

# **Field Experiences Improving Wind Turbine Gearbox Lubrication Systems With Advanced Filtration**

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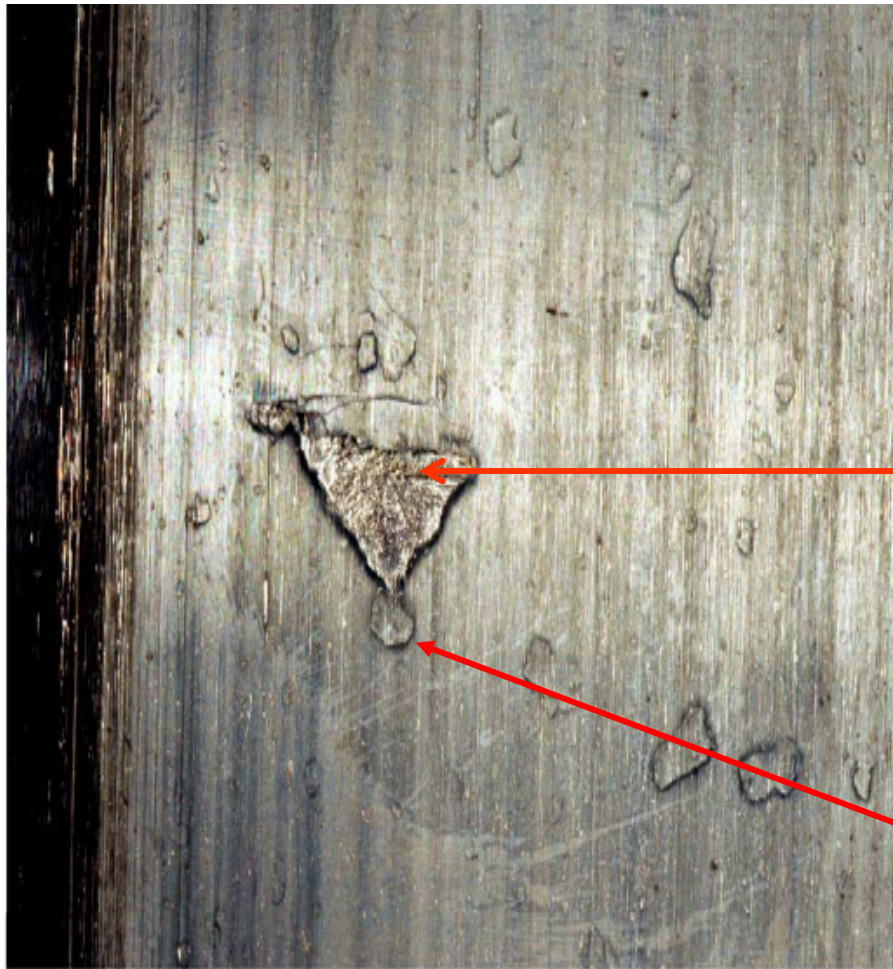
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# **OUTLINE**

- 1. Types of Damage Caused By Particle Contamination**
- 2. Gear Oil Filtration**
- 3. Field Test Protocol**
- 4. Field Test Results**
- 5. Conclusions**

