October 2015

Wind Turbine Gear Lubricants

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PCIMA TIR: External 2 JLPrince

Overview

- Wind Turbine Gear boxes
  - Challenges and Lubrication Impact
- Lubricant Formulation Approaches
  - Balanced Performance
  - Key Performance Parameters
- Next Generation Wind Turbines

Gear Box Lubrication Challenges

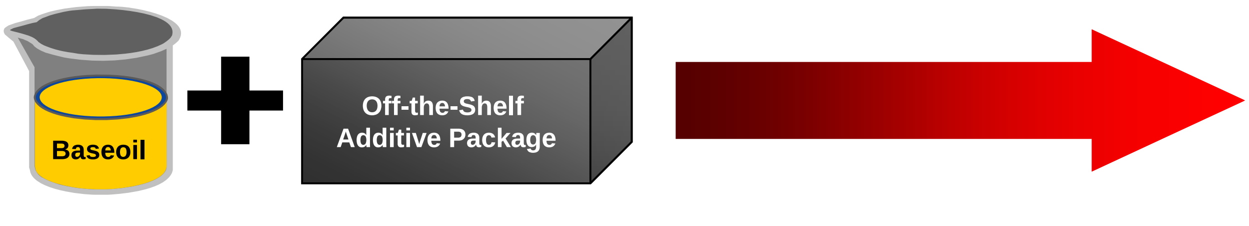
WT Gearbox Lubrication Challenges

Industry / OEM Challenge	Impact to Lubricant	Key Lubricant Formulation Parameter
Weight restrictions on gear box: • compact design; • high load handling capability; • case hardening of gears	Creates environment susceptible to micropitting and wear	Micropitting Protection Gear and Bearing Protection
Demand for extended oil drain intervals	Demands oil performance retention over time	Oxidative Stability Viscometrics Foam and Air Release
Use of fine filtration	Wet oil filterability	Filterability
Off-shore wind turbines	Creates environment for water contamination	Filterability Water Tolerance Rust and Corrosion Protection
Changing ambient temperatures and non-permanent operation	Requires stable operation of lubricant in wide ambient temperature range	Viscometrics Low Temperature Performance

