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Thermal Life Evaluation of High Temperature Insulation Systems and Hybrid Insulation Systems in Mineral Oil

R. J. Whearty

W. J. McNutt

R. L. Provost

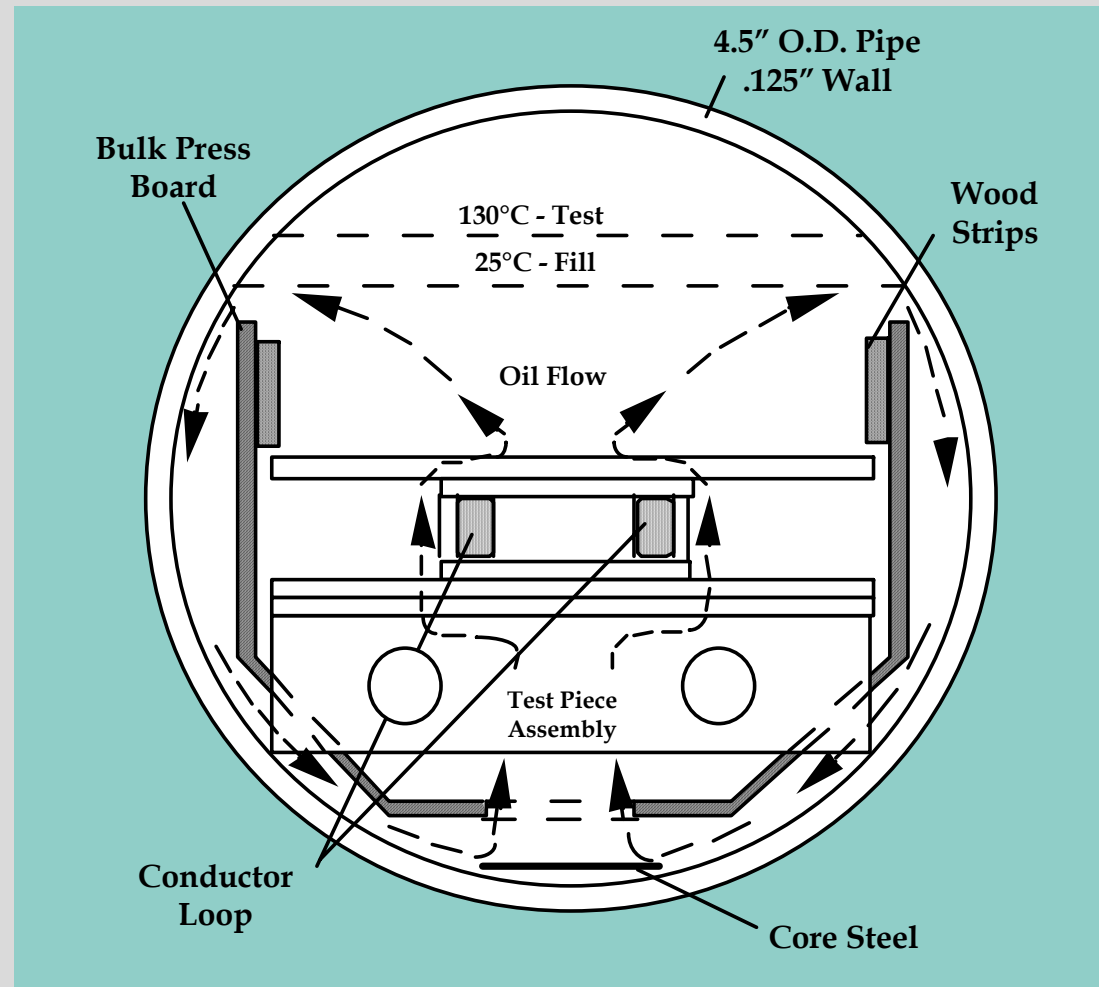
Thermal Aging of Solid/Liquid Insulation Systems

- **Current State-of-the-art testing limited**
 - Sealed tube laboratory aging
 - Full scale transformer model
- **New combinations difficult to test**
 - High temp. solids with low temp. fluids
 - Low temp. solids with high temp. fluids
 - High temp. solids and fluids

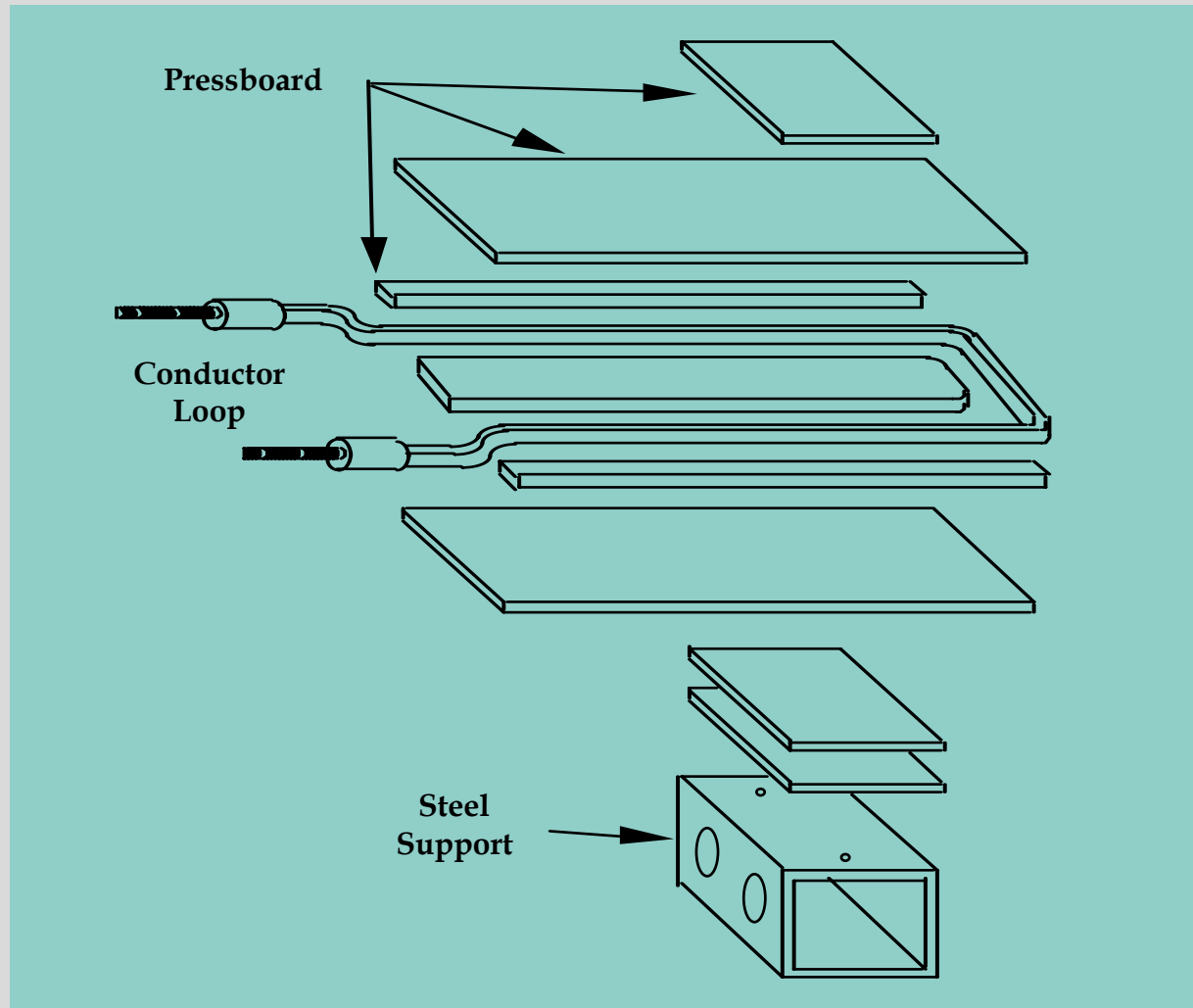
Thermal Aging of Solid/Liquid Insulation Systems

