Additive: ALUB ®

(used by Ab Nanol Technologies Oy as NANOL®-Additive)

Additive used by Nanol Technologies AB has won the Award
for the European Enterprise Award for 2021
as the Most Sustainable Lubricant Additive 2021

Competitive Advantage

- Theory well documented with >12 years of solid academic research and investment of 12 Mio. Euro
- Unique technology; self structuring nano-thin protective layer (no S or P!)
- Excellent test results
- Extensive application potential:
  - Anti-wear & EP agent
  - Friction reducer
  - Lubricant stabiliser

What is NANOL / ALUB® - Technology?

- ALUB® is a unique micelle technology-based lubricant additive

- ALUB® forms a nano-thin protective layer on, and only on the friction surfaces, thanks to perfectly suspended soft metal ions contained in the lubricant.

  → *Reducing friction and operating temperature of the components*

  → *Lowering wear and protecting the friction surfaces*

  → *Extending lifetime of components and lubricant*

  → *Increasing the efficiency of industrial applications*

ALUB® TECHNOLOGY

Surface Activation → **Redox Reaction** → **Formation of Copper Layer**

Surface Activation

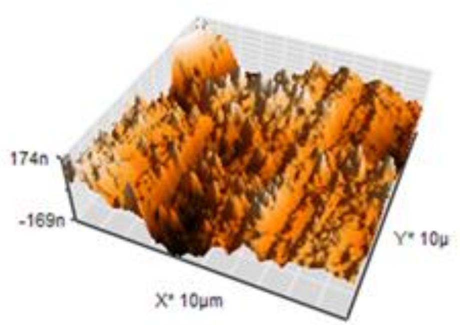
- Interaction between surface asperities → wear process
- Release of radicals/electrons (e^-)

