ARNOLD TROSS KOLLOQUIUM

Eine Veranstaltungsreihe des
Labores für Maschinenelemente und Tribologie
Department für Maschinenbau und Produktion
Hochschule für Angewandte Wissenschaften Hamburg

14. ARNOLD TROSS KOLLOQUIUM

HAW Hamburg Mai 2018

SHAKER VERLAG

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Labor für
Maschinenelemente und
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14. ARNOLD TROSS KOLLOQUIUM

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(MuT)

Department für Maschinenbau und Produktion

Institut für Konstruktion und Produktentwicklung

Fakultät für Technik und Informatik der

HAW Hamburg

Berichte aus dem Maschinenbau

Erik Kuhn (Hrsg.)

14. Arnold Tross Kolloquium

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Preface

Campus Berliner Tor

It was a pleasure for me to welcome Tribologists to the 14th Colloquium to have an exchange of new ideas and experiences in different fields of Tribology.

A group of scientists from Netherland, Spain, Iraq and Germany had arrived at the colloquium to discuss intensively different problems related to friction and wear. In this year the papers came exclusive from university research.

Many talks were held between the presentations and during the lunch. I hope some of the participants got some new ideas or at least some suggestions for her own research work.

During the evening dinner talks about tribology, politic and society were continued.

Thanks to all participants and I would like to welcome you at the 15th Arnold Tross Colloquium at 24th of May 2019 in Hamburg.

Prof.Dr. E.Kuhn

14. ARNOLD TROSS KOLLOQUIUM - PROGRAMM

25. Mai 2018 HAW-Hamburg

10:00-10:05	*Prof.Dr.E.Kuhn (HAW Hamburg)*: Welcome and opening of the colloquium
10:05-10:20	*Prof.Dr.E.Kuhn (HAW Hamburg)*: Some comments to the wear of lubricating greases
10:20-10:45	*M.Sc.E.Cortez Trivinio[1], Prof.Dr.C.Valencia[1], Prof.Dr.E.Kuhn[2], Prof.Dr.J.M.Franco[1] ([1]Uni Huelva, [2] HAW Hamburg)*: Tribological behaviour of epoxidized pulp gel-like dispersions in castor oil.
10:45-11:10	*Dr.Dr.U.Gunst (ATN Münster)*: Sensorik und Zustandsüberwachung für Tribosysteme in Produkten und Technologien - Tribo 4.0
11:10-11:35	*Dr.Laith Sabri[1], Dr. Kawan Othman[2], Dr.O.Abdullah3, 4, Dr. Suza Faraj[2], M.Sc. J. Akhtar[3] ([1]Case Western Reserve University,[2]University of Sulaimani,[3]Hamburg University of Technology, [4]Uni Bagdad)*: Stress analysis for the edentulous mandible rehabilitated with implant supported denture
11:35-12:00	*Univ.Doz. H.v.Leeuwen (TU Eindhoven)*: More accurate alpha values using an indirect approach - through a more accurate central film thickness formula
12:00-14:00	GRUPPENPHOTO + MITTAGSPAUSE
	Chairman: Univ.Doz. H.v.Leeuwen
14:00-14:25	*Dipl.-Ing. N.Bader (Leibniz Uni Hannover)*: Traction in EHL-contacts - considering local fluid properties.
14:25-14:50	*Prof.Dr.H.Abdel-Aal (Drexel Uni Philadelphia)*: Influence of contact pressure on partition of friction and heat in dry sliding contacts.
14:50-15:15	*M.Sc. J.Grün; M.Sc. N.Dakov;M.Sc.S.Feldmeth; Dr. F.Bauer (Uni Stuttgart)*: Computational Fluid Simulations of Lip Seals made of PTFE- Compound
15:15-15:40	*M.Sc. H.C.Liu[1], M.Sc.B.B.Zhang[2], Dr.N.Bader[1], Prof.Dr.G.Poll[1] ([1]Leibniz Uni Hannover,[2]University of Twente)*: On the crucial role of solid body temperature to EHL traction.
15:40-16:05	*B.Sc. M Winkel, B.Sc.D.Vehring, Dr.Dr.U.Gunst (ATN Münster)*: Analytische Tribobologie vs. Bionik, Medizin und Medizintechnik - Themenfelder, Ressourcen und Systemlösungen.
ab 16:05	Kaffee im Labor
17:30	kleines Abendessen für Vortragende im Gasthaus an der Alster

