TEST AND FIELD EXPERIENCE WITH ELASTOMERIC TERMINATIONS

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Silicone tape terminations were probably the first elastomeric terminations and have been in use since the early 1960's. Many other designs followed, as did various test methods to evaluate them. Over time, three general types have prevailed. Factory molded push–on designs, usually EPDM polymers, molded cold shrink silicone terminations, and factory supplied heat shrink designs typically using ethylene vinyl/acetate (EVA) as the base polymer.

Material development and test methods first concentrated on evaluating and improving the elastomers ability to resist high discharge currents. Recent work is concentrating on the elastomers ability to resist formation of discharge currents on the terminations surface.

I. Material

Both EPDM and EVA based compounds have carbon–to–carbon molecular structures, while silicone has a silicon–oxygen linkage which is much stronger and accounts for its inherent resistance to sunlight (UV) (Table 1) as its bond energy exceeds that available from sunlight. Various chemicals are added to these polymers to enhance properties such as UV stabilizers, oils or waxes to increase hydrophobicity, alumina trihydrate (ATH) for tracking resistance, etc.

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Test performance can vary substantially depending on actual parameters due to these different materials. For example, while ATH is an excellent material to prevent electrical discharges from causing surface erosion or tracking, sufficient energy must be available to trigger the protection mechanism, i.e., dissociation of the water of hydration. Thus, highly accelerated tests can give more favorable results for some filled materials than those at lower acceleration (salt content of fog) [1]. If the ATH is not activated, the lower energy discharges attack the polymer changing the failure mechanism. As discharges in field conditions are often of low magnitude, the more highly accelerated test could result in misleading conclusions.

Table I Polymer Bond Energies

Bond	Bond Energy (KJ/m)
Si–O*	445
C–H	414
C–O	360
C–C**	348
Si–C	318
Si–H	318
C–S	275
Si–Si	222
S–S	205
Sunlight (300 nanometers)	398

* Silicone
** EPDM, Polyethylene

Equally or more important is the material's ability to maintain high surface resistance to resist formation of discharges across dry bands which are developed when the termination is exposed to severe conditions (fog, light, rain, etc.). Most elastomeric terminations have initial high surface resistances (hydrophobic), but can lose this when exposed to discharges. Some material formulations have additives which help maintain hydrophobicity, but silicone inherently maintains its hydrophobic surface and will regenerate it if lost to excessive discharges [2]. This recovery is shown in Fig. 1 and is repeatable over time. Silicone elastomer also has the unique ability for low molecular weight fractions to permiate through pollutants on the surface and render the polluted surface hydrophobic (Fig. 2).

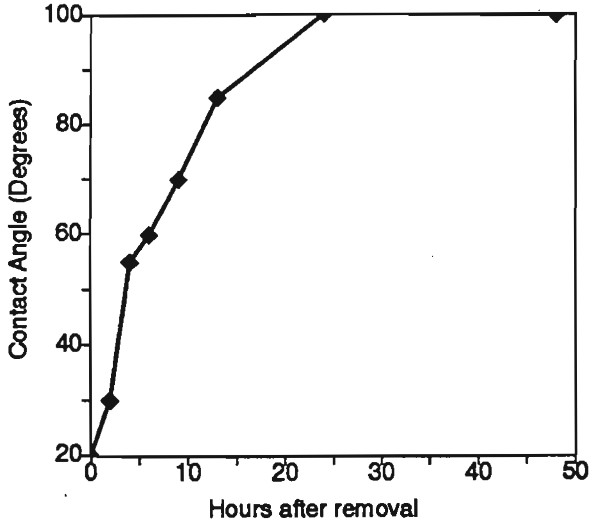


Fig. 1 Recovery of contact angle for the silicone rubber termination material.

