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Role of Semiconducting Screens on Water Treeing in Medium Voltage XLPE Cables

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Abstract. Water treeing is a predominant mechanism of premature failure of underground XLPE distribution cables. Recent studies show that insulation degradation is due to injection of hydrophilic ionic species into the insulation and its rupture under the action of electromechanical and electro chemical processes operating at the microscopic level in the presence of strong field enhancement. Therefore, the ionic contamination in semicon screens as well as in the matrix of insulation play dominant role. But, most of these findings are based on the studies carried out on molded insulation plaques. The present study focuses on the role of contaminants in the semiconducting screens of medium voltage XLPE insulated cables commonly used in electric power utilities. Effect of two purposely selected ionic aqueous species on the treeing parameters evolved in these cables as a result of accelerated stress aging in the presence or absence of outer semiconducting screens, has been studied. Results show that ionic impurities present in semicon screens that belong to transitional metallic group, do catalyze the treeing process. If the semiconducting screens are produced and extruded over insulation using extra clean carbon then these will act as a barrier toward the degradation of cable's insulation. Based on the results and their analysis it is postulated that if some suitable ion trapping materials are blended in the base matrix of semiconducting screens, the water tree growth in polymeric insulation can be effectively retarded.

Keywords: Water treeing; XLPE insulation; Medium voltage cables; Semiconducting screens.

Introduction

It is well established that water treeing is a serious cable degradation phenomena that causes premature failure of polymeric insulated high voltage cables. However, there does not exist consensus on a single mechanism that can explain water tree inception and growth. Crine [1] has summarized seven different parameters that play some role at different stages of its emergence, that too, partly concurrently or partially in contradiction. These include effects of voltage, frequency, temperature, mechanical stress, material morphology, ionic solution and presence of oxygen. It is now generally agreed that degradation of polymer due to water treeing is in fact a combination of all these processes; but their relative contribution is not clearly known. Damage of the insulation surface with probable chain scission due to strong field enhancement, and the presence of various contaminants are found instrumental for the tree inception process. Likely water tree inception processes are the injection of hydrophilic species into a certain depth of the insulation and electro-mechanical rupture after which electro-osmosis occurs. For propagation processes at service stresses, particularly the electro-osmosis plays the role, while at higher stresses electro-chemical processes become more likely. The degradation as a whole is therefore both electrochemical as well as electro mechanical in nature [1-14]. However, the dominant role of oxidation as emphasized in earlier publications, has been found in more recent findings to act only as a secondary process [15].

Ionic impurities present either in the matrix of cable insulation or entering from surroundings are the other factors that are being addressed now. Several researchers have tried hard to find out the chemical composition of water trees as well as the neighboring polymer of the aged cable insulation. Techniques such as electronic micro probe, Micro Proton Induced X-ray Energy (PIXE) and Energy Dispersive X-ray (EDX) spectrometries have been utilized with some success [16-19].

Generally, the propensity of water treeing in different materials is studied through needle grown vented water trees either in molded or in sliced samples of the insulation. In this context, semi-conducting screens are also extruded over the surface of these plaques to investigate their role as well. However, these results do not replicate the impact of such degradation factors on the actual lengths of cables that are in service of power utilities. Only limited studies have been reported that deal on this subject [1, 7, 13].

In this experimental investigation the role of semiconducting screens and different ionic species towards the propensity of water tree generation in the insulation of commercial grade medium voltage XLPE cables, have been evaluated. The cable's insulation as well as semicon screens were pricked in a well defined manner with sharp needle at several spots along the length of cable samples which were then immersed in PVC jackets filled with ionic aqueous solutions and then subjected to accelerated electrical stress aging for long periods. In addition, elemental analysis of semicon material and degraded insulations of these cable samples were also carried out. A comparison of the needle grown vented trees in cable insulation due to different aqueous salt solutions, and the role of semicon have thus been examined in order to have a better understanding of the mechanisms that operate in the initiation and growth of vented water trees in the outer layers of cable's insulation when it comes in contact with chemical species and moisture in the presence of electric stress. The paper presents results, analysis and discussion on the observations made.

Experimental Setup and Procedures

Cable samples used in this work were cut from a new, 185 mm^2 cross-section, copper conductor, 15 kV rated XLPE insulated cable produced by a local manufacturer in 1999. These cables are commonly being used by electric power utilities in Saudi Arabia. Each cable specimen had a length of 4 m and its outer sheath and earthing shields were removed. For the purpose of testing and comparison the outer semiconducting screens were stripped away from two samples. For rapid generation of water trees the middle 150 cm portion of the cable samples was pricked with steel needle. To get a good statistics of the tree parameters, 15 points spaced 10 cm apart, were pricked, along the selected length of the cable, which was to be surrounded by the ionic solutions. To prick cavities, Ogura jewelry high carbon steel needle which had 1 mm shaft diameter and a tip radius profile of 30 µm was used and held in a brass holder. The precise lengths of the needle tip end that had to be inserted in insulation was adjusted under the microscope. The insulation was heated to 65 ^oC in an oven before the needle was inserted to avoid any cracks due to mechanical stress. For this purpose the cable sample was clamped in a mechanical jig made for this purpose, and the needle holder was pushed against the insulation till the needle tip was gently inserted in the insulation.

The samples without semicon screen were pricked down to a depth of 1.5 mm, whereas unstripped cables were pricked down to 2.5 mm to account for the semicon screen thickness of 1.0 mm. The average thickness of insulation of these cables was 4.5 mm. These samples were immersed in aqueous solutions contained in 10 cm. diameter, 150 cm long, thermal PVC fluid jackets. These were specifically designed for these tests. The sample under test, which was without semicon layer, was provided with ground wire by wrapping around it a chromal wire of 1.0 mm^2 cross section and connecting it to the stress cone's ground point. The conductor interstices of each cable sample were filled with deionized water. The ends of the cable terminations were fitted with PVC cylindrical funnels that were kept filled with deionized water at room temperature. Fig. 1 illustrates complete arrangement of a sample ready for testing. A thermo fluid circulator was connected with the inlet/outlet ports of the fluid jacket and provided circulation and agitation of the aqueous ionic solution which surrounded the cable test specimen.