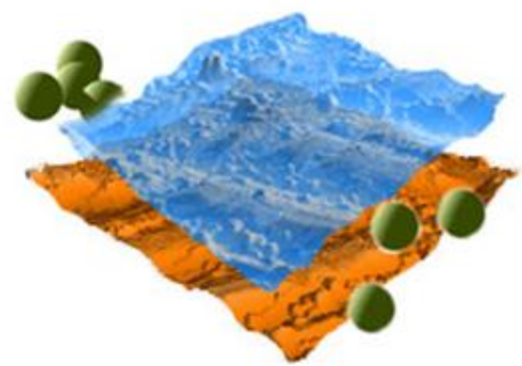
Redox Reaction

- Reduction of copper ions (Cu^{2+})
- $Cu^{2+} + 2e^- \rightarrow Cu^0$

Formation of Copper Layer

- Protective copper (Cu) layer formed only on the friction surfaces





Source: Fraunhofer KIT MIKROTRIBOLOGIE CENTRUM µTC

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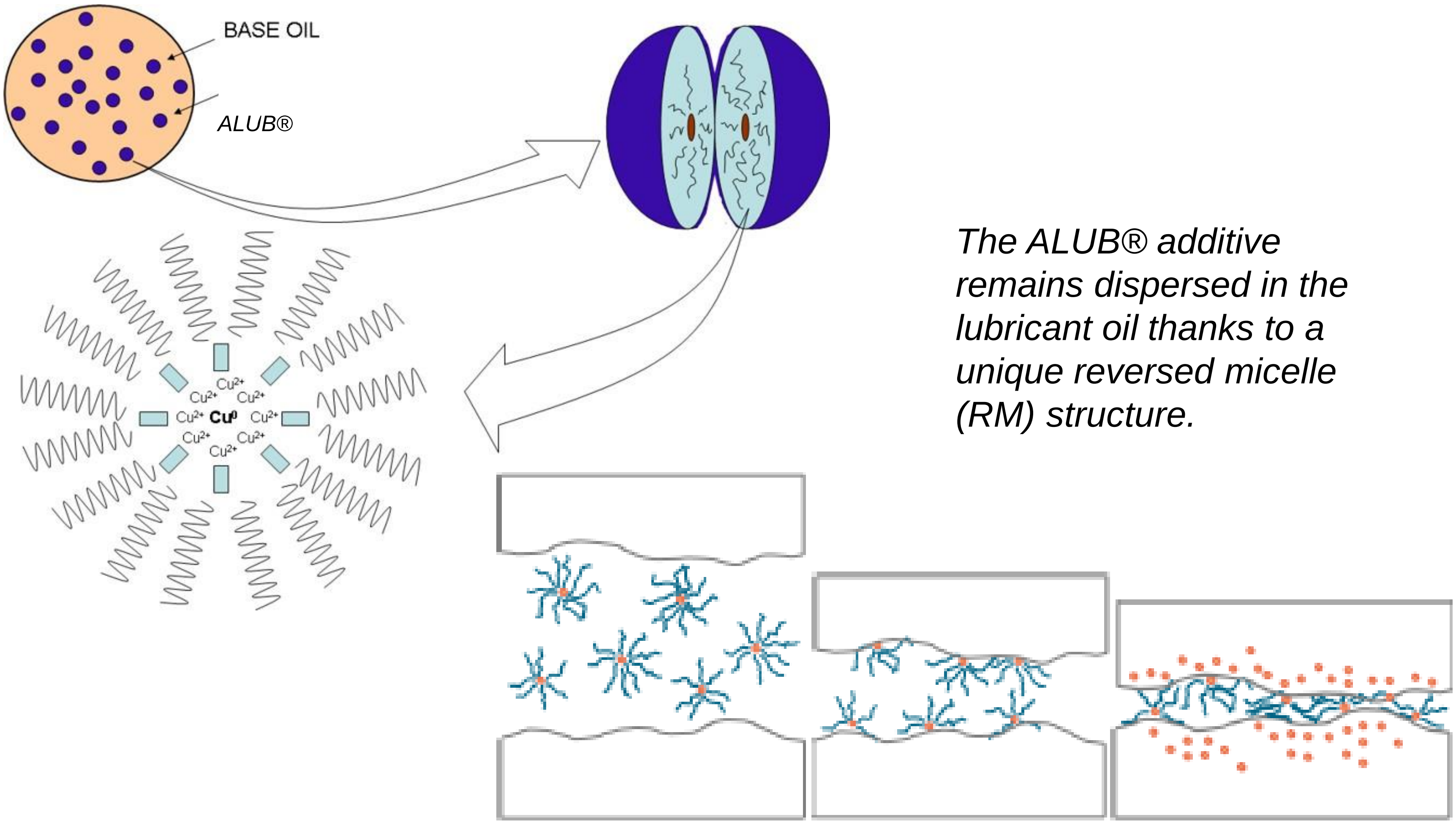
NANOL/ ALUB - TECHNOLOGY

- Antiwear and antifriction based on the formation of a tribo-chemical film coating.
- Formation of metallic copper durable film on the friction surfaces due to following tribochemical reaction (*selective transfer*):
- $Cu^{2+} + 2\ e^{-} \rightarrow Cu^{0}$
- $CuO + e^{-} \rightarrow Cu^{0}$
- $2\ Fe^{2+}$ (or Fe^{0}) $+ 3\ CuO + 2H_2O \rightarrow Fe_2O_3 + 3Cu^{0} + 4H^{+}$

ALUB® TECHNOLOGY

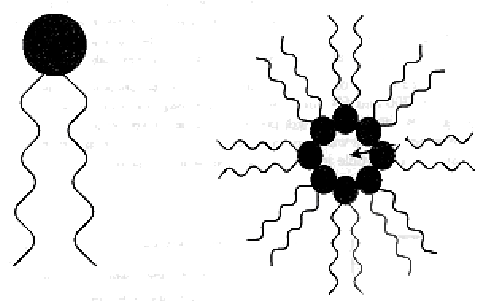


The ALUB® additive remains dispersed in the lubricant oil thanks to a unique reversed micelle (RM) structure.

CONFIDENTIAL

NANOL / ALUB - COMPOSITION

- The ALUB™ additive is a hard core reverse micelles (RM) in hydrocarbon environment.
- The micelles are arranged to larger agglomerates. Agglomerates up to 1 micron (1µm) have been analyzed.
- Micelle size ~30-40nm.
- Hydrocarbon tails from the copper(II) oleate are exposed to the solvent while the polar heads point toward the interior, possibly towards a Cu^{2+} / CuO / Sn/Cu core.

