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ELECTRICAL AND PHYSICO-CHEMICAL ANALYSIS OF BELGIUM MEDIUM VOLTAGE CABLES DATA BANK

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ABSTRACT

The Belgian Medium Voltage "MV" distribution network consists of a great diversity of under ground cables coming from many manufacturers. This results in a variety of cables executions due to manufacturing processes and used materials.
In service, these various cables, in particular their polymeric insulation can react differently under the effect of the applied combined constraints. It is well known that the electrical constraints applied to insulation strongly influence its electrical properties, in particular its condition in time (ageing).
In this work, we studied the electrical behaviour of cables resulting or intended to use in the Belgian MV network. The ageing markers are the space charge whose harmful effects on the electrical behaviour on the cable insulations are well known. The measurement technique to detect these space charges on cable samples is the Thermal Step Method "TSM" installed at LABORELEC. We have studied the influence of the electrical and thermal constraints applied to various MV cables on the appearance and the development phenomena of space charges in the insulation. The observed phenomena: space charge injection from the electrodes and/or polarization phenomenon have been studied and discussed. These observed phenomena have been also consolidated by some physicochemical characterizations (DSC , FTIR, XRF) performed on each insulating and semiconductor materials used in the analyzed cables.
The final analysis of the results of this work and their interpretation confirms the influence of the couple material insulator-semiconductor in the injection and polarization phenomenon.

KEYWORDS

Medium voltage cable insulation, space charge, polarisation, injection, morphology.

INTRODUCTION

Electrical and physicochemical properties of insulating materials used in high or medium voltage applications can evolve in time. This phenomenon, called « ageing », is strongly related to the external factors acting upon the materials (electric field, temperature, humidity etc.) and to the manufacturing process. Thus, considerable efforts have been made to understand, to interpret and to prevent ageing.

Considering the electrical properties, an insulating material is supposed electrically neutral; however, electric charges (space charges) can penetrate or can be already present within the insulating material [1]. These space charges can be related to several phenomena such as injection and /or polarization. It has been shown that these electric charges trapped in insulations, could play a significant role on ageing, by creating a supplementary internal field [2-5]. Indeed, it seems that the more the insulation stores space charge, the more its ageing is accelerated by the global electric field increasing (sum of the applied field and the supplementary internal field). Sometimes, these charges can cause significant field distortion to affect the insulation performance and to reduce its lifetime. In this work, the space charge measurements have been performed by using the Thermal Step Method "TSM" [5]. A physicochemical analysis by microscopy, infrared spectroscopy (FT-IR) and differential scanning calorimetry of the insulating materials and semiconductor materials has also been performed to explain and/or consolidate the observed phenomena [6].
This study has been carried out on several cables (with several dates of manufacturing) quoted above in order to control their faculty to accumulate the space charges when they are subjected to combined constraints (electric field, temperature, duration).
- Cable 1A (1978), used in network (with water treeing)
- Cable 1C (1978), used in network (with water treeing)
- Cable 2A (1998), electrical lightning tests
- Cable 5C (1992), unknown historic
- Cable 21D (1994), used in network (thermal annealing 120℃)
- Cable 22B (1992), various tests

EVOLUTION OF THE SPACE CHARGES VERSUS THE APPLIED CONSTRAINTS

The various samples of the Belgium medium voltage cable bank were analyzed after having undergone various electrical, thermal and temporal constraints. We present here the evolutions of the space charge profiles according to the applied constraints.

Note: All the distributions presented in this paper present space charge density profiles according to the cable radius. The anode (electrode submitted to the plus of the poling voltage - cable core) is at the left, and the cathode is at the right of figures. The highlighted phenomena, namely polarization and injection will give:
- For charge injection: the presence of homocharges (same

charges signs than the electrodes) near to the electrodes, namely, positive charges close to anode and negative charges close to cathode.
- For polarization: the presence of heterocharges near the electrodes (opposite sign of charges at the electrodes): namely, negative charges close to anode and positive charge close to cathode.

