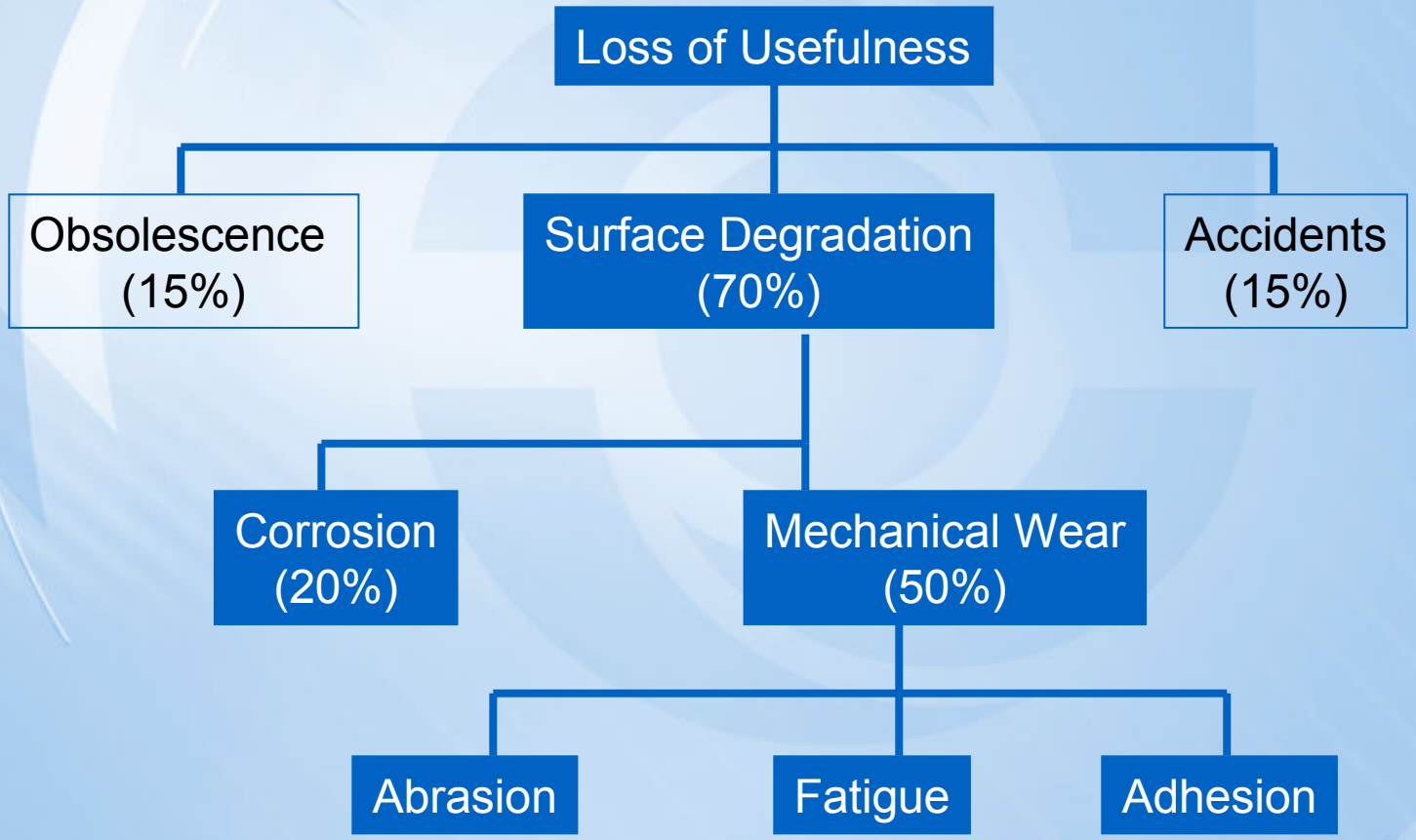
Contamination Control For Wind Turbines

ASME Graduate Student Workshop October 2009

Bill Needelman
Chief Science Advisor
Donaldson Company, Inc

Study by Professor E. Rabinowicz, MIT

"Six to seven percent of the Gross National Product is required just to repair the damage caused by mechanical wear."
Note: Currently ~$1 trillion



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Wind Turbine Reliability & Performance

- 25 % of Cost of Ownership of Wind Turbines is Maintenance
- Reliability Problems

  Gearbox > Blades > Generators
- 80% Of Operating Problems Due to GBX

  Mostly Gearbox Repair & Replacement
- Bearings are #1 Cause of Gearbox Failures
- Most Gearbox Warrantees ~2 Years,

  Costly Repairs Start ~4th Year
- 90% Anticipated Energy Production

  5% GBX, 3% Wind, 2% All Others

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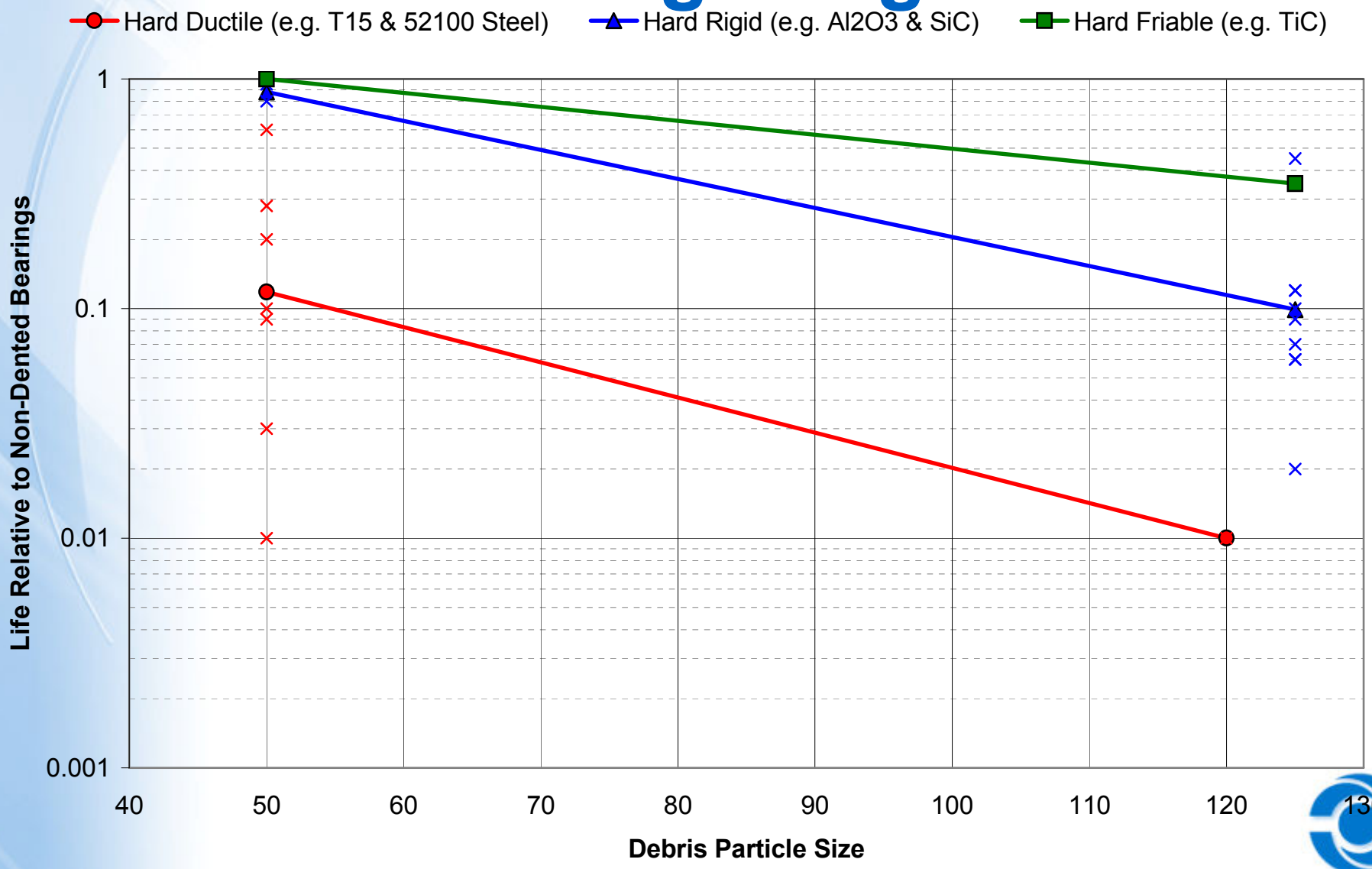
Hard Particle Damage
Bearing Fatigue



Ref: Kotzalas & Needelman, AWEA Wind Power Conf, 2008

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National Renewable Energy Laboratory
Innovation for Our Energy Future

Wind Turbine Gearbox Issues and Lubrication:

"If it Ain't Clean it's F!#@ed!"

ASME Conference on Lubrication and Gearing

October 22, 2008

Sandy Butterfield
Chief Engineer
National Wind Technology Center
National Renewable Energy Laboratory
Bob Errichello: GEARTECH
Brian McNiff: McNiff Light Industry

Operated for the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy by Midwest Research Institute • Battelle

Outline

- Problems Caused by Oil Contamination
- Particle Filters
- Water Contamination Control
- Best Practices
- Benefits & Conclusions

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Types of Contaminants

Particles - Hard & Soft

Water

Air/Gases

Fuels, Acids, Glycols

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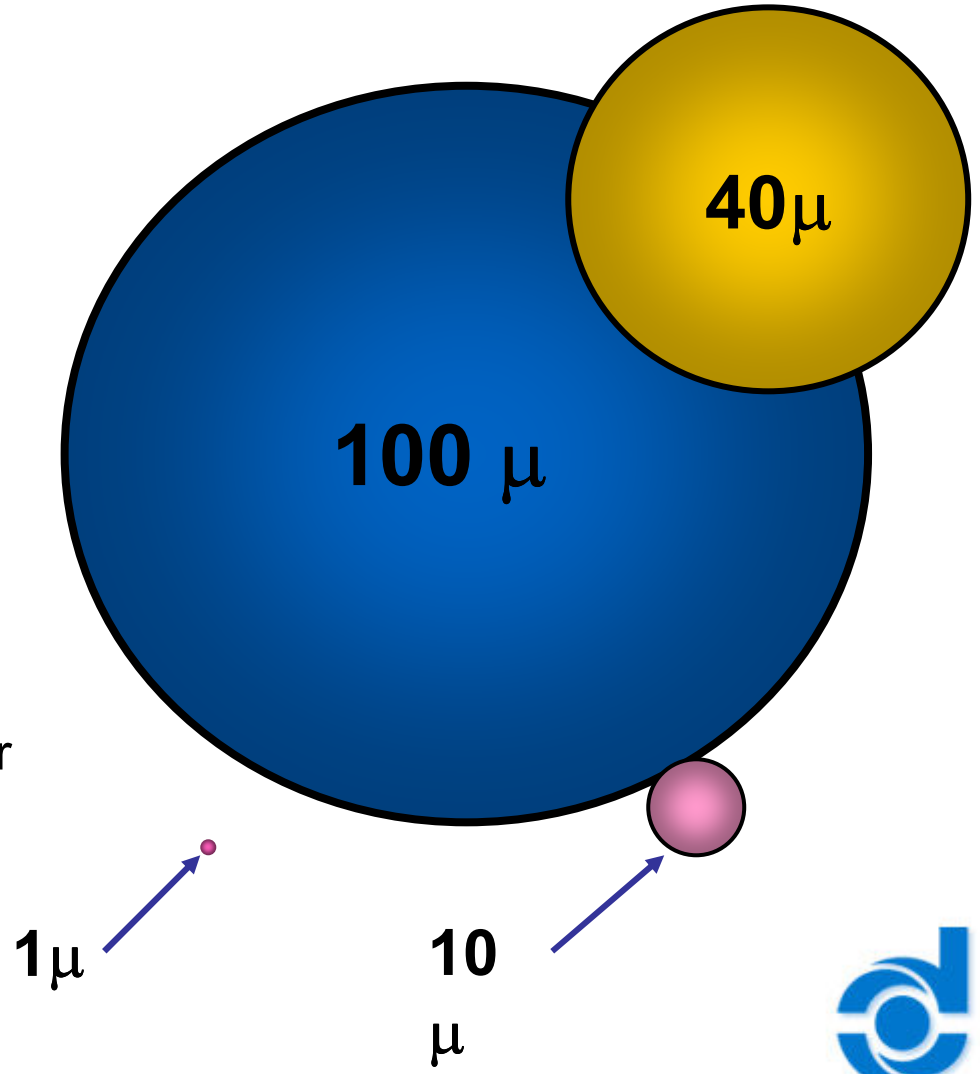
What is a MICRON ?

MICRON

Unit of Measurement
1 Millionth of a Meter (micrometer)
Or .000039"
μ = Micron Symbol

PARTICLE SIZE

100μ=Grain of table salt
70μ=Typical human hair diameter
40μ=Lower limit of visibility
10μ=Talcum powder
2μ=Bacteria



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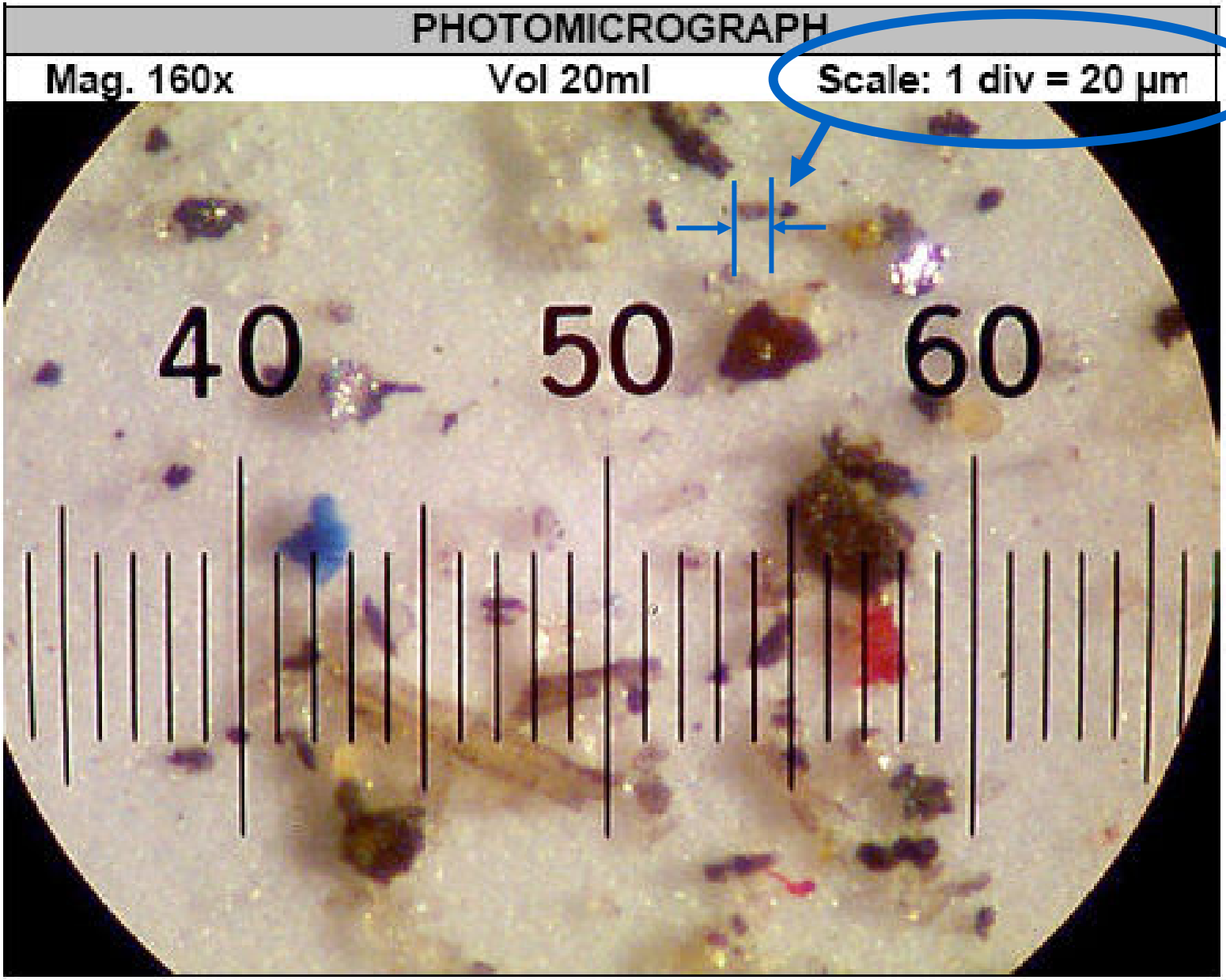
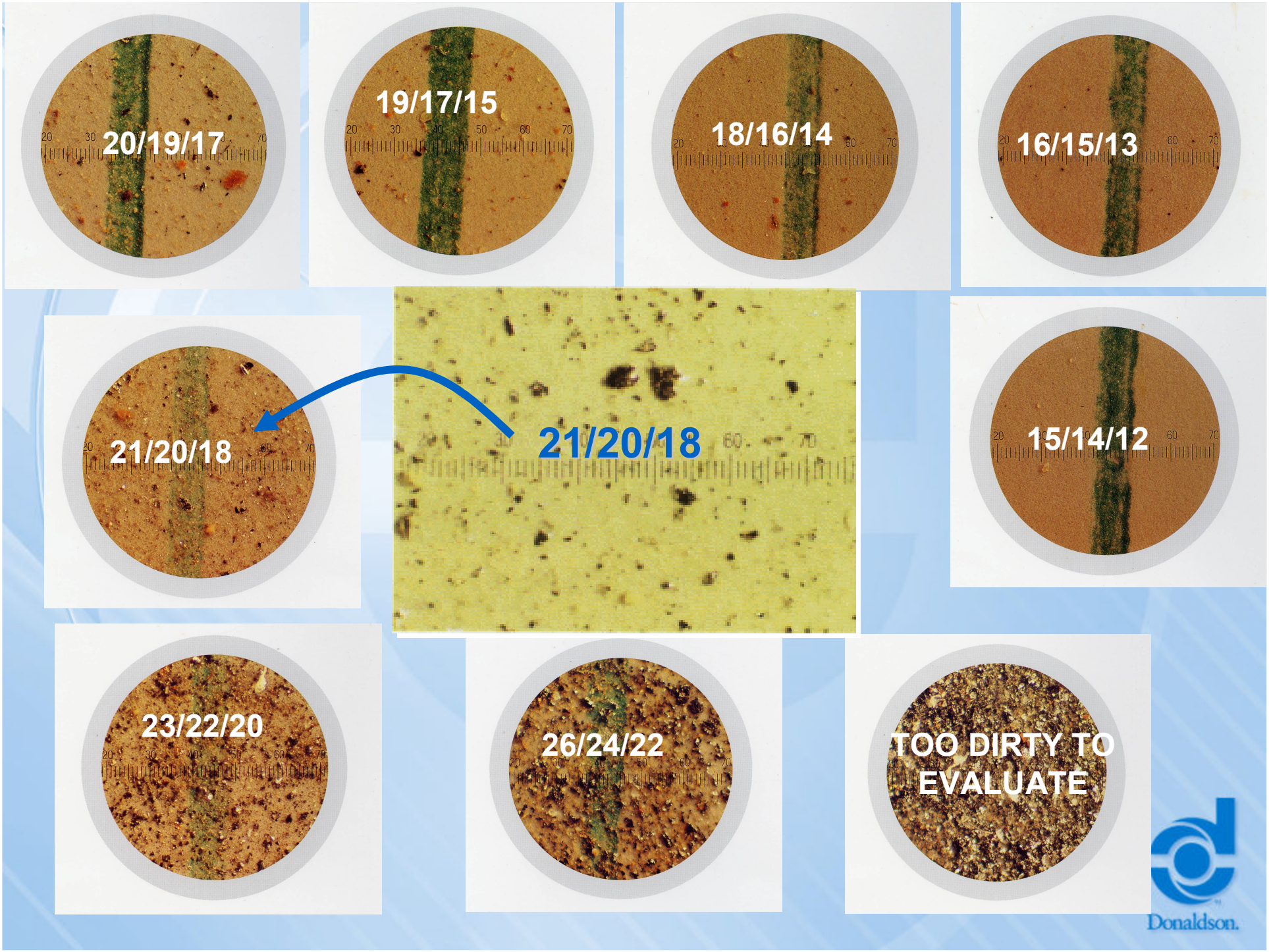
The Particle Zoo