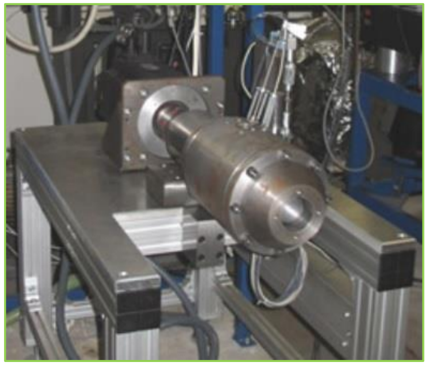


Experiences / Applications

- Laboratories
- Shipping
- Railways
- Mining
- Trucking
- Industrial Applications
  - Bearings
  - Gear boxes
  - Compressors

FE8 WEC TEST

- FE8 tests for WEC (White Etching Cracks) and pitting damage



- In roller bearings under hard operating conditions
  - Axial load 60 000 N
  - RPM 750 1/min
  - Temperature 100 °C

Test 1

- Reference oil worked 40 hours.
- Reference oil with 3,5% ALUB® run 425 hours until material fatigue.

Test 2

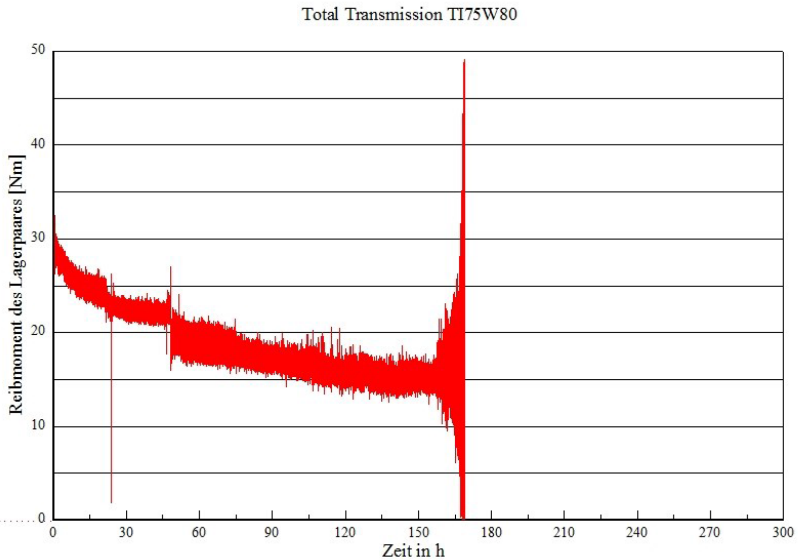
- Reference oil worked 40 hours until a sharp rise in temperature. With a special cooler continuously applied to cool down the oil, the oil could run 170 hours until failure of the bearings due to severe damage.

  Heavy pitting on the bearing surfaces; material weight loss 4.834 g.

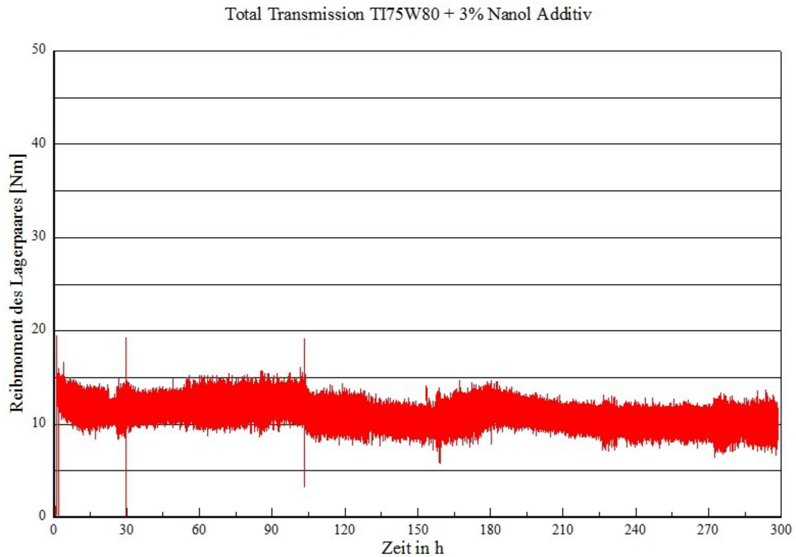
- Reference oil with ALUB® run 300 hours after which the test was stopped due to time constraints.