Influence of the poling electric field

We voluntarily did not represent the evolutions of space charges obtained for the following electrical poling (0, 2, 5 and 10 kV/mm; 1 hour; 25 ℃ like 0 and 2 kV/mm, 1hour , 60 ℃). Indeed, all these distributions are very close to those presented on figure 1 obtained after an electrical poling of 5 kV/mm, 1 hour, and 60 ℃. That means that these various poling influence lightly the space charge evolutions. On the other hand, it should be noticed a strong accumulation of space charges for a 10 kV/mm/1 hour/60℃ poling characterized by a dominant phenomena of charge injection at the anode and the cathode (homocharges).

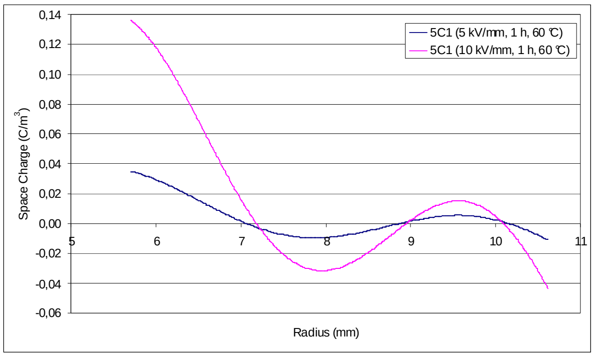


Figure 1: space charge profiles of cable 5C vs. applied electric field

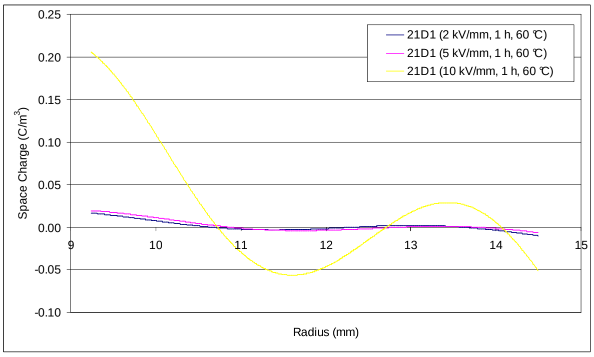


Figure 2: space charge profiles of cable 21D vs. applied electric field

As for the cable 5C reinforcement of charge injection phenomena at the electrodes is also observed on the cable 21D for 5 kV/mm and 10 kV/mm/1 hour/60℃ poling conditions (Figure 2).
All the poling performed under 25 ℃ did not give exploitable TSM signals (lower than the sensitivity of the TSM about 1 mC/m^3). For the cables 1A, 1C, 2A and 22B, we could not highlight the influence of the poling electric field on the space charge distributions because only the poling performed under the strongest electric fields (7.7 kV/mm or 10 kV/mm according to the cable) gave exploitable TSM signals. The influence of the poling electric field amplitude assessment appears interesting because it is necessary to reach strong constraints to act on the space charge accumulation phenomena in these cable insulations.

Influence of the poling temperature

The figures below present the evolutions of space charges on the same zone of each cable of the data bank by only increasing the poling temperature.

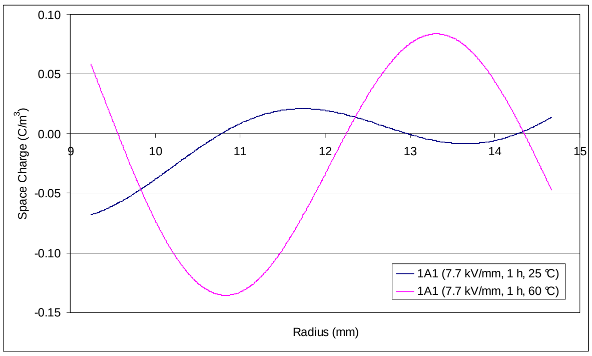


Figure 3: space charge profiles of cable 1A vs. poling temperature

Figure 3 reveals a reinforcement of the space charges when the poling temperature increases. This phenomenon seems general for all the analyzed cables. We can notice on figure 3 a transition from a dominant polarization phenomenon towards a dominant injection phenomenon close to electrodes.

