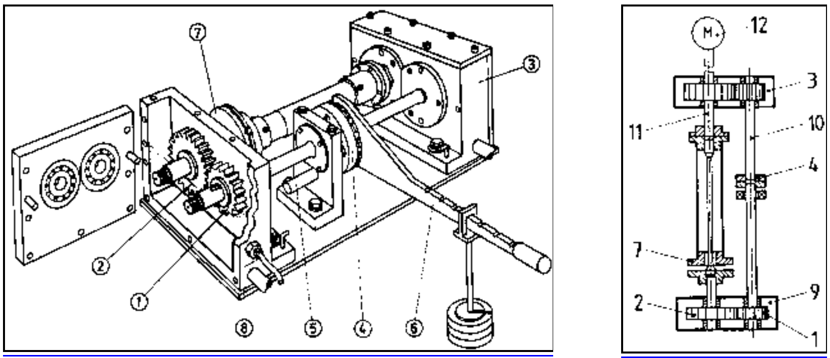
2.4 Rezultati z naprave FZG

Odpornost olj proti zajedanju, jamičenju in normalni drsni obrabi je bila določena na zobniškem preskuševališču FZG. Zaradi zmanjšanja stroškov so bila za nadaljnjo preskušanje izbrana olja R1, S1, G, H in M6. Podroben opis naprave FZG in postopka preskušanja je predpisan s standardom DIN 51 354 in ISO CD 1435-1 ([11] in [12]).

The similarities between the results for some oils, which have been observed during previous tests, are here no longer seen. The best results were obtained with the oils labelled M7 and R1, whereas the oil labelled H acheived the poorest result.

2.4 Results obtained on the FZG test device

The investigations of scuffing-load capacity, pitting resistance and slow-speed high-load-wear resistance were performed with the FZG gear test rig, see Fig 6. The experiments are based on a failure of a standard test gear set, lubricated with the test oil under specific test conditions. A detailed description of the FZG test rig and the procedure can be found in the standards DIN 51 354 and ISO CD 14635-1 ([11] and [12]).



1	preskusni pastorek test pinion	5	zatič za blokado sklopke locking pin	9	preskusno gonilo test gearbox
2	preskusni zobnik test gear	6	ročica za obremenjevanje load lever and weights	10	torzijska gred 1 shaft 1
3	prenosno gonilo slave gearbox	7	sklopka za merjenje vrt. momenta torque measuring coupling	11	torzijska gred 2 shaft 2
4	blokada sklopke brace coupling	8	temperaturno zaznavalo temperature sensor	12	elektromotor electric motor

Sl. 6. *Shematični prikaz preskuševališča FZG*
Fig. 6. *Schematic section of the FZG gear test rig*

2.4.1 Odpornost proti zajedanju

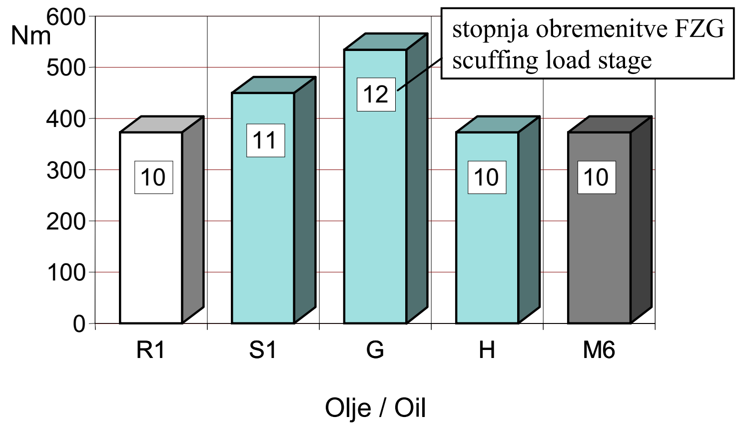
Odpornost proti zajedanju smo določili s standardnim testom FZG A/8,3/90. Oznaka obremenitvene stopnje, ko vsota poškodb vseh zobnih bokov pastorka preseže širino zobnega boka, se poda kot rezultat. Če se poškodba ne pojavi tudi v dvanajsti obremenitveni stopnji, se ta vrednost upošteva kot končni rezultat [11].