20/19/17
19/17/15
18/16/14
16/15/13
21/20/18
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15/14/12
23/22/20
26/24/22
TOO DIRTY TO EVALUATE
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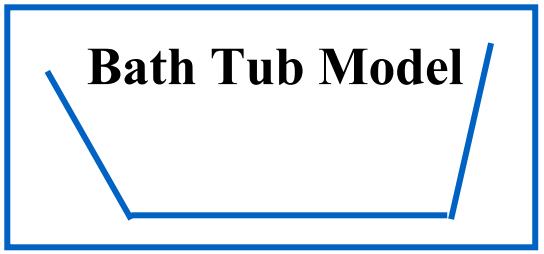
Major Types & Sources of Hard Particle Contaminants in Wind Turbines

- Hard Particles
  - Manufacturing Swarf
    - Machine Chips, Casting Sand, Debris, Abrasives
  - Internal Wear Debris
    - Gear Tooth Wear
  - Internal Corrosion Products
    - Rust, Aluminum Oxide
  - Environmental Grit
    - Airborne Mineral Dust, Sand

Grinding



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Hard Particle Problems

- **Rolling Contact Fatigue**
- **Abrasive Wear & Erosion**
- **Lubricant Oxidation**

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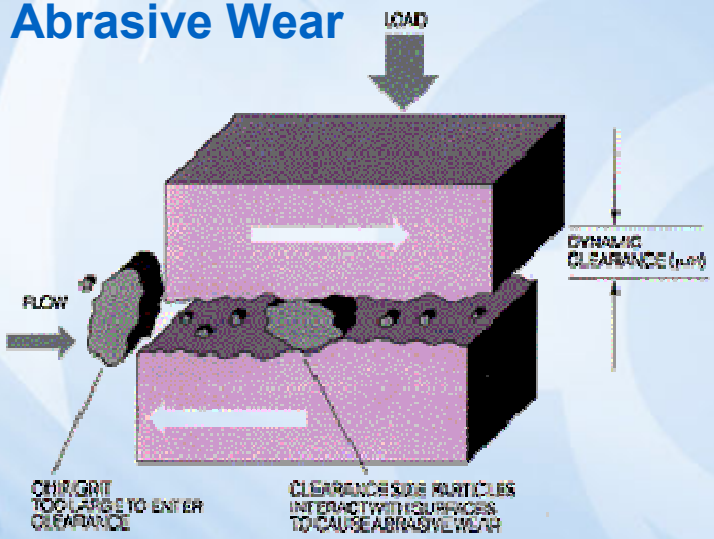
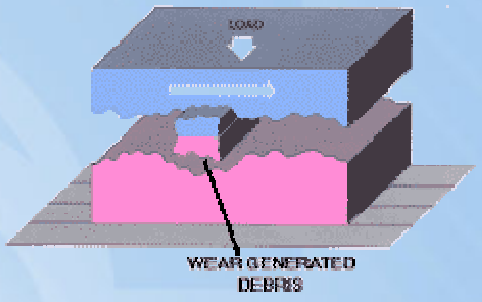
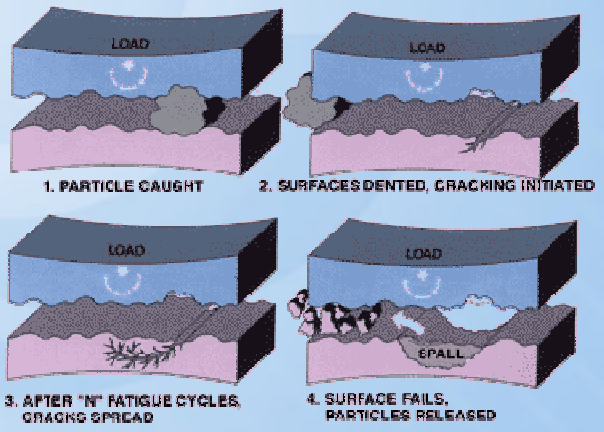
Mechanical Wear By Hard Particles

Abrasive Wear



Adhesive Wear





Rolling Contact Fatigue

All Three Forms of Wear Result in Loss of Clearance, Rough Surfaces, and Greater Friction

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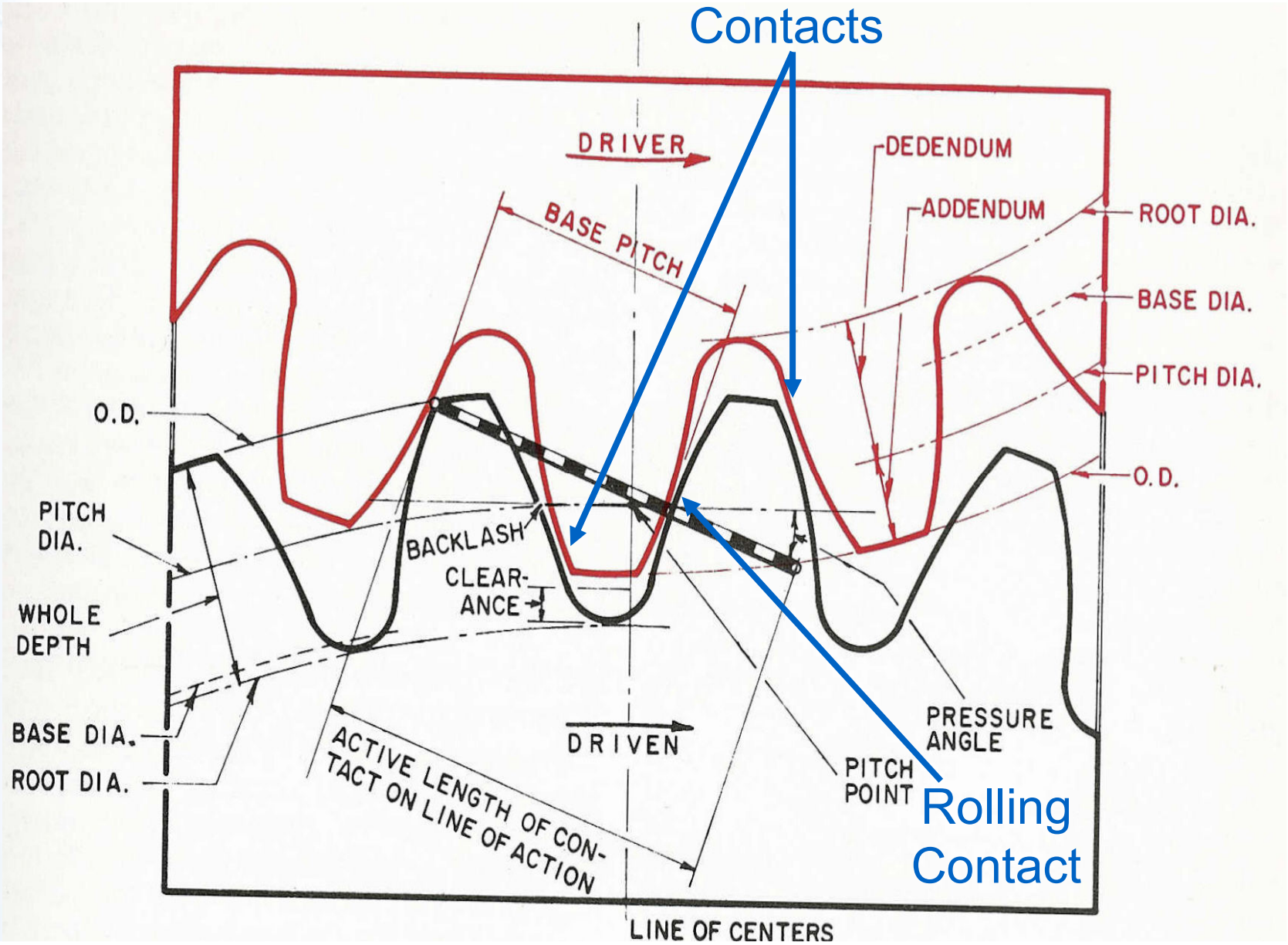
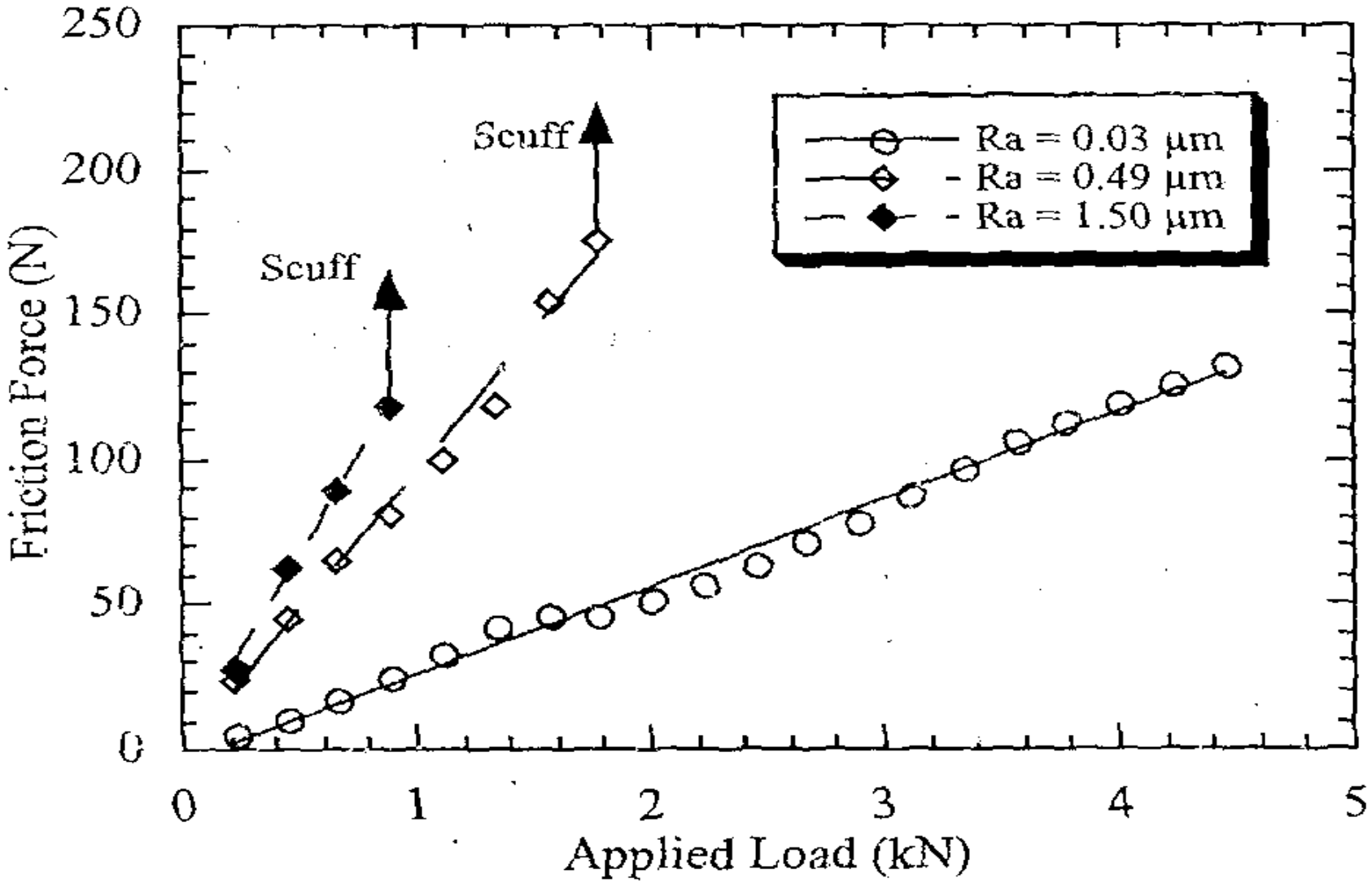
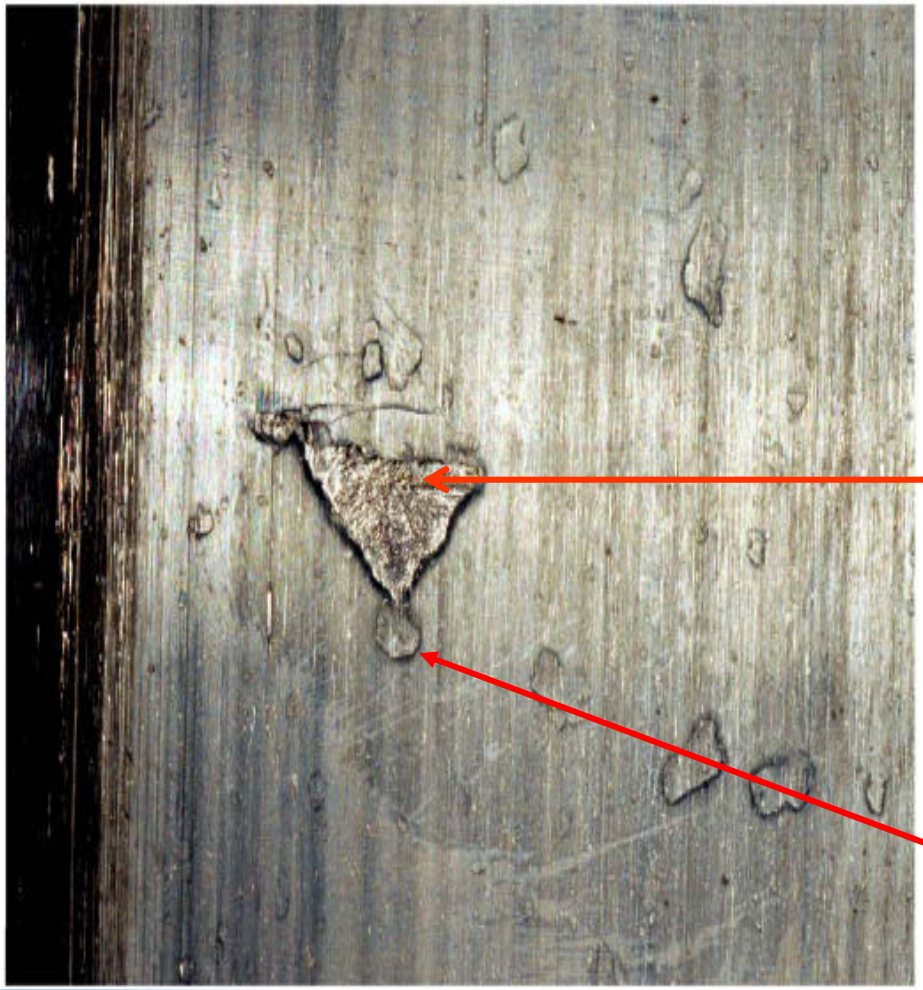
Gear Tooth Contacts



