Ester Transformer Fluids

IEEE/PES Transformers Committee

Meeting October 7, 2003

C. Patrick McShane, Cooper

T.V. Oommen, ABB

Charles Tanger, Cargill

Meeting Mission: General Education Purpose Only

Overview

- What are Ester Based Dielectric Coolants?
- How do they compare to Mineral Oils?
- What are the Key Benefits?
- Where, in What, are EBDCs Applied
- How have they Performed in the Field?

Ester Transformer Fluids

Natural Ester Sourcing & Processing

Charles Tanger

Cargill, Inc.

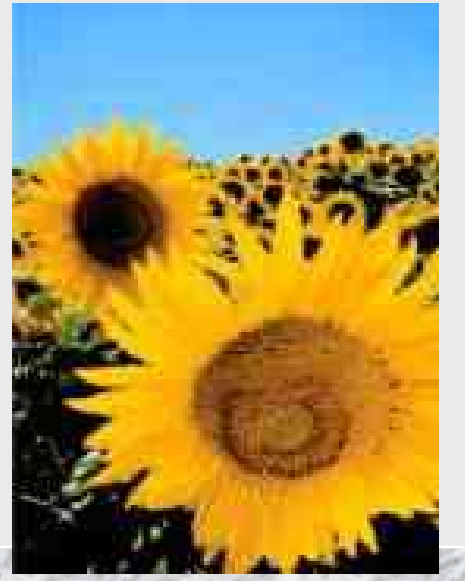
Natural Esters (Vegetable Oils)

- Sources
- Chemistry - Comparison to Mineral Oil
- Refining
- Key Properties - Comparison to Mineral Oil

Natural & Synthetic Esters

- Synthetic Polyol Esters have been used as a PCB substitute in specialty transformer applications since the early Eighties in the USA. They are formed by processing fatty acids and alcohols.
- Natural Esters are produced from seeds.

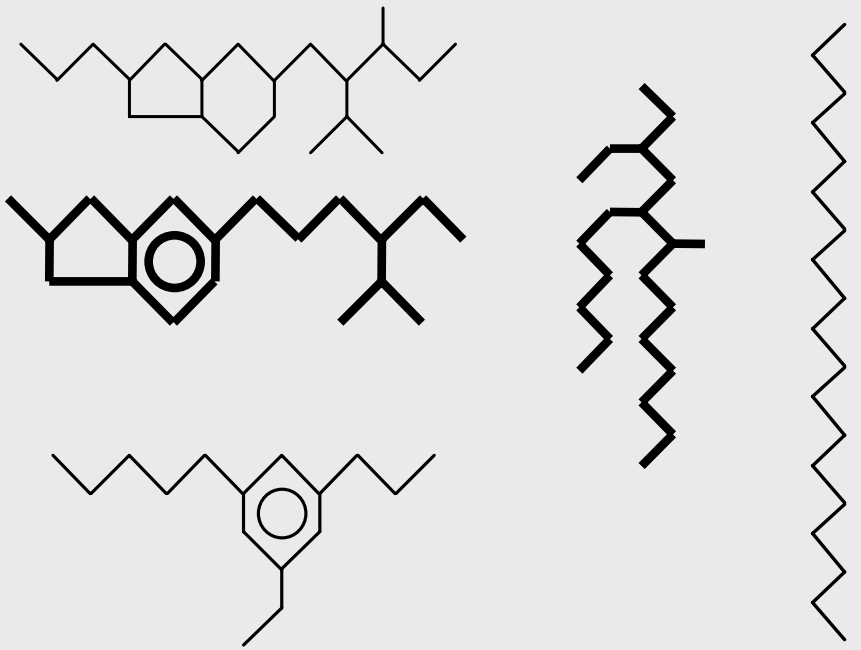
Vegetable Oils are Natural Esters



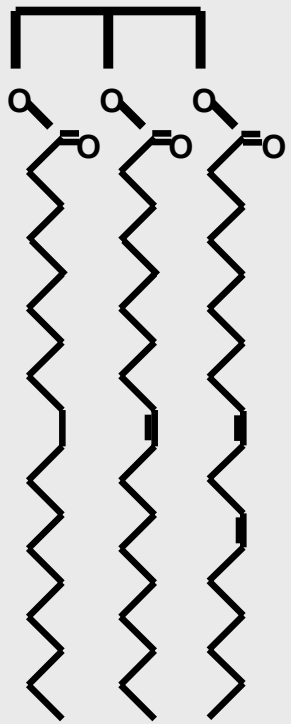
Vegetable Oil vs. Mineral Oil

Advantages	Limitations
• Renewable Resource • Much Higher Flash & Fire Points • Environmentally Friendlier • Several Performance Improvements	• Inferior oxidative stability • Poorer low temperature properties • Higher Viscosity • Higher Cost to Produce

