

# Experimental Characterization of Electric Power Insulator Subjected to an Accelerated Environmental Ageing

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**Abstract.** The aim of the study is to investigate the effect of the temperature, salinity and ultra-violet (UV) radiation on the Silicone Rubber (SiR) insulator degradation. The evolution of the insulator surface condition during an ageing cycle is diagnosed either by measuring contact angle (CA) or by the wettability class index (WCI). The correlation between these two approaches is discussed. The DC surface current is monitored during an ageing cycle. The reliability of the tool used to diagnose the insulator ageing is analyzed. Experimental results show that the thermal stress appears to differently affect the surface condition of the SiR material depending on the applied temperature (2°C-110°C). The same insulator installed in a cold weather environment exhibits a better hydrophobicity performance than when installed in a hot weather environment. Moreover, its ability to withstand moisture is much better at high UV level places. The solution conductivity level (3µS/cm-138mS/cm) affects the hydrophobicity during the immersion period. CA is proportional to the conductivity level during the first hours, afterwards this influence becomes more complex depending on the immersion duration especially at higher conductivity levels.

**Keywords:** High-voltage, Electrical performance, Insulation testing, Overhead line, Polymeric insulators.

## Okoljski vplivi na kompozitne izolatorje v električnih distribucijskih omrežjih

V prispevku analiziramo vpliv temperature, slanosti in UV-sevanja na kompozitne izolatorje v daljnovidih. Med postopkom staranja ugotavljamo stanje na površini izolatorja z meritvijo kota stika ali z indeksom omočljivosti. Eksperimentalni rezultati potrjujejo, da temperatura okolja različno vpliva na staranje izolatorja. Izolator, ki se uporablja v hladnem okolju, ima boljše hidrofobne lastnosti kot izolator v vročem okolju. Odpornost proti vlagi je boljša v okolju z visokim UV-indeksom. Kot stika je sorazmeren stopnji prevodnosti v prvih urah meritev, pozneje je ta odvisnost bolj kompleksna, še zlasti pri višji prevodnosti.

## 1 INTRODUCTION

Silicone rubber (SiR) insulators used in transmission and distribution electric power systems are characterized by their surface hydrophobicity which represents the resistance to the formation of a continuous water film. During their service, insulators are exposed to different constraints, such as electric field, rain, moisture, snow, sunlight, air pollution,

corona discharges, etc., which altogether degrade their performance and are the reason for their hydrophobicity loss. When the hydrophobicity is temporarily lost, the insulators become more vulnerable to external factors like surface partial discharges e.g. corona, dry-band arcs, moisture absorption by the housing material and others. This further degrades the material properties, e.g. increase electric permittivity and dielectric dissipation factor [1], fracture fiberglass core [2], etc. However, it is known that the SiR insulators can recover their hydrophobicity after removing the applied stress, but some studies show that in certain cases, the initial hydrophobicity cannot be recovered even after a long period of time [3, 4].

Ageing of composite insulators is a complex phenomenon because of the synergy of the involved factors, e.g. electrical, mechanical, thermal and environmental. Many researchers prefer to study separately the action of each factor in order to better understand the phenomena and the mechanisms included in the hydrophobicity deterioration. In this context, the effect of the electric field, corona discharges, temperature, ultra-violet (UV) radiation,

humidity, acid rain, pollution and others have been extensively investigated.

The SiR insulators are sometimes exposed to severe temperature conditions that can in some regions reach up to 88°C [5]. However, the sun is not the only source of heat. In fact, partial surface discharges, especially dry band arcing, are another source. Temperatures above 400°C are recorded on the insulator surface during a dry band arcing activity [6]. Many studies have been performed to understand the temperature effect on the material hydrophobicity. Chang and Gorur [7] report that a high temperature favors the recovery process of the hydrophobicity lost following a hexane treatment. Ali and Hackam [8] show that the hydrophobicity improves during a thermal treatment. Manjang et al. [9] find the relationship between the value of the leakage current and the applied temperature insignificant. The behaviour of high temperature vulcanized (HTV) SiR insulators, when exposed to the UV radiation is a subject of several studies [10, 11]. Farhadinejad et al. [12] report that the application of the UV<sub>C</sub> radiation to the insulator has a negligible effect on the AC leakage current value when the insulator is dry and clean. However, the radiation effect becomes more obvious when a wet pollution layer is applied to the insulator. Venkatesulu and Thomas [5] perform a long-term accelerated ageing on a silicone insulator and study a combined effect of temperature, UV<sub>B</sub> radiation and AC voltage. Studies have been conducted on the effect of the SiR permeation to water and other aqueous solutions on different material properties. Ali and Hackam [8] investigate the variation in the weight, surface roughness and hydrophobicity of a HTV SiR insulator immersed in saline solutions with different concentrations and temperatures. Water diffusion into a bulk of a silicone rubber material can lead to an increase in the dielectric dissipation factor and conductivity. Wang et al. [13] study the characteristics of additives and the effect of the type of the solution, its concentration and temperature on the HTV SiR water absorption. They show that the increase in the conductivity of aqueous solutions slows down the water absorption.

The primary goal of our study is to understand to what extent the silicone insulator surface is affected by the applied constraints, i.e. the temperature, UV radiation and immersion during and after a stress period. Indeed, the properties evolution after stress is rarely investigated in the literature, although it can further contribute to understanding the ageing mechanism of silicone insulators, which is a necessary step to develop methods and more suitable procedures for the characterization of the outdoor insulation and to improve the materials used for insulators manufacturing. Surface characteristics of the HTV SiR insulator during ageing are investigated. The contact angle (CA), wettability class index (WCI) and DC surface current are the main key measurements and our

objective is to find the possible correlation between them against ageing.