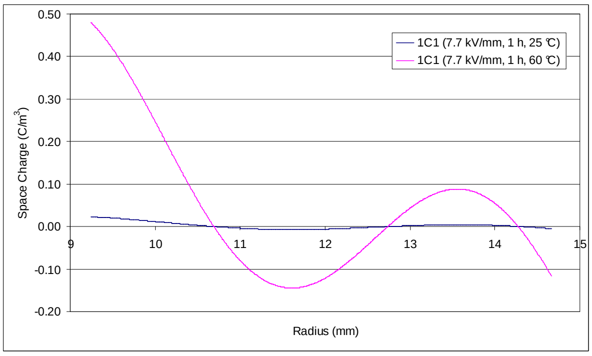


Figure 4: space charge profiles of cable 1C vs. poling temperature

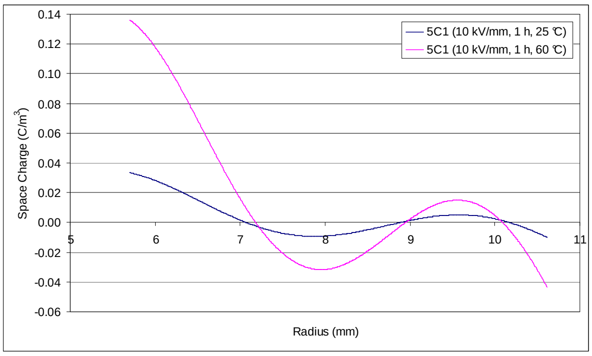
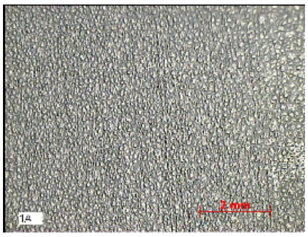
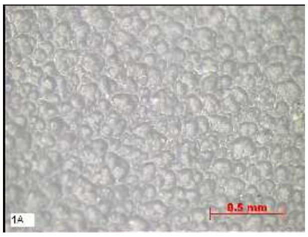


Figure 5: space charge profiles of cable 5C vs. poling temperature

The cables 1C and 5C show both a dominant injection phenomenon, as well for 25 ℃ and 60 ℃, although this phenomenon appears higher for the cable 1C. This is probably due to the age of this cable (in network during nearly 30 years), whereas the cable 5C was manufactured in 1992. The DSC analysis of the cable 5C insulation gives the highest crystallinity and the greatest thickness of the lamellas of all the analyzed cables. The cables 1A and 1C semiconductors are very granulous and very sensitive with temperature (picture 1.a). They can soften at high temperatures. Moreover, their insulation is very rough and can lead to a high risk of charge injection due to the possible electric field enhancement in the asperities of polymer surface (picture 1.b). This can also explain the birth and the presence of water trees in these insulations [7]. We can also highlight that 60 ℃ is close to the avera ge service temperature of MV distribution network cables.



Picture 1.a: Cable 1A semiconductor microscopy



Picture 1.b: Cable 1A insulation microscopy

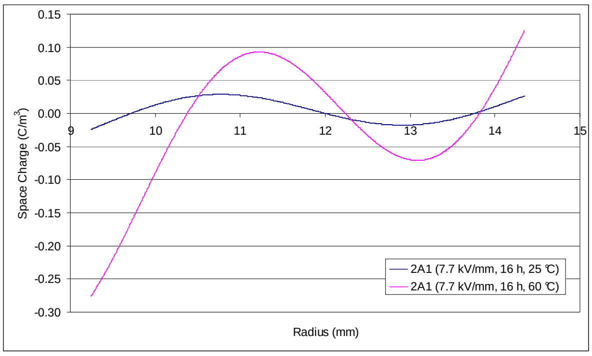


Figure 6: space charge profiles of cable 2A vs. poling temperature

Figure 6 shows a dominant polarization phenomenon for poling at 25 ℃ and 60 ℃, characterized by the pre sence of heterocharges close to electrodes; this phenomenon is reinforced at 60 ℃. The semiconductor used in this cable contains a high limestone capacity and seems to be lightly influenced by the temperature. The contact between the semiconductor and the insulation at high temperatures could then be bad and prevent the charge injection at the electrodes.