- **New Model Aging Cell Concept removes many of the problems**
 - **Separate thermal aging of high and low temperature portions**
 - **Simulates material ratios comparable to real transformers**
- **Initial Testing with combined materials in mineral oil verify the model effectiveness**

Cross Section of New Cell Model



Conductor Assembly Detail



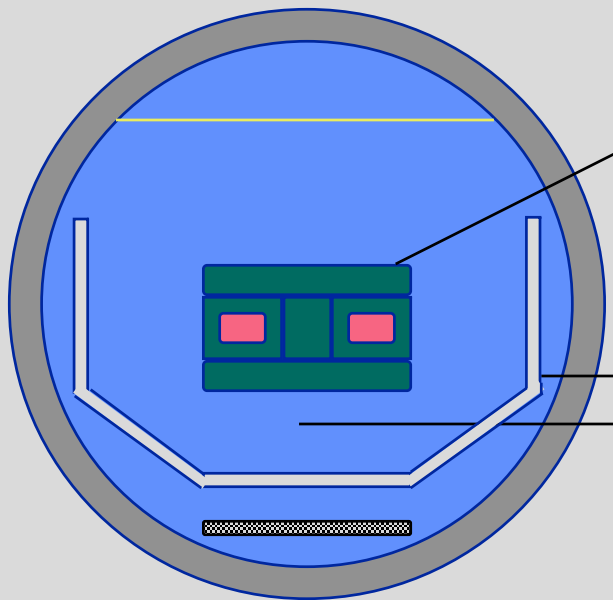
Aging Program Parameters

Initial Test Set

<u>Insulation System</u>	<u>Conductor Temp.</u> (°C)	<u>Bulk Oil Temp.</u> (°C)
Control: Cellulose-Mineral Oil	160	115
High Temp.: Nomex® - Mineral Oil	240	130
Hybrid: Nomex® - Cellulose - Mineral Oil	240	130

