OKONITE

105°C/140°C

RATED INSULATION SYSTEM

MADE IN THE USA
QUALITY CABLES SINCE 1878

THE OKONITE COMPANY

Setting the Standard in Quality Since 1878

OKOGUARD®

EPR POWER CABLES RATED 105°C/140°C

INTRODUCTION

Over 50 years ago, The Okonite Company introduced Okoguard, a cable insulation system based on EPR insulation and EPR-based semiconductive layers. From the beginning, this system has provided trouble-free service and excellent reliability under a wide range of conditions and voltagesfrom 5 to 69kV.

Okoguard has been rated at 90°C for continuous service and 130°C for emergency operations since its inception. After many years of field service, continuous testing, and evaluation at Okonite and other laboratories, it became evident that the Okoguard EPR system could be assigned a higher temperature rating.

A major program was completed in 1996 to evaluate the possibility of raising Okoguard's rating. **The results demonstrated it is completely justifiable to rate the Okoguard system at 105°C for continuous service and 140°C for emergency service.** Since 1996, Okoguard insulated cables have been sold as 105°C rated cables and UL marked as MV-105.

This report presents a description of our evaluation program and its results, along with discussion of other pertinent areas. The following subjects are covered:

A- Analysis of thermal-oxidative aging data and comparison with older insulation.

B- Measurement of Okoguard's power factor and ac dielectric strength during multiple cycles and after continuous exposure to the elevated temperatures. Comparisons of the resulting data with measurements made at current 90°C/130°C temperatures are given.

C- Measurement of the insulation's physical properties after exposure to the proposed higher temperature and measurement of screen resistivities after cyclic and continuous exposure to current and proposed temperatures.

D- Deformation of the Okoguard system versus temperature.

E- Measurement of impulse strength after temperature exposures.

F- Examples of ampacity increases available.

G- Suitability of jacketing materials.

H- Moisture resistance of the Okoguard system.

I- Summary

THE RESULTS SHOW:

1. The increased temperature rating allows ampacity increase of 7-8%. In some cases, it might be possible for the system designers to use smaller size conductors and achieve significant cost savings and reduced diameters.

2. The fact that the Okoguard EPR system behaves in a monotonic fashion as temperature increases up to the emergency temperature - coupled with the excellent thermal-oxidative aging resistance and retention of electrical properties - serve to justify the increased rating.

3. In addition to their poor aging behavior, polyethylene (XLPE)-based systems exhibit dramatic changes in density, expansion coefficient, physical strength (tensile and modulus) and dielectric strength when temperatures rise above 100°C. This is due to melting of polyethylene's crystalline phase.

4. The test program described on the following pages shows that the Okoguard EPR insulation system has unprecedented thermal and electrical stability. This fact is further supported by an unbroken 50+ year record of superior performance where ever it has been put in service. No other insulation has been able to match this standard of excellence.

A-THERMAL AGING

Early on, it was known that the 90°/130°C rating for Okoguard EPR insulation was conservative. Tables I and II below show a comparison of Okoguard aging versus that of the older insulations, making it clear that Okoguard warrants a higher rating due to its oxidative-thermal aging characteristics.

TABLE I

Comparative Thermal-Oxidative Aging Behavior of Various Insulations

	Rating	ICEA/UL Requirements	Okoguard Values
Insulation	Continuous/Emergency	% Retention T&E	% Retention T&E
Butyl	85°C/105°C	168 hrs. @ 100°C -60/60	100/95 - 4200+ hrs.
PVC	105°C/NA	168 hrs. @ 136°C -70/65	95/90 - 840 hrs.
Silicone	125°C/NA	168 hrs. @ 200°C -65/50[1]	90/85 - 168 hrs.[2]
Synthetic Rubber	90°C/130°C	168 hrs. @ 121°C -60/60	95/95 - 2856 hrs.
EP Rubber	90°C/130°C	168 hrs. @ 121°C -75/75	95/95 - 2856 hrs.

It should be noted that Okoguard meets 125°C-rated silicone aging in cable form.

1 - Based on original and aged absolute values
2 - Based on samples of 15kV Okoguard insulated cable

All other Okoguard data is measured on #14 wire insulated with 45 mils of Okoguard EPR insulation.

TABLE II

Comparative Aging Behavior of Okoguard and Butyl at Various Temperatures to 40% Retention of Elongation			
Time to 40% Retention of Elongation (hrs.)			
Temperature	Butyl	Okoguard	Ratio Okoguard/Butyl
121°C	600	5000+	8.3
136°C	150	1200	8.0
150°C	60	450	7.5

The data above indicates a seven-to-eight-fold superiority of Okoguard over butyl in the terms of thermal aging. Butyl rubber insulation was rated at 80°/85°C, depending on voltage.