  No visible wear on the bearings; material weight loss 0.029 g.

FE8 WEC Test



Total Transmission TI75W80
Reibmoment des Lagerpaares [Nm]
Zeit in h



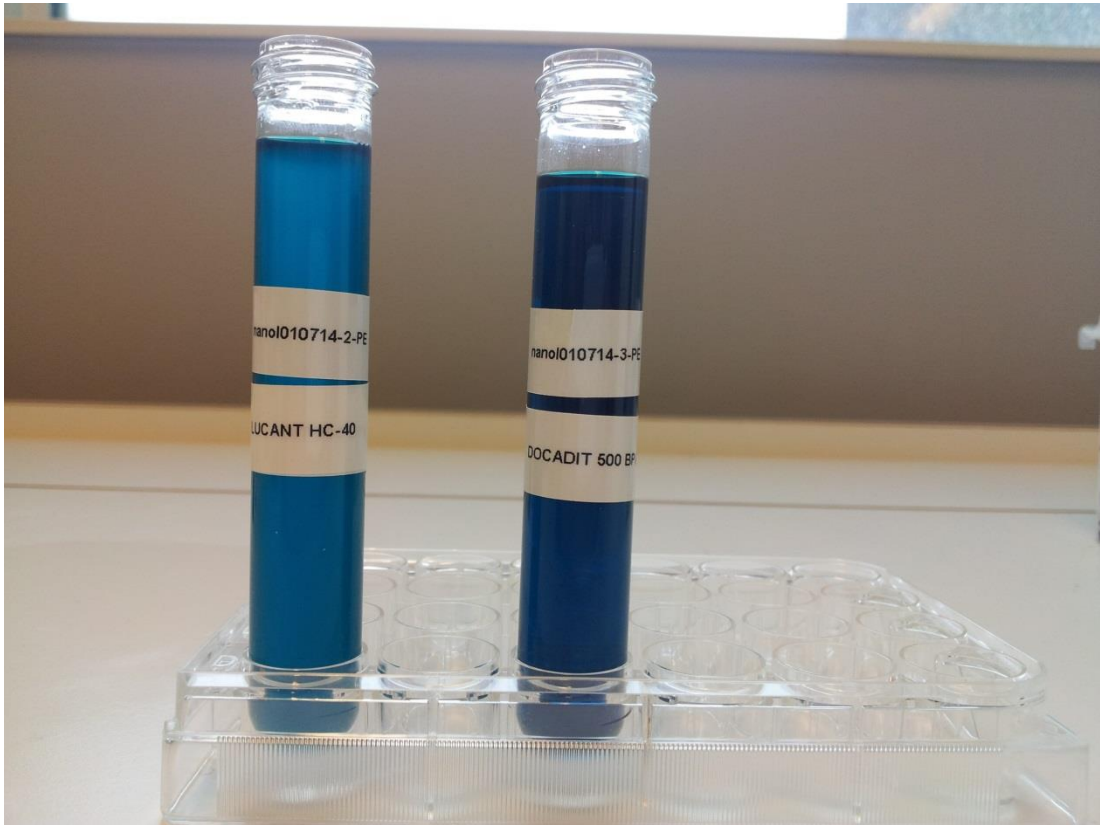
Total Transmission TI75W80 + 3% Nanol Additiv
Reibmoment des Lagerpaares [Nm]
Zeit in h

HOW TO USE ALUB®

- ALUB® is dark green paste form at room temperature (shelf stable).
- Before adding ALUB® to the finished greases, you need to put the canister of ALUB® into another container of hot water to warm it up to 80 °C, then it becomes liquid form.
- Then add liquid ALUB® into the storage facility of greases to blend it in 1 hour.
- If the blending process is just after the production of greases, the storage facility could be still warm, as long as it is over 80 °C, you can put ALUB® directly into the storage facility to blend it with the grease in 1 hour.