Aging Program Parameters

Initial Test Set



Cellulose

Cellulose
Paper &
Board

160 °C

Cellulose
Board

115 °C

Mineral Oil

Nomex®

Aramid
Paper &
Board

240 °C

Aramid
Board

130 °C

Mineral Oil

Hybrid

Aramid
Paper &
Board

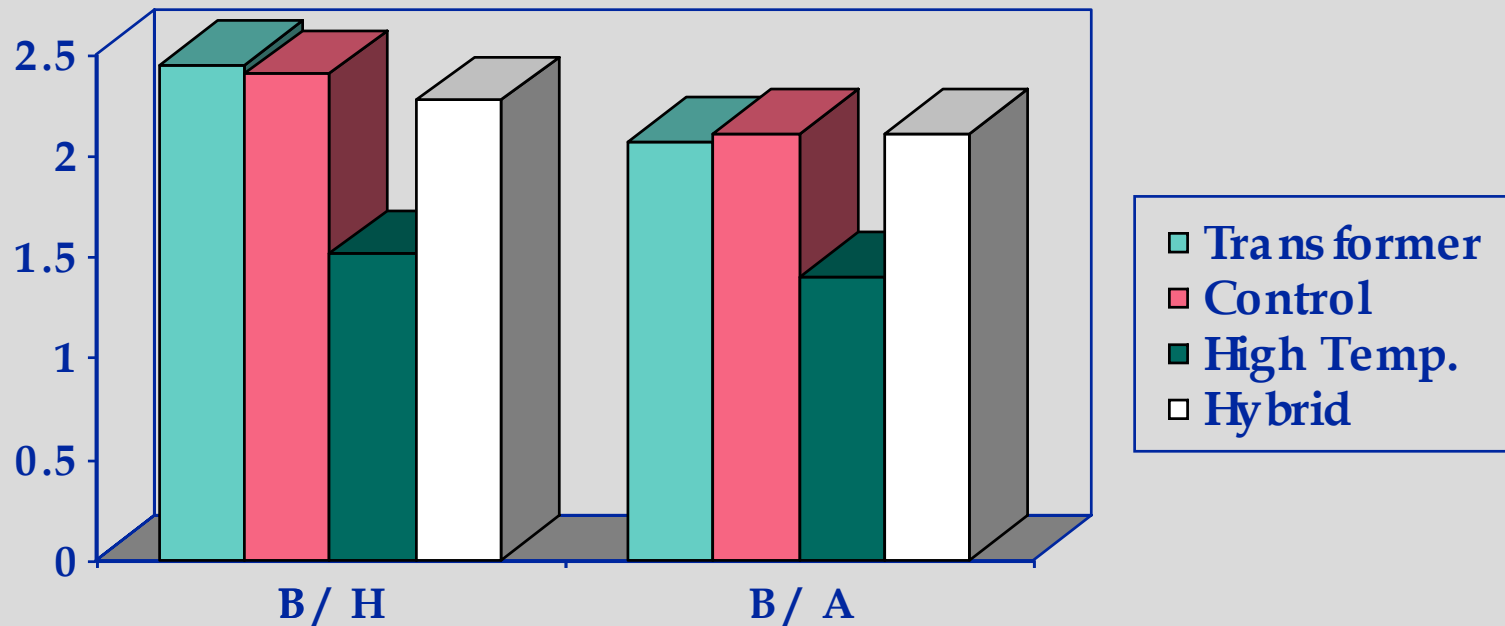
240 °C

Cellulose
Board

130 °C

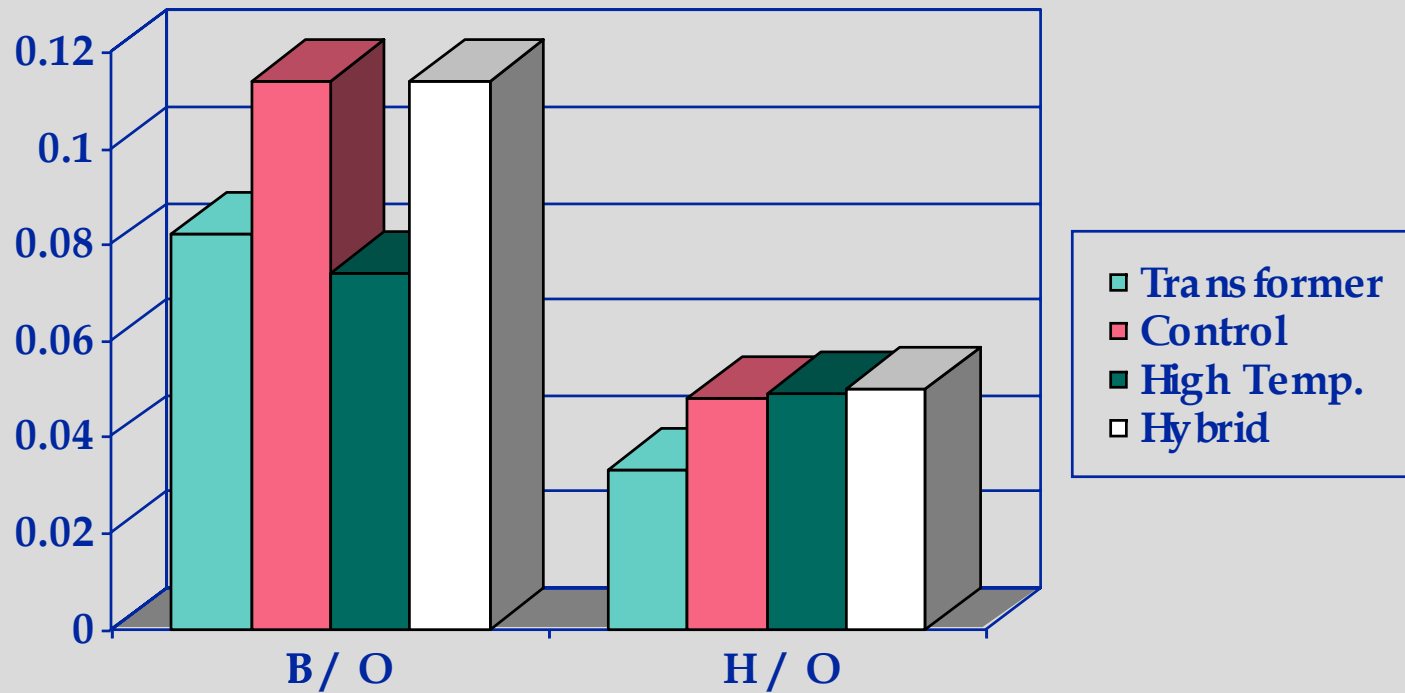
Mineral Oil

Material Area & Volume Ratios



H - Hot Insulation Volume
B - Bulk Insulation Volume
A - Area of Core Surface

Material Area & Volume Ratios



H - Hot Insulation Volume
B - Bulk Insulation Volume
O - Mineral Oil Volume

Test Program

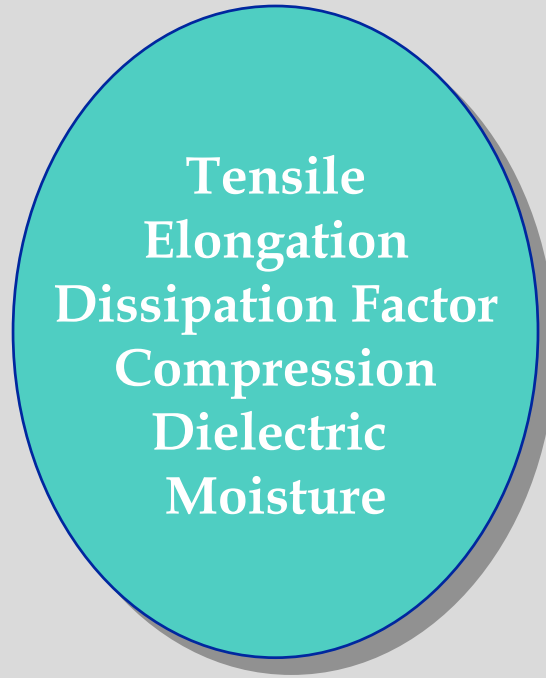
<u>Duration</u> (hours)	<u>Number of Control Cells</u>	<u>Number of High Temp. Cells</u>	<u>Number of Hybrid Cells</u>
500	3	1	2
1500	2	2	1
5000	1	1	1
10000		1	1
	<hr/>	<hr/>	<hr/>
Totals	6	5	5