The results reported here are for the aging carried out at room temperature. Four of such cable assemblies were prepared and mounted on a platform. The fluid jackets of two of these were filled with aqueous solutions with 0.5 mole concentration of $AgNO_3$, while the other two were filled with solutions of 0.5 mole concentration of NaCl. In each type of solution two cable specimen (one with semicon screen and one without) were inserted. NaCl is common in the soil of Saudi Arabian terrains, whereas $AgNO_3$ was used since it is known that it generates the water trees in XLPE insulation with a relatively much faster growth rate as compared to several other salts [7, 26]. Similarly concentrations of 0.5 mole used have been shown to give optimum growth of water trees with respect to other levels of salt concentrations [7]. All the samples were connected

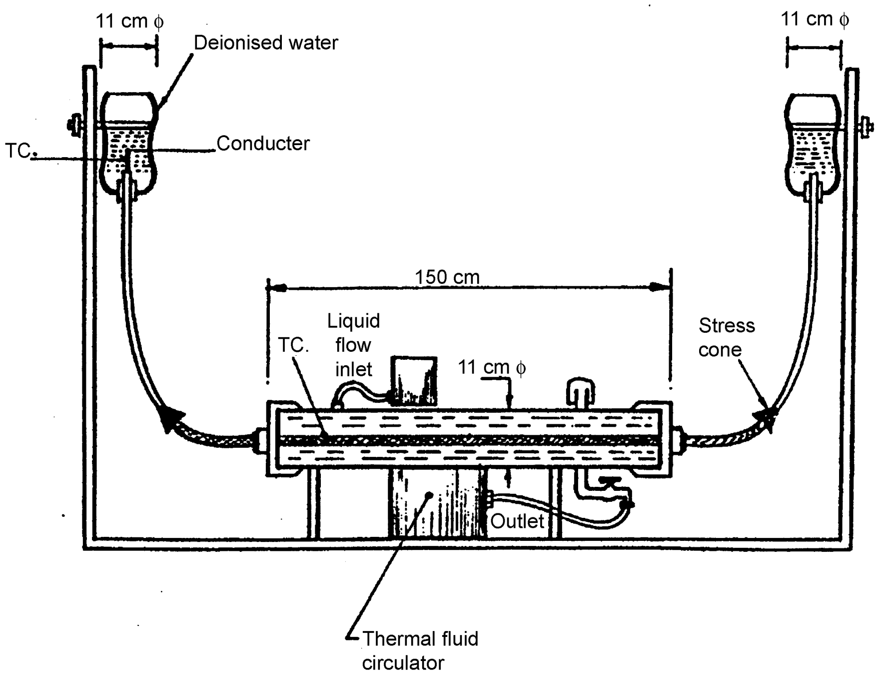


Fig. 1. Complete set of cable sample with fluid jacket and thermal fluid circulator.

in parallel to a partial discharge free AC, 50 kV, 30 kVA, 60 Hz power source. A voltage of three times the rated line to ground voltage (3 V_o) was connected to the cables and maintained without any interruption for 1000 hours. A time of 1000 hours of aging was selected so as to minimize the accelerated aging time while having optimum growth of water tree lengths. From the studies of Jow [28] carried out on different types of XLPE cables, it was reported that such an optimum time for tree growth is around 1000 hours. The voltage of $3V_o$ was selected on the basis of accelerated water tree testing techniques specified in AEIC [29]. After the completion of aging period, the samples were removed from the test platform, and 0.6 mm thick insulation wafers of the needle depressions were microtomed, stained and subjected to microscopic inspection for tree parameter evaluation.

Results and Analysis

Needle grown water trees

In each cable sample, 15 water trees emerged from the needle depressions. These trees exhibited different sizes and shapes despite the presence of same accelerating conditions. The results obtained in cable samples with and without semiconducting outer screens and due to two different ionic aqueous solutions are given next.

Treeing in cable samples without semicon

Figure 2 shows two of needle grown water trees in the case of 0.5 mole $AgNO_3$ solution in cable insulation without outer semiconducting screen layer. These trees had crossed almost 30% of the stressed insulation thickness under the experimental conditions mentioned above. The variation in the axial length of these trees in the direction of the applied electric field was from 261 µm to 958 µm. These trees were visible even without dying; however, their growth complexion became more clearer and contrasting when they were stained. In some cases, beside the growth of the main tree at the needle tip, either some small sized trees appeared on the walls (termed here as "tree trunk") due to the aqueous solution filled needle depression or the entire sides of the trunk got degraded. This clearly indicates that, whereas the main tree appears at the tip of needle where the stress is the highest, the sides are also attacked by the aqueous solution that degrades its surface to varying depths in the form of blurring. This is likely due to the electro-oxidation of XLPE which is taking place due to development of the electropotential between the aqueous solution and the chemical species embedded in the matrix of XLPE insulation matrix.

Figure 3 shows two examples of needle grown water trees as a result of 0.5 mole NaCl solution without the presence of outer semiconducting screen. Contrary to $AgNO_3$ solution, the length of the trees in this case is smaller. With the exception of a few, most of these trees have emerged only slightly from the highly stressed needle tips. However, the attack of this ionic solution is more prominent on the tree trunk, which recedes as the degraded region moves upward, where the stress is comparatively weaker. As compared to $AgNO_3$ generated water trees which had expanded with well defined branches, the trees due to NaCl solution are different as is clear from Fig. 3.a where the tree growth seems to have emerged in the form of very fine structured filaments through which the hydrophilic aqueous solution has diffused towards the filament tips forming roughly round shaped diffused regions. It is most likely that micro-cavities were already embedded in the insulation at these diffused regions of the tree and when the initial filaments of this tree approached these empty cavities, the flow of ionic solution has filled them and this is what appears as the diffused regions at the extended tips of otherwise fine filamentary water tree.