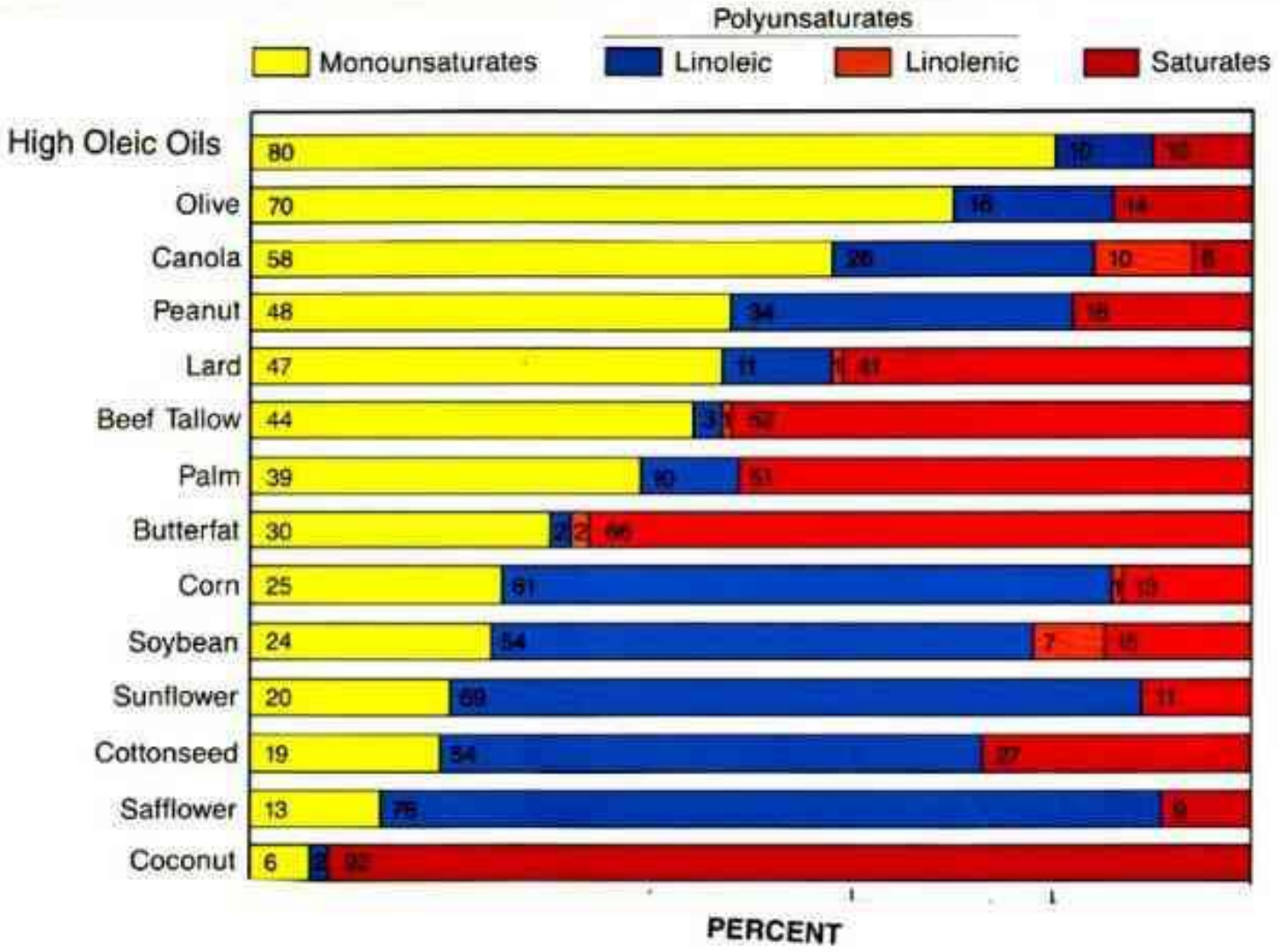
Vegetable Oil vs. Mineral Oil



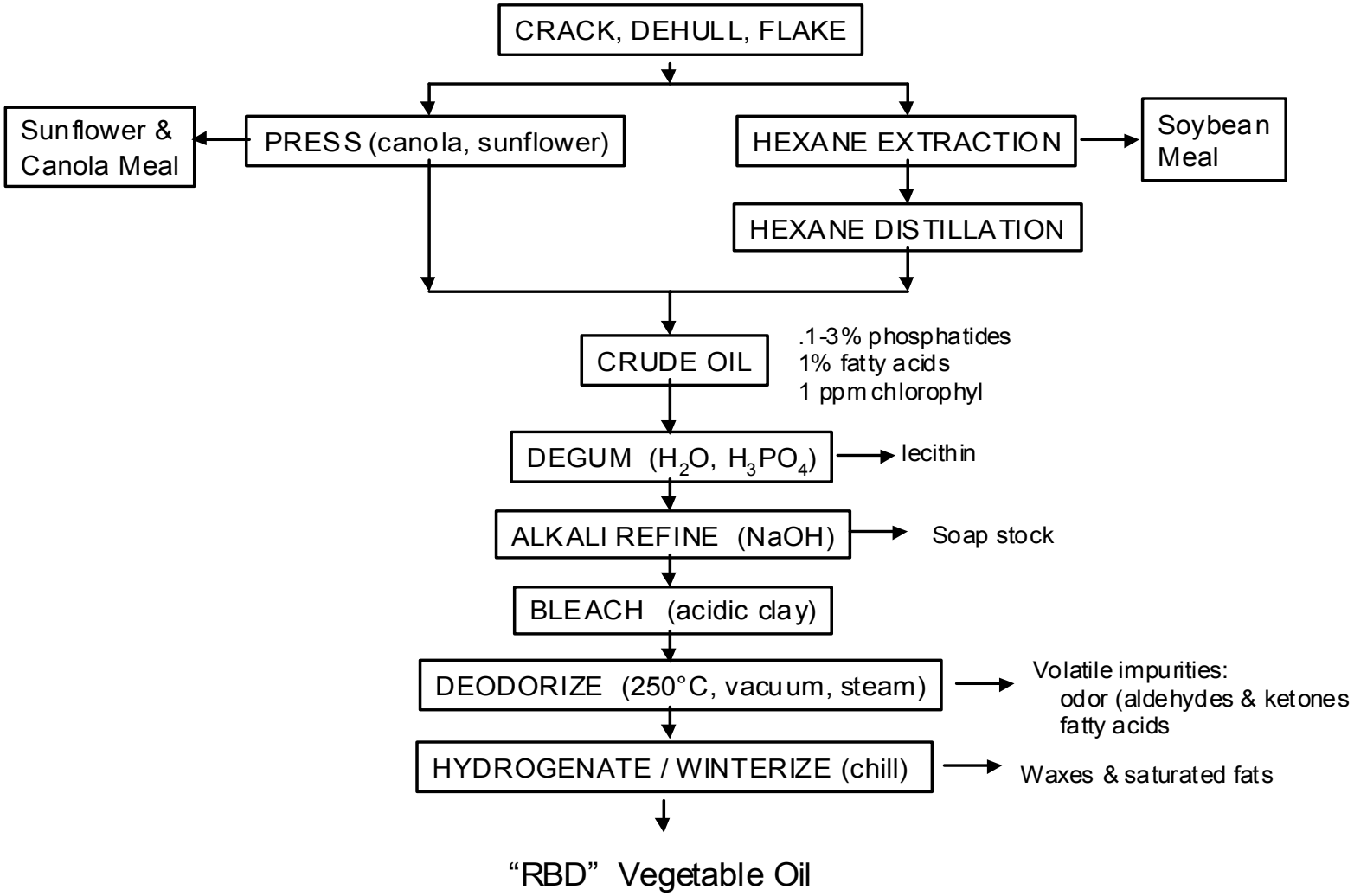
Naphthenic Mineral Oil



Vegetable Oil


COMPARISON OF VEGETABLE OILS
Polyunsaturates
Monounsaturates
Linoleic
Linolenic
Saturates
High Oleic Oils
Olive
Canola
Peanut
Lard
Beef Tallow
Palm
Butterfat
Corn
Soybean
Sunflower
Cottonseed
Safflower
Coconut
80
70
58
48
47
44
39
30
25
24
20
19
13
6
PERCENT

Seed Oil Refining



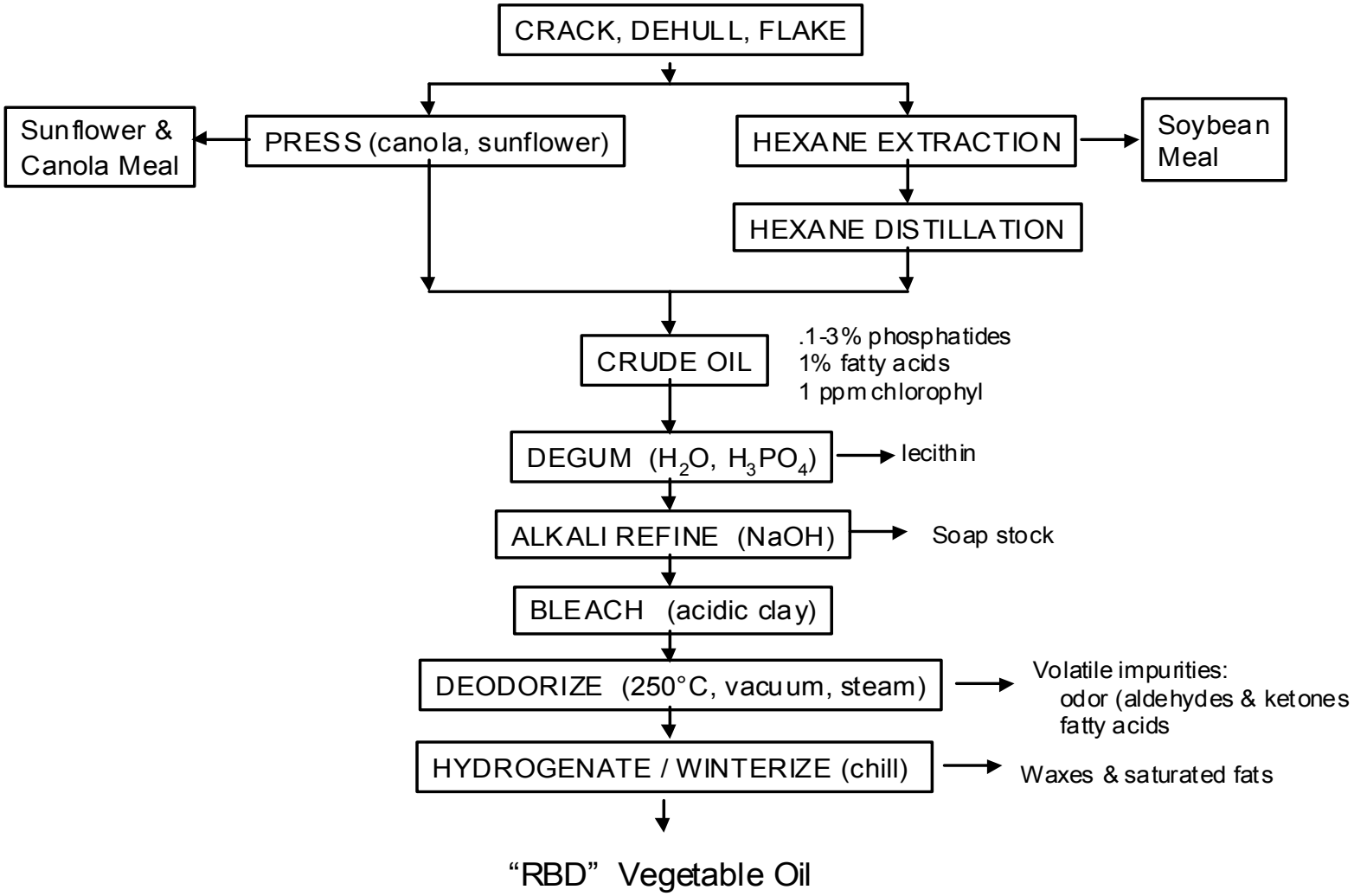
Beans to Crude Vegetable Oil

Soybeans

Cracked Soybeans

Crude Soybean Oil

Seed Oil Refining



RBD Oil
(Refined, Bleached, Deodorized)

RBD SBO

Vegetable Oil Refining

- Start with beans or seeds.
- End with purified oils.
- Purified oils are the **starting point** for transformer oils

Ester Transformer Fluids

Key Properties & Standards

T.V. Oommen, Consultant

ABB, Inc.

Natural Esters for Transformers

- RBD edible vegetable oils used for base.