Characterization Parameters

Liquid



**Hot
Insulation**



**Cool
Insulation**

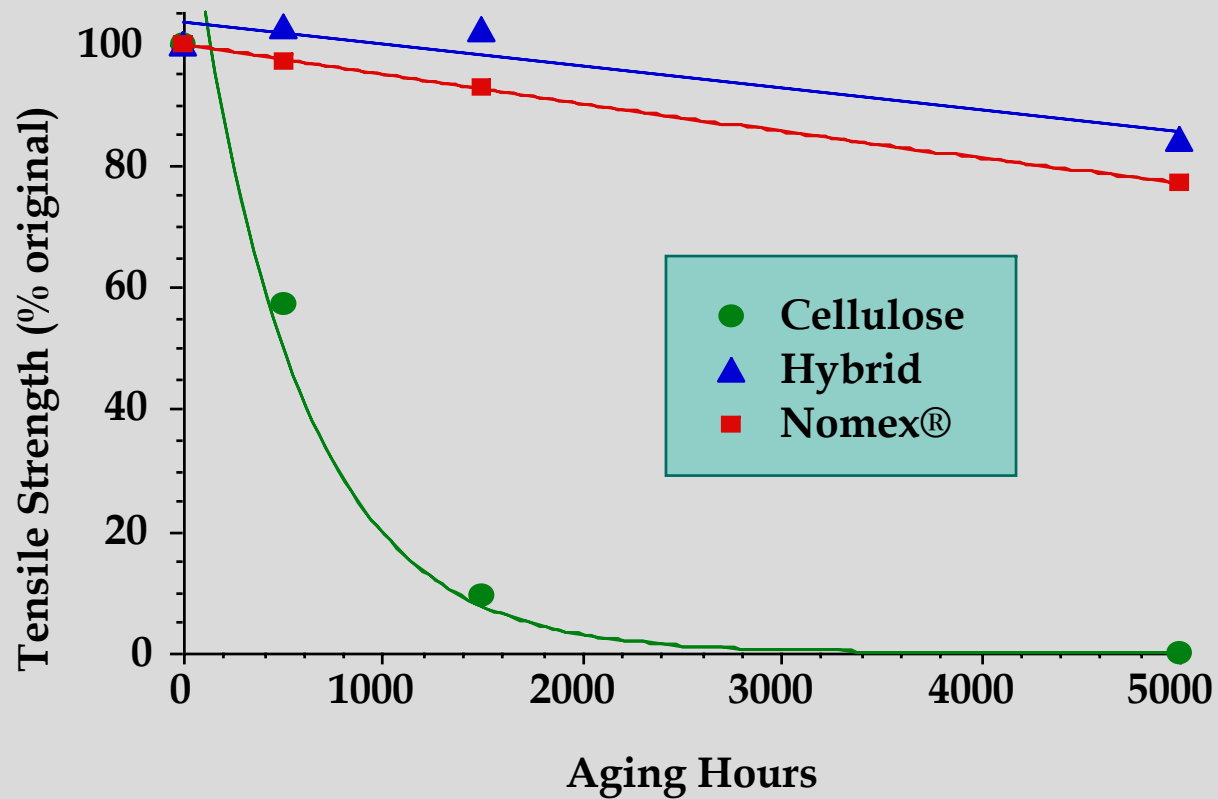


Aging Results - Conductor Wrap

<u>Model Type</u>	<u>Aging Temp. (°C)</u>	<u>Aging Time (hours)</u>	<u>Avg. Retained Tensile(%)</u>	<u>Avg. Retained Dielectric (%)</u>
Cellulose	160	500	49	74
			57	92
			64	76
Cellulose	160	1500	13	74
			6	88
Cellulose	160	5000	0	73
Hybrid	240	500	102	67
			103	69
Hybrid	240	1500	102	72
Hybrid	240	5000	84	60
		10000	26	75
NOMEX®	240	500	97	63
NOMEX®	240	1500	91	74
			94	80
NOMEX®	240	5000	77	71
		10000	9	52