Rezultati odpornosti proti zajedanju so predstavljeni na sliki 7. Najboljši rezultat smo dobili pri testiranju olja G, kar je za reduktorska olja pričakovan rezultat, preostala olja UTTO pa so dosegla enakovreden rezultat.

2.4.1 Scuffing-load capacity test

The scuffing-load capacity of the tested oils was investigated by using the standard FZG A/8.3/90 test. The failure load stage is the one at which the summed total width of the damaged areas on all the pinion tooth faces equals or exceeds one gear-tooth width. If the test is completed without failure, then the test finishes at the 12th stage [11].

The data from the scuffing-resistance tests on the selected oils are presented in Fig. 7. The oil formulation G acheived the best results, which is normal for the gear oil, while the UTTO oils acheived the 10th stage pass.



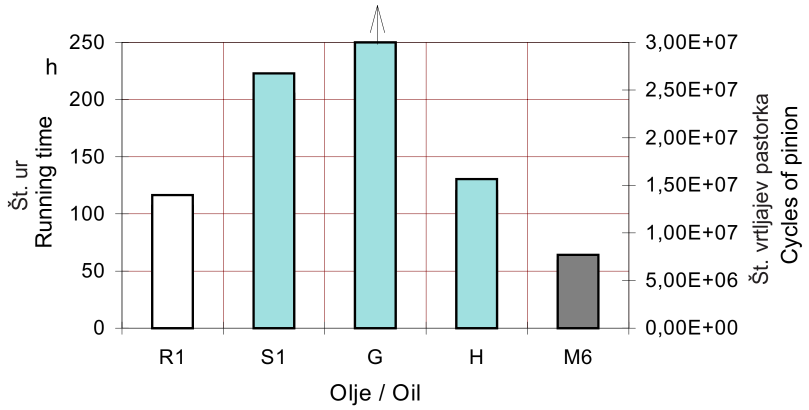
Sl. 7. *Rezultati preskusov zajedanja*
Fig. 7. *Scuffing-load capacity*
stopnjevanje obremenitve od 1 do 12/load, increased in stages 1 to 12; hertzov tlak/ Hertzian stress, 146 do/ to 1841 N/mm; hitrost na kotalnem krogu/pitch line velocity, 8.3 m/s; vrtilna frekvenca pastorka/pinion rotating speed, 2175 mni^{-1}/2175 rpm; temperatura olja/oil temperature, 90 °C.

2.4.2 Odpornost proti jamičenju

Odpornost proti jamičenju smo določili na napravi FZG z uporabo testnih zobnikov tipa C. Število vprijemov manjšega zobnika pred pojavom poškodbe se upošteva kot rezultat. Če poškodovana površina zobnega boka presega dovoljeno vrednost, se preskus ustavi. Kritično število obremenitvenih ciklov pred nastankom poškodbe je 4 odstotke površine zobnega boka (približno 5mm^2) [13].

2.4.2 Pitting resistance test

Investigations of the pitting resistance were performed on the FZG gear test rig by using C-type test gears. The number of load cycles which cause damage to the tooth flanks is recorded. If the damaged area of the pinion flanks exceeds the permissible area, then the test run is stopped. The critical number of load cycles occurs when the damaged area of the mostly damaged tooth flanks exceeds 4 % (about 5 mm^2) [13].



Sl. 8. *Rezultati preskusov jamičenja*
Fig. 8. *Pitting test results*
obremenitvena stopnja/load, torque stage 9; hertzov tlak/Hertzian stress, 1651 MPa; hitrost na kotalnem krogu/pitch line velocity, 8,3 m/s; vrtilna frekvenca pastorka/ pinion rotating speed, 2175 mni^{-1}/2175 rpm; temperatura olja/oil temperature, 90 °C.