## 2 EXPERIMENTAL AND METHODOLOGICAL APPROACH

### 2.1 Test specimen

Samples are cut from an HTV silicone insulator using Boehm jlb250p hollow punches. The insulator is new and has never been in service. The samples are circular with a 40mm diameter and 4.7mm average thickness. After cleaning their surface with a distilled water using a soft sponge, the samples are allowed to dry at a room temperature in a desiccator.

### 2.2 CA measurement

The static CA is measured in several positions on a sample surface. An average of three measurements is done for each sample. The CA measurement is performed compliantly with the IEC 62073 [14] standard by applying 20 µl of a distilled water droplet on the sample surface. A photograph is taken with a high-resolution camera and then transferred to a computer in order to determine the CA value using a contour analysis software. A schematic diagram of the CA measurement procedure is shown in Figure 2.

### 2.3 WCI evaluation

WCI is evaluated by the spray method according to the IEC 62073 standard. A distilled water is sprayed onto a sample surface at a distance of 30 cm for 20 seconds. The surface wettability is determined in ten seconds after spraying. A comparison is made with different WCI (from WCI1 to WCI6) given in [14].

The material hydrophobicity is generally determined either by WCI or by measuring CA formed by a droplet, insulator and air. The more CA, the more the insulator is hydrophobic. The hydrophobicity evaluation by WCI is more practical in the field, however it depends on a subjective visual examination of the surface. On the other hand, the hydrophobicity evaluation by measuring CA is more accurate, but it requires withdrawing the insulator for an in-lab assessment, as well as cutting-out a sample from the shed to mount it on a measuring instrument, thus making it a destructive method. A correlation between these two methods to estimate the hydrophobicity is therefore advantageous.

### 2.4 DC surface current measurement

The DC surface current measurement is a relatively simple approach. It may give an indication of the insulator electrical performance with regard to its surface state, e.g. it may reveal the presence of a conductive contamination or surface degradation. Using a three-electrode system as foreseen by the IEC 93 standard [15] (Fig. 3), the surface current is measured on a specimen surface between the guarded electrode and ring electrode. The guard electrode is used as a

protection electrode to drift the bulk current from the electrometer via conductor a. A 1 kV DC voltage is applied using the Keithley 240A power supply. The energization time is one minute after which the current value is measured using the Keithley 610C electrometer.

2.5 Saline solutions

The study of the salinity effect consists of immersing samples in an electrolyte solution at a room temperature for a determined duration. Five conductivity levels are used: 3µS/cm, 7mS/cm, 18mS/cm, 46mS/cm and 138mS/cm. 3µS/cm is the distilled water electrical conductivity. The other conductivities are obtained by dissolving the NaCl salt in a volume of the distilled water. The conductivity level is measured using a liquid conductivity meter (Inolab cond720). These conductivity levels are chosen to cover the entire salinity range in the field, i.e. from the very low to the very high [16-18]. On other hand, the choice of NaCl as a salt is governed by a previous measurement of the insulators pollution on the west side of the Algerian high-voltage power grid [19].

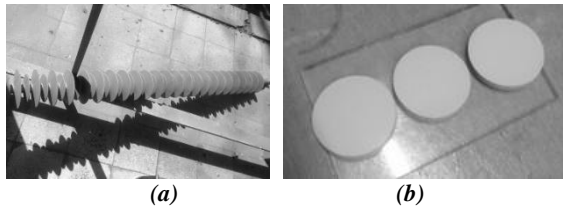


Figure 1. SiR used in experiments: (a) insulator chain, (b) cutted samples.

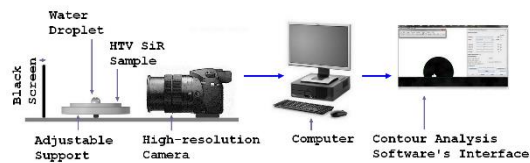


Figure 2. CA measurement procedure.

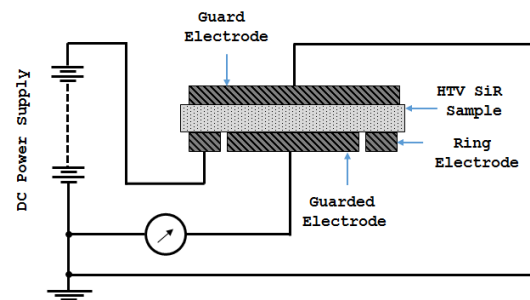


Figure 3. Basic connection for measuring the surface current.

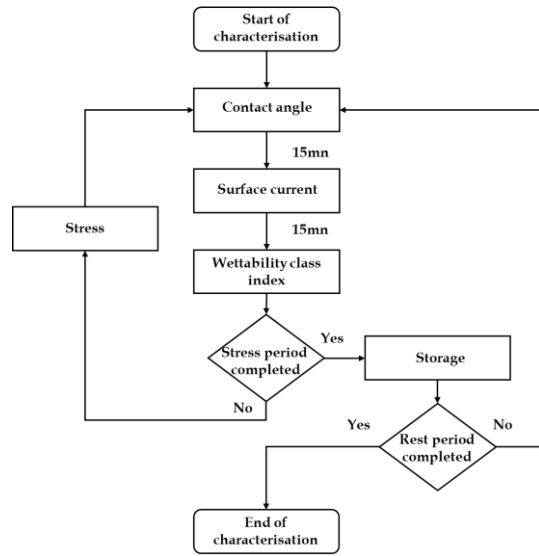


Figure 4. Adopted methodology of the study.