Lubrication Approaches

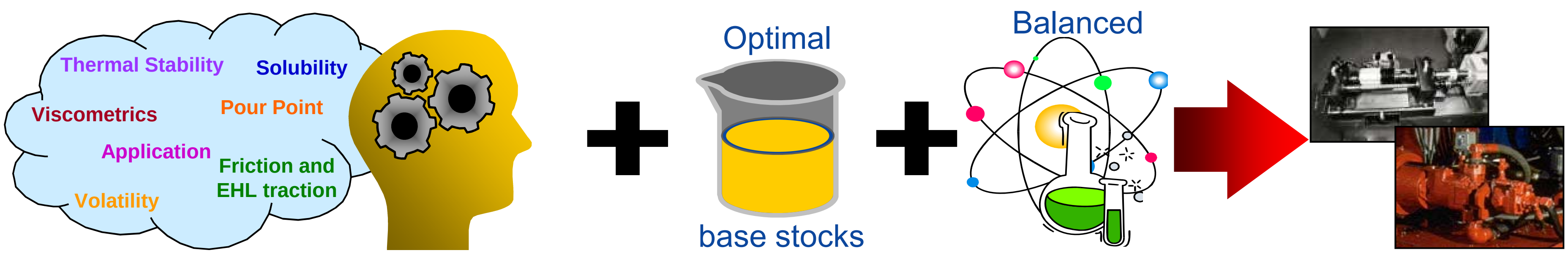
Balanced Formulation Approach

Common Approach



Lubricant Product with reasonable performance

Step Out Formulation Approach



Optimal base stocks

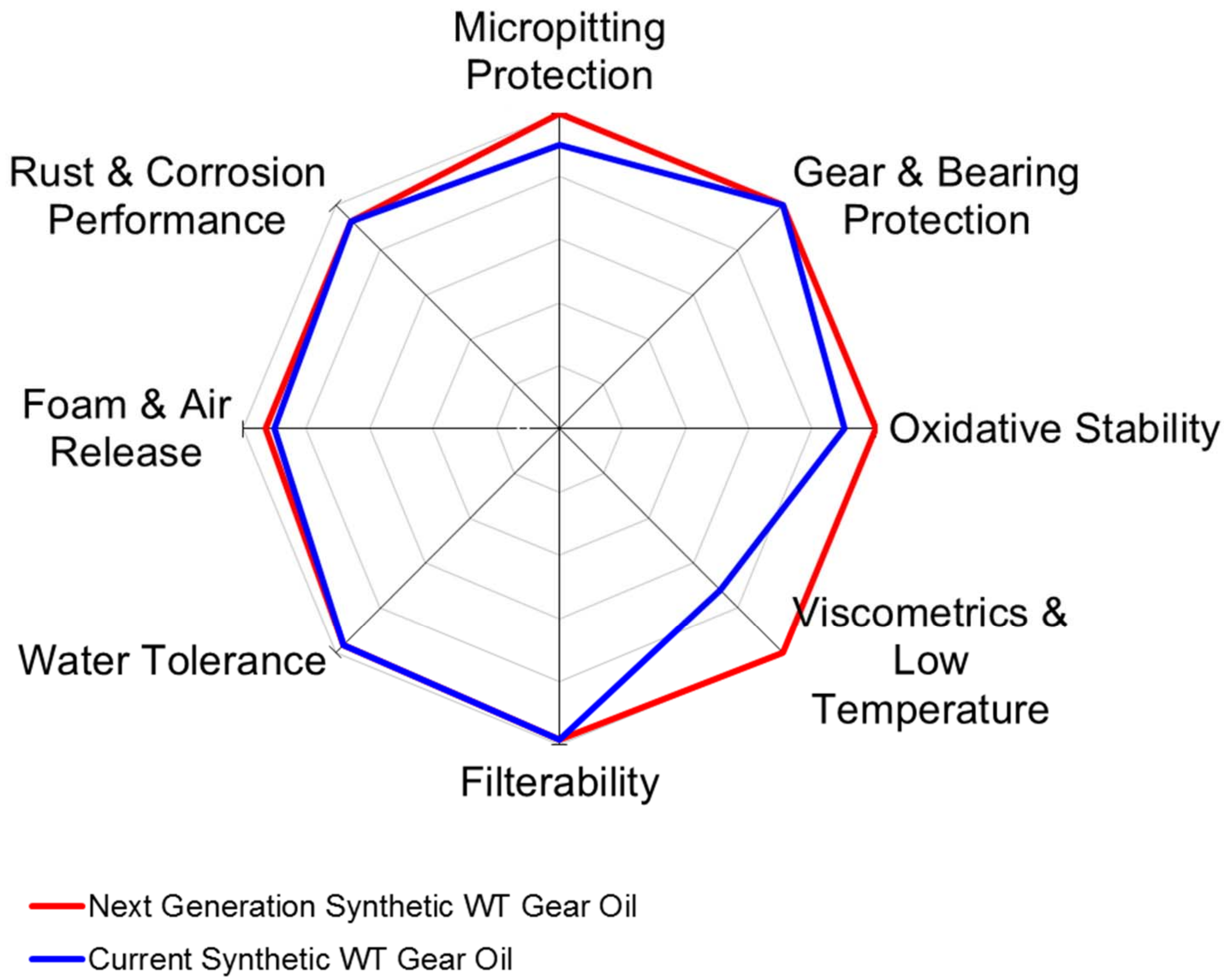
Balanced additive system

Many years of experience in formulation and application

Major investment in extensive testing using industry standard glassware, proprietary rig, and field tests

Balanced Formulation Approach

Key Lubricant Formulation Parameter
Micropitting Protection Gear and Bearing Protection
Oxidative Stability Viscometrics Foam and Air Release
Filterability
Filterability Water Tolerance Rust and Corrosion Protection
Viscometrics Low Temp Performance