- Further processing e.g. Removal of polar contaminates. Addition of performance enhancing additives

- Dielectric fluids from natural esters, remain highly biodegradable, with high flash and fire points, and can test non-toxic to sensitive species .

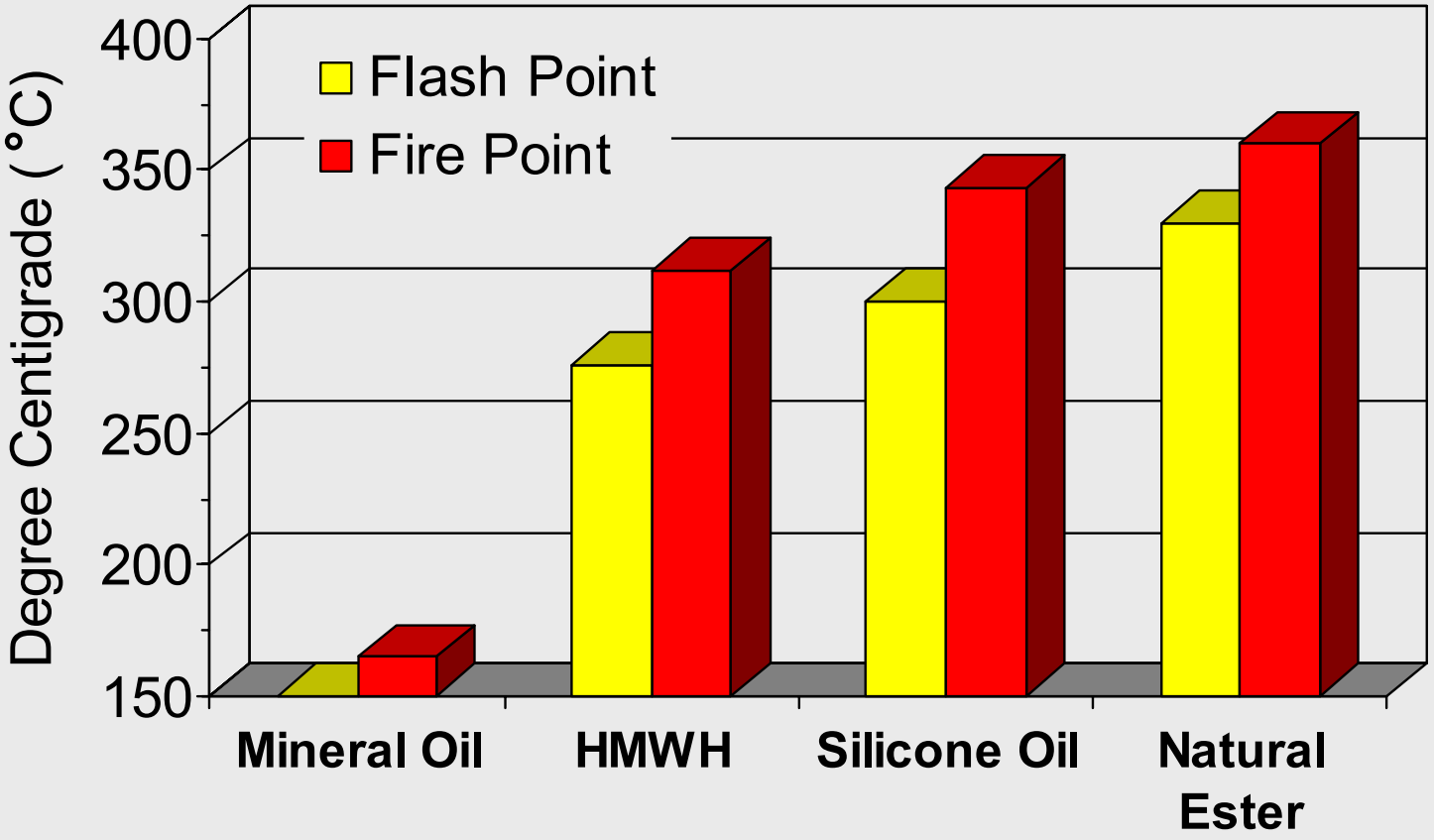
Use of Natural Esters in Electrical Equipment

- **New and Retrofill Application in the Field:**
  - **Distribution Transformers: Single and Three Phase Pole and Pad-mounted, Small Power.**
  - **Medium power Transformers**
  - **Mobile Substation Transformers**
  - **Voltage Regulators**
  - **Switchgear**
  - **Transformer- Rectifier Sets**

Transformer Oils – Physical Properties

PROPERTY	STD. MIN OIL D 3487	HI FIRE PT D 5222	BIOBASED D 6871
Color, max.	0.5	2.5	1.0
Visual Examination	B&C	B&C	B&C
Flash Point, °C, min.	145	275	275
Fire Point, °C, min.	--	300	300
Interfacial Tension, 25°C, dynes/cm, min.	40	40	--
Pour point, °C, max.	-40	-21	-10
Spec. Grav., 15°C, max.	0.91	0.91	0.96
Viscosity, max. cSt: 100°C	3.0	14	15
40°C	12	130	50
0°C	76	2500	500

Relative Flash and Fire Points



Transformer Oils – Electrical Properties

PROPERTY	STD. MIN OIL D 3487	HI FIRE PT D 5222	BIOBASED D 6871
Dielectric breakdown, KV min.:			
Disk electrodes, min.	30	30	30
VDE elect., 0.04" gap, min.	20	--	20
VDE elect., 0.08" gap, min.	35	--	35
Impulse,1" gap, 25°C, min.	145	--	130
Gas. tend., µL/min, max.	30	30	0
Diss. Fact. % max, 25° C	0.05	0.05	0.2
100°C	0.30	0.30	4.0