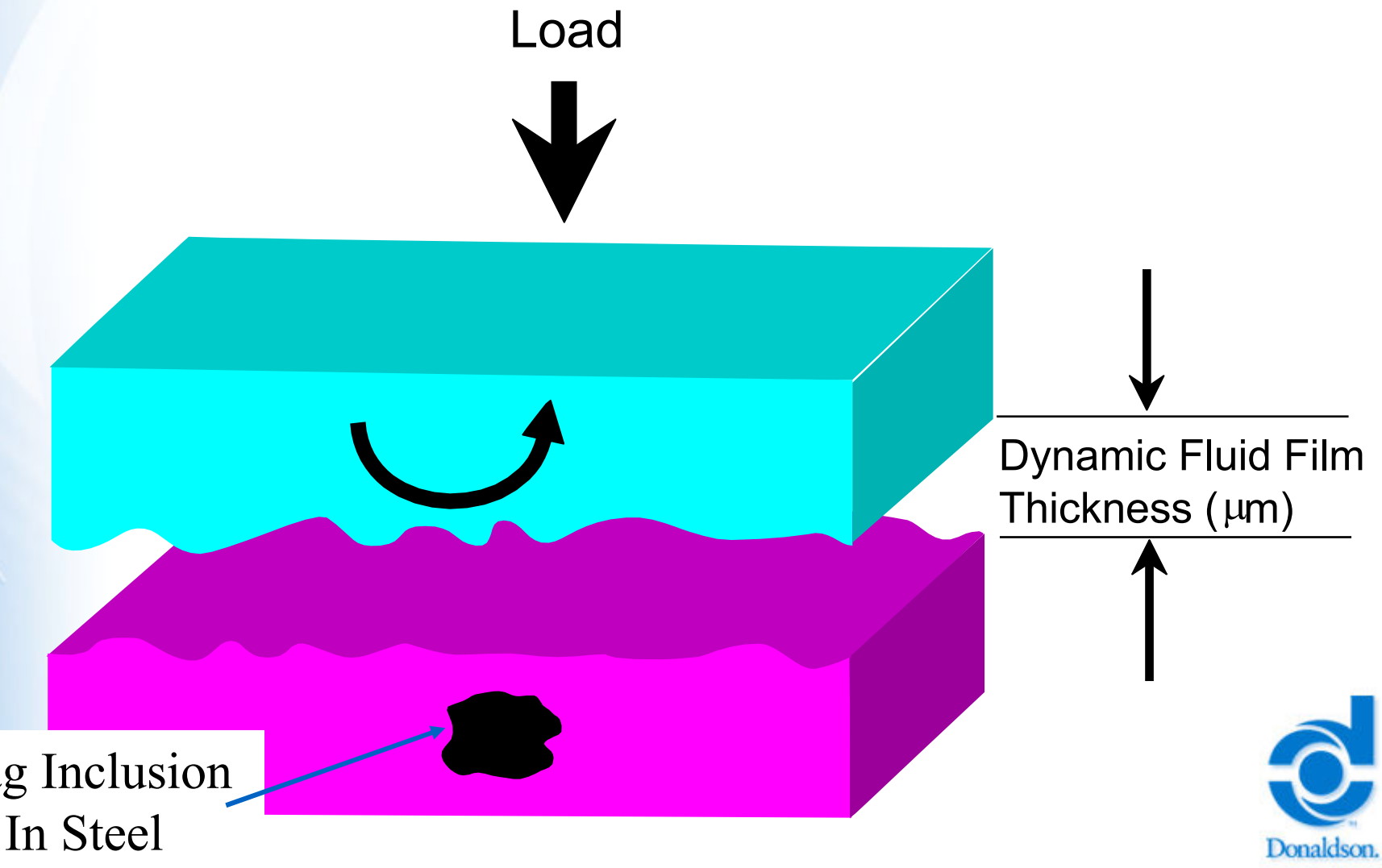
Gear Friction Increases As Gear Tooth Surface Roughens



Rolling Contact Fatigue: Surface Origin Spalls



Older Bearings Failed By Sub-surface Initiated Fatigue Spalling



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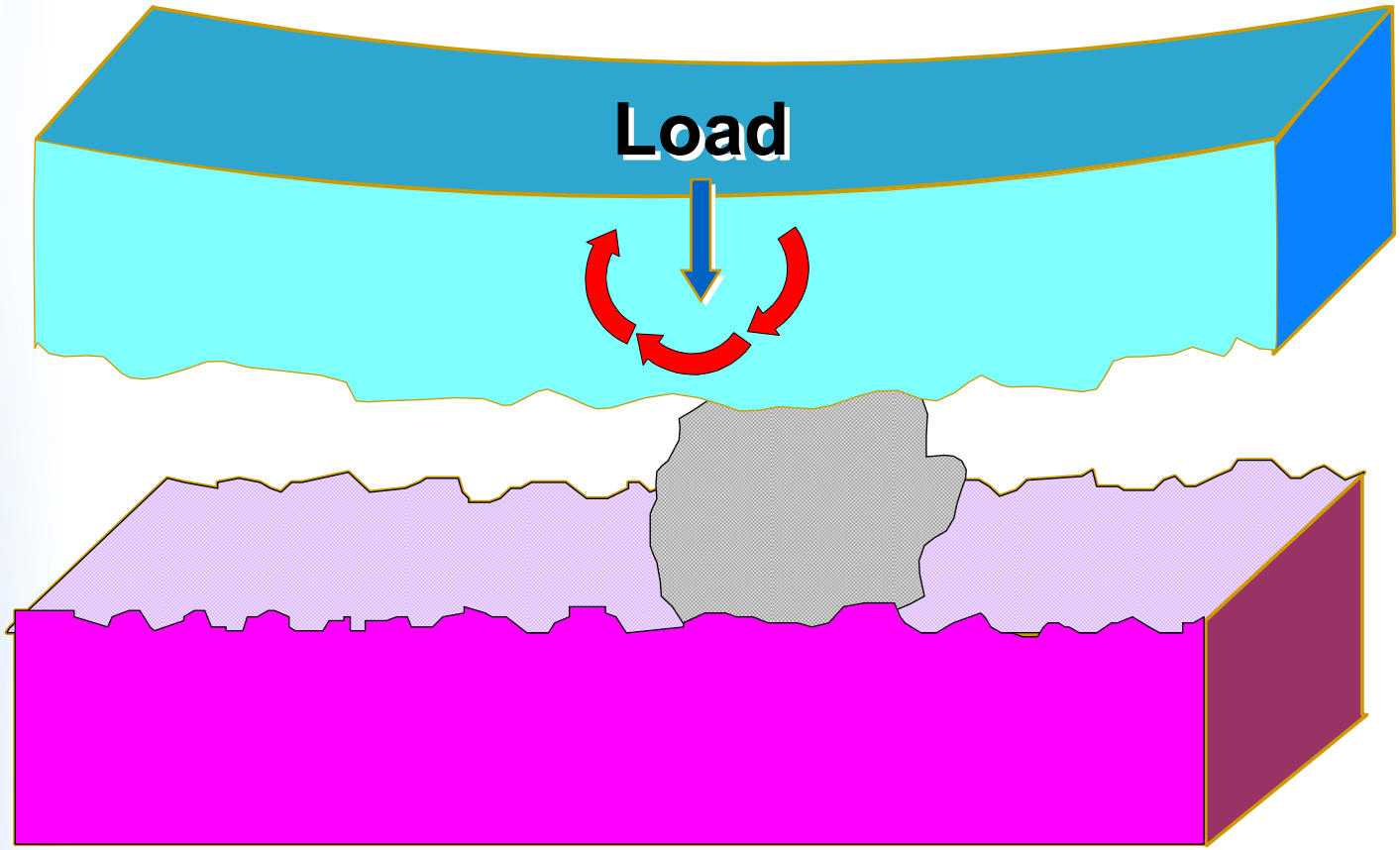
Particles & Surface Initiated Fatigue

Particle Caught



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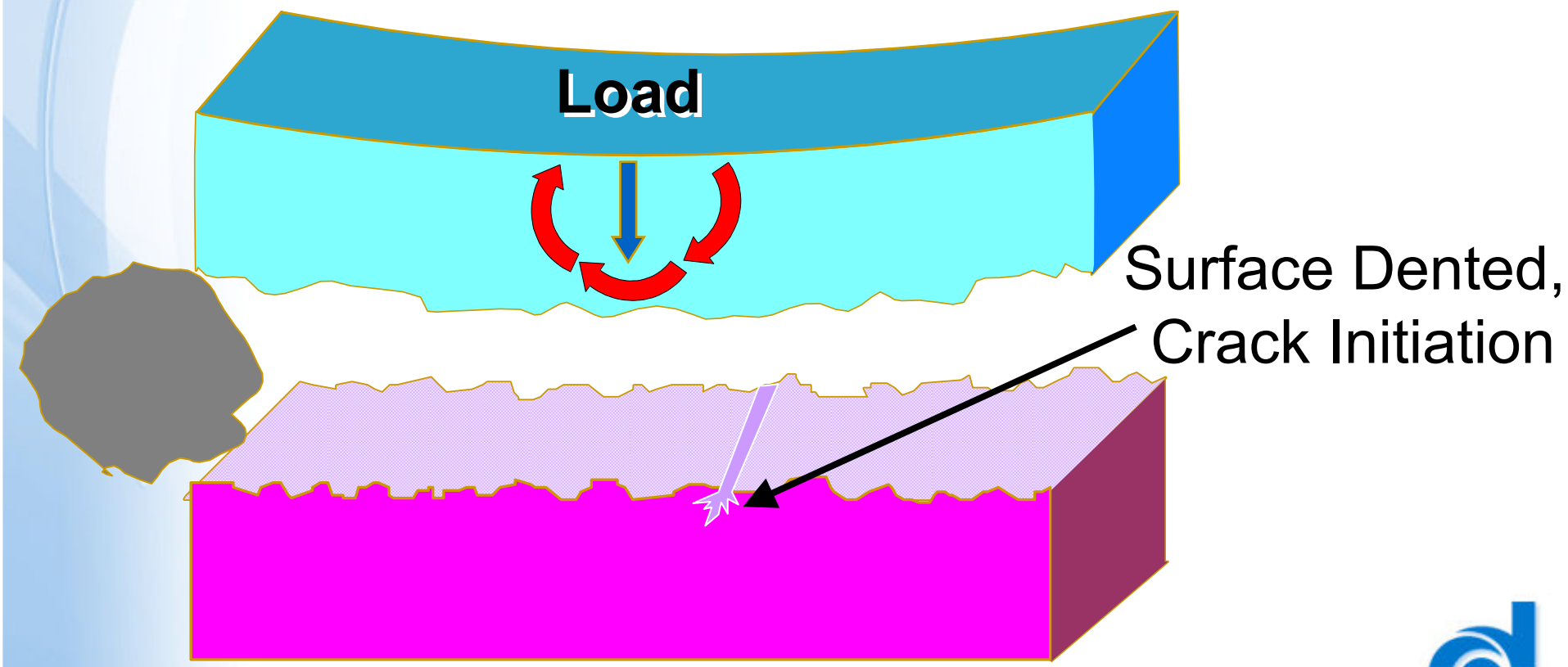
Particles & Surface Initiated Fatigue



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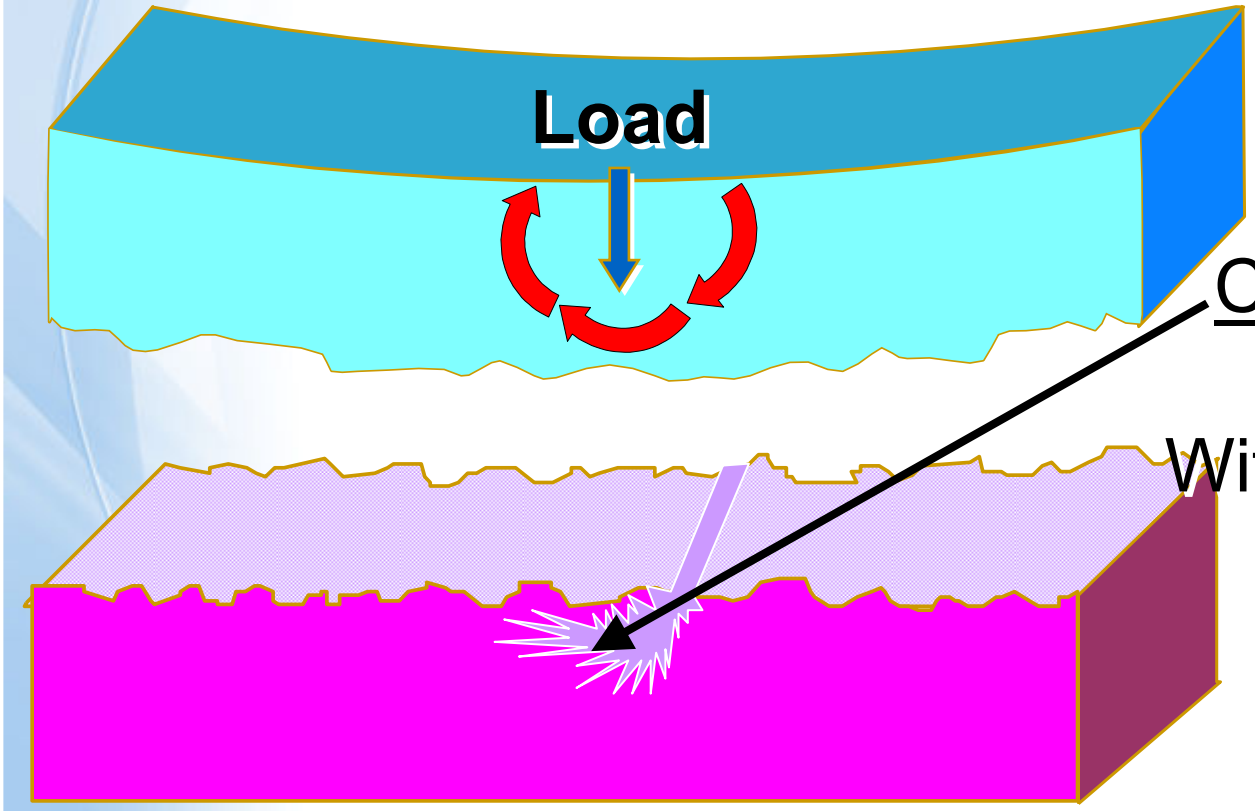
Particles & Surface Initiated Fatigue



Crack Propagation
Cracks Spread
With Repeated Cycles

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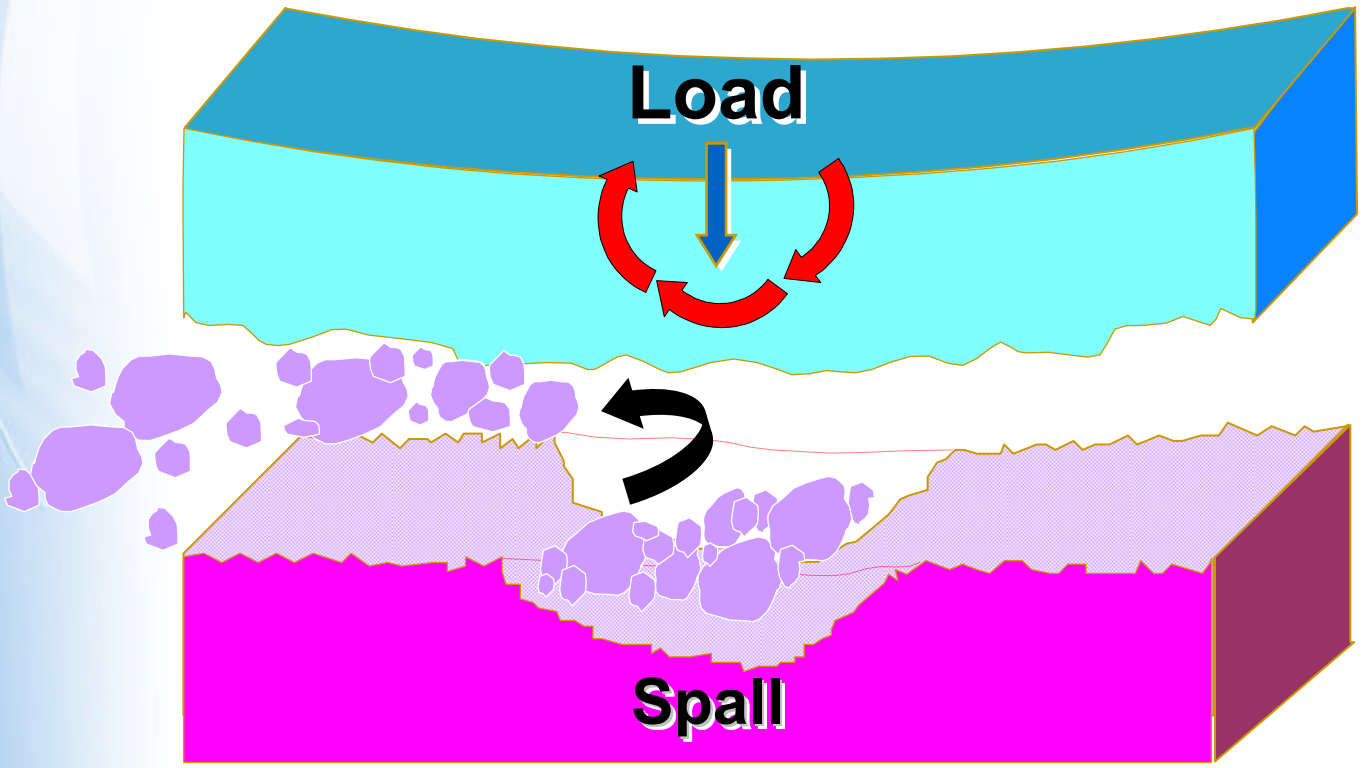
Particles & Surface Initiated Fatigue