# Surface Origin Fatigue Spalls



Spalled  
Area

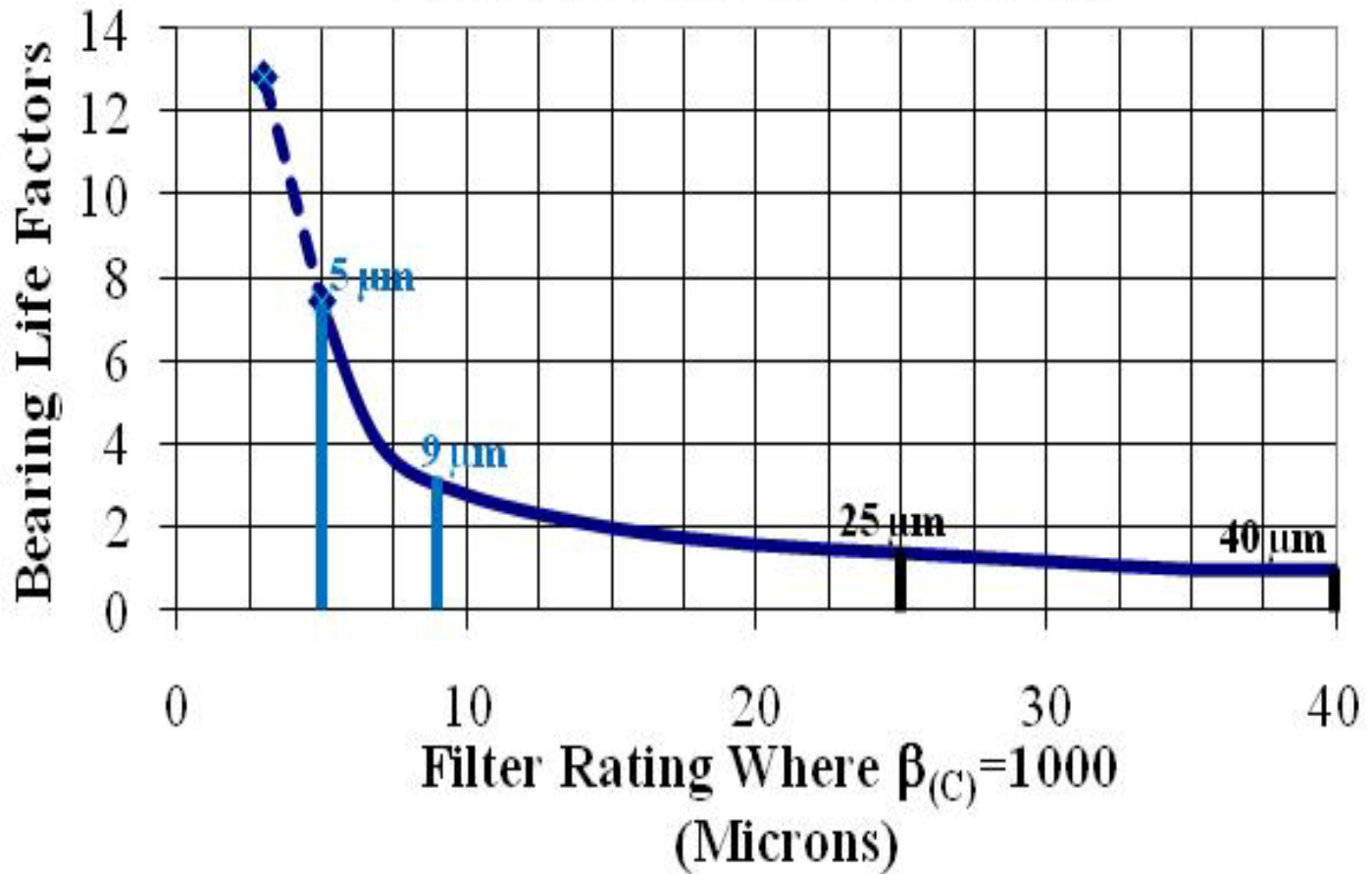
Initiation point

↑  
Roller Path

From Butterfield et al (NREL), ASME Wind Tribology Conference, Oct 2008

# Bearing Life Factors & Filter Ratings

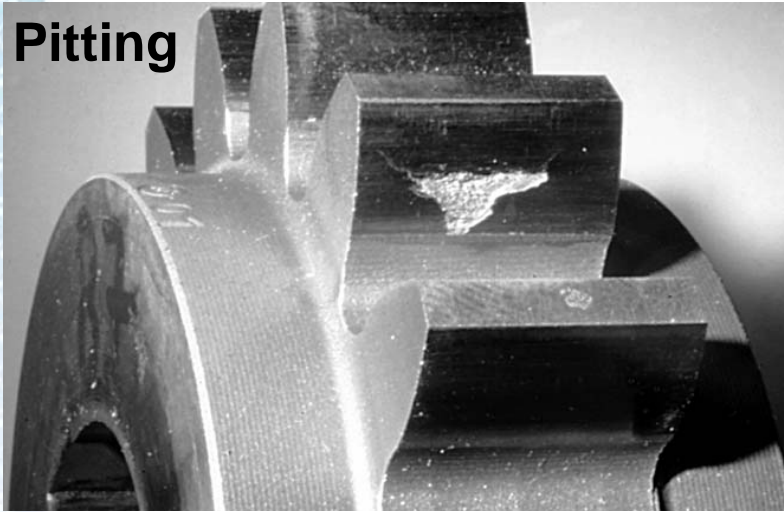
## NASA/STLE Roller Bearing Life Factors for Gearboxes