Treeing in cable samples with semicon

Figure 4 shows two of the water trees grown as a result of aqueous solution of 0.5 mole $AgNO_3$ in the presence of insulation screen. Comparing to the former case of no screens, the axial lengths of the trees in the field direction in this case are much smaller (between 21 and 160 µm). Moreover, the trees in this case do not originate directly from the tip of the needle but instead propagate initially in the form of a thin jet. The main water tree originates and expands at the end of the jet's tip. Also, in the presence of insulation screen no electrochemical degradation/formation of small trees in the form of blurring occurs on the side walls of the tree trunk. The above observations, therefore, show that the outer screen acts as a weak barrier toward the formation and growth of water trees in the polymeric insulation.

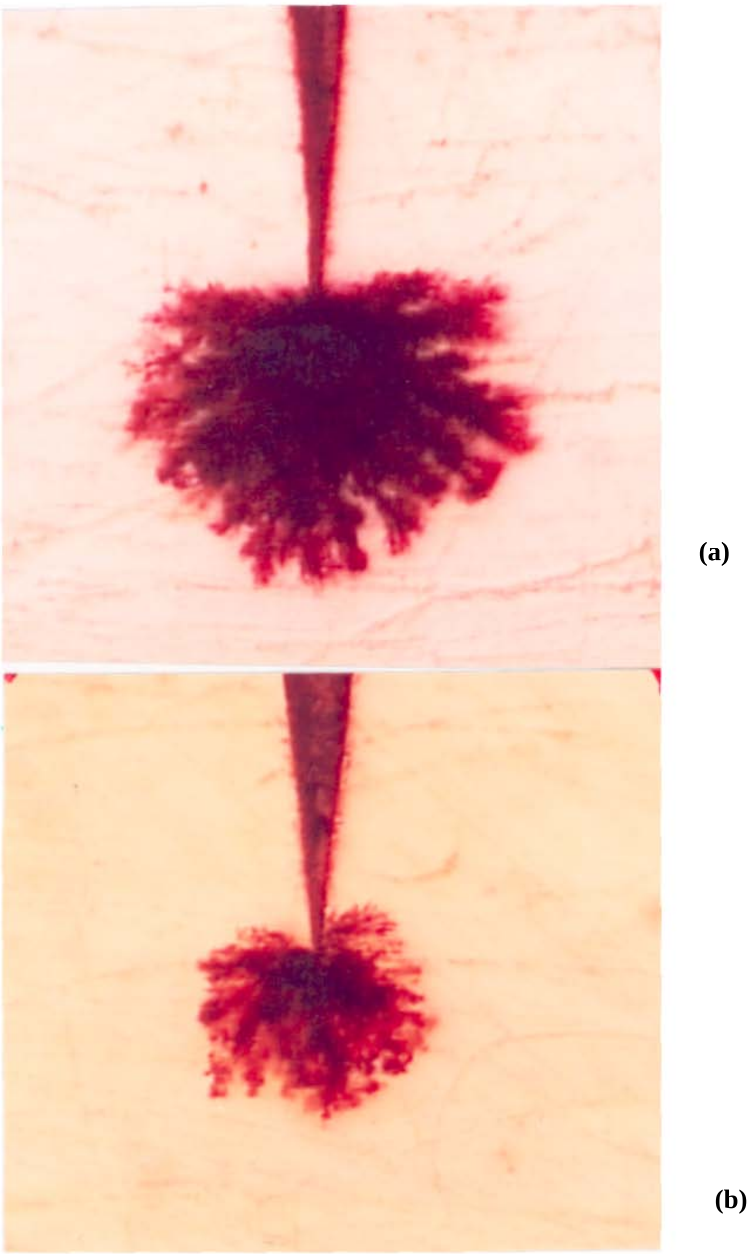


Fig. 2. Needle grown water trees due to $AgNO_3$ aqueous solution in cable sample without outer semiconducting screen. The tree length in (a) 556 µm, and (b) 530 µm.