2.6 Temperature and ultra-violet (UV) radiation

The temperature generated during discharges and the effect of the long-term ambient temperature are some of the ageing mechanisms that affect the polymeric insulators [5]. To study the thermal effect, the samples are placed into a convection oven where they are exposed to 50°C or 110°C temperature for a specified duration. The stress applied at 2°C consists of cooling the samples in a freezer.

The sunlight and corona discharge are two sources of the UV radiation that affect the SiR insulator performance. The emission spectrum of the corona discharge extends from 210 nm to 900 nm [20]. In air emissions, the light is mainly in the 230-405 nm range [21], and it is considered to severely affect the materials. In our study the samples are exposed to a radiation of a fluorescent lamp (11W, UV<sub>C</sub> (254)) with the main emission in a 254nm wavelength. The lamp has a quartz glass tube to avoid the ozone formation. The samples are deposited at a distance of 11 cm from the ultraviolet source during the stress period.

2.7 Methodology of the study

Before applying any stress, the values of CA, DC surface current and WCI are determined when the samples are new. They are then considered as reference values. During the stress period, the samples are taken out periodically from the ageing device for assessment. The used characterization techniques follow a precise order, i.e. starting by measuring CA, then measuring the surface current and finally determining WCI. The time interval between two successive examinations is 15 minutes, which is the time required to prepare the measuring instruments and carry out the characterization operations. When the stress period is completed, the samples are stored in a desiccator at a

room temperature. In the rest period, the same samples are evaluated periodically by applying the above three techniques. All the measurements are performed at 20-23°C and 50-55% of the relative humidity. The methodology used in this study is summarized in Fig. 4.

### 3 RESULTS

#### 3.1 Temperature effect

Figs. 5-7 show the evolution of the insulator surface properties during a temperature stress period.

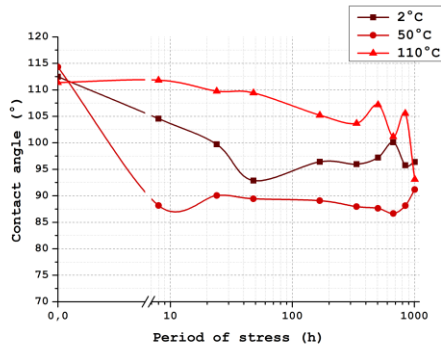


Figure 5. CA during a temperature exposure.

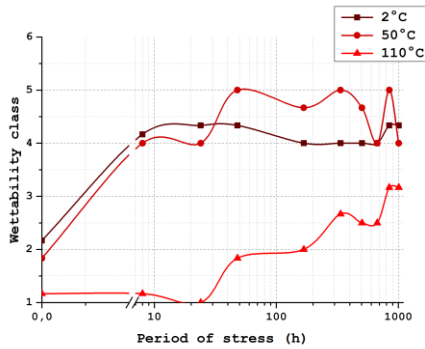


Figure 6. WCI during a temperature exposure.

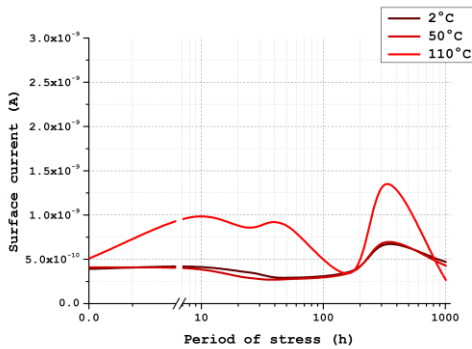


Figure 7. Surface current during a temperature exposure.

Fig. 5 shows a decrease in CA during a heating/cooling period. For the 2°C and 50°C samples, the decrease is initially important (during the first 48 hours). Then it becomes relatively stable during the stress period. At 110°C, CA decreases more slowly and presents fluctuations during the last stage of the stress. Generally, the CA values of the samples heated at

110°C are higher than those cooled at 2°C and those heated 50°C. The 50°C samples show the lowest CA.

The WCI variation during the heating period is shown in Fig. 6. According to the IEC 62073 standard [14], a high WCI means a total wettability of the insulator surface, so the WCI increase over the time results in a hydrophobicity loss. It is interesting to note that there is some similarity in WCI of the 2°C and 50°C samples what is not revealed by the CA measurement.

Fig. 7 shows a variation in the surface current during the heating period. The samples heated at 110°C present a higher surface current than the 2°C and 50°C samples where the difference in their surface current is small. The variation in CA, WCI and surface current during the rest period is shown in Fig. 8-10, respectively.

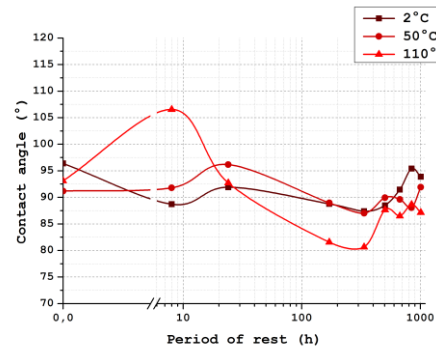


Figure 8. CA during a rest period subsequent to a temperature stress.