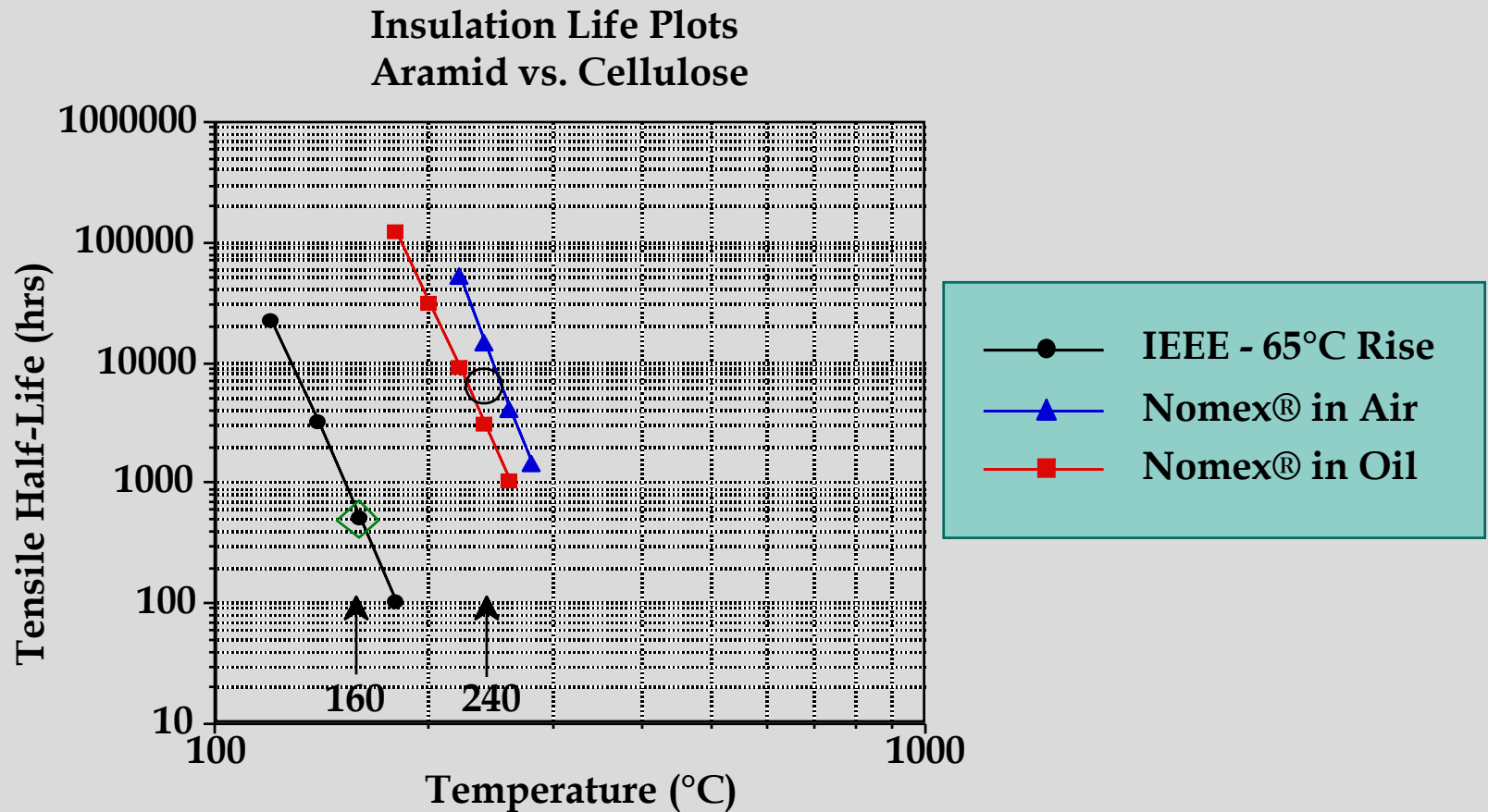
Conductor Wrap Aging Profile

Tensile Strength



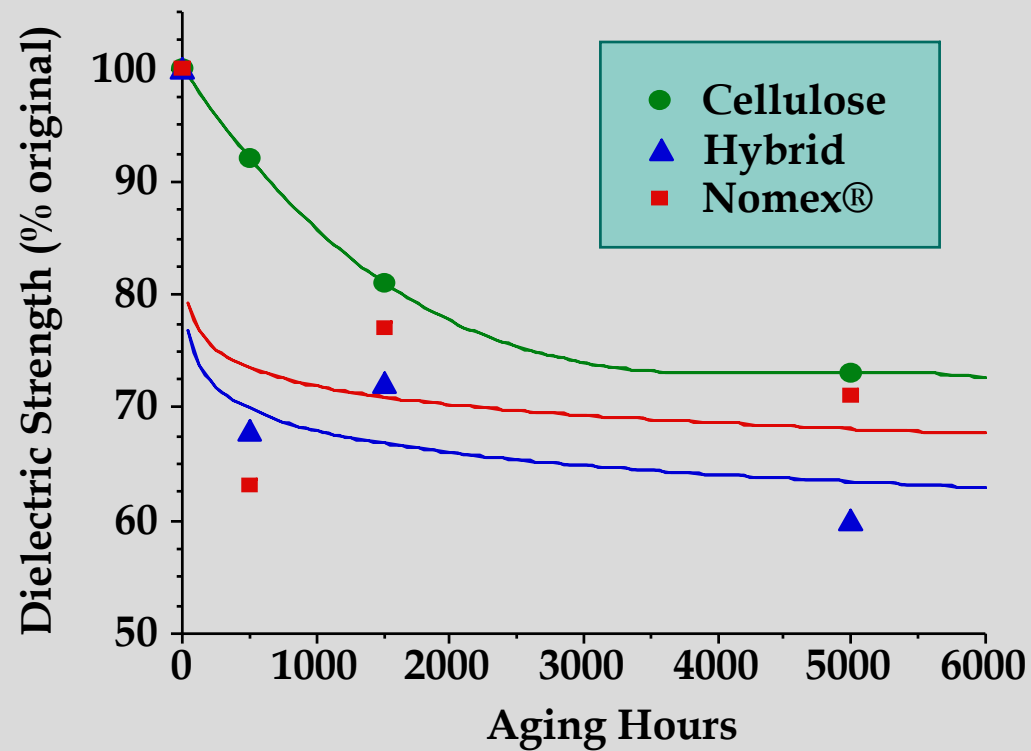
Historical Aging Data

Comparison of Model Results



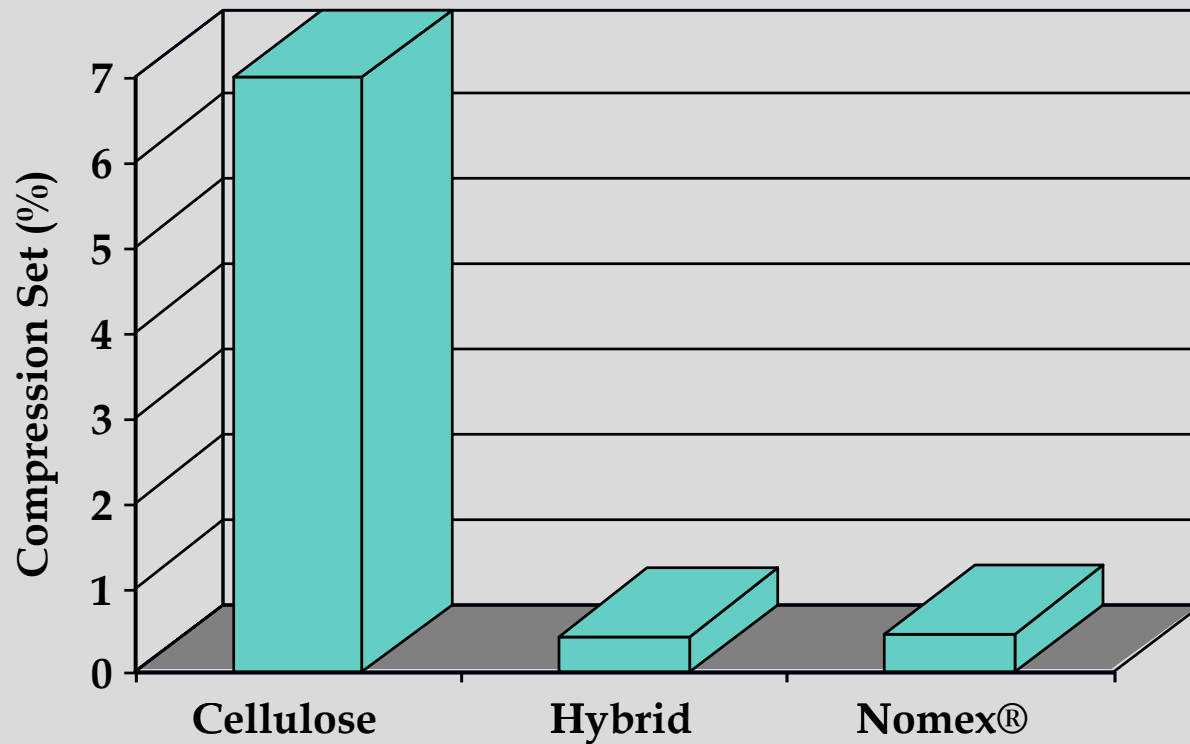
Conductor Wrap Aging Profile

Dielectric Strength



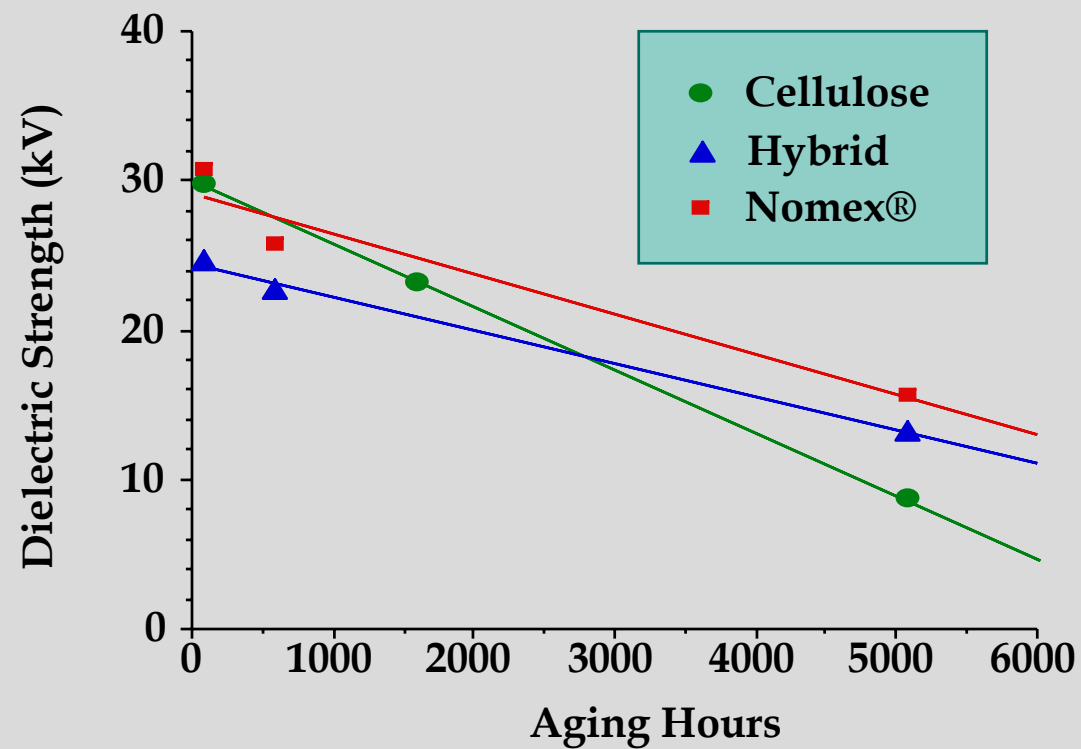
Spacer Board Aging Profile

Compression Characteristics - 1500 h



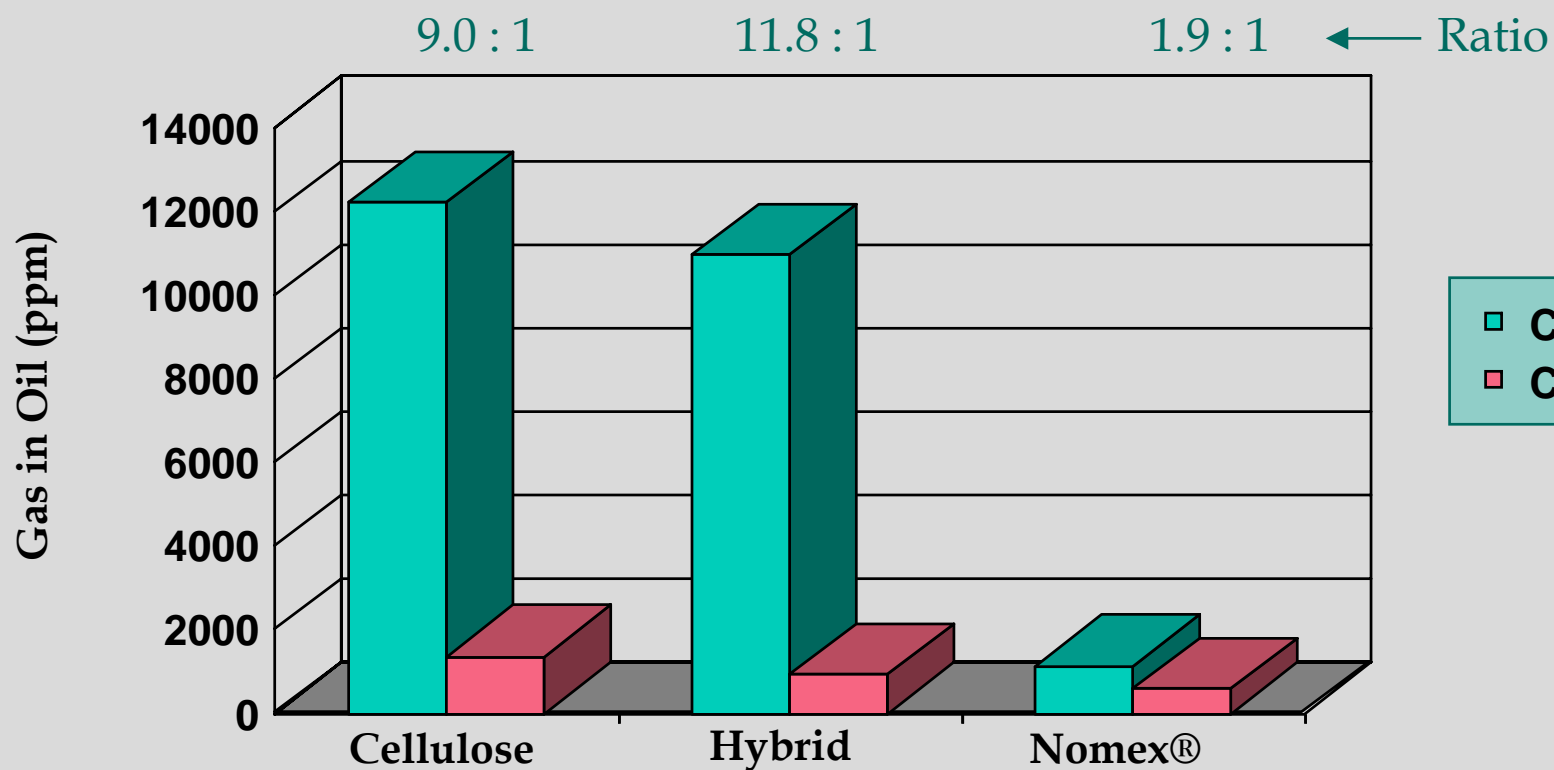
Oil Aging Profile

Dielectric Strength