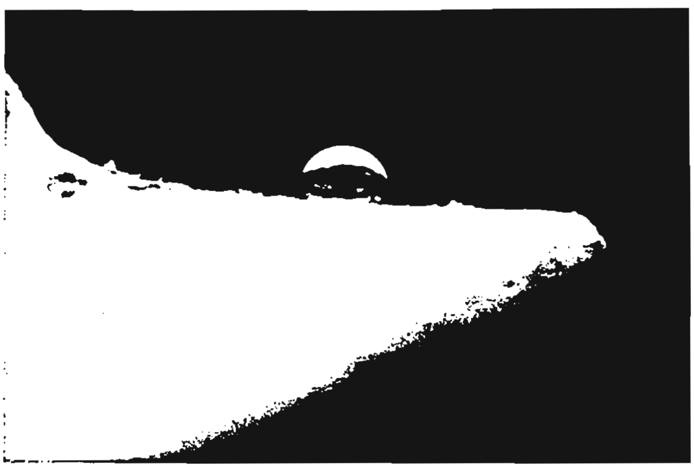


Fig. 2 Contaminated silicone surface is non–wetting.
Contact angle over 110°

II. Surface Degradation

Weathering effects are varied and complicated as shown in Fig. 3. Ultraviolet light is destructive to many polymeric surfaces. If ultraviolet energy exceeds the bond energy between atoms in the polymer chain, breakdown of the molecular structure will occur. This results in surface chalking, crazing, or even cracking. Effects are at least two–fold. Hydrophobicity of the insulating polymer is compromised and the crazed surface becomes a depository for pollutants, promotes definite paths for discharges, and further lowers hydrophobicity. Table 1 compares bond energies of silicone and organic materials with sunlight intensity.

Micron sized pollutants will have an electrostatic charge and be directed towards the higher stressed areas of the termination. The deposits tend to adhere to the termination surface. If deposited by fog, the particles are also deposited underneath the skirts and are inaccessible to rain. In seacoast areas, fog, wind, rain, and subsequent drying can deposit salt on the insulator. These contaminants will not cause destructive leakage currents or flashover when dry. Water is necessary to render the polluted surfaces conductive. Fog and drizzle are worst cases as no cleansing action occurs; the surface is made conductive, and leakage currents concentrate on the insulator surfaces.

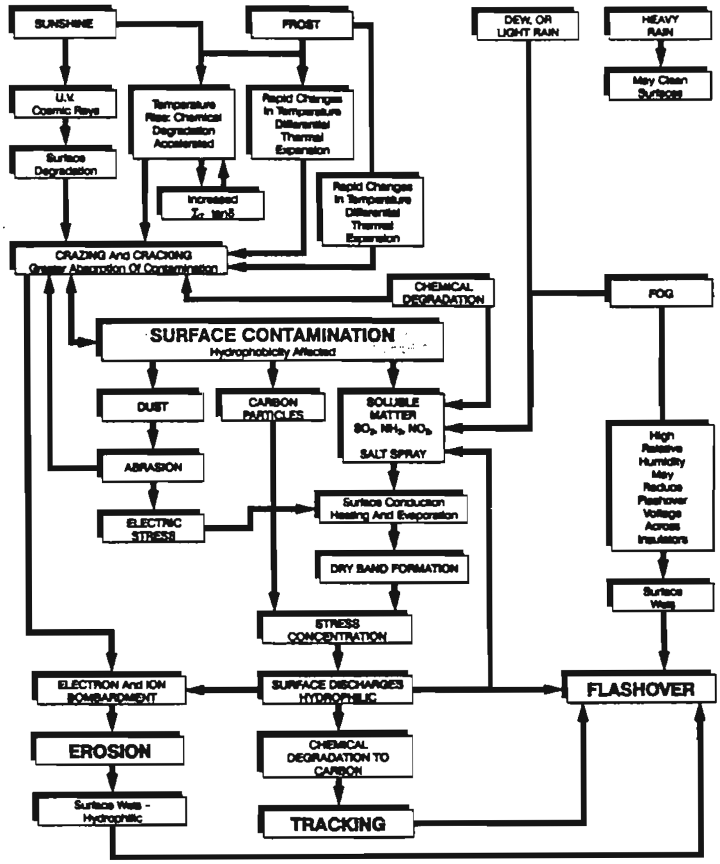


Fig. 3 Factors in surface degradation
(Loss in surface resistivity)

Leakage currents will change any insulator surface from hydrophobic to hydrophilic with enough time and intensity. This further lowers surface resistance, which in turn pomotes leakage current formation. Thus, silicones ability to regenerate its hydrophobic (high resistance) surface is very important as it stops this destructive cycle.

III. Test Methods

Originally, test methods and material development concentrated on improving the material's resistance to leakage current, trying to approach porcelain, and most tests used very high salinities to generate high currents. Alumina trihydrate ($Al_2O_3 \cdot 3H_2O$) or ATH was found to greatly improve resistance to leakage currents. If the leakage current energy has enough intensity, the water of hydration will be released as steam, which both raises the arc off the surface and cools it. Pure alumina is left, which unfortunately is hydrophilic and will wet.

Generally, both voltage and water resistivity are accelerated in all test methods to establish leakage current formation. Voltage is usually no more than 173% of rated voltage, but water resistivity has varied from 250 µS/cm to 16,000 µS/cm. The average resistivity of coastal rain is in the area of 30 µS/cm and the water for flashover test used in IEEE 4 and 48 is 56 µS/cm for comparison.