POSTER

The 14th Arnold Tross Colloquium
25th of May 2018
Hamburg University of Applied Sciences, Hamburg, Germany

Rheological Behaviour of New Completely Biogenic Lubricating Greases

N. Acar, E. Kuhn
Dep. M+P, Laboratory of Machine Elements and Tribology (MuT) - Hamburg University of Applied Sciences

Abstract

Against the background of raw material shortage and the ever-expanding environmental consciousness, the use of biodegradable greases becomes more and more important. In the Project "Tribiogen", which is funded by German Ministry of Education and Research, rheological characteristic of complete biodegradable greases are examined.

Rotational transient flow measurements were carried out on a rheometer at different temperatures to monitor the evolution of the shear stress with time at a constant shear rate, and to characterize the internal friction behavior by quantifying the energy density.

Materials & Methods

Materials

Complete biodegradable lubricating greases were formulated with high-oleic sunflower oil (HOSO) and/or castor oil, and different biodegradable thickener agents such as natural cellulose fibers of different lengths and some derivatives, as well as glyceryl and sorbitan stearates. To compare the tribological behavior of the greases, two reference grease samples (R1 and R2) were added for the investigation.

Grease Sample (Code)	Base Oil	Substance of Content
R1	Synthetic Ester	Lithium/Calcium Soap
R2	HOSO	Lithium-12-hydroxystearate
1	HOSO and Castor oil	Beeswax, glyceryl monostearate and cetyl alcohol
2	HOSO and Castor oil	Cetyl alcohol, glyceryl- and sorbitan monostearate
3	HOSO	Cellulose ether and glycerin
4	HOSO	Isoprene derivative
5	HOSO	Lignosulfonate
6	HOSO	Natural cellulose fibers 18 µm
7	HOSO	Corncob grits 80–120 µm
8	HOSO	Natural cellulose 20–40 µm
9	HOSO	Natural wood pulp from softwood 70–150 µm
S1	Castor Oil	Lignin/PEGDGE [1] (weight ratio of 1/0.25)
S2	Castor Oil	Lignin/PEGDGE (weight ratio of 1/1)
S3	Castor Oil	Lignin/HMDI [2] (weight ratio of 1/2)
S4	Castor Oil	Lignin/HMDI (weight ratio of 1/1)

Biogenic lubricating greases was produced by Fuchs Europe Schmierstoffe GmbH (Mannheim, Germany) and Fuchs Lubritech GmbH (Kaiserslautern, Germany)

Biogenic lubricating greases was produced by Pro2TecS (University of Huelva (Spain))
[1] PEGDGE: polyethylene glycol diglycidyl ether
[2] HMDI: hexamethylene diisocyanate

Rheological (Rotational Transient Flow) Tests

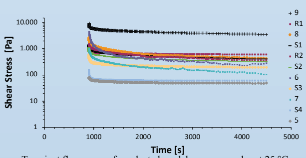
Rheological characterization of complete biogenic greases was carried out on a MCR-302 rheometer (Anton Paar GmbH, Graz, Austria) in the Laboratory for Machine Elements and Tribology (MuT) of HAW-Hamburg.

Rheometer MCR 302

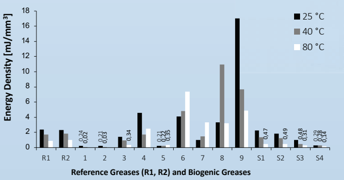
- Constant shear rate: 1 s^{-1}
- Measuring system: Plate-Plate system "PP15s" with a gap of 1mm
- Temperature measurement: 25°C, 40°C and 80°C
- Measurement duration: 3600 s
- Every measurement for each grease was repeated three times at each temperature.