Fatigue Spall Crater Forms
Hard Particles Released



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The Challenge

Cleaner Gear Oil
Drier Gear Oil
Same For Hydraulic Fluids

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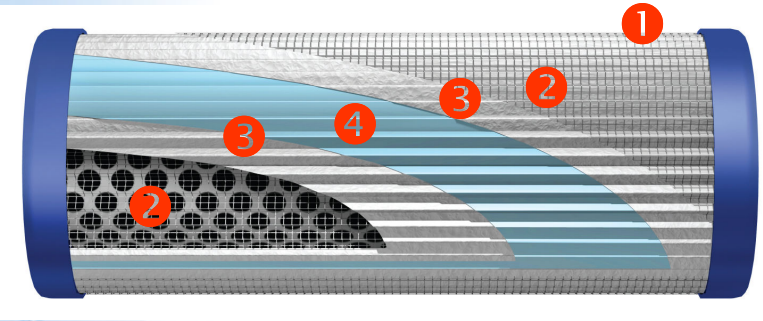
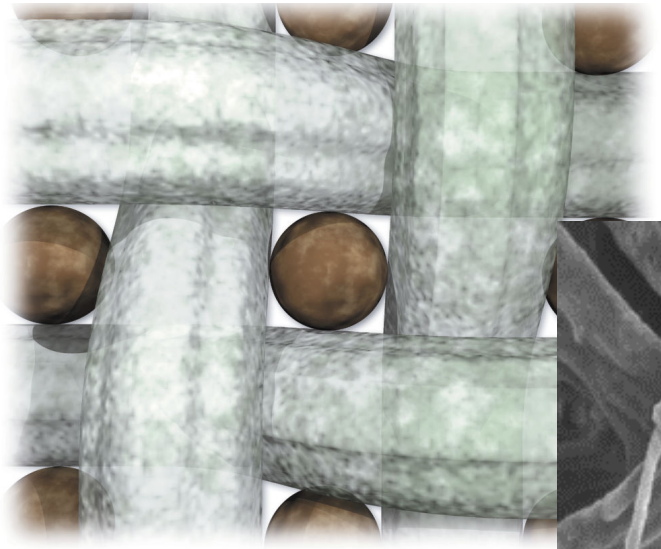


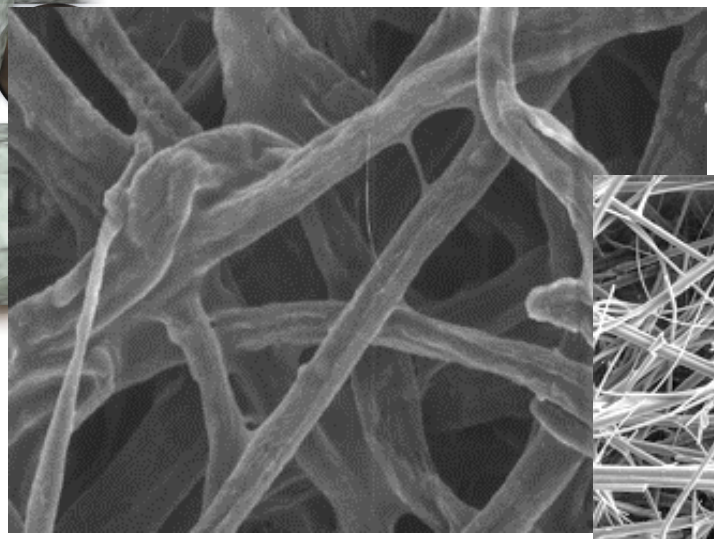
Element Design

	DT Steel Std Collapse	High Collapse	DT Steel Coreless
1 **Outer Wrap**	n/a	n/a	n/a
2 **Support Mesh (2)**	epoxy coated steel for support and spacing	stainless steel for support and spacing	epoxy coated steel for support and spacing
3 **Flow Control Layers (2)**	synthetic layers to strengthen media	synthetic layers to strengthen media	synthetic layers to strengthen media
4 **Synteq® Media**	thin glass-fiber media for performance	thin glass-fiber media for performance	thin glass-fiber media for performance

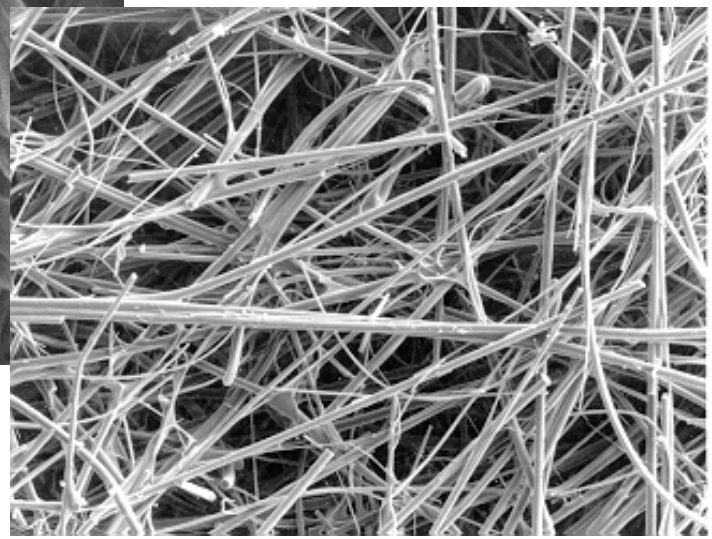
Filter Media Types



- Wire Mesh



- Cellulose



- Synthetic (Glass Fiber)

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Pressure Loss Across A Filter Element (ΔP)

Pressure Loss $\propto$ Flow Rate

X Viscosity

X Tortuosity

Gear Oil Oils: High Viscosity

Gear Boxes: Moderate Flow Rates

Fine Filters: High Tortuosity

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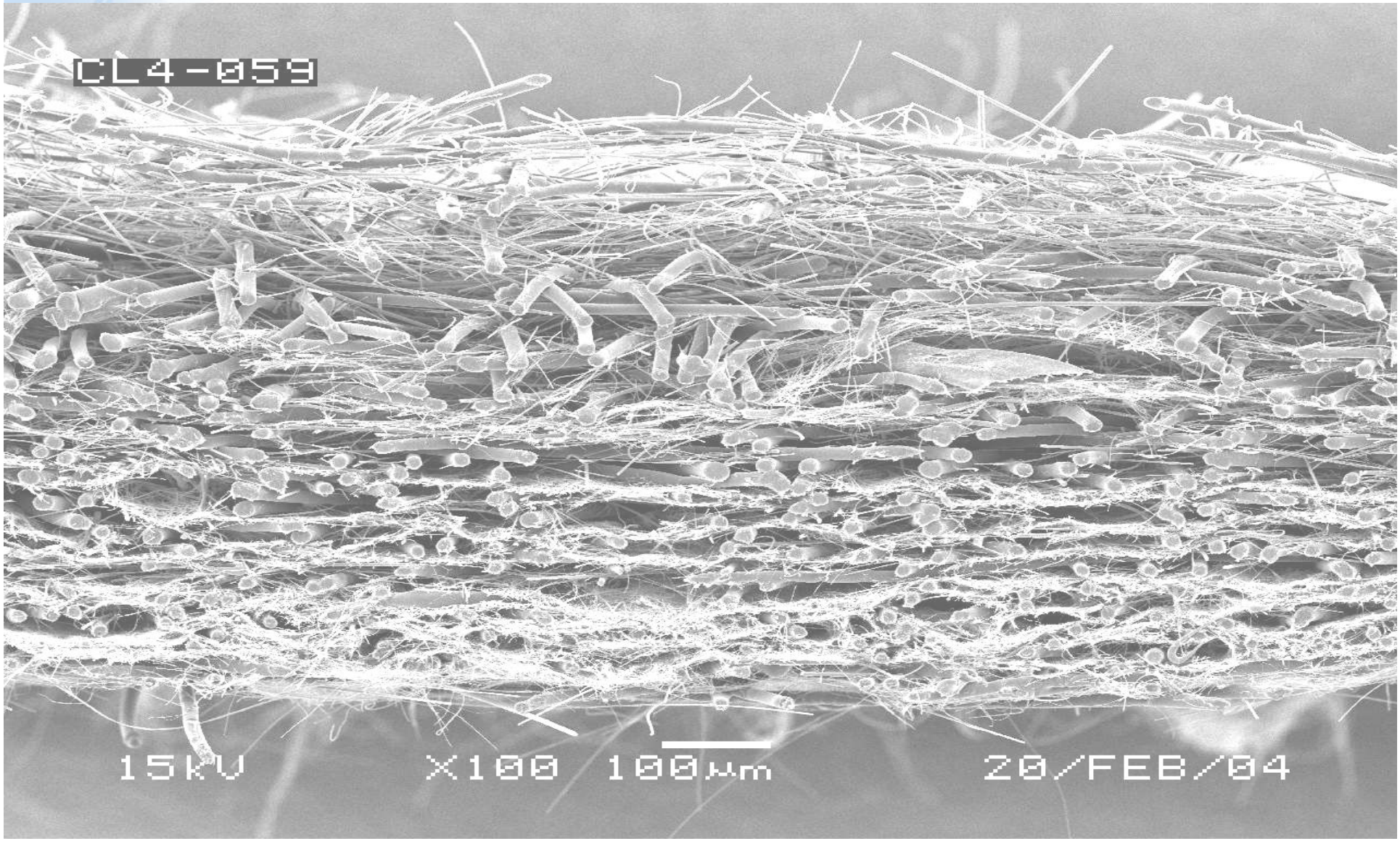
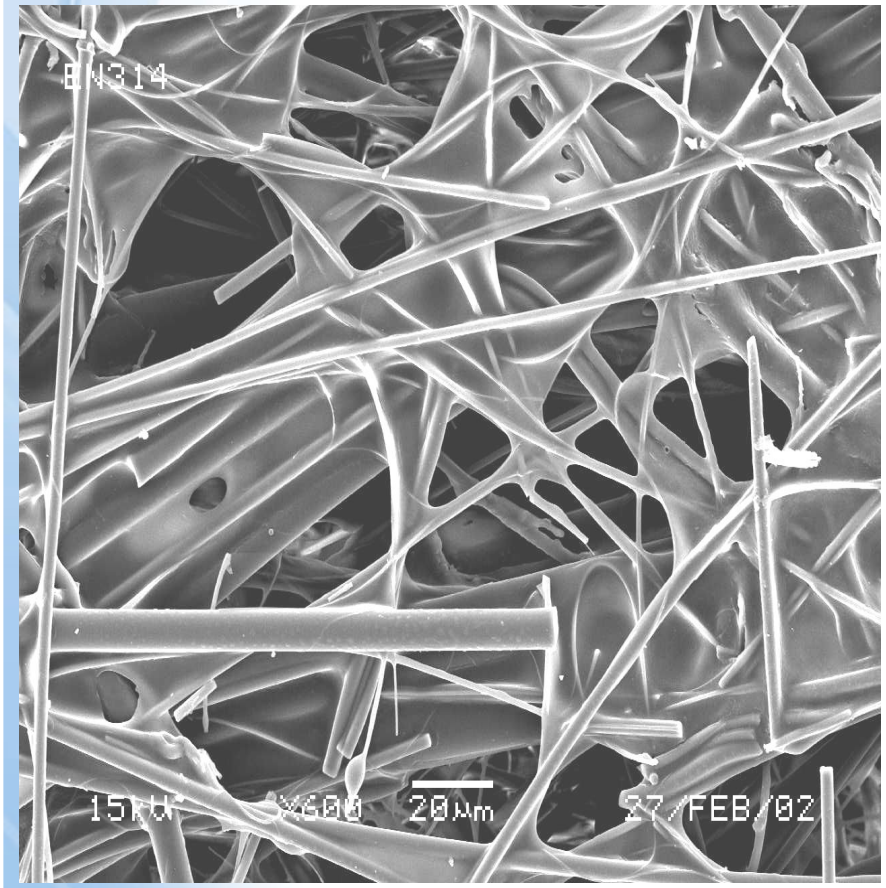
Pore Structure
Graded Pore Filter Media