Assuming a conservative activation energy (doubling the rate of aging for each 10°C increase in temperature), the data above clearly would justify a 30°C increase in the rating of Okoguard over butyl, i.e. 115°C. A 105°C conductor temperature rating for Okoguard is therefore conservative. It should be remembered that butyl insulations have been in use for over 40 years.

It is important to recognize that the above data was obtained on 47 mil wall. Okoguard aged in 15kV cable form (175 mil walls) show essentially no change in elongation after 450 hours at 150°C This is due to the fact that changes in aging are oxidative and oxygen diffusion is rate-controlling. Thus, when Okoguard is put into actual service as shielded-jacketed cable with semicons in place, its aging will be insignificant at the proposed 105°C operating temperature.

The aging behavior of the Okoguard system EPR-based semicon is very similar to that of Okoguard insulation and it remains highly conductive even when aged to the point of embrittlement.

On the basis of their thermal-oxidative aging behavior, the Okoguard EPR insulation and EPR semicons can be rated at conductor temperatures of 105°C continuous and 140°C emergency.

The AEIC specification and ICEA standard call for no more than 1500 hours at emergency temperature over the life of the cable. Unjacketed Okoguard insulated 15kV cables show in excess of 90% retention of tensile and elongation of the insulation when aged 1500 hours at 140°C.

B-ELECTRICAL TESTING

Lengths of 1/0 aluminum 15kV Okoguard unjacketed insulated cable were energized continuously at three times operating voltage, with the following temperature cycles applied.

Cycle A	Cycle B
90°C Conductor - 2 months	105°C Conductor - 2 month
130°C Conductor - 100 hours	140°C Conductor - 100 hours

The conductors for the 2 month periods were current loaded to the 90°C and 105°C temperatures for 8 hours/day and for 16 hours/day with no current. The current loading to 130°C and 140°C was continuous for the 100 hour portion of the cycle.

The cycles were repeated several times. Initially and after each cycle, measurements were taken of the power factor versus voltage stress and the ac dielectric strength. Impulse strengths were determined at the end of the test program.

In addition, samples were run continuously at 90°C, 105°C, 130°C and 140°C for the time periods shown in the tables.

Power factor data is shown on Charts 1 and 2.

Chart 1 shows the power factor versus stress from operating voltage to three times operating voltage measured at the temperatures indicated for the test protocol of Cycle B, (e.g. two month at 105°C plus 100 hours at 140°C). Data was taken initially and after each test cycle.

Chart 2 compares the power factor behavior at operating voltage versus test cycles for both test Cycles A and B. This data demonstrates that the power factor is virtually the same regardless of the temperature conditioning applied.

The data indicates that except for the slightly higher power factor at 140°C, as would be expected, the cables are essentially identical in all respects no matter which cycle is applied.

AC breakdown behavior after exposure to cyclic and continuous temperatures further substantiates the fact that the higher temperatures do not affect ac breakdown strength. Data appears in Tables III and IV.