# Gear Wear Modes

**Pitting**



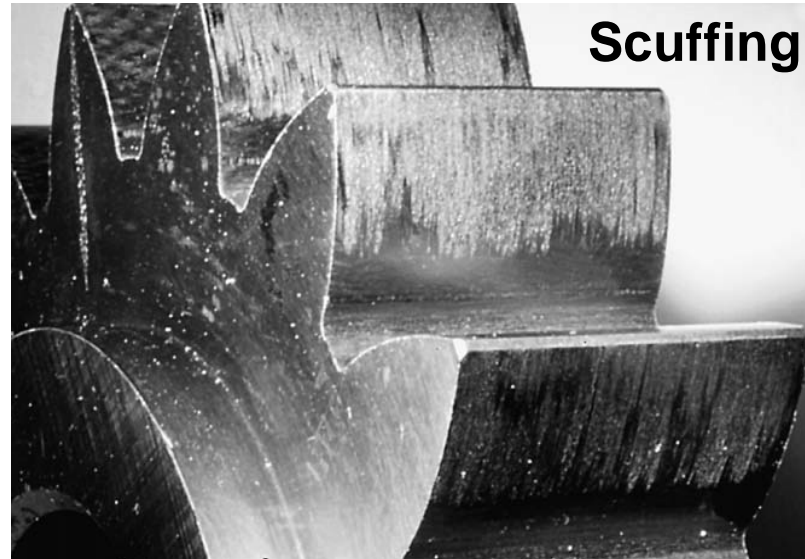
**Abrasive Wear**



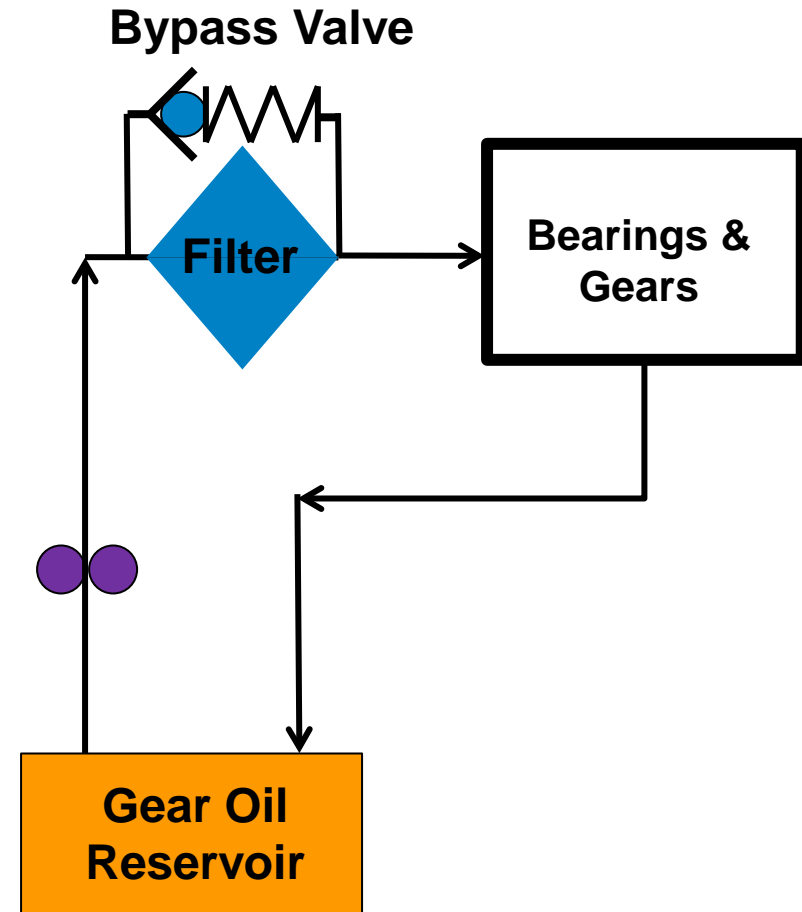
**Micropitting**



**Scuffing**



# Gearbox Full-Flow Filtration



# Full-Flow Filter Assembly

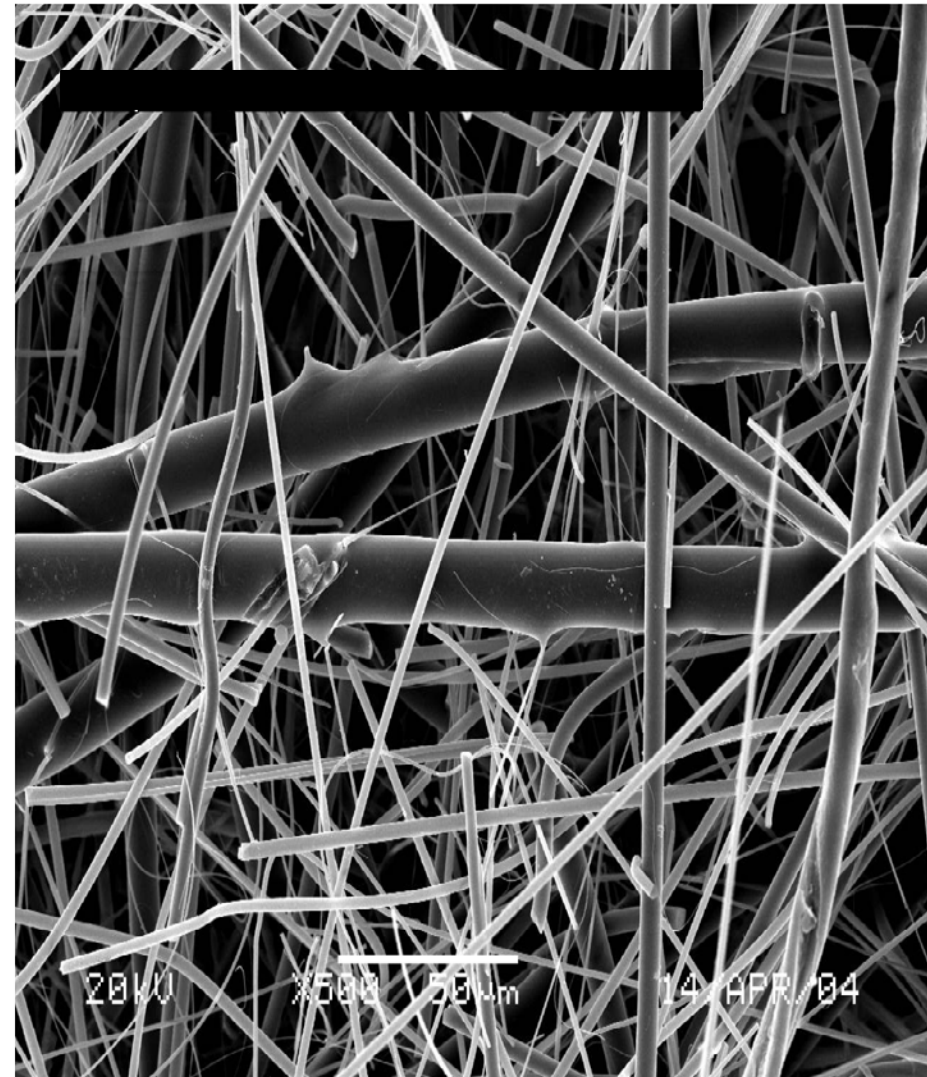
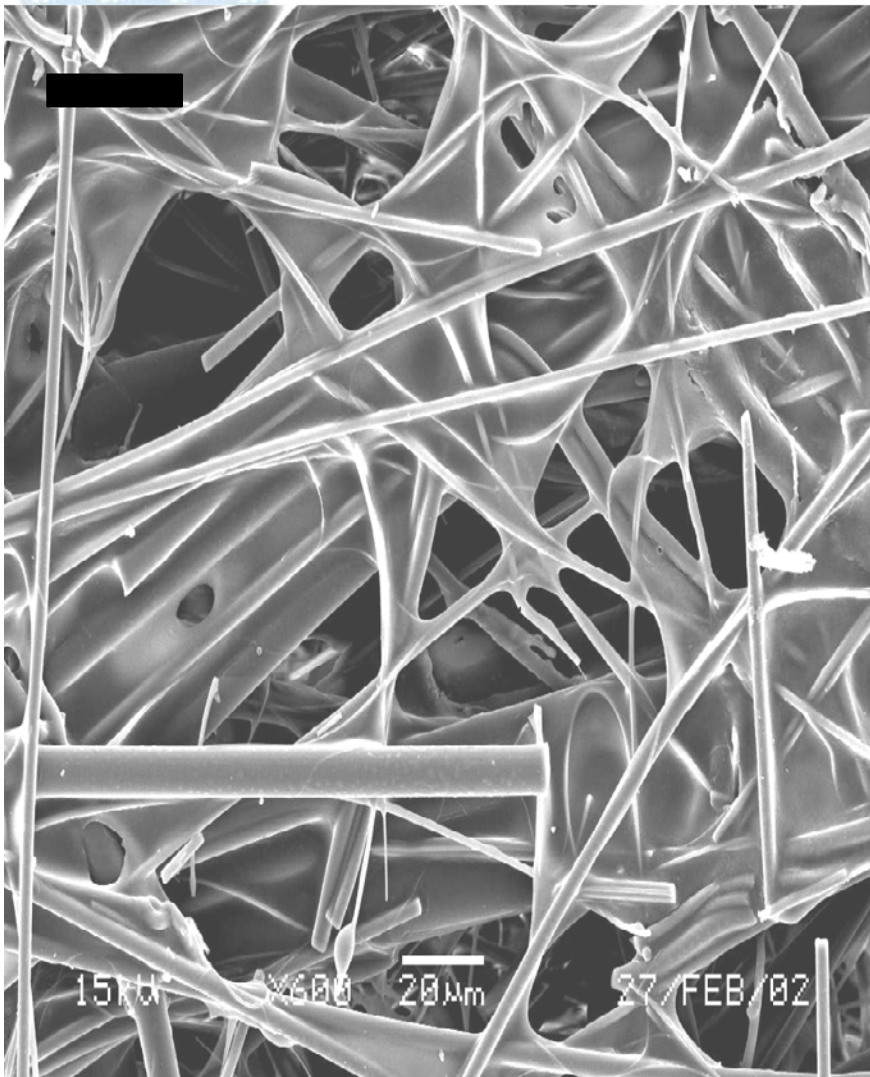