Balanced Formulation Approach

Key Lubricant Formulation Parameter
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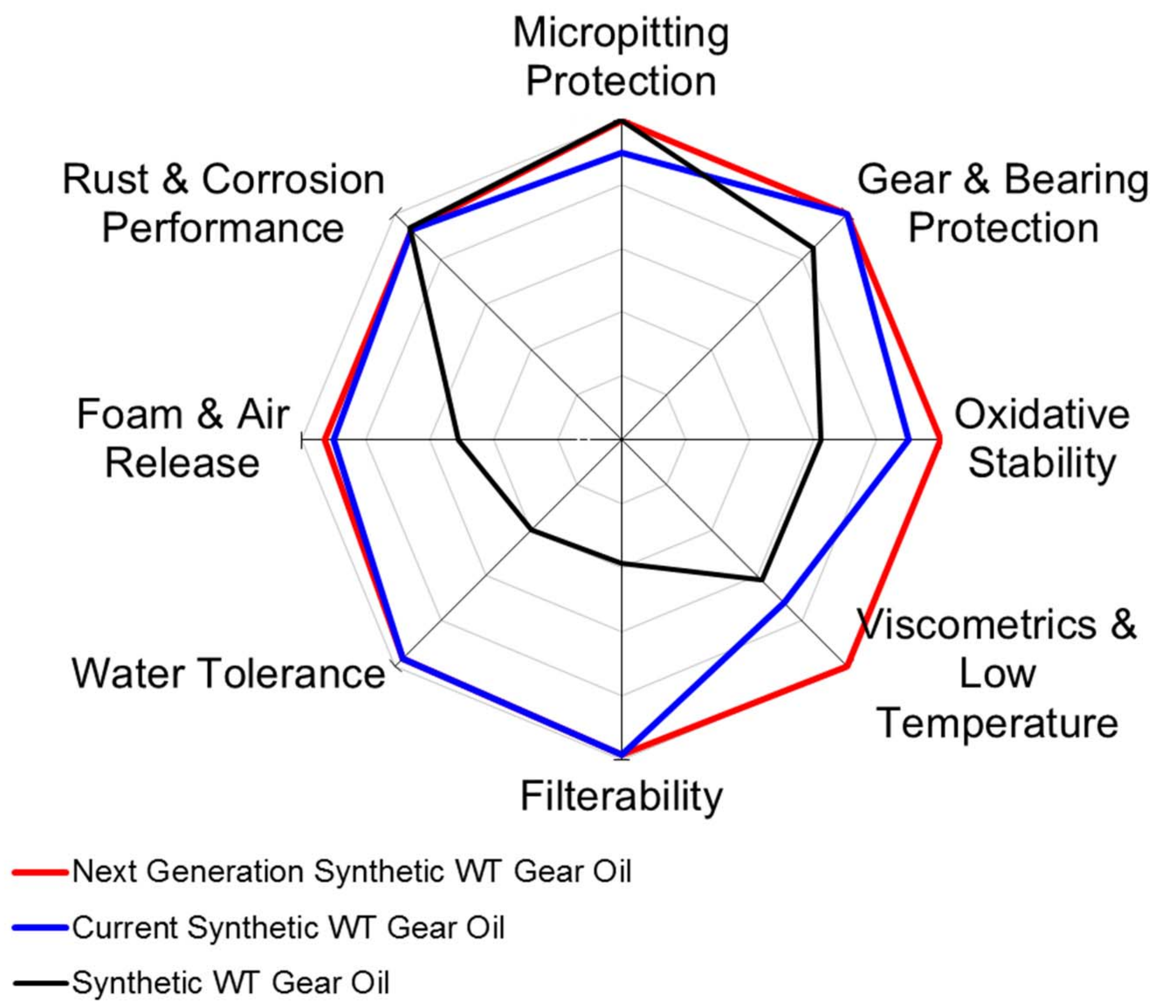
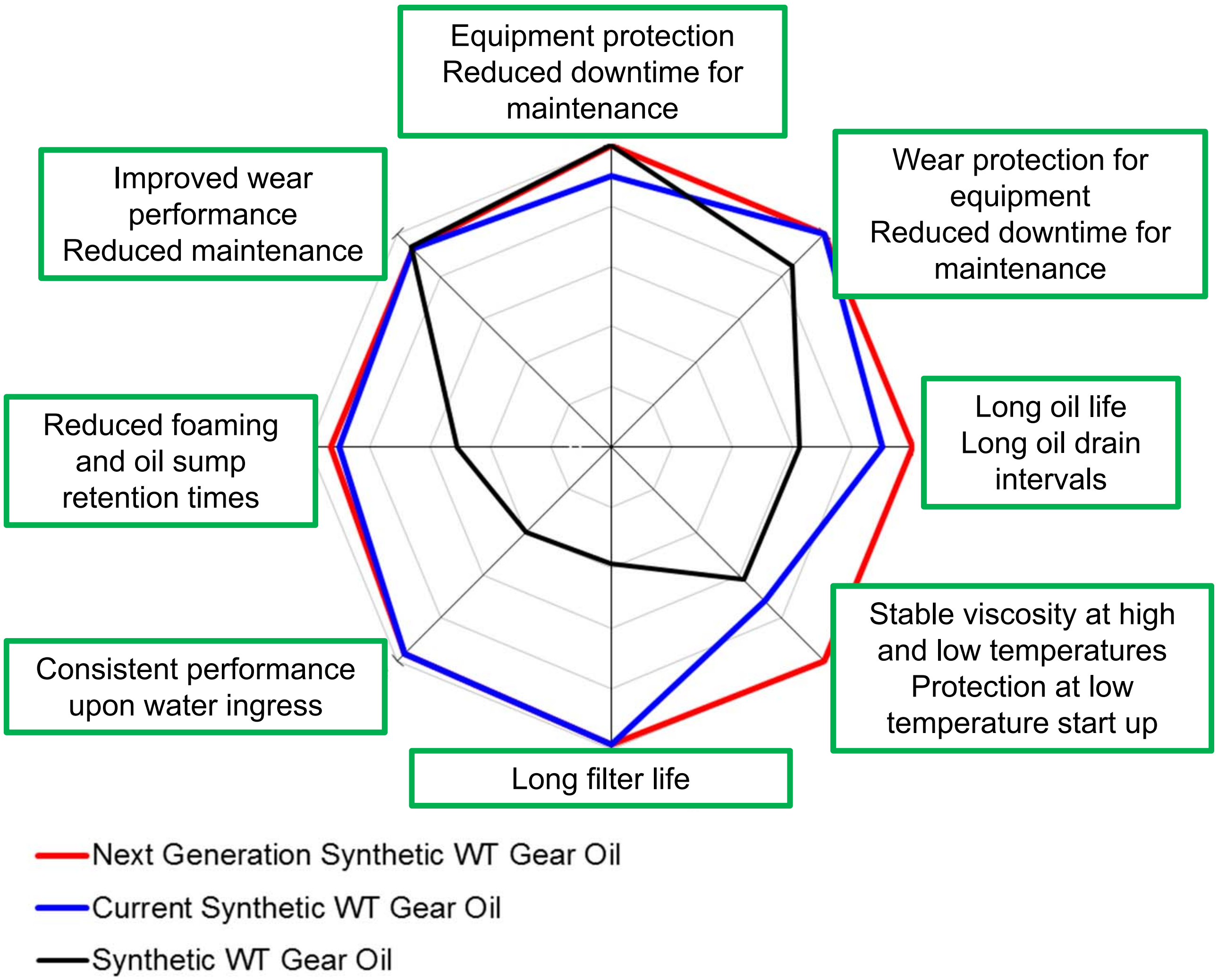


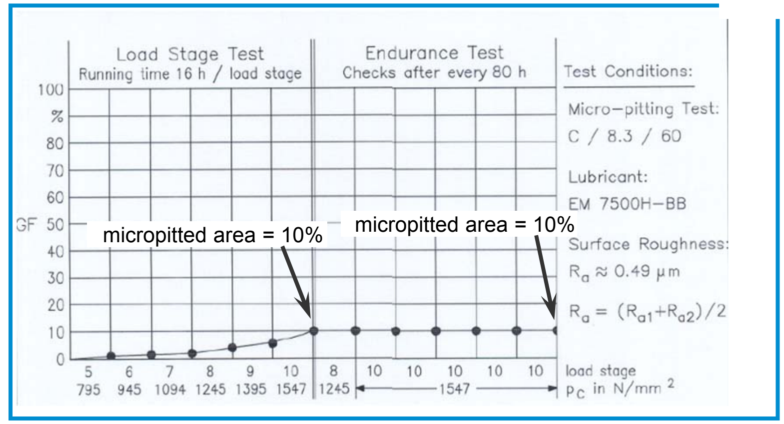
Balanced Formulation – Customer Value

Key Lubricant Formulation Parameter
Micropitting Protection Gear and Bearing Protection
Oxidative Stability Viscometrics Foam and Air Release
Filterability
Filterability Water Tolerance Rust and Corrosion Protection
Viscometrics Low Temp Performance