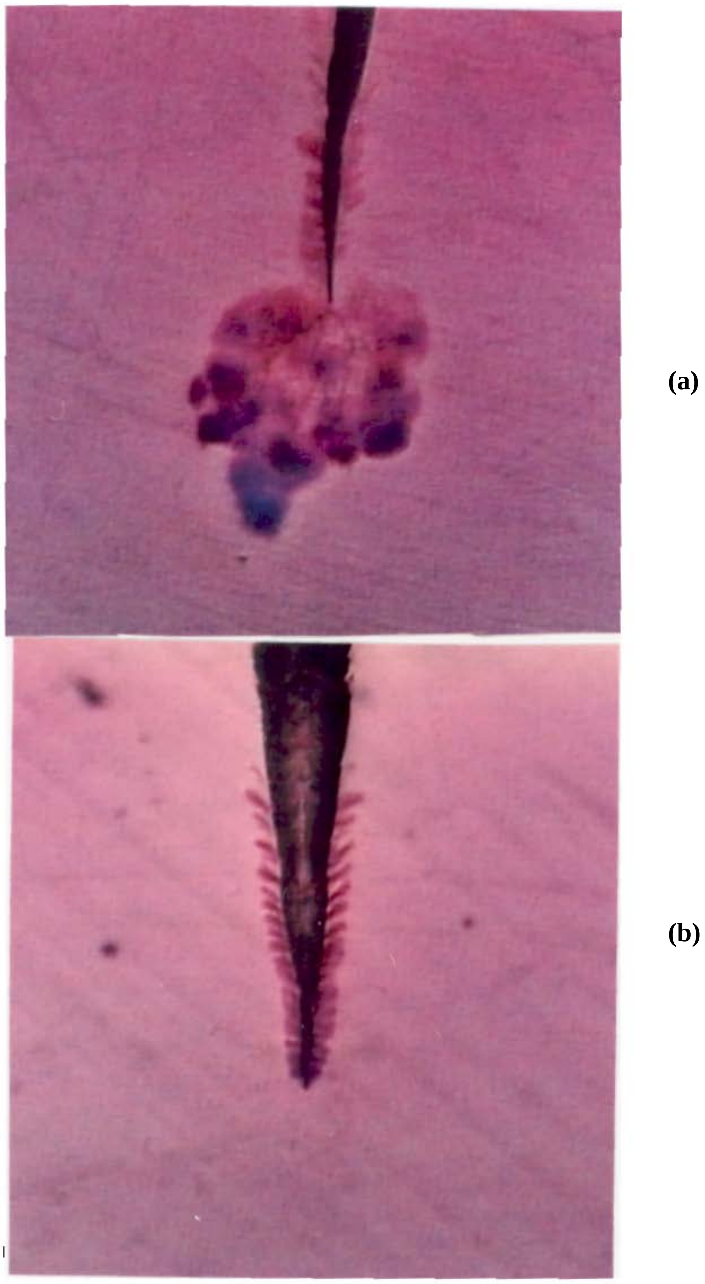


Fig. 3. Needle grown water trees due to NaCl aqueous solution in cable sample without outer semiconducting screen. The tree length in (a) 798 µm, and (b) 106 µm.

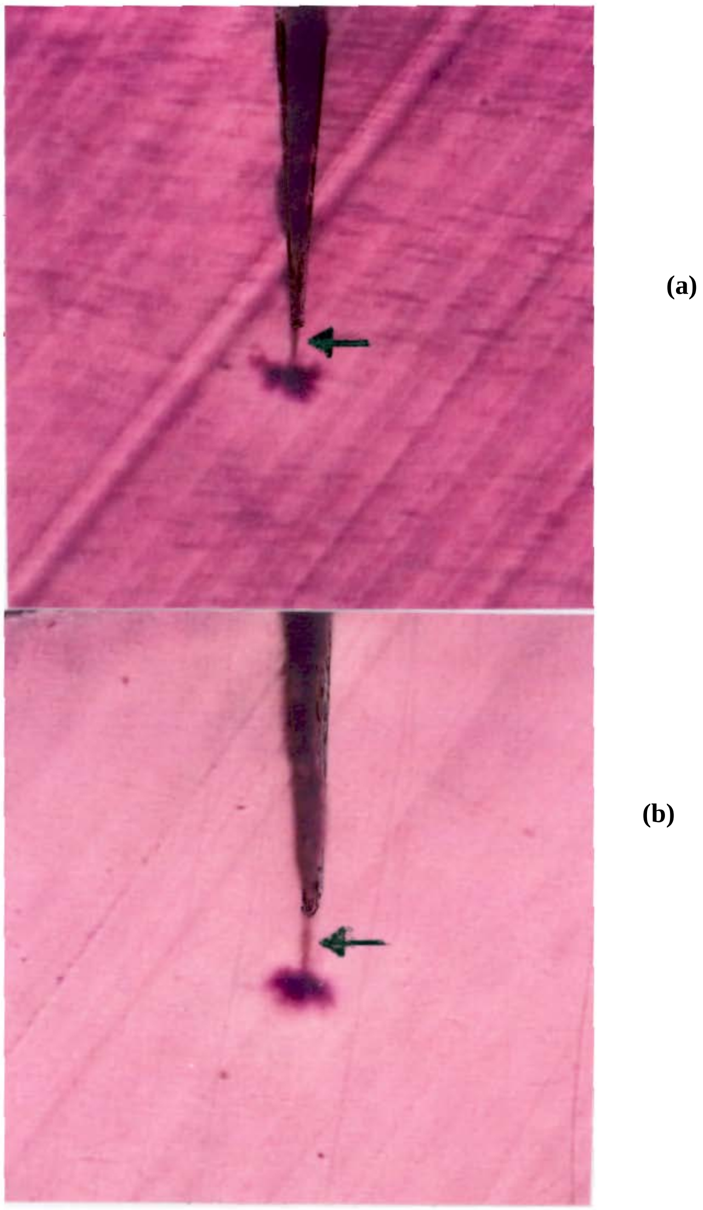


Fig. 4. Needle grown water trees due to $AgNO_3$ solution for cable with outer semiconducting screen. Tree length in (a) 160 µm, and (b) 138 µm. Arrow shows thin jet appearing from the needle's tip, while the main water tree originates at the end of jet's tip.

Figure 5 shows one of the needle grown water trees, formed in the presence of 0.5 mole NaCl aqueous solution. In this case too, the water trees are smaller than the ones that initiated without semiconducting screen and their formation are similar to these of $AgNO_3$. These trees varied in length in the range of 32 µm to 266 µm, so that their average lengths are comparatively larger than those due to $AgNO_3$ solution in the presence of semiconducting screen. This shows that strong effect of $AgNO_3$ becomes significantly weaker in the presence of the insulation screen. However, the trees in this case are somewhat branched but diffused structures, whereas these are thickly branched in case of $AgNO_3$ solution. This demonstrates the nature and effect of degradation due