Several test methods are being used to evaluate polymeric insulators, including salt fog chambers, salt spray rotating wheel, IREQ tracking wheel, clean fog solid contaminant, and 3M solid contaminant tests. Equipment and procedures are shown in Appendix A.

Results of these tests are greatly influenced by the salinity or conductivity of the water used. One study using a salt–fog chamber found a silicone polymer lasted much longer than EPDM using a salinity of 250 µS/cm, but at 1000 µS/cm the EPDM was superior. The same inconsistency was found using the 3M solid contaminant procedure. When the salinity was raised from 180 to 700 µS/cm time to failure for an EPDM termination increased and the failure mode was largely due to massive erosion instead of tracking. Using high conductivity water the leakage current intensity was very intense and had sufficient energy to release the water in the ATH and protect the EPDM polymer. At low conductivities leakage current was insufficient and the EPDM tracked.

Another experiment used 16,000 µS/cm water as specified in a European standard and all test samples lasted over 500 hours with no deterioration [2]. This extreme salinity actually made the test easier as the leakage currents were contained in the water. This also shows the degree of test acceleration is very important in developing test methods. The greater the acceleration factor, the greater the opportunity for error.

The 3M procedure attempts to simulate an industrial, high humidity, seacoast environment [3]. The water spray is light, and about six times as conductive as reported for coastal rain. The paper pulp adheres the particles to the insulator to prevent washing. Humidity inside the chamber is 90% RH and water resistivity is 180 µS/cm. Voltage is 150% above operating voltage. No one factor is accelerated to the extreme. The accelerating factor of the contaminant is very significant. One set of silicone terminations was not contaminated and tested with 700 µS/cm water. After 12,000 hours there was no significant surface change. Typical results for various types of terminations are shown in Table II.

Table II Summary of the results obtained by testing various types of terminations using 3M contamination test (170 µS water)

Style Termination	Hours to Failure
Tape Termination (No protection on tail)	1–10 Hours
Tape Termination (Silicone tape protection on tail)	100–200 Hours
Tubular QT Termination	300–500 Hours
Elastomeric Termination B	2000–2500 Hours
Elastomeric Termination C	1000–1500 Hours
Skirted QT Termination	2600–3200 Hours
Heat Shrink Termination	1500–1600 Hours

Unfortunately, none of the tests evaluate resistance to ultra violet light, although we may presume the manufacturer has evaluated this most important property separately. The silicone used in cold shrink terminations has been tested up to 6000 hours without surface crazing.

Various field and life test results have been conducted on silicone cold shrink terminations which substantiate various laboratory work indicating long service life.

IV. Field Evaluations

The following information is from several sources, the 3M Life Test Yard, and field trials from various test sites in cooperation with users.

3M Life Test Yard

This facility has various voltage and current sources and silicone terminations have been on test since 1974 at 2, 3, and 5 times rated voltage. In 1988, equipment and samples were relocated from St. Paul, Minnesota to Austin, Texas. The three voltage levels are used to develop life curves. The present QT II design using high dielectric stress grading has been on test since 1978.

Even after fourteen years of test, insufficient data has been generated to predict product life. From a statistical basis this is disappointing, but extremely encouraging for product confidence.

This testing shows excellent stability at these test voltages and continues to do so. We have removed samples and examined them for surface degradation, both visually and chemically, and also for physical stability.

Results are shown in Fig. 4 and Table III. Fig. 4 shows excellent retention of memory, which indicates sufficient pressure on the cable and connector to insure interface integrity well past a thirty year life.

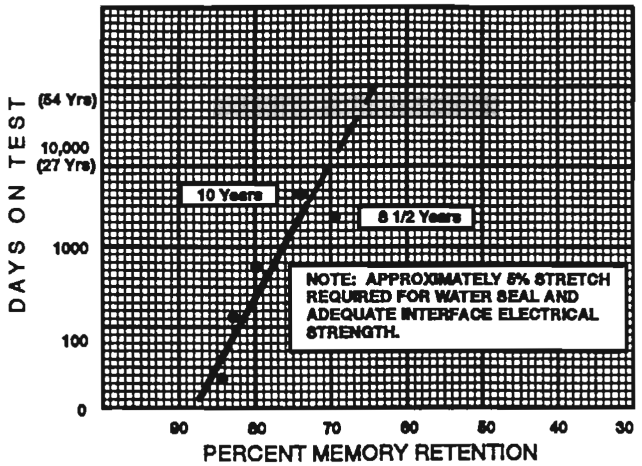


Fig. 4 Silicone Insulator Elastic Memory Retention Vesus Time Installed on Cable

In Table III, the ESCA Analysis (Electron Spectroscopy for Chemical Analysis) shows the surface chemistry to be almost unchanged compared to the control sample even though each was exposed to extreme conditions over a long time period.