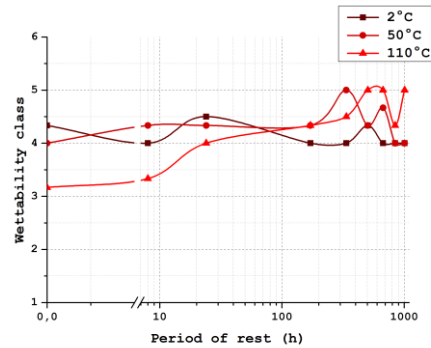


Figure 9. WCI during a rest period subsequent to a temperature stress.

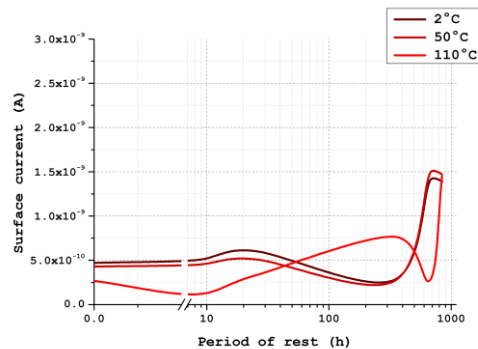


Figure 10. Surface current during a rest period subsequent to a temperature stress.

It appears that the previously heated samples at temperatures of 2°C and 50°C do not show a significant difference in CA during the rest period (the maximum difference is about 4°). CA improves slightly compared to the last stage of the applied stress for the samples heated at 50°C. For the samples cooled at 2°C, CA decreases during the rest period compared to the stress period. The samples previously heated at 110°C behave differently than the others: CA increases significantly (+13°) during the first eight hours after the end of heating, then it decreases in the same way (-14°) after 24 hours until reaching 80°, to stabilize afterwards at around 87° in the last rest stage.

Except for 110°C where WCI continues to increase, there is no significant difference in WCI in the rest period compared to the stress period.

The surface current in the case of the 110°C samples differs from that of the 2°C and 50°C samples with almost the same values. However, according to Figs. 5-7, there is a relationship between CA, WCI and the surface current for the temperature of 110°C during 306-1008 hours of the heat stress. It is especially in Figs. 5 and 7 that the surface current follows the CA variations. The same is observed from Figs. 8 and 10 after stress. It can be concluded that the CA variation modulates the surface charges.

### 3.2 Salinity effect

The variation in CA, WCI and surface current during the immersion period is shown in Figs. 11-13.

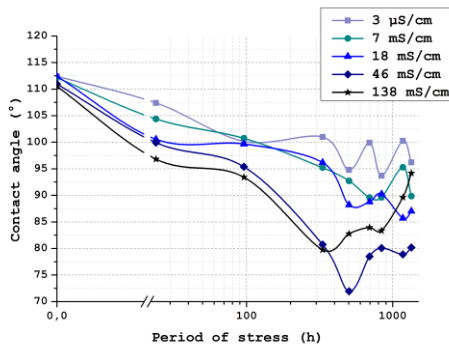


Figure 11. CA during the sample immersion in saline solutions.

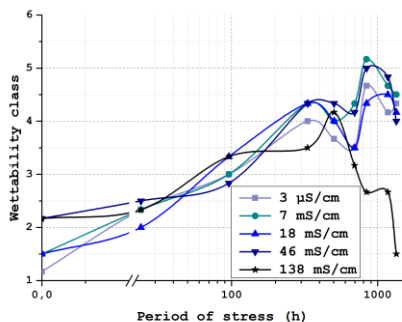


Figure 12. WCI during the sample immersion in saline solutions.

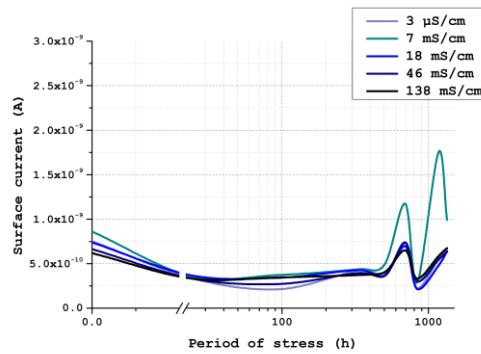


Figure 13. Surface current during the sample immersion in saline solutions.

As seen from Fig. 11, CA decreases during the 96 hours following the sample immersion. It is obvious that the decrease is proportional to the increase in the electrical conductivity of the solution during the first 24 hours. The CA variation seems to be related to the conductivity of the solution in the first immersion stage.

Subsequently, CA continues to decrease and then stabilizes in the last sample immersion stage in solutions of 3μS/cm, 7mS/cm, 18mS/cm and 46mS/cm. The samples immersed in a distilled water retain higher CA than other samples. For the samples immersed in the 138mS/cm solution, CA continues to decrease until reaching the threshold value, from where it starts to increase. Generally, CA decrease during the immersion period is proportional to the increase in the volume conductivity of the solution, except for the 138mS/cm solution. Indeed, CA of the samples immersed in this solution starts to increase after about 332 hours which is unexpected.

It appears from Fig. 12 that WCI increases with the immersion duration which means that the samples immersed in all the saline solutions lose their hydrophobicity. Unlike CA, WCI does not seem to depend on the conductivity in the range from 3μS/cm to 46mS/cm. For the 138mS/cm samples, WCI reaches the minimum value at 503 hours from which it begins to decrease until it reaches a lower value than the reference one, which means that the hydrophobicity improves during the immersion.

The link between the surface current and the solution conductivity is not evident. In general, the samples immersed in 7mS/cm have a higher surface current during the period of the immersion, particularly in the late immersion phase. It can be seen that during the immersion, the surface current decreases compared to that before the immersion.