Results & Discussion

Rotational Transient Flow Tests



Transient flow curves for selected model grease samples at 25 °C

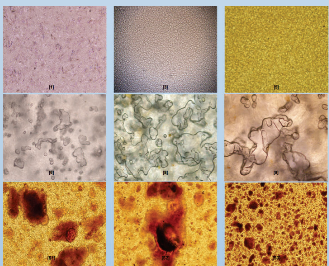


$$e_{\text{rheo}} = \dot{\gamma} \cdot \int_{t_{\max}}^{t} \tau(t) \cdot \mathrm{d}t \qquad \tau(t) = \tau_{lim} \cdot \left(\frac{t}{t_{lim}}\right)^{-n}$$

- e_{rheo} : Energy expenditure per stressed grease volume [mJ/mm^3]
- $\dot{\gamma}$: Shear rate (constant) [s^{-1}]
- $t_{\max}$: Time necessary to reach the maximum shear stress [s]
- τ_{lim} : Steady-state shear stress [Pa]
- t_{lim} : Time necessary to reach τ_{lim} [s]
- n : Dimensionless exponent

Energy densities (e_{rheo}) determined by integration of the shear stress vs. time plots at 25 °C, 40 °C, and 80 °C.

- Model greases 1 and 2 could not be tested at 80 °C on the rheometer, because sorbitan and glyceryl monostearates melted below this temperature.



Transmitted Light Microscope micrographs for biogenic grease samples (window sizes of 683,5 µm × 536 µm)

The estimation of the energy density from the shear stress versus time curve revealed that the amount of energy expenditure per stressed volume (e_{rheo}) strongly depends on the test temperature. → e_{rheo} decrease by increasing the test temperature.

The opposite tendency was found for some biogenic greases, 5,6,7 and 8.
This unusual temperature-influenced flow behavior of these biogenic greases can be explained by the weak interactions between the base oil and thickeners, which significantly decrease with temperature. This may favor oil separation (oil bleeding) at high temperatures, resulting in higher viscosity and therefore higher energy density.

The biogenic grease samples 1 and 2, consisting of a combination of HOSO and castor oil as the base oil and glyceryl- and/or sorbitan monostearate as thickener → the lowest energy expenditure at 25 °C and 40 °C.

The biogenic grease samples 6, 8, and 9, consisting of HOSO as a base oil and natural cellulose fiber of length of 18 µm and 20–40 µm and natural wood pulp from softwood 70–150 µm as thickener agents → the highest values of energy density in all test series, probably because these formulations need higher thickener concentrations to be physically stabilized.

The characteristics and type of the thickener microstructure influence the friction behavior of the grease in the tribological process. In general, the more homogenous structure and small particle size, the lower the resulting energy density.

References

[1] E. Kuhn, Zur Tribologie der Schmierfette, Expert Verlag, Renningen, Germany, 2017.
[2] M.A. Delgado, J.M. Franco and E. Kuhn, "Effect of rheological behaviour of lithium greases on the friction process" Ind. Lubr. Tribol. ,60, pp. 37–45, 2008.
[3] Slabka, I. Rheologische Charakterisierung biogener Modellfette. Master Thesis, Hamburg University of Applied Sciences, Hamburg, Germany, 2017.
[4] Acar, N.; Kuhn, E.; Franco, J.M. Tribological and Rheological Characterization of New Completely Biogenic Lubricating Greases: a Comparative Experimental Investigation. Lubricants 2018, 6(2), 45.

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Tribological Behaviour of New Completely Biogenic Lubricating Greases

N. Acar, E. Kuhn
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Abstract

Against the background of raw material shortage and the ever-expanding environmental consciousness, the use of biodegradable greases becomes more and more important. In the Project "Tribiogen", which is funded by German Ministry of Education and Research, tribological characteristic of complete biodegradable greases are examined.

The main aim of the application of a lubricant is the prevention of the direct contact of the two solid rubbing bodies. That means for a friction balance that the friction behavior (the so-called fluid friction) of the lubricant plays an important role for the friction of a whole tribo-system. In addition, the loss of material as one type of wear will be reduced. In most practical situations, grease-lubricated contacts work in a state of mixed friction. This means the friction energy consists of a part of fluid friction and a part of solid friction.

To investigate the friction process, the model greases were tribologically examined with a nanotribometer at a normal force of 200 mN using a material combination of a steel ball on a steel disc.

Materials & Methods

Materials

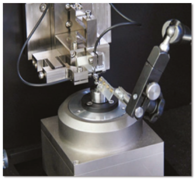
A series of completely biogenic lubricating greases was produced by Fuchs Europe Schmierstoffe (Mannheim, Germany), Fuchs Lubritech (Kaiserslautern, Germany) and Pro2TecS (University of Huelva, Spain). To compare the tribological behavior of the greases, two reference grease samples (R1 and R2) were added for the investigation.