Rezultati odpornosti proti jamičenju, prikazani na sliki 8, kažejo veliko boljšo odpornost biorazgradljivih olj v primerjavi z mineralnim oljem UTTO.

The pitting test results presented in Fig. 8 show the superior pitting resistance of the vegetable oils and the synthetic esters compared to that of the mineral UTTO oil.

2.4.3 Normalna drsna obraba

Za zmanjšanje drsnih hitrosti na vrhu zoba in s tem preprečitev možnost zajedanja smo v tem testu uporabili testne zobnike tipa C. Preskus je razdeljen na dve stopnji. Po vsaki stopnji se testni zobniki pregledajo vizualno in stehtajo na miligram natančno. Podatki o preskusu so zbrani v preglednici 3 [14].

Slika 9 prikazuje stopnje obrabe za izbrana olja. Rezultati ne kažejo bistvenih razlik v obrabi za testirana olja. Repično olje UTTO, označeno z R1, kaže najmanjšo stopnjo obrabe, toda razlika glede na preostala olja je zelo majhna.

2.4.3 Normal rubbing wear test

In this test, C-type gears were chosen to reduce the sliding velocity and therefore the probability of scuffing. The test procedure is divided into two stages. After each stage the test gears are inspected visually and weighed to the nearest mg. The test conditions are summarised in Table 3 [14].

Figure 9 shows the wear-rate data for the selected oils. The results indicate no significant difference in the wear investigations between the tested oils. The rapeseed UTTO, labelled R1, shows the lowest wear rate at the first stage, but there is just a slight difference between the tested oils.

3 OBRAVNAVA

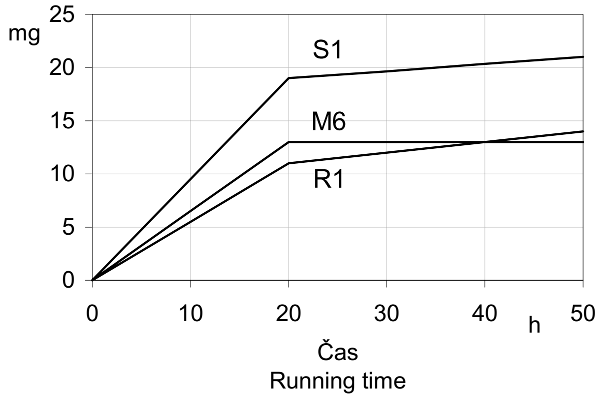
Razvito olje UTTO mora zadostiti visokim zahtevam glede preprečevanja obrabe in pogojem pri visokih obremenitvah, hkrati pa mora imeti nizko viskoznost zaradi boljših lastnosti pri nizkih temperaturah. Te zahteve smo pri formulaciji olj UTTO na rastlinski osnovi R1 in S1 dosegli z uporabo Zn, P, Ca, B in S kot dodatnih elementov.

3 DISCUSSION

The new UTTO oils need to satisfy high-wear and EP performance, while at the same time using low-viscosity-based oils for improved low-temperature performance. These demands were achieved by the formulation of the vegetable-based UTTO oils labelled R1 and S1, using new additive components which contain Zn, P, Ca, B, N and S. Despite the positive effects of borated

Preglednica 3. *Preskusni pogoji normalne obrabe pri majhnih hitrostih*
Table 3. *Parameters of the slow-speed wear test*

stopnja preskusa / stage of the test	1	2
stopnja obremenitve /load stage (DIN 51 354)	10	10
obremenitev / gear torque [Nm]	372,6	372,6
obodna hitrost / circumferential speed [m/s]	0,35	0,20
vrtilna frekvenca / rotational speed		
pastorek / pinion [min^{-1}]	93	53
zobnik / gear [min^{-1}]	62	35
temperatura olja / oil temperature [°C]	120	120
čas / duration [h]	20,0	30,0



Sl. 9. *Izmerjena stopnja obrabe*
Fig. 9. *Measured wear rate*

Kljub pozitivnemu delovanju boratov na lastnosti EP/AW, lahko ti dodatki povzročijo v olju hidrolitično nestabilnost. Za preprečitev tega problema smo za zaščito boratovih spojin uporabili kalcijev sulfonat, ki poveča stabilnost olja pri kontaminaciji z vodo [6].