# Barriers To Fine Full-Flow Gear Oil Filtration

- **High flow restriction + High viscosity  
= Excessive  $\Delta P$**
- **Cold-start by-passing generates  
spikes of contaminants**
- **Short service life, < 6 month cycle**



# Visual Comparison Conventional & New Generation Filter Media



# Field Test Protocol

## İ Full-Flow Filtration

- Conventional 10 µm filters
- New Generation 10 µm filters
- New Generation 5 µm filters

## İ Two Wind Farm Sites

- Both located in Northern North America

## İ Turbines

- 1.5 MW
- Total of 27 units

## İ Gearbox Lubricants

- 3 different manufacturers: A, B, C
- All PAO-based ISO 320 gear oil lubricants

## Wind Farm #1 Goals

1. Cleaner oil.
2. 12 month service life for 5  $\mu\text{m}$  filters.

## Wind Farm #2 Goals

1. Cleaner oil.
2. 6 month service life for 5  $\mu\text{m}$  filters.

# Field Test Limitations

## • Gear Oil Sampling

- Bonus climbs.
- Difficult environment for obtaining representative samples.
- Background counts likely.

## • Gear Oil Particle Counting

- Good: All performed at same lab.
- Accuracy confounded by phantom counts.

## • Overall

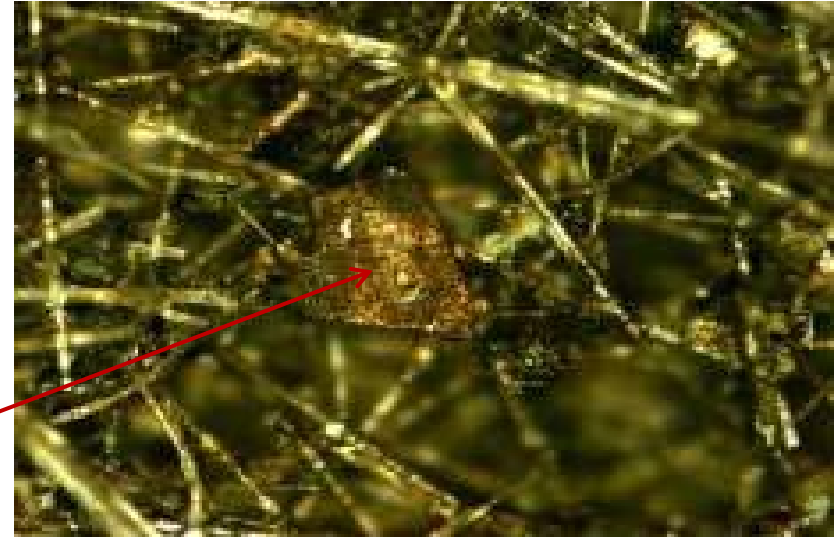
- Reported particle counts higher than system.
- Greater relative error for cleaner systems.

## • Operating Environment

- Conform to wind farm test goals.



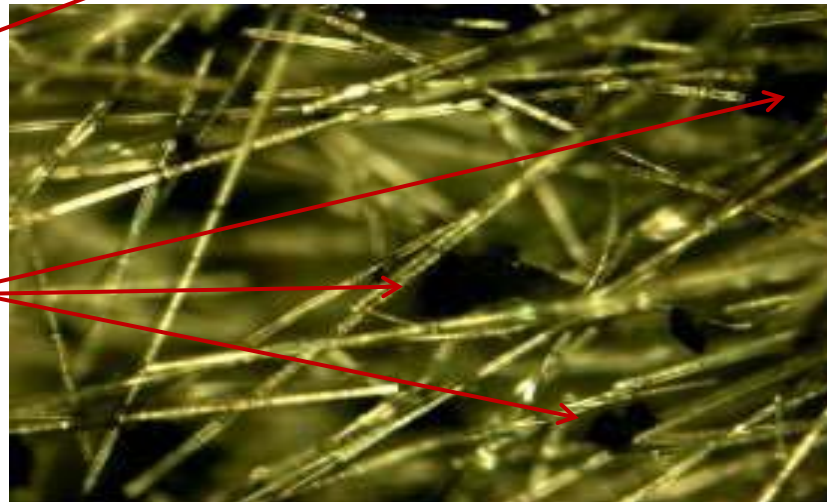
# 10 $\mu\text{m}$ Filter, 6 Months Service Upstream Surface (Top Layer) Optical Microscope