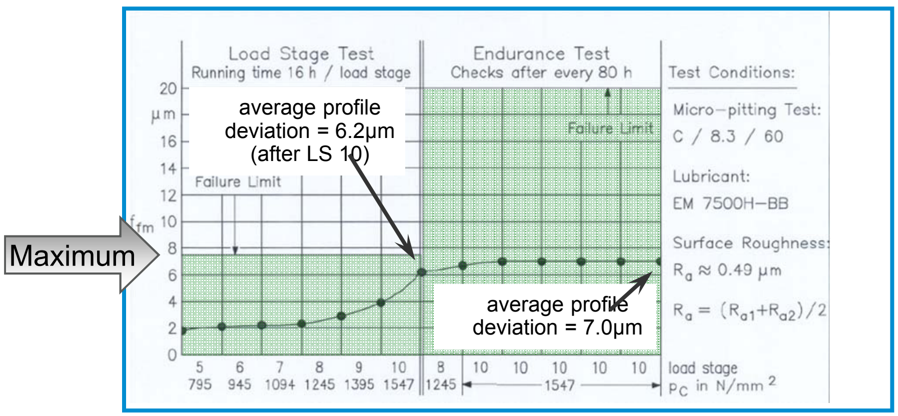


Micropitting Protection at 60°C

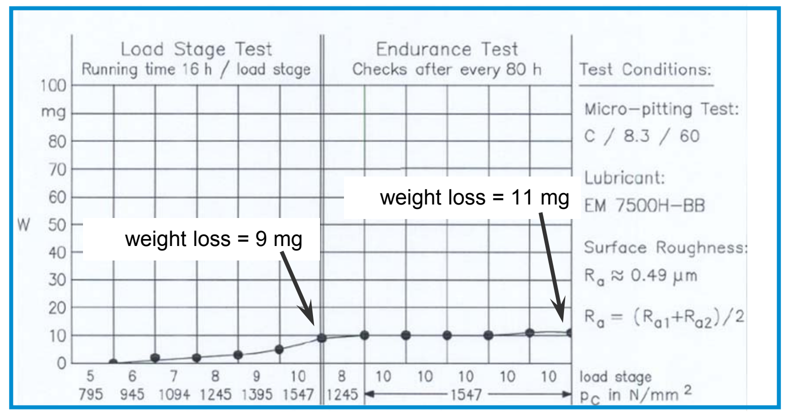
- FVA 54 Test at 60°C
  - Load Stage Result: > 10
  - Endurance Test Result: GFT=high



Micropitted area GF of the test pinion



Average profile deviation of the test pinion

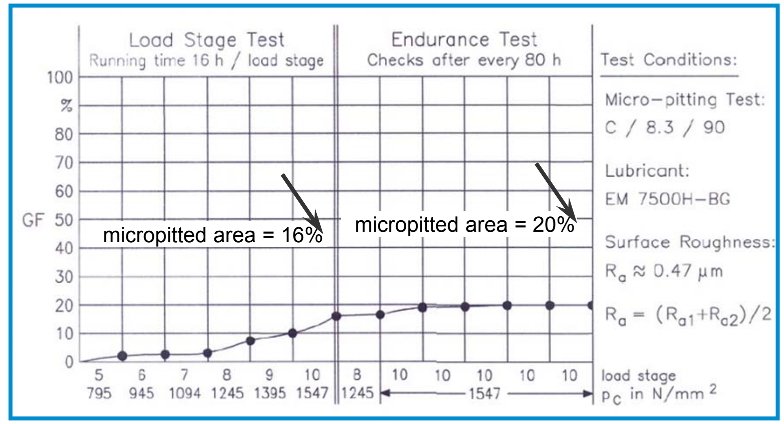


Weight loss of the test pinion

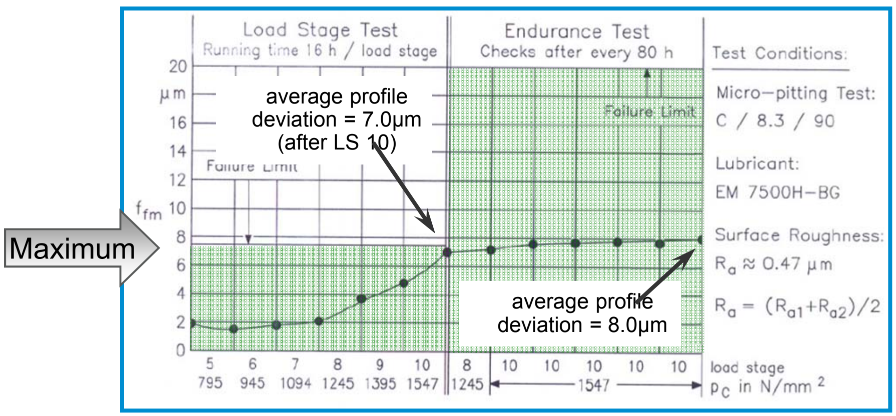
Lubricant should provide excellent resistance to formation of micropitting and retention of micropitting protection over time

Micropitting Protection at 90°C

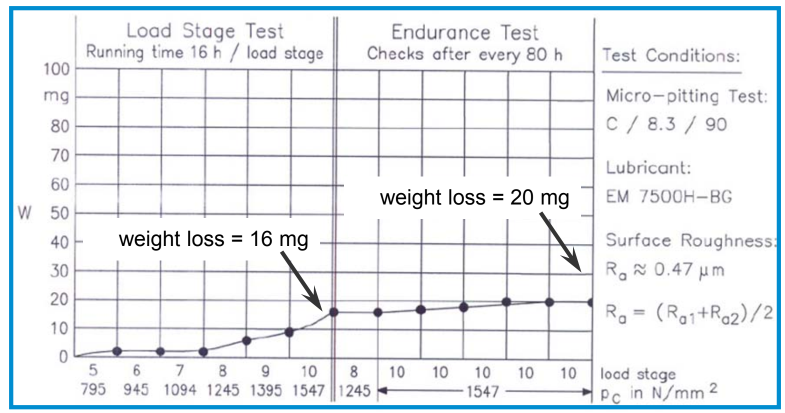
- FVA 54 Test at 90°C
  - Load Stage Result: > 10
  - Endurance Test Result: GFT=high