Transformer Oil – Chemical Properties

PROPERTY	STD. MIN OIL D 3487	HI FIRE PT D 5222	BIOBASED D 6871
Oxidative Stability:			
72 hrs - % sludge, max.	0.15 / 0.1	0.15	not estab.
Acid number, max.	0.5 / 0.3	0.30	not estab.
164 hrs - % sludge, max.	0.3 / 0.2	0.3	not estab.
Acid number, max.	0.6 / 0.4	0.60	not estab.
RBOT minutes, min.	- / 195	195	not estab.
Corrosive Sulfur	pass	pass	pass
Water, ppm, max.	35	35	200
Acid number	0.03	0.03	0.06
PCB Content	not detectable	not detectable	not detectable

Test & Verification Data Available

- Physical, chemical and electrical characteristics
- Heat transfer properties
- Water solubility data
- Decomposition under thermal and electrical stress
- Functional life test data
- Long term aging data
- Field performance in commercial units
- Environmental performance data
- Retrofilling units having other fluid types

Test & Verification Data Available

References:

- IEEE, CIGRE, ACS, CIRED Publications and Proceedings
- ASTM D6871-03 Standard
- Manufacturers/Suppliers Literature
- Published Testing Laboratories Reports (e.g. Doble Engineering, EPRI, US EPA ETV, UL, FM)

Ester Transformer Fluids

Performance & Applications

C. Patrick McShane
Cooper Power Systems

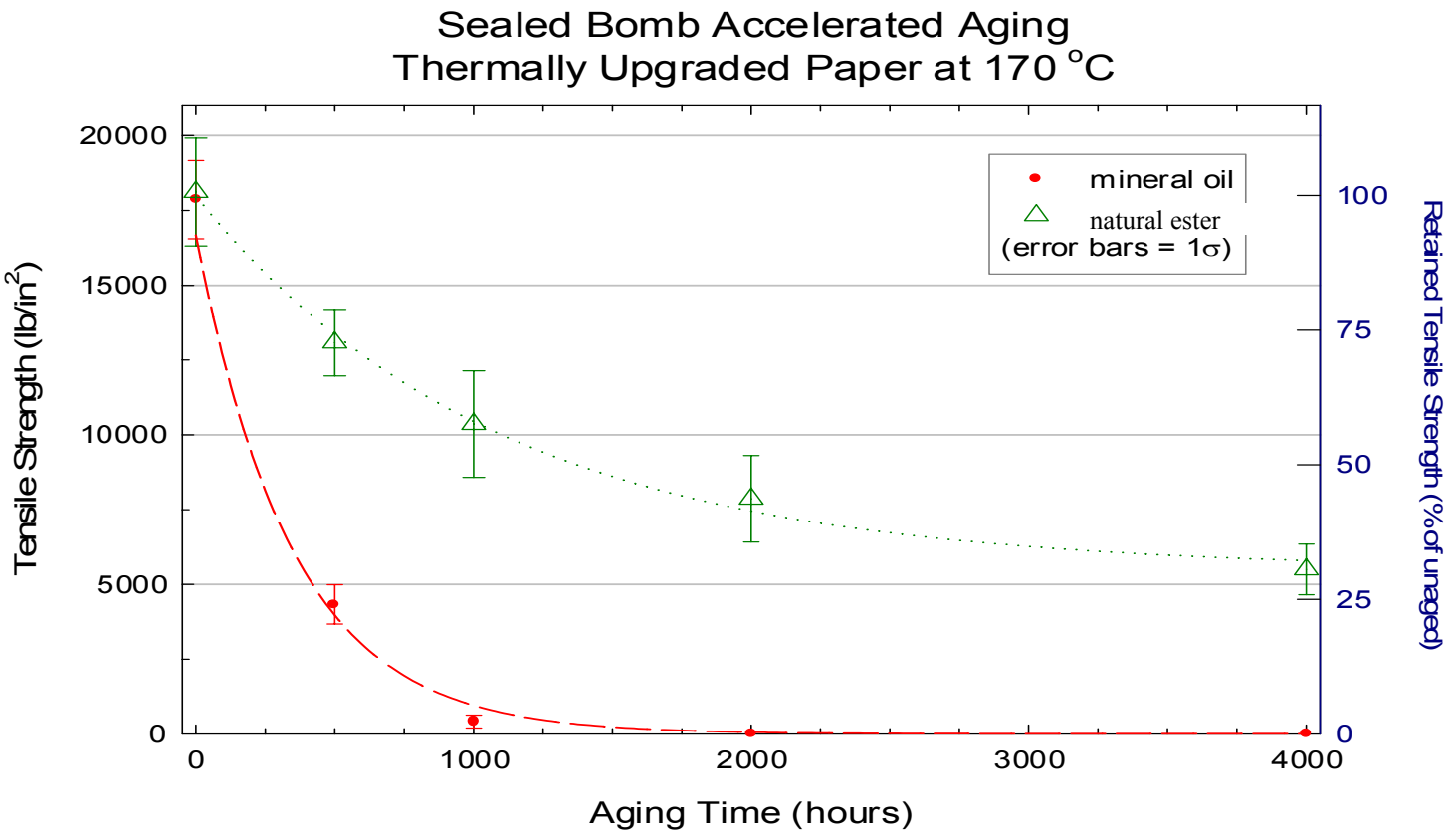
Performance Improvements vs. MO

- Insulating Paper Aging Rate Reduced
- Essentially no Sludge Precipitate
- Reduction of Paper Moisture Levels
- Much Lower Gassing Tendency Value
- Reduced Coking on Bare Copper
- Potential Self Sealing “weeping” leaks

Insulation Paper Aging Rate Reduced

- **Accelerated Paper Life Testing using the Sealed Tube Method, comparing aging in natural ester fluid versus mineral oil to reach a defined life end point:**
  - **Thermal Upgraded Kraft: Up to 8 times longer.**
  - **Non-Upgraded Kraft: > 10 times longer.**