Figs. 14-16 present the evolution of CA, WCI and the surface current respectively of the samples during the rest period.

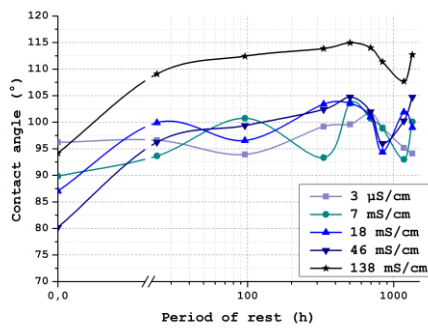


Figure 14. CA during a rest period after the immersion in saline solutions.

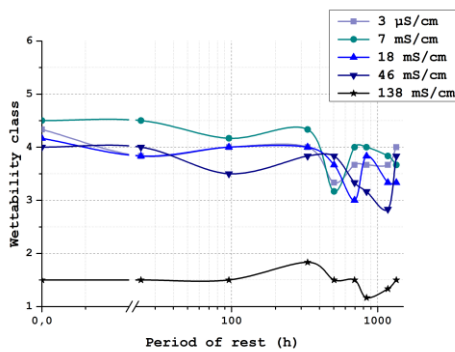


Figure 15. WCI during a rest period after the immersion in saline solutions.

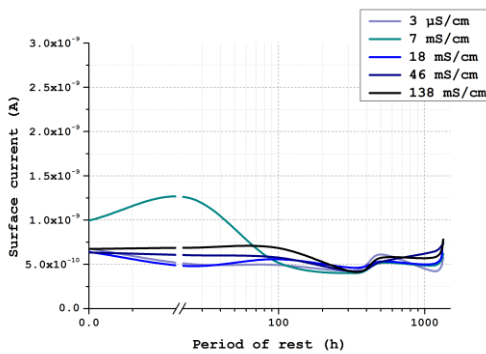


Figure 16. Surface current during a rest period after the immersion in saline solutions.

According to Fig. 14, CA increases rapidly during the first 24 hours after removing the samples from the 18mS/cm, 46mS/cm and 138mS/cm solutions. For the 7mS/cm and 3μS/cm samples, the increase is slower. Afterwards the CA evolution tends to be more stable over time. During the first 24 hours of the rest period, CA seems to be related to the solution conductivity which increases with the solution conductivity.

WCI in Fig.15 does not show any significant variation during the rest period depending on the conductivity, except for the samples previously immersed in 138mS/cm. it can be concluded that the solution conductivity does not affect WCI during the rest period.

Compared with the immersion period, the surface current increases slightly during the rest period for all

samples and remains practically stable. At the start of the rest period, the surface current increase is more pronounced for the samples immersed in the 7mS/cm solution.

### 3.3 UV radiation effect

Figs. 17-19 show the CA, WCI and surface current evolution during the period of the exposure to the UV radiation. There is a slight decrease in CA, WCI changes from 1 to about 2.5 and the samples remain hydrophobic during the exposure period. The surface current is generally stable during the exposure period, although it decreases in the first 24 hours.

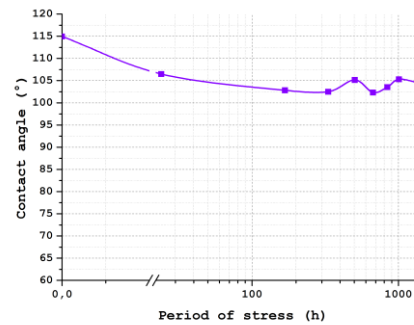


Figure 17. CA during the exposure to the UV radiation.

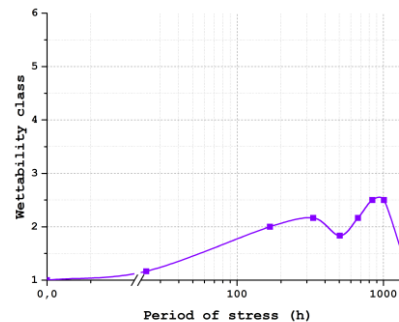


Figure 18. WCI during the exposure to the UV radiation.

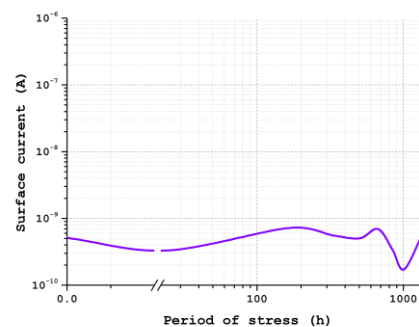


Figure 19. Surface current during the exposure to the UV radiation.

In the rest period (Fig. 20), CA decreases considerably (-23.43°) during the first 24 hours and continues to decrease less rapidly during the 168 hours to finally achieve a certain stability. Fig. 21 shows that WCI varies from about 1.5 to 5.5, which is the total

wettability of the samples surface. It can be seen from Fig. 22 that the surface current becomes very high during the last rest stage, reaching about  $10^{-7}$ A, which means that the surface resistivity becomes about 93 times lower than the reference value.

On other hand, there is a relationship noted between the insulator hydrophobicity and surface current during and after a UV radiation stress. According to Figs. 17 and 19, variations in the surface current and CA are almost the same during the UV exposure. In Figs. 21 and 22, WCI and surface current also behave in the same way in the range 168-1008 hours after a UV stress. Our conclusion is that the decrease in the hydrophobicity affects the quantity of the surface charges after the UV radiation.