Micropitted area GF of the test pinion



Average profile deviation of the test pinion



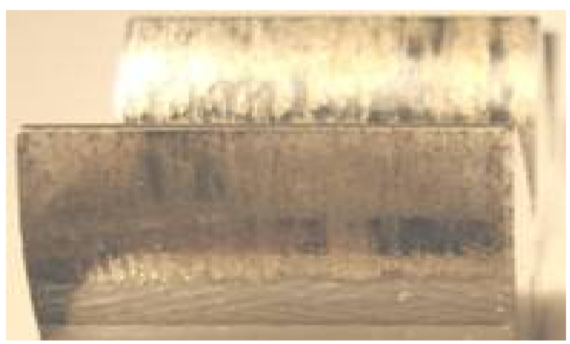
Weight loss of the test pinion

Lubricant should provide excellent resistance to formation of micropitting and retention of micropitting protection over time

Gear Scuffing Protection

- Gear protection from wear and scuffing is critical to long equipment life
-
- Gear Protection performance was evaluated based on the results of
  - FZG Scuffing Test (ISO 14635-1 mod)
    - Measures scuffing resistance and anti-wear performance under increasing loads using a standardized gear set. Modified from standard method to exceed load stage 12.
    - Single speed: A / 8.3 / 90 — FLS >14
    - Double speed: A / 16.6 / 90 — FLS >14

Example of scuffing on gear tested in FZG test stand



Gear and Bearing Protection

- Gear and bearing protection from scuffing and wear are critical to long equipment life

- Evaluated based on the results of:
  - FZG Scuffing Test (ISO 14635-1 mod)
    - Measures scuffing resistance and anti-wear performance using a standardized gear set
    - Single speed: A / 8.3 / 90 Result: FLS >14
    - Double speed: A / 16.6 / 90 Result: FLS >14

  - FAG FE8 4-Stage Test for Wind Turbine Gear Oils
    - Measures lubricant performance in a bearing under varying load, speed, and temperature conditions.
      - Result: 1.0 (Scale = 1 to 5, 1 being highest)

Bearing Protection: FAG 4-Stage Test

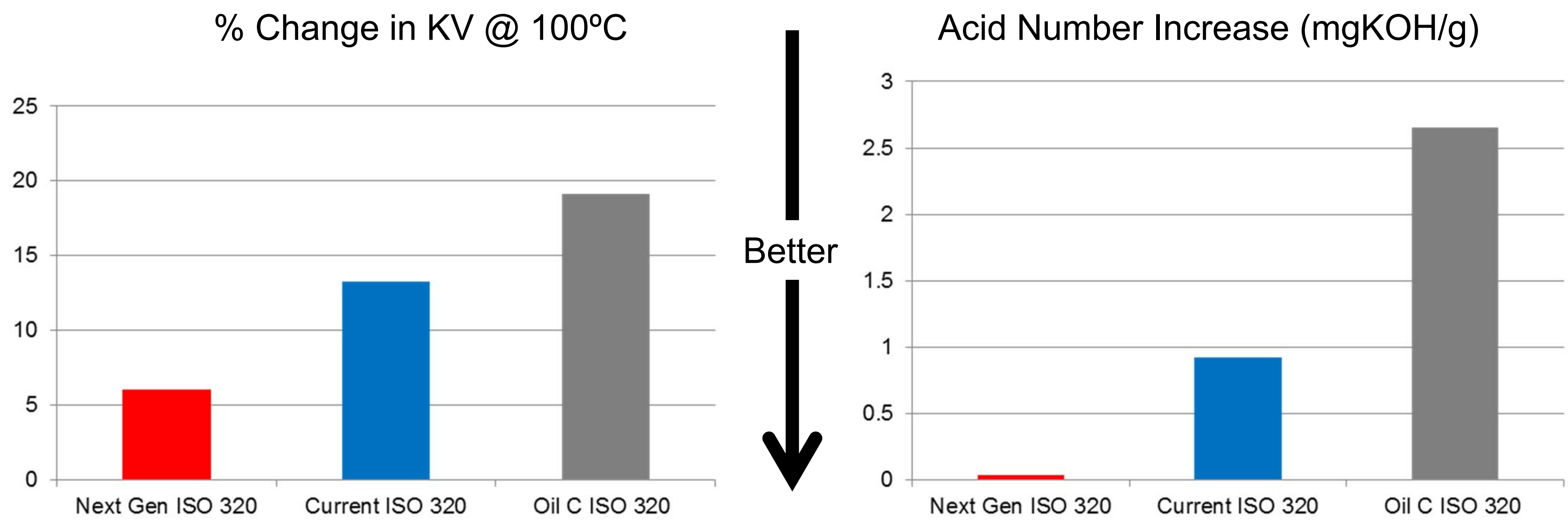
	criterion	test	result	
Stage 1*	wear at boundary lubrication	FE8-80h	1,0	passed
Stage 2	fatigue beh. at mixed friction cond.	FE8-800h	1,0	passed
Stage 3**	fatigue behaviour at EHL-cond.	L11-700h	1,0	passed
Stage 4	fatigue behaviour and residues with water added	FE8-WKA	1,0	passed
		Summary	1,0	passed