Metallic  
Wear Debris



Organic



All photos  
at 25 X  
magnification



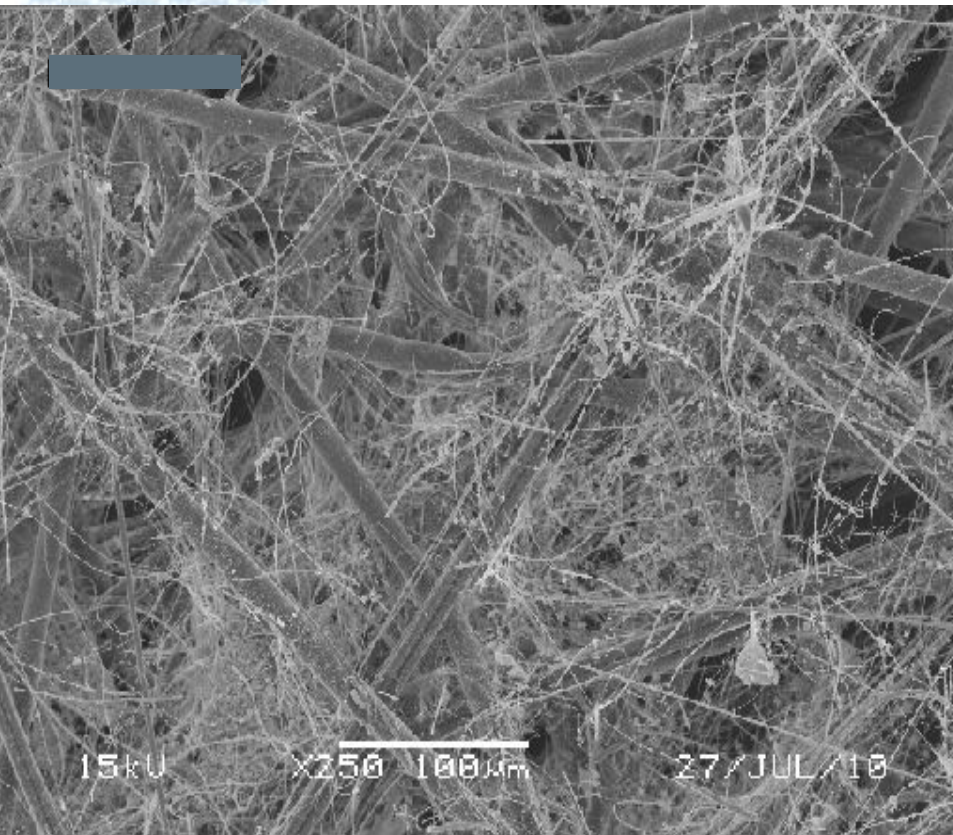
# 5 $\mu\text{m}$ Filter, 14 Months Service Upstream Surface (Top Layer) Optical Microscope