Comparison of Tensile Strength vs. Time



Visual Comparison vs. Aging Time

Natural Ester Mineral Oil

Sealed Tube Test - ML 152-2000
Upgraded Paper 500 hr @ 170°C

Natural Ester Mineral Oil

Sealed Tube Test - ML 152-2000
Upgraded Paper 1000 hr @ 170°C

Natural Ester Mineral Oil

Sealed Tube Test - ML 152-2000
Upgraded Paper 2000 hr @ 170°C

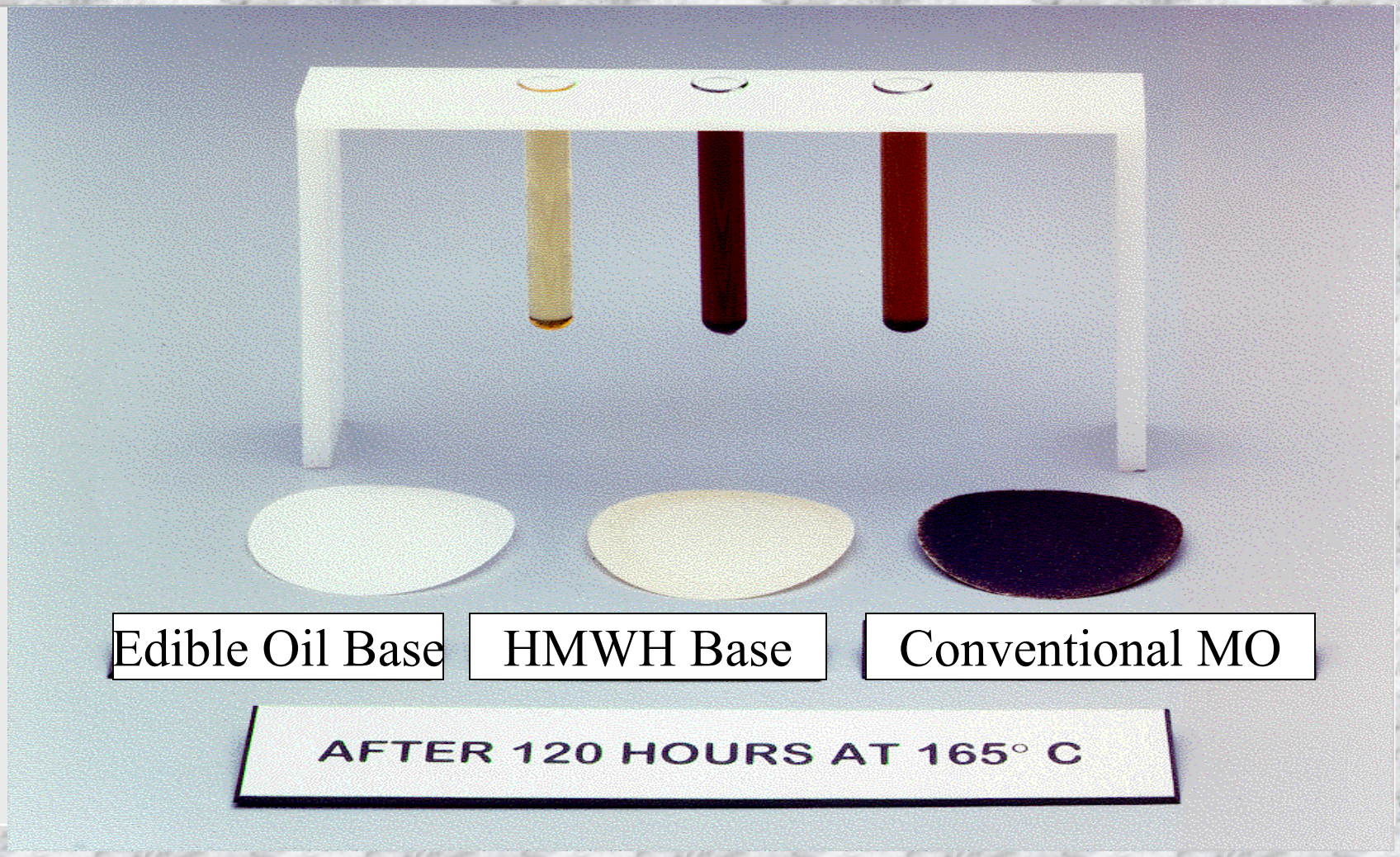
Natural Ester Mineral Oil

Sealed Tube Test - ML 152-2000
Upgraded Paper 4000 hr @ 170°C

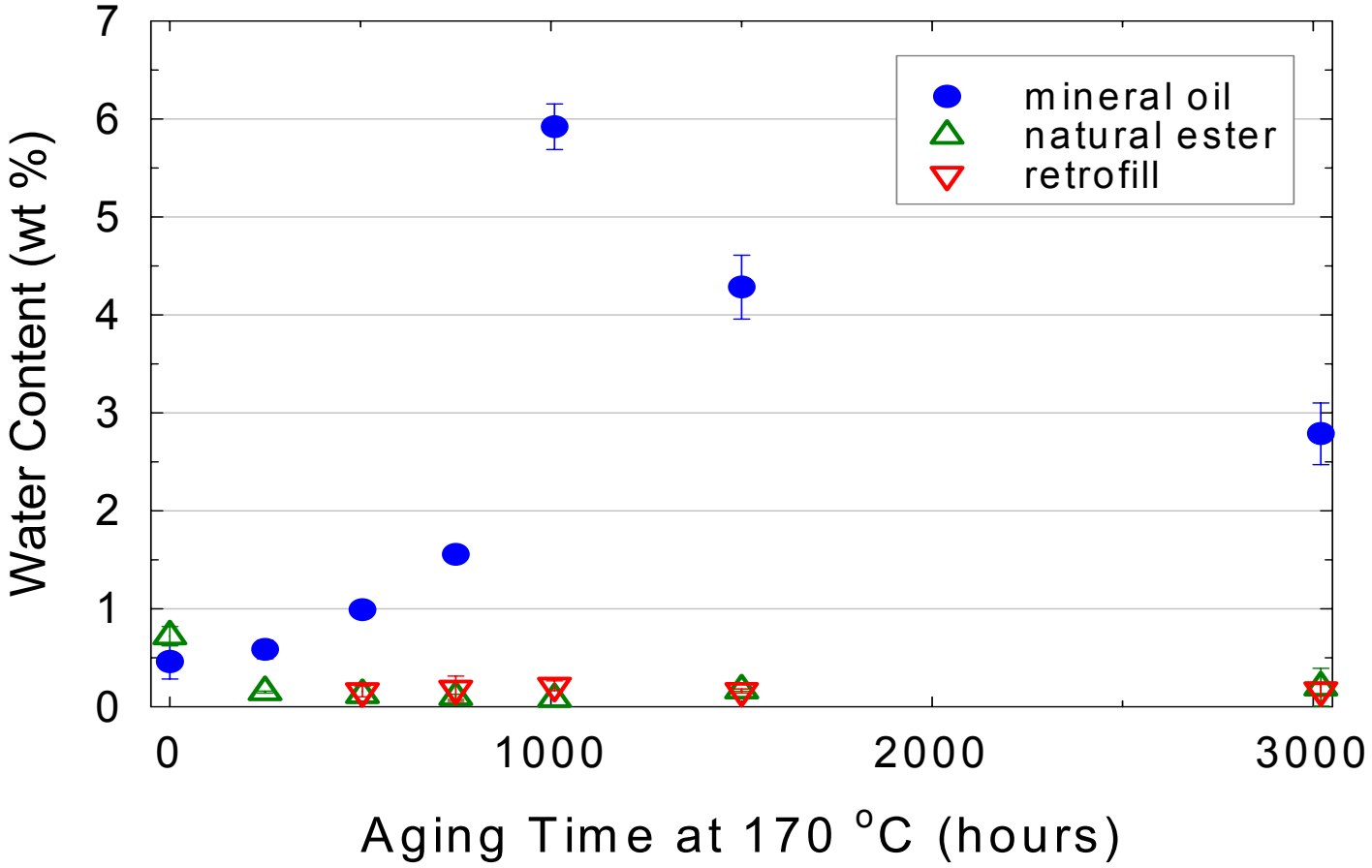
Essentially no Sludge Precipitates