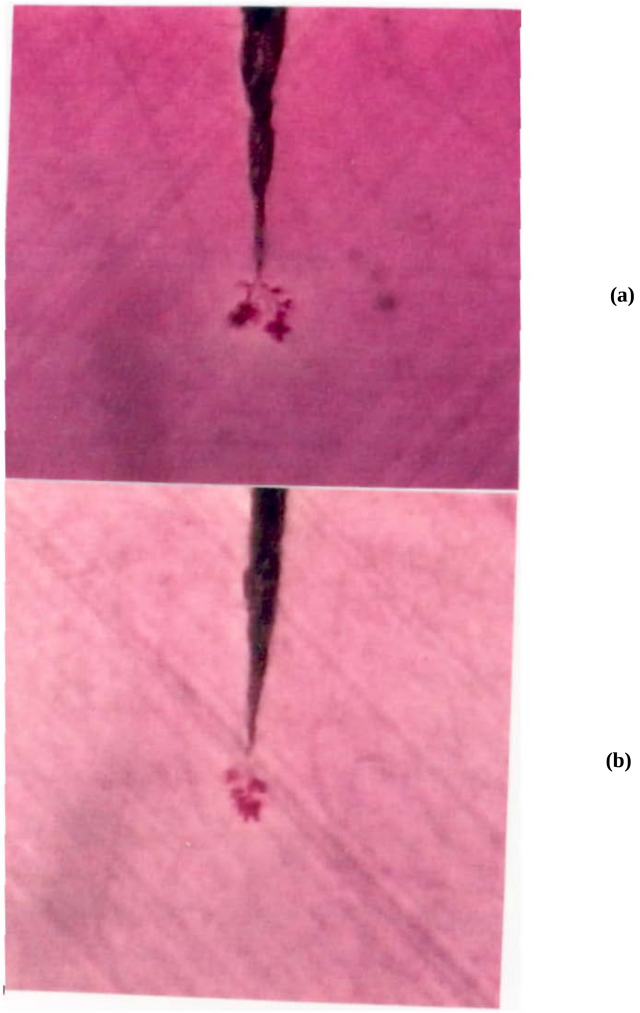


Fig. 5. Needle grown water trees due to NaCl solution for cable with outer semiconducting screen. Tree length in (a) 266 µm, and (b) 250 µm.

to the two different ionic species reacting with the macro molecules of the XLPE insulation and also indicates a strong role of semiconducting screen on the treeing phenomena.

Beside the needle grown water trees that mostly resemble the vented water trees, some of the trees were found to have different growth structures. These generally resembled electrical trees and originated only in the presence of $AgNO_3$ solution in cable samples with semiconducting screens. One of such trees is shown in Fig. 6. Most likely it has emerged from the outer tip of the extended filamentary jet of water tree just at the end of the aging period. The applied stress Laplacian at the needle tips calculated according to the Mason's [20] equation stands around 290 kV/mm, which is close to the average inception stress of electrical trees in commercial grade XLPE insulation [21]. Therefore, there is a strong likelihood that with the onset of initial thin jet of water tree that emerges in the insulation covered with semicon and surrounded by $AgNO_3$, the electrical tree can be initiated if the tip radius of this jet is ≤ 5 μm, and provided that it is highly conducting.

Fig. 6. Propagation of electrical tree from the tip of water tree due to $AgNO_3$ for cable with outer semiconducting screen. Tree length 426 μm.

Elemental analysis

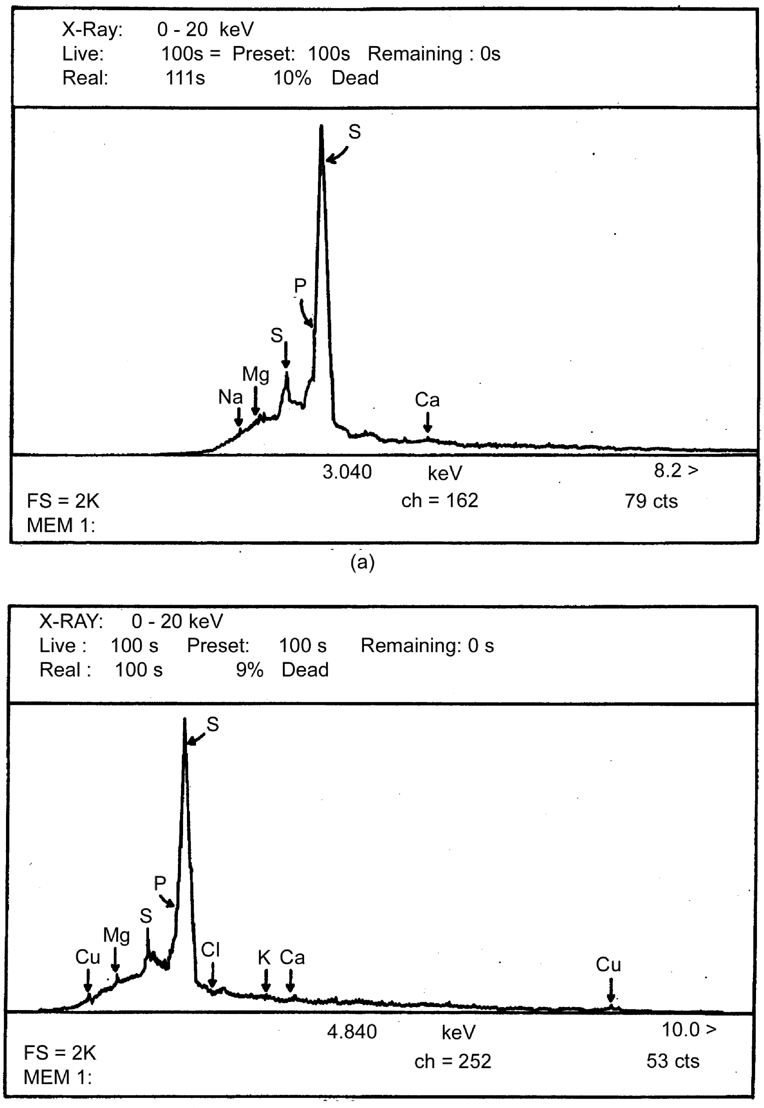
The semiconducting screens extruded on the XLPE insulation and conductor are a mixture of polymer and conductive materials. The most common polymer used in their formulation is ethyle vinyle acetate (EVA), in which carbon black is dispersed evenly in ratio of 15 – 50 per hundred of polymer. These carbon particles are not pure carbon as they contain range of cationic impurities, like sulphur Al, Ca, Cu, Fe, Mg, P, K, Si, Na and Zn, while the major anions are in the form SO_4, CO_3 and halides. In addition, oxygen based groups like carbonyls and hydroxyls are also present [22]. However, all of these impurities are present only in trace amounts. To understand the role of insulation screen on water tree manifestations, elemental analysis of chemical impurities present both in outer semicon as well as in XLPE insulation were carried out using the EDX-SEM technique, and the resulting elemental spectrograms are shown in Fig. 7. It is clear that XLPE insulation of the tested cable samples contains elements like Na, Mg, Si, P and S while the semicon screen is contaminated with elements like Cu, Mg, Si, P, S, Cl, K and Ca. This shows that screen, which is to be kept as clean as possible, has extra impurities like Cu, Cl and K in addition to impurities present in the insulation. Nevertheless, these screens are much cleaner than the old versions of cables as reported in literature [22-24].