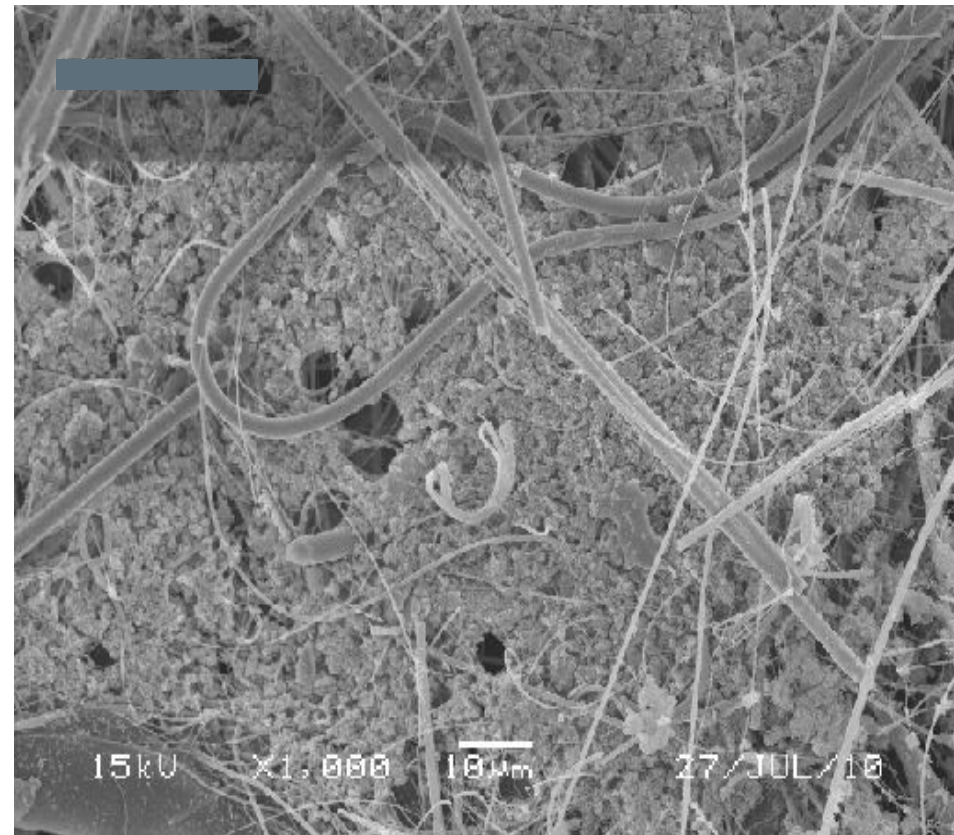
Metallic  
Wear Debris

All photos  
at 25 X  
magnification

# 5 $\mu\text{m}$ Filter, 14 Months Service Upstream Surface (Top Layer) Scanning Electron Microscope



250X  
Magnification



1000X  
Magnification

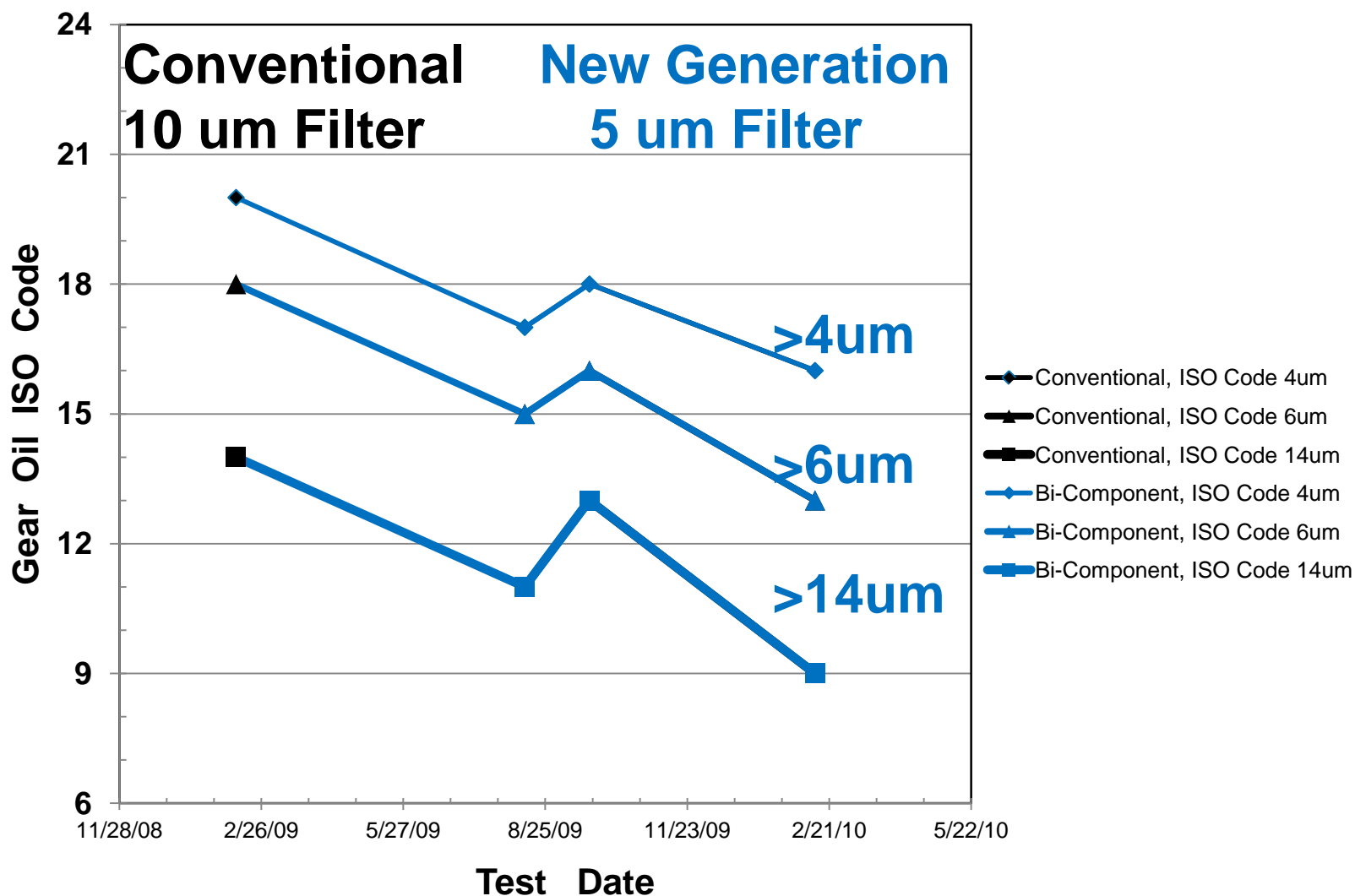
# 5 µm Filter, 14 Month Service Upstream Surface (Top Layer) EDS Analysis

ELEMENT	WEIGHT %	ATOM %	
CARBON	22.2	44.1	Organics
OXYGEN	15.7	23.2	
SODIUM	2.2	2.2	
MAGNESIUM	1.0	1.0	
ALUMINUM	0.5	0.5	
SILICON	5.0	4.2	
PHOSPHORUS	2.0	1.5	
SULFUR	2.7	2.1	
POTASSIUM	0.5	0.3	
CALCIUM	1.1	0.6	
CHROMIUM	0.2	0.1	
IRON	47.0	20.3	Wear Debris
TOTAL:	100	100	