Grease Sample (Code)	Base Oil	Substance of Content
R1	Synthetic Ester	Lithium/Calcium Soap
R2	HOSO [1]	Lithium-12-hydroxystearate
1	HOSO and Castor oil	Beeswax, glyceryl monostearate and cetyl alcohol
2	HOSO and Castor oil	Glyceryl monostearate, cetyl alcohol and sorbitan monostearate
3	HOSO	Cellulose ether and glycerin
4	HOSO	Isoprene derivative
5	HOSO	Lignosulfonate
6	HOSO	Natural cellulose fibers 18 µm
S1	Castor Oil	Lignin/PEGDGE [2] (weight ratio of 1/0.25)
S2	Castor Oil	Lignin/PEGDGE (weight ratio of 1/1)
S3	Castor Oil	Lignin/HMDI [3] (weight ratio of 1/2)
S4	Castor Oil	Lignin/HMDI (weight ratio of 1/1)

[1] HOSO: high-oleic sunflower oil, [2] PEGDGE: polyethylene glycol diglycidyl ether,
[3] HMDI: hexamethylene diisocyanate

Tribological Tests

A nanotribometer from CSM Instruments (Peseux, Switzerland) was used to determine the friction values of tribologically stressed material combinations. In the Laboratory for Machine Elements and Tribology (MuT) of HAW-Hamburg, all tests were performed using material combinations of steel ball (100Cr6) with 1 mm diameter on a steel disc (115CrV3, hardness 60-62 HRC) in rotational mode.



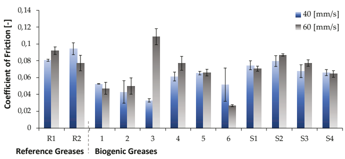
Nanotribometer from CSM Instruments

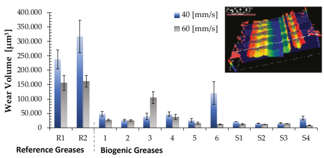
- Load application (F_N): 200mN
- Hertzian stress: 1,2 GPa
- Relative speed (V_R): 40 mm.s^{-1} and 60 mm.s^{-1}
- Wear path (s_R): 80m
- Ambient temperature: 22 ±1 °C
- Every measurement for each grease was repeated three times.
- All the steel discs were metallographically grinded and polished with a soft finish diamond paste of particle size 3 µm in the last polishing step.

The wear marks, which were produced from the three-time repetition of measurement in the same track at the nanotribometer, were analyzed by means of white light Interferometry (by Zygo Nexview).

Results & Discussion

Frictional Behavior and Wear Results





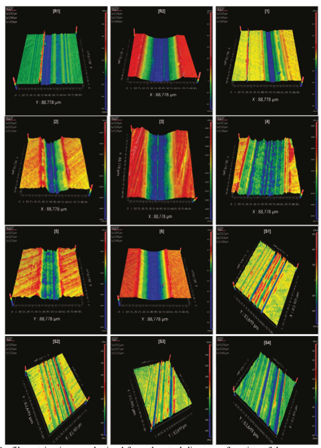
Results show a different influence of completely biogenic model grease components on frictional and wear behavior.

- In almost all cases, the use of biodegradable model greases produce lower values of the friction coefficient than the reference greases (R1,R2).
- Model greases 1, 2 and 6, provide lower values of the friction coefficient than the other model greases.
- The friction coefficients of the greases 1, 5, S1, and S4, remain stable in almost all test series. It shows that the friction coefficients of these grease samples are not highly influenced by relative speed differences.
- Reference greases, R1 and R2, produce higher values of the wear volume on the steel plate despite exhibiting only slightly higher friction coefficient values than the other model greases.
- The biogenic grease samples, S1,S2,S3 and S4, present higher values of the friction coefficient than the other biogenic greases, but the least wear on the steel plates. Under an assumption, these results could be explained by the better mechanical stability of these biogenic greases. This means that grease microstructures achieved by chemically cross-linking castor oil and lignin are not easily broken inside the tribological contact. This property of the grease microstructures could favor the grease not being easily ejected from the contact and therefore increases the efficiency of the grease in the lubricating contact.