A visual inspection after the ageing cycle shows that samples do not discolor and when handling them, it is noticed that they are harder with rougher surfaces compared to the unaged samples.

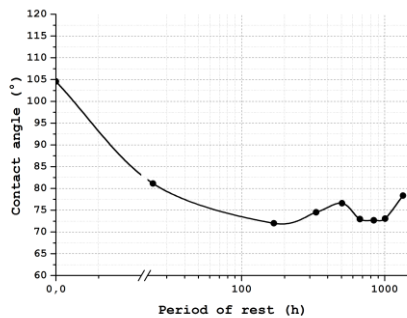


Figure 20. CA during the rest period after the UV radiation.

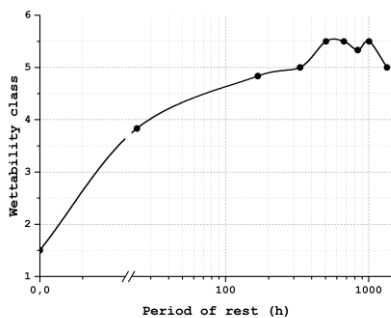


Figure 21. WCI during the rest period after the UV radiation.

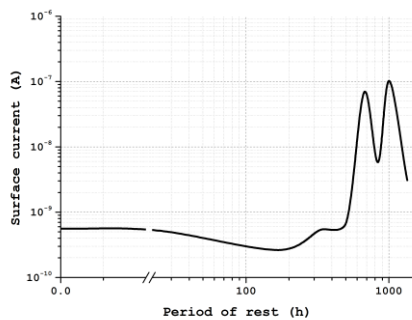


Figure 22. Surface current during the rest period after the UV radiation.

## 4 DISCUSSION

### 4.1 Temperature effect

For the three studied temperature levels, the hydrophobicity measurement results (CA and WCI) show that the samples do not recover their hydrophobicity even after a rest period of 1008 hours, which means that the degradation of this property can be irreversible (ageing is reached). Recent work [22] indicates that the end-of-life of a polymer material is associated with a severe hydrophobicity loss and a considerable delay in the recovery process caused by the depletion of low molecular weight (LMW) chains. Decreasing the temperature can lead to a decrease in the diffusion rate of the LMW species from the insulator bulk to the pollution layer [23]. It has been noted, however, that under certain temperature values i.e.  $2^{\circ}\text{C}$  and especially  $110^{\circ}\text{C}$ , and for a certain stress duration, the material hydrophobicity is better compared to the rest period. In addition, heating at  $110^{\circ}\text{C}$  is likely cause a scission of chemical bounds in the long polydimethylsiloxane (PDMS) chains that decompose into low mass oligomers PDMS chains. These LMW chains continue to diffuse toward the surface and ensure the material hydrophobicity. Yoshimura et al. [24] report that the hydrophobicity of the HTV silicone insulators heated at temperatures of  $250^{\circ}\text{C}$  and  $300^{\circ}\text{C}$  during 100 hours does not decrease.

Measurement of the DC surface current reflects the material surface resistivity. It appears that the difference in the surface current value is negligible in the temperature range of  $2\text{-}50^{\circ}\text{C}$ . Heating in this range does not seem to affect the surface resistivity even in the rest period. Heating at  $110^{\circ}\text{C}$ , on the other hand, increases the current value. This is probably due to the appearance of electric charge carriers on the material surface which increases the surface conductivity. Methyl ( $\text{CH}_3$ ) groups are responsible for the PDMS hydrophobicity. As their dipole moment is very weak, they are considered non-polar. On the other hand, the siloxane ( $-\text{Si-O-Si}-$ ) group bond confers a polar or ionic character to the PDMS species which is likely to contribute to the electrical conduction on the material surface. Indeed, Jahn et al. [25] report that the electrical conductivity of the silicone rubber increases as a function of the temperature. During the rest period, the surface conductivity decreases compared to the stress period.

In several studies, scholars use a  $100\text{-}120^{\circ}\text{C}$  temperature range for hours as a pretreatment procedure for specimens conditioning. However, applying such high temperatures affect the material properties and can provide incorrect measurement results. Pretreating silicone specimens at such high temperatures is not recommended, and more care should be taken when utilizing this approach. Indeed, is the surface current increases after samples conditioning for eight hours at  $110^{\circ}\text{C}$ .

#### 4.2 Salinity effect

The immersion effect is evident during the first 24 hours. The more saline solution (i.e. the higher its conductivity), the lower CA. According to [8], the decrease in CA is due to the diffusion of the solution into a silicone insulator during the immersion. Wang et al. [13] show that the increase in the conductivity of an aqueous solution slows down the water absorption of HTV SiR and this phenomenon may be due to two effects i.e. decreased free volume size inside the material bulk due to the shielding effect of the counter ions, or reduced water diffusion due to a lower chemical potential solution.

However, this effect becomes more complex depending on the immersion duration because of the CA fluctuations for the case of the distilled water and CA recovery for the 46mS/cm solutions and especially that of 138mS/cm. Ali and Hackam [8] report that CA of the samples immersed in a 100mS/cm NaCl solution decreases but retains a higher value compared to other samples immersed in lower conductivity solutions. However, no improvement has been reported of the hydrophobicity of the silicone material during immersion in a saline solution. To understand the mechanism responsible for this phenomenon, further investigations are needed. A continuous water diffusion into a material does not explain the reason about the CA increase in high conductivity solutions. This phenomenon may be due to the "encapsulation effect". In fact, 138mS/cm is a saturated solution which contains non dissolved NaCl salt particles, which adsorb to the silicone surface and the LWM species are transferred to them which consequently promotes the hydrophobicity recovery and makes the solution diffusion more difficult.