CHART #1

% POWER FACTOR vs NUMBER OF TEST PERIODS AT VARIOUS TEMPERATURES AND STRESSES

NOTE: ONE TEST PERIOD CONSISTS OF 2 MONTHS DAILY LOAD CYCLES AT 105°C CONDUCTOR TEMP. PLUS 100 HOURS CONTINUOUS AT 140°C

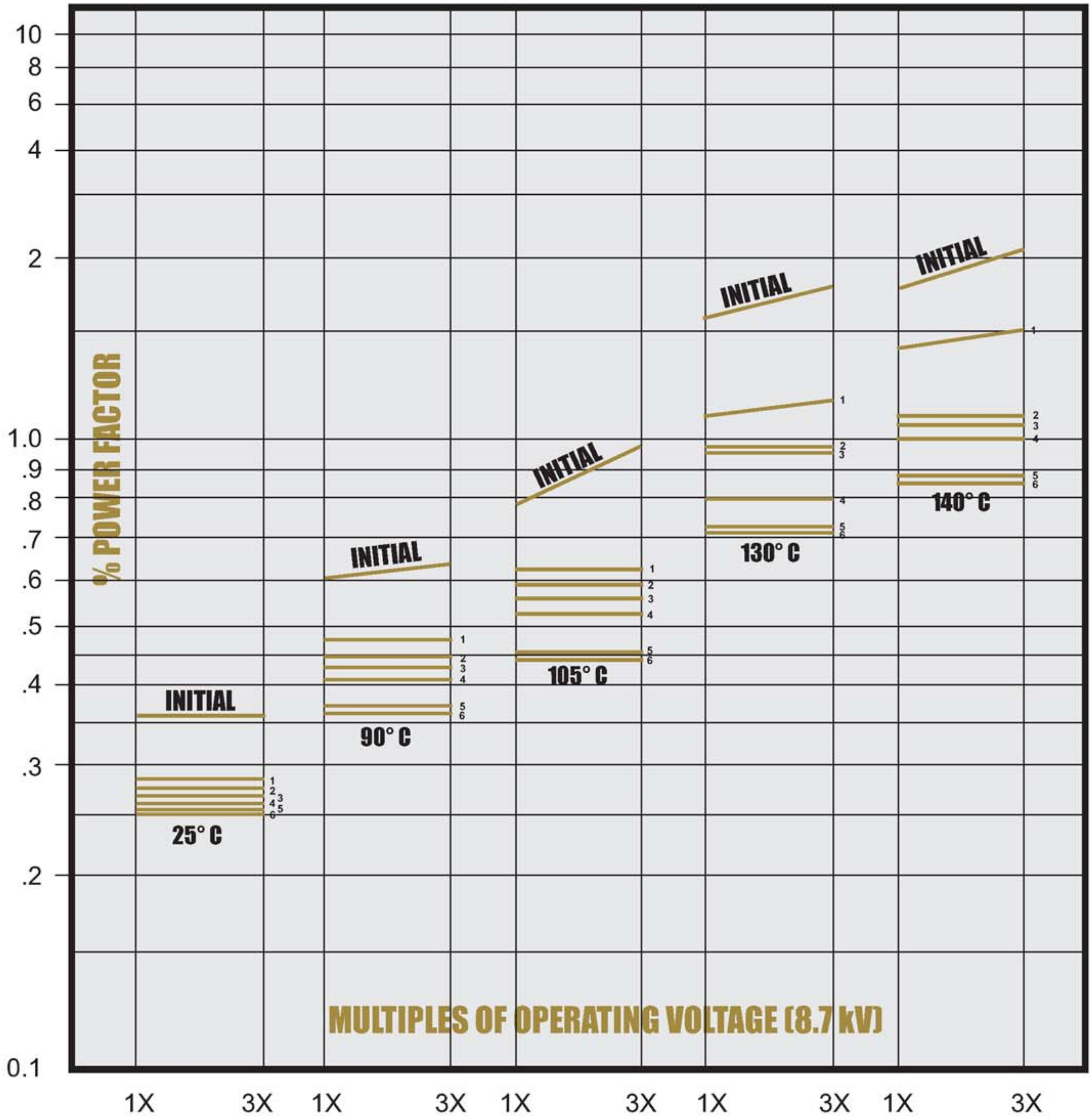


CHART #2

OKOGUARD - % POWER FACTOR vs TIME (TEST PERIOD) AT VARIOUS TEST TEMPERATURES

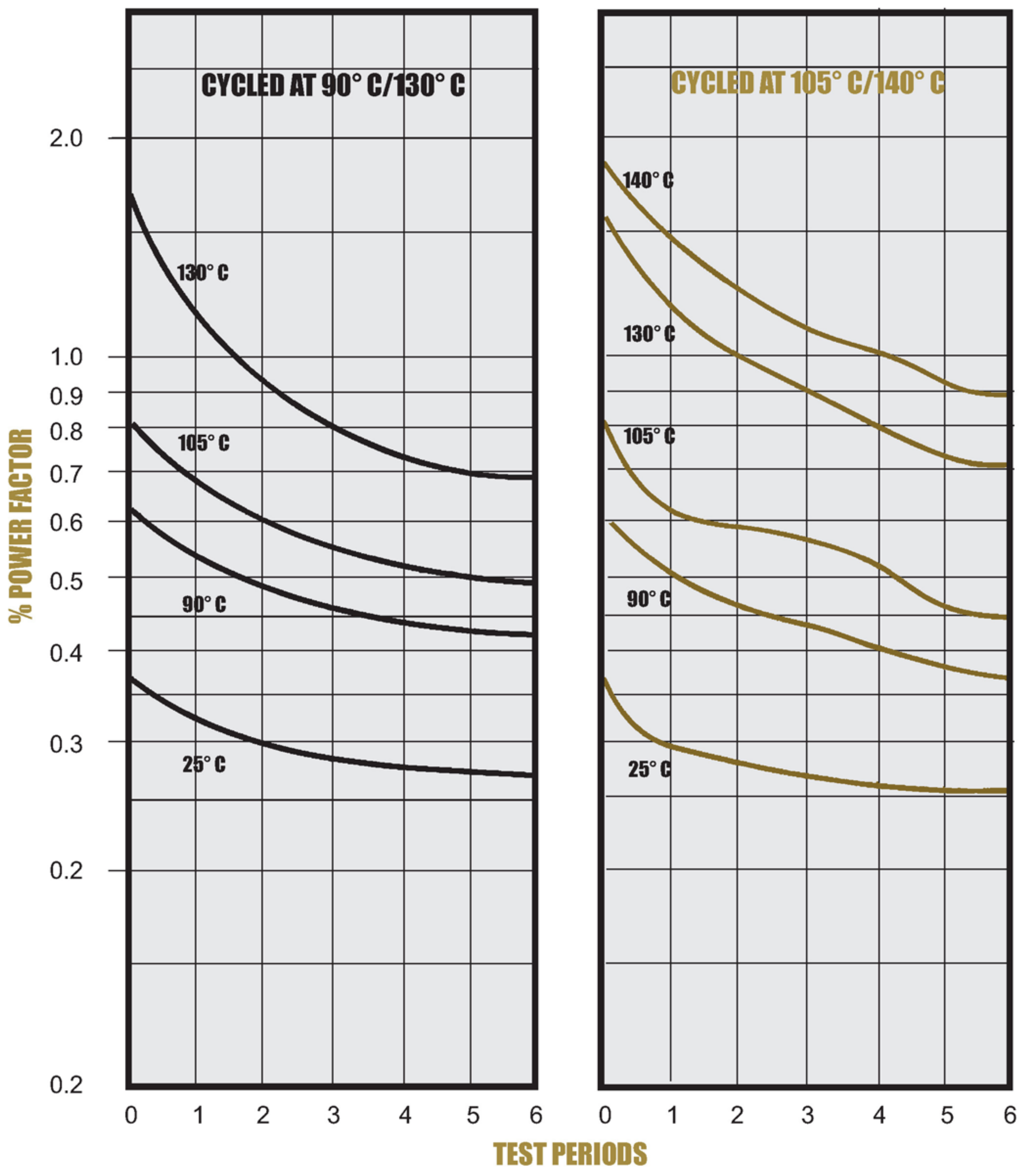


TABLE III

% Retention of Okoguard ac Dielectric Strength Cyclic Temperature Exposure		
Cycles	Cycle A - 90°/130°C	Cycle B - 105°/140°C
	% Retention	
Initial	100	100
1	127	125
2	121	110
3	118	105
4	111	109
5	121	119
6	117	120

- Okoguard's initial ac dielectric strength is above 600 V/mil average stress.
- After temperature exposure, the increase in dielectric strength from initial values is normal behavior for this system.
- % Retention based on two to three breakdowns per test period.

TABLE IV

% Retention of Okoguard ac Dielectric Strength Continuous Temperature Exposure				
Temperature	90°C	105°C	130°C	140°C
Time - Weeks	% Retention			
Initial	100	100	100	100
1	--	--	119	129
3	137	129	118	134
5	--	--	127	118
6	141	134	--	--
7	--	--	125	117
9	--	--	112	109
12	142	135	--	--
18	126	143	--	--
24	134	130	--	--

- Initial Okoguard dielectric ac strength is above 600 V/mil average stress.
- % Retention based on two to three breakdowns per test period.

C-RETENTION OF PHYSICAL & RESISTIVITY PROPERTIES

To further demonstrate the previously mentioned aging behavior of the Okoguard system, physical properties of the Okoguard insulation taken from the cables that were subjected to continuous conductor loading of 90°C, 105°C, 130°C and 140°C were measured, as were the physical properties of the insulation after the multiple cycles shown above. This data presented in Table V reveals no significant deterioration of the insulation. Table VI presents the resistivity values of the semiconducting screens after the various test regimes. The data indicates no significant change in screen resistivity.

TABLE V

Physical Properties			
	Tensile, psi	200% Modulus, psi	Elongation, %
Original	1390*	1060*	350*
After 3024 hrs. 90°C	1375	1070	330
After 3024 hrs. 105°C	1390	1060	320
After 1512 hrs. 130°C	1325	1040	320
After 1512 hrs. 140°C	1295	1005	320
After 6 Cycles 90°C/130°C	1395	1050	360
After 6 Cycles 105C°/140°C	1305	1025	340