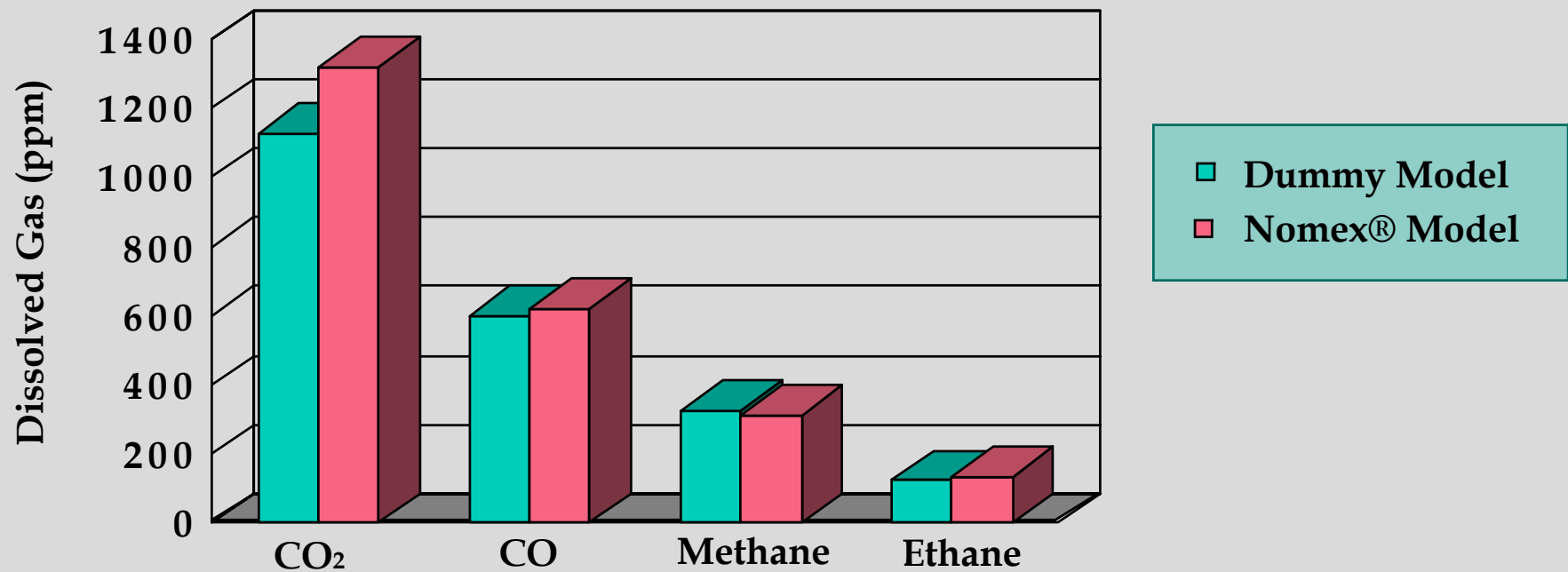


Oil Aging Profile

Dissolved Gas Analysis

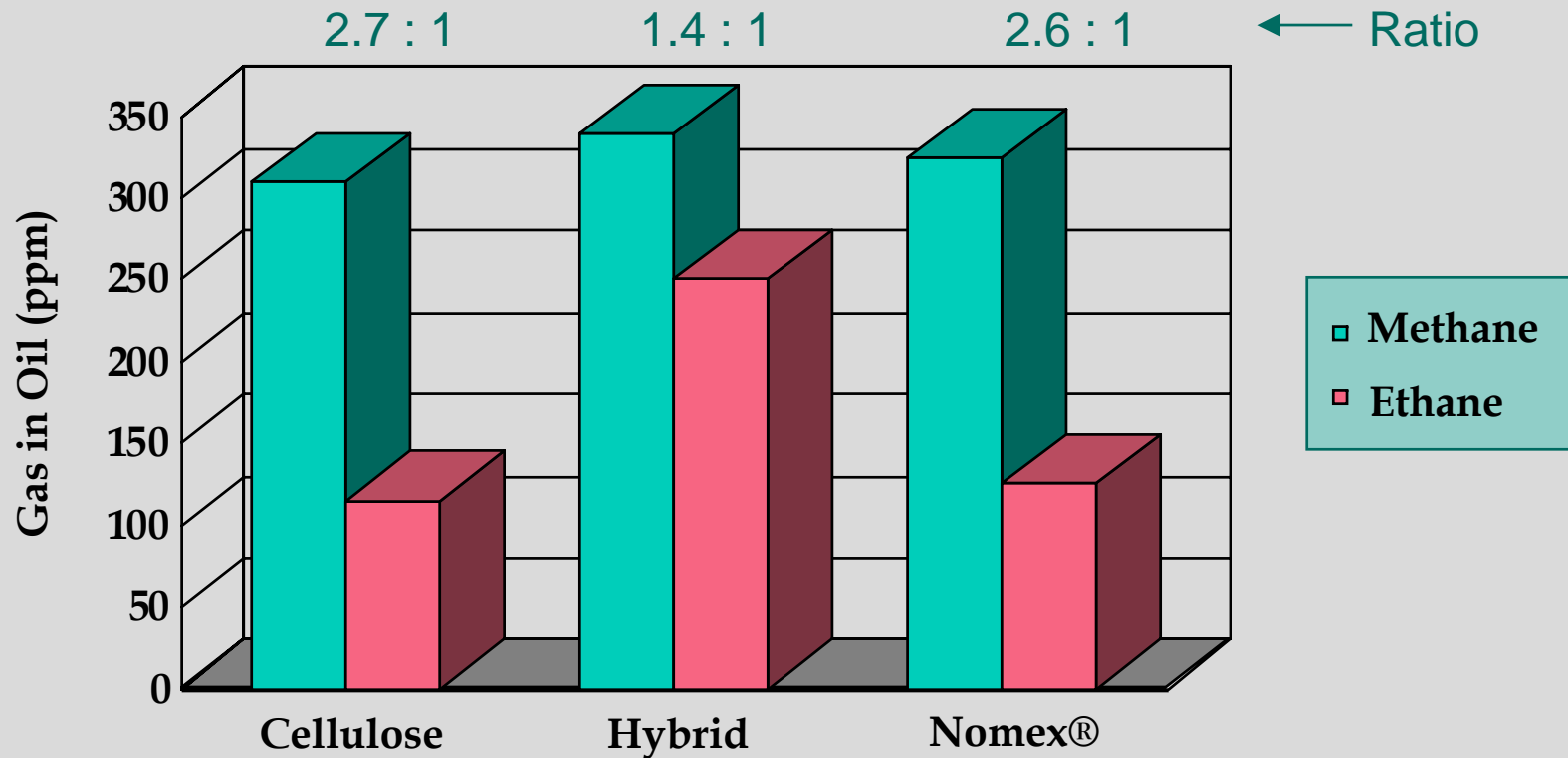


Dissolved Gas in Oil Comparison



Oil Aging Profile

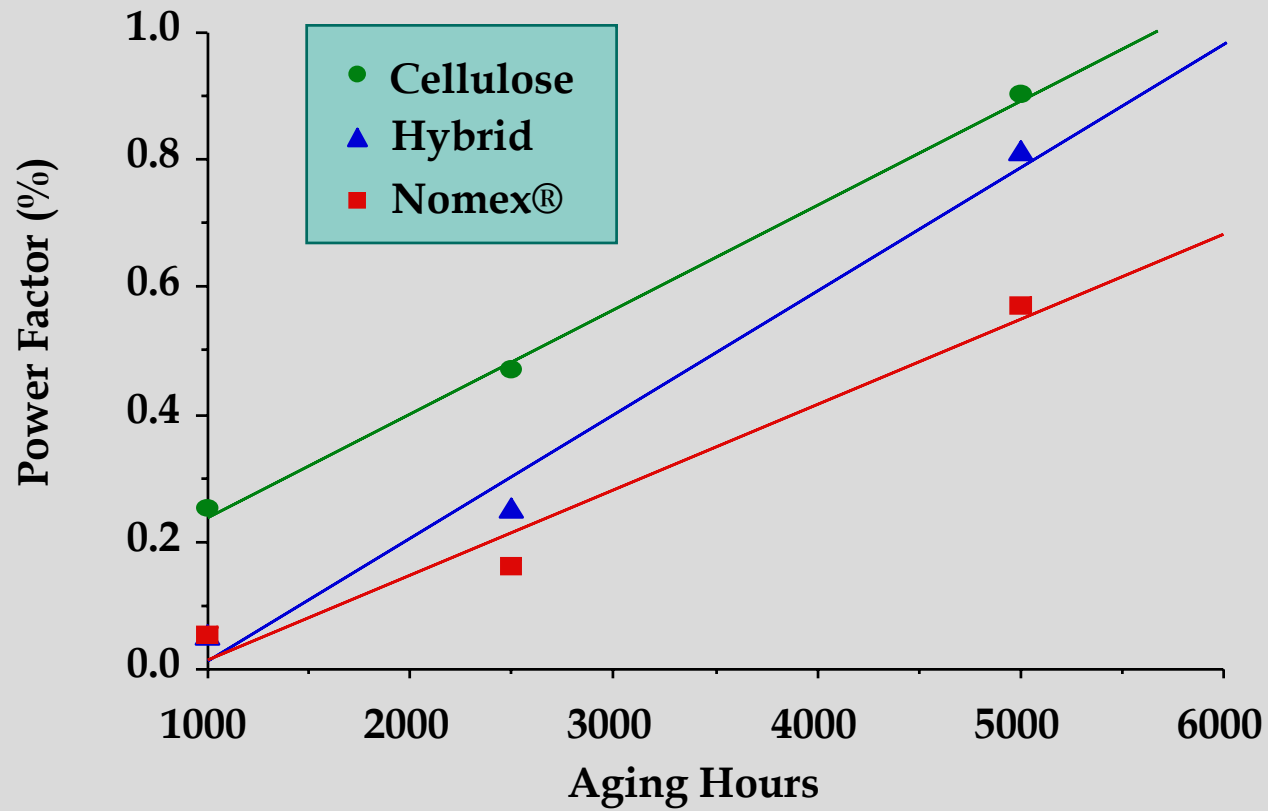
Dissolved Gas Analysis



Oil Aging Profile

Power Factor

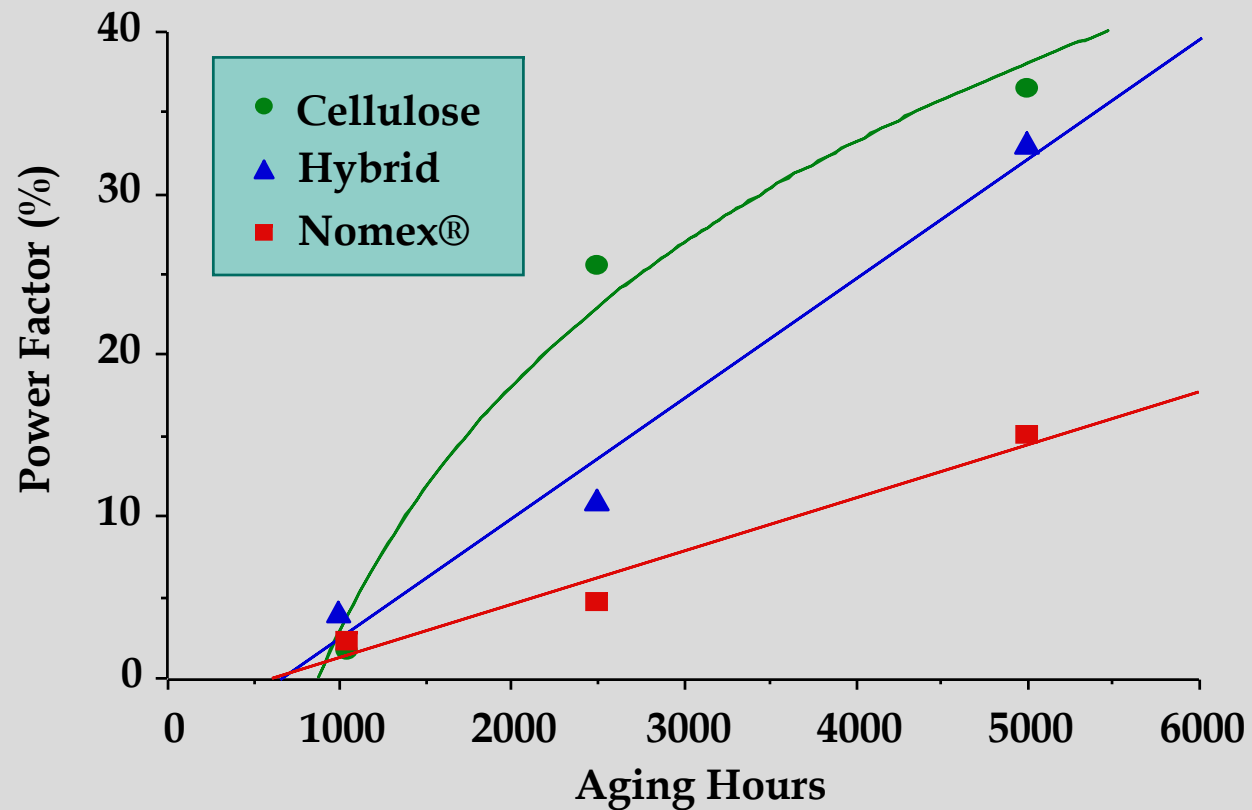
Power Factor at 25°C
(5000 h cells)



Oil Aging Profile

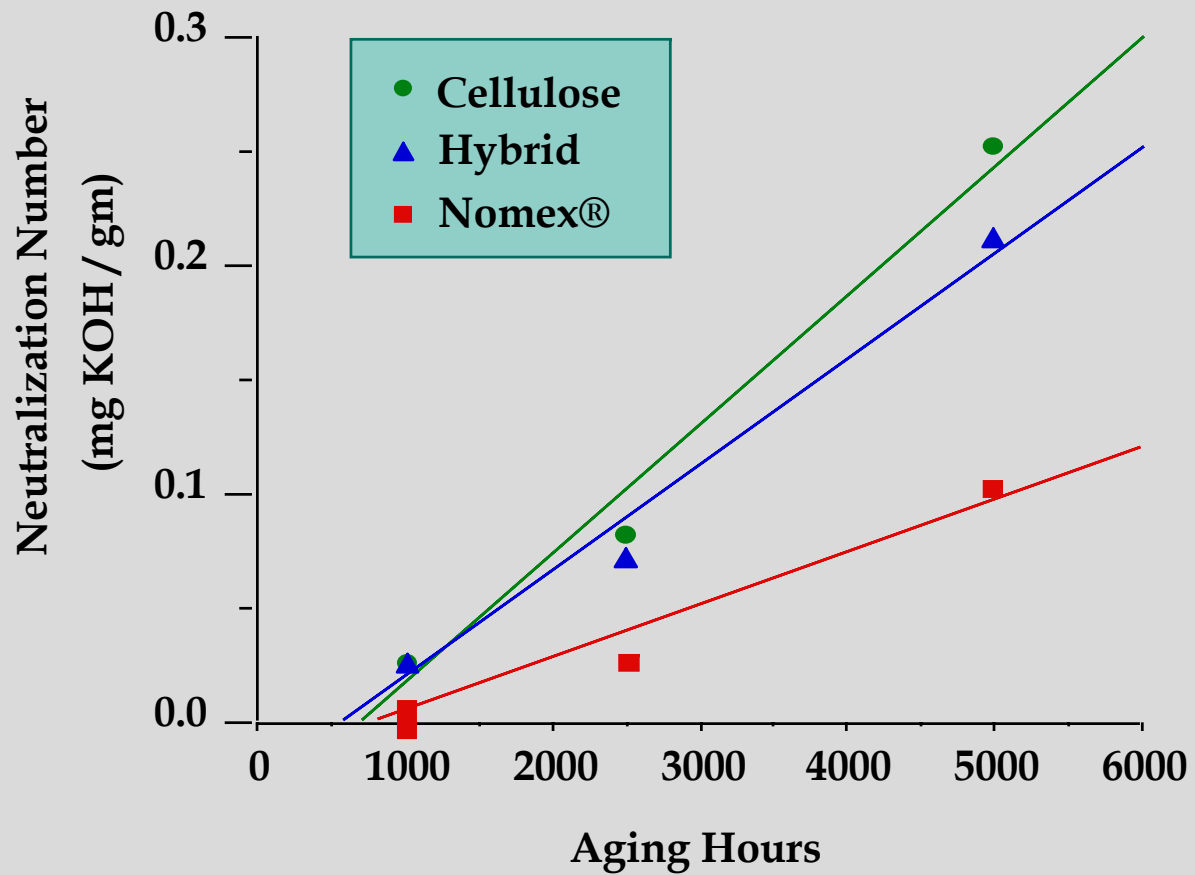
Power Factor

Power Factor at 100°C
(5000 h cells)



Oil Aging Profile

Neutralization Number



Oil Aging Profile

Furan Generation

2 - Furaldehyde Concentrations

<u>Aging Time</u> (hours)	<u>Cellulose</u> (ppb)	<u>Hybrid</u> (ppb)	<u>NOMEX®</u> (ppb)
500	127		6
1500	1390		5
5000	17199	300	12

Program Conclusions

1. A new proposed model for dual temperature thermal aging provides valid results
2. All-Nomex® / oil insulation system has longer life than previously determined
3. Conductor wrap life characteristics in hybrid systems are similar to those in all-Nomex® systems

Program Conclusions

4. Oil quality showed the greatest degradation over time in all-cellulose test cells.
5. Furan measurements verify the correlation between cellulose degradation and oil quality

Future Test Program

- **Complete three temperature aging for development of full life curves**
- **Establish life data using other fluids**
- **Promote adoption of this dual temperature model concept as an industry standard**

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