Analysis and Discussion

Figure 8 summarizes and compares the needle grown water tree lengths due to $AgNO_3$ and NaCl aqueous solutions, both in the absence and presence of semiconducting screens. It is clear that in the absence of semicon screens, large trees are produced. Particularly the chemical specie ($AgNO_3$) causes more degradation of XLPE insulation as compared to NaCl solution by water treeing. Beside the propagation of trees to larger lengths, the tree trunk also gets blurred which is similar to multitude growth of micro sized water trees and is most likely due to the electro-oxidation of that surface.

In the presence of semiconducting screen, the lengths of the needle grown water trees are much smaller than in their absence. This shows that semicon screen acts almost like a weak barrier towards the propensity of the water tree growth. Moreover, the trees do not start growing from the tip of the needle depression but instead a jet like region appears initially which extends to a certain length in the direction of the applied field, before the tree starts taking shape at its extended end. In addition to that, the blurring of the internal surface of needle depression does not take place at all. Moreover, contrary to the tree growth in case of cable sample without insulation screen, the three growth due to $AgNO_3$ solution is smaller than that due to NaCl solution.

Analysis of the results shows that the two salts behave differently in the presence and absence of semiconducting screens. To understand the role of these ionic species on the growth of water trees in XLPE insulation, one should look into the latest model that leads to the understanding of the mechanism of water tree initiation and growth. There



(a)

(b)

Fig. 7. EDX – SEM elemental spectrographs for (a) XLPE cable insulation, and (b) outer semiconducting screens.

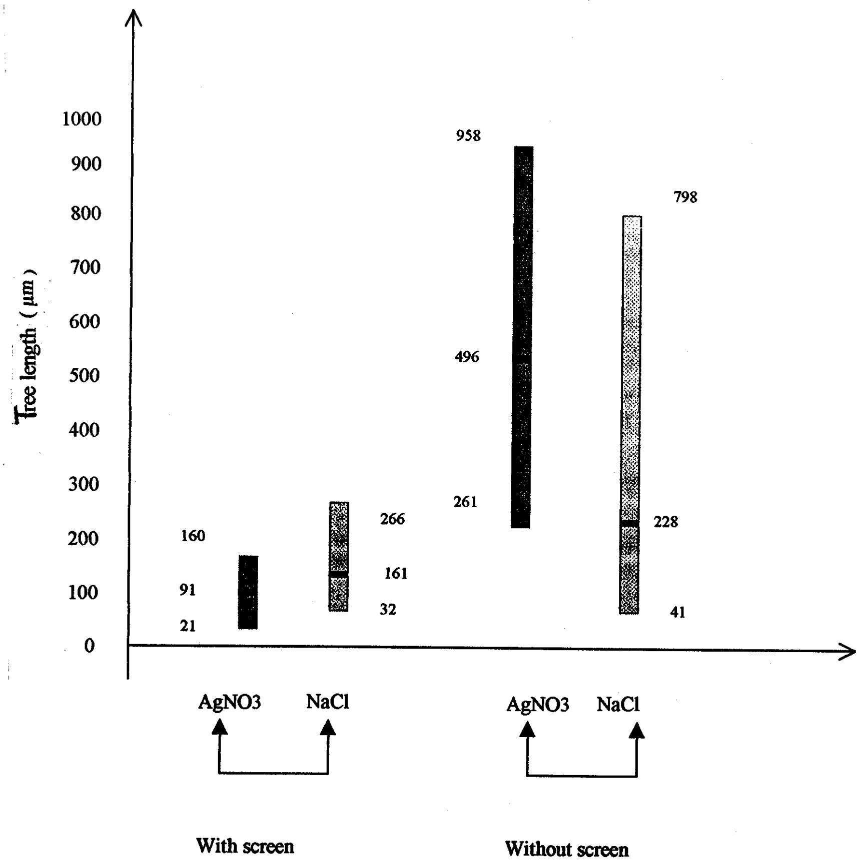


Fig. 8. Comparison of growth of needle grown water trees in XLPE insulation due to $AgNO_3$ and NaCl solutions in the presence and absence of semiconducting screens.

is now general consensus among the researchers [23, 24] that water treeing can range from predominantly electromechanical to essentially electrochemical in nature. The tree growth under electromechanical damage is caused by the application of very high fields applied at the needle shaped water filled cavities indented in the polymer under test. The electromechanical stress near the needle tip weakens the polymer to the extent that it exceeds its yield stress, thus resulting in formation and extension of the water tree. In this case, micro Fourier transform infrared (micro-FTIR) spectra of the resulting trees indicates presence of only a minor electro-oxidation. However, in case of commercial cables operating at 2-3 kV/mm stress level, although the electromechanical forces are weak, the micro-FTIR analysis shows evidence of appreciable electro-oxidation. This implies that though electrochemical degradation is a slower process, it also produces yield stresses in the polymer in which the water tree can initiate and propagate. Therefore, both cases elucidate that electro-oxidation is the main contributing factor in the water tree degradation of the polymer. Once initiated, the front of the water molecule in the filament of the oxidized region can get electrolyzed into species like H_2O_2 and O_2, in the presence of electric field. These are found to react with the amorphous regions of the polymer to form oxidized polar groups such as carboxylates. These polar groups are hydrophilic in nature and attach with the hydrophobic macro-molecules of the polymer's matrix. As a result the water molecules in the polymer condense in the form of liquid moisture in the hydrophilic degraded regions. Such a situation becomes self propagating if, (i) condensation of moisture in oxidized region enhances field at the growth front, and/or (ii) agents responsible for catalyzing the polymer oxidation can migrate along the oxidized paths (i.e. tree branches). Many metallic ions such as Cu, Ag, Zn, Fe, Ni and Mn which belong to transitional metal group are known to act as catalysts in the intermediate reactions of polymer oxidation [24, 27]. This is how the water tree is initiated and then propagates in the matrix of the insulating polymer. The aqueous solution present in the stem of the needle water tree, as in the present investigation, could become an additional source of moisture to accelerate the tree growth by supplying ample amount of water as well as the elemental ionic impurities.