SOLUBILITY IN PAO AND ESTER OILS

- Solubility of 1%, 2%, 3% and up to 10% of ALUB® tested
- In all samples ALUB perfectly soluble



EXPANDING ALUB

APPLICATION POTENTIAL:

- Reducing of production costs for engine oils up to 10 % and fuel consumption up to 4 %
- Reducing of production costs for greases by 30 %
- Minimization of WEC (White Etching Cracks) effect

INSTITUTE REPORTS

Fraunhofer-Institut für Werkstoffmechanik, Mikrotribologie Centrum µTC (Germany):

Fraunhofer KIT
MIKROTRIBOLOGIE CENTRUM µTC

Status report of friction and wear tests of marine oils with and without Nanol additives

By means of a PLS simulator friction and wear between a chromium-plated steel piston ring and a gray cast iron liner was evaluated in real-time to determine friction coefficients and wear rates. The test setup simulates the upper dead center of an engine. The machine parts were selected to be similar to original marine diesel engine parts. Nanol oils with different concentrations (0.3%, 1%, 3%) were compared with a pure marine diesel engine oil. Figure 1 shows the test setup with the PLS and the RNT wear measuring unit. All tests exhibited wear rates smaller than 5 nm/h which are common for diesel engines. However, it has to be pointed out that Nanol 0.3% showed a three-times lower wear rate than the pure marine oil, i.e., 1.1 nm/h in comparison to 2.8 nm/h!

Fig. 1: Piston ring – liner simulator connected to a radionuclide wear measurement system.

With respect to friction the PLS showed only minor reductions of friction due to Nanol additives. Since in the PLS the piston ring moves with a constant velocity of 0.2 m/s (except at the turning points) an additional test with a high-resolution ball on flat setup was used. With this machine the velocity range between 1E-4 m/s and 1 m/s was

It was shown that Nanol additives induce a significant reduction of friction.

velocities were related to the acting pressures between piston ring and liner, that means that low values of w/p can were achieved by either low sliding velocities and/or high pressures as common for the upper dead center.

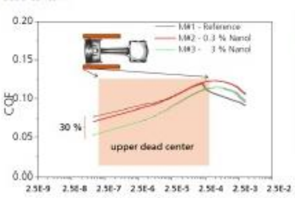


Fig. 2: Ball on flat measurements.

The brown inset of Fig. 2 indicates the w/p ratio acting in a real combustion engine. With the PLS only the range around w/p = 2.5E-4 was covered, explaining the small differences between Nanol and the reference oil. However, when the full v over p range is covered, a reduction of friction of up to 30% was detected.

The third group of experiments was carried out with a ball on flat setup as well. This time

With respect to wear the additives do not impose a hazard to the engine, on the contrary, in the tested stressing range Nanol clearly reduced wear.

Summary: It was shown that Nanol additives induce a significant reduction of friction. It seems that an energetic corridor exists were the additive performs best. With respect to wear the additives do not impose a hazard to the engine, on the contrary, in the tested stressing range Nanol clearly reduced wear. The acting friction-reducing mechanism, however, is still under investigation.

VTT – Technical Research Centre of Finland:

VTT

15.10.2013 1 (1)

Johan von Knorring
Nanol Technology
Helsinki

Dear Johan,

On your request I would like to summarise my view on Nanol based on the experience we have at VTT

The recent results from field testing by Nanol Technology show that they nave found a way to further develop and benefit this technology in an impressive way. The reports I have seen are convincing that the Nanol additive can reduce friction considerably in marine engines.

At VTT we have recently managed to reproduce this lubricating mechanism with marine oils including Nanol additives in our twin-disk test equipment. Our first tests showed that in elastohydrodynamic rolling-sliding conditions the friction was reduced by about 10% when Nanol was added to the oil. These contact conditions represent a considerable part of the lubricating contacts in an engine. Our recent published studies show that in an internal combustion engine a reduction in friction would have a triple energy consumption effect on fuel savings because it will at the same time also reduce both exhaust and engine cooling at a similar rate.

This friction and wear reducing effect has up to date been shown in various conditions including boundary, mixed, elastohydrodynamic and hydrodynamic conditions. Still the fundamental mechanism of this lubricating mechanism is not fully understood and our joint investigation on this continues. For this is further investigations needed in controlled laboratory conditions with tribological test equipment like pin-on-disk, twin-disk and piston-ring simulators.

Sincerely

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Our recent published studies show that in an internal combustion engine a reduction in friction would have a triple energy consumption effect on fuel savings because it will at the same time also reduce both exhaust and engine cooling at a similar rate.

Thank you for your attention!