Agenda

01  Our company at a glance
    facts and figures

02  Digitization in the lubricants industry
    simulation / calculation / sensor technology / big data

03  Lubricant applications in Industry 4.0
    internal fluid control / chemical-mechanical interaction

04  Limitations
    sensor technology / economics / access to data
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FUCHS Lubricants is your smart technology partner

Established 3 generations ago as a family-owned business

- Technology and Innovation market leader in strategic product lines
- Present on all continents with 24 laboratories
- No. 1 among independent suppliers of lubricants
- 57 companies worldwide
- Fuchs family holds 54% of ordinary shares
- A full range of over 10,000 lubricants and related specialties
- 447 employees working in R&D
- More than 2.3 bn euro sales in 2016
- Almost 5,000 employees

GERMAN SUSTAINABILITY AWARD
Germany’s Most Sustainable Medium-sized Company 2014
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Digitalization is shortening the development cycle

- Increase of efficiency and accuracy by introducing automation
- Speed up during the development and shorten the time to market
- Reducing the number of trials
- Developing test methods for screening during the development phase with a high level of predictability
- Challenge: parametrisation of the lubricant and its properties to fit into the calculation models
Digital Methods are making chemistry smarter

- Development of methods to describe the lubricant correctly in tribological sense for further application in simulations and calculation
- Simulations and calculation to support and speed up R&D works
- Calculation of molecules and their in between interaction and with the surfaces.
- Design of Experiments: Support of R&D to analyze complex tests, establishing of new technics of panning of experiments and their evaluation
- Sensor technology: „smart lubricant“
Digitalization will fundamentally change value creation

- Data collection throughout the whole value-chain will be widened compared to today's standards
- Direct and automated usage of information generated at a later step of the process will affect all steps before
- An extended exchange in between you and your lubricants company will allow for new services and therewith add extra value to your business
The data ecosystem governs tactical & strategic decisions

- Introducing online-monitoring for lubricants in addition to offline-analyses
- Combine lubricants data with machine data (e.g. vibration or load) to generate a more holistic view
- Provide a basis for decisions on immediate actions to keep the fluid healthy
- Support the local fluid management
Monitoring application and creating data driven services

1 **Traditional data sources**
   - Nominal values as determined in the new lubricant
   - Historical data
   - R&D data
   - Lab analysis data
   - Field service data
   - Machine data

2 **Online sensors**
   - Realtime measurement of key parameters
   - Continuous determination of relative changes

3 **Central data base and data analytics**
   - All data collected from traditional data sources and online sensors
   - All data converted into a single format
   - Data analysis and visualisation
   - Realtime evaluation of measured parameters as basis for decision-making

4 **Immediate actions**
   - (Automated) fluid adjustments
   - Optimization of process parameters
   - Preservation of process stability
   - Avoidance of process breakdowns
   - Prevention of health hazards

5 **Trend analytics**
   - Comparison of current data with historical data to predict the remaining useful life
   - Supports predictive maintenance approaches
   - Identification of complex correlations
Traditional data will be augmented by field data

- **Laboratory**

  Viscosity, acid number, water content, purity, wear elements, IR spektrum (oxidation, losses of additives) ...

  According to DIN, ASTM, ISO etc.

- **Sensors**
Using digitized tools to support lubricant development

• Transform product development from being empirically-driven to using data and simulation approaches!
• In doing so, application related information such as field data or test field results serve as a statistical backbone.
• A more focused development will be granted by implementing the later application into product development by introducing simulation approaches into R&D.
Using digitized tools to support lubricant development

1. lubricant development
   - application-oriented design
   - today: mostly characterized by know-how & empiricism

2. laboratory & tribometer
   - identification of relevant lubricant’s properties (simplified test rigs)
     - chemical & physical
     - friction & flow behaviour

3. simulation
   - chemical & mechanical modeling of tribological problems
   - prediction of tribological behavior with regard to chemical composition, operating conditions as well as interdependencies
   - identification of product requirements
   - gathering and process relevant data
   - optimized work-flow to develop effective product

4. test field
   - qualification test with operating conditions close to real application
   - costly in terms of time and labor
   - benefit from preselection with digital methods