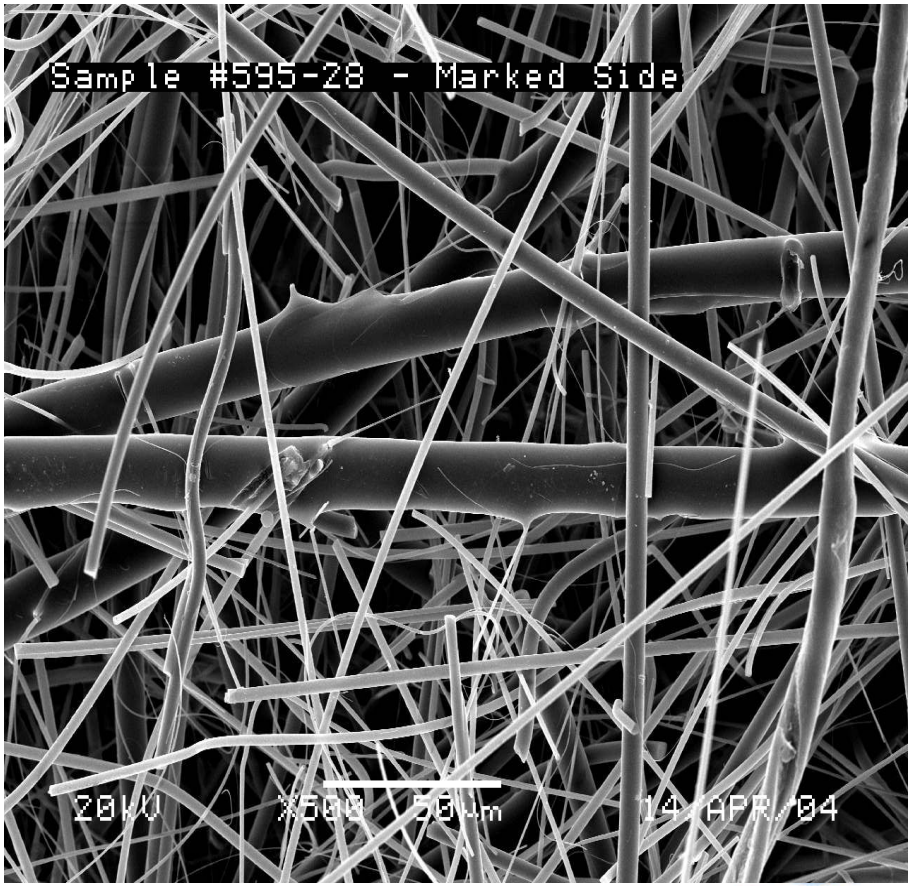


State-Of-The Art Filter Media

Conventional Media
Resin Bonded



New Media
Bi-Component



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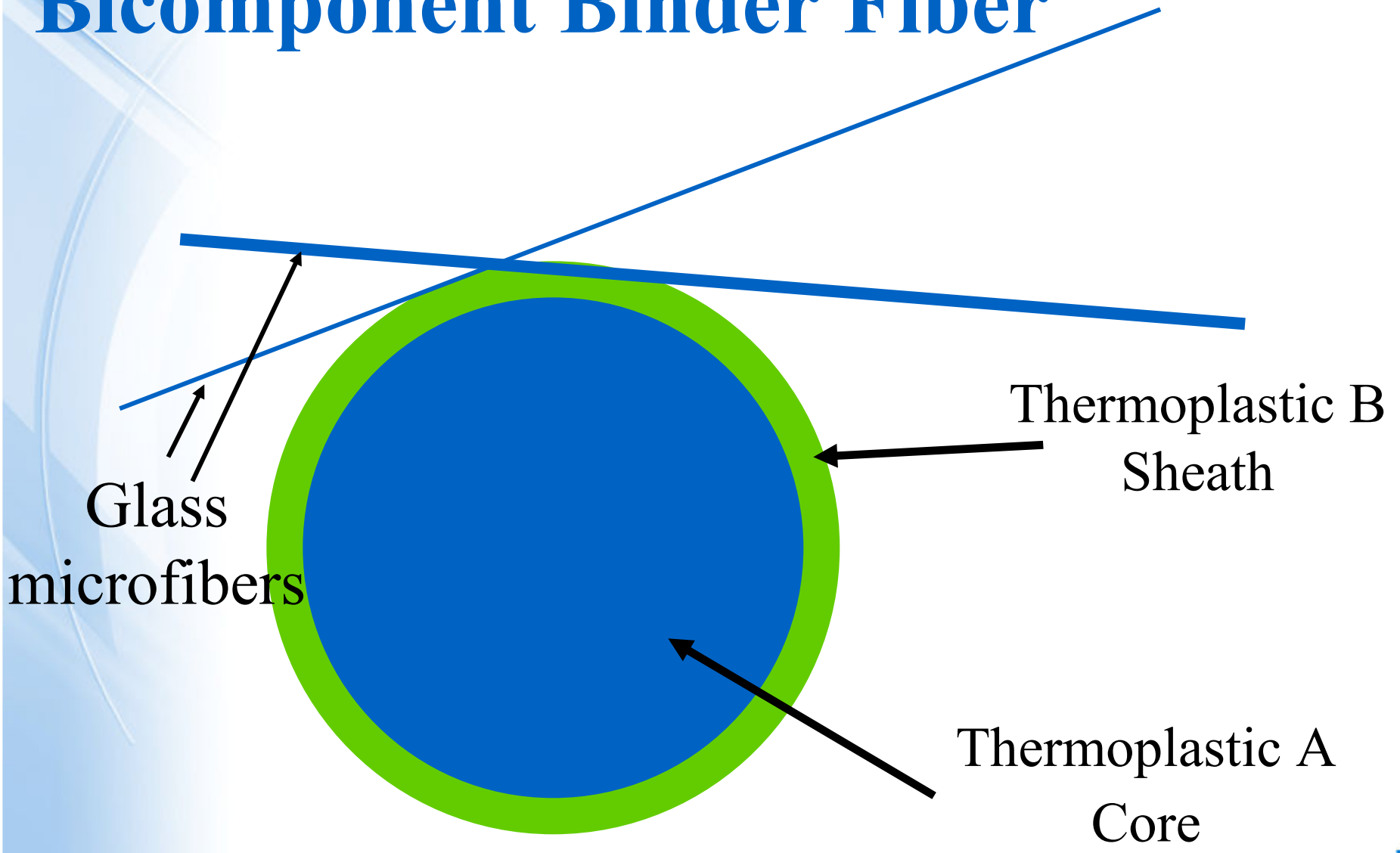
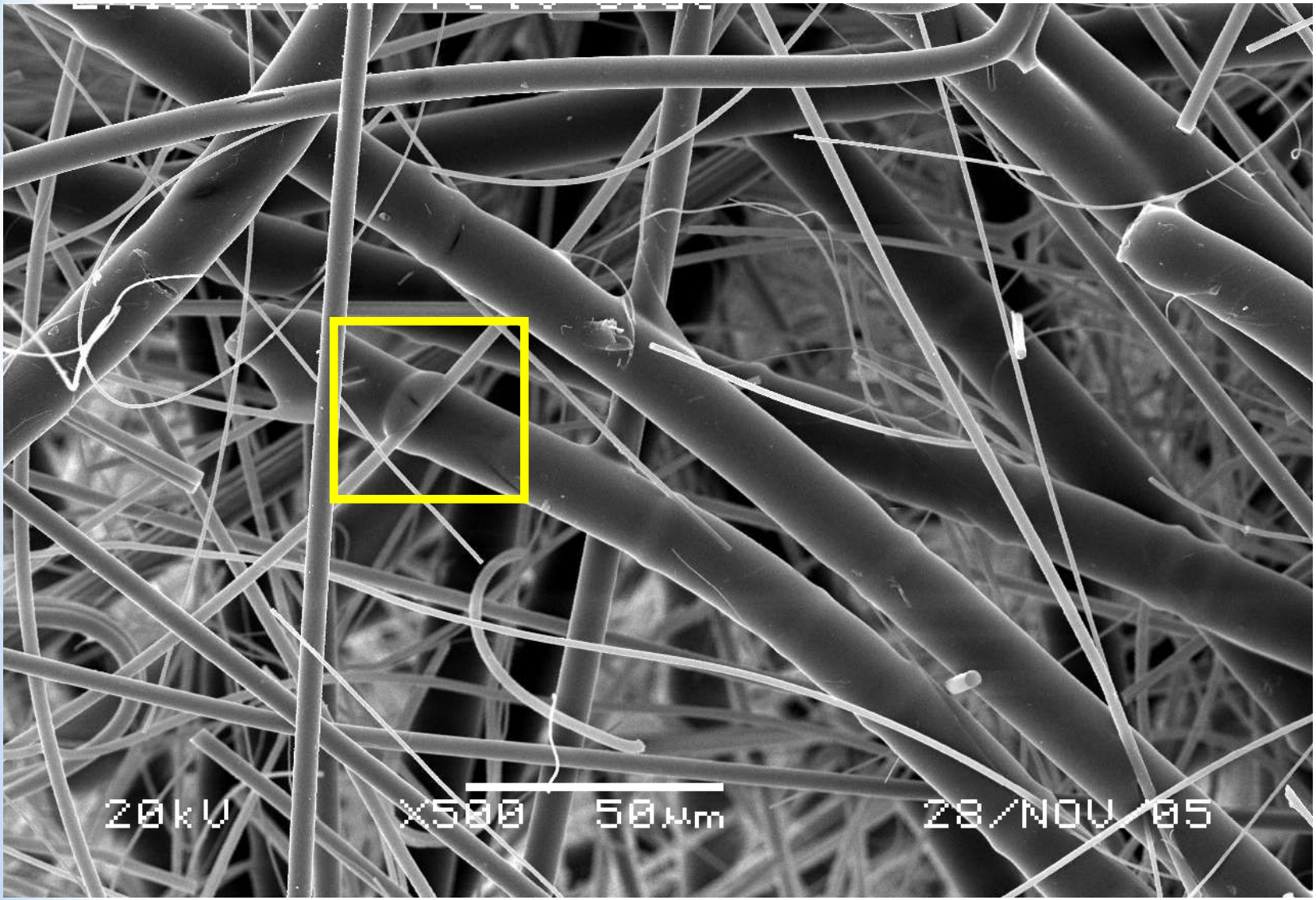
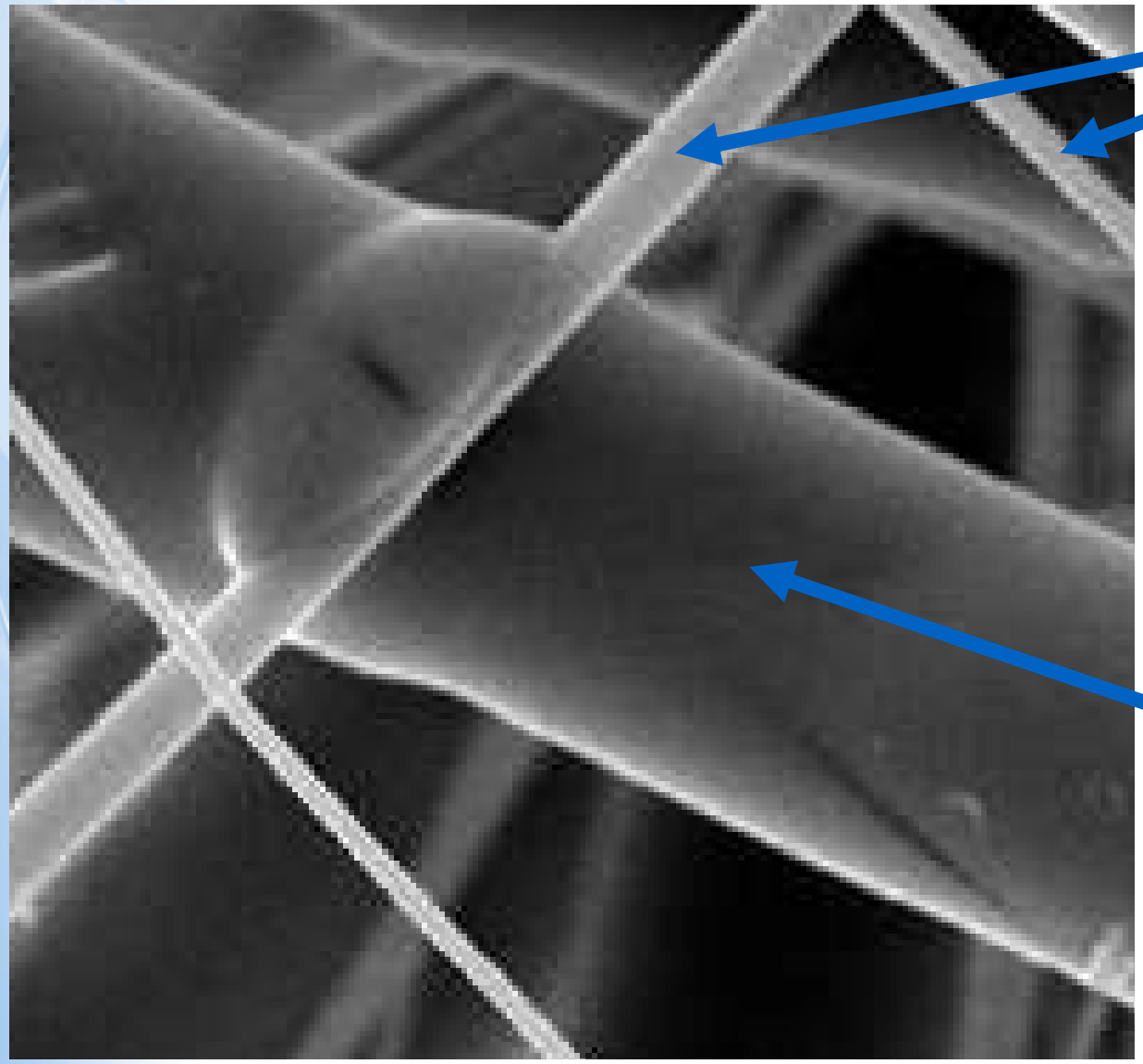
Bicomponent Binder Fiber



Bi-Component Filter Medium



Bi-Component Filter Medium



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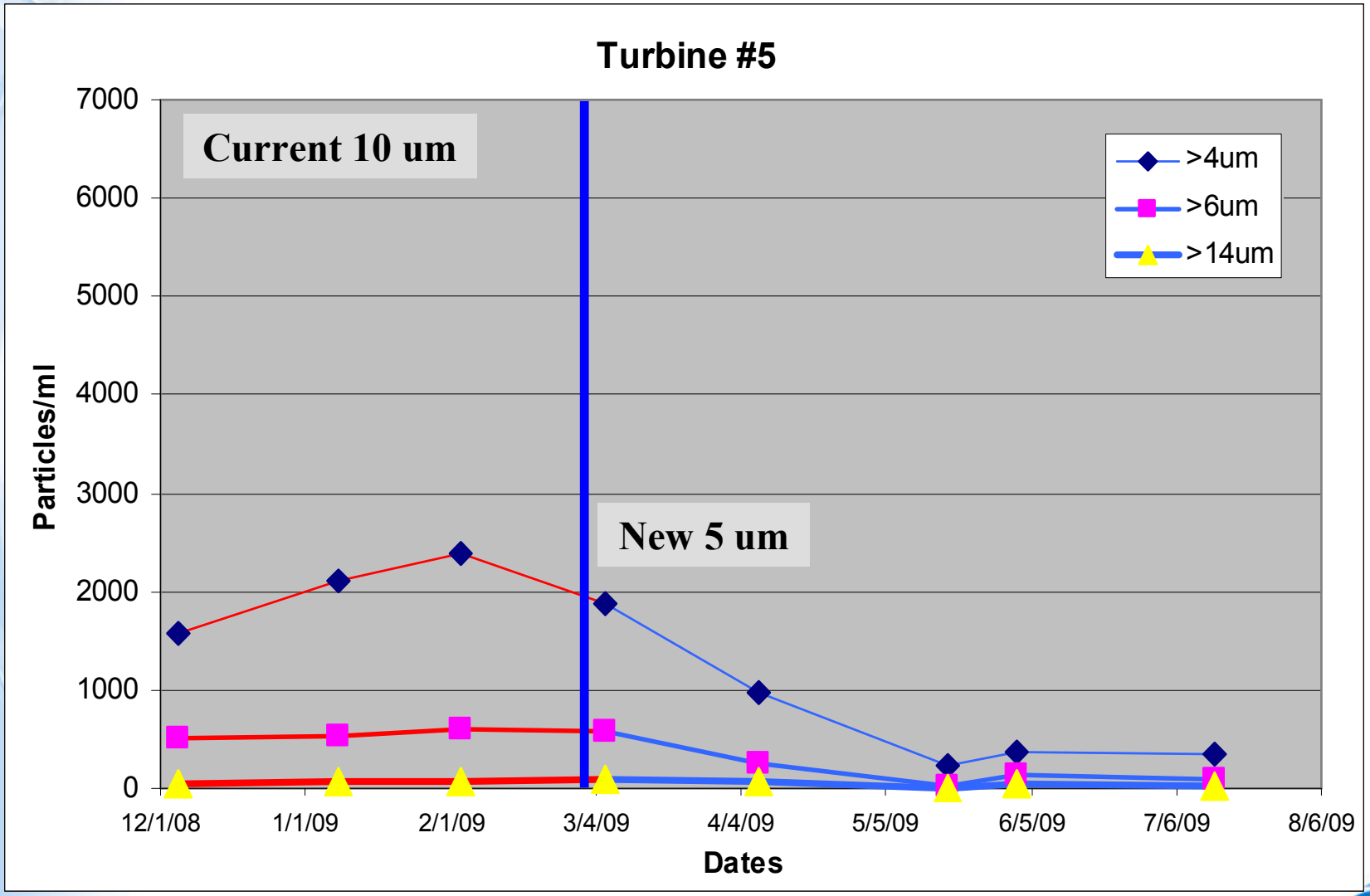
Field Data: GE 1.5 MW



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Dissolved & Free Water

Major Sources of Water Contamination in Wind Turbines

- **Water Vapor - Humidity**
- **Rain (Through Vents & Seals)**
- **New Oil**

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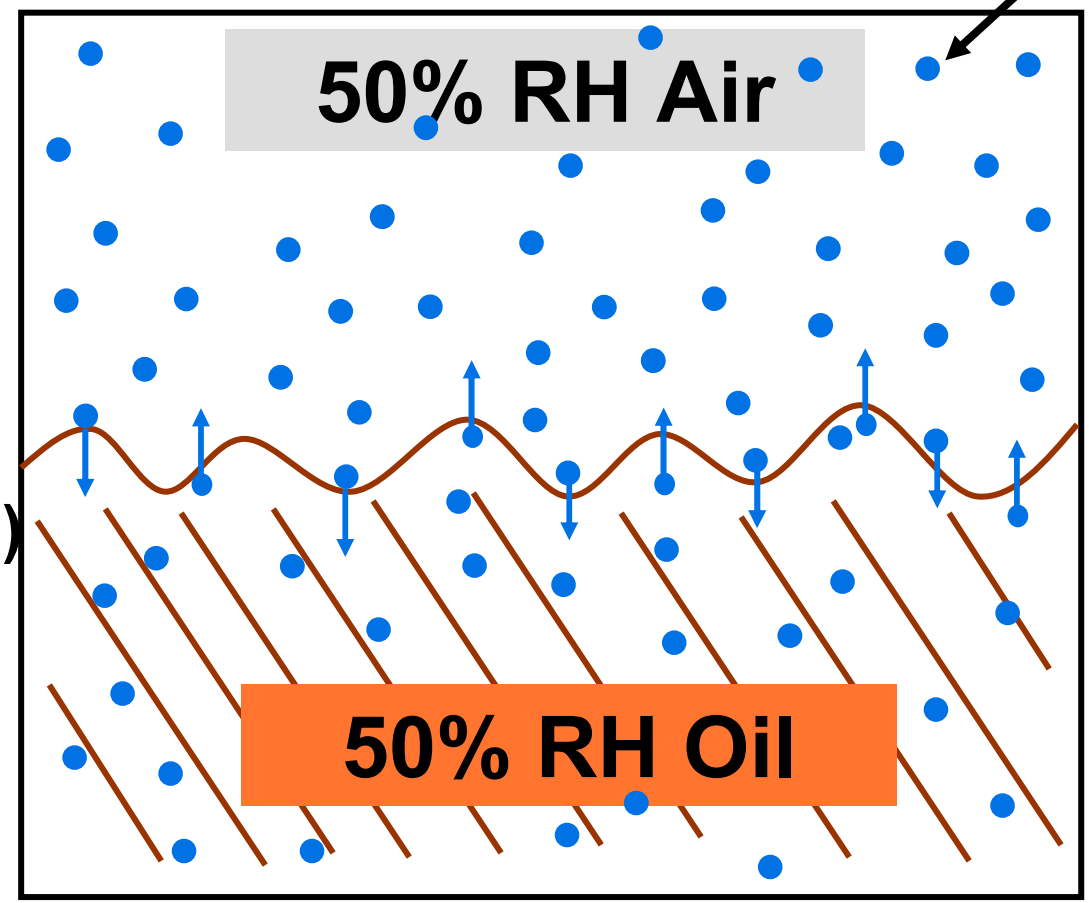
Oil Has A Relative Humidity (RH)

At Equilibrium
RH of Air
Equals
RH of Oil
(RH Oil = %Saturation)