Stage	Test Parameter	Friction Regime	Bearing Type	Test Conditions
1	Wear	High Load / Low Speed (Extreme Mixed Friction)	FE8 Cylindrical Roller Thrust Bearing	100 kN 7.5 rpm 80°C, 80 h
2	Fatigue	Moderate Mixed Friction	FE8 Cylindrical Roller Thrust Bearing	90 kN 75 rpm 70°C, 800 h
3	Fatigue	EHL	L11 Ten Deep Groove Ball Bearing	8.5 kN 9000 rpm 85°C, 700 h
4	Deposit Formation	Mixed	FE8 Cylindrical Roller Thrust Bearing	60 kN 750 rpm 100°C, 600 h

Excellent performance in this test ensures robust bearing protection up tower, leading to improved equipment reliability and reduced downtime for maintenance

Oxidative Stability

- Evaluated based on results of:
  - US Steel Oxidation Test (ASTM D2893*: 150°C, 312 h)
    - Test oil is heated to specified temperature in the presence of air.

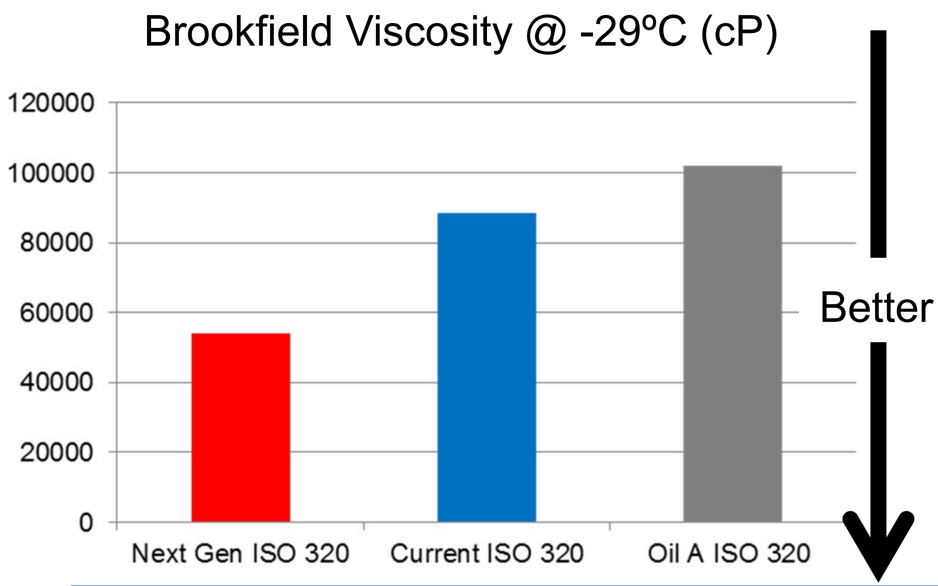


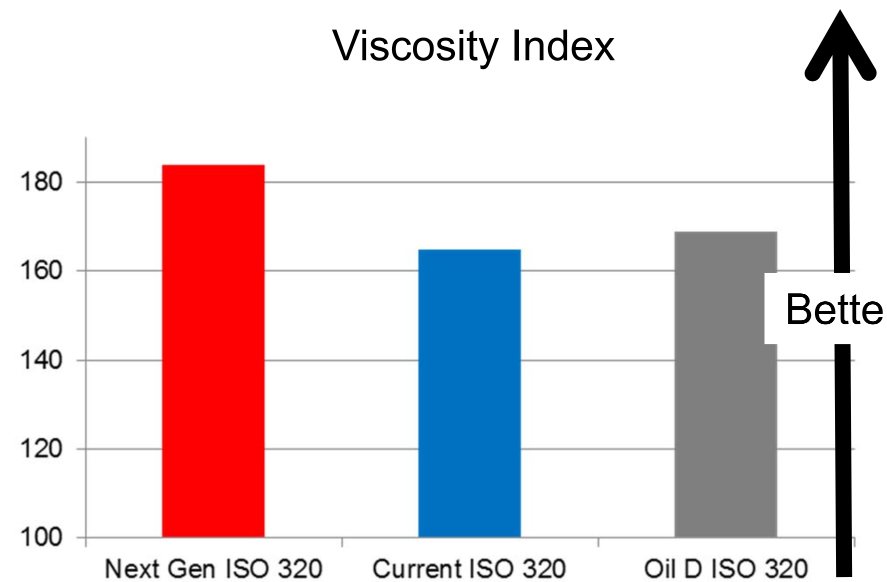
Oxidative stability is a key factor in achieving extended oil life and oil drain intervals

** ASTM D2893 Modified in accordance with ISO 12925-1:1996 CKT specification*

Viscometrics & Low Temp Properties

- Evaluated based on results of:
  - Viscosity Index (ASTM D2270)
  - Brookfield Viscosity (ASTM D2983)
    - Measures the apparent viscosity of oils at low temperatures
  - Pour Point (ASTM D 5950)
    - Lowest temperature at which sample moves when container is tilted