- Mineral oils, when oxidized tend to form and precipitate sludge, potentially reducing dielectric and thermal performance.
- Natural ester oils, when oxidized, tend to polymerize but not form sludge precipitates.

Hot Oil, Open Beaker Aging Test



Reduction in Paper Moisture



Lower Gassing Rate

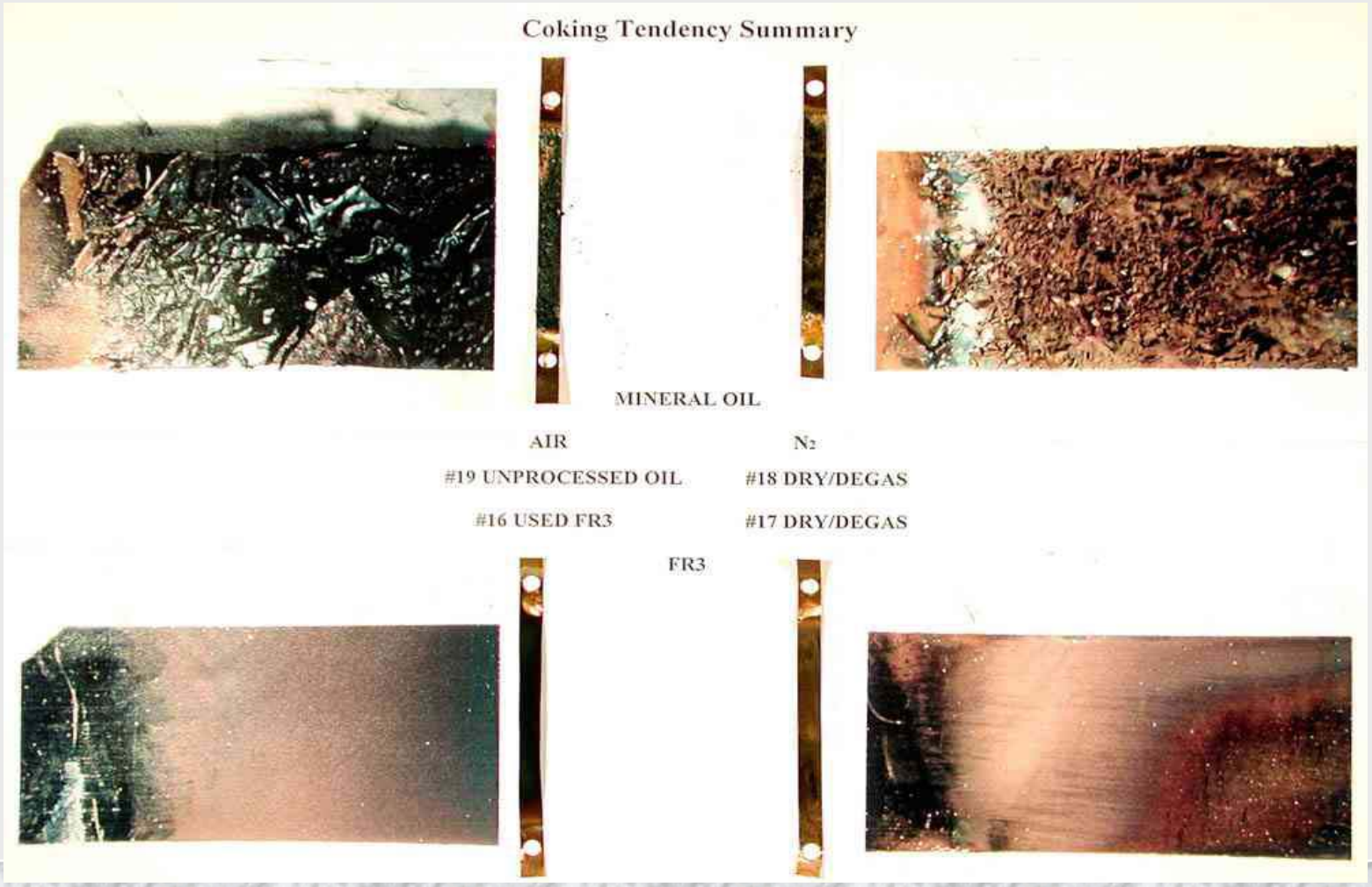
- ASTM D2300 Gassing Tendency:
  - Mineral Oil typically around -5μL/min.
  - Natural Esters between -50 to - 80 μL/min.
- Doble Partial Discharge -TCG:
  - Mineral Oil ---------- ≈ 1,500 ppm
  - Natural Esters ---------- ≈ 1,100 to 1,300 ppm