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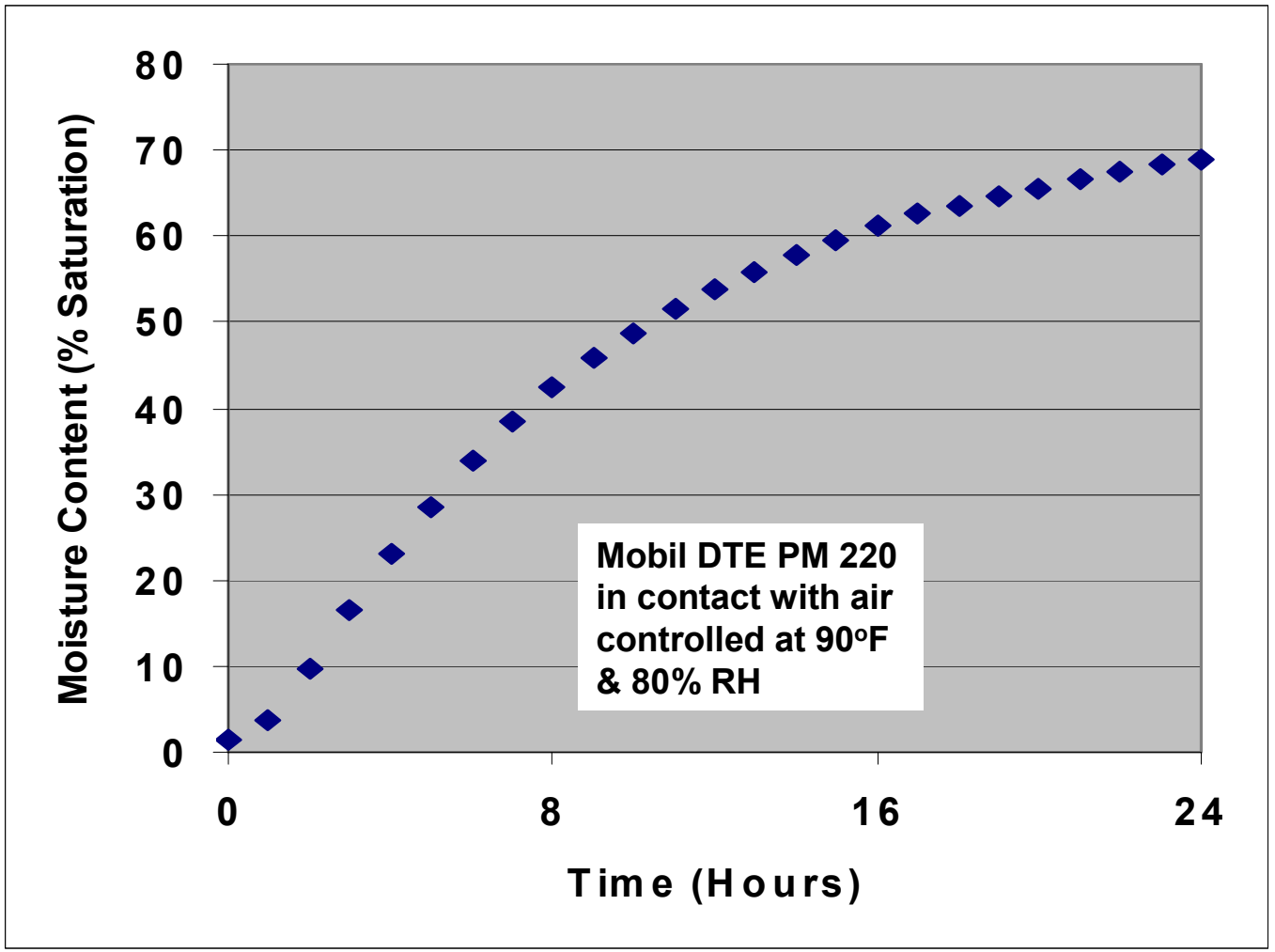
Humidification

Water moves from high relative humidity to low relative humidity



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Problems Caused by Water Contamination in Wind Turbines

- Rolling Contact Fatigue
- Adhesive Wear
- Additive Dumping
- Oil Oxidation

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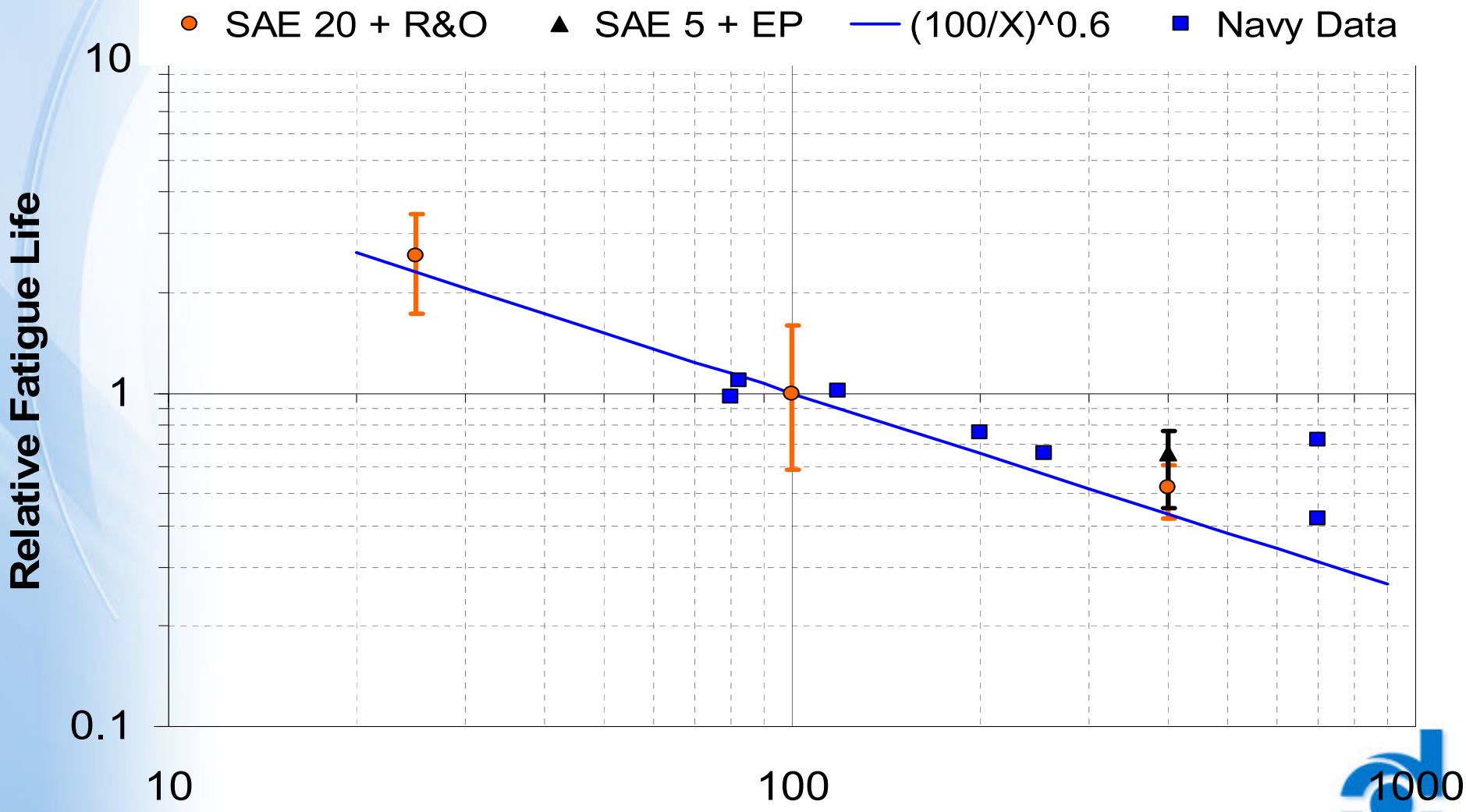
Water Damage
Bearing Fatigue



Ref: Kotzalas & Needelman, AWEA Wind Power Conf, 2008

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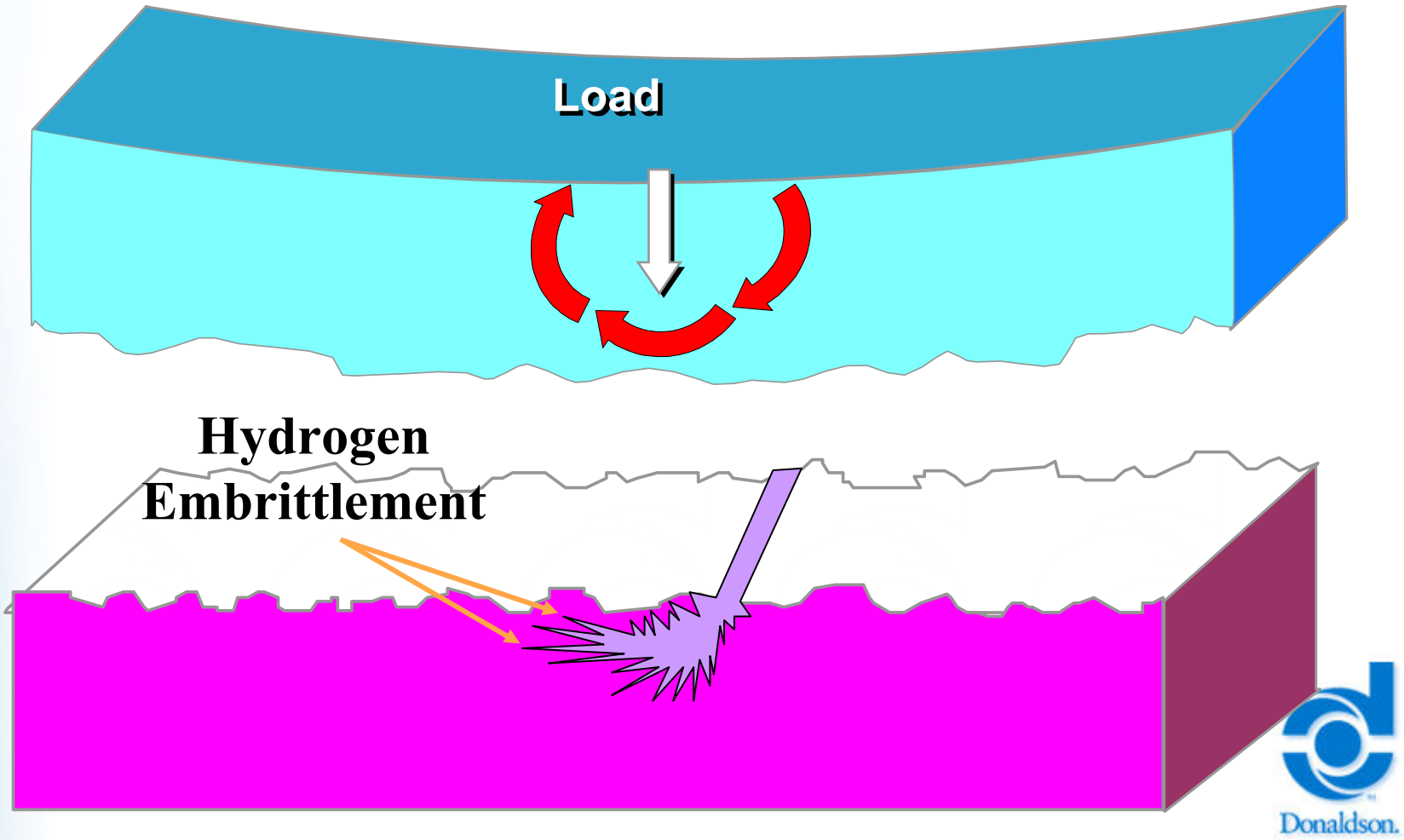
Water & Fatigue Crack Propagation

Oil + Dissolve Water Forced Into Cracks in the Contact Zone



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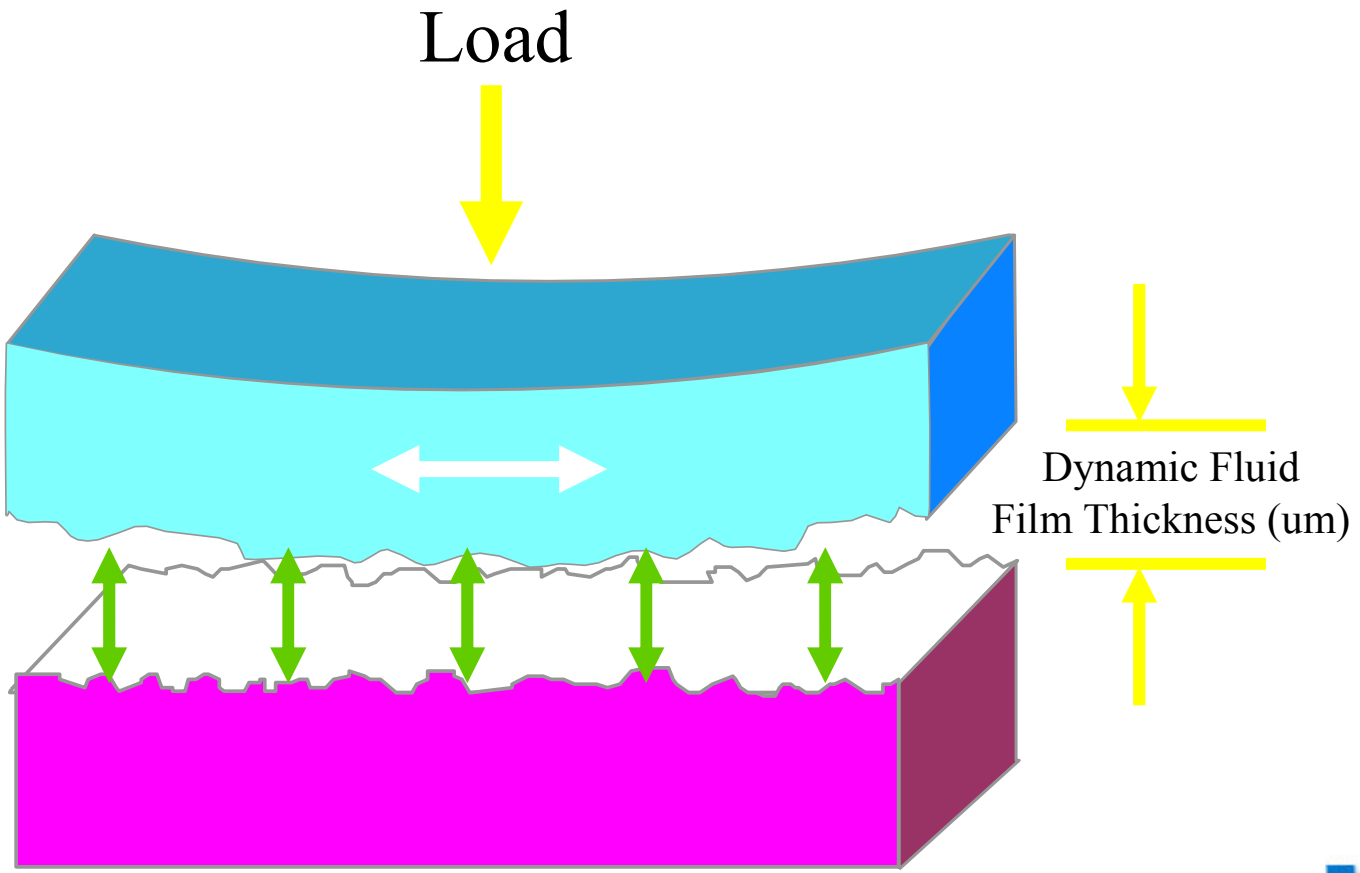
Loss of Fluid Film Lubrication & Adhesive Wear

Low Viscosity
Water Not Able
To Support Load
Film Collapses



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Water Damage
Additive Drop-Out

Fouled & Disabled Oil-Level Sensor

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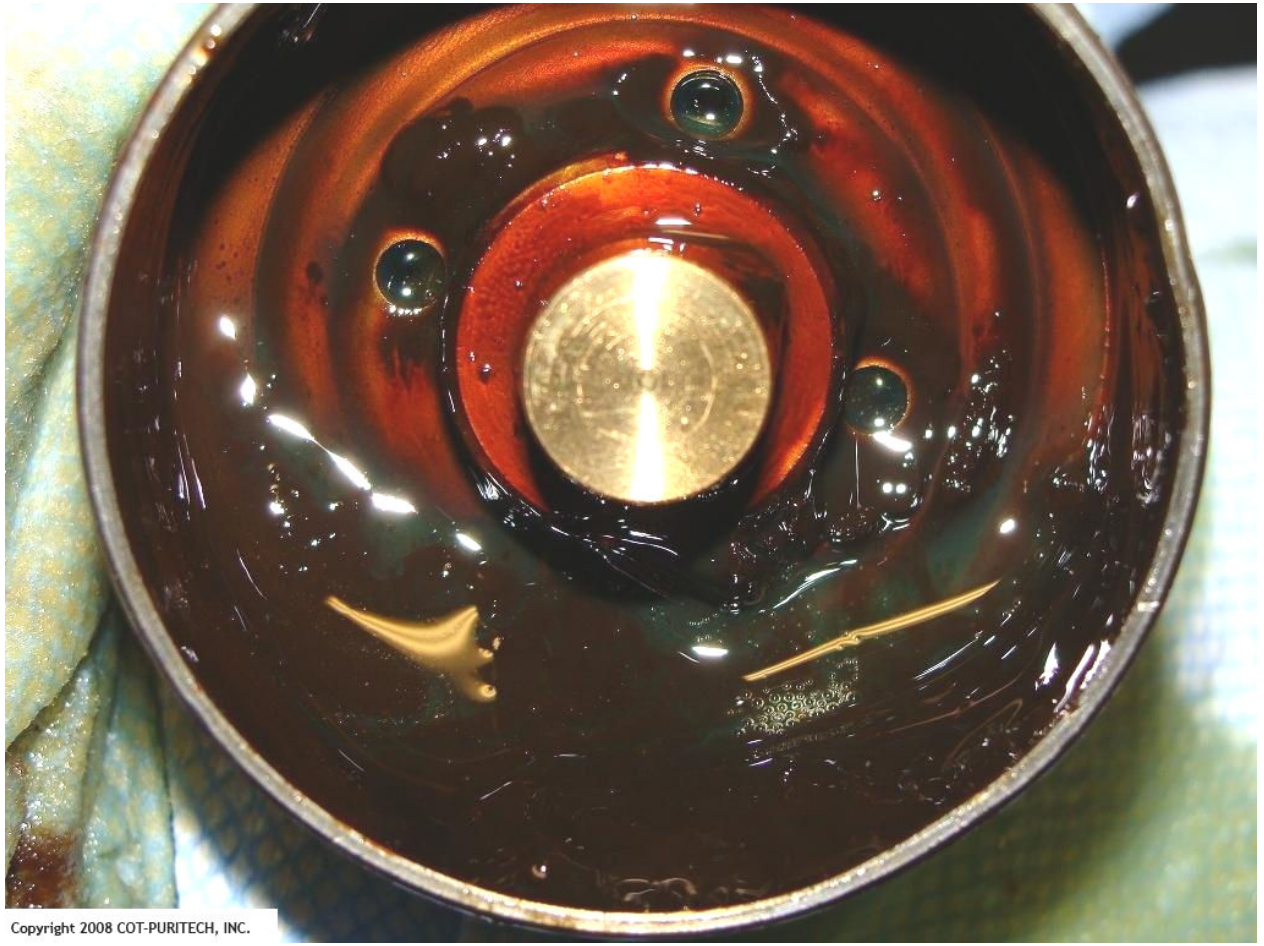
Water Damage
Additive Drop-Out



Courtesy COT-Puritech, Inc.