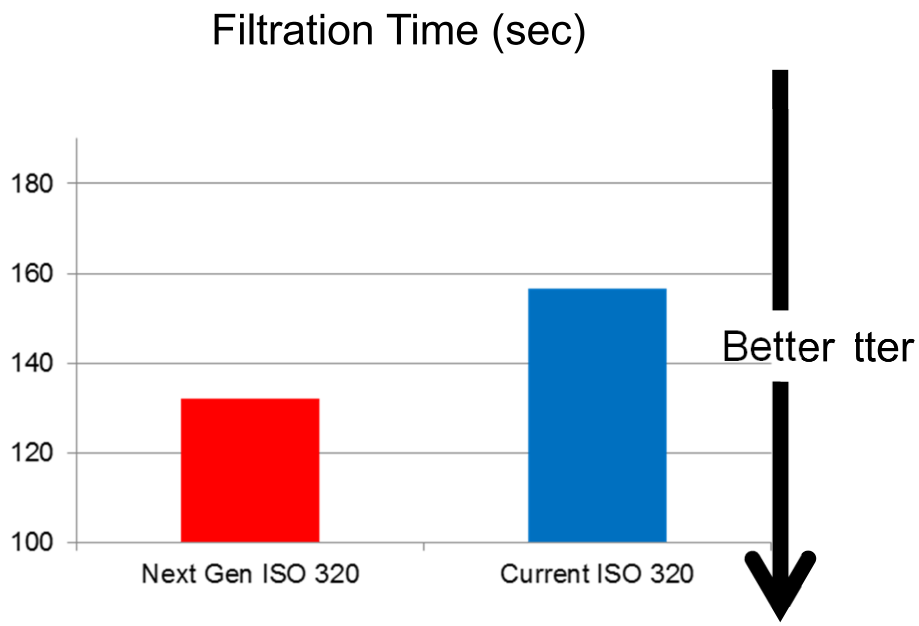


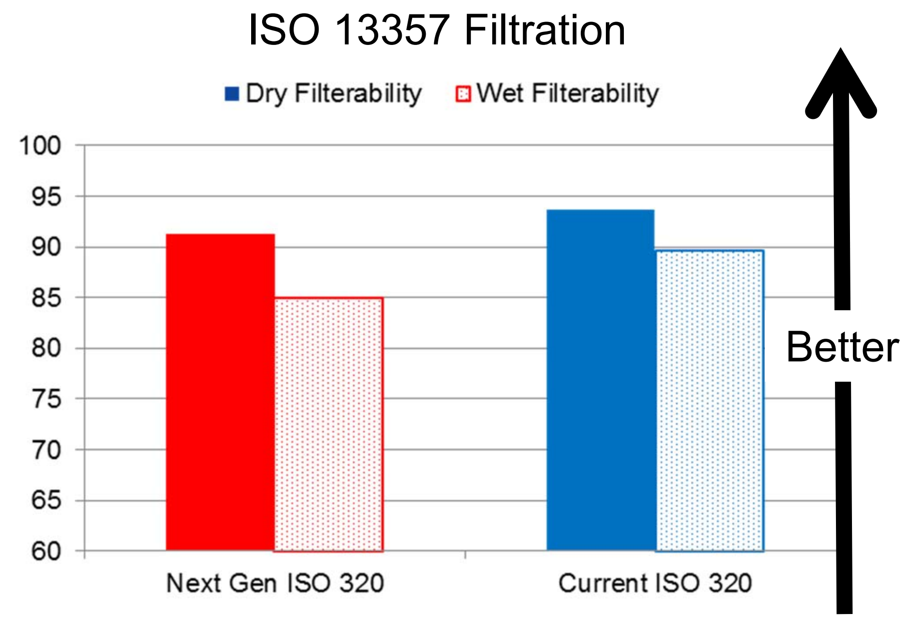


Excellent low temperature properties protects equipment start up in extreme conditions
Stable viscosity enables long oil life and equipment protection at high and low temperatures

Filterability

- Evaluated based on results of:
  - Dry and Wet Filterability (ISO 13557)
  - Internal filtration method

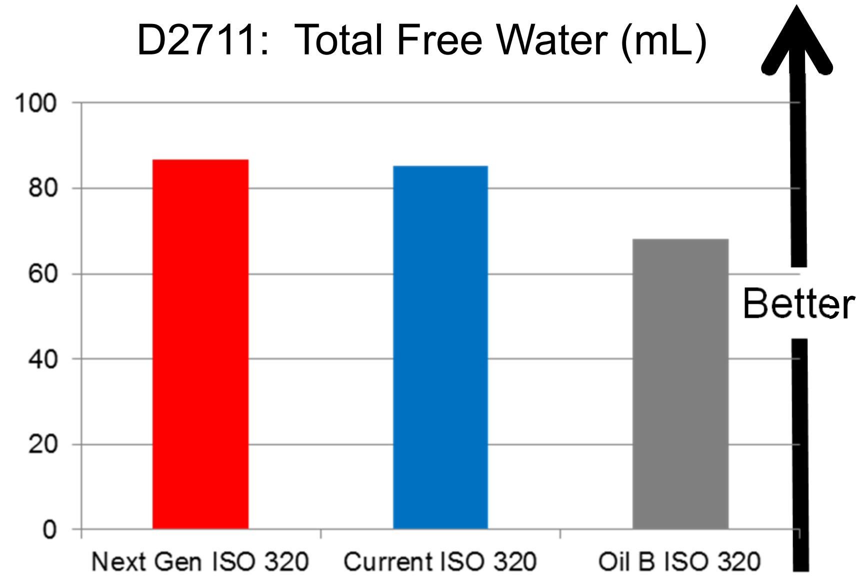




Maintaining filterability even in the presence of water is critical in applications where water contamination may occur

Water Tolerance

- Water tolerance is an important performance characteristic of a wind turbine gear oil, due to the operating environment
- Evaluated based on results of:
  - Demulsibility (ASTM D1401)
    - Measures the ability of the oil to rapidly shed water
  - Demulsibility of EP Gear Oils (ASTM D2711)
  - ISO 13357- modified (wet filterability)



Poor water tolerance could lead to lubrication failure due to emulsion formation or oil breakdown under wet conditions