Elementna sestava aditivov kaže, da mineralna olja UTTO vsebujejo 0,05 do 0,12 %m/m fosforja, 0 do 0,36 %m/m kalcija, 0 do 0,15 % cinka in 0,63 do 1,57 % m/m žvepla. Preostala olja imajo občutno manjši delež žvepla. Sintetično olje UTTO z oznako H vsebuje enako količino cinka kakor mineralno olje, medtem ko je delež fosforja in kalcija 0,07 %m/m ter žvepla 0,17 %m/m. Elementna sestava olj UTTO na rastlinski osnovi R1 in S1 je zelo podobna sestavi sintetičnega olja UTTO z oznako H.

Srednja vrednost koeficienta trenja v razmerah mejnega mazanja je zelo podobna za olja R1, S1 in H. Elementna sestava dodatkov je podobna za vsa našteta olja. Malce višji je koeficient trenja za mineralna olja UTTO M5, M6 in M7, ki imajo največji delež kalcija in veliko koncentaracijo žvepla. Najnižjo vrednost smo izmerili pri oljih R2, S2 in G.

Slika 10 prikazuje potek koeficienta trenja v odvisnosti od časa za olji UTTO R1 in M6. V poteku krivulje za repično olje R1 je opaziti precej konic. Te konice kažejo na preboj mazalnega filma

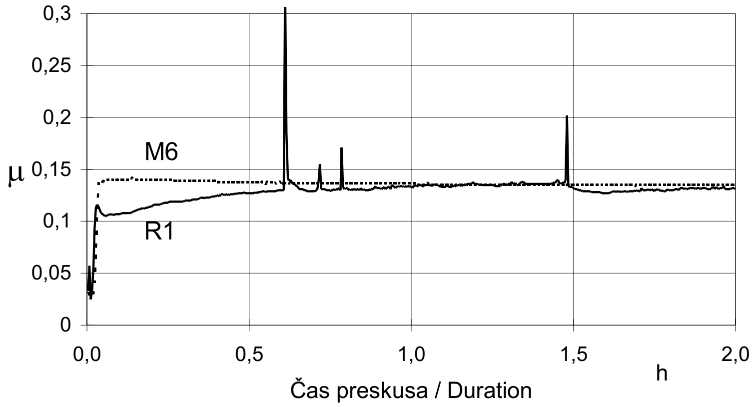
additives on the EP/AW properties, some of these additives can suffer the drawback of hydrolytic instability. To circumvent this problem the present application utilises borated overbased calcium sulfonate, which was stable in the presence of water contamination [6].

The elemental composition of the additives has shown that the mineral UTTO oils contain 0.05 to 0.12 %m/m of phosphorous, 0 to 0.36 %m/m of calcium, 0 to 0.15 %m/m of zinc and 0.63 to 1.57 %m/m of sulphur. The other oils exhibited a much lower content of sulphur. The synthetic ester-based UTTO oil labelled H contained the same level of zinc as the mineral oils, while the amounts of phosphorous and calcium were 0.07 %m/m, and the content of sulphur was 0.17 %m/m. The elemental compositions of the vegetable-based UTTO oils labelled R1 and S1 were quite similar to that of the synthetic ester- based UTTO formulation, labelled H.

The average friction coefficient during the boundary-lubrication conditions was quite similar for oils labelled R1, S1, H and for the reference mineral UTTO oil labelled M4. The elemental composition of the additive systems is similar for all these oils. The coefficient of friction was slightly increased for the mineral oils which contained the highest amount of calcium and sulphur. The lowest friction coefficient was obtained for the oils labelled R2, S2 and G.