Table III 3M ESCA Analysis of Aged QT II Silicone

	C%	O%	Si%
Control as molded	45	33	22
Field aged surface*	50	30	20
Field aged bulk	47	31	22
3M life test (10 Years)	49	28	23
Desert aged (15 Year Equivalent)	49	27	24

*12 Years Adjacent to Cement Plant

While several accelerated test methods have been developed and a large number of technical papers published, there are virtually no papers showing any correlation between service life and test life. In defense, meaningful correlation is extremely complex given the extreme diversity of environments terminations can be exposed to, and complex surface degradation process. The best we can do is to compare outdoor sites, accelerated tests, material properties, and general product history to estimate service life. Fortunately, some elastomeric designs have been in service for many years to give a good basis for comparison.

Field Tests

Field tests often consist of installing the termination in an area of extreme contamination, based on the utilities experience, and checking periodically for degradation. Often samples are run at 173% of rated voltage, which greatly increases the frequency and intensity of surface discharges, as well as the integrity of interfaces and seals.

We have participated in several over the years, all successful results. Two of the most rigorous were with Southern California Edison and Electricity de France.

The SCE test site was near four generating units located less than 1/4 of a mile from the ocean near Long Beach. Frequent salt laden fog was present at night and early morning. Both 15 kV and 35 kV terminations were tested at 173% of rated voltage. After about 1 1/2 years, the circuit tripped–out due to a porcelain insulator coated with silicone grease. After 3 1/2 years the test was terminated. The terminations were dirty to filthy, but no erosion or tracking from surface discharges were found, nor any crazing from UV.

One 4–skirt from a 15 kV test loop was high pot tested as is, after a modest water wash, and then after being cleaned with trichlor. Sixty–five kV was applied and leakage measured (micro–amps). Results are shown in Table IV.

Table IV High Pot Testing of 4–Skirt Termination from a 15 kV Test Loop

	Initial	30 Sec	1 Min.	2 Min.	5 Min.
Contaminated	22 μα	22 μα	22 μα	20 μα	20 μα
Water Wash	28 μα	25 μα	24 μα	23 μα	22 μα
Trichlor Clean	20 μα	20 μα	20 μα	18 μα	18 μα

There was virtually no difference between the contaminated and clean readings, with the water wash sample somewhat higher, but decreasing as the water evaporated.

Voltage was raised to 100 kV for two minutes without flashover. The terminations were "no worse for wear" after the 3 1/2 years of accelerated field testing.

The EdF test site is located near Marseilles, France adjacent to the Mediterranean Sea. The area has industrial pollution, salt fog, and low rainfall. Terminations were energized at 173% of rated (20 kV) voltage and current cycled. Although polluted, no failures or erosion was reported after eight years.

In these environments, and especially at 173% of rated voltage, conditions would be expected to produce frequent high discharge currents. However, there was no erosion, which indicates no or little discharge current formation occurred.

Summary and Conclusions

Accelerated testing of outdoor terminations is an essential step for developing products to meet customer expectations for long service life. Generally, resistance to surface discharges is the primary focus of this work. However, the total weathering process is extremely complex and variable and difficult if not impractical to duplicate in the laboratory. Because of this, it is also necessary to both choose materials based on their intrinsic resistance to weathering, especially UV, and to initiate life studies both internally and in actual service conditions.

Maintaining the terminations surface resistance is also essential for long service life, especially in polluted areas.

The silicone cold shrink terminations have shown excellent stability over time as evidenced by visual and analytical measurements from units installed in various test sites. We are confident these designs will perform to users expectations, including those in polluted environments.

Bibliography

[1] R. S. Gorur, E. A. Cherney, R. Hackam and T. Orbeck, "The Electrical Performance of Polymeric Insulating Materials Under Accelerated Aging in a Fog Chamber," IEEE Trans PWRD, Vol–3, pp. 1157–1164, July 1988.

[2] R. S. Gorur, L. A. Johnson and H. C. Hervig, "Contamination Performance of Silicone Rubber Cable Terminations," IEEE Transaction 90 WM 074–5 PWRD.