In the light of the above illustrated scenario of electro-oxidation of polymer and growth of water tree, it becomes clear that the occurrence of blurring of needle depression on XLPE walls in the absence of semiconducting screen, is due to the electrochemical oxidation. Since silver belongs to the transitional metal group which acts as a catalyzing agent in the intermediate reactions of oxidation process (whereas sodium is not), it becomes a strong source of electro-oxidation of the polymer, resulting in the formation of much larger and well developed trees. However, in case of NaCl solution, the degradation takes place purely based on its electropotential. Since most of the ionic content in this case has been consumed in electrochemical oxidation and degradation of side walls, the net ionic conductivity of the liquid trapped in the indented needle's capillary is reduced, thus the tree growth is also retarded.

Although several ionic elemental impurities are present in the semiconducting screen, yet the tree growth is considerably blocked due to its presence on the XLPE insulation. This shows that the dominant role in this case is being played by the carbon particles. These particles can be ejected into the needle depression, either (i) during its indenting and/or (ii) they can leach into the aqueous salt solution under the action of the applied electric stress. These carbon particles act here like activated charcoal filter which is known to absorb ionic impurities from water. This filtering action reduces the conductivity of the saline solution and hence the growth of the water trees. However, in this case silver nitrate will be more active than sodium chloride, for it is known that in the presence of squeous solution the carbon gets oxidized. The anodic oxidation of carbon consists mainly of carboxylic and phenolic groups [25]. In aqueous solution these oxides produce H^+ ions in the presence of electric field. When $AgNO_3$ is present in this solution, the cationic exchange of the H^+ with Ag^+ converts Ag^+ to metallic silver. Stepp *et al.* [26] have indeed shown using high resolution transmission electron microscopic technique, the presence of metallic silver embedded in the branches as well as at the tips of water trees produced due to the $AgNO_3$ solutions. Thus, the conductivity of $AgNO_3$ solution in the needle's depression is reduced which results in the weakening of the degradation of polymer in the presence of applied electric stress and hence the smaller growth of water trees as compared to the NaCl solution in the presence of semicon screens. These results, therefore, also lead to the finding that carbon loaded semiconducting screens extruded over the cable insulation act as barrier toward the growth of water treeing or as tree retardants. It can, therefore, be postulated that if some suitable ion trapping materials are blended in the base matrix of the insulation screens, the water tree growth in polymeric insulation may be significantly reduced.

Conclusions

From this experimental work, the following conclusions are derived:

1) Semiconducting screens produced using the extra clean carbon and extruded over the polymeric insulation act like a weak barrier which tends to reduce the propensity of water tree degradation in the cable's insulation.

2) Impurities that belong to the transitional metal group present in semiconducting screens do catalyze the intermediate reactions that are responsible for oxidation of insulating polymer. Therefore, the base materials used in the manufacture of semiconducting compounds should be kept absolutely free of such impurities.

3) Based on the experimental results, it is postulated that if some suitable ion trapping materials are blended in the base matrix of semiconducting screens, the water tree growth in polymeric insulation can be very effectively controlled.

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References

[1] Crine, J.P. "Electrical, Chemical and Mechanical Processes in Water Treeing", *IEEE Trans. on Dielectrics and Electrical Insulation*, 5, No. 5 (1998), 681-694.

[2] Bahder, G., Katz, C., Lawson, J. and Vahlstrome, W. "Electrical and Electrochemical Treeing Effect in PE and XLPE Cables." *IEEE Trans. on PAS*, 93 (1974), 977-990.

[3] Feddors, R.F. "Water Treeing as an Osmotic Phenomena." *Polymer Communication*, 21 (1980), 863-867.

[4] Dissado, L.A., Wolfe, S.V. and Fothergill, J.C. "A Study of the Factors Influencing Water Tree Growth." *IEEE Trans. on Elect. Insul.*, 18 (1983), 565-585.

[5] Parpal, J.L., Guddemi, C., Amyot, N. and Lamarre, L. "Development of Water Treeing Test Using Laboratory-molded Sample." *Canadian Electrical Association Report 117D793A*, 1996.

[6] Filippini, J.C. and Meyer, C.T. "Water Treeing Testing Using the Water Needle Electrode." *IEEE Trans. on Electr. Insul.,* 23 (1988), 275-278.

[7] Qureshi, M.I., Malik, N.H. and Al-Arainy, A.A. "Effect of Different Ionic Solutions on Statistical Length Distributions of Water Trees in XLPE Cable Insulation." *Proceedings of the 6th Int'l. Conf. on Properties and Applications of Dielectric Materials*, Xian, China, June 2000, 513-516.

[8] Qureshi, M.I., Al-Arainy, A.A. and Malik, N.H. "Study of Laboratory Grown Water Trees in XLPE Cable Insulation in the Presence of Ionic Impurities." *11th Seminar of GCC-CIGRE on Materials for Electrotechnology*, Manama, Bahrain, October, 2000.

[9] Pelissou, S. "Impurities in XLPE Cables." *Proc. ISEI*, (1990), 339-342.

[10] Patsch, R., *et al*. "Hydration of Ions: How Does it Influence Water Treeing." *Proc. 5th ICPADM,* (1997), 410-413.

[11] Jocteur, R., Favrie, E. and Auclair, H. "Influence of Surface and Internal Defects in Polythene on Electric Routine Tests on VHV Cables." *IEEE Trans. on PAS 97*, (1997), 513-523.