# Field Test Particle Count Data

## Gearbox Timelines

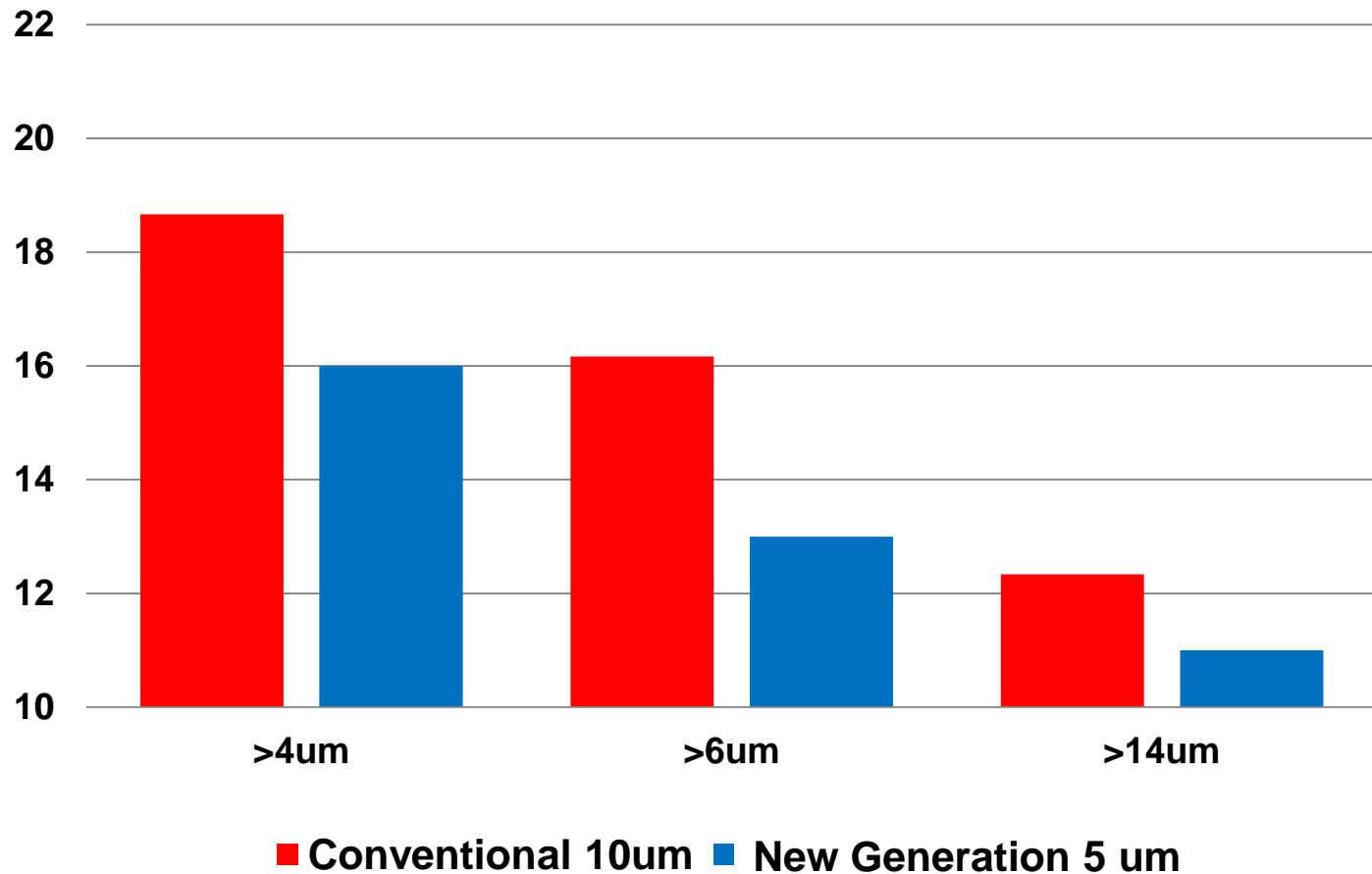
Wind Farm #1: Turbine 8 Gear Oil B





# Field Test Particle Count Data Averaged ISO Cleanliness Codes

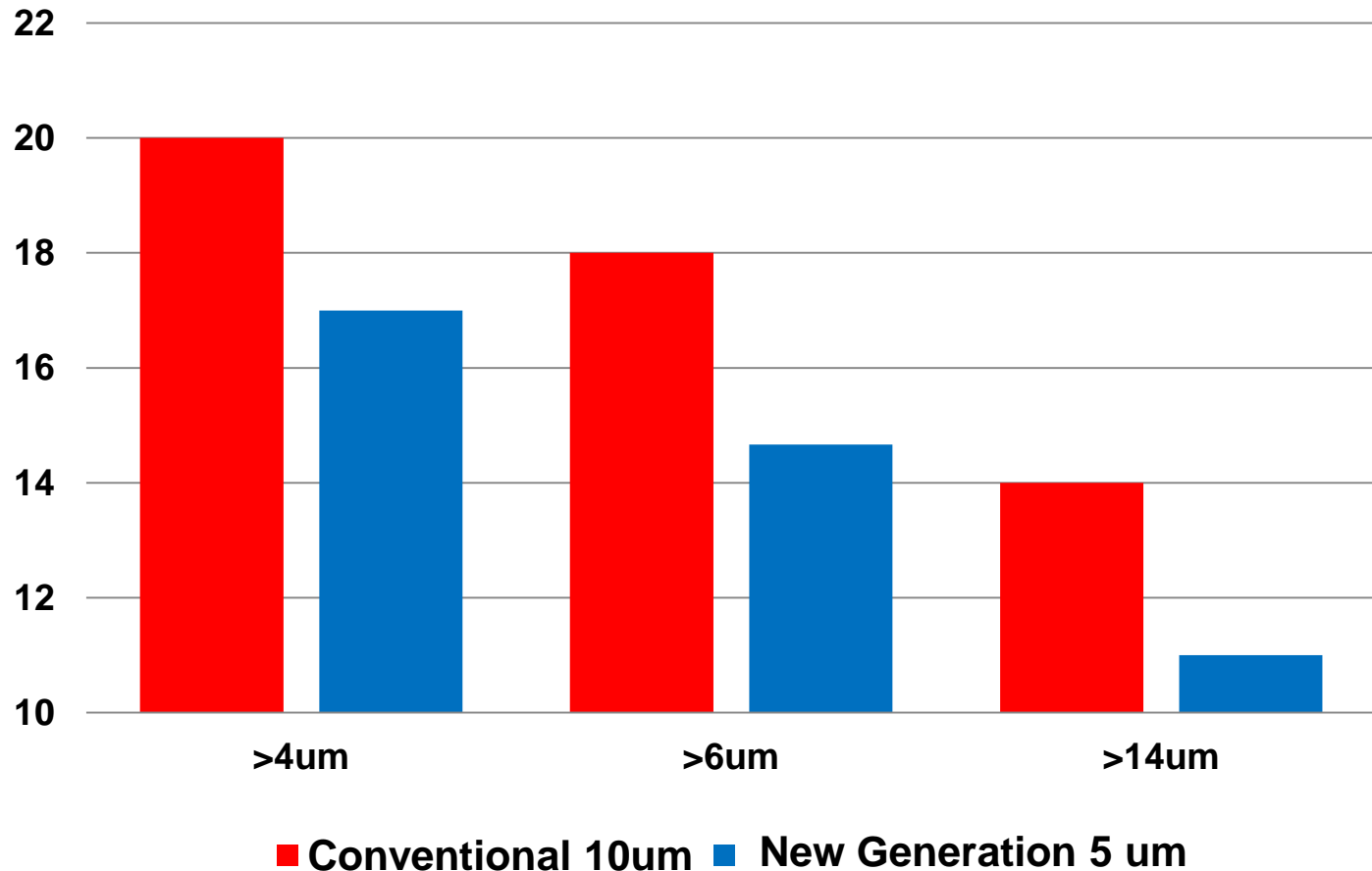
**Wind Farm #1: Turbine 1 Gear Oil A**





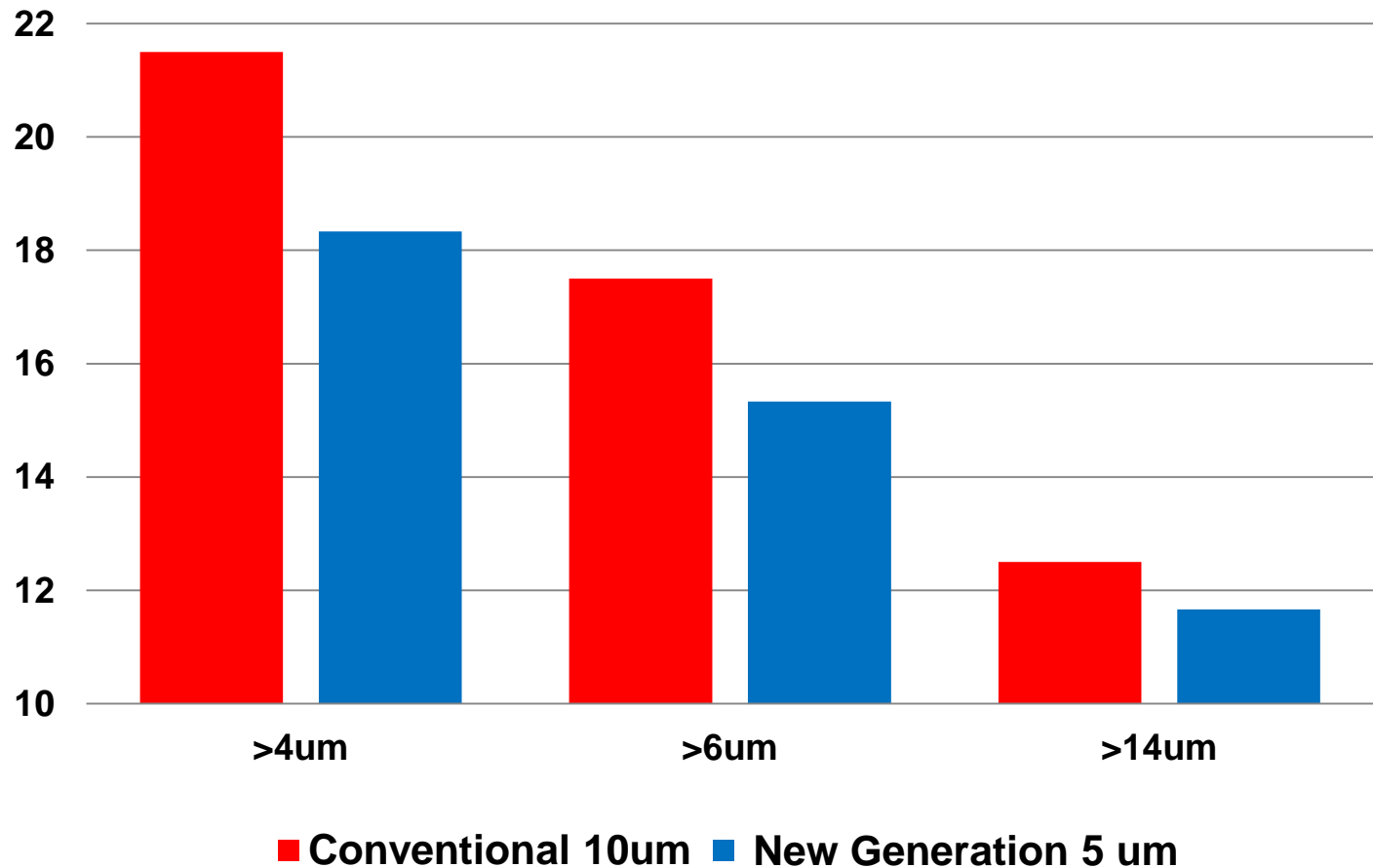
# Field Test Particle Count Data Averaged ISO Cleanliness Codes

Wind Farm #2: Turbine 8 Gear Oil B



# Field Test Particle Count Data Averaged ISO Cleanliness Codes

**Wind Farm #2: Turbine 9 Gear Oil C**



# Field Test Particle Count Data

## Averaged ISO Codes

<b>Gear Oil</b>	<b>Filter Type</b>	<b>ISO Averages</b>
<b>Brand A</b>	<b>Conventional</b>	<b>19/16/13</b>
	<b>New Generation</b>	<b>17/15/12</b>
<b>Brand B</b>	<b>Conventional</b>	<b>21/17/13</b>
	<b>New Generation</b>	<b>19/16/12</b>
<b>Brand C</b>	<b>Conventional</b>	<b>21/18/13</b>
	<b>New Generation</b>	<b>19/16/11</b>



# Wind Farm #1

## 1. Goals

- Cleaner oil.
- 12 month service life for new generation 5  $\mu\text{m}$  filters.

## 2. Results

- Both goals met.
- Test terminated after all 5  $\mu\text{m}$  filters went well past the 12 month target.
- Several filters removed at 16 months.
- All new gen filters were not plugged and had several months remaining life.

# Wind Farm #2

## **1. Goals**

- Cleaner oil.
- 6 month service life for new generation 5  $\mu\text{m}$  filters.

## **2. Results**

- Both goals met.
- Per site manager request, test terminated to conform to 6 months maintenance cycle.
- All new generation filters were not plugged and had many months remaining life.





# Conclusions

- 1. Wind turbine gear oil filters remove metallic wear debris and organic particles.**
- 2. New Generation wind turbine filters improve oil cleanliness by at least:**
  - 1) 2 ISO Codes.**
  - 2) 4 times cleaner.**
- 3. New Generation filters extended change intervals from 6 months to • • • • •**
- 4. Similar results for three different gear oils.**

**Thank You  
For Your Interest**

**For Additional Information  
Please Visit  
The Donaldson Booth  
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