Fouled & Disabled Thermostat

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Keeping Gear Oils & Hydraulic Fluids Dry in Wind Turbines

- **Prevention**
  - **Minimize Ingression**
- **Removal**
  - **Rapid**

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Regenerable Breather Dryer

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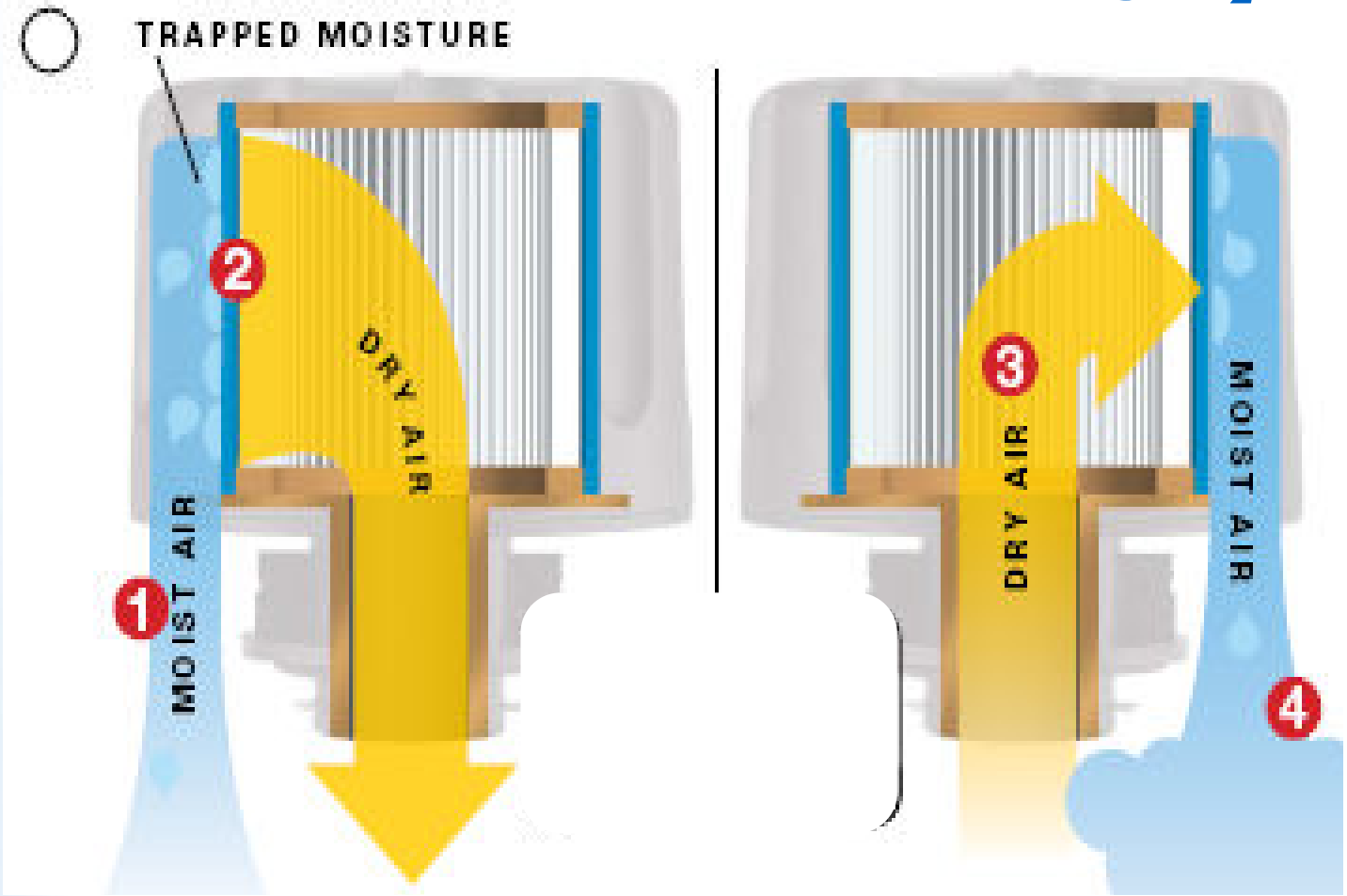
Inhalation

Captures H_2O

Exhalation

Regenerates By Releasing H_2O



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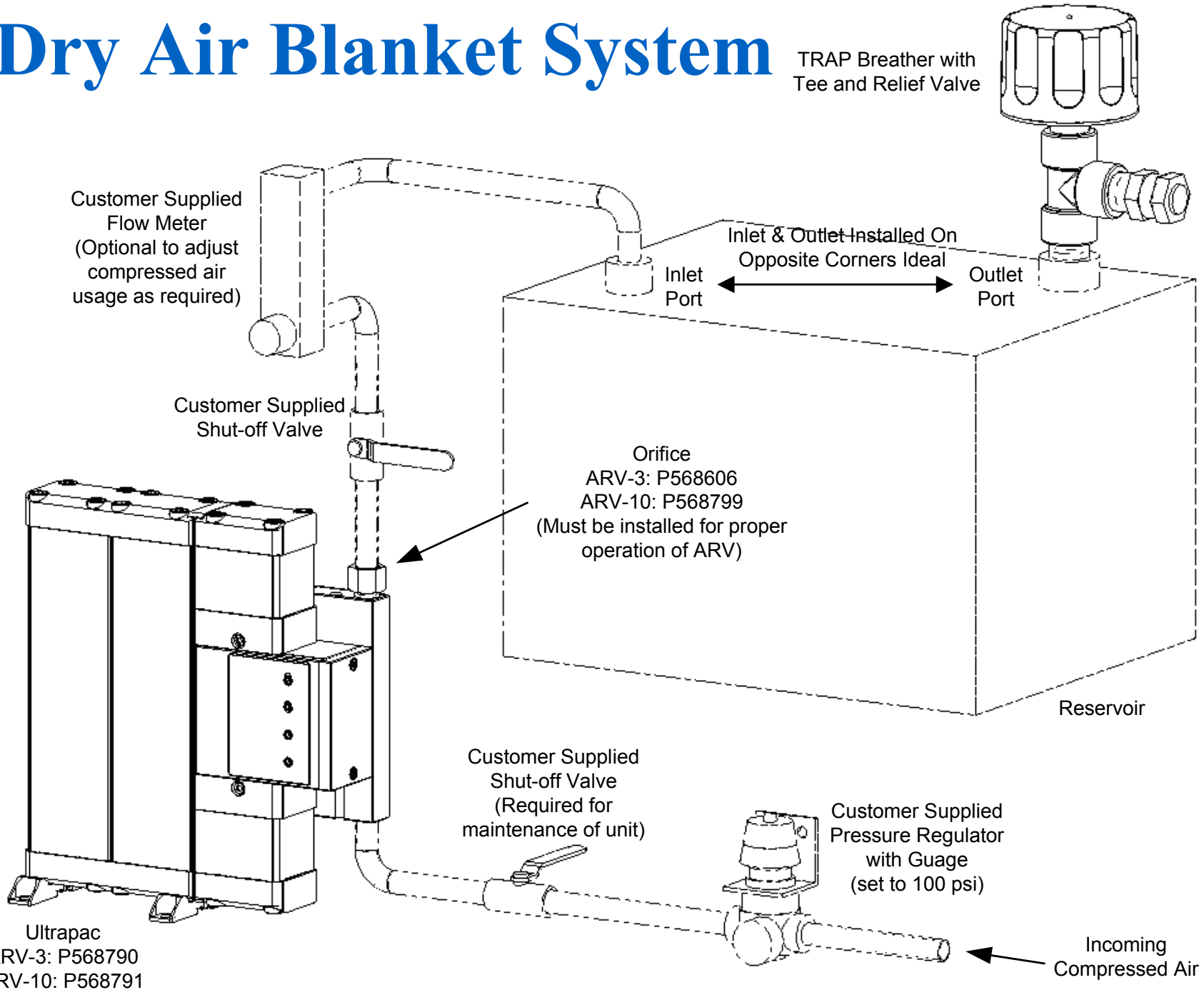
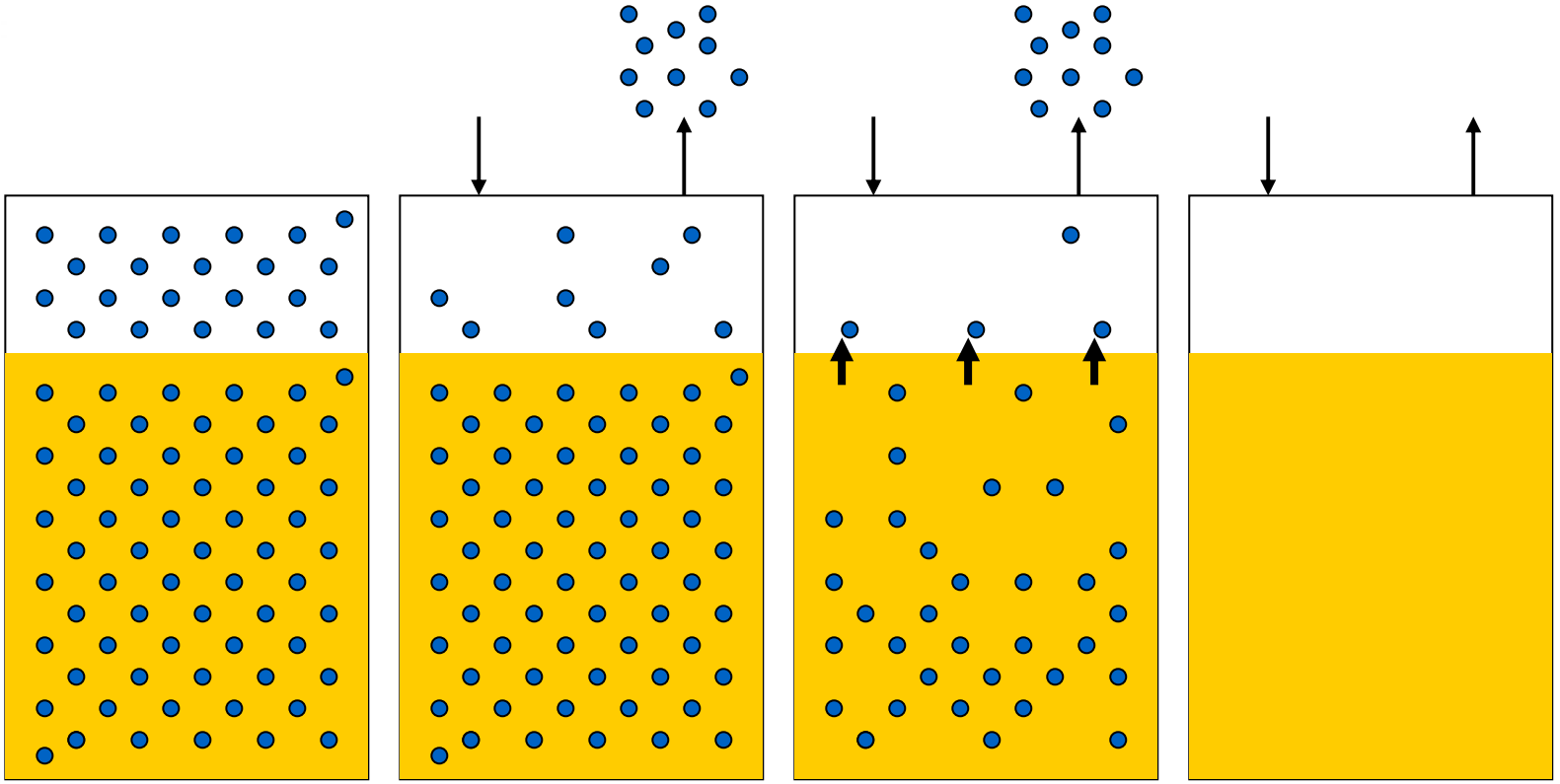
Dry Air Blanket System



Dry Air Blanket System



- Humid Air
- Saturated Oil

- Purging Humid Air
- Saturated Oil

- Dry Air
- Moisture Desorbing from Oil

- Dry Air
- Dry Oil

Time

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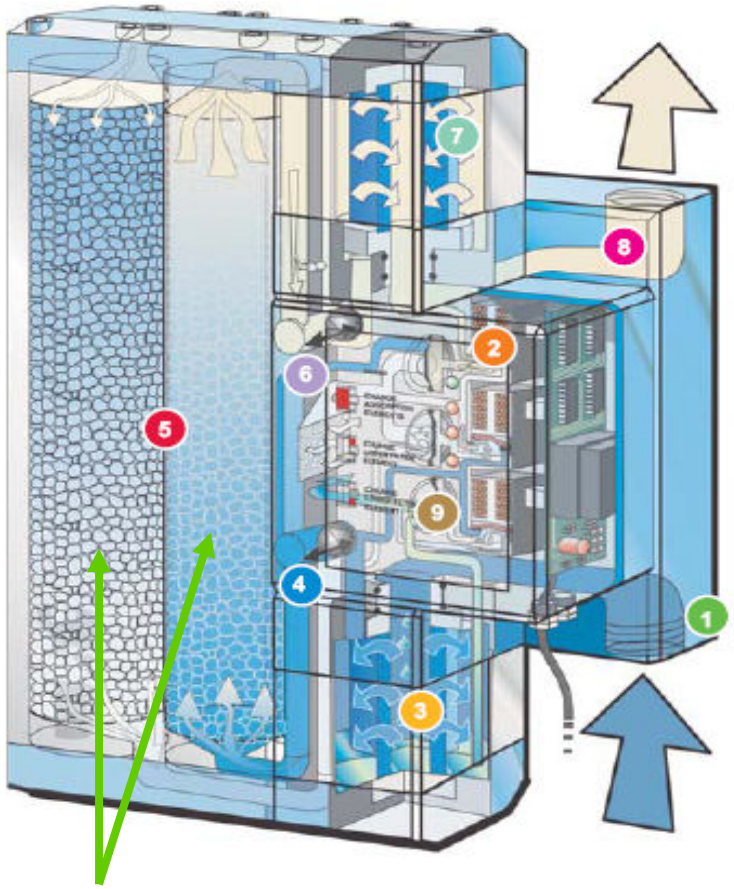
Pressure Swing Adsorption Dryer



1. Dryer Inlet
2. Processor Control
3. Prefilter
4. Lower Shuttle Valve
5. Desiccant Cartridges
6. Upper Shuttle Valve
7. Afterfilter
8. Dryer Outlet
9. Condensate Drain

