Polyalkylene Glycol-based Wind Turbine Gear Oil for Long Life and High Energy Efficiency

Jan Ukonsaari  Vattenfall AB, R&D  Luleå, Sweden
Daniel Zweifel  Research & Development, Dow Europe GmbH  Horgen, Switzerland
Agenda

- Polyalkylene glycol (PAG) as gear oil
- Typical product properties
- Application-oriented performance data
- Field trial test result
- Conclusions from field trial
Who are we?

Vattenfall is a major energy company in Europe continuously expanding the operation by adding new wind turbines to the production every year, always with a focus to decrease energy costs.

Dow is a major producer and supplier of polyalkylene glycol base stock for the lubricant industry.
Polyalkylene Glycol (PAG): Lubricants

Background:
- Dow is a world leader in PAG production, blending and formulation
- PAGs form a class of high-performance synthetic lubricants

Key properties include:
- Excellent lubricity, heat capacity, viscosity, and thermal stability
- Broad spectrum of demonstrated success in lubricant applications

Industrial: Gear lubricants, compressor & hydraulic system lubrication, Metal working fluid

Chemistry:
- Characteristics can be tuned by varying molecular weight and/or monomer feedstock monomer composition
- Prepared via ring-opening polymerization of epoxides (ethylene oxide, propylene oxide or butylene oxide)

\[ R_1 \quad \text{Derived from initiator} \]
\[ R_2 = H \text{ (EO)} \]
\[ = \text{Me (PO)} \]
## Generic Differences - Base Lubricants

<table>
<thead>
<tr>
<th>Properties</th>
<th>Mineral oil (MO)</th>
<th>Polyalphaolefin (PAO)</th>
<th>UCON™ Gear Lubricant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity index (-)</td>
<td>&lt;140</td>
<td>&lt;170</td>
<td>&gt;220</td>
</tr>
<tr>
<td>Cold temperature behavior; Viscosity (cSt) at 4°C (ASTM 445)</td>
<td>&gt;4000</td>
<td>~ 3000</td>
<td>&lt;3000</td>
</tr>
<tr>
<td>Coefficient of friction (-)</td>
<td>0.06</td>
<td>0.05</td>
<td>0.035</td>
</tr>
<tr>
<td>Expected oil change interval (years)</td>
<td>1-2</td>
<td>4-5</td>
<td>5-6</td>
</tr>
<tr>
<td>Expected energy efficiency gain (%)</td>
<td>0</td>
<td>0.5–1.0</td>
<td>1.5–3.0</td>
</tr>
<tr>
<td>Volumetric heat capacity Cv (kJ/Kg °K)</td>
<td>1.8</td>
<td>1.8</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Typical properties, not to be construed as specifications.
## Typical Physical Properties: UCON™ Gear Lubricant

<table>
<thead>
<tr>
<th>Property</th>
<th>Results: Range</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>Amber clear fluid</td>
<td>Visual</td>
</tr>
<tr>
<td>Viscosity@40° C, [cSt]</td>
<td>288-352</td>
<td>ASTM D445</td>
</tr>
<tr>
<td>Viscosity@100° C, [cSt]</td>
<td>47-55</td>
<td>ASTM D445</td>
</tr>
<tr>
<td>Viscosity index</td>
<td>&gt;220</td>
<td>ASTM D2270</td>
</tr>
<tr>
<td>Water [%]</td>
<td>&lt; 0.5%</td>
<td>ASTM E203</td>
</tr>
<tr>
<td>Density @25° C[Kg/m³]</td>
<td>1000-1100</td>
<td>ASTM D891</td>
</tr>
<tr>
<td>Pour point [° C]</td>
<td>&lt; -35</td>
<td>ASTM D97</td>
</tr>
</tbody>
</table>

- ISO 320 viscosity grade (international standard organisation)
- High VI value due to intrinsic viscosity profile of polyalkylene glycol
- Excellent water tolerance
- Low pour point

Typical properties, not to be construed as specifications
Application-oriented performance data

- SKF specification catalog for wind turbine gear lubricants
- Low friction coefficient: 0.03 - benchmark: 0.05
- Step load test (ASTM D7421-08): >3500 MPa - benchmark: 3400 MPa
- FAG Schaeffler: “Four-Step-Test for Oils in Wind Turbine Gears”
- FZG gear efficiency: 20-35% lower friction power loss - benchmark: PAO
- Film thickness 20% higher compared to PAO benchmark
- FVA micropitting test GT-C/8.3/60
- Field trial oil analysis (oil ageing, additive depletion, contamination)
Tjaereborg and the Gearbox

- Prototype of Horns Rev 1 turbine
- Production of more than 68 GWh corresponding to 34,000 full load hours from turbine start
- From 2009 to 2015-08 corresponds to about 31 GWh or 15,600 full load hours
- Potential running with PAG time is 52,000 h
Reliability Calculation

The graphic representations are presented here for illustrative purposes only and should not be construed as product specifications.
Ring Gear
Planetary Gear
Sun Pinion
Low Speed Shaft Gear
Low-Speed Shaft, Spline and Output Shaft
Conclusions

- Successfully completed five-year field trial
  - One machine still running – seven years
- PAG-based fluids increase the gear oil exchange intervals compared to hydrocarbon-based technology
- Allow for increased energy efficiency
- Significantly contributing to cost decrease
- PAG oil with same ISO viscosity as the PAO can increase the planetary stage reliability in this gearbox
Disclaimers

© ™ Trademark of The Dow Chemical Company ("Dow") or an affiliated company of Dow

NOTE: Any photographs of end-use applications in this document represent potential end-use applications but do not necessarily represent current commercial applications, nor do they represent an endorsement by Dow of the actual products. Further, these photographs are for illustration purposes only and do not reflect either an endorsement or sponsorship of any other manufacturer for a specific potential end-use product or application, or for Dow, or specific products manufactured by Dow.

NOTICE: No freedom from infringement of any patent owned by Dow or others is to be inferred. Because use conditions and applicable laws may differ from one location to another and may change with time, Customer is responsible for determining whether products and the information in this document are appropriate for Customer's use and for ensuring that Customer's workplace and disposal practices are in compliance with applicable laws and other government enactments. The product shown in this literature may not be available for sale and/or available in all geographies where Dow is represented. The claims made may not have been approved for use in all countries. Dow assumes no obligation or liability for the information in this document. References to "Dow" or the "Company" mean the Dow legal entity selling the products to Customer unless otherwise expressly noted. NO WARRANTIES ARE GIVEN; ALL IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE ARE EXPRESSLY EXCLUDED.
Thank You

Please visit www.dow.com

VATTENFALL

Dr. Jan Ukonsaari
Senior Research Engineer
Vattenfall AB, R&D
Jan.Ukonsaari@vattenfall.com
+46 706105802

Daniel Zweifel
Technical Service and Development
Dow Industrial Solutions
dzweifel@dow.com
+41 447282819