[12] Shaw, M.T. and Saw, S.H. "Water Treeing in Solid Dielectrics." *IEEE Trans. on Electrical Insulation,* 19 (1984), 419-452.

[13] Dissado, L.A. and Forergill, J.C. *Electrical Degradation and Breakdown in Polymers*. London: Peter Perigrinus Ltd., 1992.

[14] Ross, R. "Inception and Propagation Mechanism of Water Treeing." *IEEE Trans. on Dielectrics and Electrical Insulation*, 5, No.5 (October 1998), 660-667.

[15] Bulinski, A.T., *et al*. "Polymer Oxidation and Water Treeing." *IEEE Trans. on Dielectric and Elect. Insulation*, 5, No.4 (1998), 558-570.

[16] Sletback, J. and Botne, A. "A Study of Inception and Growth of Water Trees and Electrochemical Trees in PE and XLPE Insulation." *IEEE Trans. on Elect. Insulation*, EI-12, No. 6 (1977), 385-392.

[17] Hinrichsen, P.F., *et al*. "Allocated Trace Element Analysis of Water Trees in XLPE Cable Insulation by Micro-PIXE and EDX", *IEEE Trans. on Electrical Insulation.*" 23, No. 6 (1988), 971-978.

[18] Timbrell, P.K., *et al*. "Backscattered Electron Imaging and Energy – Dispersive X-ray Studies of Water Treed Polymeric Insulation." *IEEE Trans. on Electrical Insulation*, 25, No. 4 (1990), 730-736.

[19] Ahmed, M., *et al*. "Analysis of Water Trees in Underground HV Cables Using the KFUPM Micro-PIXE Facility." *IEEE Trans. on Dielectric, and Electrical Insulation*, 6, No. 1 (1999), 95-99.

[20] Mason, J. "Breakdown of Solid Dielectric in Divergent Fields." *IEEE Monograph*, No. 127M (1955).

[21] Jiang, G., Kuang, J. and Boggs, S. "Critical Parameters for Electrical Tree Formation in XLPE." *IEEE Trans. on Power Delivery*, 13, No. 2 (1998), 292-296.

[22] Burn, N.M., Eichhor, R.M. and Reid, C.G. "Stress Controlling Semiconductive Shields in MV Power Cables." *IEEE Electrical Insulation Magazine*, 8, No. 5 (1992), 8-24.

[23] Boggs, S.A. and Xu, J. "Water Treeing: Filled Versus Unfilled Cable Insulation." *IEEE Electrical Insulation Magazine*, 17, No. 1 (2001), 23-29.

[24] Xu, J. and Boggs, S.A. "The Chemical Nature of Water Treeing: Theories and Evidence." *IEEE Electrical Insulation Magazine*, 10, No. 5 (1994), 29-37.

[25] Jannakoudakis, A.D., *et al.* "Electrochemical Oxidation of Carbon Fibres in Aqueous Solutions and Analysis of the Surface Oxides." *Journal of Applied Electrochemistry*, 20 (1990), 619-624.

[26] Stepp, D., *et al*. "High Resolution Study of Water Trees Grown in Silver Nitrate Solution." *IEEE Trans. on Dielectrics and Electrical Insulation*, 3, No. 3 (1996), 392-398.

[27] Boggs, S.A. and Mashikian, M.S., "Role of Semiconducting Compounds in Water Treeing of XLPE Cable Insulation." *IEEE Electrical Insulation Magazine*, 10, No. 1 (1994), 23-27.

[28] Jow, J. "Material Differentiation by Water Tree Tests." *Proceedings of IEEE Conference on Electrical Insulation and Dielectric Phenomena*, (1999), 500-503.

[29] AEIC-94. *Specification for Thermoplastic and XLPE Shielded Power Cables Related 5 Through 46 kV.* 10th ed., 1994.

دورة الأحجبة النصف موصله في التشجير المائي في كابلات الجهد المتوسط المعزوله بالبولي إيثيلين ذات التشابك العرضي

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جامعة الملك سعود– الرياض

(قدم للنشر في ٢١/٣/٢٠٠٣ م ؛ قبل للنشر في ٨/٣/٢٠٠٤ م)

ملخص البحث . يمثل التشجير المائي آليه مهمة في الانهيار المبكر لكابلات التوزيع الأرضية. تشير الدراسات الحديثة إلى أن تناقص جودة العازل تكون بسبب تغلغل أيونات الماء في العازل ومن ثم تكسرها تحت تأثير عمليات كهروميكانيكية وكهروكيميائية ذات مستويات متناهية الصغر وتحت تأثير مجال كهربائي مركز، ولهذا يلعب التلوث الايواني في الأحجبة النصف موصله وفي خلايا العازل دور مهم. تلك النتائج أتت من دراسات عملت على عوازل صبت على شكل ألواح. هذه الدراسة تركز على دور الشوائب في الأحجبة النصف موصله لكابلات الجهد المتوسط المعزول بالبولي إيثيلين ذات التشابك العرضي والمستخدم بكثرة في شركات الكهرباء، وقد درس تأثير نوعين من المحاليل المائية والمختارة عمداً على نمو الأشجار في تلك الكابلات المعرضة للتعتيق المتسارع بسبب زيادة المجال الكهربائي على العازل وذلك في حالة وجود أو عدم الأحجبة النصف موصله الخارجية. النتائج تشير إلى أن الشوائب الايوانية الموجودة بتلك الحواجب والتي تنتمي إلى المواد الانتقالية تحفز تكوين الأشجار. إذا أنتجت تلك الحواجب باستخدام كربون نقي جداً وبثقت على العوازل فإنها ستكُون موانع لتناقص جودة عزل الكابل، وبناء على نتائج هذا البحث وتحليلها فإنه بالإمكان إعاقة نمو الأشجار المائية في عزل الكابلات في حالة مزج مواد امتصاصية مع مواد الأحجبة النصف موصله.