*Average of 5 samples

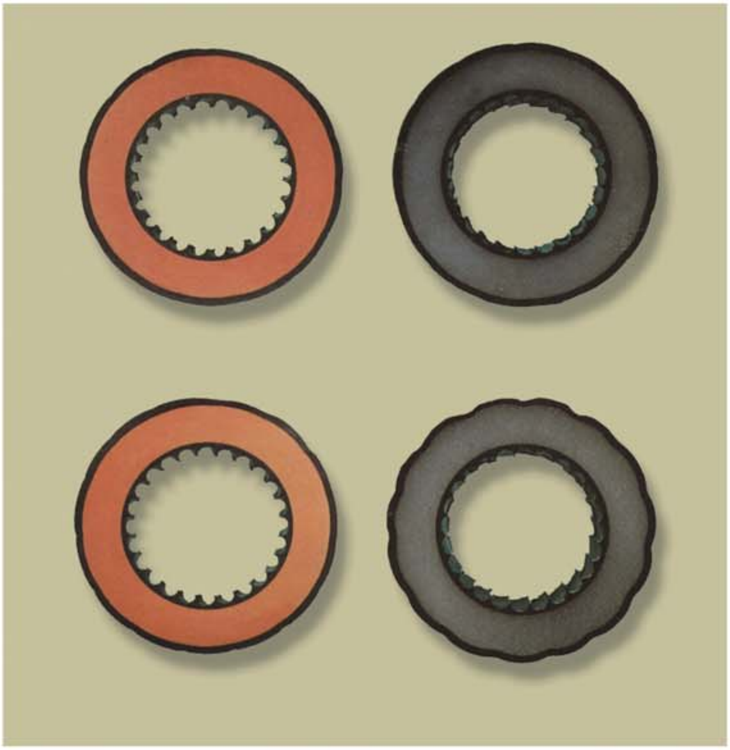
TABLE VI

Resistivity of the EPR Semiconductive Screen		
	Resistivity, Ω - Meters	
Original	.43/25°C .45/90°C	.88/105°C .76/140°C
After 3024 hrs. 90°C	.07/25°C	20/90°C
After 3024 hrs. 105°C	.12/25°C	.25/105°C
After 1512 hrs. 130°C	.30/25°C	.82/130°C
After 1512 hrs. 140°C	.27/25°C	.91/140°C
After 6 Cycles 90°C/130°C	.59/25°C	1.05/90°C
After 6 Cycles 105°C/140°C	.53/25°C	1.06/105°C

The AEIC specifications call for 500 and 1000 Ω - meters for the insulation screen and the conductor screen, respectively.

D-DEFORMATION OF THE OKOGUARD SYSTEM vs TEMPERATURE

The monotonic behavior of the Okoguard system versus temperature as regards to physical, electrical and expansion properties in the temperature ranges of interest is of importance when considering raising the temperature rating of the insulation.



The other widely used medium-voltage insulation (XLPE) does not warrant an increased rating because it has a true melting point slightly above 100°C, resulting in severe discontinuities in its physical, electrical and expansion properties at higher temperatures.

To demonstrate one effect of XLPE's melting point, standard URD cable constructions with jacket were subjected to the thermomechanical qualification test procedure as outlined in Section 15.3 of AEIC CS8-13. The cables tested were 750 kcmil aluminum, 220 mils of Okoguard, and 220 mils of XLPE with concentric wires and a polyethylene jacket. At the conclusion of the the tests, samples were cut and photos taken. The photos show severe deformation of the XLPE cable due to the expansion on melting and minimal, if any, deformation of the Okoguard system.

E-IMPULSE STRENGTH

Impulse strength of the Okoguard system is not affected by the increased temperatures. Data in Table VII shows the percent retention of room temperature and elevated temperature impulse strength of the Okoguard system following the various test programs.

TABLE VII

% Retention of Okoguard Impulse Strength			
	Room Temp.	130°C	140°C
Initial	100	100	100
After 6 Cycles 90°C/130°C	100	100	--
After 6 Cycles 105°C/140°C	100	--	115
After 9 Weeks 130°C	90	115	--
After 9 Weeks 140°C	100	--	100

The unaged impulse strengths of the construction used, e.g. 1/0 aluminum, 175 mil wall Okoguard insulation, normally run in the range of 260-290kV at room temperature and 200-260kV at 130°C and 140°C. The industry requirement BIL for 15kV cable is 110kV.

F-AMPACITY INCREASES

A rating of 105°C/140°C for the Okoguard system leads to an approximately 7-8% higher current-carrying capacity. Tables VIII and IX show 90°C, 105°C, 130°C and 140°C ampacities for various conductor sizes with both copper and aluminum for typical constructions.

Although a reduction from one standard conductor size to the next lower size cannot be made, it can be seen that a smaller size conductor can be used leading to lower cost and smaller diameter cables when 7-8% more ampacity is required than can be accommodated at 90°/130°C rating for the insulation system.

TABLE VIII

15kV 3-1/C Okoguard, Tape Shielded and Jacketed in Underground Duct One Circuit, 20°C Ambient, 100% Load Factor				
Copper Conductors				
Size	90°C*	105°C	130°C	140°C
2	155	165	185	190
1	175	190	205	215
1/0	200	215	235	245
2/0	230	250	270	280
3/0	260	280	305	315
4/0	295	320	350	360
250	325	350	385	395
350	390	420	460	475
400	415	445	490	505
450	440	475	520	535
500	465	500	550	565
600	505	545	595	615
650	525	565	620	640
750	565	610	665	690
1000	640	690	755	780

*Ampacity values at 90°C from NEC Table 310.60 (C)(77) (rounded values of ICEA P-46-426). Ampacity values at all other temperatures rounded to the nearest 0 or 5.