During the rest period, CA of the samples immersed in 138mS/cm increases rapidly, exceeds the reference value after a few hours and remains higher compared to other samples. The increase in CA is more important when the solution conductivity is large, this is in agreement with [26]. Afterwards, the conductivity effect on CA becomes less pronounced. WCI shows a hydrophobicity degradation during the immersion period (except for 138mS/cm where the hydrophobicity begins to recover after 695 hours). However, it seems that WCI does not depend on the solution conductivity. This also applies for the rest period, with the exception of the 138mS/cm samples where they show a significant difference in WCI compared to other samples.

The dependence on the solutions volume conductivity of the surface current is also low. The peaks observed during a late immersion phase and the start of the rest period reveal a degradation of the material surface resistivity, however, this degradation is not permanent since the current returns to its steady level after 96 hours of rest. The decrease in the surface resistivity is likely due to the presence of microscopic traces of water or saline solution on the insulator

surface, that have not been completely removed after the CA measurement.

#### 4.3 UV radiation effect

Experimental results show that the hydrophobicity is maintained during the stress period by the UV radiation, this is in agreement with [10, 11]. This means that the material exposure to the UV radiation does not considerably affect the hydrophobicity (a maximum difference of about 13° in CA and a difference of about one WCI). Yet, the evaluation of the hydrophobicity in the rest period shows the opposite. In fact, the hydrophobicity begins to degrade and the material surface becomes constantly hydrophilic. During the UV radiation and due to the heat released by the UV lamp, the temperature inside a UV ageing chamber is of the order of 30°C which in our case is above the room temperature. The combination of the temperature and UV radiation might be a responsible parameter for the hydrophobicity maintaining in the stress period.

The surface current recorded during the last rest phase reveals a considerable degradation of the surface resistivity. This may be due to the increase in the quantity of the charge carriers previously existing on the material surface and originating from impurities or at the appearance of new carriers. In fact, the UV radiation can be responsible for the formation of hydroxyl (O-H) bonds [12] which are strongly polar. These (O-H) groups can be easily oriented by applying an electric field, thus favoring the passage of the current on the insulator surface. Due to their polar character, these groups contribute considerably to the surface hydrophilicity.

### 5 CONCLUSION

A long-term ageing test cycle is applied to an HTV SiR insulator to investigate the effect of the temperature, UV radiation and immersion in saline solutions and distilled water. The obtained results led to the following conclusions:

CA and WCI can be used as two complementary tools to evaluate the hydrophobicity of the silicone material. To better estimate the hydrophobicity, they should be used together.

The fluctuations observed in WCI and in CA between two successive measurements reflect the dynamic character of the hydrophobicity. This means that a visual inspection of the composite insulator based on a hydrophobicity measurement results is unreliable, unless it is done over a continuous and sufficiently long period of time.

An occasional disagreement between the CA and WCI results, is due to the hydrophobicity non-uniformity on the insulator surface because of the inhomogeneity of its material.

The thermal stress appears to differently affect the hydrophobicity and surface resistivity of the HTV SiR material depending on the applied temperature.



Under a UV radiation stress, the hydrophobicity is better than in the post-stress period, although the other surface properties are degraded. To estimate the insulator ageing degree, it is not sufficient to measure only its hydrophobicity.

The solution conductivity affects the hydrophobicity during the immersion period. This effect varies as function of the immersion duration especially for high solution conductivity level. The DC surface current measurement does not reliably reflect the physicochemical change on the insulation material surface during immersion ageing.

The paper describes important aspects affecting the SiR housing ageing. Our study results may be helpful to better understanding the ageing phenomenon and to develop test method for the SiR insulator assessment. In our future work the insulator bulk behaviour will be investigated based on the impact of the ageing process on the relative permittivity, dielectric loss tangent and the bulk resistivity. The correlation between these parameters and the flashover mechanism will also be studied.