$Na_{12}[(AlO_2)_{12}(SiO_2)_{12}] \times H_2O$ - 10 Angstrom Molecular Sieve

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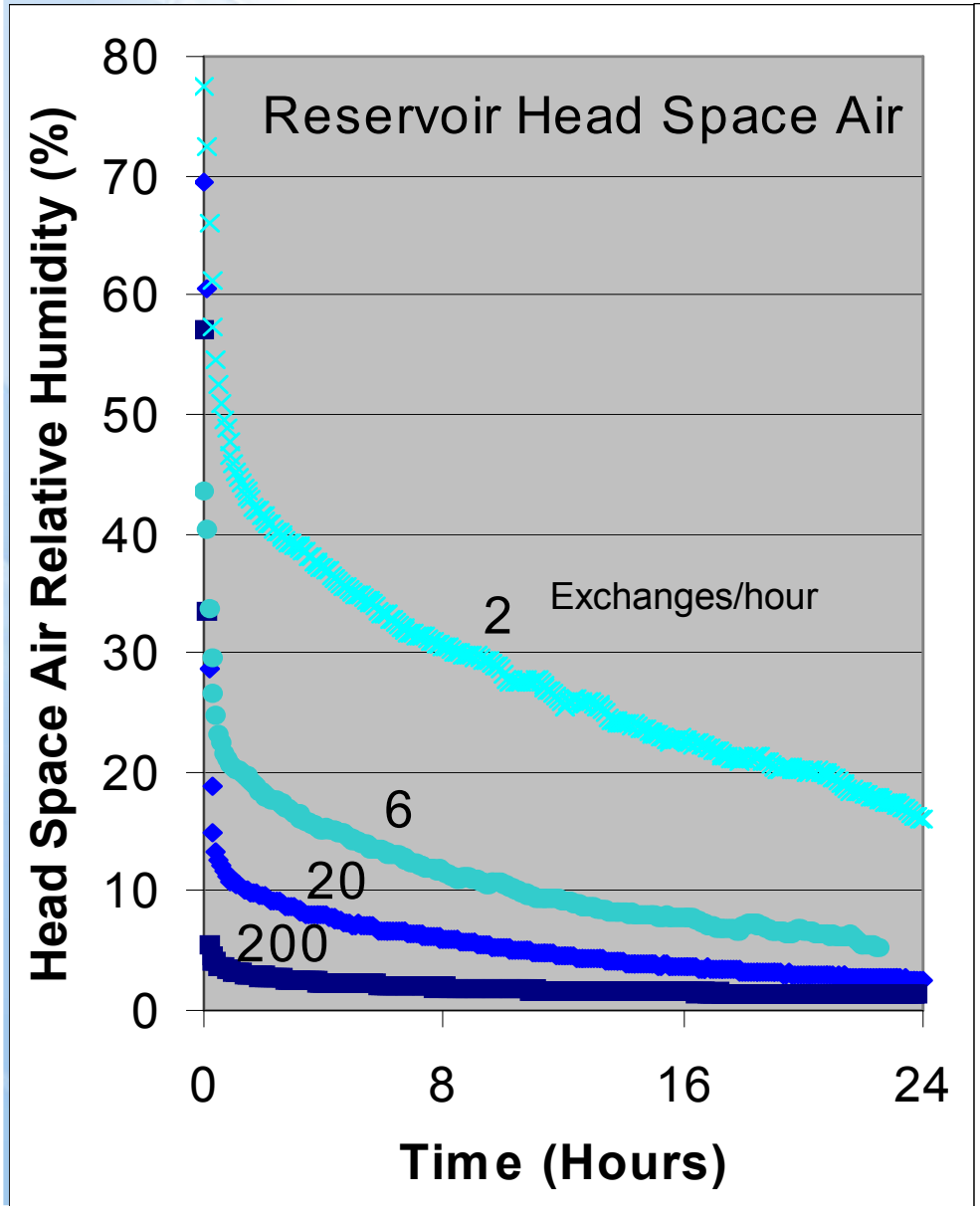
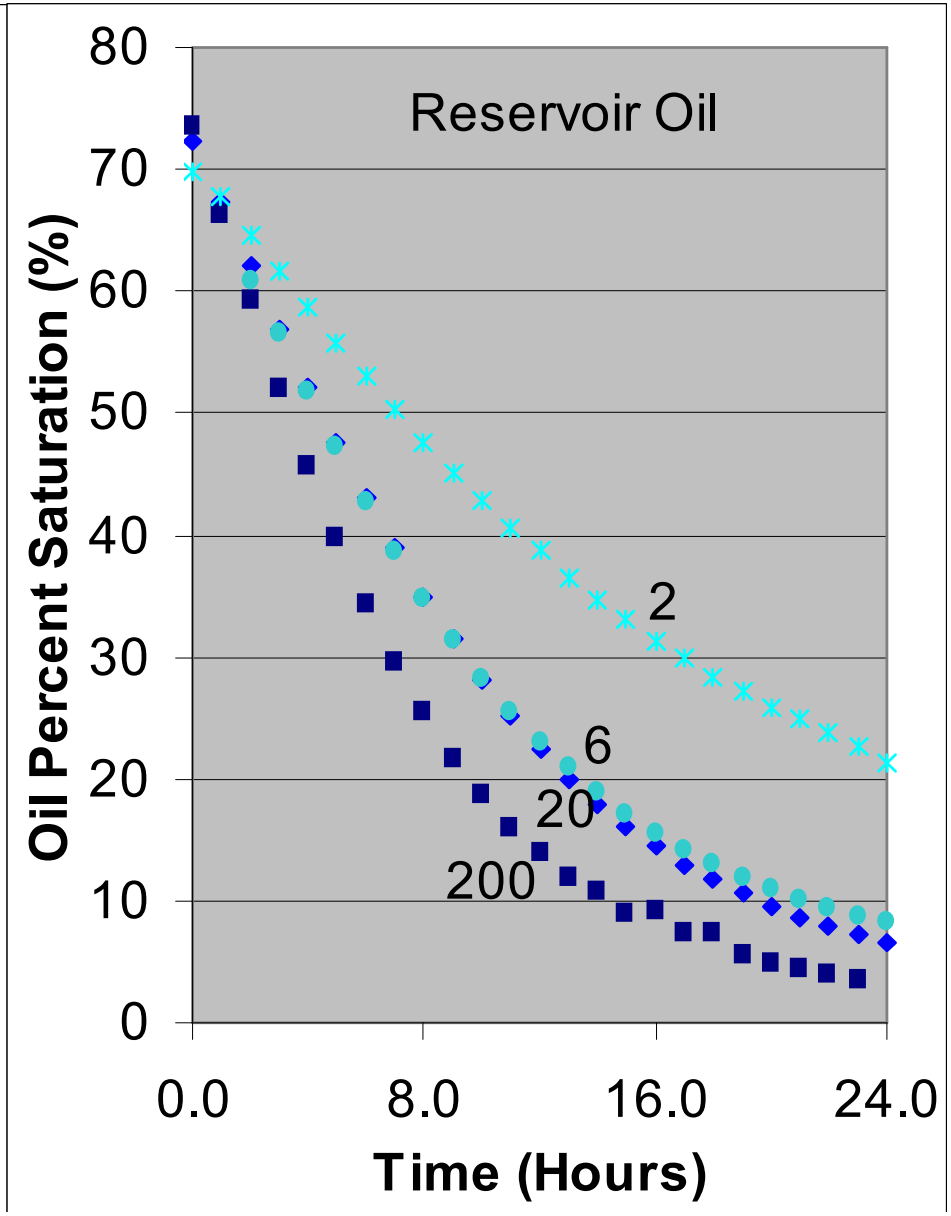
Dry Air Blanket
Keeping Oil in Contact With Very Dry Air





Best Practices
Total Contamination Control Plan

1) Design
2) Roll-Off Cleanliness
3) Transportation
4) On-Site Storage
5) Clean Maintenance Practices
6) Ingression Prevention
7) Rapid Removal

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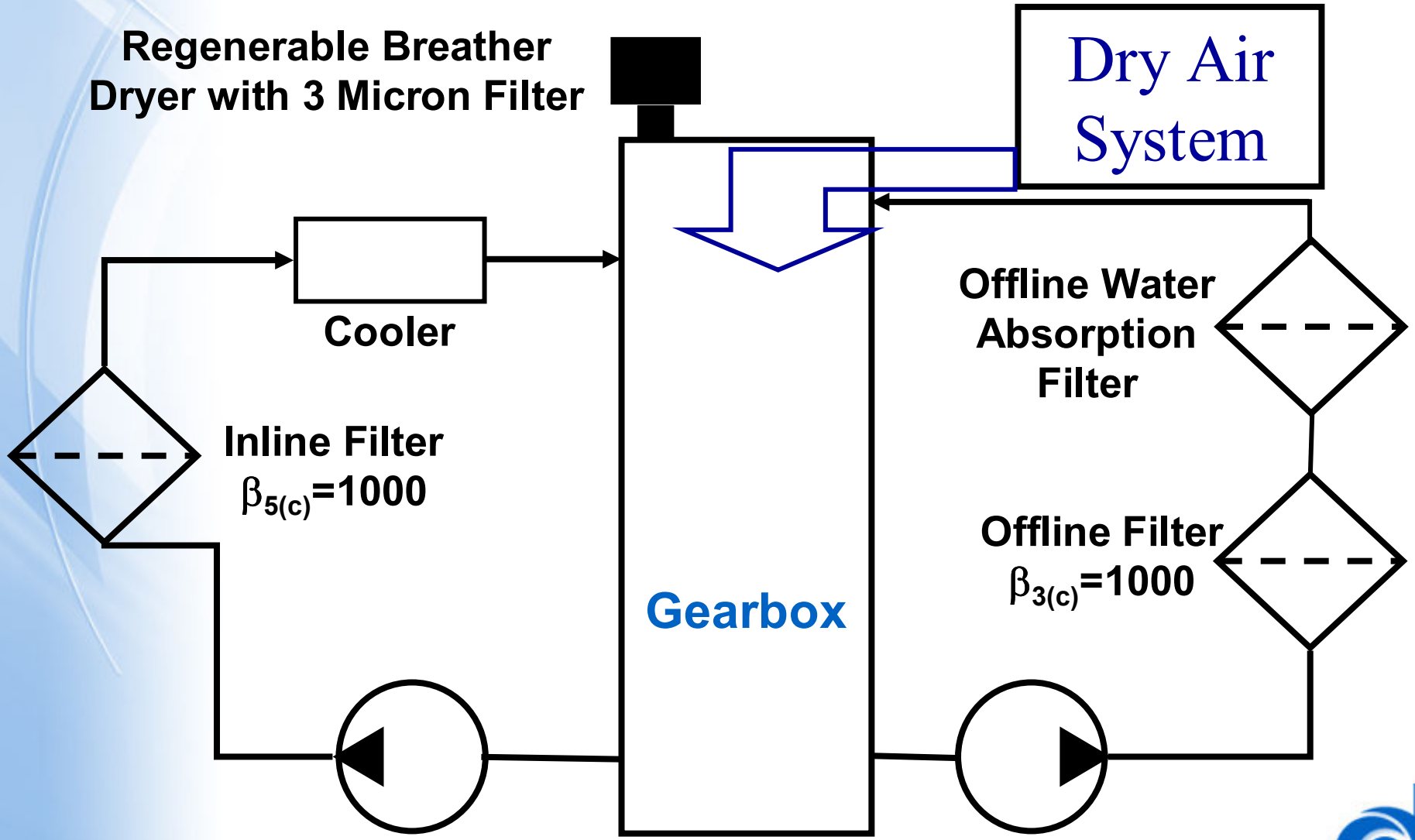
Best Practices For Ingression Prevention & Rapid Removal



Objectives: ISO 14/12/10

. 125 ppm max

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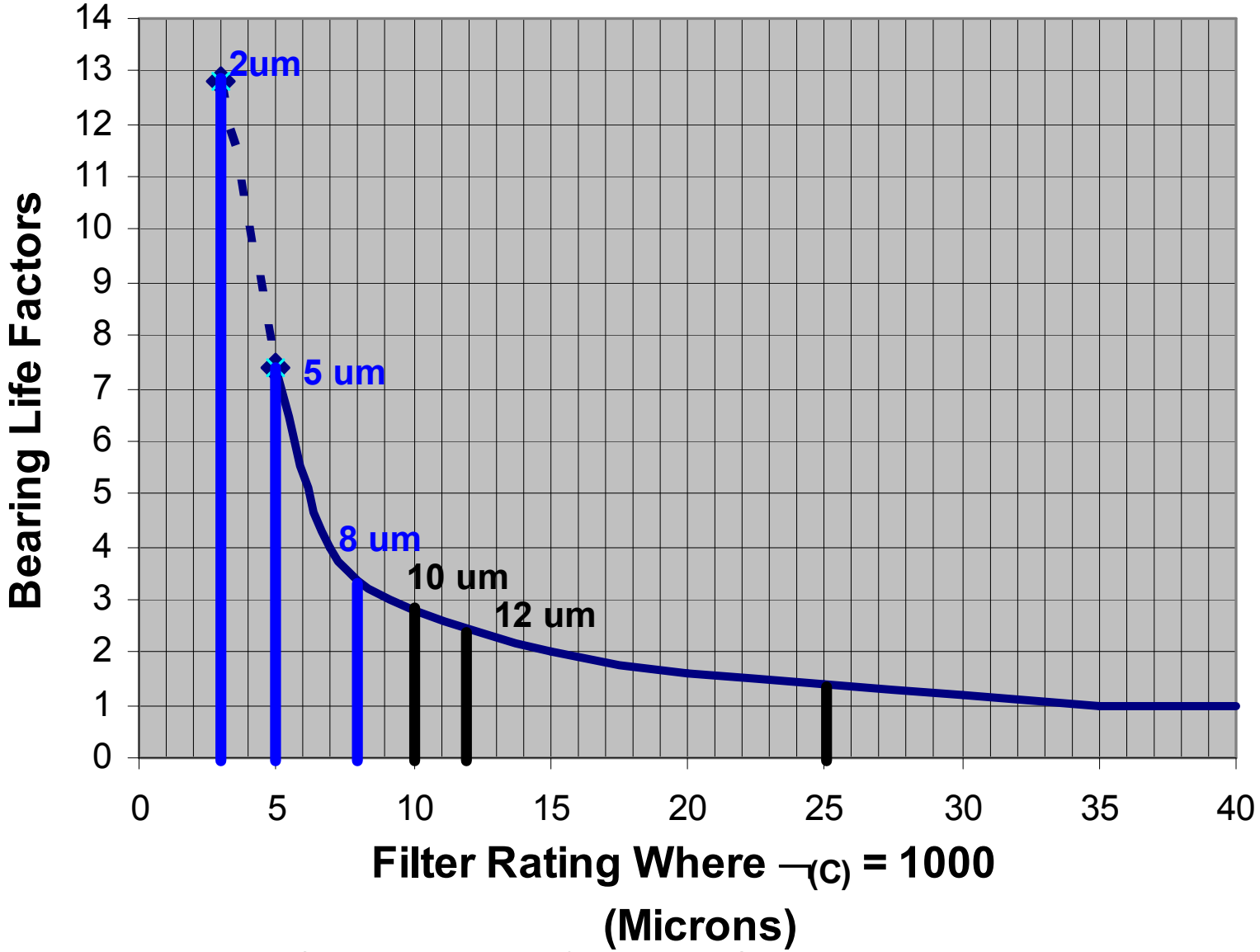
NASA/STLE Roller Bearing Life Factors for Wind Turbines



Adapted from Needelman & Zaretsky, STLE Annual Mtg. Proc. May 09

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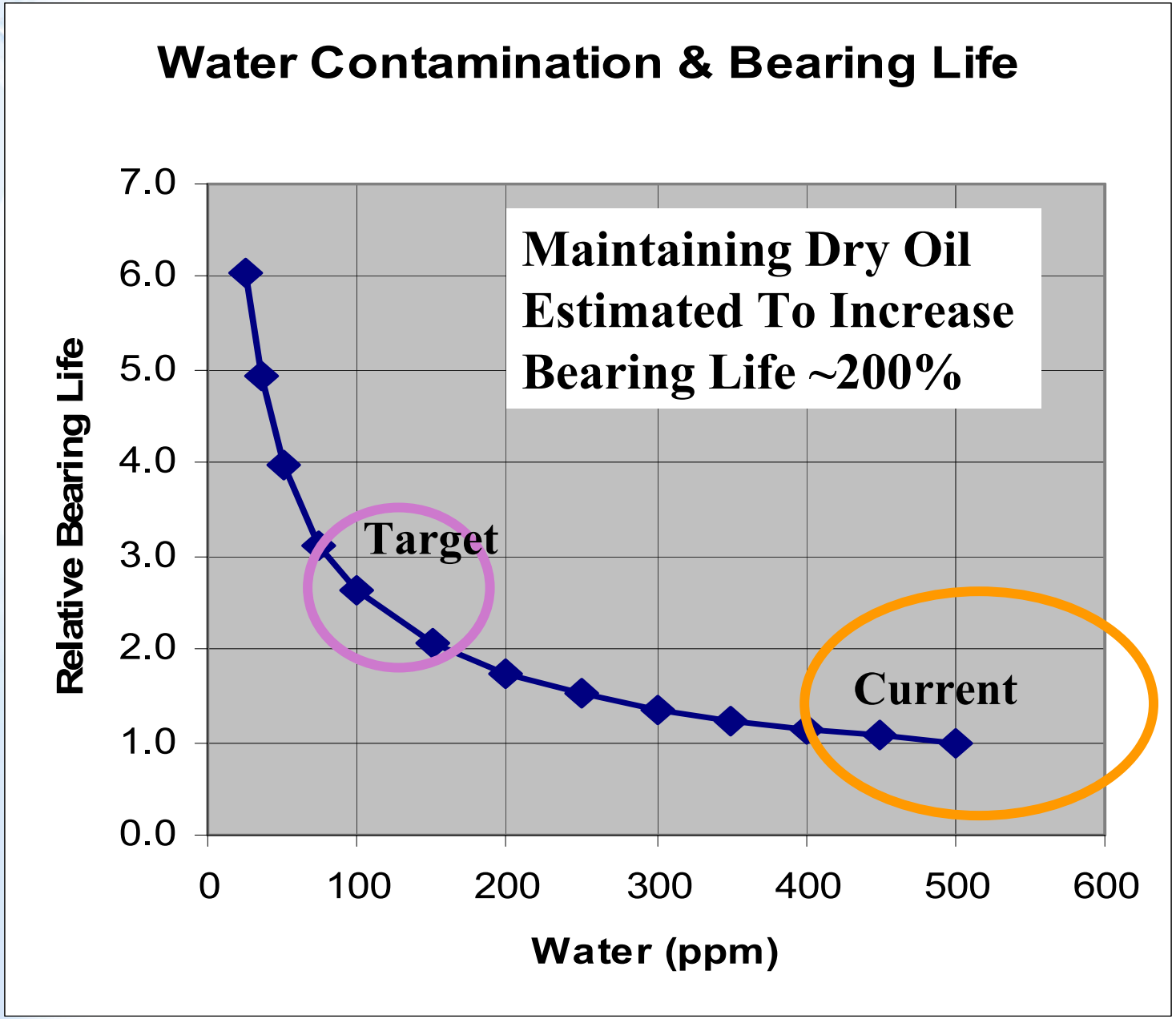
NASA/STLE Model



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Conclusions

- **Benefits Of Excellent Contam Control**
  - **Greater Gearbox Reliability**
  - **More Uptime, More Production**
  - **Extended Warrantees**
  - **Up To 5 Year Gear Oil Life**
- **Needed**
  - **Coherent Contamination Control Plan**
  - **Use Best Technologies & Practices**

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Thank You
For Your Interest

Questions?

Comments?

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