[3] L. A. Johnson and W. C. Osborn, "Contamination Testing of Distribution Class Cable Terminations," IEEE 1976 Underground T&D Conference, Pub. 76 CH 119–7–PWR, pp. 383–9.

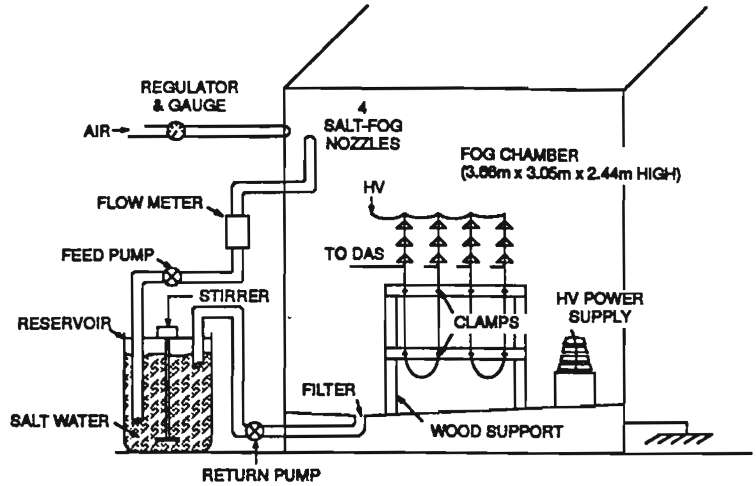
APPENDIX A

TEST METHODS

a) Fog Chamber:

Schematic of the fog chamber at Arizona State University. It is made from stainless steel sheets and its dimensions are 3.6m x 3.05m x 2.5m high. There are four IEC dimensioned fog nozzles, one on each wall of the chamber. Water of the required conductivity is made by adding NaCl to distilled water. The saline solution is recycled and changed everyday in order to limit the increase in the conductivity to less than 10% of the initial value.

The high voltage supply is provided by a 15 kVA 50 kV/120 V, transformer bank located inside the fog chamber. The output voltage is controlled by a 50 A, 0–120 V variac, located outside the fog chamber. The HV supply is suitably protected with a fuse and circuit breaker. Interlocks are provided in the fog chamber for safe operation.



Schematic Diagram of Fog Chamber

b) 3M Solid Contaminant Test:

Contaminant: ASTM D–2132 (Flint, clay, paper pulp, salt)

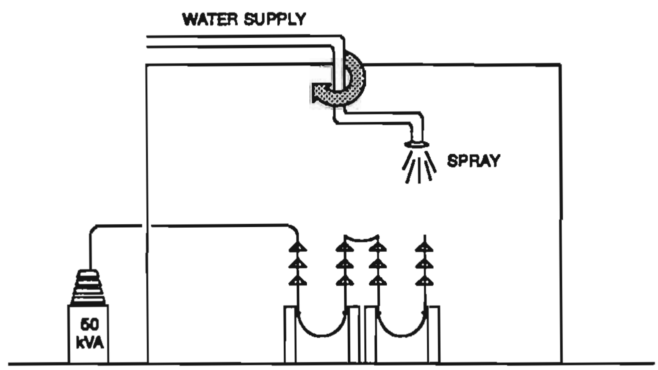
Samples contaminated every 300 hours

Water Spray .32 liters/mm

Nozzle Rotation 3.5 Revolutions/Minute

Voltage 150% of Operating

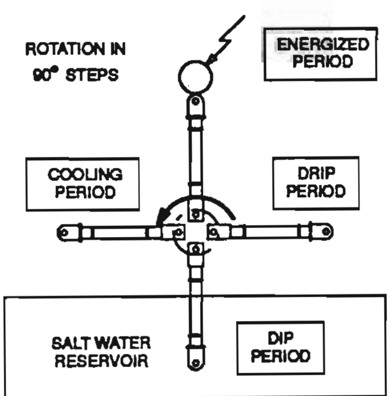
Up to 14 terminations mounted around diameter 2.5 meter



Schematic of 3M Contamination Test

c) IREQ Tracking Wheel:

Each insulator remains stationary for about 20 seconds in each of the four positions. The 90° rotation from one position to the next takes six seconds. The insulator is first dipped into a saline solution. The second part of the cycle permits the saline solution to drip off the insulator, insuring that the light wetting of the surface gives rise to sparking across dry bands which will form in the third part of the cycle. When the insulator is submitted to a 60 Hz voltage, the insulator surface is then allowed to cool. Conductivity of the water is 3000 μS/cm.



IREQ Tracking Wheel