Fig. 10 shows the evolution of the coefficient of friction versus time for the UTTO oils R1 and M6. There are a lot of peaks in the coefficient of friction profile for the rapeseed oil R1. These peaks in neposreden stik kovinskih površin. Posledica tega je adhezivna obraba in s tem večji premer obrabne kotanje. Pri preskušanju mineralnih olj smo torej ugotovili boljše protiobrabne lastnosti ([15] in [16]).

point to a lubrication-film breakdown, and a metal-to-metal contact which results in adhesive wear and thus a much greater wear scar diameter. The best antiwear characteristics were therefore obtained for the mineral oils ([15] and [16]).



Sl. 10. *Potek koeficienta trenja s časom*
Fig. 10. *Coefficient of friction as a function of time*

Nosilnost oljnega filma smo določili na napravah SRV in s štirimi kroglami. Rezultati na napravi SRV kažejo, da se nosilnost oljnega filma povečuje z večanjem deleža kalcija kot aditivnega elementa. Na preskuševališču s štirimi kroglami te odvisnosti nismo opazili.

Po optimiranju stroškov smo za nadaljnja testiranja na napravi FZG izbrali olja z oznakami R1, S1 G, H in M6. Rezultati preskusov kažejo, da je odpornost na obrabo biorazgradljivih olj R1, S1 in H enakovredna rezultatu za mineralno olje UTTO M6. Testirana UTTO olja so prestala 10 ali 11 obremenitveno stopnjo, kar je za tovrsten namen uporabe dober rezultat.

Znano je, da imajo viskoznost, temperatura in vrsta maziva odločilen vpliv na odpornost proti jamičenju, vrsta in koncentracija dodatkov pa le postranski pomen. Glede na dejstvo, da je obremenitev stika konstantna, imajo torne lastnosti baznega olja poglaviten vpliv na poškodbe jamičenja. Preskusi odpornosti proti jamičenju so pokazali boljšo odpornost rastlinskih olj UTTO R1 in S1 v primerjavi z mineralnim oljem UTTO M6.

The load-bearing capacity of the oils was determined on the SRV and the Four-Ball test rig. The results obtained on the SRV test device indicate that the load-bearing capacity of the oils increased when a higher content of calcium and zinc were employed as additives. On the Four-Ball test rig we did not observe the same phenomena.

In the case of optimisation, the oils labelled R1, S1, G, H and M6 were selected for further investigations on the FZG gear test rig. The test results have shown that the scuffing-load capacity of the biodegradable UTTO oils labelled R1, S1 and H is equivalent to that of the mineral UTTO oil M6. The UTTO oils in the test exhibit a scuffing-load stage between 10 and 11, which is normal for this application.

It is well known that lubricant viscosity, lubricant type and the lubricant temperature have a strong influence on the pitting resistance, while the additive type and its concentration have only a minor influence on the endurance level. Since the contact pressures were the same in all cases, the friction characteristics of the base oil have a major influence on pitting fatigue. The test showed better pitting resistance for the vegetable UTTO oils R1 and S1 than for the mineral UTTO oil M6.

4 SKLEPI

Iz predstavljenih rezultatov izhaja, da je mogoče izdelati olje UTTO na osnovi oljne repice z enakovrednimi mehanskimi lastnostmi, kakršna imajo mineralna olja UTTO.

Rezultati kažejo, da vzorci olj na rastlinski osnovi, onesnaženi z 1% vode in 10% mineralnega olja, ne kažejo večjih odstopanj od rezultatov nekontaminiranih vzorcev.

4 CONCLUSIONS

The results of this study demonstrate that it is possible to formulate a rapeseed-based UTTO oil that has mechanical properties comparable to the mineral UTTO oils.

The results show that the contaminated vegetable oil samples with 1% of water and with 10 % of mineral oil do not show a significant difference in the lubricating properties with respect to the uncontaminated oil samples.

Pred končnim testiranjem na traktorju je treba za izbrano olje UTTO optimirati torne lastnosti, določiti združljivosti s tesnili, oksidacijsko stabilnost in izmeriti biorazgradljivost.

Before practical experiments on a farm tractor, further investigations for the selected new rapeseed-based UTTO oil should determine the friction properties, seal compatibility, oxidative stability and biodegradability.

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