TABLE IX

15kV 3-1/C URO-J 1/3 Neutral in Underground Duct One Circuit, 20°C Ambient, 100% Load Factor				
Copper Conductors				
Size	90°C*	105°C	130°C	140°C
2	175	190	205	215
1	200	215	235	245
1/0	225	245	265	275
2/0	255	275	300	310
3/0	290	315	340	355
4/0	305	330	360	370
250	330	355	390	405
350	400	430	470	490
400	420	455	495	510
500	470	510	555	575
600	505	545	595	615
650	525	565	620	640
750	550	595	650	670
1000	640	690	755	780
Aluminum Conductors				
Size	90°C*	105°C	130°C	140°C
2	135	145	160	165
1	155	165	185	190
1/0	175	190	205	215
2/0	200	215	236	245
3/0	230	250	270	280
4/0	240	260	285	295
250	260	280	305	320
350	320	345	380	390
400	340	365	400	415
500	360	390	425	440
600	385	415	455	470
650	420	455	495	510
750	470	510	555	575
1000	550	595	650	670

*Ampacity values from ICEA P-53-426. Ampacity values at all other temps. rounded to the nearest 0 or 5.

G-JACKETS

Increasing Okoguard's temperature rating to 105°C also raises the question of what type of jacketing materials should be used. The governing criteria are heat distortion and aging behavior.

Under normal circumstances, jackets must withstand 15°C lower temperatures than conductors. PVC jackets rated 90°C and 105°C are suitable. The aging and deformation behavior of CPE and TPR jackets make them suitable for use with 105°C-rated insulations. With a 10°C higher melting point than that of low-density polyethylene, and excellent aging behavior, linear low-density polyethylene is also a suitable jacket material for 105°C-rated insulation. Thermoset jackets all show excellent resistance to deformation at elevated temperatures with selection of a specific jacket dependent on such characteristics as oil resistance, aging, flame resistance and smoke emission on combustion. Suffice it to say that there are many thermoset materials available which can be used with 105°C-rated insulation.

H-MOISTURE RESISTANCE OF OKOGUARD

In addition to demonstrating Okoguard's aging and electrical stability at 105°C/140°C temperatures, it is necessary to prove the insulation system's ability to withstand electrical stress in wet environments.

It is not experimentally practical to maintain liquid water both inside and outside a cable at 105°C. Therefore, Okonite decided to extend the well-known AEIC treeing test beyond the one-year period mandated by the specification AEIC CS6-87 at that time, for information for 90°C rated continuous service insulation systems.

The data presented on Chart 3 shows Okoguard's ac dielectric strength during the AEIC/ICEA treeing test. Assuming that the dielectric deterioration rate doubles for every 10°C rise in temperature, changing the rating from 90°C to 100°C requires a two-year test period, and changing from 90°C to 105°C requires somewhat less than a three-year test period. Note that ICEA S-94-649 & S-97-682, require an ac dielectric strength of 340 V/mil after only 360 days of testing.

It should be emphasized that the plot on Chart 3 shows a 420 V/mil breakdown stress in the Okoguard system after four years of exposure in the AEIC treeing test. Such excellent behavior, after an extended time period during this highly accelerated test, offers additional justification for increasing Okoguard's rating to 105°C.

Also included is a plot (Chart 4) of the Okoguard system's dissipation factor versus time in 90°C water for a period of seven years.

One more indication of Okoguard's long-term moisture resistance in the presence of high electrical stress can be found in the tests done at Conductor Products Incorporated Laboratories using the CPI test protocol. For this test, twelve samples of 1/0 aluminum 15kV Okoguard insulated cable were subjected to the test conditions.

CHART #3

OKOGUARD LONG TERM AGING - AEIC TREEING TEST (BREAKDOWN LEVEL E_{AVG} VS ELAPSED TIME)