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### REFERENCES

- [1] Spellman, C.A., Young, H.M., Haddad, A., et al. "Survey of Polymeric Insulator Ageing Factors", *Int. Symp. on High Voltage Engineering (ISH)*, London, UK, 23-27 August 1999, pp. 160-163
- [2] Wang, Z., Zhao, L.H., Jia, Z. D., et al. "Water and Moisture Permeability of High-temperature Vulcanized Silicone Rubber", *IEEE Trans. Dielectr. Electr. Insul.*, 2017, 24, (4), pp. 2440-2448
- [3] Barsch, R., Lambrecht, J., Jahn, H. "On the Evaluation of the Hydrophobicity of Composite Insulator Surfaces", *IEEE Annual Report Conf. on Electrical Insulation and Dielectric Phenomena (CEIDP)*, San Francisco, October 20-23, 1996, pp. 468-471
- [4] Liang, Y., Ding, L., Yang, K., et al. "Study on Hydrophobicity Recovery Characteristics and Mechanism of HTV Silicone Rubber after Corona Deterioration", *IEEE Annual Report Conf. on Electrical Insulation and Dielectric Phenomena (CEIDP)*, Vancouver, BC, Canada, 14-17 Oct. 2007, pp. 308-311
- [5] Venkatesulu, B., Thomas, M.J. "Long-term Accelerated Weathering of Outdoor Silicone Rubber Insulators", *IEEE Trans. Dielectr. Electr. Insul.*, 2011, 18, (2), pp. 418-424
- [6] Bashir, N., Ahmad, H. "Ageing of Transmission Line Insulators: The Past, Present and Future" *2nd IEEE Int. Conf. on Power and Energy (PECon)*, Johor Baharu, Malaysia, December 1-3, 2008, pp. 30-34
- [7] Chang, J.W., Gorur, R.S. "The role of backbone chain rotation in the hydrophobicity recovery of polymeric materials for outdoor insulation", *Proceedings of the 4th Int. Conf. on Conduction and Breakdown in Solid Dielectrics*, Sestri Levante, Italy, 22-25 June 1992, pp. 270-274
- [8] Ali, M., Hackam, R. "Effects of Saline Water and Temperature on Surface Properties of HTV Silicone Rubber", *IEEE Trans. Dielectr. Electr. Insul.*, 2008, 15, (5), pp. 1368-1378
- [9] Manjang, S., Mustamin, Nagao, M. "Characteristics of High Voltage Polymer Insulator Under Accelerated Artificial Tropical Climate Multi Stress Aging", *Conf. Proceedings of Int. Symp. on Electrical Insulating Materials (ISEIM)*, Kyoto, Japan, 6-10 September 2011, pp. 221-224
- [10] Wang, X., Liang, X., Zhou, Y. "Aging effect of UV radiation on SIR insulators' hydrophobicity property", *IEEE Annual Report Conf. on Electrical Insulation and Dielectric Phenomena (CEIDP)*, Boulder, CO, USA, 13 December 2004, pp. 241-244
- [11] Youn, B.H., Huh, C.S. "Surface Degradation of HTV Silicone Rubber and EPDM Used for Outdoor Insulators under Accelerated Ultraviolet Weathering Condition", *IEEE Trans. Dielectr. Electr. Insul.*, 2005, 12, (5), pp. 1015-1024
- [12] Farhadinejad, Z., Ehsani, M., Ahmadi-Joneidi, I., et al. "Effects of UVC Radiation on Thermal, Electrical and Morphological behavior of Silicone Rubber Insulators", *IEEE Trans. Dielectr. Electr. Insul.*, 2012, 19, (5), pp. 1740-1749
- [13] Wang, Z., Jia, Z. D., Fang, M. H., et al. "Absorption and Permeation of Water and Aqueous Solutions of High-temperature Vulcanized Silicone Rubber", *IEEE Trans. Dielectr. Electr. Insul.*, 2015, 22, (6), pp. 3357-3365
- [14] IEC TS 62073 "Guidance on the measurement of wettability of insulator surfaces", 2003
- [15] IEC 60093 "Methods of test for volume resistivity and surface resistivity of solid electrical insulating materials", 2nd edn, 1980
- [16] IEC 60815 "Guide for the selection of insulators in respect of polluted conditions", 1st edn, 1986
- [17] IEC 60507 "Essais sous pollution artificielle des isolateurs pour haute tension destinés aux réseaux à courant alternatif", 2nd edn, 1991
- [18] Arshad, Nekahi, A., McMeekin, S.G., et al. "Investigating Flashover Behaviour of Silicone Rubber Insulators under Contaminated Conditions", *IEEE Annual Report Conf. on Electrical Insulation and Dielectric Phenomena (CEIDP)*, Ann Arbor, MI, USA, 18-21 October 2015, pp. 856-859
- [19] Slama, M. A., Hadi, H., Flazi, S., et al. "Etude du dépôt de pollution responsable du contournement des isolateurs des lignes aériennes du réseau électrique THT national", *Sciences & Technologie B*, 2007, (25), pp 43-50
- [20] Grum, F., Costa, L. F. "Spectral emission of corona discharges", *Appl. Optics*, 1976, 15, (1), pp. 76-79
- [21] Pinnangudi, B., Gorur, R. S., Kroese, A. J. "Quantification of Corona Discharges on Nonceramic Insulators", *IEEE Trans. Dielectr. Electr. Insul.*, 2005, 12, (3), pp. 513-523
- [22] Cherney, E. A., Marzinotto, M., Gorur, R. S., et al. "End-of-Life and Replacement Strategies for RTV Silicone Rubber Coatings", *IEEE Trans. Dielectr. Electr. Insul.*, 2014, 21, (1), pp. 253-261
- [23] Li, C., Zhao, L., Xiong, J., et al. "Influence of Seasons on Hydrophobicity of Silicone Rubber Insulators in Semi-wet Warm-temperature Zone of China", *IEEE Trans. Dielectr. Electr. Insul.*, 2008, 15, (4), pp. 1081-1088
- [24] Yoshimura, N., Kumagai, S., Nishimura, S. "Electrical and Environmental Aging of Silicone Rubber Used in Outdoor Insulation", *IEEE Trans. Dielectr. Electr. Insul.*, 1999, 6, (5), pp. 632-650
- [25] Jahn, H., Barsch, R., Wendt, E. "The Influence of Temperature on the Recovery of the Hydrophobicity on Silicone Rubber Surfaces". *IEEE Conf. on Electrical Insulation and Dielectric Phenomena (CEIDP)*, Victoria, BC, Canada, 15-18 October 2000, pp. 242-245
- [26] Ali, M., Hackam, R. "Recovery of Hydrophobicity of HTV Silicone Rubber after Accelerated Aging in Saline Solutions", *IEEE Trans. Dielectr. Electr. Insul.*, 2009, 16, (3), pp. 842-852

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