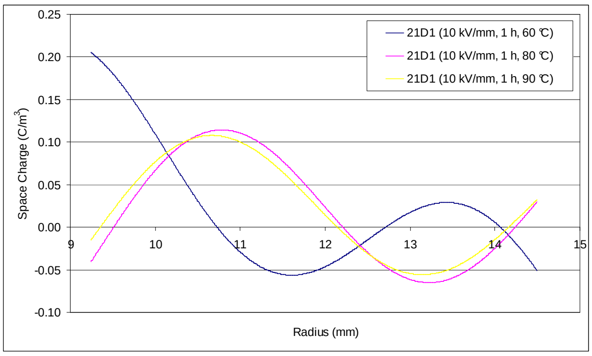


Figure 7: space charge profiles of cable 21D vs. poling temperature

The cable 21D did not give significant results at 25 ℃ (even for a 10 kV/mm applied field), while to 60 ℃, we ca n note a dominant injection phenomena both at the anode and the cathode (Figure 7). On the other hand, for poling temperatures of 80 ℃ and 90 ℃, we observe a reduc tion of the injected charges close to the anode and a charge migration toward the cathode probably due to the increase of the electrical conductivity of the material at higher temperatures.

COMPARISON OF DIFFERENT CABLES SUBMITTED TO THE SAME CONSTRAINT.

Here, we compare 5 lengths of cables submitted to the same poling conditions and we note a strong fluctuation of the space charge distributions.

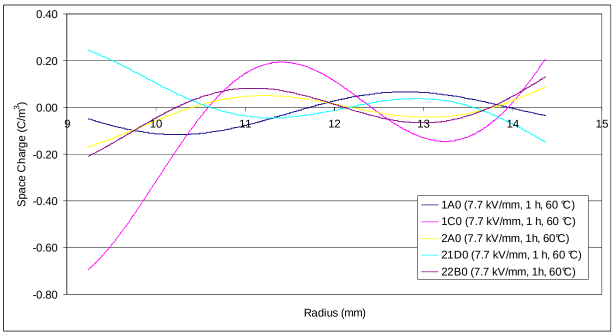


Figure 8: comparison of space charge profiles of different cables submitted to the same constraints

In figure 8, the cable 1C shows the strongest space charge level with heterocharges close to electrodes. Only the cable 21D presents homocharges both at the anode and the cathode. The cable 1A presents only an injection of electrons at the cathode and a polarization phenomenon at the anode. However, the longitudinal heterogeneities sometimes observed on cables do not facilitate the interpretation of these results [2, 8]. Indeed, these results are not inevitably representative of the behaviour of the totality of each cable, but only of one particular zone (thus only 20 cm length). A statistical study on a great number of zones of the same cable would be necessary to facilitate the interpretation of these results. For all the space charge density distributions obtained in our study, we observe four space charge zones: 2 zones corresponding to injection (or polarization) close to electrodes, and 2 zones corresponding to polarization (or injection) in the bulk.

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CHARACTERIZATION OF THE DIFFERENT PARTS OF THE STUDIED CABLES.

The charge injection, the polarisation and the charge trapping depend of the chemical composition of the different part of the cables. Different primordial analyses have been carried out in order to characterize the insulation and the semiconductor (SC) and are presented here as examples.

- X-ray fluorescence analysis (elemental) for the SC
- FT-IR (molecular) analysis of the semiconductor (SC) on film (PE insulation) or Attenuated Total Reflectance (ATR) with a Ge crystal (black semiconductor).
- Differential Scanning Calorimetry (DSC) of the SC and the PE insulation (morphology) [6].