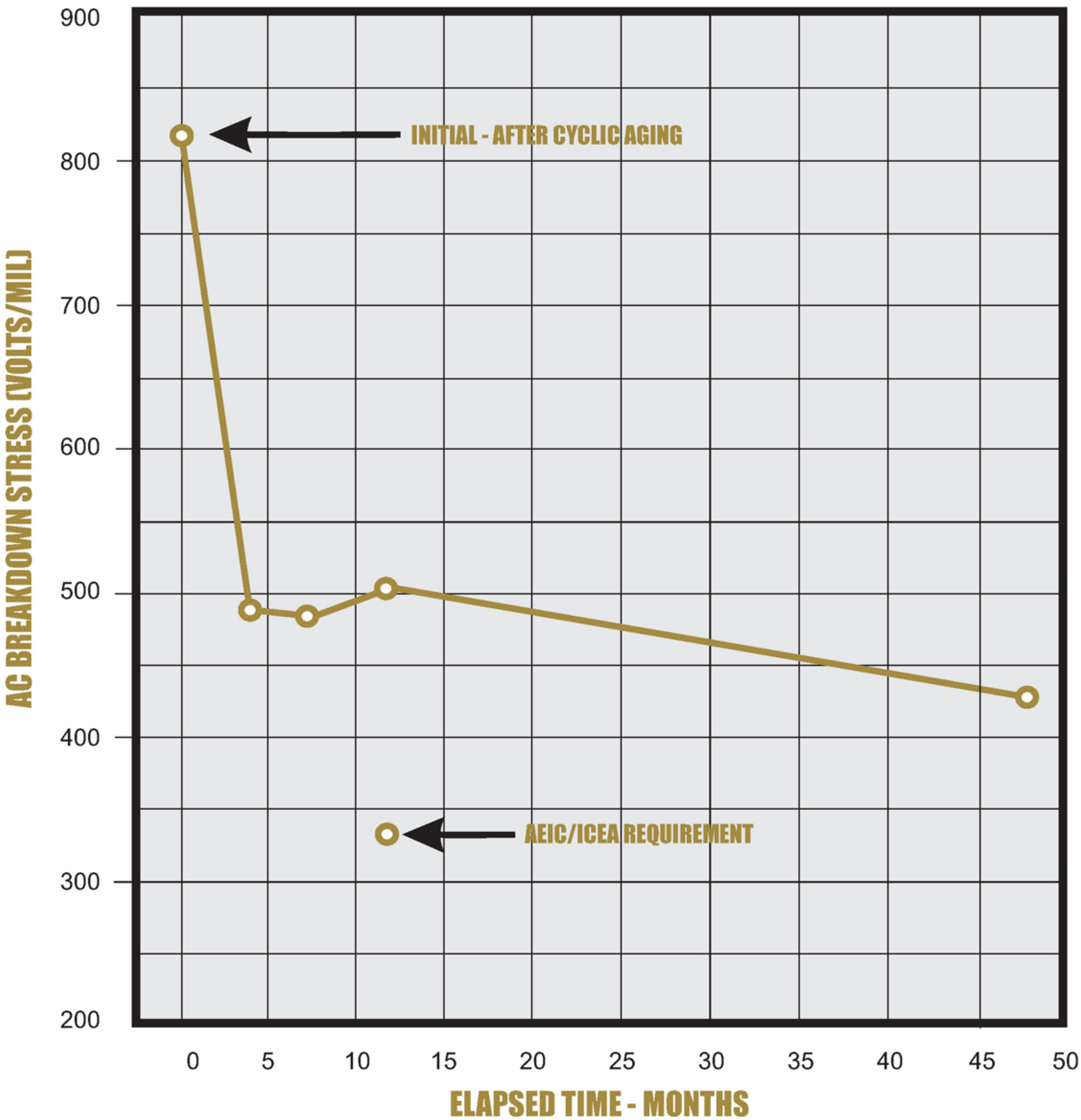
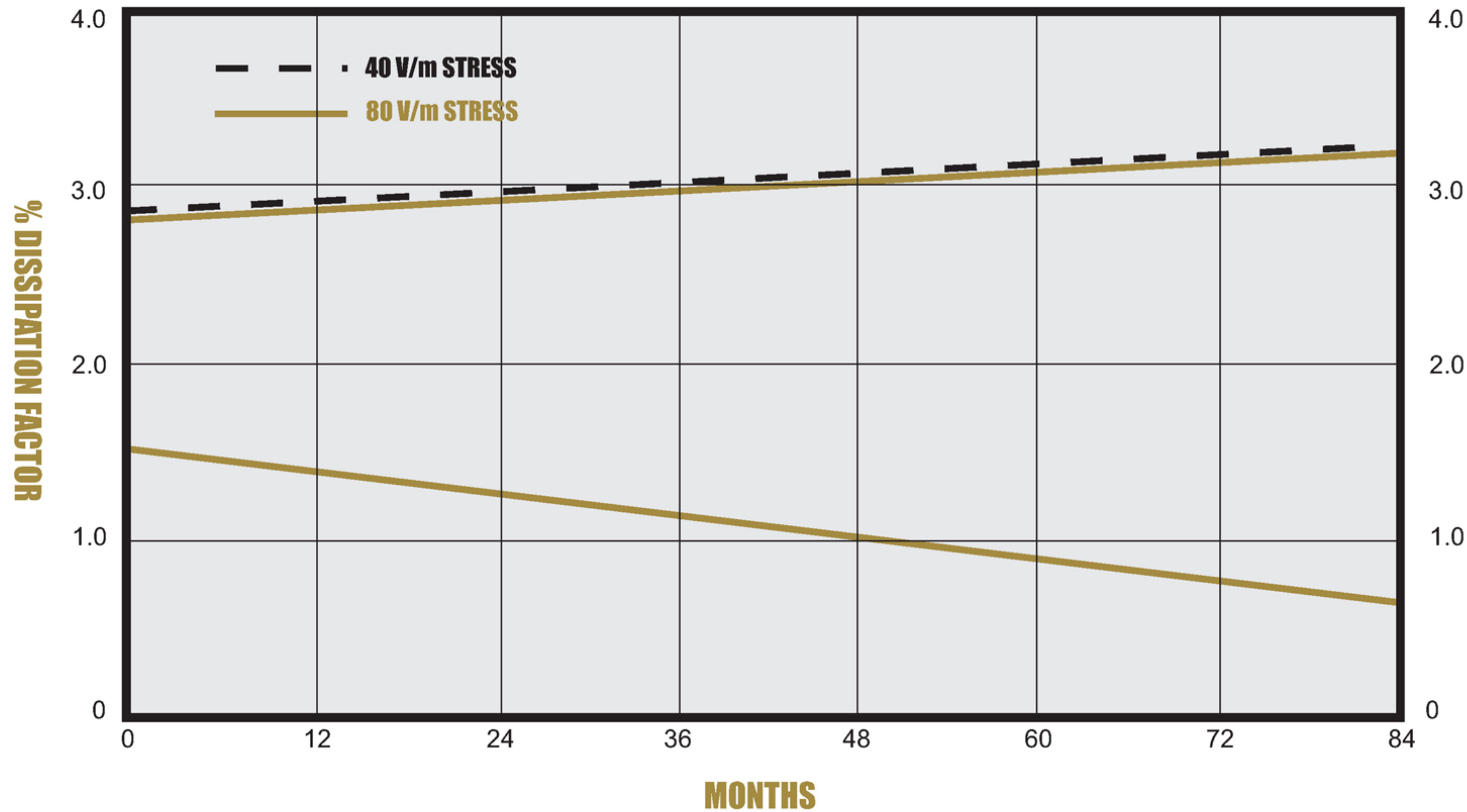