Reduced Coking Tendency

- Immersed Hot Copper Surface Test:
  - With air head space, natural ester produced 1/40 coking relative to mineral oil.
  - With nitrogen head space, natural ester produced non-detectable coking.

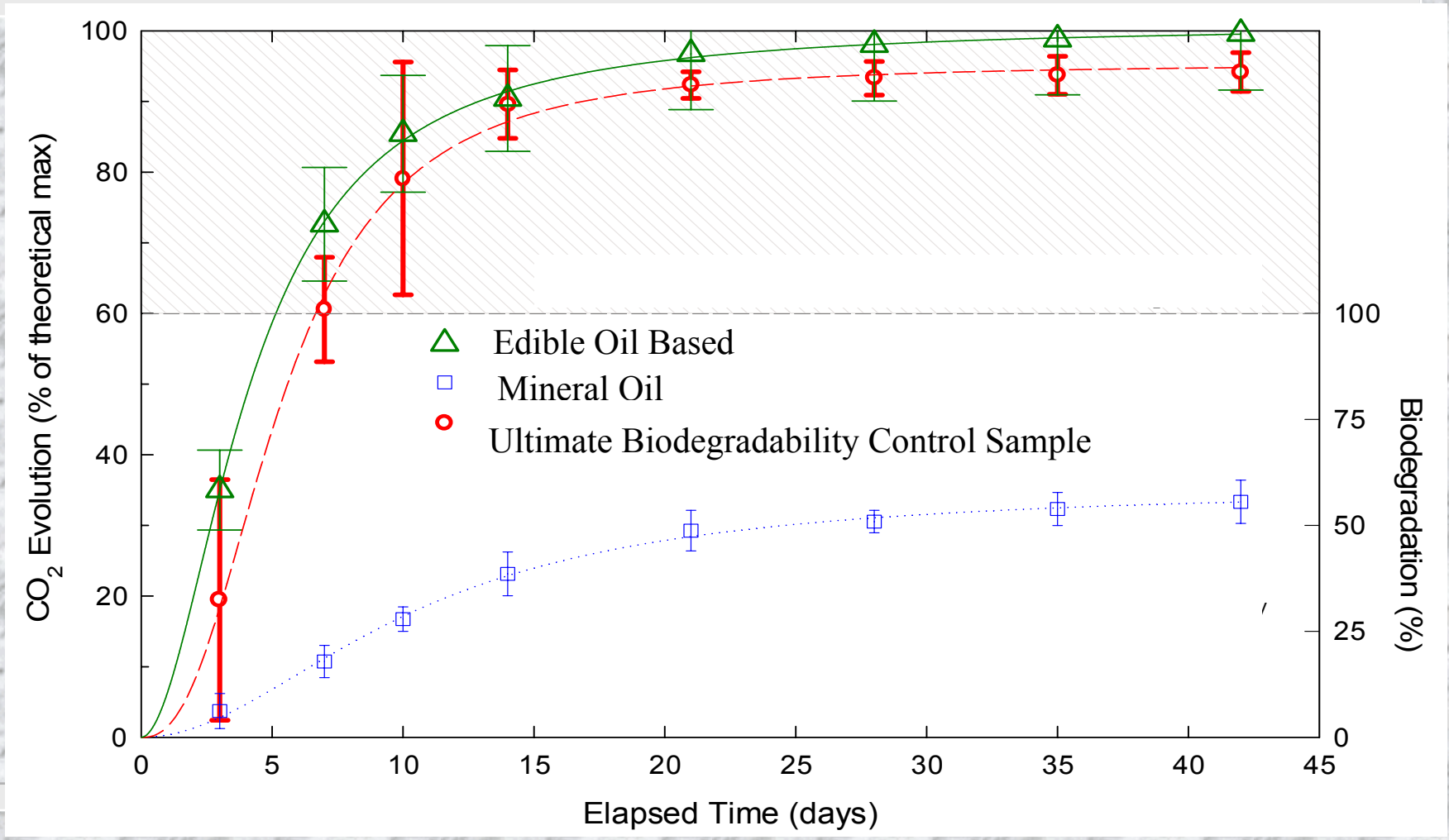
Relative Coking on Hot Copper

Mineral Oil Produced Up to 40 Times by Weight



Aerobic Aquatic Biodegradation

Test Method: EPA OPPTS 835.3100



Initial Commercial Uses of Natural Esters

- Distribution and small power units:
  - New Units 1999
  - Retrofill 1999
- Medium Power Transformers:
  - Retrofill 2001
  - New Units 2003
- TR Sets
  - Retrofill 1999:
- Switchgear
  - New Units 2002:

Field Performance

Average Values of Nine 3 Phase Pad-Mounted Transformers 77th Month Samples

	New	Ave.	Std. Dev.
Moisture ppm	15	33	14
Dielectric Strength	62	70	10
Fire Point	359	359	2
Viscosity	32.7	32.4	0.3
Dissipation Factor	0.12	.15	.03

Thank You ! - Questions?