The wear marks on the steel discs, obtained after performing the frictional tests with the normal load of 200 mN and a relative speed of 40 mm·s^{-1} in the nanotribometer, were investigated using the optical 3D surface profilometer.

- R2, 3, 4 and 6 ⟶ very wide and strong abrasive wear on the steel plate
- R1 and 1 ⟶ narrowest wear tracks but pronounced abrasive wear
- S1, S2, and S3 ⟶ wide but less pronounced wear scars on the steel plate

These wear results can be explained by the different components in grease formulations.



Profilometric pictures obtained from the steel discs as a function of the grease used as lubricants
(window sizes of 88,778 µm × 88,778 µm and 83,485 µm × 83,649 µm)

References

[1] R. Sanchez, J.M. Franco, E. Kuhn and M. Fiedler, "Tribological characterization of green lubricating greases formulated with castor oil and different biogenic thickener agents: a comparative experimental study" Industrial Lubrication and Tribology, Vol. 63, pp.446–452, 2011.
[2] Mohr, H. Tribologische Untersuchung komplett biogener Schmierfette. Master Thesis, Hamburg University of Applied Sciences, Hamburg, Germany, 2017.
[3] Acar, N.; Kuhn, E.; Franco, J.M. Tribological and Rheological Characterization of New Completely Biogenic Lubricating Greases: a Comparative Experimental Investigation. Lubricants 2018, 6(2), 45.

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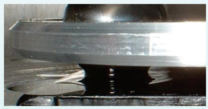
Estimating dynamic grease viscosity in an EHD-contact

shear rate maximum with a rheometer:

$$\dot{\gamma} = 2 \cdot \pi \cdot n_{rheometer} / \alpha_{cone} < 10.000\ s^{-1}$$

real shear rate at a ball disc tribometer:

$$\dot{\gamma} = (v_{disk} - v_{ball})/h_{min} > 100.000\ s^{-1}\ !$$



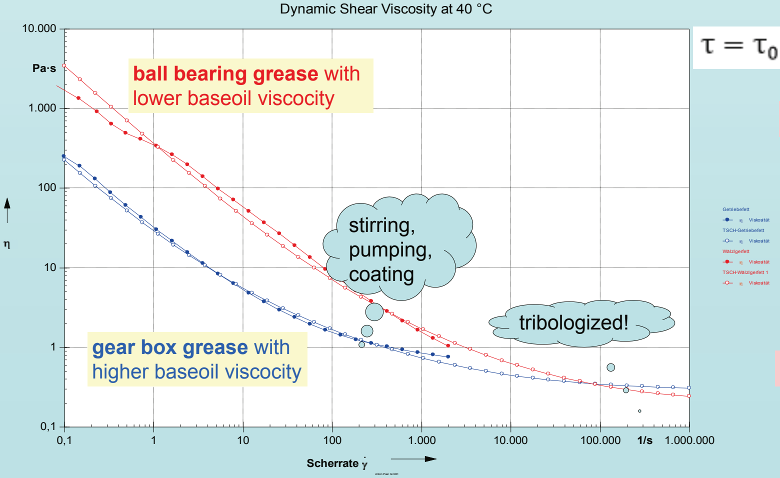
Hamrock & Dowson's model (from 1978) – not the newest but easy appliable for our lab data **delivers**:

$$h_{min} = 1{,}82 \cdot \frac{U^{0,68} \cdot G^{0,49}}{W^{0,073}} \cdot (1 - e^{-0,70}) \approx 1\ \mu m\ !$$

With **Yang & Qian's** $\frac{h_{grease}}{h_{oil}} = \left(\frac{\eta_g}{\eta_o}\right)^{0,74}$ we need the grease viscosity from another model:

... and **Tscheuschner's** for chocolate and other desires does well considering yield stress, base oil viscosity and measuring values (here up to 2000 s^{-1}):

Dynamic Shear Viscosity at 40 °C



$$\tau = \tau_0 + \eta_0 \cdot \dot{\gamma} + \eta_S \cdot \dot{\gamma}^p$$

shear rate
↓
shear viscosity
↓
lubfilm thickness
↓
new shear rate

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