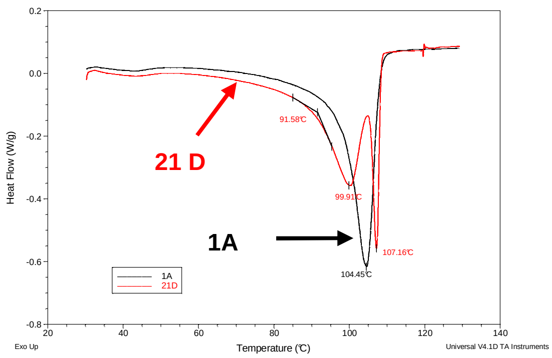

Figure 9: comparison of the DSC of PE insulation (cable 1 A with water trees and cable 21 D after 120 °C thermal treatment)

For the cable PE insulation (21 D) there is a lamellar increase of the crystallites after the thermal treatment. The order reached in the polyethylene structure after annealing is displayed by the diminishing of the polyethylene relaxation hydrocarbon chains in function of the temperature. Two peaks are observed. All the studied cables have about the same DSC profiles than the cable 1A.

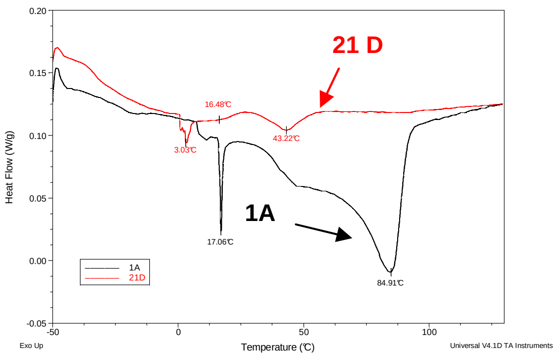

Figure 10: comparison of the FT-IR ATR of SC polymer (cable 1 A with water trees and cable 21 D after 120 °C thermal treatment)

The semiconductor of the cable 1A and 1C are XLPE (low density) with a copolymer vinylacetate.

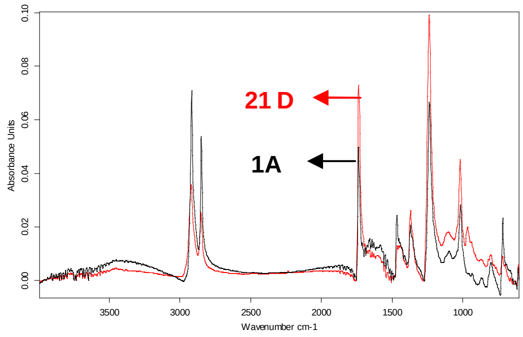

Figure 11: comparison of the FT-IR of semiconductor (cable 1 A with water trees and cable 21 D after 120 °C thermal treatment)

The semiconductor of the cable 21 D contains four times more vinylacetate than cable 1A The semiconductors are of the type polyethylene vinyl acetate but the relationship between the quantity of basic polymer, i.e. polyethylene and the copolymer vary from one semiconductor to another. The report/ratio of the quantities of copolymer varies roughly in a range from 1 to 4.

CONCLUSION

Concerning the influence of the poling constraints applied to the various cables, the results lead to the following conclusions:
- The poling voltage applied to the cables did not modify the space charge profile but only amplified the phenomena.
- The effect of the increasing of the poling temperature combined with the maximal poling electric field, amplified the space charges level and can sometimes totally modify the cable electrical state. In this case, it is observed a modification of the electrical state from a majority polarization phenomenon towards a majority injection phenomenon.
- The results show generally a predominant injection phenomenon at high temperatures.

The correlations between space charge measurements and physicochemical characterizations have allowed us to particularly understand the behaviour of four cables, namely:
- Cables 1A and 1C: cable aged in network since 1978 with water trees. The semiconductor containing the less of copolymer of the studied cable is granulous and modifies the surface of the polyethylene, which is faded. The injection of the space charges would be facilitated by the asperities with the interface semiconductor and polyethylene and may be by water trees itself. The temperature modifies the SC and PE morphology as well as the space charges injection.
- Cable 2A: semi conductor more rigid than the other cables with a high limestone concentration (27.8%). The effect of the temperature reinforces polarization and not the injection.
- Cable 5C: semi conductor extruded (containing a silicone derivate) and insulation morphology characterized by a strong crystallinity and a great thickness of lamellas.

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- Cable 21D: cable submitted to a temperature of 120 °C and the most ordered one. The cables 21 D have the greatest quantity of copolymer. This cable loads at T beyond 60°C. It belongs to the cables, which take c are less. Its annealing decreases considerably its possibility to store space charges

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