5. application
   - successful product due to dedicated lubricant design
   - experience in the field as input for Big Data
Using digitized tools to support lubricant development

deduction of relevant frictional behaviour

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<tr>
<th>Tribometer test rig: friction mapping</th>
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<tr>
<td>i.e. ball-on-disk (MTM)</td>
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<td>tempered lubricant</td>
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<td>disc</td>
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<td>load</td>
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<td>heating unit</td>
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<th>High pressure viscosimetry</th>
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<td>i.e. quartz viscosimeter</td>
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<td>PAO40</td>
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<th>Fluid model / shear behaviour</th>
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<tr>
<td>coefficient of friction μ</td>
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<td>velocity n₀</td>
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<td>slide-roll-ratio</td>
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<th>Coefficient of friction μ / shear behaviour</th>
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<td>simulation</td>
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<td>tribometer measurement</td>
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</table>
Current atomistic simulations

- Calculation of polarity and reactivity of molecules in the gas phase
- Calculation of the viscosity of base oils / VII
- Calculation of the viscosity of base oils
- Calculation of the friction of base oil / friction modifier
- Reaction of additives on metal surfaces
- Methods: quantum mechanics, molecular mechanics, molecular dynamics

D. Dini: Calculation of the friction coefficient of stearic acid / hexadecane on Fe surfaces (2016)

A. Martini: Viscosity calculation of PAMA / dodecane (2016)

JM Martin: Simulation of the reaction of fatty acids on Fe, Fe₂O₃ surfaces by chemisorption (2016)

D. Dini: Calculation of the viscosity of hexadecane (2016)

P. Nair: Orbital structure and reactivity of ZnDDP (2006)

D.Dini: Calculation of the viscosity of hexadecane (2016)
Current atomistic simulations

- Many tribological questions can be answered today with computational chemistry methods:
  - Stability of additives
  - Reaction on surfaces
  - Viscosity
  - Density
  - etc.
- However, the computational capabilities still limited and not suited to compute complex oils, big cells and long time axis
- Future trends will implement faster algorithms for quantum mechanical calculation and molecular dynamics
- Further improvements in the computer hardware are expected in the near future.
Future Trend: Improved algorithms

- Chemical reactions are characterized by the change in the electronical structure
- It is mathematically described by the Schrödinger equation
- In 1980 the DFT improves the quantum mechanical calculation by magnitudes and reduces the computational time tremendously
- These algorithms are further developed
- In 2016, e.g. the DC-DFTB was developed (linear-scaling divide-and-conquer technique with the density functional based tight binding)
- This approach is suitable for massive parallelized computers (e.g. 128 000 cores)
- Millions of atoms and complex reactions with many different molecules can be computed simultaneously with DC-DFTB
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Manufacturing process can be optimized by simultaneously adjusting application and fluid parameters.
Manufacturing process can be optimized by simultaneously adjusting application and fluid parameters

1 Application monitoring
- Tooling
- Machine
- Material
- Environment
- Quality control data

2 Application correction
- Feed rate
- Cutting speed
- Tool change
- Workholding pressure
- Fluid delivery pressure

3 Fluid monitoring
- Concentration
- Microbial growth
- Tramp oil content
- Corrosion protection
- Lubricity
- Foaming
- Detergency

4 Fluid correction
- Concentration
- Biocides
- pH boosters
- Corrosion additives
- Antifoam
- Emulsifiers
- Lubricants
- Turn on skimmers

5 Application – fluid interaction
- Adjust machining parameters to fluid condition (i.e. Age)
- Adjust fluid parameters to application capability
Smart control of application & fluid parameters ensure process optimization

1 Application parameters
- Cutting speed
- Feed rate
- Metal removal rate
- Tool life

2 Material parameters
- Hardness
- Alloy composition
- Microstructure
- Environment
- Downstream processes
- Storage time

3 Lubricant parameters
- Concentration
- Lubricity
- Wetting
- Detergency
- Corrosion protection
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Limitations to achieving Industry 4.0 with lubricants

- Variety of sensor technology to measure relevant lubricant parameters
- Robustness & reliability of sensors in real world environment
- Economical cost structure
- Lubricants designed to be measured
- Access to data
Thank you for your attention.