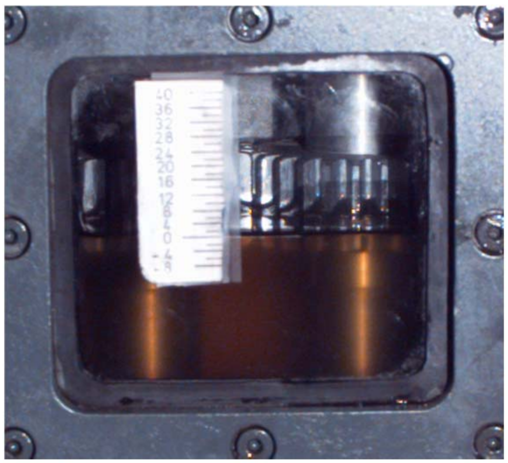
Foam and Air Release

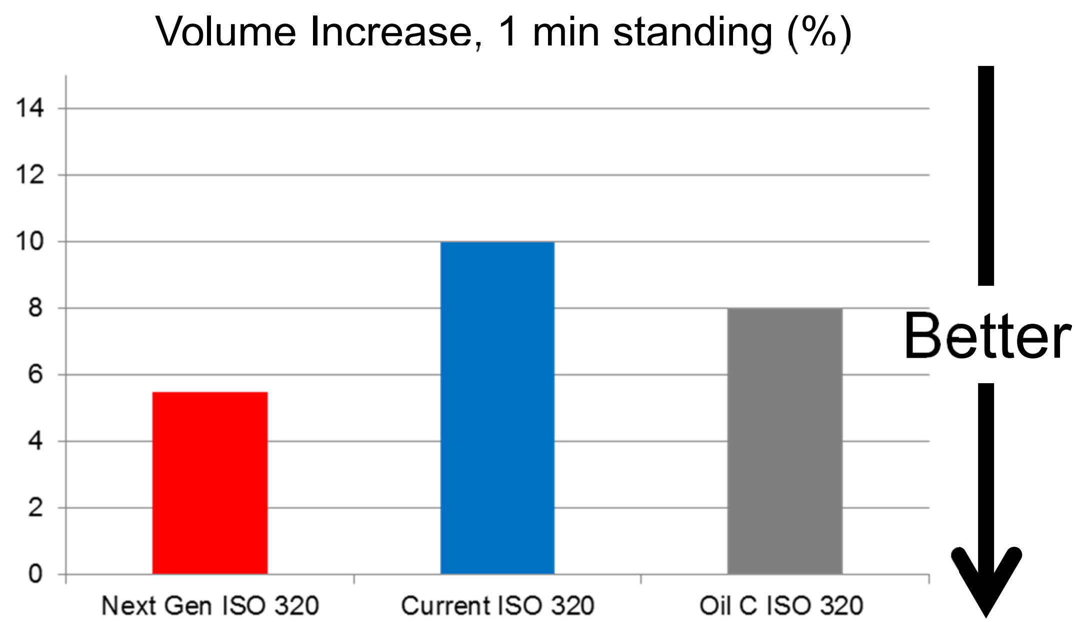
- Release of air from the bulk oil (air release) and from the oil / air interface (foam) are critical to wind turbine gear oil
- Foam and air release characteristics were evaluated based on
  - Air Release Properties (ASTM D3247
  - Foaming Characteristics (ASTM D892 I, II, and III)
  - Flender Foam Test (ISO 12152)
    - Assesses air release and foam performance after air is churned into the test oil using high-speed gearbox (~1500rpm) test apparatus

Excessive entrained air in oil prevents proper lubrication and can lead to cavitation in pumps
Poor foam performance could lead to oil leakage from seals

Foam and Air Release

- Flender Foam Test:
  - Volume increase due to entrained air and foam is recorded after 1 minute standing (Pass < 15 %)





Foam Performance In-Service

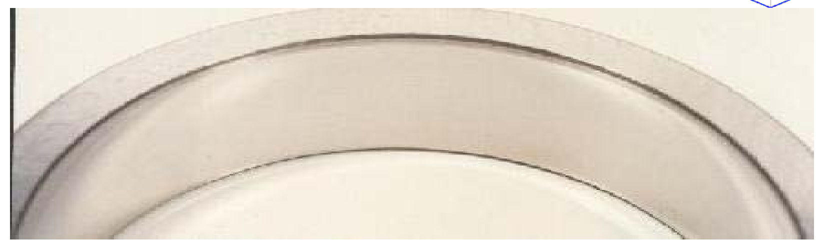
Next Gen ISO 320

Current ISO 320

Excessive entrained air in oil prevents proper lubrication and can lead to cavitation in pumps
Poor foam performance could lead to oil leakage from seals

Rust & Corrosion Performance

- Evaluated based on results of:
  - Copper Corrosion (ASTM D130)
  - ASTM Rust Test (D665)
    - D665A – Distilled Water
    - D665B – Salt Water
    - D665Mod – Syn Sea Water
  - SKF Emcor Bearing Rust Test
    - Distilled Water
      - Result: 0,0
    - 0.5% NaCl
      - Result: 1,1



0 rating – best

5 rating – unacceptable

Oils with poor rust and corrosion performance may not be able to adequately protect steel from rust or yellow metals from corrosion

Future Trends / Lubrication Considerations

Common Industry Trends

- Seals and Fill-for-Life
- Oil filtration
- Test selection for used oils
- Vibration sensor technology
- Failure Modes:
  - White Etching Cracking

White Etching Cracking

- Subsurface damage
  - Occurs without warning
  - Results in component failure with costly repair
- Critical factors
  - Lubrication variables
  - Tribological contact
  - Subsurface conditions
- Working toward improved capability for future prediction and prevention

Summary

- Gear box design and wind turbine application require specific demands from gear oil lubricant
- Capability of a lubricant to meet the required demands depends on formulation approach
- Understanding key focus parameters and appropriate test methods improves gear oil performance in the real world
- Understanding impact of failure modes and the lubricant’s role in prevention will continue to enable the next generation of wind turbine lubricants

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Questions?

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