CHART #4

MOISTURE RESISTANCE

OKOGUARD DEMONSTRATES LONG TERM STABILITY IN WATER

SEVEN YEARS 90°C WATER TEST, - #2 AWG CONDUCTOR WITH
220 MIL OKOGUARD WALL-VOLTAGE TESTED AT 40 AND 80V/MIL



There were zero failures in these cables after 1422 days, at which time the testing was terminated. These results are far superior to those published by others in the Insulated Conductor Committee Minutes for identical tests on XLPE and TR-XLPE.

All the data reinforces Okoguard's outstanding stability when submerged in water.

I-SUMMARY

Based on their aging and electrical stability, it may well be that EPR insulations, other than Okoguard, can also be rated higher than 90C°/130°C. But other factors must be carefully considered before an increased rating can be justified.

A medium-voltage cable is more than insulation, it is a system of semiconductive screens and insulation. The Okoguard system is unique in that it is made up of EPR-based screens and EPR insulation. Other systems use screens which are based on materials other than EP polymers; CSPE and ethylene/vinyl acetate copolymers, for example.

In the case of semiconducting CSPE, its thermal aging behavior precludes its use as screens. In our view, the quality of semiconducting CSPE aging is not even good enough to merit its current 90°C/130°C rating.

In the case of EVA, it is necessary to determine if hydrolysis of the vinyl acetate moiety-yielding acetic acid has any effect on the insulation. Such an effect has already been tested on several EPR formulated insulations in our laboratories. We have found that acetic acid produced from EVA copolymer hydrolysis causes unacceptable levels of deterioration of the dielectric strength of the EP insulations. This offers one more reason why it is advantageous to use an all-EPR system- e.g. EPR insulation and EPR screens.

In order to justify a higher temperature rating for a cable, it is mandatory not only to show the ability of the insulation to meet increased thermal-oxidative aging parameters; but it is also necessary to consider possible chemical interactions of the insulation with the screens. Data from extensive long-term electrical testing of full-size cables under both wet and dry conditions mut also be made available before an increased rating can be recommended.

All of the above mentioned studies have been performed on the Okoguard system.

One final factor lending a high degree of confidence about Okoguard's ability to operate reliably at the increased rating is its record of over 50 years of trouble-free service when rated at temperatures of 90°C/130°C for voltages from 5 to 69kV. This service record has not even been remotely matched by other EPR insulated cables. It should also be pointed out that the quantity of Okoguard cable already in service amounts to over a billion conductor feet in applications ranging from URD, industrial, to Class 1E nuclear plant cables.

In summary, the unique Okoguard system with EPR-based compounds in both its insulation and screens, has been proved reliable for operation at 105°C for continuous service and 140°C for emergency service. These values allow for increases in ampacity and offer additional proof of Okoguard's superiority for medium-voltage applications, as compared to XLPE and other EP insulations where EP semicons are not used.

Okonite Cables

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